University of Liege

Faculty of Sciences

Department of Environmental Sciences and Management

Spheres Research Unit

Energy and Sustainable Development Research Team

The human factor in the energy performance assessments for renovation strategies of existing urban houses in Wallonia

Dissertation submitted by Stéphane MONFILS, Ir. arch.

in completion of the requirements to obtain the degree of Doctor in Sciences

Academic year 2017-2018

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Abstract

In order to reach energy efficiency at any level, the importance of the human factor has to be acknowledged. On one hand, efficient solutions (regarding, for example, building energy consumptions) have to be implemented by an authority who understands the complexity of the urban context and its impacts on the environment; on the other hand, it is important to improve citizens' awareness of their environmental impact and to lead them to use available solutions to their full potential. In the field of residential use of energy, people are therefore a crucial parameter of both the problem and its solution.

The EPC has been designed by authorities to "provide clear information about the energy performance of a building", in order to influence the real-estate market, promote energy performance improvements and help build up comprehensive benchmarking databases, fundamental for shaping strategies on a local or regional level. The EPC, however, offers in return of a 200€ visit, results that are often too distant from reality and difficult to understand for the lay person. "Consumers do not understand CO_2 or kWh". They do not understand "primary energy" either, given that their only knowledge of their energy consumption are the final energy bills. The procedure might be necessary, but the general picture shows a great opportunity remaining underexploited, a potential driver to reducing energy consumption and CO_2 emissions, surrounded by barriers and obstacles that render its use all the more difficult.

While appreciating the necessity of presenting a "legal" result as a comparison base, following the approved standardized calculation method, it is believed that the input data used in the quasi-steady state calculation method could be used to display complementary results. Additional data on the household's composition, their practices and behaviours related to energy consumption, as well as a more accurate search in the description of the energy system, could help close the gap between real and theoretical consumptions, allowing future owners to better understand and appropriate the EPC results, foresee a rough monthly energy bill, and make better decisions for their real-estate renovation ambitions.

This PhD-thesis therefore first sets the context of residential energy use in Wallonia, before questioning the uncertainty parameters of the certification procedure. A questionnaire, built for this research, allowed the interview of 16 case studies, and the collection of their energy-related behaviours and practices. Based on the existing inputs, protocol and global philosophy of the EPC procedure, a modification of the calculation method is suggested in order to integrate the answers to the questionnaire. The results of the many simulations, and those of the sensitivity analysis on the modifications, are presented in the second part of this thesis, followed by conclusions and perspectives for the future.

Thanks…

… to Jean-Marie HAUGLUSTAINE, head of the EnergySuD Research Team, mentor and supervisor of this thesis, for his infallible faith in me from the first moment I entered the University. Thank you for your great teaching skills, for waking the scientist in me, and for always be up to share a laugh… or a beer.

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Chapter 1: Introduction

For several years now, the lay public has been made aware of the "energy problem", finding its roots in our lifestyle, which now creates economic difficulties, geopolitical tensions, social disparity and environmental damages which need to be addressed with urgency.

"Reducing energy consumption and eliminating wastage are among the main goals of the EU. They are embedded in Europe 2020 – the EU's strategy for smart, sustainable and inclusive growth. EU support for improving energy efficiency will prove decisive for competitiveness, security of supply and for meeting the commitments on climate change made under the Kyoto protocol."[1]

With around 40% of energy consumed in buildings, the residential sector is responsible for one of the greatest shares in energy consumption and Green House Gases emissions, but is also harbouring one of the greatest potential in energy improvement that could be "easily" mobilized. The IPCC has basically defined that energy savings potential as a "low-hanging fruit" just waiting to be plucked.[2] McKinsey shared the same view through their estimated costs of CO_2 abatement; as a result, their "pathways to world-class energy efficiency in Belgium"[3] place the existing residential segment in a strategic position. It is largely responsible for this high share in energy consumption. In Wallonia, it is composed of a wide range of different types of dwellings, ancient historical buildings, old brick houses, lightly insulated concrete buildings and recent highly-efficient homes, gathering all possible typologies, techniques, particularities, and diversities of the buildings' shape and structure (age, location, geometry, design…).

To that end, several thermal regulations have been implemented by public authorities for decades, mainly aiming at the preservation of non-renewable energy resources and the reduction of buildings' energy demand. The most recent part of this legislation is the Energy Performance of Building Directive (EPBD), which requires all EU member states to tighten their building energy regulations. This exercise has been realised, in Wallonia as elsewhere, for the past years. It has mainly targeted new buildings, easy to manage a priori, more than the existing stock, difficult to manage a posteriori. There is a real (and quite well known) asymmetry between construction and renovation markets views and ease in energy implementation. In the construction of new buildings, EPB regulations impose the presence of an energy actor to overview the respect of EPB energy requirements. Renovation is much more complex, for having to deal with an existing situation and

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[1] EPBD Concerted Action, 2011. *Implementing the Energy Performance of Buildings Directive (EPBD), Featuring Country reports (2010)*, EU Publications Office

[2] IPCC, 2013: *Summary for Policymakers*. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [STOCKER, T.F., D. QIN, G.-K. PLATTNER, M. TIGNOR, S.K. ALLEN, J. BOSCHUNG, A. NAUELS, Y. XIA, V. BEX and P.M. MIDGLEY (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

[3] D. N. EYKERMAN, P. C. PEETERS, R. VERHOEVEN, 2009. *Pathways to World-Class Energy Efficiency in Belgium*. Belgium, Mckinsey & Company.

present standards. These already standing buildings are often poorly insulated and hard to render energy-efficient at reasonable cost. They also often present more risks and specific problems than new construction, in terms of unpredictability and on-site thermo-physical problems, for example, which do not allow them to be treated like new buildings. Architects (let alone auditors) are not always involved in renovation projects, leaving owners and contractors as sole deciders. Globally, there is very few regulatory constraints acting on renovation projects. Incentives replace obligations.

Homeowners are hardly aware of the determiners of their energy consumptions, but faced with the (administrative, practical, financial) complexity of renovation works, they generally cannot boast to know more about the available solutions. They often either get discouraged or turn to aesthetics or curative more than preventive works integrating sustainability aspects. Preliminary diagnoses, therefore, are essential to guarantee the best renovation. Wallonia implemented two tools with the praiseworthy intention to bring the general public to integrate energy into their dwelling decision-making processes (in terms of purchase, renovation or daily consumption): the Energy Performance Certificate (EPC), and Energy Audit Procedure (EAP). An EPC is a residential unit's energy-ID, required by the EPB Directive[4] at any important moment of its life (construction, sale, rental) in order to inform future owners or tenants of its energy performance, according to a standardised calculation method. Its introduction in Wallonia in 2010 was followed, as in every other countries in Europe, by a period of slow adaptation from the public to this new information, and it must be admitted that though it is now quite well installed in the Walloon real-estate market, EPC results often present an important gap between theoretical and real energy consumptions, which tends to undermine its goal of promoting energy performance as a crucial real-estate decision-making criterion. The EAP, introduced before the EPC as a voluntary energy assessment of an owner's house, has known a nice success before the withdrawal of its status of prerequisite to get financial incentives for renovation. Both the EPC and the EAP faced some relatively bad press in the last few years, therefore, with several critiques firing at their layout, their complexity, their price… Neophytes seem to find it too complex and technical, while experts hardly find it interesting.

"To increase the impact of EPCs on people's home purchase-related decision-making, the energy label needs to provide information that is interesting, useful and meaningful to people. Although this sounds straight-forward and obvious, it is not an easy task to communicate complex information in a way that is easy to understand and meaningful to all. […] To realise the large energy saving potential in European housing stock, the EPC needs to become an active and engaging tool, rather than a passive information "device"."[5] It is indeed important to accentuate messages to which people are sensible, adapt speeches to the general public. The message delivered by those tools has to be made practical and easy to understand, with the right level of technicity, which could be adapted to the owner of the dwelling and its competence in the matter.

At the same time, part of the energy transition towards a more carbon-literate society means that everyone will have to master new skills and information. Is this information too technical? Or is there sufficient effort put into helping users of various kinds to understand it? Information is crucial,

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[4] EUROPEAN PARLIAMENT AND COUNCIL, 2002. *Directive 2002/91/CE Approved the 16th of December 2002, about Energy Performance of Buildings. 2002*. Official Journal of the European Communities 4.1.2003 L 1/65 Available online: http://eur-lex.europa.eu/eli/dir/2002/91/oj (accessed on November 9th, 2016).

[5] J. BACKHAUS, et al., 2011. *Key findings & policy recommendations to improve effectiveness of Energy Performance Certificates & the Energy Performance of Buildings Directive*, IDEAL EPBD Research Project, Netherlands.

getting EPCs right is a necessary but not sufficient condition to ensure that markets value energy performance.[6] The EPC needs to succeed in connecting people and information, in developing and intensifying the relationships between the households and their energy consumption, in order to enhance its impact.

In order to develop a true culture of energy management, an interesting path is to render energy more visible, concrete, through another billing strategy (feedback techniques), the opportunities to discuss with energy counsellors, or a better visibility of immediate consumption (of household appliances, for example). But giving information is not enough ("We give "information" and "awareness" some mysterious powers"[7]): the message needs to be understood, and appropriated, for it to work, which indicates a real need for professional accompaniment for some users.

Modifications have already been implemented to the Walloon EPC, with the objectives to improve and clarify the message towards the lay public. Iconography, colours, clear layout and additional information in order to explain the results are examples of improvements. But the modifications probably need to go deeper. For example, L. LAINE indicates that "consumers do not understand CO_2 or kWh. […] kWh and CO_2 emissions generally mean nothing to consumers and can deter them from reading on."[8]

Up until now, energy performance calculation methods and tools have been developed by engineers, physicians, mathematicians and economists, who share an idealised image of the final consumers. Their expected behaviour can be guessed by the standard testing of equipment, for example, which can clash seriously with the real array of possible behaviours inside the "black boxes" that are the households for producers and industrials. "Expected results might differ if users' behaviour is inappropriate" is a phrase that can raise eyebrows on those who can place themselves in the users' shoes. What is the "appropriate" use of a heating system? Is there a good and a bad way to heat one's home? Are householders the one to adapt their behaviours to the "standard testing" in order to satisfy technicians and thermal engineers? The population to whom these products are destined is more complex and variable than developers expect. In his home, the occupant can adopt several positions towards energy, from a routine use (where energy is no longer a subject of emotion) to a constant tracking down of all energy wastes, via a multitude of behaviours. Users even generally know very little about their own energy-consuming behaviours because they possess very few information about the ins and outs, besides their energy bills that cannot allow any deconstruction. They do not appropriate CO_2 or kWh.

Those two tools have been foreseen to merge into one great informative procedure that could be used at any point in the life of a building. This fusion is indeed much needed, not least in order to simplify the procedures for the lay public, but also for the administration, which could also gain in coherence in the image sent to the public. The EPBD Concerted Action remarks: "there is a clear distinction between EPC recommendations providing guidelines for potential energy savings, EPC

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[6] Bio Intelligence Service, R. LYONS & IEEP, 2013. *Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries*, Final report prepared for European Commission (DG Energy)

[7] G. WALLENBORN, C. ROUSSEAU, K. THOLLIER, H. AUPAIX, 2006. *Politique d'Appui Scientifique à une Politique de Développement Durable PADDII: Détermination de Profils de Ménages Pour une Utilisation Plus Rationnelle de L'énergie, Partie 1: Modes de Production et de Consommation Durables*; Politique scientifique fédérale: Bruxelles, Belgique.

[8] L. LAINE, 2011. *As easy as EPC? Consumer views on the content and format of the energy performance certificate*, in Consumer Focus, June 2011

tailor-made recommendations, and the detailed energy audit providing detailed and specific data for renovation planning of complex buildings. The detailed energy audit is not regarded as part of the EPC scheme, but as a necessary next step after having completed the EPC. This distinction is necessary for clients' acceptance: an EPC cannot substitute for detailed refurbishment planning, nor has it been designed to do so."[9] The distinction between the schemes is necessary, but the tool (in all its acceptance: protocol, assessors, software…) could be unique.

M. DELGHUST et al.[10] described quite accurately the difficulties and opportunities this situation brings: "a single calculation procedure cannot be optimal both for performance assessment within a regulatory and policy framework and for accurate prediction of the energy use of a specific household. Indeed, these can become conflicting aims when defining user profiles and default values. However, conscious modelling choices and increased knowledge about the building characteristics can already considerably reduce the gap between theoretical figures from the assessment procedure and real energy figures. Furthermore, the workload for performing both types of calculations could be lowered drastically by embedding them both in the same calculation tool, sharing required inputs and algorithms, however with different default values and allowing additional inputs such as personalized user profiles."

An important difference lays, for example, in the input data collection. The EPC standardised, regulatory calculation method withdraws any human factor from the equations, in the honourable and understandable objective to ease the comparison between buildings. This leads to the use of a tight and strict protocol in the certification procedure that regulates the acceptable proofs of performance, and delivers many default values to fill the holes. This does not necessarily apply in the Energy Audit Procedure, where the assessor can consider the occupants' real consumptions and deliver an information that is more tailored to the owners' reality and desires.

M. SUNIKKA-BLANK and R. GALVIN[11] reported the words of D. WALBERG et al.[12], that, in the German context: "For a realistic assessment of the thermal condition of the built environment only the analysis of actual, measured energy consumption can be used. Theoretically calculated energy ratings give us an unrealistic picture of the energy savings potential that can be achieved through thermal renovation." Although the standardised light on the stock's energy performance is much needed, this research stresses the importance of the EAP's increased accuracy in the energy system's description, and proposes to nuance the EPC standardisation, based on statistics and added information, in order to deliver more accurate results in final energy consumption. It then proposes to deepen the EAP data collection by integrating, in the calculation method behavioural determiners of energy consumption, believing, as A. INGLE et al.[13], that "though recognizing that there are

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[9] EPBD Concerted Action, 2015. *Implementing the Energy Performance of Buildings Directive (EPBD), Featuring Country reports (2016)*, EU Publications Office

[10] M. DELGHUST, W. ROELENS, T. TANGHE, Y. DE WEERDT, A. JANSSENS, 2015. *Regulatory energy calculations versus real energy use in high-performance houses*, Building Research & Information, 43:6, 675-690

[11] M. SUNIKKA-BLANK, R. GALVIN, 2012. *Introducing the prebound effect: the gap between performance and actual energy consumption*, Building Research & Information, 40:3, 260-273

[12] D. WALBERG, A. HOLZ, T. GNIECHWITZ, T. SCHULZE, 2011. *Wohnungsbau in Deutschland – 2011 Modernisierung oder Bestandsersatz: Studie zum Zustand und der Zukunftsfähigkeit des deutschen 'Kleinen Wohnungsbaus'*, Arbeitsgemeinschaft für zeitgemäßes Bauen, eV, Kiel.

[13] A. INGLE, M. MOEZZI, L. LUTZENHISER, R. DIAMOND, 2014. *Better home energy audit modelling: incorporating inhabitant behaviours*, Building Research & Information, 42:4, 409-421

challenges and limits to parameterizing behaviour and to what can be achieved in the context of a home energy audit, there may be some benefit that can be gained from bridging the divide affecting home energy audits for owner-occupied dwellings. […] One of the most important consequences of asking occupants about behaviour, and incorporating behaviours into modelling, is that doing so makes behaviour visible to occupants, to home energy auditors and analysts, to efficiency advocates, to researchers and to policy-makers. In doing so, behaviour becomes a negotiable component of energy use versus the typical behaviour-neutral approach that invites the belief that technology is of chief importance and that technical efficiency is independent of behaviour."

This objective to reintegrate the final user into the calculation process passes by several steps, the obvious first one being the contextualisation. The second chapter of this research will therefore focus on the Walloon context, its different types of dwellings and profiles of the population. Many determiners of the stock's energy consumption need to be looked for and positioned in a global setting. The third chapter will explore the teachings of the branch of sociology that takes interest into the main behaviours of the dwelling's occupants that are related to their energy consumption. Sociology of energy, namely, has for decades focused its knowledge on society and individuals on the study of behaviours and practices that explain the energy consumption and will be considered as determiners in this research. The fourth chapter presents the EPC procedure in Wallonia, assessing the different sources of uncertainty in its calculation method and protocol of data collection, that often lead to exaggerated energy consumptions. A questionnaire, built for this research in order to interview homeowners on their energy consumption habits and practices, is presented. The chapter ends on propositions of modifications to the calculation method that integrate the data collected through the questionnaire and the interview.

The fifth chapter presents 16 houses, selected for this research based on the observations of chapters 2 and 3, in order to offer a diverse range of case studies. Only single-family urban brick houses, inhabited by their owners for more than a year, presenting an array of particularities (either in the description of the energy system, in the composition of the households or in their heating patterns) were chosen here. Variants on the case studies are tested in order to assess, mainly, the more accurate description of their protected volume. This chapter presents the results in the revaluation of their energy consumptions, obtained with the modified calculation method. Real data of final energy consumption have been collected among the interviewed owners in order to allow comparisons and analyses. The sixth chapter presents a sensitivity study of the modified method, as presented in chapter 4. The main objectives were to sort the necessary from the superfluous in the added parameters, but also to find the determiners of the remaining theoretical consumptions that were exceeding the real data. Two case studies have been submitted to temperature monitoring campaigns in order to assess the method in itself, but also to try and explain their extreme results for such comparable houses. The seventh and final chapter closes on these results and the perspectives of this exercise. If this sample cannot be considered representative of the whole Walloon stock and population, it nevertheless opens the reflexion and the discussion on the possible future for the EPC and EAP procedures. Further research is necessary to seek generalisation of the reflexion through statistics on a broaden sample. It is believed that a more complex database of default values, for example, based on the age and typologies of dwellings, would help linking EPC and EAP and approach more realistic energy consumption evaluations. Reliability of the EPC, which can only be obtained through improvement of accuracy and usefulness, is crucial for its acceptance and appropriation by the lay public.

Chapter 2: Contextualisation

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2.1 Environment and energy

2.1.1 Generalities

The environmental context in which this research takes place is now widely known. We know now natural resources are limited, but much of our society is built on the assumption that oil was infinite and, for all we knew, harmless. Since 1900, mankind's energy consumption multiplied by 30, by more than 150 since 1850[1]. Along with energy consumption, population, economy, and research grew hand in hand for decades, and the use of fossil fuels have since long proved to bring much harm to the environment in all its forms. We now face great difficulties in managing the pollution of the seas, airs and lands. Waste replaced trees, Green House Gases are sent in clouds to the atmosphere, biodiversity of ecosystems is threatened, which in turn affects the basic vital needs of humans that are healthy food to eat, clean water to drink and pure air to breath. Weather changes, temperatures go wild, storms, tornadoes and hurricanes multiply, droughts and floods alternate in bringing starvation and sicknesses…

Fig. 2.1.1 "I'm afraid you have humans", New Yorker cartoon designed by Eric LEWIS, published on October 14, 2002. Photo licensed from the Condé Nast Collection.

In the scientific community, and especially the subgroup of environmental researchers, the IPPC's views of the environmental situation on Earth, their theories and scenarios are globally believed to be quite accurate. And one important of those theories is that the collective responsibility of humankind cannot really be questioned anymore. The following illustration (Figure 2.1.2) shows that the observation of particular parameters (like sea ice extents, continental land surface air temperatures and upper ocean heat content) follows simulated scenarios that take anthropogenic (=human) forcing into account better than scenarios that do not[2]:

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[1] J.-M. JANCOVICI, A., GRANDJEAN, 2006. *Le plein s'il vous plaît! La solution au problème de l'énergie*, Editions Seuil, France
[2] IPCC, 2013: *Summary for Policymakers*. In: *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* [T.F. STOCKER, D. QIN, G.-K. PLATTNER, M. TIGNOR,

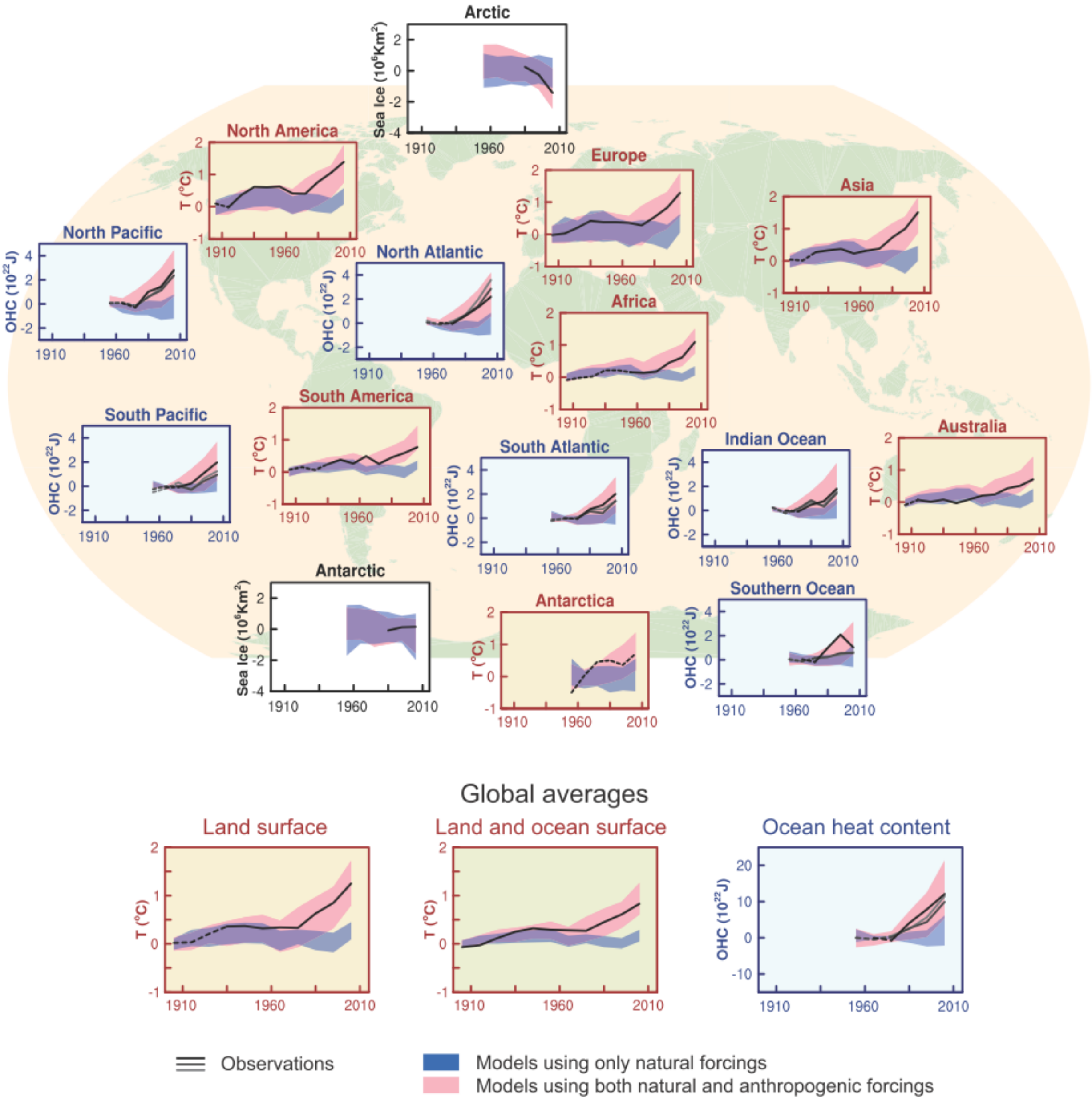

Fig. 2.1.2 Comparison of observed and simulated climate change based on three large-scale indicators in the atmosphere, the cryosphere and the ocean: change in continental land surface air temperatures (yellow panels), Arctic and Antarctic September sea ice extent (white panels), and upper ocean heat content in the major ocean basins (blue panels). Global average changes are also given. Anomalies are given relative to 1880–1919 for surface temperatures, 1960–1980 for ocean heat content and 1979–1999 for sea ice. All time-series are decadal averages, plotted at the centre of the decade. For temperature panels, observations are dashed lines if the spatial coverage of areas being examined is below 50%. For ocean heat content and sea ice panels the solid line is where the coverage of data is good and higher in quality, and the dashed line is where the data coverage is only adequate, and thus, uncertainty larger. Model results shown are Coupled Model Intercomparison Project Phase 5 (CMIP5) multi-model ensemble ranges, with shaded bands indicating the 5 to 95% confidence intervals. For further technical details, including region definitions, see the Technical Summary Supplementary Material. (Source: IPCC, 2013)

S.K. ALLEN, J. BOSCHUNG, A. NAUELS, Y. XIA, V. BEX and P.M. MIDGLEY (eds.)]. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

The OECD[3] acknowledges several sides to the influence that humans have on consumption:

- Economic growth, and increase in available revenue per inhabitant;
- Population growth: the increase in single-households number, in number of working women, in longevity and health improvements, in number of retired people…
- Changes in modes and lifestyles; development of leisure activities, cultural preferences for diversity, increased demand for processed and wrapped products, high equipment levels…
- Other elements like technology availability, institutions, infrastructures, political framework in place, products, services and available information on those products and services…

Further worry for Europe lies in the central position held by oil in our economy, and the pessimistic prospects for that particular resource which bring understandable financial, economy and political concerns. Europe, Belgium and Wallonia find themselves in position of energy dependency; growing demand for maintaining (or improving) our lifestyle imposes to keep buying fossil fuels which knowingly damage our environment and are increasingly difficult or expensive to extract. Economic growth itself is now threatened, along with the model of consumerism. For 50 years now, since the first oil crisis, strategies have been developed to get ourselves out of that uncomfortable situation, where global energy dependency for consumption, Earth population, depletion and prices of resources have all been following the same tendencies, leading to social, political and geopolitical tensions…. *Sustainable development* has largely dominated debates since then, to the point where it appeared hackneyed; other expressions have slowly replaced it in order to keep the debate central, for it carries important wishes for the future of humankind. Nowadays, *energy transition* refers to a long-term structural change in energy systems in finding new ways to reach better synergy between humans and their planet through better, more rational and integrated management of energy. This does not only imply production and supply, but also demand and consumption.

On an international level, the Kyoto Conference in 1997 is one of those important events that still shape the policies nowadays, and several Conferences of Parties (COPs) have since then come with important statements of political will[4]. On the European level, several Directives that fit in the frame of Community initiatives for climate change and supply security have been issued for the last twenty years, leading to many policies on improvements in energy efficiency, demand-side management and energy and environment management and conservation. A clear example of the European Union's strategy for sustainable growth is the 2002/91/CE[5] EPB Directive, central to this research, which makes the energy consumption reduction of the building sector a key objective for meeting the international commitments on climate change. *Energy transition* can also be seen on smaller levels, where patterns of behavioural shift in consuming ways can be found in circular economy, consumption of local/organic/ethical products and regular installations of solar panels, for example.

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[3] OECD, 2002. *Towards Sustainable Household Consumption? Trends and Policies in OECD Countries*, OECD Publishing, 164p.

[4] Although one might regret the lack of binds

[5] European Parliament and Council, 2002. *Directive 2002/91/CE Approved the 16th of December 2002, about Energy Performance of Buildings.* Official Journal of the European Communities 4.1.2003 L 1/65 Available online: http://eur-lex.europa.eu/eli/dir/2002/91/oj (accessed on 9 November 2016).

2.1.2 Belgian / Walloon context

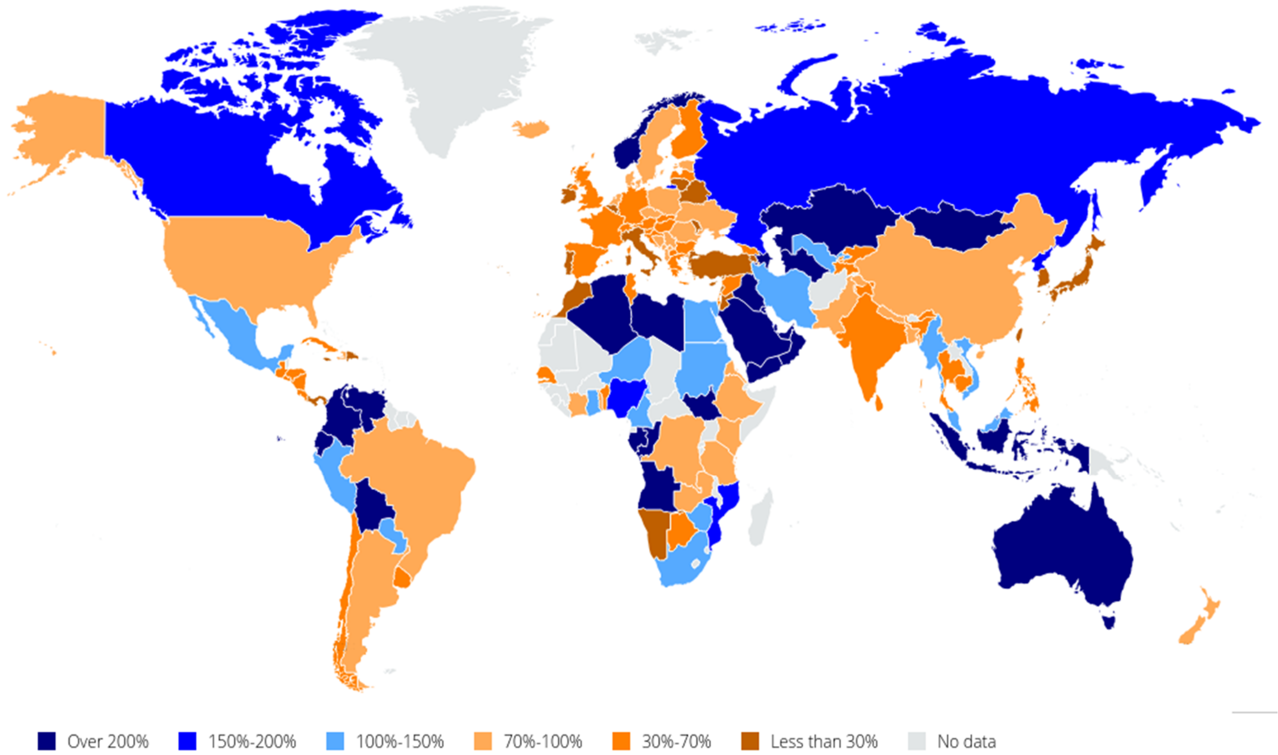


Fig. 2.1.3 Overall energy self-sufficiency (%) (2014). (Source: IEA, 2016)

The Fig. 2.1.3 above describes the energy self-sufficiency of different part of the globe. According to the same source[6], Belgium self-sufficiency reached 24% in 2014. The energy assessment of Wallonia, made by the ICEDD[7], shows (Fig. 2.1.4) that Wallonia's energy autonomy culminated at 9.4% in 2012 (although the progress made in renewable energy production should have followed the emerging tendency since 2008 and increased that share since).

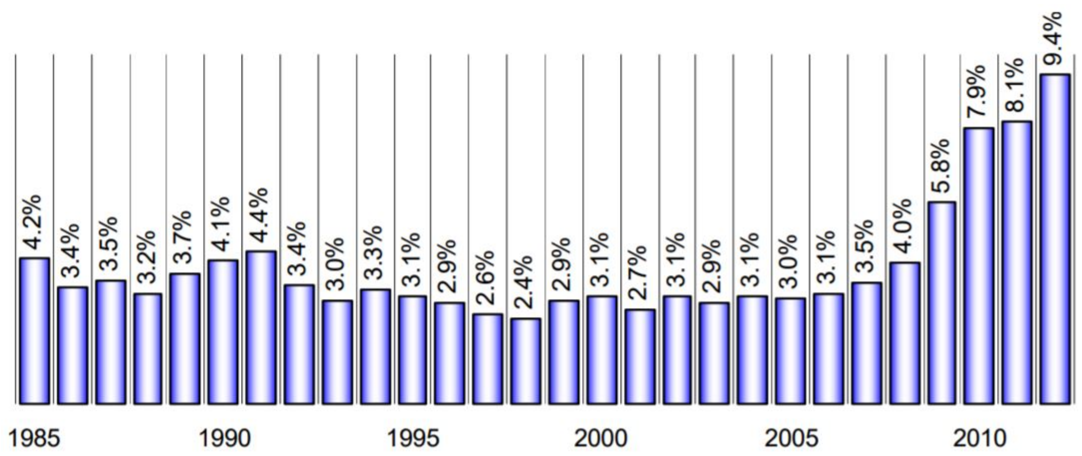
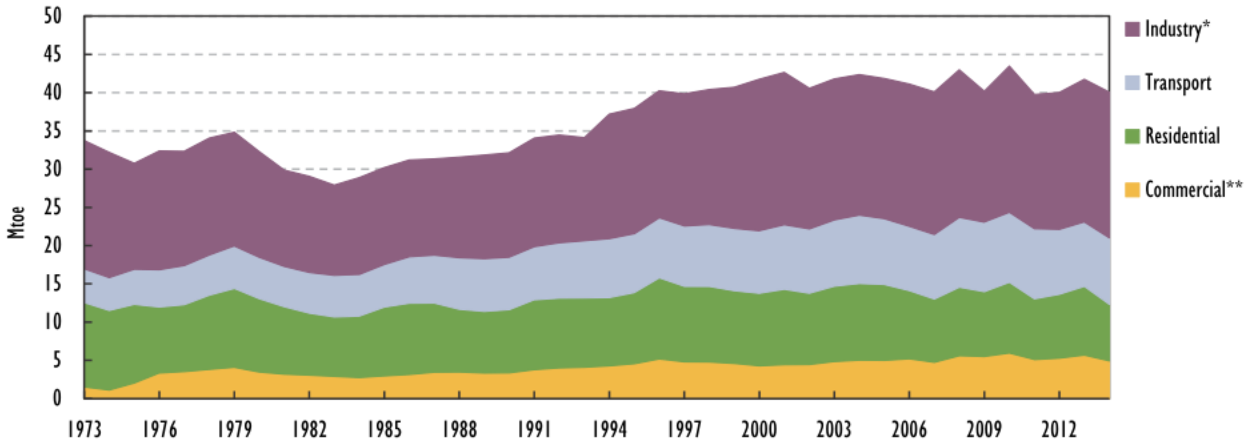


Fig. 2.1.4 Energy autonomy of Wallonia (1985-2012) (Source: ICEDD, 2014)

[6] IEA, 2016. *Energy Policies of IEA Countries: Belgium. 2016 Review*. INTERNATIONAL ENERGY AGENCY, Paris, France. www.ieal.org/statistics.

[7] ICEDD, 2014, *Bilan énergétique de la Wallonie 2012, bilan de l'industrie et bilan global*, ICEDD asbl pour le Service Public de Wallonie, Namur, no ed., 80p.

Total Final Energy Consumption (TFEC) for Belgium remained essentially constant since 2000, albeit with moderate fluctuations, peaking at 43.5 Mtoe[8] in 2010 and reaching 40.1 Mtoe in 2014. That consumption is shared between fuel oil (51.6%), natural gas (22.4%), electricity (17.3%), biofuels and waste (4.4%), coal (2.9%), heat (1.3%) and solar (0.1%). In the frame of this work, it is worth noting that the residential sector accounts for 18.4% of that total final consumption in 2014 (Fig. 2.1.6), although that year appeared to be particularly warm (1,424 degree-days 15/15, compared to the normal 1,894[9]). The residential share was 26.3% in 2013[10], by comparison.



* *Industry* includes non-energy use.

** *Commercial* includes commercial and public services, agriculture, fishing and forestry.

Fig. 2.1.5 Total Final Energy Consumption (TFEC)[11] of Belgium by sector, 1973-2014. (Source: IEA, 2016)

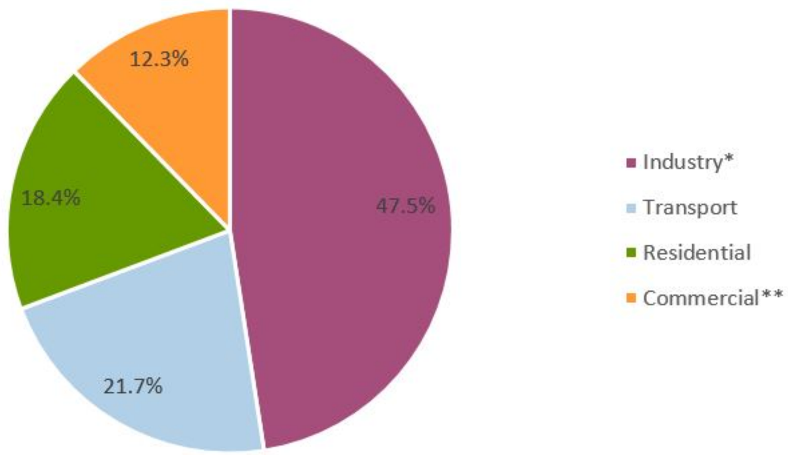


Fig. 2.1.6 Total Final Energy Consumption (TFEC) of Belgium by sector, 2014. (Source: IEA, 2016)

The Fig. 2.1.7 hereunder[12] shows the brutal decrease in total final energy consumption that appeared in Wallonia after the crisis of 2008, mainly due to a brutal decline in industrial activity. In the years

[8] 1 toe = 1 tonne of oil equivalent ≈ 42 GJ ≈ 11,630 kWh; 1 Mtoe = 1.10^6 toe.

[9] ICEDD, 2015. *Bilan énergétique de la Wallonie 2014, bilan provisoire*, ICEDD asbl pour le Service Public de Wallonie, Namur, no ed., 54p.

[10] ICEDD, 2015. *Bilan énergétique de la Wallonie 2013, secteur résidentiel et équivalent*, ICEDD asbl pour le Service Public de Wallonie, Namur, no ed., 152 p.

[11] TFEC is the final consumption by end-users, i.e. in the form of electricity, heat, gas, oil products, etc. As it excludes fuels used in electricity and heat generation and other energy transformations (oil refining, iron and steel, cement), it represents around 75% of the Total Primary Energy Supply (TPES). (Source: IEA, 2016)

[12] ICEDD, 2012. *Bilan énergétique de la Wallonie 2011*, ICEDD asbl pour le Service Public de Wallonie, Namur, no ed., 80p.

following 2010, the TFEC reached 128.9 TWh in 2013, 121.0 TWh in 2014 and 124.4 TWh in 2015, which is nearly 15% less energy consumption, when compared to 1990.

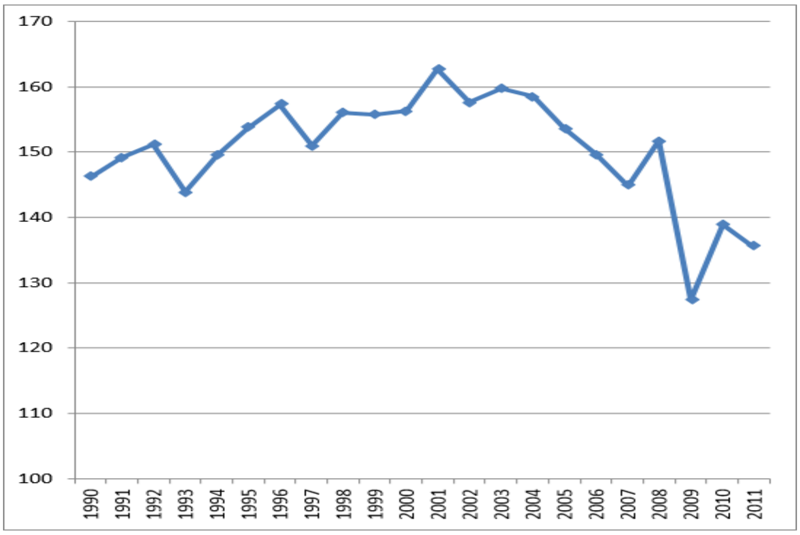


Fig. 2.1.7 Total Final energy Consumption (TFC) of Wallonia, 1990-2010. (Source: ICEDD, 2012)

Related to energy consumptions are their most used environmental indicator among GHG: CO_2 emissions, which reached 89.1 $MtCO_2$ in 2013 (-16% since 1990)[13], considering the fuel combustion for the whole Belgium.

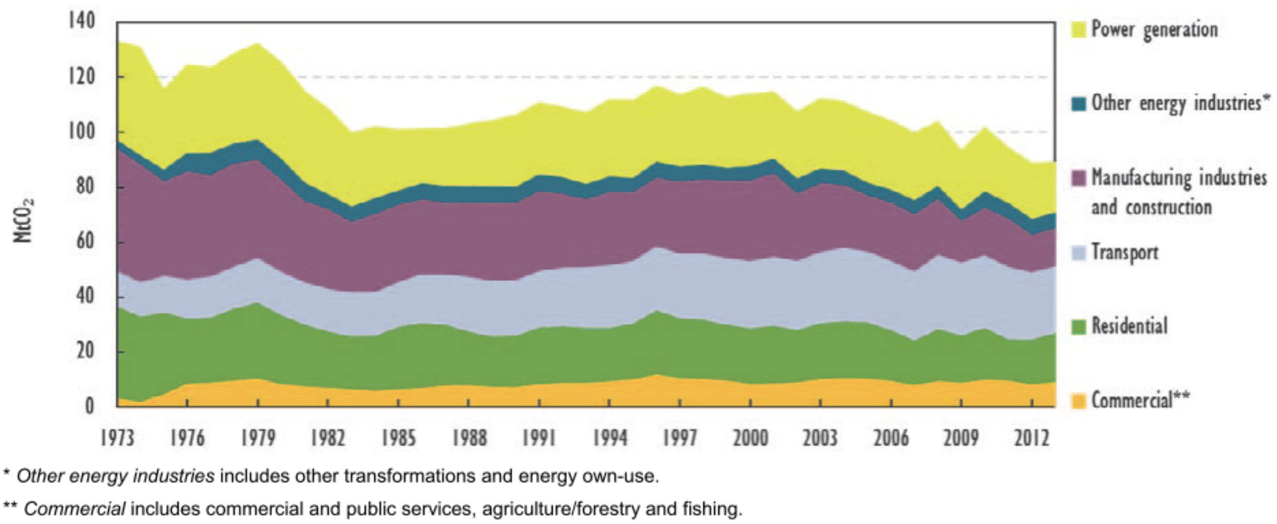


Fig. 2.1.8 CO_2 emissions of Belgium by sector, 1973-2013. (Source: IEA, 2016)

Quite visibly in the Fig. 2.1.8, the "manufacturing industries and construction" sector is the one that presents the most important decrease in CO_2 emissions since 1990. CO_2 emissions from residential (households) use and the commercial sector have increased during the same period (those sectors had a 17.5 and 7.1 share, respectively, in the 1990 emissions). The residential sector accounts for 20% of those 2013 emissions, a normal-to-cold year, when considering degree-days (2,138 DD 15/15). 2013 CO_2 emissions are shared between fuel vectors thus: fuel oil (47%), natural gas (35.4%), coal (13.8%) and others (3.8%)[14].

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[13] IEA, 2016. *Energy Policies of IEA Countries: Belgium. 2016 Review*. INTERNATIONAL ENERGY AGENCY, Paris, France.

[14] IEA, 2016. *Ibid*

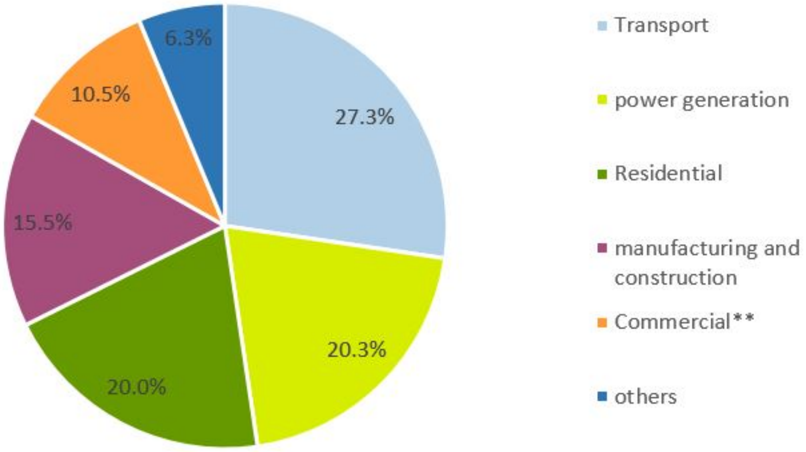

Fig. 2.1.9 Total CO_2 emissions of Belgium by sector, 2013. (Source: IEA, 2016)

In Wallonia, the 2012 CO_2 emissions were two third (=2/3) of the 1990 emissions, when the target that was fixed at the 1997 Kyoto conference was -7.5%. The total GHG emissions follow similar evolutions, with 2015 Walloon emissions (around 36 MtCO2eq, 31% of total 117.4 MtCO2eq Belgian emissions) around 65% of 1990 emissions (78% for Belgium)[15].

Fig. 2.1.10 Evolution of total Green House Gases emissions, 1990-2015. The **orange** curve marks the evolution of Belgian emissions and the **red** curve, the Walloon emissions (base 100 = 1990 emissions). The **grey** marker indicates the Kyoto objective (Source: PSW, 2017)

Reasons for these positive results are to be found in less joyous contexts, among which the crisis of 2008 that lead to the closing of industries (mainly in the steel sector), and the decline of agricultural activities. The crisis is visible in Fig 2.1.10 above as well as Fig 2.1.11 hereunder, as it is marked by more prudent consumption (and related emissions) in 2009 and a rebound effect in 2010 (for more

[15] SPW - SERVICE PUBLIC DE WALLONIE, AWAC - WALLOON AGENCY OF AIR AND CLIMATE, 2017. *Inventory: May 2017*, Namur, Belgium.

on the rebound effect, see chapter 3.6). 2006, 2007, 2011 and 2014 have all been among the warmer recent years, a consequence of climate change that brings visible less heating needs and GHG emission in Belgium and Wallonia. Positive context also brought those CO_2 emissions reductions, however, like the valorisation of methane, the increased use of wood and natural gas as heating sources, or the improvement of energy consuming processes and efficiencies.

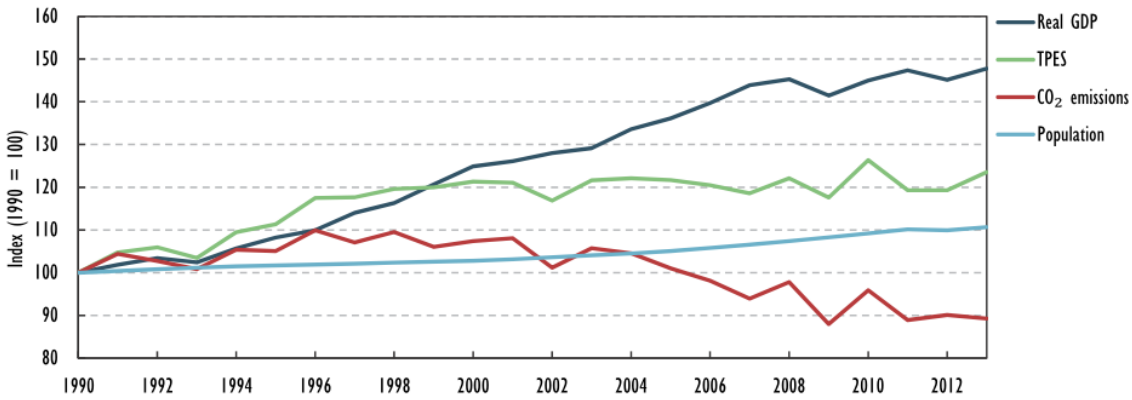

Fig. 2.1.11 CO_2 emissions and main drivers in Belgium 1990-2013. (Source: IEA, 2016)

On the Belgian level, it is important to note that CO_2 emissions decreased, when the total primary energy supply stayed quite stable since 1998, and the Gross Domestic Product (GDP) kept growing. The GDP of Belgium reached 35,195 €/capita in 2017, whereas Wallonia's GDP was slightly lower, at 25,245 €/capita. Energy supply by capita has dropped to 4.8 toe for Belgium (with the IEA average around 4.4 toe for 2014, see Fig. 2.1.12), which is a 15.7% decrease since 2004[16].

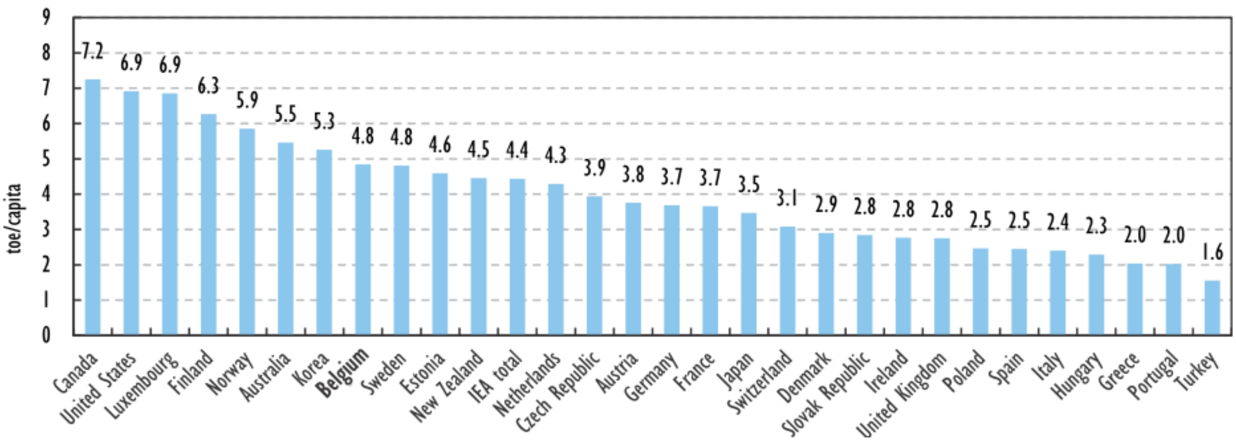

Fig. 2.1.12 Total Primary Energy Supply per capita in IEA member countries, 2014. (Source: IEA, 2016)

This translates into the decrease of Belgium's energy intensity over the years (see Figure 2.1.13), meaning that less energy was needed to produce the same wealth. Energy intensity, measured as the ratio of total primary energy supply (TPES) per unit of real GDP (adjusted for Purchasing Power Parity: GDP PPP) was 0.12 toe/USD 1 000 in 2014. The ratio is higher than the IEA Europe average of 0.10 toe/USD 1 000 PPP, in part reflecting the weight of Belgium's refining and petrochemicals complex[17]. The country's energy intensity is ranked eighth-highest among IEA member countries.

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[16] IEA, 2016. *Energy Policies of IEA Countries: Belgium. 2016 Review*. INTERNATIONAL ENERGY AGENCY, Paris, France.
[17] IEA, 2016. *Ibid*.

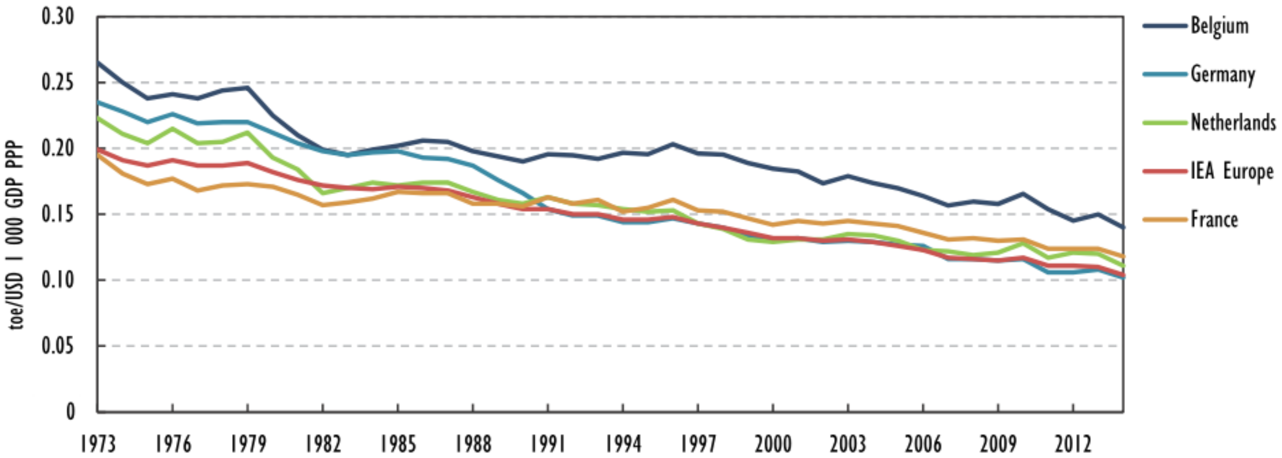

Fig. 2.1.13 Energy intensity in Belgium and in other selected IEA countries, 1973-2014. Note: data for 2014 are provisional for Belgium and estimated other countries. (Source: IEA, 2016)

The residential sector represented 26.3% of the 2013 total final energy consumption of Belgium, and 20% of its total GHG emissions. The IPCC[18] has acknowledged the great economic potential hidden in the reduction of energy consumption and GHG emissions of this sector, meaning that whatever the cost value given to one ton of CO_2 (20, 50 or 100 US$/t$CO_2$-eq, see Fig. 2.1.14 hereunder), existing buildings are the most accessible reduction (and savings) potential.

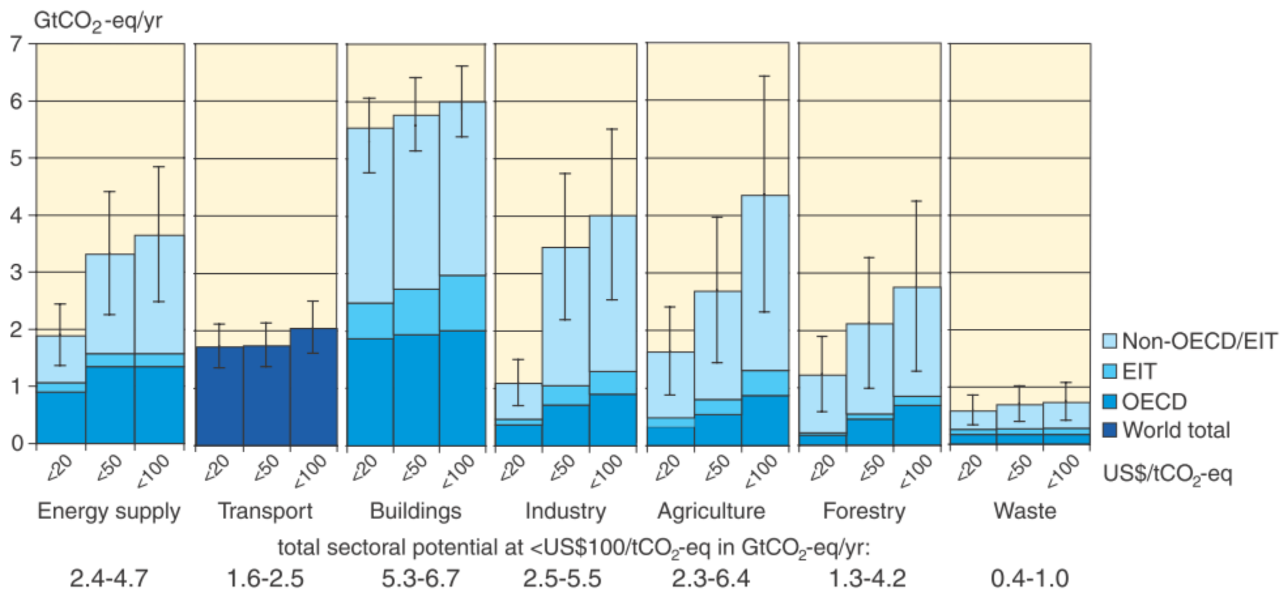

Fig. 2.1.14 Estimated economic mitigation potential by sector in 2030 from bottom-up studies, compared to the respective baselines assumed in the sector assessments. The potentials do not include non-technical options such as lifestyle changes. Categories excluded are: non-CO_2 emissions in buildings and transport, part of material efficiency options, heat production and co-generation in energy supply, heavy duty vehicles, shipping and high-occupancy passenger transport, most high-cost options for buildings, wastewater treatment, emission reduction from coal mines and gas pipelines, and fluorinated gases from energy supply and transport. The underestimation of the total economic potential from these emissions is of the order of 10 to 15%. (Source: IPCC, 2007)

[18] IPCC, 2007: *Summary for Policymakers*. In: *Climate Change 2007: Synthesis Report. Contribution of Working Groups I, II and III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, R.K. PACHAURI and A. REISINGER, (eds.)]. IPCC, Geneva, Switzerland, 104 pp.

Carbon prices are not as high nowadays (8.84 €/tCO_2 on February 2018[19]) but no real taxation has been implemented yet, at least not enough to incite faster energy transition.

New-build stock typically accounts for only 1– 2% of the annual rate of change in the existing residential building stock in developed countries. Some researchers propose that this rate should quadruple in order to meet emissions targets[20]. Rates are slower in Wallonia: after the post-war economic "boom" and the economy and energy crisis of the 70's, the residential stock growth rate dropped from 1.6% in 1971 to 0.6% in 1981, and stabilised since around 0.65%/year.[21] It seems to have reached 1% in recent years, which is still low when compared to the 1.5%/year average among Belgium's neighbours.[22] On the other hand, the demolition rate of old buildings is also quite low at 0.75%/year, one the lowest in Europe[23].

Given that residential growth rate, buildings that stand today will still represent 80% of the 2050 stock[24]: it is therefore of great importance to tackle the energy saving potential that constitutes the rehabilitation of the old stock, by fastening the renovation rate.

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[19] http://www.finances.net/matieres_premieres/co2-emissionsrechte (last visit on February, 28th, 2018)

[20] B. BOARDMAN, 2007. *Examining the carbon agenda via the 40% House scenario*. Building Research & Information, 35(4), 363–378.

[21] F.-L. LABEEUW et al., 2011. *Morphologie urbaine et consommation énergétique du bâti résidentiel pour répondre aux objectifs de réduction des émissions de gaz à effet de serre*, Liège

[22] P. MARBAIX, J. P. VAN YPERSELE 2009. *Etude sur la réduction des émissions de CO_2 dans le parc immobilier du futur*. Belgium, UCL – Institut of Astronomy and Geophysics G Maître.

[23] P. M. BOULANGER, J. COUDER, Y. MARENNE, S. NEMOZ, J. VANHAVERBEKE, A. VERBRUGGEN, G. WALLENBORN, 2013. *Household Energy Consumption and Rebound Effect, Final Report*. Brussels: Belgian Science Policy – 100 p. (Research Programme Science for a Sustainable Development)

[24] CPDT, 2012. *Diagnostic territorial de la Wallonie 2011*, Conférence Permanente du Développement Territorial, Namur, Belgique

2.2 Residential context

2.2.1 Population

On January 1st, 2017, the population of Belgium was established at 11,322,088 inhabitants, distributed among the three Regions[25]:

- Region of Brussels-Capital (RBC): 1,191,604 inhabitants (10.5%);
- Region of Flanders (norther part): 6,516,011 inhabitants (57.6%);
- Wallonia (southern part): 3,614,473 inhabitants (31.9%).

Like in similar parts of the globe, the population has grown quite steadily for decades to reach those numbers. Between 2000 and 2017, the populations have grown 8.2% in Wallonia (average a little below 0.5%/year), and 10.6% globally for Belgium (average a little below 0.6%/year).

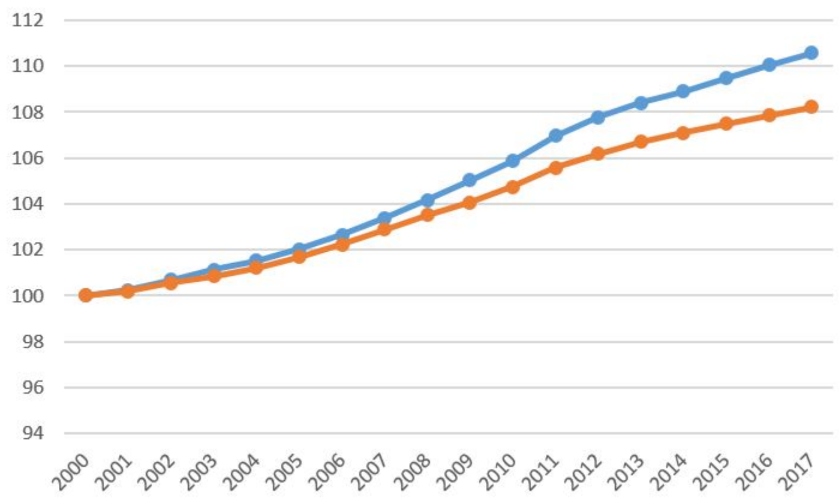

Fig. 2.2.1 Evolution of the population of Belgium (blue curve) and Wallonia (orange curve) (base = 100 in 1990) (Source: official statistics of Belgium[26])

Wallonia covers 16,844 km² of land: an increase in population therefore translates in an increase in population density, which reached 214.6 inhabitants/km² on January 1st, 2017, making it the less dense of Belgium's Regions (Flanders had a density of 479 inhabitants/km² on January 1st, 2016; at the same time, the RBC reached 7,361 inhabitants/km²).[27]

The Walloon population can first be distinguished between genders: 51% are women, 49% are men (and the variations, mostly in favour of women, are of very little amplitude and rates).

Wallonia knows a sensible ageing of its population, linked to the continuous increase in life expectancy and the massive arrival of "baby boomers" into the third age (according to the Federal Planning Bureau, the share of people aged 65 years old or older is to raise to 24.9% by 2061, compared to 17.8% nowadays)[28].

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[25] Official statistics of Belgium, available on https://statbel.fgov.be/fr/themes/population/, last visited on February 5th, 2018.
[26] available on https://statbel.fgov.be/fr/themes/population/, last visited on February 5th, 2018
[27] IWEPS, 2017. *Key numbers of Wallonia, 2017 edition*, Wallonia.
[28] IWEPS, 2017. *Ibid.*

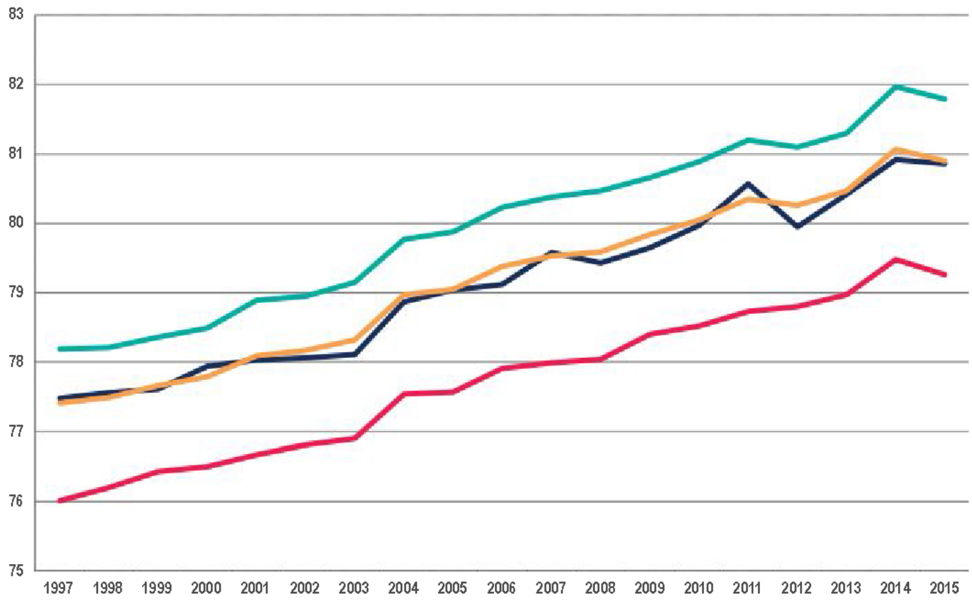

Fig. 2.2.2 Evolution of life expectancy at birth (men and women). The red curve marks the evolution for Wallonia, green for Flanders, dark blue for RBC and orange for Belgium. (Source: IWEPS, 2017)

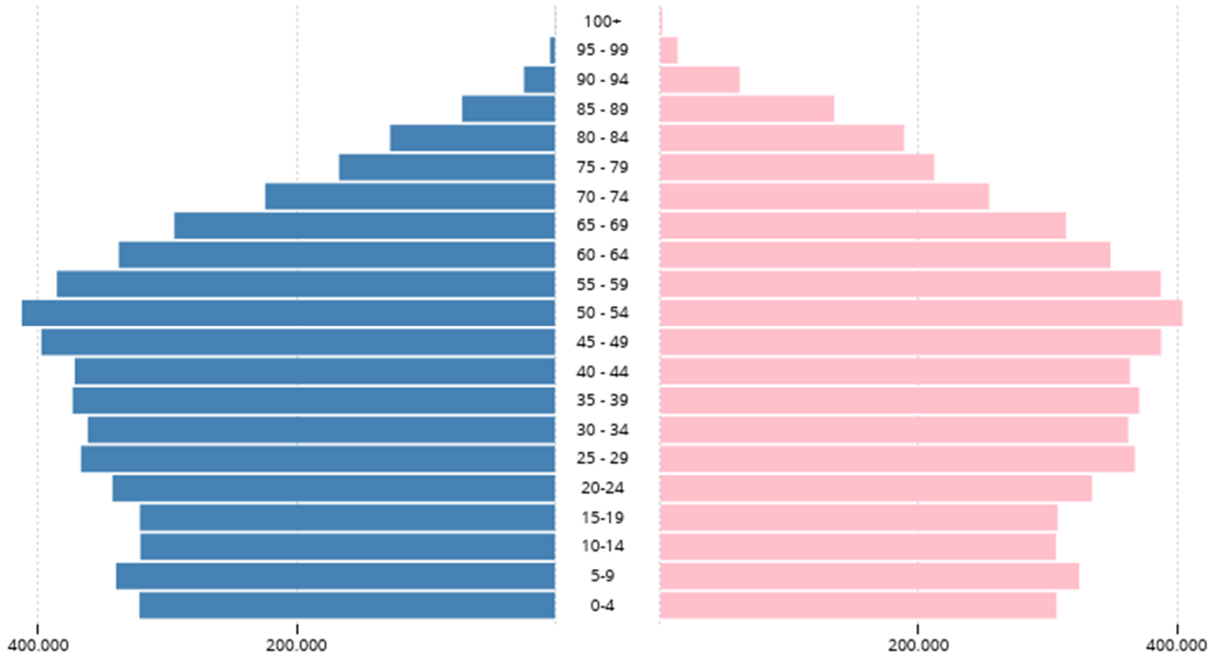

Fig. 2.2.3 Age pyramid of the Walloon population on January 1st, 2017. (Source: official statistics of Belgium[29]).

The age "pyramid" is more and more shaped like a "haystack". The average age of the Walloon population increases by a year every 9 years (38.1 years in 1990, 40.4 years in 2010, 41.0 years in 2016… and previsions of an average 44 years old in 2061).[30] The head of 31.2% of Walloon households is aged 45 years or less. 21.1% of households' heads are 45 to 54 years old, 19.1% between 55 and 64 years old, and 28.6%, 65 years old or more.[31]

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[29] available on https://statbel.fgov.be/fr/themes/population/, last visited on February 5, 2018

[30] CPDT, 2012. *ibid.*

IWEPS, 2017. *ibid.*

[31] M.-N. ANFRIE, S. CASSILDE, M. KRYVOBOKOV, S. PRADELLA, 2014. Enquête sur la qualité de l'habitat en Wallonie – Résultats clés, Rapport du Centre d'Études en Habitat Durable, Charleroi, 71 pages.

On January 1st, 2017, 47.6% of Belgians (49.7% of Walloons) were single, 37.3% (33.5%) were married, 6% (6.5%) were widow(er)s, and 9% (10.2%) were divorced[32]. If marital status is in itself a relevant factor, it cannot alone define the composition of the household or the number of inhabitants. Figure 2.2.4 hereunder considers another kind of repartition, also (but not only) based on marital status:

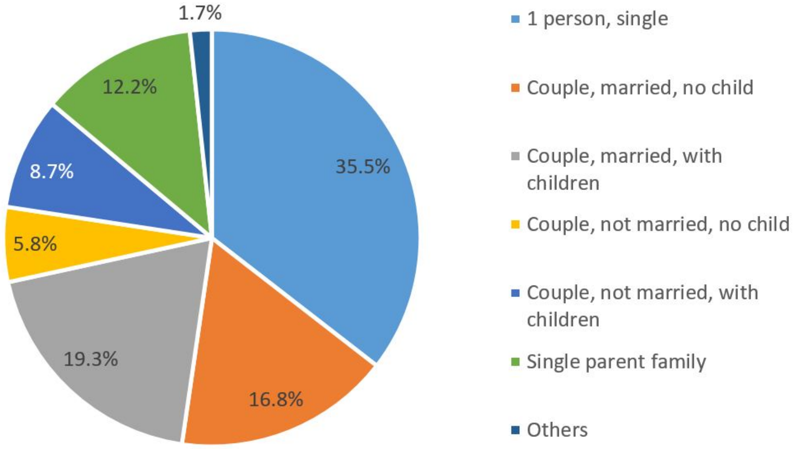

Fig. 2.2.4 Repartition of Walloon households according to type on January 1st, 2017. (Source: Official statistics of Wallonia[33])

2.2.1.1 Households

A household is defined[34] as an ensemble of persons that usually inhabit the same dwelling and live together. It can be constituted by one person living alone, or two or more persons united (or not) by family links. One could say that the evolution of households' structure has shown instability for decades now in western civilisation, which basically translates into a growing number of isolated and single-parents households, along with a fast decrease in the average household size.

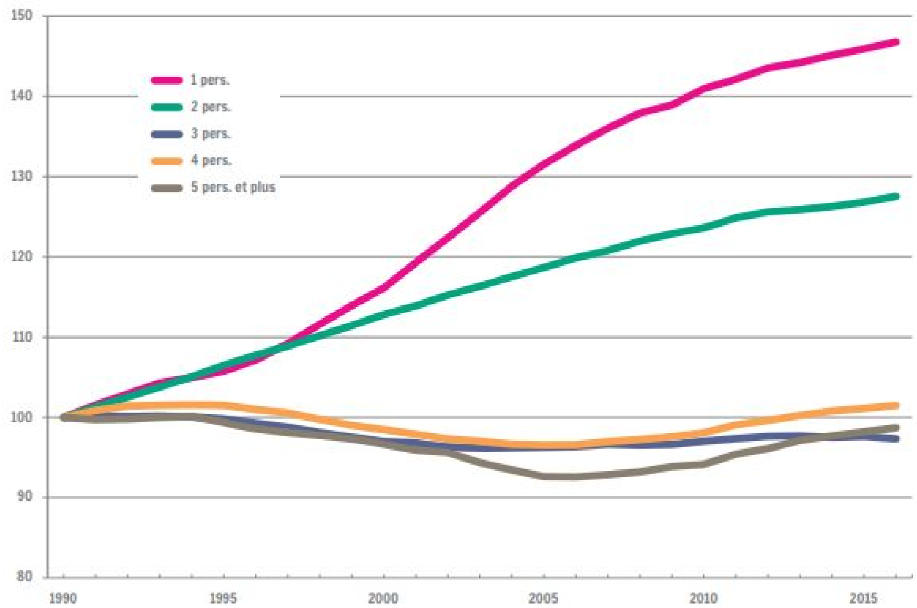

Fig. 2.2.5 Evolution of private households' size in Wallonia (base 100 = 1990) (Source: IWEPS, 2017)

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32 Official statistics of Belgium, available on https://statbel.fgov.be/fr/themes/population/, last visit on Feb. 5th , 2018

33 available on https://statbel.fgov.be/fr/themes/population/, last visited on February 6th, 2018

34 SPF-Economie / Direction générale Statistiques, https://statbel.fgov.be/fr/themes/menages, last visited on May 17th, 2018

Between 2002 and 2008, Wallonia added 58,000 isolated households units and 54,000 single-parents households units to its count, while the number of couples with children decreased by 43,000 units[35]. The main reason for this might be found in the multiplication of possible lifestyles and life paths in today's society. The main consequence is the decrease in households' size, which in Wallonia went from 2.54 members in 1991[36] to 2.3 members in 2016[37]. During that period, the only households that grew in absolute numbers are those composed of one or two members, so that the absolute increase in households' number is superior to that of inhabitants' number. Graphs hereunder could be read thus: "households of one person represent 15.3% of the population and 35.1% of households", etc. Given that we can approximate that one household corresponds to one residential unit, this gives hints of the size of the stakes related to that demographical tendency.

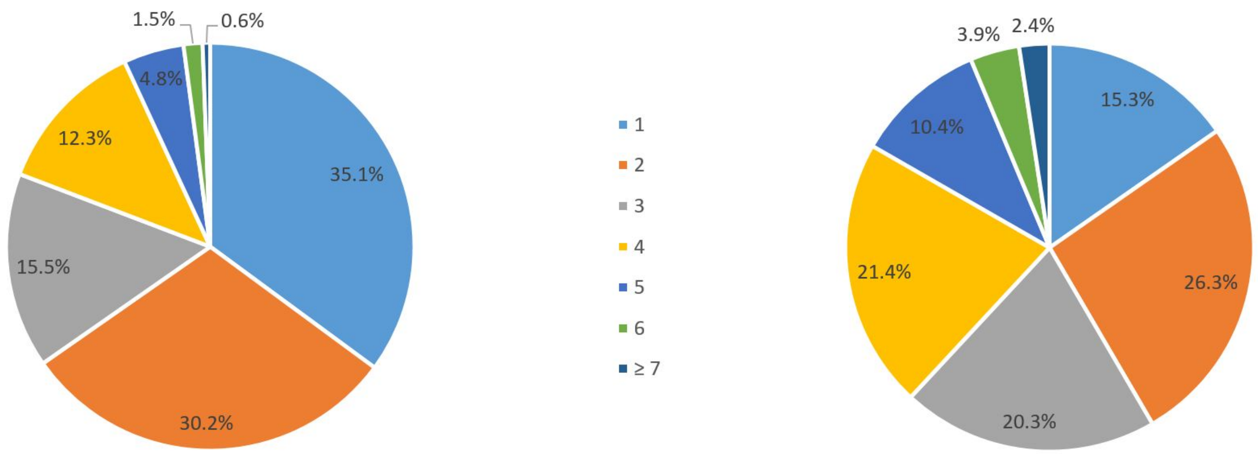

Fig. 2.2.6 Repartition of the number of private households (**left**) and total population (**right**) according to the number of persons per household (Source: ICEDD, 2015)

The recent increase in "small" households, combined with the economies of scale that can be achieved in bigger households, indicate that the average households' energy consumption might have grown in the last few years, but the Fig. 2.2.7 hereunder[38] shows that it actually fluctuated and fell around 50% between 1975 (around 3 toe/household) and 2010 (1.5 toe/household). The ICEDD (Institut de Conseil et d'Etudes en Développement Durable - *Institute for Council and Studies in Sustainable Development*) released similar results in its energy assessment of Wallonia in 2015, adding that between 1990 and 2014, the total final energy consumption per household dropped from 21.8 to 16 MWh/dwelling (-27%), after removing the influence of climate. In the meantime, electricity consumption went up by 22% (from 3.6 to 4.4 MWh/dwelling).[39]

Boulanger et al. observe three periods in which the energy consumption obeys to different dynamics linked to economy (see Figure 2.2.7):

- The first period, 1960-1973, showed a continuous increase of energy consumption that followed an increase of household incomes, while energy prices were low.

[35] CPDT, 2012. I*bid.*

[36] CPDT, 2012., I*bid.*

[37] IWEPS, 2017. I*bid.*

[38] P. M. BOULANGER, et al., 2013. *Ibid.*

[39] ICEDD, 2015. *Ibid*

- Energy consumption decreased after the first oil crisis in 1973 (when energy prices were high), while household incomes were only slightly increased. After that drop, consumption stabilised until 1998.
- Since 1998, energy consumption has begun to decrease progressively, due to another increase in energy prices, whereas incomes remained stable.

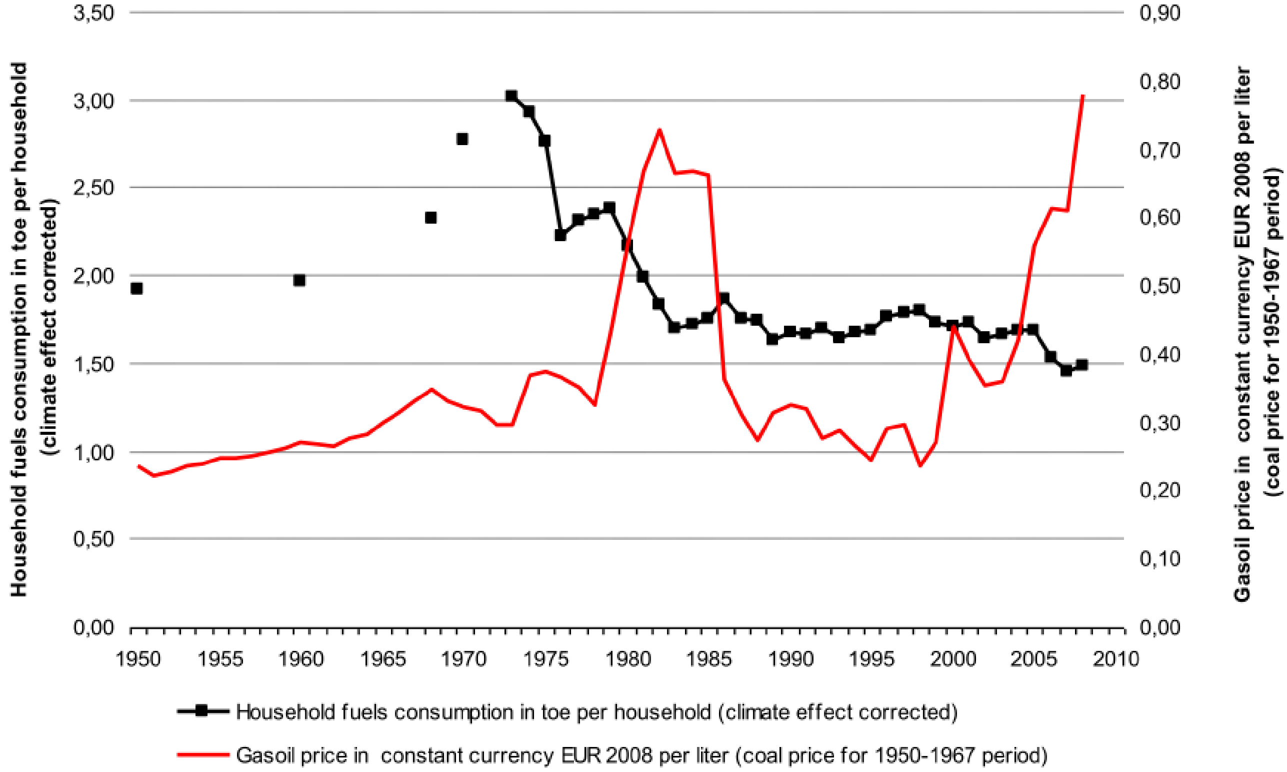

Fig. 2.2.7 Evolution of fuel consumption per household (climate effect corrected), compared to the gasoil price in constant 2008 € per litre. (Source: Boulanger et al., 2013)

2.2.1.2 Wealth

Wealth is an important factor, as it is proven that direct and indirect energy consumption grow with financial income, as does the ecological problem awareness (see chapter 3). An important indicator for Wallonia can be found in the GDP, which growth rate (in volume) for 2015 was 0.9%. Average growth rate between 2003 and 2015 is a little higher, at 1.2% (inferior to Flanders' 1.8% and superior to Brussels' 0.8%, still similar to Eurozone rate at 1.0% and EU-28 rate at 1.2%)[40].

In 2014, the average adjusted disposable income of Walloon households was 23,107 €/inhabitant. The saving rate in Wallonia has dropped to 8.3% in 2014, after continuous decrease (at least since 1990 according to available data). The graph hereunder (Fig. 2.2.8) shows the repartition of tax reporting according to levels of total net taxable annual income. It is based on 2011 income tax return data, provided by the Public Federal Service Economy – Operational Directorate-General for statistics and economic information. It underlines some disparities on income levels that are relevant to explain (or influence) the energy consumption of households.

[40] IWEPS, 2017. *ibid.*

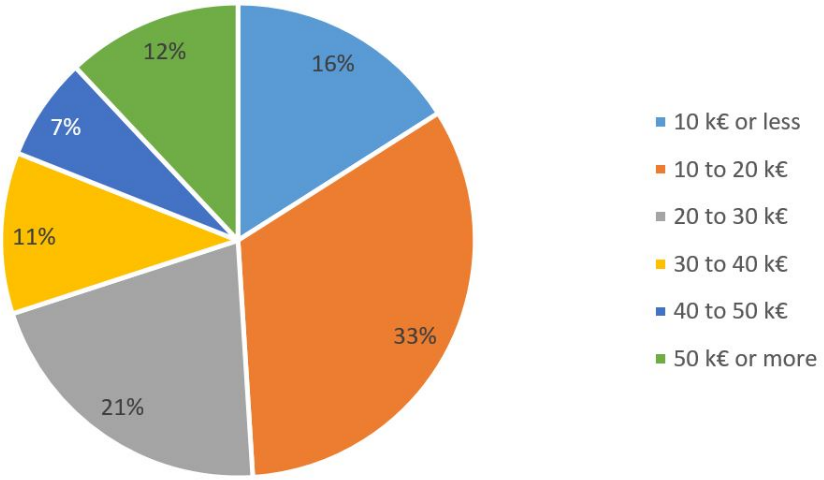

Fig. 2.2.8 Repartition of tax reporting according to levels of total net taxable income (2011 income) (Source: Public Federal Service Economy – Operational Directorate-General for Statistics and economic information, 2012)

Small households, composed of one or two members (isolated, single-parents, elderly…) show higher shares of socially and financially weakened households[41]. Considering that nearly 50% of the Walloon households live under 20,000 €/year, and that in 2014, 18.3% of the Walloon population lived in a household which equivalent net income was inferior to the poverty threshold (40% among single-parents households)[42], one could postulate that an important portion of the population cannot afford the level of comfort that we came to expect in our western civilisation. The average households' expenses are shown in Fig. 2.2.9 hereunder, which shows an average 30% of income devoted to the dwelling and its energy consumption (although it must be noted that these 30% also incorporate the rent or loan payments and water uses, for example).

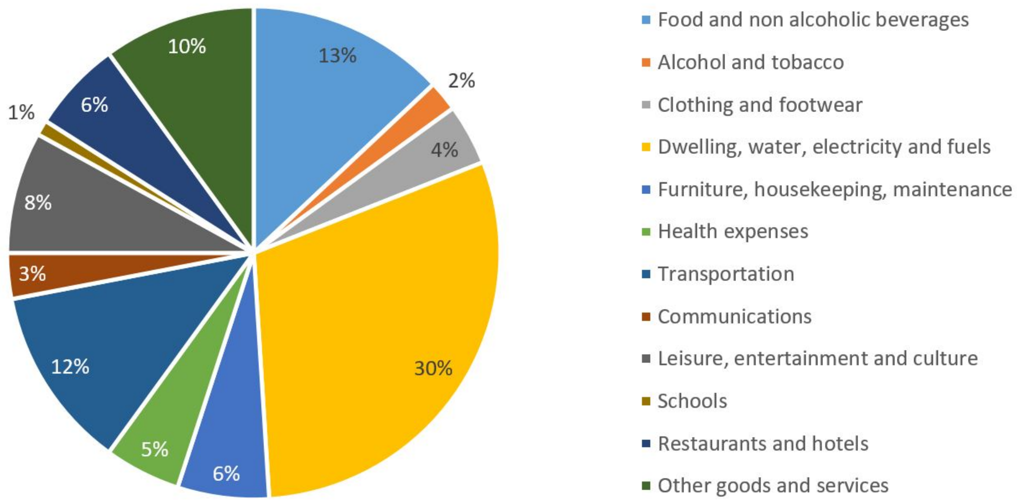

Fig. 2.2.9. Average repartition of expenses in final consumption products for Walloon households in 2016 (Source: Official statistics of Belgium[43]).

[41] P. M. BOULANGER, et al., 2013. *Ibid.*
[42] IWEPS, 2017. *Ibid.*
[43] available on https://statbel.fgov.be/fr/themes/menages/, last visited on February 6th, 2018

2.2.1.3 Education and employment

Education is the next important parameter for analysing the Walloon population. The improvement of education levels in Wallonia is shown in the last decades by key indicators[44]:

- The share of population aged under 25 that did not pursue school and obtained more than primary level diploma dropped from 40% in 1991 to 16% in 2016.
- Two third of the Walloon population, aged 25 and more, held a diploma from secondary school or more in 2016. That is twice the number from 1991.
- A little less than half the people who successfully went through secondary school went on and gained a diploma from superior education, representing 31% of the 2016 population aged 25 or more.

The following graph (Fig. 2.2.10) shows the repartition of levels of education in the Walloon population for 2015 (left) and the evolution of that repartition, from 1991 to 2016 (right). The evolution is, indeed, quite clear: the global level of education rises in Wallonia. This does not mean that there is no more illiteracy, nor does it necessarily means that this global improvement in education automatically translates into smarter behaviours, but it is generally related to a globally better understanding of stakes and solutions (see chapter 3).

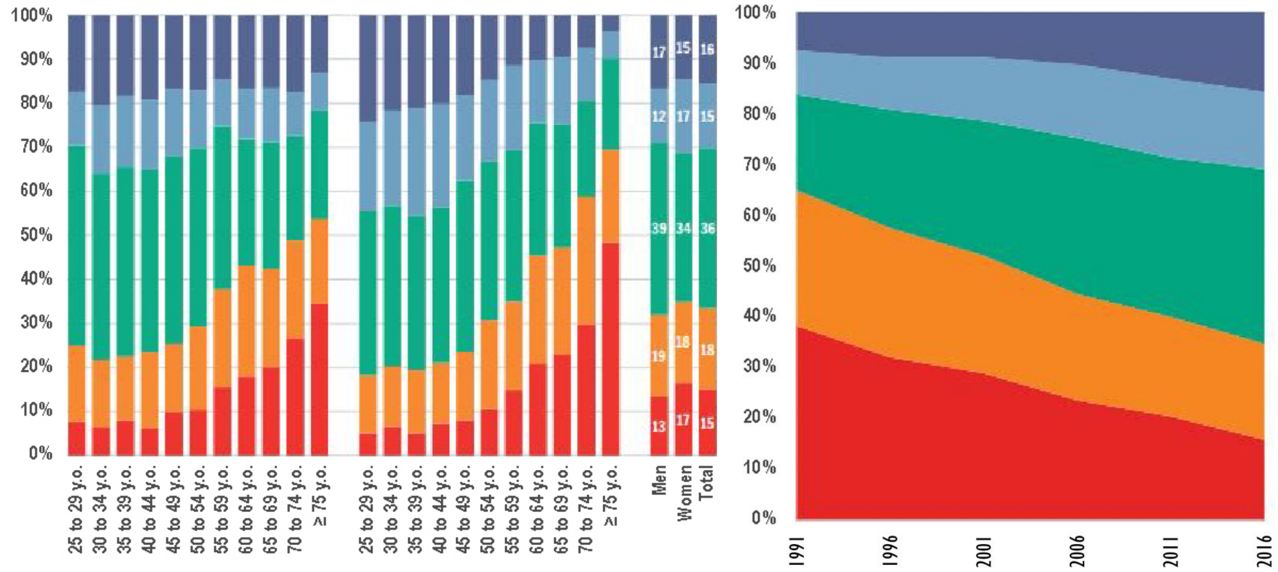

Fig. 2.2.10 Level of education of the Walloon population in 2015, according to gender and age (**left**) and evolution of education levels in Wallonia (1991 – 2016) (**right**) **Red** indicates people with "no diploma or primary school diploma", **orange** "inferior secondary school (1-3)" diploma, **green** "superior secondary school (4-6)" diploma, **light blue** "superior education, short" diploma and **dark blue** "superior education, long" diploma. (Source: IWEPS, 2017)

The level of education obviously has an influence on professional insertion, as the employment rate increases with the level of the diploma: 89% of Walloons, aged 25 to 49, with superior education, have a job, as do 75% of people with a diploma from superior secondary school, 57% of people with a diploma from inferior secondary school, and 36% of people with a diploma from primary school.[45]

Employment and unemployment rates, job creations or interior job growth rate are sensible indicators, used for analysing the job market as well as for measuring the health of economy and

[44] IWEPS, 2017. *Ibid.*

[45] IWEPS, 2017. *Ibid.*

efficiency of economic and social policies. Based on data from the recent federal survey on the workforces, the employment rate of people aged 15 to 64 was evaluated at 57.1% in Wallonia in 2016 (meaning that 57.1% of people in working age are occupied, compared to 66.5% in Flanders and 55.3% in RBC). Among 20 to 64 years old, the rate grows to 62.6% in Wallonia, still inferior to the Belgian average (67.7%).

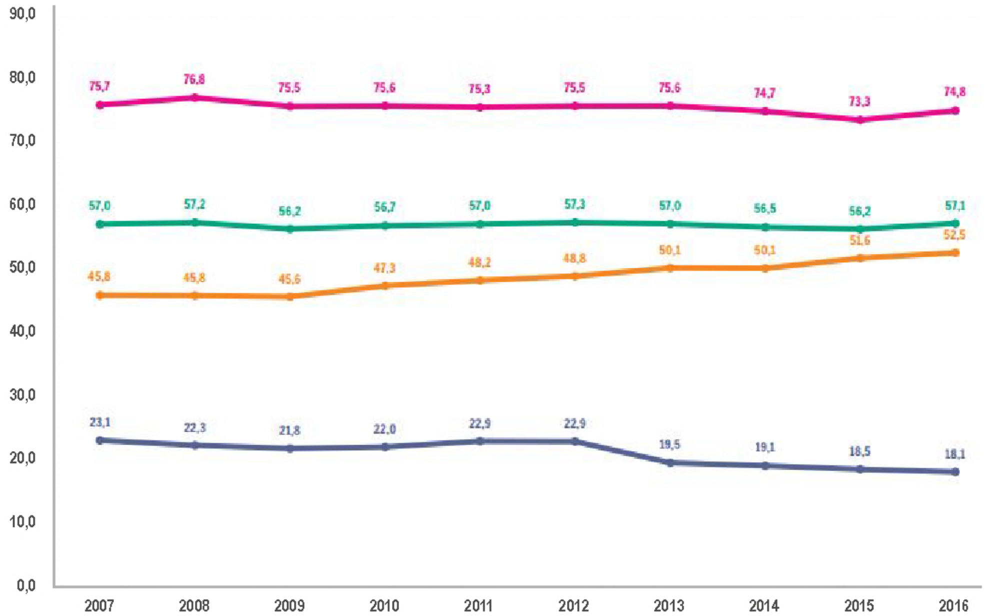

Fig. 2.2.11 Evolution of employment rates (in %, by International Labour Organization - ILO standard) according to age brackets in Wallonia. Dark **blue** curve is for 15 to 24 years-old; **pink** for 25 to 49 years old; **orange** for 50 to 64 years old; **green** for the whole population in working age (15 to 64 years old) (Source: IWEPS, 2017)

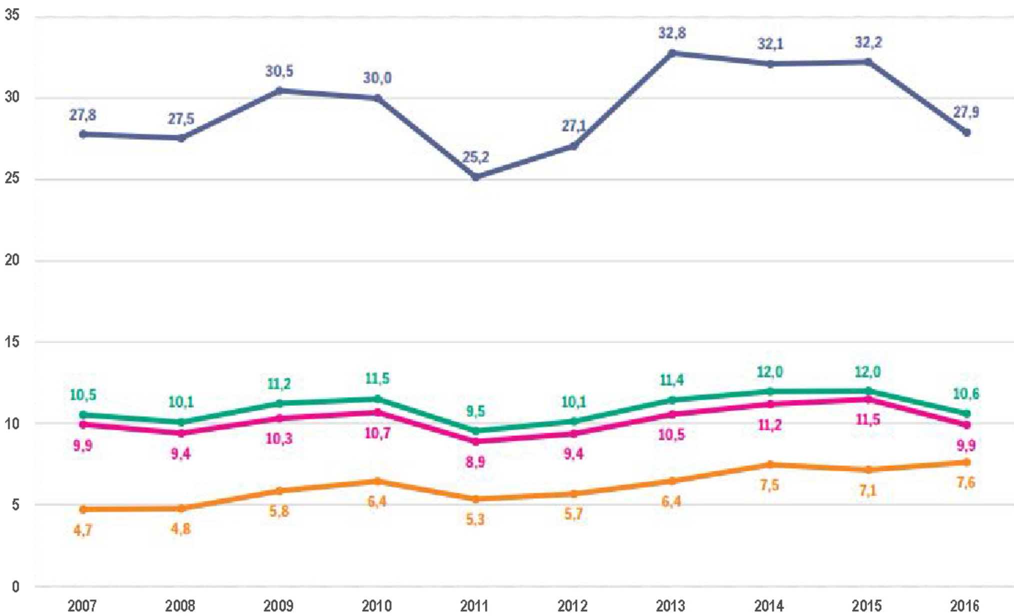

Fig. 2.2.12 Evolution of unemployment rates (in %, by International Labour Organization - ILO standard) according to age brackets in Wallonia. Dark **blue** curve is for 15 to 24 years-old; **pink** for 25 to 49 years old; **orange** for 50 to 64 years old; **green** for the whole population in working age (15 to 64 years old) (Source: IWEPS, 2017)

The unemployment rate, in 2016 in Wallonia, was of 14.6% according to the administration, and 10.6% according to the survey data used in international comparisons. Unemployment has been higher among women than men for a long time (it has been registered continuously between 1983 and 2011), but the situation has reversed in the past few years.

26.6% of people worked part-time in 2016 (around 10% among men, 45% among women, 35% among 15 to 24 years old, 25% among 25 to 49 years old and 30% among 50+ years old). 10.7% of people had temporary employment in 2016, with similar rates among men and women; youngsters are the only overly represented sociodemographic group, with 48.4% of 15 to 24 years old are concerned. On December 31st, 2015, Wallonia had a little more than 270,000 independent workers, which represent a little more than 25% of total employments, and a little more than a 20% increase since 1995. During that period, part-time independents' number grew much more than full-time independents' number (+87.4%, compared to +7.6%).

2.2.1.4 Territory distribution

The population of Wallonia is not evenly distributed on the territory. The chart hereunder (Fig. 2.2.13) highlights a clear concentration of the population along what is called the Walloon Backbone which links the main industrial cities of Wallonia (Mouscron, Tournai, Mons, Charleroi, Liège and Verviers), following the Sambre and Meuse rivers furrows.

Other high density places surround the Region of Brussels-Capital, mainly municipalities that must contain Brussels' urban sprawl since the 1950's. The same situation is arising in municipalities that surround the Grand-Duchy of Luxemburg, on the extreme south of the Region, due to employment attractiveness. The rest of the southern part of Wallonia is composed of low-density areas.

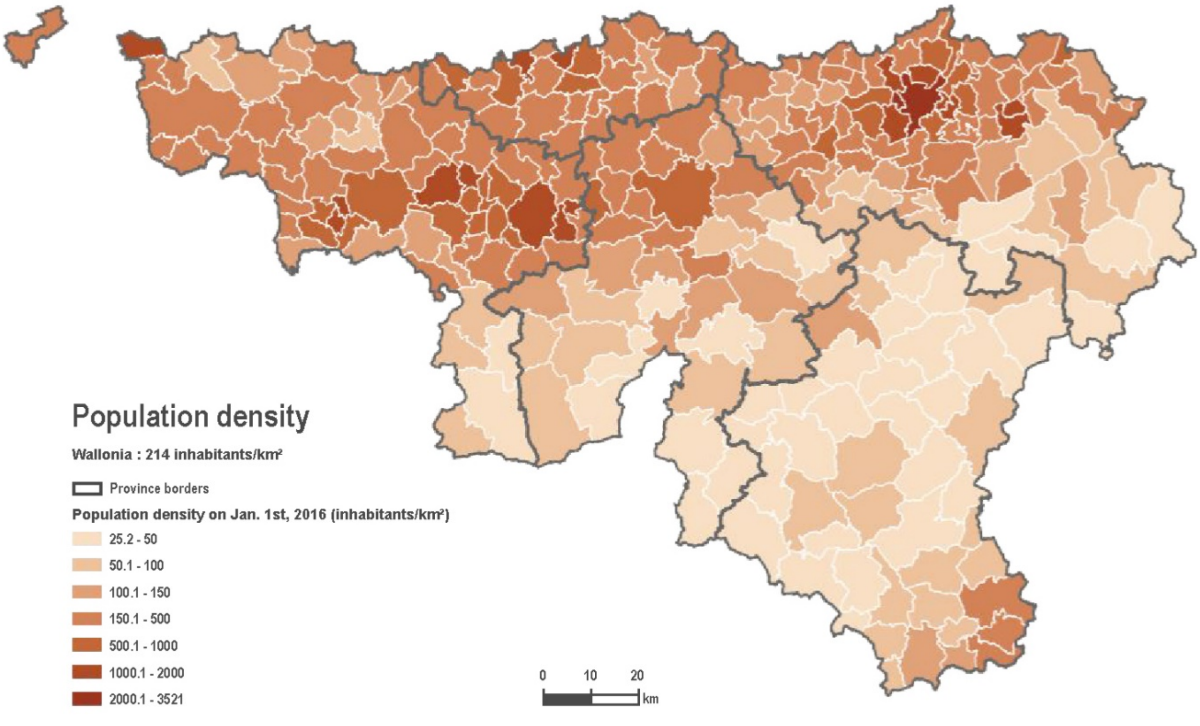

Fig. 2.2.13 Population density of Wallonia on January 1st, 2016. (Source: IWEPS, 2017)

On January 1st, 2016, 54% of the Walloon population was living in urban regions (not only centres). Liege holds the largest number of inhabitants in Wallonia, with nearly 200,000 in the city itself, nearly 500,000 in the agglomeration (13 municipalities), and 670,000 in the "urban region" (35 municipalities).[46]

[46] IWEPS, 2017. *ibid.*

The real-estate stock is characterised by a centrifugal structure around (big) city centres that notably followed the development of Walloon steel industry in the second half of the 20th century. From urban centres to the outskirts, the average age of buildings decreases, as do the shares of apartments and small row houses and real-estate prices (purchase or rent); the share of big, isolated houses and gardens, increase. This centrifugal force is still visible today: between 2006 and 2016, urban regions municipalities have grown by nearly 80,000 inhabitants (+4.3%), whereas the other parts of Wallonia grew by nearly 110,000 inhabitants (+7%).[47] This tendency is visible since the 1970's, when territories outside urban regions gained more (or lost less) inhabitants than urban regions.

Fig. 2.2.14 Annual variation of population in (**pink** columns) and out (**green** columns) of urban regions (Source: IWEPS, 2017).

In 2016, every Walloon inhabitant used, on average, 296 m² of land for his/her residence (including the dwelling, garden, garage…). It is obviously linked to the evolutions of population and households' numbers, but also to the modes of dwelling production. When related to the number of inhabitants, the use of residential area in Wallonia shows signs of loosening (as opposed to a densification): it was 225 m²/inhabitant in 1985. During the same period of time (1985-2016), the population grew by 12.3%, and the urbanised residential stock grew by 47.7%.[48] This tendency, however, is not evenly spread on the Walloon territory, as municipalities from the southern parts of Wallonia show clearer signs of residential loosening that could be linked to lower real-estate prices and large availabilities in residential zones.

[47] IWEPS, 2017. *ibid.*

[48] IWEPS, 2017. *ibid.*

2.2.2 Residential estate stock

2.2.2.1 Introduction

A number of recent studies can be used to deepen the analysis of the residential stock, and have been used to brush this general overview, among which:

- M. DESCAMPS, *Approche d'un gisement d'économie d'énergie par la rénovation du secteur résidentiel wallon*, TFE présenté en vue de l'obtention du Diplôme d'Etudes Approfondies en Faculté des Sciences Appliquées, Université de Liège, Liège, 2008
- P. M. BOULANGER, et al., 2013. *Household Energy Consumption and Rebound Effect, Final Report*. Brussels: Belgian Science Policy – 100 p. (Research Programme Science for a Sustainable Development)
- F.-L. LABEEUW, et al., 2011. *Morphologie urbaine et consommation énergétique du bâti résidentiel pour répondre aux objectifs de réduction des émissions de gaz à effet de serre*, Liège
- D. N. EYKERMAN, P. C. PEETERS, R. VERHOEVEN 2009, *Pathways to World-Class Energy Efficiency in Belgium*. Belgium, Mckinsey & Company.
- T. DE MEESTER, et al., 2009. *Guide de la Rénovation basse énergie des logements en Belgique*, Low Energy Housing Retrofit Program, Politique Scientifique Fédérale, Bruxelles.
- CPDT (Conférence Permanente du Développement Territorial), 2012. *Diagnostic territorial de la Wallonie 2011*, Namur, Belgique
- M.-N. ANFRIE, S. CASSILDE, M. KRYVOBOKOV, S. PRADELLA, 2015. *Les chiffres-clés du logement en Wallonie – 2015*, Rapport du Centre d'Études en Habitat Durable, Charleroi, 236 p.

2.2.2.2 Typology characteristics

Houses represent around 83% of the residential stock in Wallonia. It includes row houses, semi-detached and detached houses, farms and castles.[49] This proportion has slowly decreased for decades, as the apartment stock's growth rate is considerably higher than the average presented above (+2.9% for Wallonia in 2014).

The building stock in Wallonia, especially dedicated to housing, is relatively old. All studies concur on that point: around half of it has been built before 1945, 70% before the first oil crisis of the 1970s and 75% before the first thermal regulations, in 1985. An example is given hereunder (see Fig. 2.2.15), with data from the 2013 energy assessment of Wallonia by the ICEDD[50]

The Belgian data is mainly there for the comparison, and to highlight the much higher share in old dwellings in Wallonia. Zooming on the analysis level, one could see that those rates are even higher in the province of Hainaut (West part of Wallonia), where the pre-war buildings reach nearly 60% of the total. Provinces of Namur (49.9%) and Liege (48.1%) follow. This can be linked to the (extra-) urban developments along the Sambre-and-Meuse furrows mentioned before. Confirming this, is the top trio of cities with higher share of old (pre-war) residential housing: Charleroi (63.6%), Liege (58.4%) and Mons (56.1%), main industrial centres of the "Walloon Backbone". Given that this axis

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[49] S. PRADELLA, 2015. *Les chiffres-clés du logement en Wallonie – 2015*, Rapport du Centre d'Études en Habitat Durable, Charleroi, 236 pages.

[50] ICEDD, 2015. *Ibid.*

also shows higher share of lower income families, it should therefore appear as particularly strategic to any policymaker trying to help households reduce their energy consumption.

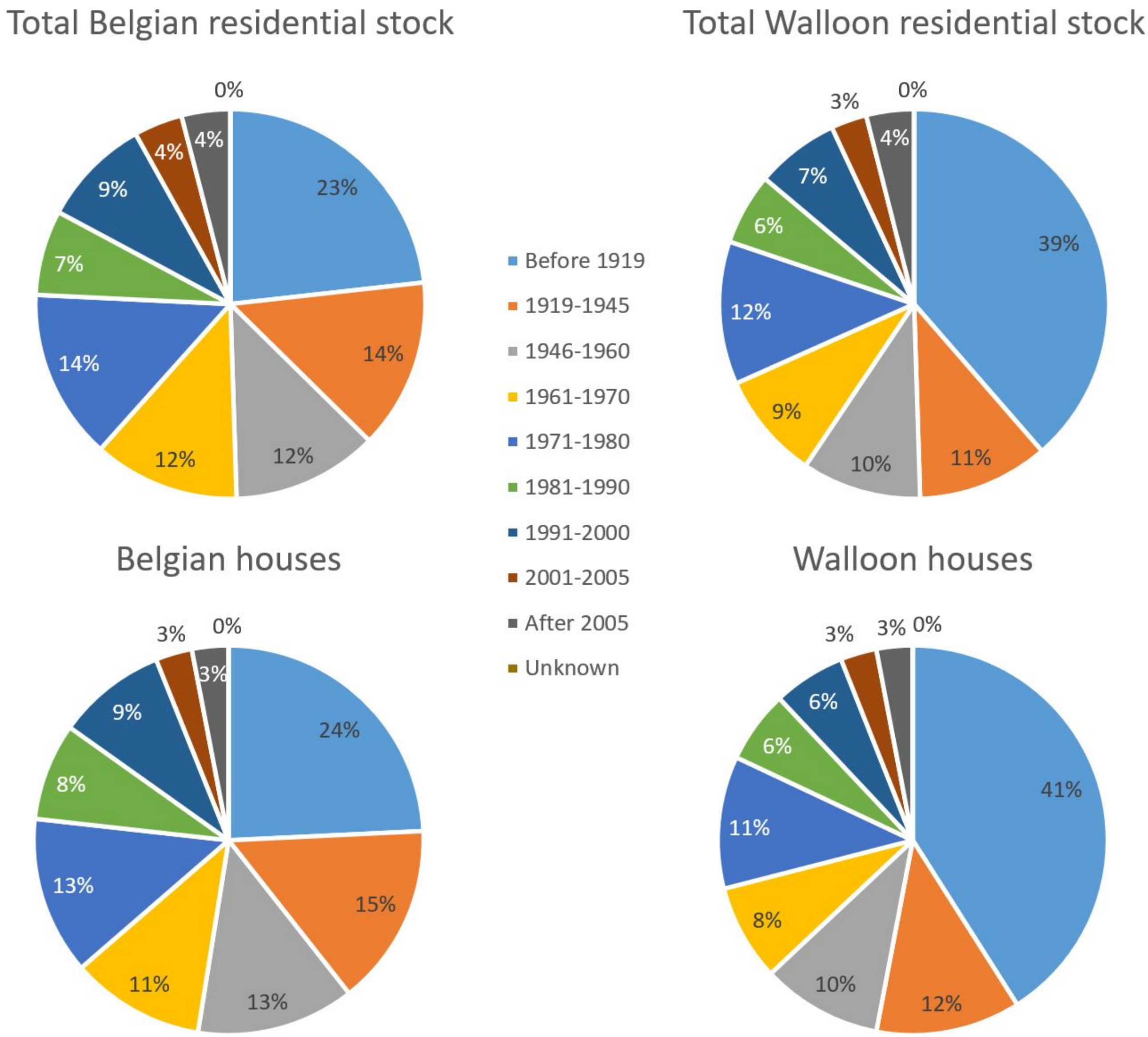

Fig. 2.2.15 Distribution of the Walloon (**left**) and Belgian (**right**) residential stock (**above**), and houses alone (**below**) according to the building period (Source: ICEDD, 2015)

An international comparison made by McKinsey in 2009[51], based on 2005 data among five European countries, confirms the higher shares of old buildings in the Belgian stock. In the Figure 2.2.16 below, the Walloon numbers would be 39% (<1919), 11% (1919-1945), 19% (1946-1970), 18% (1971-1990) and 20% (>1990). The periods defined in the Fig.2.2.16 hereunder are significant, because they are based on the evolution of buildings modes and techniques. Vernacular housing was largely made of solid walls, thick and built with local resources, like stones. The industrial evolution of the Region brought terracotta bricks, which were used in solid walls until the 50's. Cavity walls appeared and were generalised after the Second World War, making good use of concrete to separate the structure and cladding by a cavity layer. Physical links between layers are needed, creating many thermal bridges.

[51] D. N. EYKERMAN, P. C. PEETERS, R. VERHOEVEN, 2009, *Pathways to World-Class Energy Efficiency in Belgium*. Belgium, McKinsey & Company.

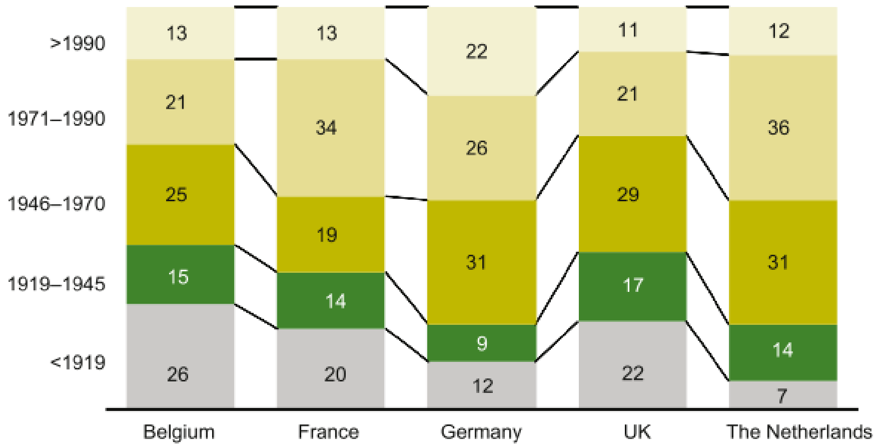

Fig. 2.2.16 Relative age of building stock in selected European countries, in % of housing stock, based on 2005 data. (Source: D. N. EYKERMAN, et al., 2009)

Some studies prefer to segment the last two periods (1971-1990 and >1990) into three. Thermal losses through cavity walls were largely decreased after 1970, when thermal insulation appeared and thermal bridges were reduced. But real improvement of the overall performance appeared in 1985, with the introduction of the first thermal regulations to new buildings, and 1996, when these thermal regulations were tightened and ventilation became regulatory.

Fig. 2.2.17 Average energy consumption [kWh/year] per age category, 2010. (Source: Eurostat, 2012[52])

The graph in Fig. 2.2.17 above shows that the construction period influences the energy consumption of the Walloon and Belgian residential stock, but also that it is not the only parameter. The dynamics are indeed interesting. The average consumption in the oldest of our buildings is also the highest (except for Walloon dwellings built between 2001 and 2007, which is quite surprising). As mentioned above, the architectural heritage is split between dwellings that are mainly outside urban centres and public buildings in cities. The Walloon pre-World War I residential stock, therefore, includes a

[52] EUROSTAT, 2012. *Energy Consumption Survey for Belgian Households*, Federal Public Service (FPS) Economy, Belgium.

high share of isolated vernacular homes in the countryside, which could be an explanation. The average consumption drops in buildings constructed during the 1921-1945 period, which can be partly explained by the generalisation of terracotta bricks. Other reasons however could be found in the higher share of attached urban dwellings, which benefit from lower wind exposure, higher heat island effect, and low areas of heat loss surfaces. Then the average consumption gradually increases between post-war dwellings and the ones that benefited from the latest (not the first) thermal regulations. Some explanations to how thermal regulations could have brought higher average consumptions in buildings could be found in the evidence of superior set temperatures in better insulated dwellings[53] (showing the first signs of a rebound effect, see chapter 3.6), or in the centrifugal development of the Walloon housing stock post war, mentioned above, which gradually expanded city centres into suburbs. People turned to the countryside for space and landscape, calm and nature: the houses gradually increased in size, and were detached from neighbouring buildings, which resulted in greater heat loss areas.

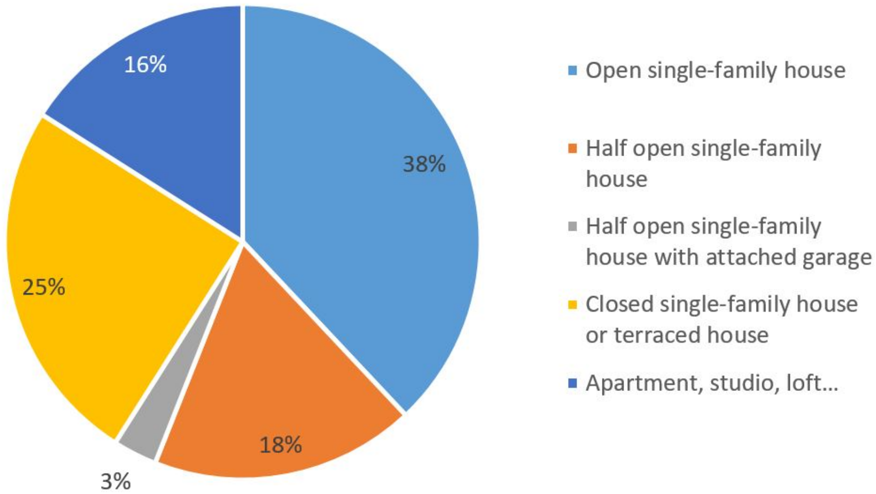

Fig. 2.2.18. Repartition of Walloon dwellings according to their isolation (detachment). (Source: Eurostat, 2012)

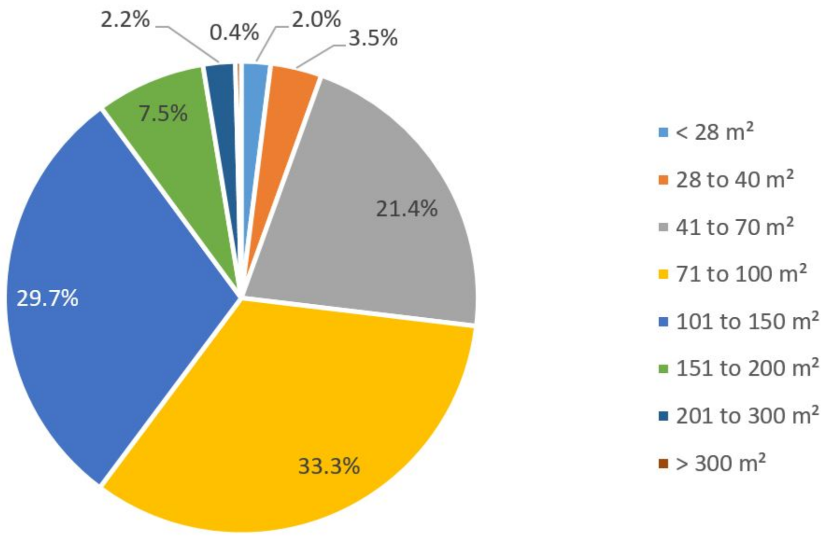

Fig.2.2.19. Repartition of liveable areas in Walloon dwellings (Source: MRW, 2007)

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[53] L. F. CHIU, et al., 2014. *A socio-technical approach to post-occupancy evaluation: interactive adaptability in domestic retrofit*, Building Research & Information, 42:5, 574-590

The 2007 Survey[54] proposes the repartition of liveable dwelling areas visible in Figure 2.2.19. The size of the dwelling influences the volume to be heated and therefore the energy consumption; as a consequence, the average energy consumption keeps increasing in Walloon dwellings built after 1973, despite the apparition of thermal insulation. It seems that it took the EPB thermal regulations to finally decrease effectively the energy consumption in dwellings.

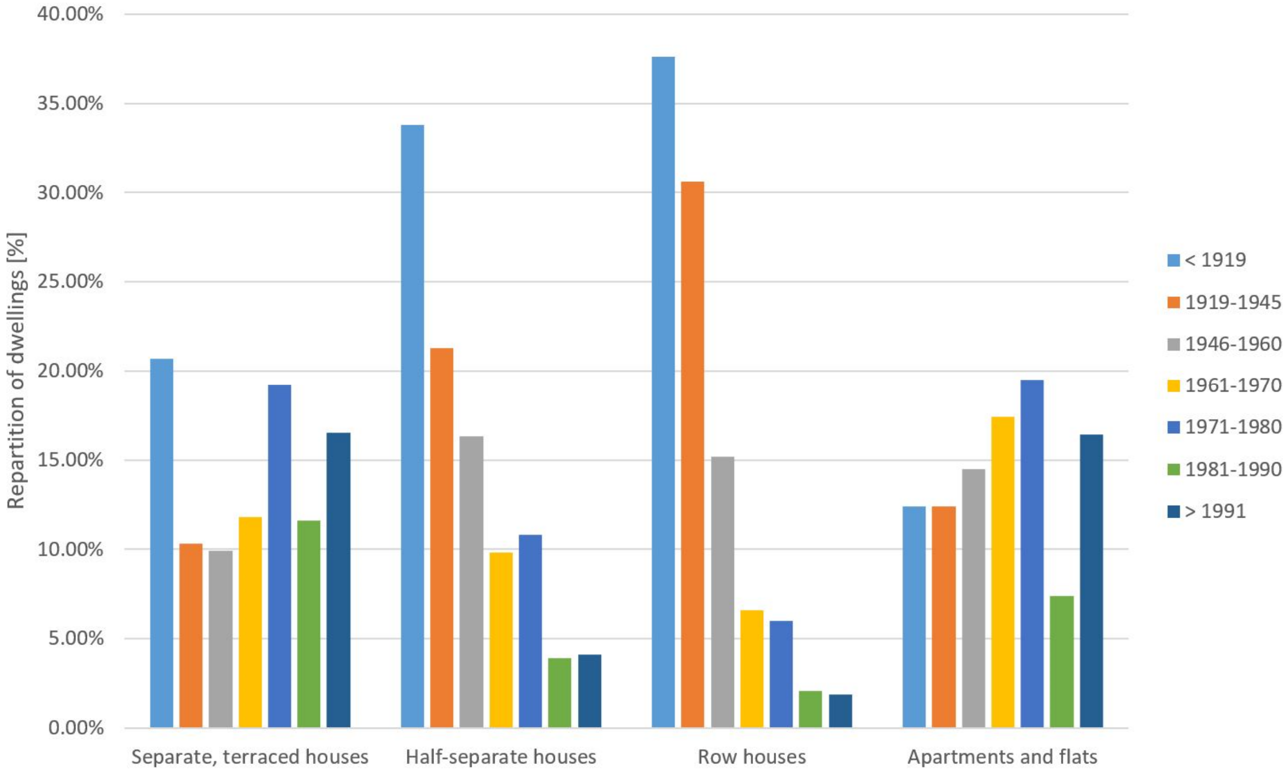

Fig.2.2.20 Repartition of Walloon dwellings according to the localisation (detachment) and age category (Source: MRW, 2007)

The results of the Walloon housing development can be seen in the 2010 repartition of dwellings above (see Figure 2.2.20). The proportion of open houses has increased gradually after 1945 and has been, with the exception of apartments, the only growing proportion for decades. The stock of separate houses show higher share of spacious homes, whereas row houses are much smaller, on average. There is also a higher share of old houses in the stock of row houses, more often found in older agglomerations (see Figure 2.2.21). 90% of row houses have been built before the 1973 old crisis, compared to 81.2% of half-separate houses and 52.7% of separate houses.

According to the EUROSTAT survey, 68% of the Walloon dwellings were occupied by their owner (67.3% for Belgium), 30% by a tenant (30.9% for Belgium). The rest is shared between usufructuary/ tenant for life, or rent-free occupation (houses or flats placed at one's disposal, free of charge). This basic "relationship" between a household and its home is central to the stakes of reducing energy consumption, as it directly influences energy consumption and the ways and extent that homes are retrofitted.

[54] MRW - MINISTÈRE de la Région Wallonne, 2007. *Enquête sur la qualité de l'habitat en région wallonne*, 2006-2007, DGATLP, Namur, Belgium.

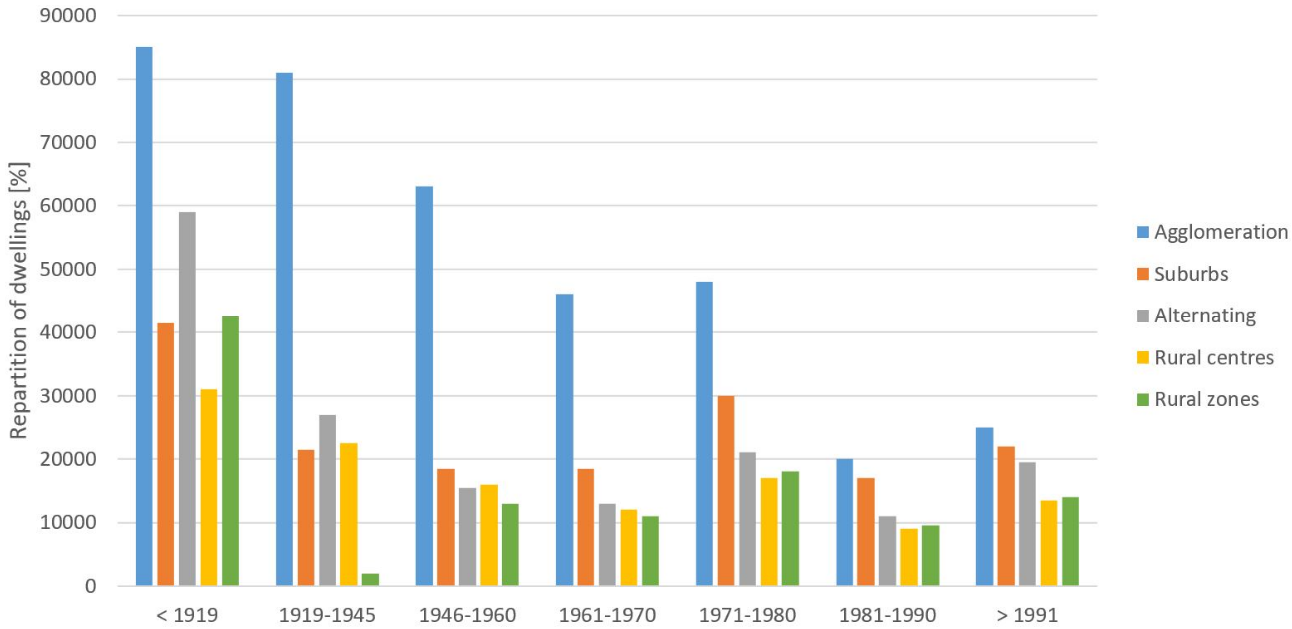

Fig.2.2.21 Repartition of Walloon dwellings according to the localisation (urban/rural) and age category (Source: MRW, 2007)

These different parameters describing the Walloon residential stock and its dwellers can be crossed in order to gain better overview of the stock. Thus, the 2007 "Housing Quality Survey"[55] in Wallonia, which was lead on 6,000 dwellings in order to "analyse the state of the Walloon housing stock and give an overview of the situation", for it to "allow the Walloon Government and Administration to orientate their housing policies (on economic, energy and social levels)", displays some interesting results that better define the research subject of this thesis, for example:

- Owners live in more spacious dwellings than tenants, as 69% of them consider living in a "spacious enough" dwelling, against 54% of tenants. On the opposite end, 15% of owners consider their dwelling to be "rather small" or "too small", against 27% of tenants.
- Owners are generally older than tenants. More than 75% of households which head is aged 45 years old or more are owners of their dwelling. The group of owners also shows higher shares of employment, couples (with or without children) and long-term occupation of the dwelling (owners stay longer in their home).

2.2.2.3 Typologies

The first part of this dissertation, describing the population and building stock of Wallonia, allows us to tighten the research subject of this thesis:

- The principal mitigation potential lays in old, urban constructions.
- Urban environment gathers higher shares of old and inefficient buildings.
- Single-family dwellings are much more important in stock, older in average and poor in insulation than multi-family dwellings, which are globally more recent.
- Ownership of a building influences the relationship between dwelling and dwellers, their energy consumption and attitudes towards energy savings and renovations.

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[55] S. Monfils, J.-M. Hauglustaine, 2009. "*Etude énergétique - typologique du parc résidentiel wallon en vue d'en dégager des pistes de rénovation prioritaires, rapport final*", Rapport final du projet Reno2020 pour la Wallonie, Université de Liège, Liège.

This research, therefore, will focus on (old) urban single-family houses, occupied by their owners. The following references have been used in order to define the following typologies:

- W. CYX, N. RENDERS, M. VAN HOLM, S. VERBEKE, 2011. *IEE TABULA - Typology Approach for Building Stock Energy Assessment*, Scientific Report.
- S. MONFILS, J.-M. HAUGLUSTAINE, 2009. "*Etude énergétique - typologique du parc résidentiel wallon en vue d'en dégager des pistes de rénovation prioritaires, rapport final*", Rapport final du projet Reno2020 pour la Région wallonne, Université de Liège, Liège.
- C. KINTS, 2008. *La rénovation énergétique et durable des logements Wallons, Analyse du bâti existant et mise en évidence de typologies de logements prioritaires*, Architecture & Climat, UCL.
- UMons, ULiège, 3E, SPW-DGO4, 2015. *Détermination synthétique du parc de bâtiments résidentiels existants en Wallonie*, first task report of the *COZEB –extension* project, for the SPW-DDO4, Department of Energy and Sustainable Building, Namur, Belgium.

The evolution of the Walloon building sector can be illustrated by the definition of the main housing typologies that were built. This selection does not necessarily represents 100% of the stock, but each of the typologies presented below is representative of a large portion of the building stock, some of which will specifically be used in this research.

1. Vernacular/historical House

These houses are most often found in rural environment, in the historical centres of ancient villages, in "rows" or in isolation from other constructions, representing different kinds of dwellings, from farms to castles. By incorporating the oldest constructions, this typology also includes all the "patrimonial" stock composed of historical buildings in city centres. Those urban areas account for less of these ancient structures, but more buildings to be saved and protected[56]. There is, however, less residential examples of this typology in urban centres, which architecture generally shows higher diversity due to higher rates of demolition and constant (re)construction (and the World Wars did leave imprints on Walloon city centres). With their high historical value that greatly lowers the renovation possibilities and techniques, they will not be part of this research.

Fig. 2.2.22 Examples of Walloon "vernacular/historical" houses (Olne and Liege, Belgium). (Source: Google maps ®)

[56] The architectural heritage is the ensemble of buildings that present historical value which continued existence is to be ensured: remarkable monuments (castles, churches, places, gardens…), vernacular or industrial architecture, "small popular patrimony"… (Source: CPDT, 2012, ibid.)

These ancient buildings were generally built with "traditional" materials and techniques. The walls were solid (and sometimes really thick, as exemplified by the churches) and made of materials from local resources: stones, clay, lime, terracotta, or wood for frames, internal floors and roofs structures. Ground floor can sometimes be as simple as dirt or tiles on the ground. Windows are generally small, except sometimes in urban environment.

Their rural position and isolation generally means that no natural gas network is available. Heat was originally provided by local stoves and wood fireplaces, but central heating has often been introduced in these houses via successive renovations. Fuel oil is, therefore, more common.

2. Brick houses

The industrial era brought local manufactures that exploited local resources to bring new techniques and materials to the construction sector. Terracotta bricks, for example, dominated the next decades when it came to erect single-family dwellings. Before the World War II, the walls remained solid, but their thicknesses remained sufficient for weather resistance.

In rural areas, this translated in bigger houses made of solid brick walls, in simple, elongated volumes, with annexes. They were still architecturally simple, without ornamentations, but better lit with natural light. Many farms were built with this kind of technicity and materials. Rural houses are not part of this research, however. In urban areas, those houses were, in first developments, mainly built in rows in the need for quick developments of city centres. Their sizes changed according to two important parameters: available space (making them bigger in rural centres) and wealth of the constructor (or those for whom these houses were built).

2.a. Blue-collar houses

Fig. 2.2.23 Examples of Walloon "blue-collar" houses (Seraing, Belgium). (Source: Google maps ®)

The most modest of those houses were built for the blue-collar workers in neighbourhoods where industries developed rapidly and were asking for labour supply. They are characterized by small dimensions and volumes, low ceilings and simple plan, usually composed of a small basement, two linked daytime rooms on the first floor (living room and kitchen) and two night rooms on the second floor, plus a bathroom. The attic has often been renovated to extend the liveable area and add (small) bedrooms; in the same purpose, there are very frequent annexes built afterwards at the back of the house. The entrance hall is often inexistent, and the circulation spaces can be reduced to the staircase. These houses usually are in poor condition, with low quality of natural light and frequent humidity problems that are also due to the building simplicity. They are very frequent: the 2008 study by C. KINTS estimated they represent 18% of the pre-1991 stock. Natural gas is often available in neighbourhoods where these houses have been built. Central heating has replaced local stoves in many of those places, although it must be noted that their smaller sizes could explain the still higher share of local heating by stoves in this typology.

2.b. Modest houses

The first upgrade level of the blue-collar house is the "modest" house, initially built for higher-ranked workers and foremen in the company ladder. They sometimes punctuated rows of blue-collar houses, which provided more natural light by the third façade on the exterior. The architecture remains globally the same, with a 10 to 20% increase in dimensions (width of façade, ceiling height). Some internal modifications appear: the entrance hall is now separate from living rooms and contains the communications like the stairs to the (bigger) basement, those to the upper levels, and the access to the back annexes. Smaller ones have comfortable attics, bigger ones have a complete third floor under the tilted roof. Some ornamentation sometimes appears on the facades. Those houses still suffer from relatively bad lighting in the first floor (although that depends on localisation) and bad overall quality, especially for the annexes built afterwards. Central heating is more spread than in blue-collar houses, and natural gas is most often used.

Fig. 2.2.24. Examples of Walloon "modest" houses (Liege, Belgium). (Source: Google maps ®)

2.c. Master houses

The third and upper-grade level of those pre-1945 brick houses is the "master" house. It benefits from a 10 to 20% increase in façade width and ceiling height, when compared to the modest house. It shows other internal improvements; for example, the third level is complete, and an attic is still often present under the tilted roof. The gardens benefit from those expanded dimensions, as well as the annexes at the back which are sometimes on two levels, in continuity with the "communication" volume, which is also wider and now always separated from living spaces. The materials are still the same, although wood could come from more noble species. Ornamentation is more spread, as a social marker for the masters that lived there, and the steel industry history of the Walloon Backbone, explain the presence of iron decorations. Stone surrounds windows and doors which are wider and taller, bringing in more light. Central heating is nearly generalised in those houses when they are used by a single-family. A high share of those house, however, have been divided into several rented apartments, which often result in separate heating systems (and in some cases, these are still local).

Fig. 2.2.25. Examples of Walloon "master" houses (Liege, Belgium). (Source: Google maps ®)

3. Apparition of concrete

Fig. 2.2.26. Examples of Walloon houses from the 50s to 70s (Liege, Belgium). (Source: Google maps ®)

The Second World War brought devastation into urban landscapes, but it also brought the massive use of new materials for civil construction, like (reinforced) concrete, liberating the structure from the facing, allowing open spaces and higher ceilings. Meeting the need in "cheap" (social) housing post-war, this implied the construction of many multi-family concrete buildings, which are not subject to this research. In the single-family housing, the apparition of industrialised concrete brought flat roofs and cavity walls, which largely dominated the urban extensions of the 50's, 60's and 70's. Bricks were still largely used as facing, and thermal bridges were very common in the first generation of cavity walls, which renders those cavities much harder to fill now efficiently with insulation. The cavity layer separating them from the structure is ventilated, to allow the bricks to dry. The new construction techniques freed the architecture, so that different typologies can be linked to the post-war period (see Fig.2.2.26 above).

4. **Apparition of insulation**

The second generation of cavity walls see the heat losses due to thermal bridges reduced, in a first time. After the oil crisis, thermal insulation appears, at first occasionally, into those cavity walls. The Walloon thermal regulations of 1985 will generalise the tendency. The architecture design being freed from structural necessities, the diversity in typologies keeps growing with every architect. Single-family housing has developed in suburbs and rural areas mainly, but there are still examples of these constructions in urban environment.

Fig. 2.2.27. Examples of Walloon urban houses from the 80s to 00s (Liege, Belgium). (Source: Google maps®)

2.2.2.4 Energy characteristics

The data given here comes from the most recent study of the kind (and they are not precisely annual in Belgium): the EUROSTAT survey[57], implemented in 2010 and published in 2012. Other studies[58] have been used to cross the results, but they globally concur in giving the same overview of the residential stock (with a few % differences).

According to this study, nearly 60% of dwellings declared complete roof or attic floor insulation. An additional 8% declared partial insulation of that particular important heat loss area, and one in three professed having no insulation at all on top of their dwelling.

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[57] EUROSTAT, 2012. *Ibid.*

[58] M. DESCAMPS, *Ibid.*

F.-L. LABEEUW, et al., 2011. *Morphologie urbaine et consommation énergétique du bâti résidentiel pour répondre aux objectifs de réduction des émissions de gaz à effet de serre*, Liège

T. DE MEESTER, et al., 2009. *Guide de la Rénovation basse énergie des logements en Belgique*, Low Energy Housing Retrofit Program, Politique Scientifique Fédérale, Bruxelles.

J.-A. POULEUR, et al., 2012. *Enquête sur la motivation des Wallons à rénover ou isoler leur logement, résumé non technique*. Espace Environnement, Charleroi.

CPDT, 2012. *Ibid*

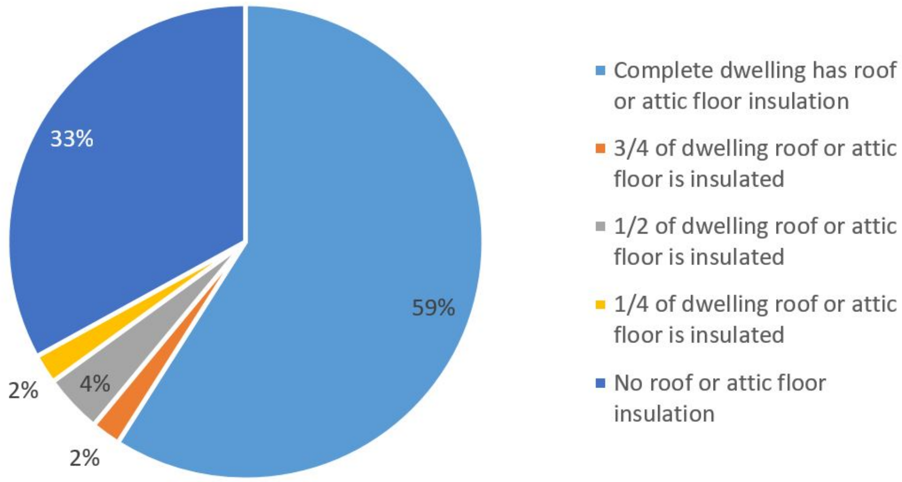

Fig.2.2.28 Presence of roof or attic floor insulation in Walloon dwellings: repartition of survey results (Source: EUROSTAT, 2012)

It is worth noting that this study gives no clue as to insulation thicknesses in place, although this could be compared to the results of the 2007 Quality Survey of the Walloon housing stock[59]. In this study, 52% of dwellings were reported to benefit from total roof insulation. It is normal that the numbers should increase, due to new buildings and thermal renovations of old dwellings. The 2007 survey added that 46% of those 'completely insulated roofs' had insulation thicknesses inferior to 6 cm, and 12% above 12 cm. Those numbers might not be accurate anymore, as people could have renovated roofs that were already considered 'completely insulated' and upgraded the thicknesses of insulation layers in the process, but it still gives a realistic overview.

Another tendency governs floor insulation, as it is absent in 77% of dwellings. Only 18% of dwellings can boast of having full floor insulation. The 2007 Quality Survey was a little higher, at 21% of complete dwelling floor insulation (both surveys were drawn on similar-sized samples; deviations between both are to be expected). The main lesson is that there seems to be no real improvement in that area (apart from new buildings), and that renovations do not generally include floor insulation.

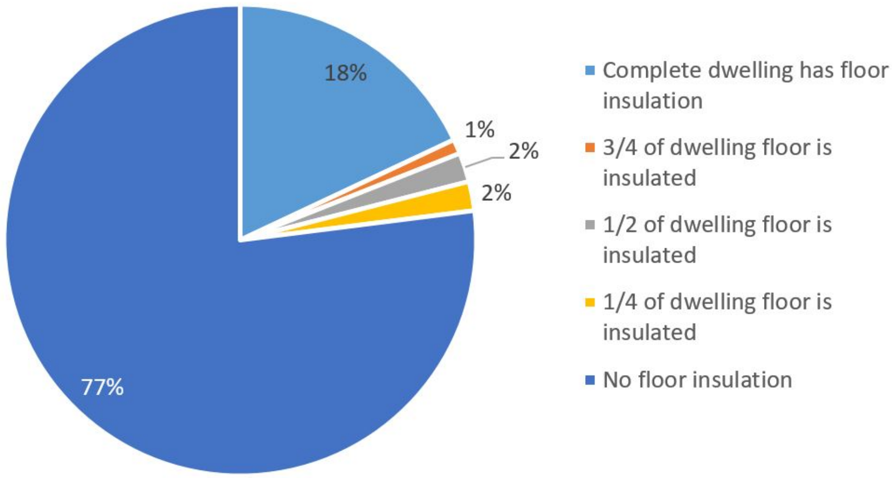

Fig.2.2.29. Presence of floor insulation in Walloon dwellings: repartition of survey results (Source: EUROSTAT, 2012)

[59] MRW, 2007. *Ibid*

Outer walls insulation seems to nearly follow the same tendency than floors, meaning that very few of them are completely insulated (27% of dwellings, which is approximately the same number as in the 2007 Quality Survey). No insulation was found in 63% of cases.

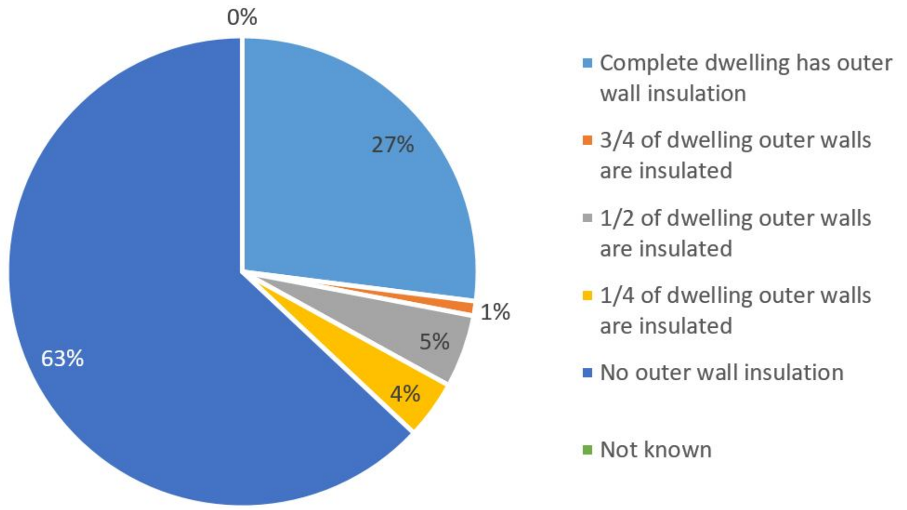

Fig.2.2.30. Presence of outer wall insulation in Walloon dwellings: repartition of survey results (Source: EUROSTAT, 2012)

The 2007 Survey[60] adds to this observation some distinction based on age categories. As it might be expected, nearly all buildings built after 1990 possess complete outer walls insulation, whereas the older buildings see that share drop under 10%. Even if we consider partial insulation, around 20% of dwellings built before 1945 are at least partially equipped with outer walls insulation.

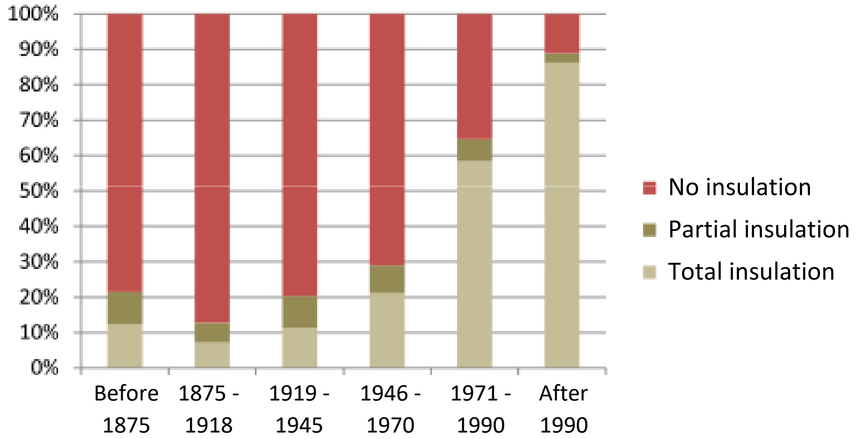

Fig. 2.2.31. Share of dwellings equipped with outer walls insulation, according to the period of construction (Source: MRW, 2007)

The replacement of windows is one of the most implemented renovation work on an old dwelling, because it does not only help in reducing the energy bills: it also increases acoustic comfort and thermal comfort through higher wall temperature and lower fresh air infiltrations. Additionally, frames and glazing have known a formidable evolution in the last 50 years. We have come from single glazing, with U-values around 5.7 W/m²K, to high performance glazing that divides the associated losses by a factor of ten. There is, therefore, a wide array of different windows on the market, and in buildings. The numbers presented here might not be accurate, therefore, if they are

[60] MRW, 2007. *Ibid*

based on an analysis made ten years ago, but they can highlight a clear tendency: the 2007 Quality Survey mentioned that two dwellings out of three (66.6%) showed no sign of single glazing, while 19% were equipped with only single glazing. In the 2010 EUROSTAT survey, these rates evolved, respectively, to 80% of dwellings without any, and 12% of dwellings with only, single glazing. "Simple" double glazing (first generation, with an air layer) still can be found in many places, though they are not the most efficient. Several possibilities to that fact: either they do a "good enough" job in reducing thermal discomfort, or people believe them to be more efficient than they really are, or their replacement is not seen as a profitable investment…

Few other energy efficiency parameters have been studied recently on the Belgian existing stock. New buildings are much more subjected to research and monitoring, and old buildings remain largely unknown. A clear example of that is air tightness, which is studied in several recent studies on the Belgian new-built stock[61], but not so much in the existing residential stock. A reason for this might be the clear dominance of heat losses by transmission through the walls, when the envelope is poorly insulated. As a result, the number of existing buildings that are submitted to blowerdoor tests remain low. Furthermore, the airtightness depends a lot on the realisation of works, which might have happened several times and by different actors over the lifetime of an old building, so that no clear determiners of airtightness levels could be put forward. The presence of ventilation systems is another parameter that remains largely mysterious in existing dwellings.

Heating installations are obviously crucial to the analysis of the residential stock energy consumption, and are also a priority investment for many households. This is symptomatic of curative renovations, rather than preventive: engineering logic would have homeowners insulate their house, reduce losses to rationally save energy and money, then invest in high-efficiency heating installations adapted to the new needs. Reality is quite different: households usually change their heater (and often domestic hot water producer) when it breaks down (or is about to) and cannot bring the expected level of comfort, as far as heat and hot water needs are concerned.

In seven dwellings out of ten, the heat is provided through individual installations of central heating (a central heat production that distributes the heat where locally needed or demanded); in one dwelling out of ten, the heat is supplied by common central heating (one central installation that provides heat for several dwellings, most often in one building). In the last two dwellings (out of ten), separate heaters (local heating) use different energy vectors (wood, coal, gas, electricity…) to bring thermal comfort. [62]

Fuel oil is still largely used in Wallonia for producing heat, especially in open and half-open houses, closely followed by natural gas, which takes the lead in closed or terraced houses and apartments, studios and lofts. Other vectors share the remaining 14%.

When analysing the energy sources used in dwellings (see Fig 2.2.33), according to their period of construction, one can see that there seems to be "modes" and variations in chosen techniques and energy vectors throughout the time. Fuel oil has been on the slide for decades now, and is mainly replaced by natural gas. Wood makes a comeback since a few years and is more often found as extra

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[61] J. LAVERGE, M. DELGHUST, N. VAN DEN BOSSCHE, A. JANSSENS, 2014. *Airtightness assessment of single family houses in Belgium.* International Journal of Ventilation, 12, 379–390.
[62] EUROSTAT, 2012. *Ibid*

heating source in open houses. Coal heating which can appear like an energy from the past, can still be found in vernacular housing (urban or rural). Natural gas cannot be supplied everywhere in Belgium (it is mainly found in city agglomerations), but gas condensing boilers are the best efficiency/cost investment nowadays, so that butane and propane, which have seen their share decrease for decades, also seem to be coming back the last few years (though still confidential).

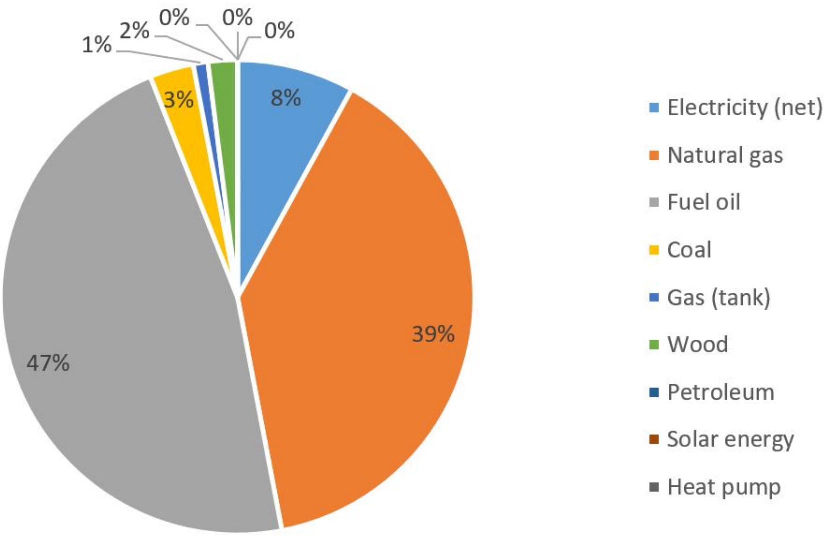

Fig.2.2.32. Repartition of main heating sources (energy vectors) in Walloon housing, in 2010. (Source: EUROSTAT, 2012)

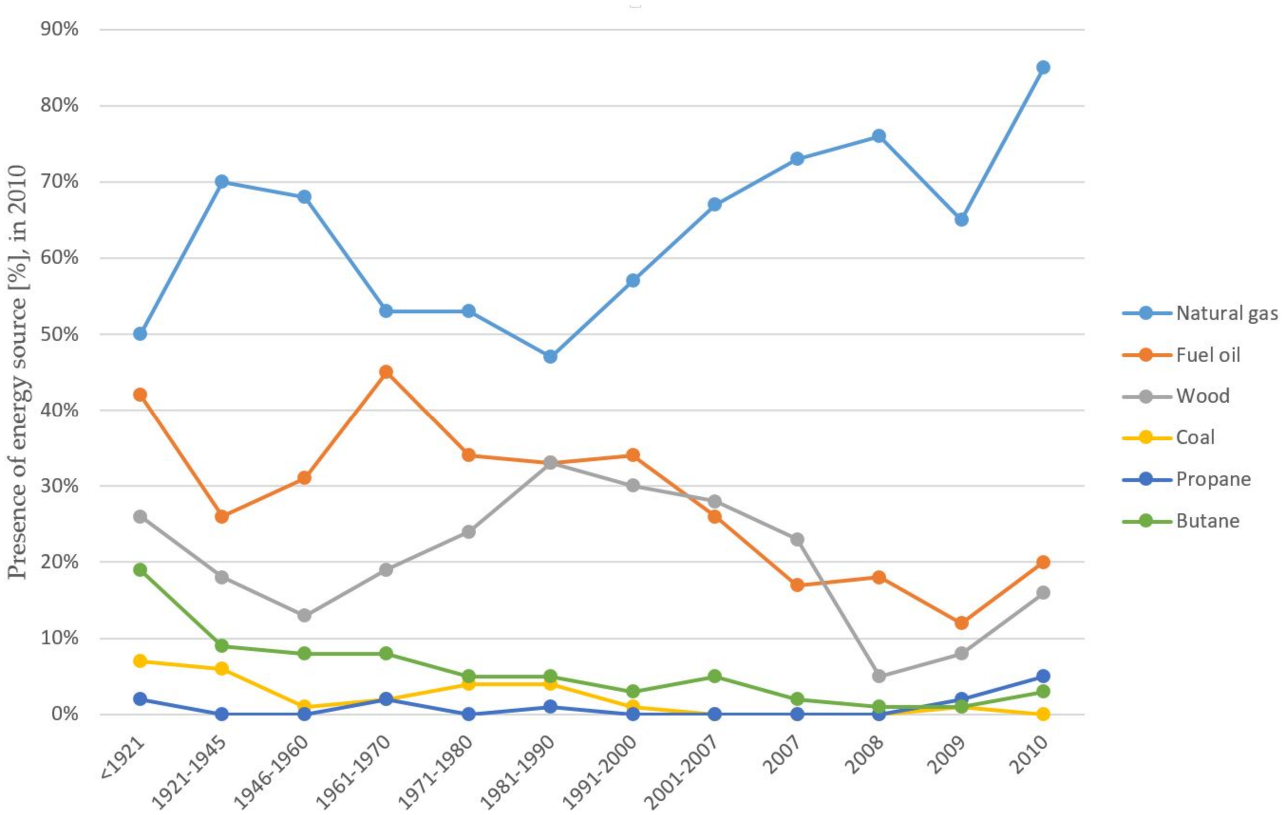

Fig.2.2.33. Presence of main heating sources (energy vectors) according to age categories in Walloon housing, in 2010. (Source: EUROSTAT, 2012)

In urban environment, fuel oil is scarcer for central heating than natural gas. When the latter is used as heating source, the survey[63] estimates that 28% of boilers are 'high efficiency' (HR+ label), 21% are condensing boilers (HR TOP label), and 51% are neither (old, inefficient high temperature boilers). Age of boilers are distributed thus, according to the same study:

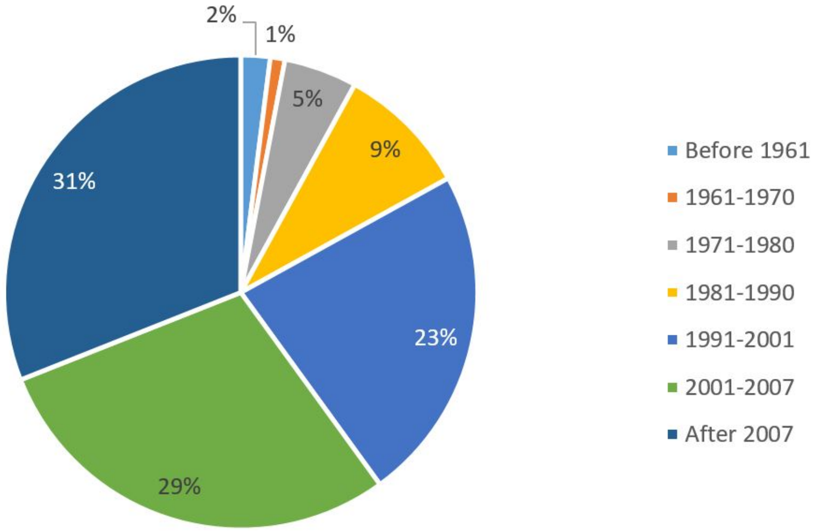

Fig.2.2.34. Repartition of heating boilers according to their age in Walloon housing, in 2010.
(Source: EUROSTAT, 2012)

Decentralised heating appliances that are mainly used in Wallonia are gas stoves (29%). Apart from electric floor heating, all other sorts of decentralised installations are quite evenly distributed:

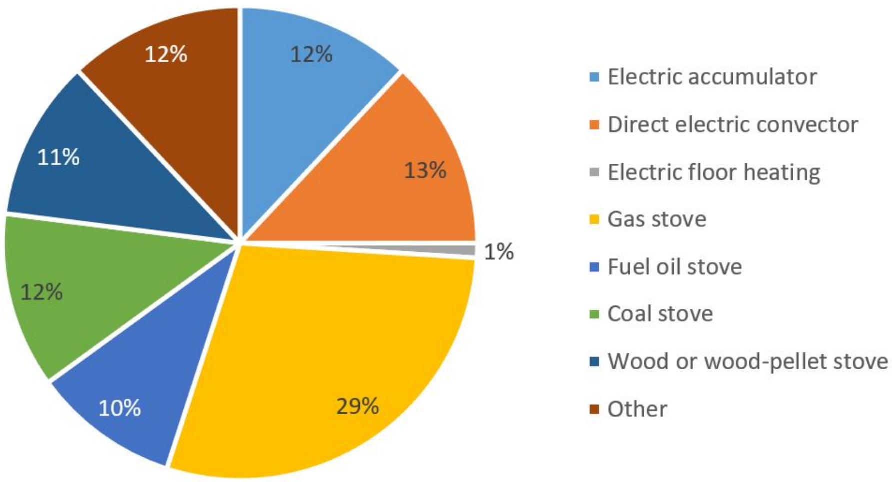

Fig.2.2.35. Repartition of decentralised heating appliances in Walloon housing, in 2010.
(Source: EUROSTAT, 2012)

Lastly, when it comes to extra heating sources (local devices that are used locally in complement – or instead – of central heating, to quicken or boost the feeling of heat), the ICEDD estimated in their *2013 Energy assessment of Wallonia*[64] the repartition shown in Fig. 2.2.36 below.

[63] EUROSTAT, 2012. *Ibid*.

[64] ICEDD, 2015. *Bilan énergétique de la Wallonie 2013, secteur résidentiel et équivalent*, ICEDD asbl pour le Service Public de Wallonie, Namur, no ed., 152 p.

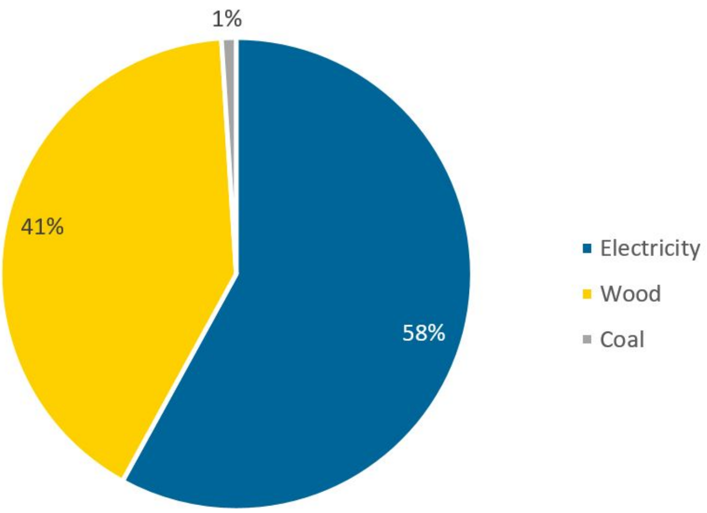

Fig.2.2.36 Repartition of extra heating sources in Walloon housing, in 2013. (Source: ICEDD, 2015)

Heating is an important part of a household energy consumption that can vary quite a lot, depending on the building performance, installation efficiencies and heating behaviour. Energy consumption related to Domestic Hot Water (DHW) production is, on the contrary, generally linked to a more stable energy consumption, because DHW is needed all year round, and the influence parameters can be reduced to the number of occupants, hygiene behaviour and DHW production installations efficiencies:

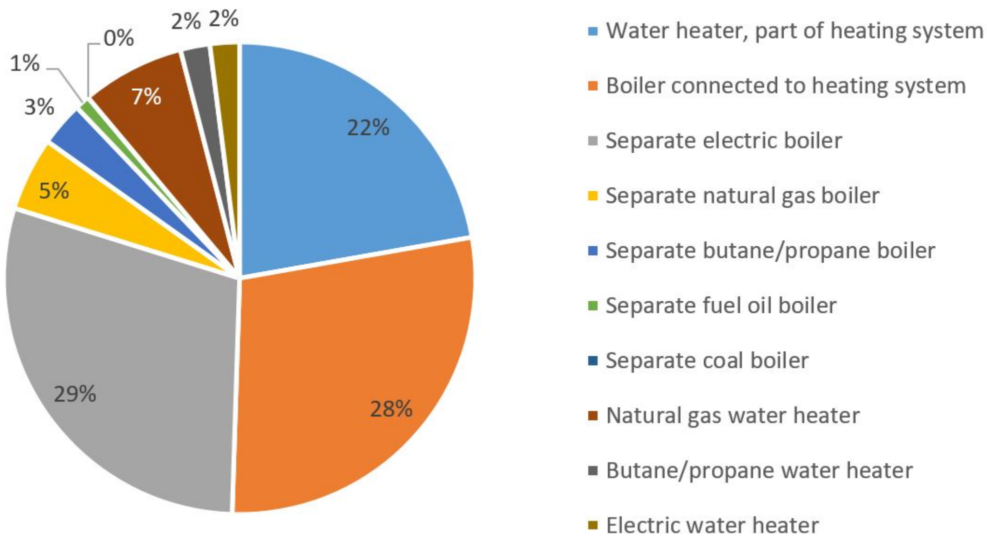

Fig.2.2.37. Repartition of Domestic Hot Water (DHW) appliances in Walloon housing, in 2010. (Source: EUROSTAT, 2012)

According to the *2017 Key Numbers of Wallonia*[65], 20 to 25% of Walloon residents live in a dwelling that present humidity problems (leaks in the roof, wall or floor humidity stains, wood frames attacked by mould…). That rate is relatively high, compared to other European countries, especially neighbouring countries like France (around 13%) or the United Kingdom (just under 15%). Even the Netherlands, known for their wet lands, have inferior rates, at 16%. The prevalence of humidity problems varies strongly with the ownership status of the residents: owners face less humidity problems (around 14%) than tenants (around 34% for private and social tenants).

[65] IWEPS, 2017. *Ibid*

2.2.2.5 Average consumption

This subchapter is based on several studies that give insight into the Belgian or Walloon residential stock energy consumption. For example, the CPDT[66] announced in 2011 that the average annual final energy consumption per square meter was about 366 kWh/m².year. McKinsey, in 2009[67], estimated that with an average energy usage of 348 kWh/m².year, the "actual" Belgian energy consumption per square meter in residential buildings is more than 70% higher than the European average of 203 kWh/m².year (see Fig. 2.2.38), and superior to the average of other Western European countries.

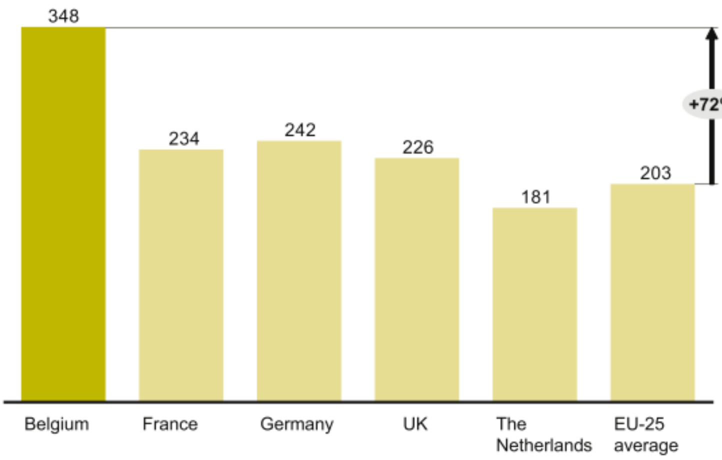

Fig. 2.2.38. Average residential energy consumption in selected European countries, in kWh/m².year (data from 2005) (Estimated from McKinsey's Global Greenhouse Gas Abatement Cost Curve Version 2, PRIMES database) (Source: D. N. EYKERMAN, et al., 2009)

F.-L. LABEEUW, et al., in 2011[68], shared the same conclusions of their assessment of the residential stock, estimating the average consumption at 350 kWh/m².year for the whole built residential stock. They proposed a distribution of this result according to building age (Fig. 2.2.39). Given the importance of the pre-war buildings in the global stock (around 50%), it appears normal that the average value of the global stock (350 kWh/m².year) should be so close to the pre-war average (407.8 kWh/m².year). Although it seems undeniable that the average consumption grows with the age of the building, the results presented in this graph are quite different from those presented in Fig. 2.2.17 above. Agreed, the EUROSTAT survey[69] is more detailed in its approach, but both are bottom-up studies that used standardisation and statistical data to obtain those results. The greater standard deviation for that period (the highest at 163 kWh/m².year, see Fig. 2.2.39) might explain the great array of buildings and consumptions that flattened in this average. The wide range of envelope performances and system efficiencies in that particular stock, as well as differences in heating behaviour, for example, could explain important deviations from the average.

Another way of approaching the average energy consumption of the residential stock is through the monitoring of specific data. For example, in 2008[70], the ICEDD Institute announced that the Walloon final energy consumption, reported to the total built area of the residential stock, was measured at

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[66] CPDT, 2012. *Ibid*

[67] D. N. EYKERMAN, et al., 2009, *Ibid.*

[68] F.-L. LABEEUW, et al., 2011. *Ibid*

[69] EUROSTAT, 2012. *Ibid*

[70] ICEDD, 2008 *Bilan énergétique de la Région Wallonne. Bilan provisoire 2008*. ICEDD asbl pour le Service Public de Wallonie, Namur, no ed., p. 45.

286 kWh/m².year. These measurements are quite below the "official" results, mainly due to those methodological considerations (and the warmer climate of 2008). In 2013, their results showed even lower numbers (see Fig. 2.2.40 hereunder).

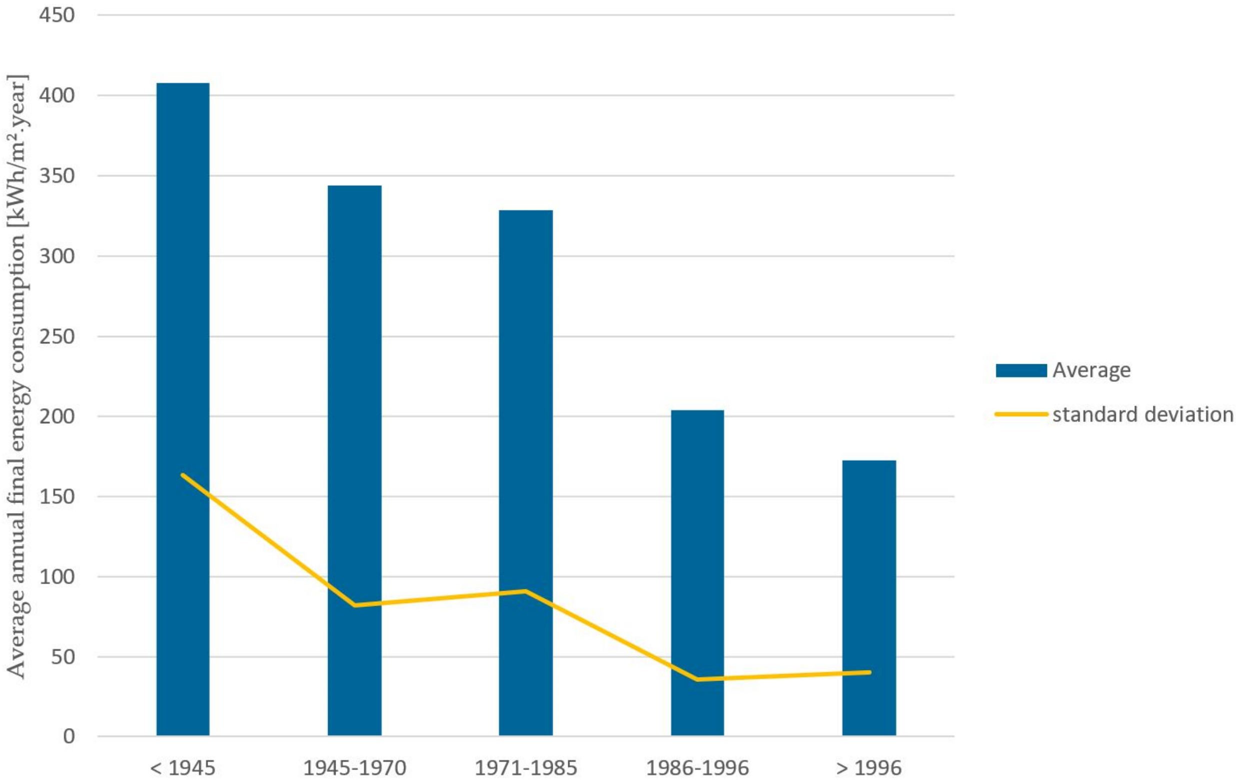

Fig. 2.2.39 Average annual final energy consumption of the Walloon stock according to building age (average and standard deviation) (Source: LABEEUW et al., 2011)

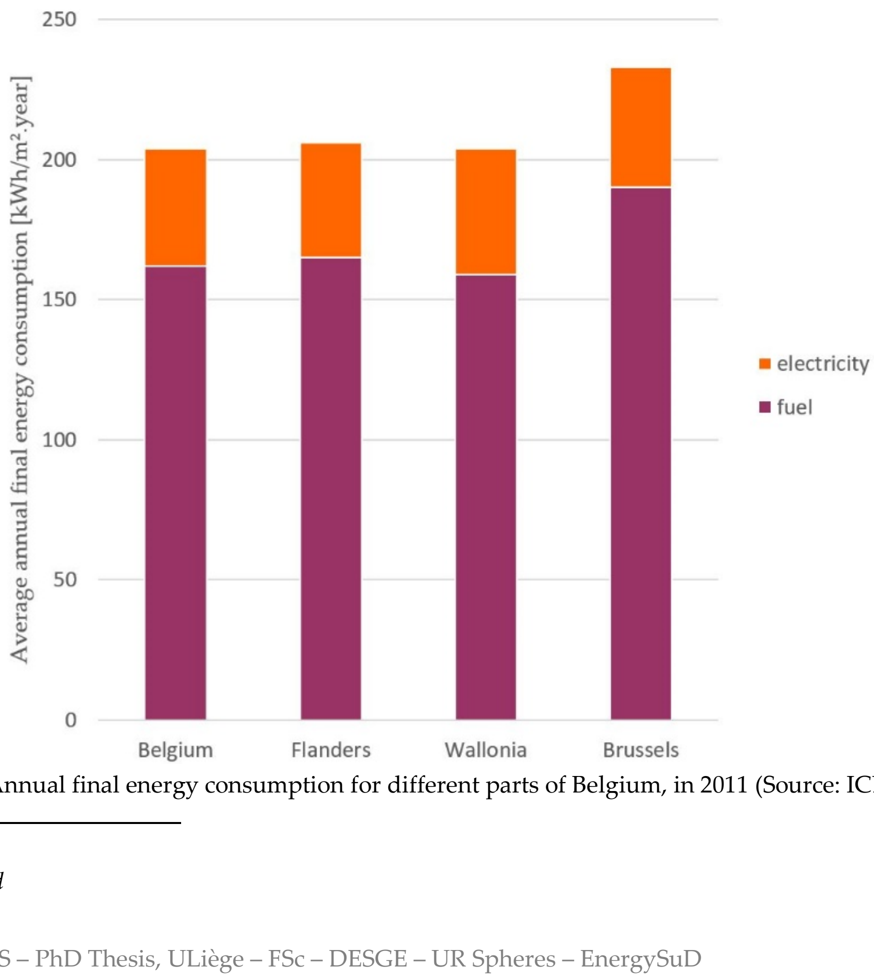

Fig. 2.2.40 Annual final energy consumption for different parts of Belgium, in 2011 (Source: ICEDD, 2013)[71]

[71] ICEDD, 2015. *Ibid*

With a total of 203 kWh/m².year in 2011, the measured energy consumption seems to be between 50 and 60% of the official calculated energy consumption. Numerous policies for the reduction of energy consumption are based on the official theoretical results which are quite different from these "monitored" ones; if theoretical energy consumption is higher than reality, then the expected energy savings seem greater than they will really be.

The "methodological considerations" mentioned above hide the reality of very different approaches when it comes to describing the residential stock. All averages are results of bottom-up assessments; except for the ICEDD study, they are all defined by their consideration of the groups of households as one aggregate element that can be qualified by a set of agreed-upon hypotheses. These are generally simplified representations of physics laws and standardized physical properties, energy characteristics and heating schedule of dwellings.

2.2.3 Residential renovation in Wallonia

The graph hereunder[72] gives the evolution of permits that were asked to the Administration between 1996 and 2010, distinguishing the newly built dwellings from the renovated ones.

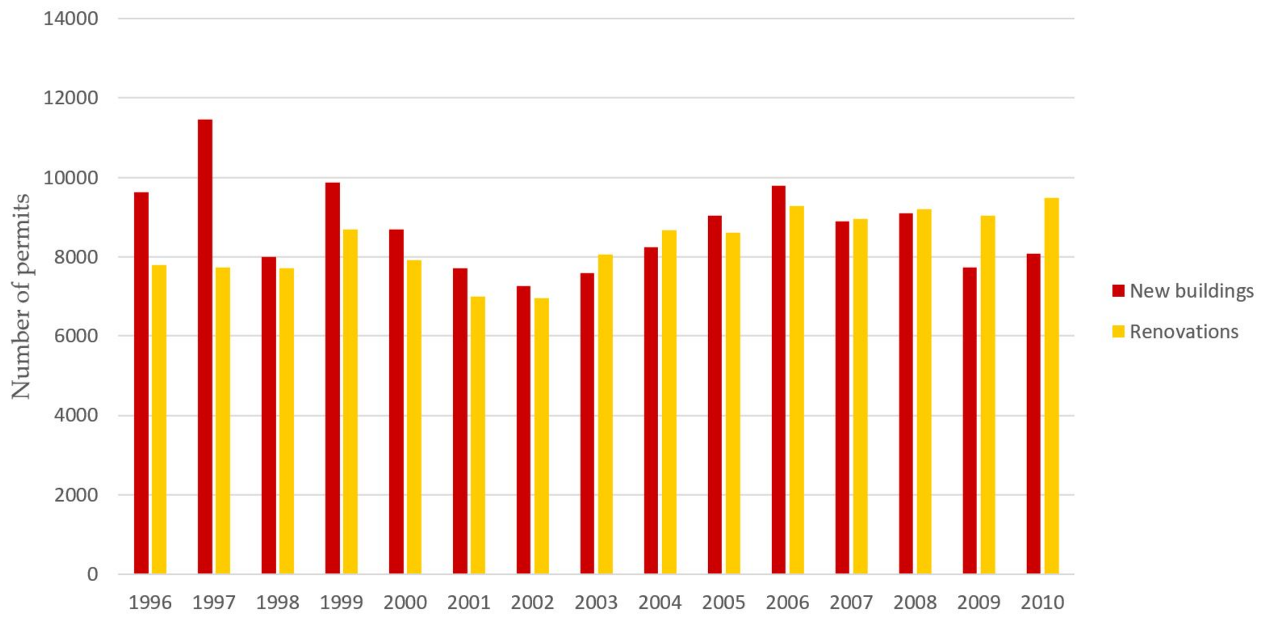

Fig.2.2.41. Evolution of permits asked for new buildings (**red**) and renovations (**yellow**) in Walloon housing, between 1996 and 2010. (Source: CPDT, 2012)

It must be noted, however, that the number of real renovations is probably higher, as some retrofits do not require a permit (for example, when the outer aesthetic aspect of the dwelling does not change – which could include inside insulation, for example).

In their "Survey on the motivations to renovate or insulate dwellings in Wallonia", J.-A. POULEUR, et al.,[73] presented the proportion of (declared) renovation works that have been realised between 2000 and 2010 (results for n=795 respondents) (see Fig.2.2.42 hereunder). Between 2000 and 2010,

[72] CPDT, 2012. *Ibid*

[73] J.-A. POULEUR, et al., 2012. *Ibid*

77.4% of Walloon households have implemented renovation or insulation works. The replacement of windows is a top priority for Walloon households (48% of respondents), followed by the replacement of heating installations with 43% of respondents mentioning it. Electric installations are third, but this could be explained by the obligation for all real-estate sellers, since July 1st, 2008, to provide certificates of control of the electric installation to potential buyers (and end-of-line buyers have 18 months to render the installation compliant with standards).

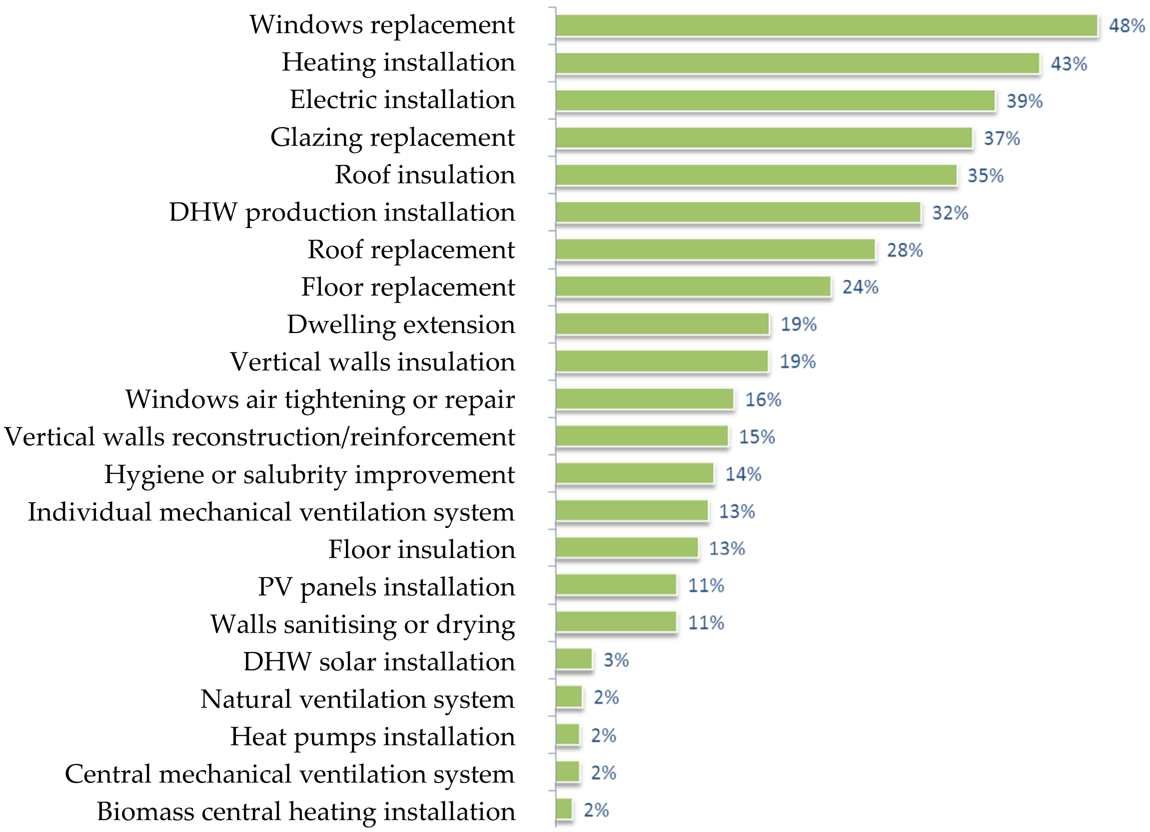

Fig.2.2.42. Percentages of renovation/insulation works realised since 2000 (n=795).
(Source: POULEUR et al., 2012)

Those numbers might have changed since the introduction of the EPB Directive and the tightening of the regulations. It must be noted that Wallonia has implemented those regulations progressively, and that they have mainly targeted the new buildings and the creation of a frame of reference of the new "efficient standards" in construction. Requirements applied to renovations are due to the "stand still" principle of the Belgian law, according to which no law modification that would induce a reduction of the citizens' protection is allowed. 1996 thermal regulations, foreseeing then the renovation requirements, have therefore been kept in the EPB regulations, targeting the (declared[74]) renovation of single-family dwellings:

- Modified (and new) walls have to meet the current insulation standards. The maximal U-values that are defined are the same for new construction and new or renovated walls in renovation works.
- When a previously unheated building's affectation is changed and it becomes heated, in addition to U-values, a global insulation "K-level" (less demanding than in new buildings) is to be achieved, forbidding the "no-insulation" solution (a valid option in other cases).

[74] submitted to permit, by an architect to the urban planning authority

- No requirements are imposed to walls that are not modified.
- When windows are changed in "dry" spaces (living rooms, bedrooms), a ventilation supply must be added to new frames, or any other ventilation supply mean that guarantees the hygienic supply in fresh air according to the NBN D50-001 standard.

As far as thermal insulation is concerned, apart from windows replacement, the decrease of thermal losses appears in the list of Figure 2.2.42 through the insulation of roofs (5th, 35%), vertical walls (10th, 19%) and floors (15th, 13%), which did not seem like priorities between 2000 and 2010. It is worth noting that they array of renovation works displayed in this assessment covers much more than the regulatory requirements mentioned above. Some works might be needed for different reasons, such as broken systems (heating and DHW installations, mainly) or comfort improvement (hygiene, air tightening, ventilation systems, windows or glazing replacement…).

As stated before, the incentives might be an important factor in the realisation of renovation works, so that another way of analysing the renovation market could be through the number of incentives that were asked by the renovators, according to the same study (see Fig. 2.2.43 hereunder). On average, one household out of two benefited from financial incentives which were mainly:

- "Direct" regional incentives for the rehabilitation of the dwelling, the insulation of the envelope, or the improvement of heating and DHW installations; the grant is given after the works, against valid proof of implementation;
- Tax reductions (at federal level);
- Loans by public authorities (social housing structures).

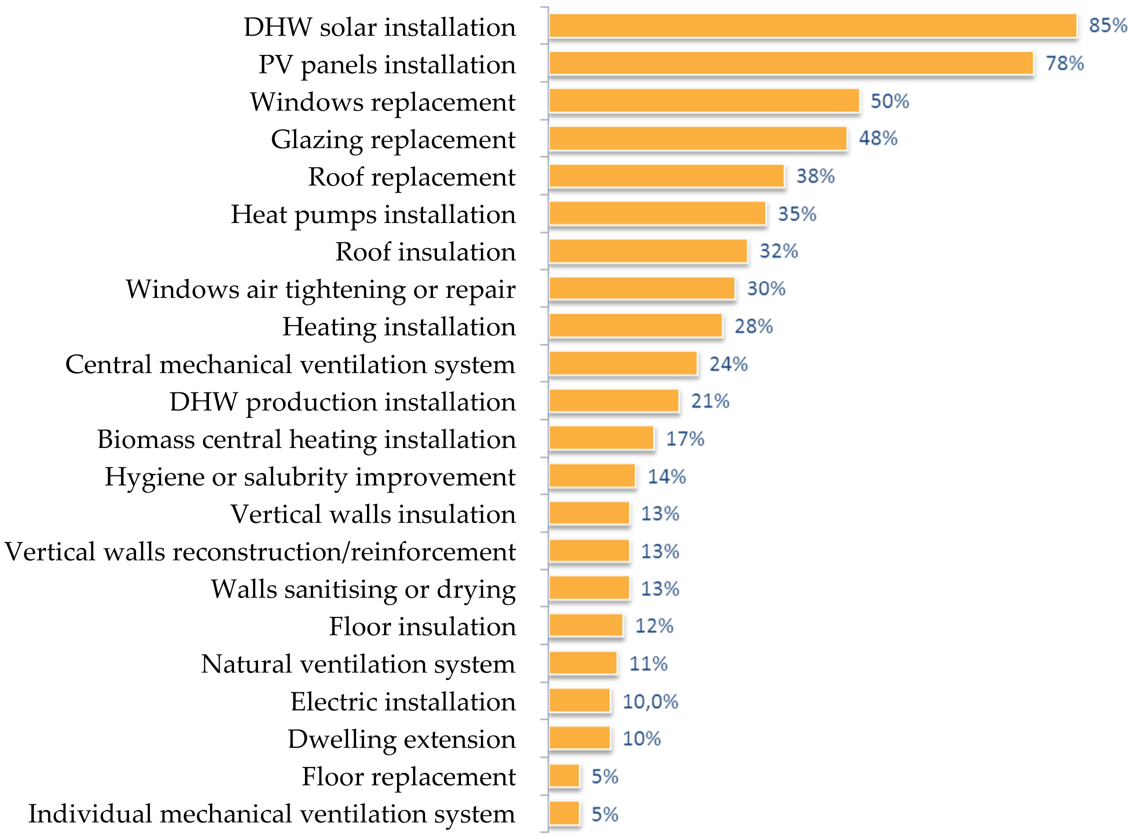

Fig.2.2.43. Percentages of incentives received according to renovation/insulation works realised since 2000. (Source: POULEUR et al., 2012)

According to the respondents, those incentives were used to call on professionals (40% of the cases), demand additional works (32%), choose better materials (natural, organic – 20% – or more expensive and noble – 20%), opt for another heating mode (19%) or produce electricity with PV panels (19%). Finding good professionals is a recurrent concern, and some renovation works are too technical to allow DIY works; it is therefore unsurprising to find solar installations, windows replacements, roof replacement, heating installations at the top of the list. When a professional is involved, furthermore, it raises the incentive allocated to roof, floor or walls insulation.

Another interesting result of the survey, however, is that 70% of respondents declared that they would have done the works, even without the incentive. It can also be read as "30% of households would not have done the works without the incentive", but nevertheless, financial "push" is not the only motivational factor in renovation.

The EUROSTAT survey[75] adds an interesting perspective to this situation, showed in the Figure 2.2.44 below. Respondents to the survey were asked to express their investments plans in the next five years for 6 types of renovation works:

- The installation of an energy-efficient heating system, high-efficiency glazing or windows or solar (thermal or PV) panels;
- The insulation of the roof or attic floor, exterior walls or the ground floor.

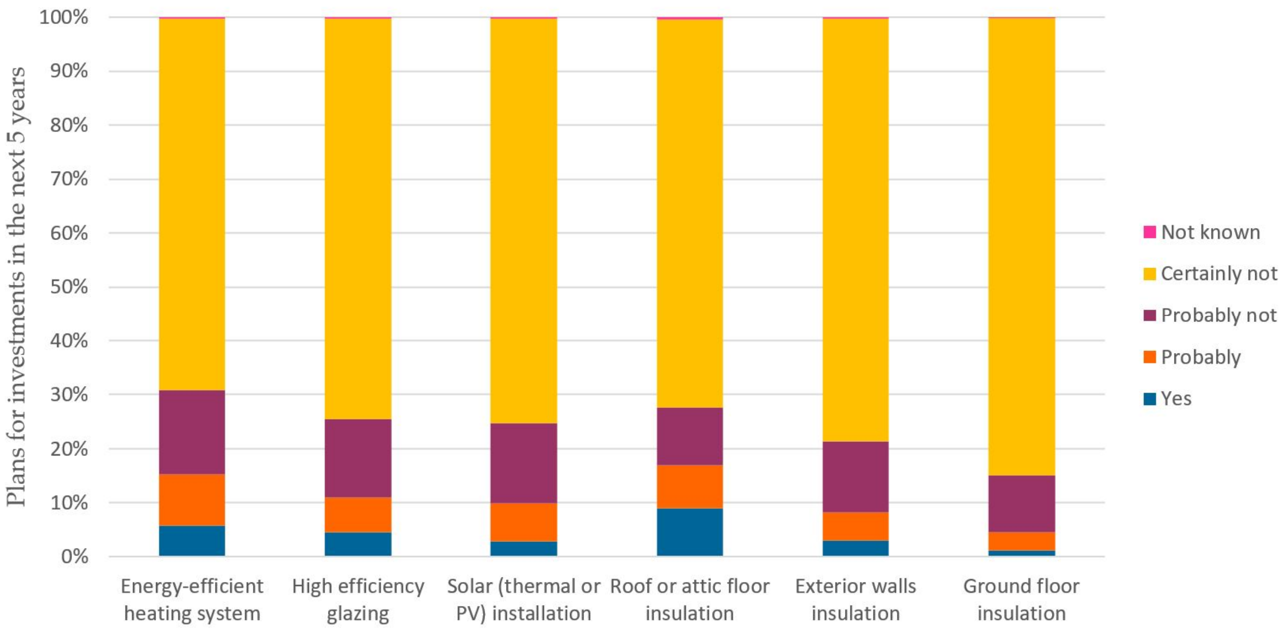

Fig.2.2.44 Investments plans for 6 renovation works in a five year perspective for Walloon households (Source: EUROSTAT, 2012)

Though the five-year perspective might be short for some respondents, it seems quite clear that few major investments plans are made. Usually, the change of the heating system happens either when a major renovation is planned and the old system becomes obsolete, or when the necessity strikes and the old heater breaks down. Although the insulation of the roof, long presented as the first and cheaper improvement work to be considered, and is still the investment plan that seems to convince most respondents, the relatively low share of positive answers might be linked to the high share of already insulated roofs, according to the statistics displayed above.

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75 EUROSTAT, 2012. *Ibid*

The survey published by J.-A. POULEUR, et al., in 2012,[76] suggests that 52% of owners who did not renovate their homes consider that the general state of their dwelling does not need improvement, mainly. 29% of Walloon households even consider that their dwelling is sufficiently insulated and therefore does not need any works. This seems contradictory with the "energy characteristics" presented above, which might indicate that people have a misconception of thermal insulation. For another 30% of respondents, financial reasons were evoked as a major barrier to renovation.

Another (but related) barrier to "deep" renovation appears as a consequence of the progressive tightening of thermal regulation. When the U-values are decreased, the thickness of insulation layers increase. Willing retrofitters are faced with a choice between heavy renovation, with an architect to pay, a permit to obtain, thick layers to implement and financial incentives to get; or the simplicity of a quite well known list of "easy" renovation works (roof or attic floor insulation, windows and heating installation replacement, home-made improvements…) that do not need permits nor architects, but still can benefit from incentives. Considering the complexity of existing buildings and the cost of global energy-efficient works, there might not always be a choice. Each increase in the regulatory thermal resistances raises the proportion of buildings with geometric difficulties, such as narrow eaves or windows. Urban houses, most of all, face difficulties linked to façade alignment and urban planning. "Complexity always engenders costs", to the point that it seems to discourage some people from renovating.

In order to stimulate the retrofitting of the residential stock, Wallonia implemented throughout the years some regulatory and non-regulatory measures, among which the incentives mentioned above have probably played the most durable part. In the "Action Plans for Energy Efficiency", one could also acknowledge the presence, at different times, of other policies and instruments to stimulate major, cost-effective renovation, including gradual major renovations. They are, for example, zero interest rate credits for energy renovation of houses, tax reductions and subsidies for energy audits (when it existed).

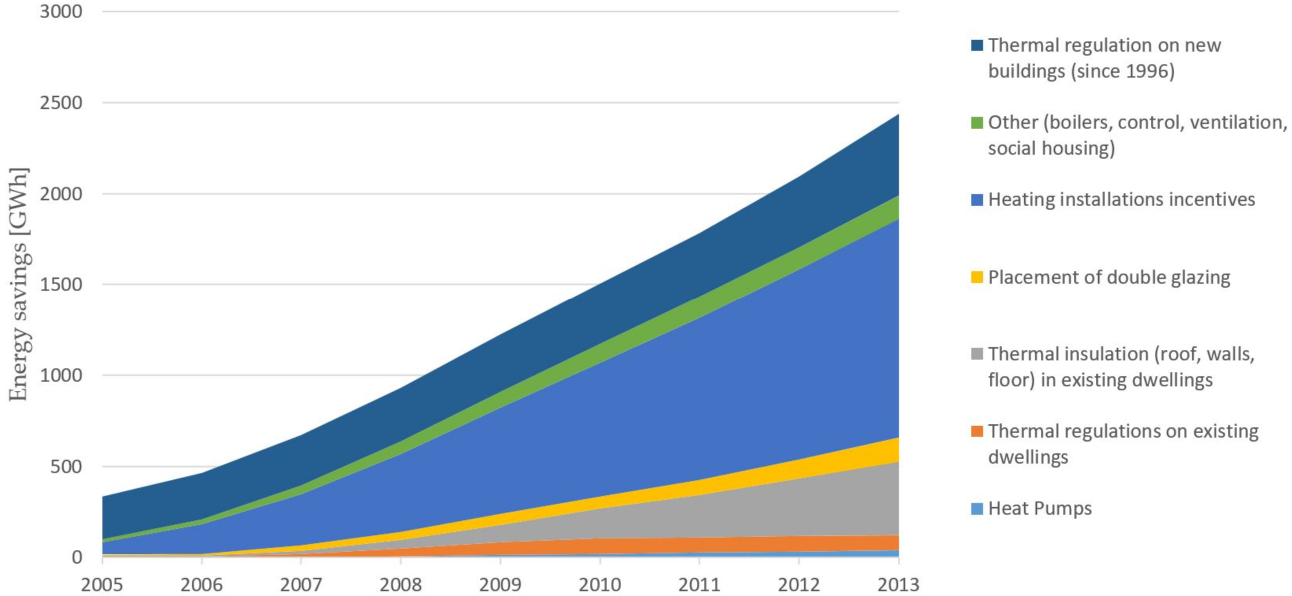

Fig. 2.2.45 Evolution of energy savings (in GWh) between 2005 and 2013 due to renovations works, incentives or regulations in Wallonia. (Source: ICEDD, 2015).

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[76] J.-A. POULEUR, et al., 2012. *Ibid.*

The graph above (Fig. 2.2.45) displays a first overview of the energy savings results, in GWh, brought by these measures between 2005 and 2013 (data released in 2015 by the ICEDD Institute). The impact of grants and other incentive or regulatory measures taken under the Action Plans for Energy Efficiency is estimated around 2.4 TWh in 2013, or approximately 8% of the normalised energy consumption. The main economy axes are the heating installations (focusing mainly on natural gas condensing boiler), thermal regulations applied to new buildings since 1996 (with progressive EPB (re)enforcement in 2008 and 2011), double glazing and thermal insulation (although the previous results might indicate that this mainly concerns roof insulation). The distribution of the 2013 energy savings is shown in Fig. 2.2.46 hereunder.

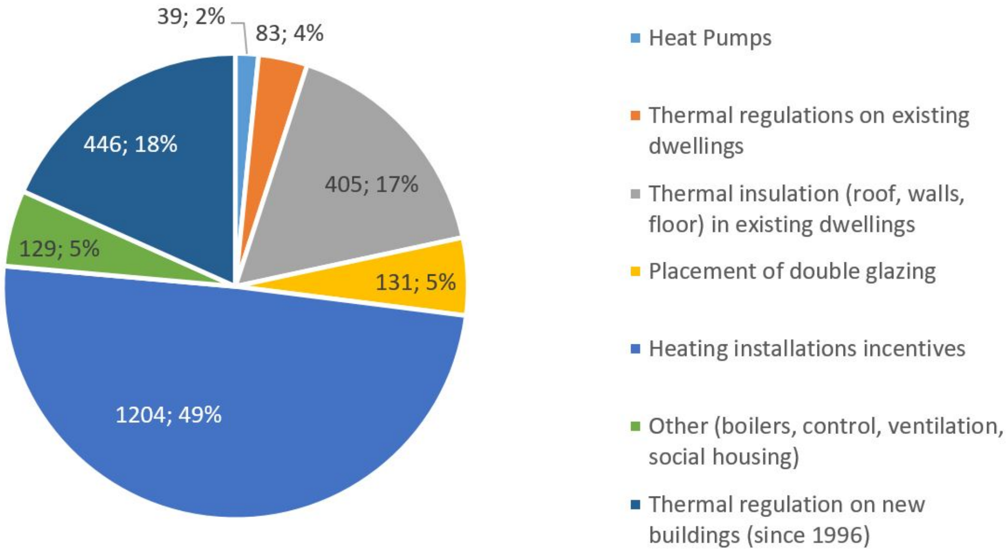

Fig. 2.2.46 Repartition of energy savings (in GWh and %) in 2013 due to renovations works, incentives or regulations in Wallonia. (Source: ICEDD, 2015).

The government and major stakeholders have also established the EEA (Employment-Environment Alliance) through the "Plan Marshall 2.Vert" in 2011, which aims at improving the environment, while promoting economic opportunities and job creation, ensuring the transition of the entire construction industry to a more sustainable model for the construction and renovation sector.[77] The first multiannual plan covered the 2011-2014 period; the second one covers the 2016-2019 period and is included in the "Plan Marshall 4.0". In 2015, the Walloon Government reported on the results of the first plan, and presented their 2020 perspective, in terms of saved MWh of final energy, and tons of CO_2 (see Figure 2.2.47).

The 2,541 GWh saved in 2014 correspond to the energy consumption of 105,000 Belgian households[78]. 2,045 of these 2,541 GWh concern the residential sector alone, and represented 6.8% of its 2014 final energy consumption. The 5,313 GWh that should be saved in 2020 represent the energy heating consumption of 220,000 households. Cumulated, the different EEA policies would lead to a final energy saving of 32.5 TWh between 2010 and 2020.

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[77] GW - Gouvernement Wallon, 2015. *1ère Alliance Emploi-Environnement : Le bilan*. Publication officielle, Namur, Belgium.
[78] CREG - Commission for Electricity and Gas Regulation: the average residential energy consumption for heating (natural gas) was around 23,260 kWh/household.year in 2014 (*Etude relative aux prix pratiqués sur le marché belge du gaz naturel en 2014*, https://www.creg.be/sites/default/files/assets/Publications/Studies/F1485FR.pdf, last visited on May 17th, 2018)

These results might appear different than those from Fig. 2.2.45, but they do not exactly cover the same data. In Fig 2.2.47 are only considered the measures (agreements, incentives or regulations) that fall under the EEA framework, while the Fig 2.2.45 considered incentives schemes and regulations from the Action Plans for Energy Efficiency.

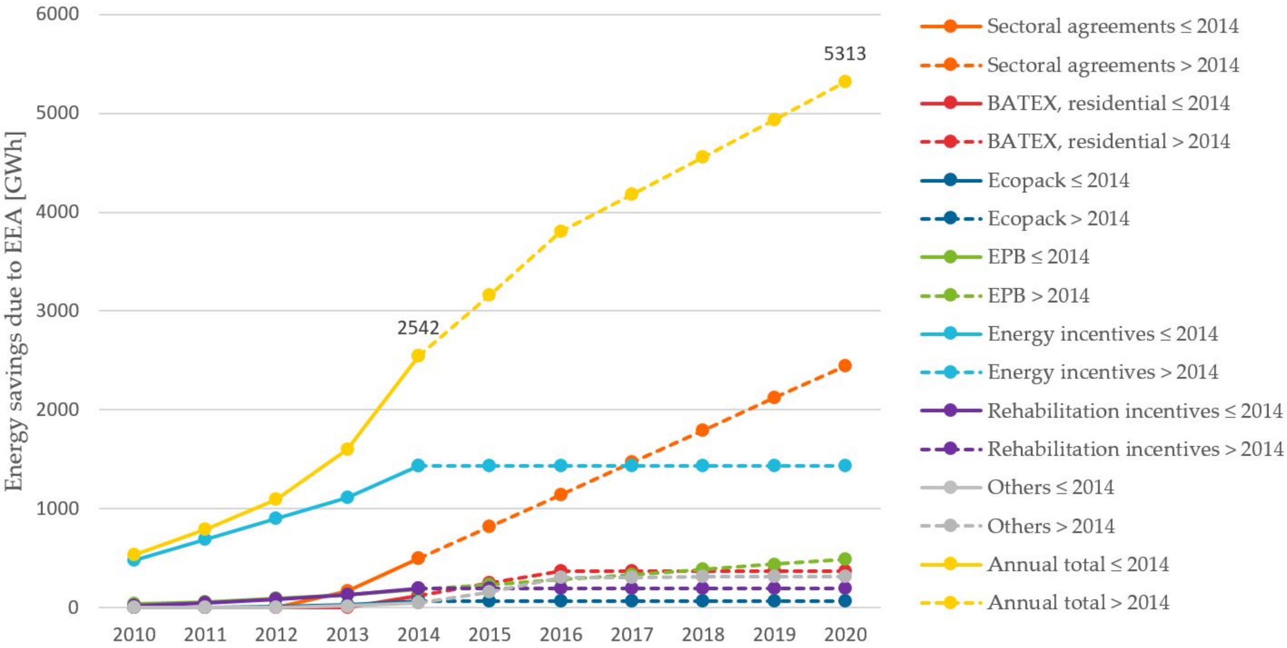

Fig.2.2.47. EEA reporting (2010-2014) and perspectives (2014-2020) in energy savings. (Source: Gouvernement Wallon, 2015). **Sectoral agreements** ("accords de branche") refer to voluntary agreements between Wallonia and industries (or federations) in order to improve the energy efficiency and reduce GHG emissions in industries. **BATEX** refers to the call for projects "BATiments EXemplaires", in which the Walloon Administration granted subsidies of 100€/m² of built or renovated buildings that proved to be exemplary in energy and environmental performances. **Ecopacks** are a particular form of loan, at a 0% interest rate, granted by the Walloon Government to willing retrofitters. The owners, sorted according to their income, defined with an assessor a series of renovation works to be done and the global costs. The Administration would loan the budget, and the owner would reimburse it gradually, minus the usual financial incentives that are granted for specific insulation or rehabilitation works. **EPB** refers to the EPB regulation, and its implementation targeting new buildings and renovations. "**Others**" category includes specific policies targeting public buildings, collective heating installations, commercial lighting…

The Figure 2.2.48 hereunder translates those results in saved tons of CO_2. The 586 ktCO_2eq saved in 2014 correspond to the annual GHG emissions of around 60,000 households[79]. When considering the only residential sector, 460.8 ktCO_2eq have been saved in 2014, representing 9% of the sector GHG emissions. 1.785 million tons of CO_2 could be saved in 2020 at that rate, which represents the 2014 emissions of 180,000 households. 2020 should see a total saving of 10 million tons of CO_2.

1.264 billion euros have been invested between 2010 and 2014 for these results. With 0.8644€/litre of fuel oil (price in December 2013[80]), the EEA would have saved 215 million euros in 2014, 556 million since 2010. Other "income" in the balance come from job creations.

[79] Official website of the administration in charge of environment: the GHG emissions in Wallonia were reported around 10.1 tCO2eq/capita in 2014, (http://etat.environnement.wallonie.be/files/Publications/ICEW2014-1_v2.pdf, last visited in May, 17th, 2018)

[80] Renouvelle, monthly web magazine of the association for the promotion of renewable energies (APERe), n°59 of December 2013 http://www.apere.org/doc/Renouvelle59.pdf, last visited on May 17th, 2018.

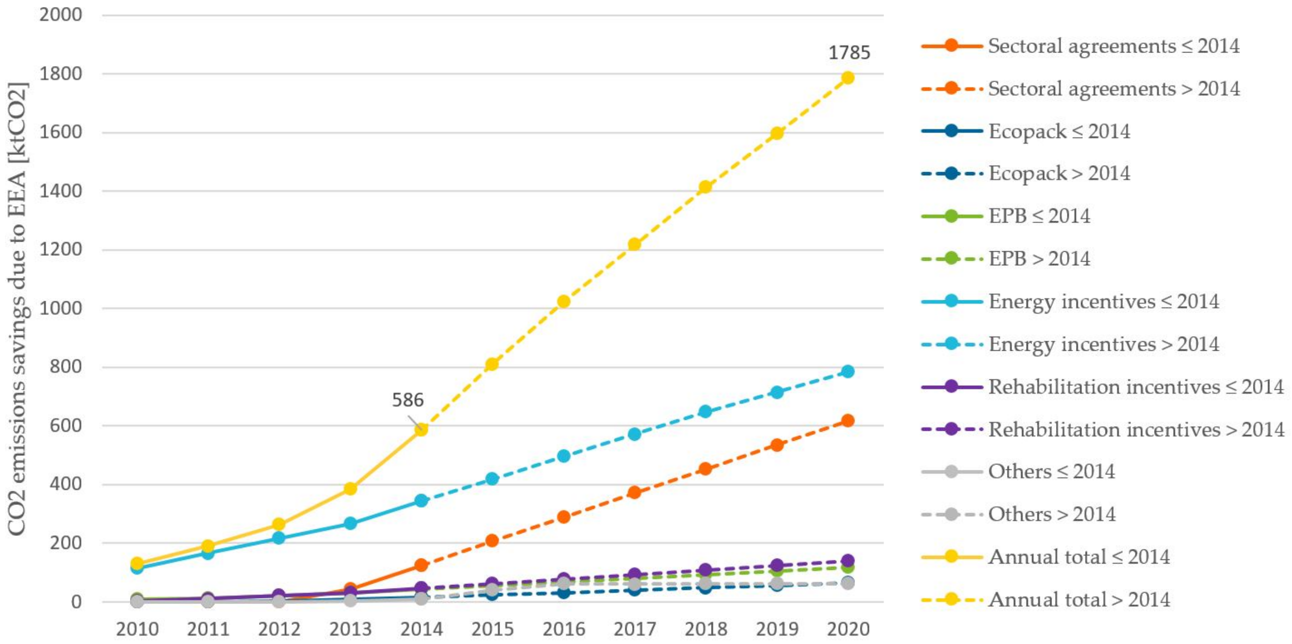

Fig.2.2.48 EEA reporting (2010-2014) and perspectives (2014-2020) in CO_2 emissions savings (Source: Walloon Government, 2015)

2.2.4 Energy Audit Procedure (EAP)

In order to stimulate the renovation sector, it is important to determine the characteristics of the stock to improve. The description of said stock, its energy parameters and characteristics in chapter 2.2.2 above, however, suggest that though there are some discernible trends and typologies, the diversity of the stock is such that those global approaches cannot be accurate enough to interest owners in possible benefits they could gain from the retrofitting of their building. They would prefer adequate information and strive for suggestions on simple and profitable renovation works related to their specific real-estate or comfort-related problems.

Since 2006, homeowners can pay for a full assessment (or 'energy audit'), receive labels and customized advice for their dwelling. The first Energy Audit Procedure (EAP1) allowed owners to inquire willingly about the global energy quality of their dwelling, on the basis of an analysis of the envelope, the ventilation, heating and domestic hot water systems. Completed by a certified assessor who produces recommendations, explanations and quantified estimates of improvement scenarios, the EAP1 can either target 1) a house or apartment with independent heating systems or 2) collective systems, 3) apartment blocks with separate heating systems or 4) with collective systems.

The procedure was adapted and improved in 2013 to produce the EAP2, which is accompanied by a new report layout and includes a stronger link with EPCs. This is an audit that provides an evaluation of the building's energy performance, taking into account the real energy consumption, as well as detailed recommendations to improve this performance.

Then came a time when the Walloon Government decided the public "sufficiently informed", and saw incentives as an excess weight in the budgetary balance. At the end of 2014, they announced a will to reach budget equilibrium in 2016, which translated in a refund of the fundamental mechanisms of incentives granting: in the 2015 reform, the EAP ceased to be an obligatory passage for energy incentives.[81] In addition with the abolition of provincial incentives when this topic left the provincial level for the regional level, this led to a collapse of the demand since January 2015: Before reform, around 335 audits were deposited each month on the Energy Administration server[82]. After the reform, 60 audits were deposited each month on the server. In May 2016, 33 certified auditors were still in activity in this field, for 483 delivered agreements.

Conclusions from 2015 workshops and a dedicated survey indicated that the audit appears as a master piece in the field of renovation strategies, a strong tool that responds to the citizens' needs and is defended by both the Administration and the audit officers. Although indicators are globally positive, it seems that the EAP is at a crossroads, which means a need to identify leads in order to redeploy it. Although some (small) improvements have already been implemented, there is a potential for deeper structural modifications: the procedure could become a full accompaniment of the owners in a renovation project. However, the financing part of this scheme could be problematic, and in desperate need for the return of incentives.

Among the reported dissatisfaction to the procedure, were cited:

- For 23% of the respondents, theoretical consumptions were too far from the real data, blaming the lack of accuracy in inputs or significance in outputs, which translate in a lack of confidence in proposed renovation scenarios (and their "profitability" analyses). If concern is raised over the gap between theoretical and real consumptions, it means that other important consumptions should be taken into account that were never really approached by any of those procedure (EPCs and EAPs), like the consumption of a hot tub, a pool…
- The lack of technical and financial information or propositions from the officer was reported by 38% of respondents to the survey. More technical services and assistance from the audit officer, such as infrared thermography or blower door tests to evaluate air tightness, would be welcomed. Light audits are prized by more technical profiles (who don't really need the audit but seek punctual technical counsel) or incentives-driven profiles (who seek a short and cheap service from the officer). Non-technical profiles want long-term project follow-up and advice added to the audit, whereas technical profiles want advice in place of the audit.
- The audit report (too complex for 8%), or the audit officer's competences, were not always satisfactory. Some auditees have expressed disappointment linked to the quantity of received information in the audit report. Its complexity (in length, in scenarios, in explanations…) led some people (especially those who just wanted clear advice) into believing that it is made 'unnecessarily hard'. Some deceptions are also linked to the gap that materialises between perceived and theoretical performance. Owners cannot relate to the results, as the expected consumptions are so far from the actual ones. Extreme opinions were shared by people persuaded to have a better understanding of the performance of their home than the EAP assessor, but at the same time confuse water tightness and insulation. They even suspect the auditor of purposefully ill-describing their home in order to get them to renovate.

Results to the survey were not all negative, however. 89% of answers showed satisfaction for the audit officer, 81% for the tool and its results. The existing tool seems well calibrated in technicity, allowing technical and non-technical profiles to move from stimulus to realization, although most

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[81] Furthermore, the remaining incentive (for the completion of an audit) was lowered from 360€ to 300€. It is now at 220 €.
[82] 27500 EAP1 audits were made between 01/09/06 and 01/01/13

still proposed improvements and add-ons. Very technical profiles generally ask for one-shot advice, and give their trust with difficulty. They do not seek complementary services. Neutral profiles rarely have a budget for complementary services, often search for cheaper and self-made renovations, seeking punctual advice on specific topics. Non-technical profiles tend to find the EAP more technical and complicated, but put more trust in the officer's help and advice, seeing a real added-value in his expertise when he can afford it. In any case, EAPs were (and still are) mainly requested by people who are already aware of the energy problem, already sensitized to renovation works.

There is also a real added value in the consideration of real consumption data given by the owners themselves (when those data exist). This is quite different from the "measured" assets in certification schemes (see below), where the real consumption data are disintegrated then re-standardised to allow buildings' comparisons. In this case, the real consumption data is used to calibrate the theoretical results and give much more accurate estimates in savings (which tends to decrease the rate of return). But more than that, it seems like the input of personal parameters into the calculation method makes the owners more invested in the process, and interested in the results. "Personal" input seems to ease the appropriation of outputs.

The EAP seems to arrive too late in the renovation process, when the insulation material is already chosen and, before reform, when owners wanted financial incentives. It needs to be brought out of its present private circle of clients, back to the lay public, at the beginning, when people need advice, information and contacts.

2.3 The Energy Performance Certificate (EPC)

2.3.1 Introduction

The Energy Performance Certificate (EPC) plays a key role in that perspective, as it informs potential tenants and buyers about the energy performance of a building unit (e.g. an apartment or office) or of an entire building, and allows for comparison in terms of energy efficiency.

The 2002/91/CE EPB Directive[83] asks that "Member States shall ensure that an energy performance certificate is issued for buildings or building units which are constructed, sold or rented out to a new tenant; Member States shall require that, when buildings or building units are constructed, sold or rented out, the energy performance certificate or a copy thereof is shown to the prospective new tenant or buyer and handed over to the buyer or new tenant."

Also, 'Energy Performance Certificate' (EPC) shall include:

- Indicators of the energy performance of the building or building unit.
- Reference values such as minimum energy performance requirements in order to make it possible for owners or tenants […] to compare and assess its energy performance.

[83] EUROPEAN PARLIAMENT AND COUNCIL, 2002. *Directive 2002/91/CE Approved the 16th of December 2002, about Energy Performance of Buildings.* Official Journal of the European Communities 4.1.2003 L 1/65 http://eur-lex.europa.eu/eli/dir/2002/91/oj (last accessed on November 9th, 2016)

- Recommendations for the cost-optimal or cost-effective improvement of the energy performance of a building or building unit. They shall be technically feasible for the specific building and shall cover:
    a. Measures carried out in connection with a major renovation of the building envelope or technical building system(s);
    b. Measures for individual building elements independent of a major renovation of the building envelope or technical building system(s);
    c. Estimates for the range of payback periods or cost-benefits over its economic lifecycle.
- An indication as to where the owner or tenant can receive more detailed information, for example on the cost-effectiveness of the recommendations made in the EPC. The evaluation of cost effectiveness shall be based on a set of standard conditions, such as the assessment of energy savings and underlying energy prices and a preliminary cost forecast. In addition, it shall contain information on the steps to be taken to implement the recommendations. Other information on related topics, such as energy audits or incentives of a financial or other nature and financing possibilities may also be provided to the owner or tenant.'

The European Union established the EPC as a policy measure to address imperfect information in the housing market. The change of occupants (through purchase or rental) seems considered to be a crucial moment in a building's lifecycle, which could be used as a trigger for home improvements. Provision of clear and reliable information (such as the recommendations) at affordable cost and at the appropriate time to prospective tenants and buyers is crucial for making energy efficiency investments more attractive. The recast of the EPBD in 2010[84] even strengthened that particular role of the EPC, by demanding publication of its indicators at the time of advertising a building for sale or rental rather than only at the time of signing a purchase agreement or rental contract. The underlying idea is that the EPC should influence the demand for buildings with excellent energy efficiency performance and a high proportion of energy from renewable sources, increase their market value, and thus influence building owners to renovate their buildings.

Although the European energy label has a common base across all Member States, they had considerable discretion when implementing the EPC and were, for example, able to decide on the calculation methods of energy indicators. The influence parameters may include climate data, national calculation procedures, national default values and calculation choices, building tradition, used and allowed building system configuration in the countries, detailed assessed energy parts in the calculation method (energy needs, energy use, primary energy), national primary energy factors or CO_2 factors, values for building system performances used in national calculation procedures, air tightness values and thermal bridges values, solar shading factors, internal gains and usage times, set room temperatures, different calculation methods for floor and building component areas and volumes (internal or external dimensions etc.). As a result, national implementation of the EPC can differ considerably and comparisons between national (or regional) results can only be done by carefully considering all the hypotheses' differences.

[84] European Parliament and European Council, 2010. *DIRECTIVE 2010/31/UE on the energy performance of buildings (recast)*. Official Journal of the European Communities 18.6.2010 L 153/13 http://data.europa.eu/eli/dir/2010/31/oj (last accessed on May 17th, 2018)

The EPC displays the energy performance of a building with a simple universal indicator of the energy consumption – the energy index, similar to the EU Energy Efficiency label. There are two main types of certificates: stepped labels or continuous coloured band strips (see Fig. 2.3.1), and the level is determined by the annual specific energy consumption in primary energy of the building, reported to one square meter of heated floor area [kWh/m².year]. In some cases, specific energy consumption is accompanied by additional data expressed in physical units. The most typical additional data is CO_2 emission in kg/m² per year, as exemplified by the UK case, which also displays a scaled CO_2 index similar to the energy index.

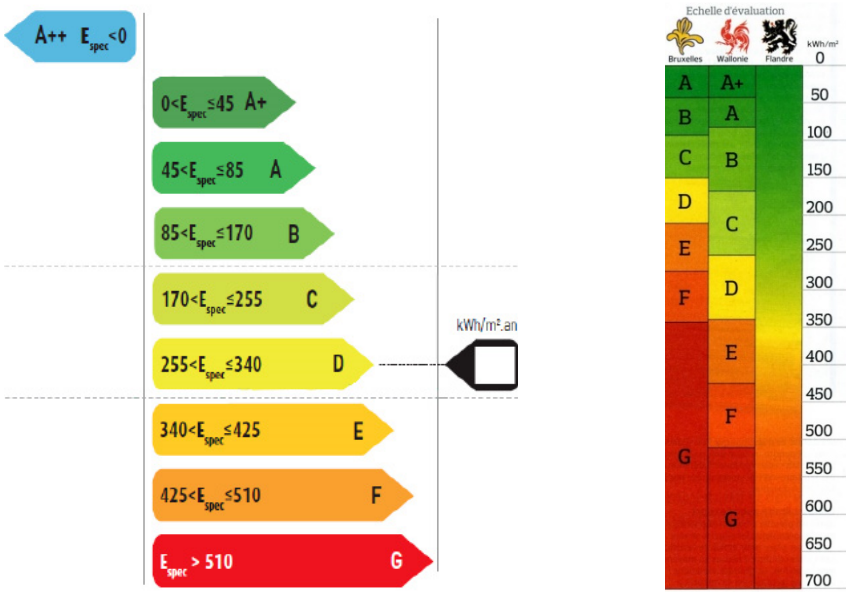

Fig. 2.3.1. EPC scale in Wallonia (right), and comparisons of EPC scales from the Regions of Brussels-Capital, Wallonia and Flanders. (Source: VANPARYS et al., 2012[85])

In a small country like Belgium, having three very different scales is characteristic of the political situation, without any regards for users' understanding of the information contained in it, or their opinion on the lack of coherence between Regions. Flanders uses a continuous coloured band strip, whereas Wallonia and Brussels use stepped labels, with EPC ranging from "A+" or ''A++'' for exceptionally energy-efficient dwellings, to ''G'' for highly inefficient dwellings. The thresholds are different between both scales, as they are calibrated on regional averages (and the differences between the residential sectors in Brussels and Wallonia, in terms of residential typologies and apartments share, can be important). In Wallonia, the A+/A++ threshold marks the theoretically null consumption of primary energy, where the few remaining uses are compensated by local production of renewable energy. The B/C threshold marks the regulatory requirement imposed to new buildings in the first implementation of the EPB thermal regulations, in 2010 (170 kWh/m².year of primary energy specific consumption). The D/E threshold indicates the average energy consumption of single-family dwellings in Wallonia, according to the EAP database (340 kWh/m².year of primary energy specific consumption). As shown below in the "by the number" section, the same average obtained from the EPC database is slightly higher, making the E/F threshold more accurate in representing the average. Reality of observed energy consumptions would have placed that average in the C level of the scale (see 2.2.2.5 above).

[85] VANPARYS, N., NICLAES, E., LESAGE, O., 2012. *Certificat énergie, la base d'un véritable audit ?*, magazine Test-Achats n°562, March 2012, pp. 10-16.

If the European Union wants to “address imperfect information”, the legitimacy of the EPBD framework depends on their quality and reliability. EPCs are official instruments and sources of information for sale and rental activities, and serve as an evidence of actual state and conditions. If correct, they should provide an explicit basis for planning of improvement measures, influence real-estate market value, offer indirect information about expected operational costs, and help built up comprehensive benchmarking databases, which are fundamental for shaping strategies on a national level. Without instruments for evaluating the quality of certificates, it is questionable whether and to what extent the above tasks are fulfilled, which could lead to problems with legislations, and give false information about compliance with the national legal requirements. A lack of quality can destroy the quality of the instrument so that in order to implement EPC as a meaningful and reliable source of information, numerous UE Member States decided to implement a quality assurance (QA[86]) system for EPC’s. The first step is, generally, the issuing of accreditations to professionally trained surveyors who will be able to perform the assessments, as did Wallonia. Other parts of QA systems applied to EPC include automatic electronic check or plausibility of data, targeted checks (i.e., triggered by complaints or out-of-range values) as well as checks on random samples (i.e. a certain percentage of all EPC of each expert gets audited once within a certain time-frame), to follow up on the quality criteria.

2.3.2 Measured vs calculated

There are two main ways to determine the energy performance of a building in an EPC: measured or calculated ratings.

Measuring the energy performance is not a straightforward matter, as there is a need to normalize real consumption data in order to reach standardized energy consumption, using calculation parameters such as climate, building size and type, behavioural habits and patterns of use[87]. Besides the need to divide the measured energy into its different uses, adjustments to standardized energy use can be a huge problem, as real consumption data are obviously greatly influenced by the behaviour of the occupants. Measured ratings will normally be cheaper than using calculated energy performance, due to the short time needed to collect information about the building, in order to be able to identify the energy performance. Recommendations based on measured ratings can be difficult to identify and give an accurate estimate of the potential energy savings.

Most European Member States use calculated energy rating, which evaluates the performance using building detailed characteristics (as close to reality as possible) about the thermal envelope and installations, default values (when no accepted proof of a more accurate value is available) and standardized parameters (which cannot be replaced by more accurate values, even if they are

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[86] Wikipedia: Quality assurance (QA) refers to the systematic activities implemented in a quality system so that quality requirements for a product or service will be fulfilled. It is the systematic measurement, comparison with a standard, monitoring of processes and an associated feedback loop that confers error prevention. This can be contrasted with quality control, which is focused on process outputs. Two principles included in QA are: "Fit for purpose", the product should be suitable for the intended purpose; and "Right first time", mistakes should be eliminated. Suitable quality is determined by product users, clients or customers, not by society in general.

[87] EPBD Concerted Action, 2011. I*mplementing the Energy Performance of Buildings Directive 2010 (EPBD), Featuring Country Reports*; EU Publications Office: Brussels, Belgium.

known). Among those standardized parameters are, for example, a calculation method based on occupancy by an average household and the use of standard loads and climate. As a consequence, it is immediately feasible to compare the energy performance of two buildings, without any kind of adjustments or standardisation. However, the time needed to collect enough information to be able to carry out an energy performance calculation is not negligible. It can also be complicated to obtain the necessary information to establish an appropriate building model, especially when dealing with old buildings that have been renovated several times since their construction. Normally, the cost of issuing an energy performance certificate using calculated energy performance will be higher than that of an EPC based on measured data for the same building, because the former is more time-consuming to issue.

2.3.3 EPC in Wallonia

2.3.3.1 Implementation

The EPBD has been implemented by a decree of the Walloon Government, and enforced by the public administration in charge of land planning, housing, built heritage and energy (also referred to as the Operational Directorate-General 4). On April, 17th, 2007, the first EPB Directive (2002/91/CE) has been transposed, and the second – or recast – Directive (2010/31/UE) was adopted on November 28th, 2013 and May 15th, 2014, and fully entered into force in May 2015. The public display of a building's energy performance is also required in frequently visited public buildings, although this has not been enforced yet in Wallonia.

Assessors are required to follow a training course of five and a half days, then pass an examination. Successful, the assessor will receive a login and password to be able to download the software and upload files onto the central database of the Walloon Administration that will actually deliver the EPCs. During the training, they are informed on thermal characteristics of materials, energy efficiencies of systems and global energy balance of the building. They are trained to certify a building with a detailed procedure, using an elaborate protocol and a short, precise and exhaustive list of accepted sources of accurate data in the dwelling description ("acceptable proofs").

For existing residential buildings, a dedicated, stand-alone software, called PACE (for "Procédure d'Avis et de Certification Energétique" – *Energy Certificates and Audits Procedure*), is used by the assessors to input the building data collected. This PACE software includes built-in validation rules, in order to avoid sending incomplete EPCs to the database (which also includes new buildings). It also contains validation rules for input data to prevent mistakes (rules to prohibit or flag certain values). All certificates are generated by a central database, on the base of output files coming from the software.

The public administration manages the independent control of a statistically significant percentage of the certificates issued annually, with an automatic tool that increases efficiency and systematises quality checks. This tool is based on a web application (called Web control) and it was finalised at the end of 2013.

2.3.3.2 Methodology

The 2002/91/CE and 2010/31/UE European Directives imposed domains of energy consumption that had to be considered for the assessment of the energy performance of a new residential building: heating, Domestic Hot Water (DHW), cooling and auxiliaries (with eventual compensation due to thermal solar or PV panels, heat pumps, or cogeneration). The definition of the calculation method in itself was left to the member states (or regions, in the case of Belgium). The Walloon regulatory calculation method is described in (SPW - Service Public de Wallonie, 2014)[88] and had to be adapted in its Annex D[89] for the assessment of existing residential buildings.

Wallonia uses a standardized consumption calculation method (asset rating) to assess the dwelling without the influence of the occupants. The consumption of energy for space heating is calculated using a single zone, quasi-steady-state, monthly calculation method. The energy use for cooking, lighting and domestic electrical appliances is not included in the regulatory procedure for residential buildings, because a) they are simply negligible, when compared to heating consumptions and b) they are too much influenced by their occupants' lifestyle, income, comfort standard, and energy-saving practices.

Default values also dominate the methodology, when no accepted proof of a more accurate value is available. Examples are legions, among which:

- The description of the envelope, a hard task in the certification process for anyone who wishes to deliver an accurate EPC. Layers are hidden, owners "know" but assessors can only trust their eyes, acceptable proofs and follow the protocol. Default values can rule on the presence of insulation, depending on the age of the construction or the renovation, impose thicknesses and thermal properties of all materials, including the insulation layers.
- The air permeability of the envelope, used to evaluate the infiltration heat losses, is expressed as a $\dot{v}_{50,heat}$ value that gives the flow rate of air infiltration at 50 Pa pressure difference, per square metre of heat loss area. In the absence of a measured value, proved by an official report, a default value of $12m^3/(h.m^2)$ is used.
- Heaters, boilers or heat pumps' efficiencies not only depend on their characteristics, but also on the installation and settings of the whole heating system. Default values are used to propose efficiencies for the production, storage, distribution or emission of heat, or in return water temperature, for example.
- The climate data (monthly average exterior temperatures and solar radiations) used in the assessment of energy demands represent an average climatic year in Belgium, neglecting spatial or temporal variations.

All calculated energy figures are converted into their primary-energy equivalents, with a conversion factor of 2.5 for electricity, and translated into a dimensionless indicator, the 'E_{spec}', which indicates the relative annual primary-energy use of the building in kWh per square meter of "heated floor area".

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[88] SERVICE PUBLIC DE WALLONIE. 2014. *Arrêté du Gouvernement Wallon du 30 Juillet 2014 Portant Exécution du Décret du 28 Novembre 2013 Relatif à la Performance Énergétique des Bâtiments*; Moniteur Belge: Namur, Belgium; pp. 56172–56294.

[89] SERVICE PUBLIC DE WALLONIE, 2014. *Annexe D: Méthode de Détermination de la Consommation Spécifique des Bâtiments Résidentiels dans le Cadre de la Certification PEB*; moniteur Belge: Namur, Belgium; pp. 61636–61767.

2.3.3.3 By the numbers

The numbers presented hereunder originate in the official reports of the public administration in charge of the EPC, through their communication channels[90] or through the EPBD Concerted Action[91].

On January 31st, 2017, there were, in Wallonia:

- 2,159 EPC assessors for existing residential buildings, accredited natural person (1,890 of which were active), and 13 accredited legal persons.
- 440,104 EPCs sent to the central database, representing 395,253 distinct dwellings. This means that approximately 26% of the residential stock had been certified at least once. More than 200 certificates are sent per day to the database.
- The certification market represented a total generated turnover over €100 million, incl. VAT.
- The average primary energy specific consumption (or "E_{spec}") was 432 kWh/m².year, rising to 485 kWh/m².year for the single-family houses only. These numbers appear quite superior to those presented in chapter 2.2.2.5, keeping in mind that EPC results are expressed in primary energy, emphasising the weight of electricity consumptions in the average.

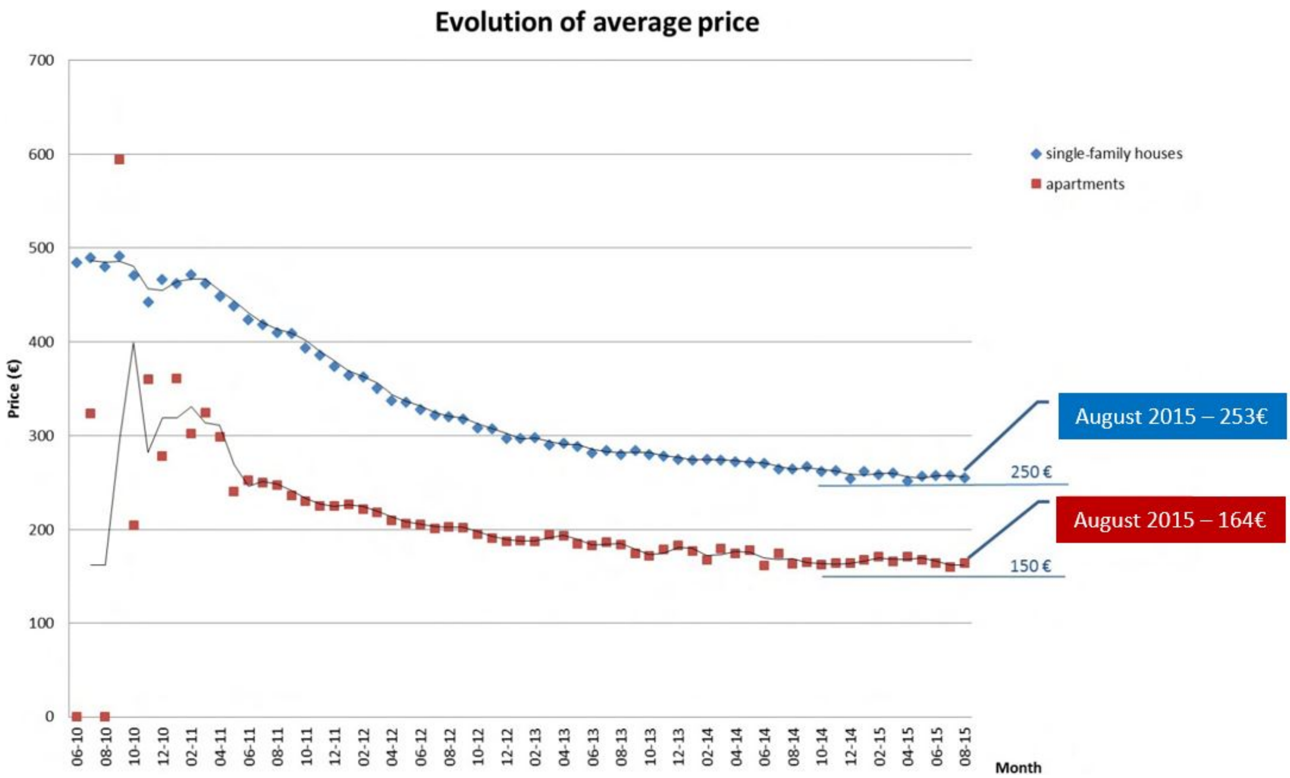

Fig. 2.3.2 Evolution of average price for an EPC in Wallonia, 2010-2015. (Source: EPBDCA, 2015)

For existing residential buildings, the certification process is quick (it takes about four hours), in order to keep the price, displayed on the certificate, low. In December 2016, the average price of an EPC for a single-family house had dropped to 240€ (it was around 480 € during the early stages of

[90] Service Public de Wallonie, 2017. *Newsflash Certificat PEB* n°10 du 24 mars 2017, Direction Générale Opérationnelle (DGO4) Aménagement du Territoire, Logement, Patrimoine et Energie, Département de l'Energie et du Bâtiment durable, Jambes, 7 p.

[91] EPBD Concerted Action, 2015. *Implementing the Energy Performance of Buildings Directive (EPBD), Featuring Country reports (2016)*, EU Publications Office. (https://www.epbd-ca.eu/)

certification, see Fig. 2.3.2 above). 77% of those EPCs showed prices between 150 and 300€. For apartments, the average price stabilised just above 150€.

The Fig. 2.3.3 displays the results of the certification of the certified quarter of the stock, showing that the results seem quite disseminated among labels. Having, on average, larger thermal losses areas, single-family houses are responsible for the higher share in inefficient buildings, as evidenced by the graph on the right.

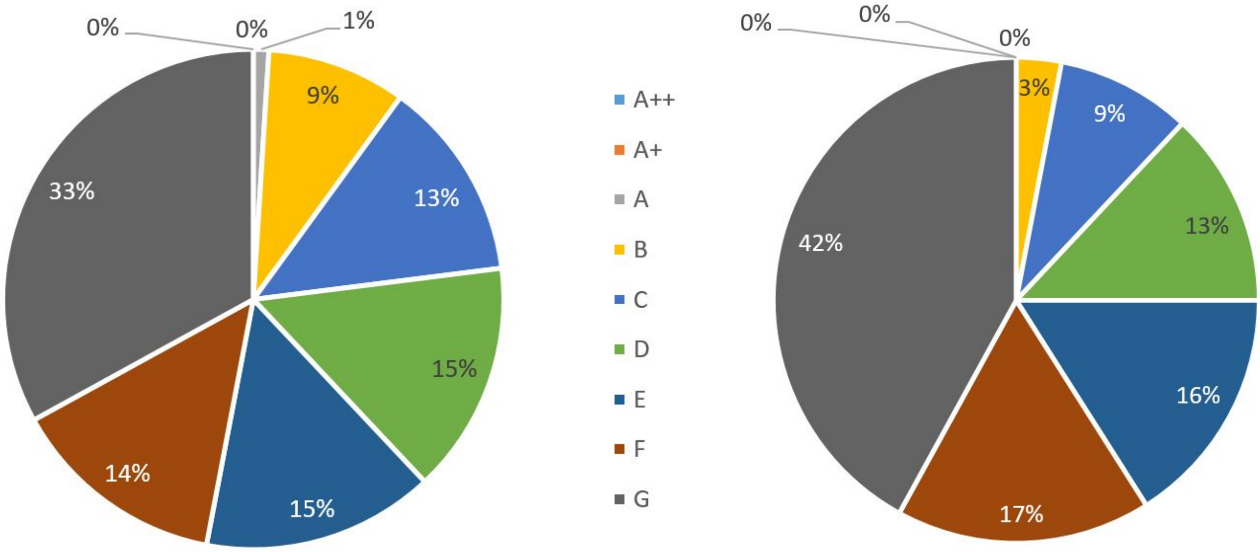

Fig. 2.3.3. Repartition of EPCs in accordance with their label levels, for the total certified stock (**left**) and the single-family houses (**right**) (status in December 2015) (Source: EPBDCA 2015).

In the same way, the EPCs of buildings built before 1970 display more often "F" and "G" labels than EPCs from the last 18 years (see Fig. 2.3.4 hereunder). The houses "in-between", built after 1970 and before 2000, are more evenly distributed, although there are few highly efficient buildings (in any category). Contrary to the popular misconception, not all old houses are G-rated, but it seems that, globally, the older the house, the worse the EPC. This is trivial to throw, and we know now that the situation is more complex than that. Other indicators are given hereunder (see Fig.2.3.5 to 7), where the same repartition has been kept between age categories (<1970, 1971-2000 and >2000).

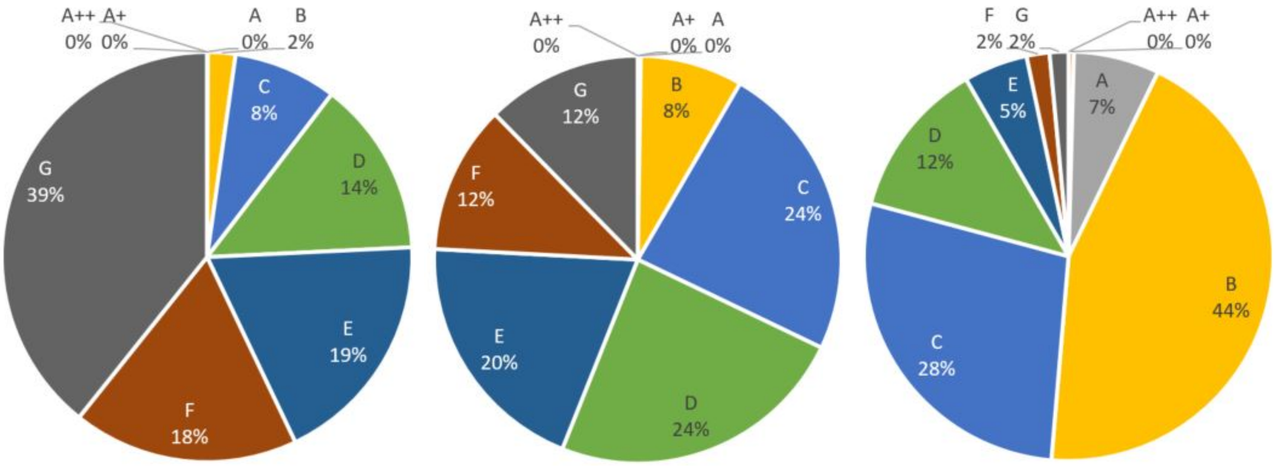

Fig. 2.3.4. Repartition of EPCs in accordance with their global label levels, for the total houses built before 1970 (**left**), between 1971 and 2000 (**centre**) and after 2000 (**right**) (status in December 2015) (Source: EPBD CA 2015).

The five indicator levels indicated in Table 2.3.1 hereunder are related to "smiley faces" informing readers of the overall performance of the envelope, the heating system or the DHW system. The envelope performance is a rating of the dwelling's net heat demand (balancing the heat losses by transmission through the envelope, the heat losses by ventilation and infiltration, and the internal and solar heat gains). Heating and DHW indicators are mainly determined by the efficiencies of the global installations, including production, storage, distribution and emission efficiencies. The results are compared to a simple scale of thresholds:

Tab. 2.3.1. Thresholds for the indicators in the Walloon EPC official method (Source: PSW, 2014[92]).

	Envelope Net Heat Demand	Global efficiency of the **heating** installation $\eta_{glob,heat}$	Global efficiency of the **DHW** installation $\eta_{glob,water}$
Very good	≤ 60 kWh/m².year	$\eta \geq 0.80$	$\eta \geq 0.60$
Good	> 60 kWh/m².year ≤ 90 kWh/m².year	$0.80 > \eta \geq 0.70$	$0.60 > \eta \geq 0.40$
Average	> 90 kWh/m².year ≤ 120 kWh/m².year	$0.70 > \eta \geq 0.60$	$0.40 > \eta \geq 0.35$
Bad	> 120 kWh/m².year ≤ 250 kWh/m².year	$0.60 > \eta \geq 0.50$	$0.35 > \eta \geq 0.30$
Very bad	> 250 kWh/m².year	$\eta < 0.50$	$\eta < 0.30$

The results are somewhat different for technical installations. Their lifespan is undeniably shorter than the lifecycle of a building's envelope. Furthermore, they have a more direct influence on important comfort issues, such as quick availability of heat and hot water. They are replaced more often than a building's envelope is renovated.

As far as the DHW installation is concerned, however, there seems to be a quite distinct segmentation between "efficient" and "inefficient" systems. To simplify the reading, a DHW installation is either good or bad.

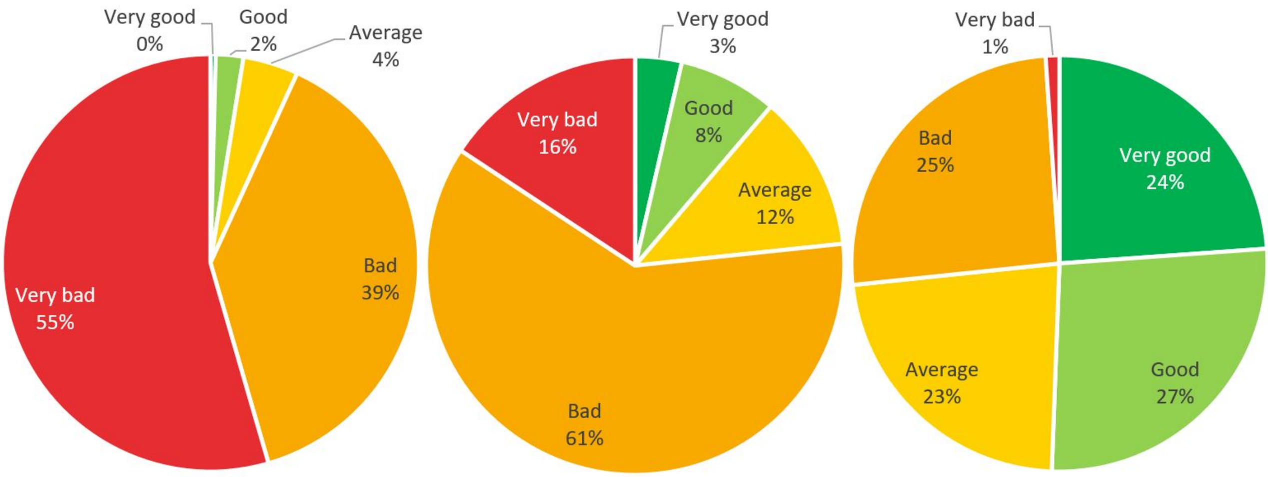

Fig. 2.3.5. Repartition of EPCs in accordance with their **envelope** indicators, for the total houses built before 1970 (left), between 1971 and 2000 (centre) and after 2000 (right) (status in December 2015) (Source: EPBDCA 2015).

[92] PUBLIC SERVICE OF WALLONIA. *Annexe D: Méthode de Détermination de la Consommation Spécifique des Bâtiments Résidentiels dans le Cadre de la Certification PEB*; Belgian Monitor: Namur, Belgium, 2014; pp. 61636–61767.

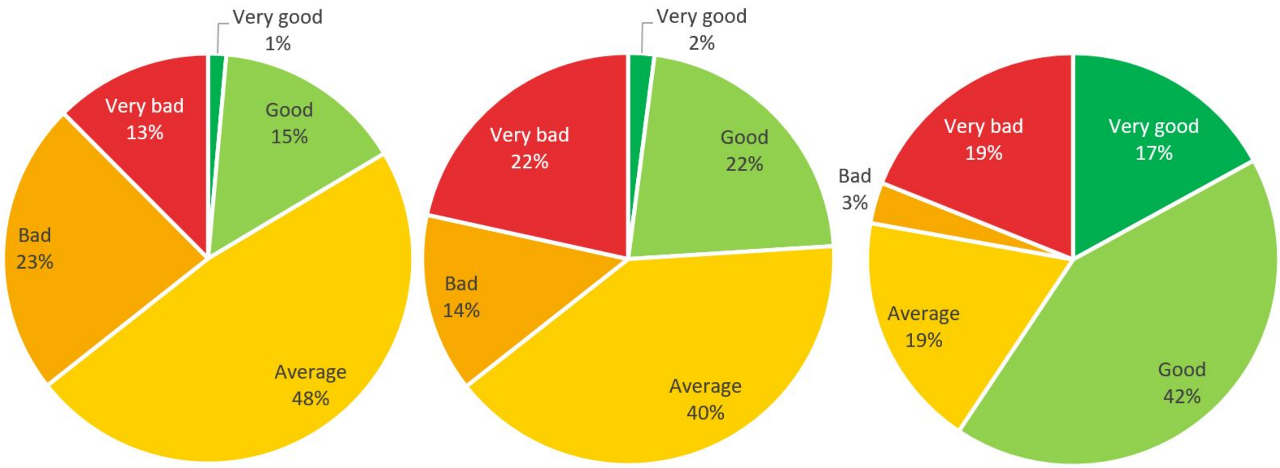

Fig. 2.3.6. Repartition of EPCs in accordance with their **heating** indicators, for the total houses built before 1970 (left), between 1971 and 2000 (centre) and after 2000 (right) (status in December 2015) (Source: EPBDCA 2015).

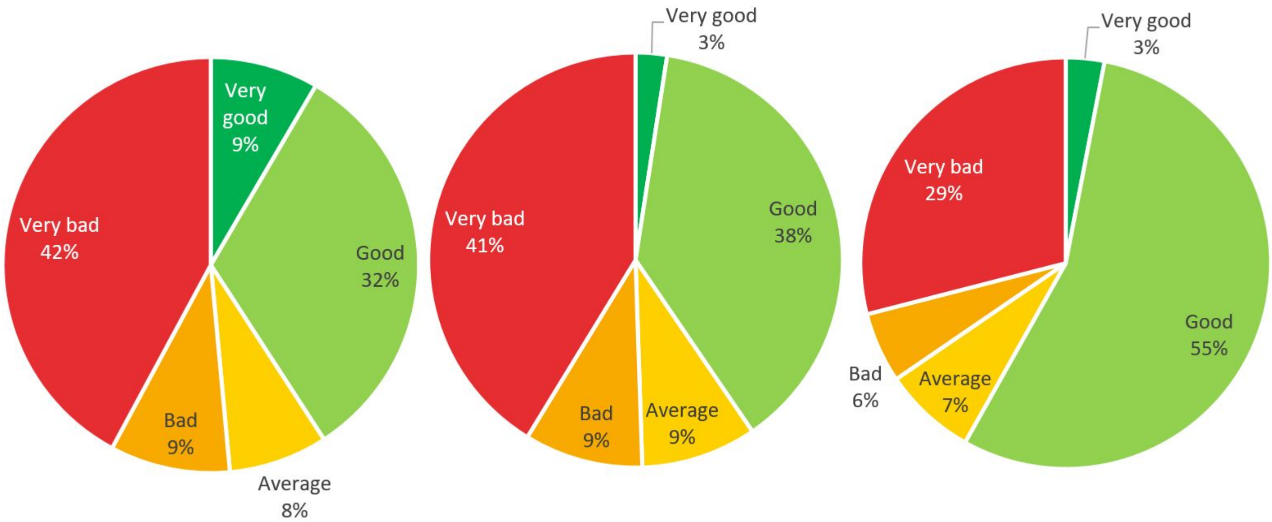

Fig. 2.3.7. Repartition of EPCs in accordance with their **DHW** indicators, for the total houses built before 1970 (left), between 1971 and 2000 (centre) and after 2000 (right) (status in December 2015) (Source: EPBD CA 2015).

Chapter 3: Frameworks

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3.1 Introduction

In June 2017, the Walloon strategy for the long-term energy renovation of buildings[1] was presented by the Public Service of Wallonia, defining the main action axes in order to achieve the European objectives: a reduction of the Greenhouse Gases (GHG) emissions of 80 to 95%, by 2050.

The residential sector mitigation potential has been translated in a particularly ambitious target: -95 to -100% of emissions reduction. In other words, no GHG emissions will be allowed in the building sector if they are not compensated by some other means. For decades now the sector has been preparing for this long announced energy transition. Architects have been trained to include energy characteristics in their architecture and to assess the solutions to implement in order to respect more constraining regulations. They and the building crews had to adopt new standards and techniques that kept evolving. Producers presented new systems, more efficient but often more complex to install, and materials producers searched for new and more efficient products in order to answer the evolving needs.

In Wallonia, the main part of the residential emissions come from the heating and DHW systems, and the emissions associated with the electricity consumption[2]. Given the state of the stock that has been described above, these ambitious objectives translate in the necessary division of the average consumption by a factor 10 before compensating the remainder with renewables. The average EPC scale level indicator must rise from a current E (according to official data) or F (according to the EPC database) to an A+. In the current building market, characterised by a low demolition rate and a relative inertia in renewal, it is expected that 80% of the existing stock will still be standing in 2050. Ambitious objectives apart, it is quite difficult to imagine the whole stock turning to A+ in the next thirty years. The share in A++ buildings would have to increase considerably, for it to compensate the inevitable share of "inefficient" buildings that are already standing and cannot be renovated to that level, because of urban planning limitations, for example, in terms of available space to insulate properly or regulations in city centres. Other barriers to that level of renovations might be found in the "problem" of the historical architectural value in buildings which could still be insulated but which "character"-istics have to be preserved, rendering the whole process less efficient and more costly; or in the lack of appropriate technologies, competences and financial incentives that would ease the process that these political ambitions want to implement.

Apart from the few "early birds", who understood and shared the motivations for energy-saving practices and measures for some times and have invested in new buildings or energy retrofits, the main blockage to an A+ stock by 2050 seems to be the homeowners themselves. They are the seekers of comfort, the users of energy (though they may not see themselves that way). Policies have been targeting their behaviour for decades, mainly towards their financial concerns and motivations. These policies regard information deficit as an important reason for 'non-rational' behaviours (like

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[1] CLIMACT, 3E, BPIE, SPW/DGO4, 2017. *La Stratégie Wallonne de Rénovation Energétique à long terme des bâtiments*, Service Public de Wallonie, Namur.

[2] The Belgian production factor spreads between summer off-peak hours (0.264 $kgCO_2eq/kWhPCI$) and winter peak hours (0.335 $kgCO_2eq/kWhPCI$), for a mean 0.29 $kgCO_2eq/kWhPCI$ value. Energie Plus website (UCL – SPW), Les émissions de polluants liée à la consommation énergétique http://www.energieplus-lesite.be/index.php?id=15568, last visited on May, 17th, 2018

the reluctance to retrofit to an A+ level), and generally view the provision of information, financial incentives, tax reductions and technology innovation, as an imperative to enable "economically rational" choices.

The pace of retrofit, however, is not (yet) to the expected levels, and needs to be quickened. There is even a sense of urgency, as 2050 is tomorrow in the current timeframe, moreover in the building sector which evolution is considerably slow. There are dwellings, today, that are "deeply retrofitted" (meaning important works for the homeowner, not necessarily to an A+ improvement level) that will probably not be renovated (again) by the same owner before 2050. Urgency in behaviour modification seems like an oxymoron, however. As the French Sociologist at the Economy and Prospective Service at ADEME, Chantal DERKENNE, said to the journal "La Recherche" in 2011[3]: "*Let's not forget that these speeches on energy control are quite recent. We grew up from a generation that knew energy abundance, which created waste behaviours. Hence, changing behaviour will take time.*"

3.2 Rationalistic VS structuralist frameworks

The next subchapter is based on the following literature sources:

- B. MARESCA, A. DUJIN, R. PICARD, 2009. *La consommation d'énergie dans l'habitat : entre recherche de confort et impératif écologique*, in Cahier de Recherche n° 264 du Centre de recherche pour l'étude et l'observation des conditions de vie (CREDOC), Paris, 87p.
- G. WALLENBORN, C. ROUSSEAU, K. THOLLIER, H. AUPAIX, 2006. *Politique d'Appui Scientifique à une Politique de Développement Durable PADDII: Détermination de Profils de Ménages Pour une Utilisation Plus Rationnelle de L'énergie, Partie 1: Modes de Production et de Consommation Durables*; Politique scientifique fédérale: Bruxelles, Belgique.
- L. LUTZENHEISER, 1993. *Social and behavioural aspects of energy use*. Annual Review of Environment and Resources 18, 247–289.
- A. HUBER, J. KORTMAN, A. M. BENITO, M. SCHARP, 2010. *BewareE: Développer et mettre en œuvre des services efficaces de sensibilisation à l'utilisation de l'énergie domestique*. Intelligent Energy Europe Program, no ed.
- T. CHATTERTON, 2011, *An Introduction to Thinking about 'Energy Behaviour': a multi-model approach*. Edited by Oliver Anderson, Customer Insight Manager, Department of Energy and Climate Change.
- P. DOLAN, et al., 2010, *Mindspace, influencing behaviour through public policy. The practical guide*. Cabinet Office and institute for Government, London, UK
- B. ALLIBE, 2012. *Modélisation des Consommations D'énergie du Secteur Résidentiel Français à Long Terme, Amélioration du Réalisme Comportemental et Scenarios Volontaristes*. Ph.D. Thesis, Ecole des Hautes Etudes en Sciences Sociales, Paris, France.
- L. F. CHIU, et al., 2014. *A socio-technical approach to post-occupancy evaluation: interactive adaptability in domestic retrofit*, Building Research & Information, 42:5, 574-590
- A. INGLE, M. MOEZZI, L. LUTZENHISER, R. DIAMOND, 2014. *Better home energy audit modelling: incorporating inhabitant behaviours*, Building Research & Information, 42:4, 409-421

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[3] J. VITERBO, *Comment changer nos comportements énergétiques*, Interview de C. DERKENNE, sociologue au service Economie et Prospective de l'ADEME, pour le journal « La Recherche », n°452, Paris, Mai 2011.

Classic economics theories on energy use see energy as a 'commodity', and its consumers are rational beings. In this framework, they are seen as *individuals* (not households) who know their needs and how to get satisfaction by evaluating their choices and possibilities and by taking the right decisions in consequence. They are capable to formulate rational choices that express the satisfaction of fix and stable preferences, but also to adapt usage in response to price signals. They analyse the various pieces of information from governments, administrations and markets, the numerous incentives offered and act in order to maximize their interests (however they, or policymakers, define their best interests), provided they are well-armed with information and prompts available to them at the right time (which can be explicit pricing structures or clear explanatory or informational literature). Their decisions are independent from institutions other than the market; to influence consumers, therefore, one would "only" need to improve information or use financial tools to render the balance between costs and individual benefits attractive. "Behaviour" is seen as the result of a rational deliberation from the individual, and "social structures" are the products of individual, controlled and rational behaviours.

Most traditional interventions in public policy follow this model. These are by definition top-down policies, based on energy assessments dominated by the bottom-up Physical–Techno–Economic Model (PTEM)[4], particularly in energy demand forecasting and policy planning. In this model, the expected rationality of occupants' behaviour allows to consider them secondary to the building's thermodynamics and the efficiencies of the technology, devices, machines, and appliances that are the actual users of energy[5]. These engineering models are based on a simplified representation of physics laws that connect technology efficiency and physical environment with energy consumptions. The descriptive input data must be physical: households are qualified by the way they use technologies (usually via standardisation), whereas the environment is qualified by the description of the physical infrastructure (equipment efficiency) and physical environment (exterior temperature, sun radiation…). Heating is, therefore, an inertial use of energy, considering the slow variations in climate and the average lifespans of its three main direct determiners: the size of the dwelling (superior to 100 years), the insulation (around 30 years) and heating equipment (around 20 years). Under that paradigm, growth or decline in energy demand results primarily from changes in buildings and equipment. For decades, therefore, the notion of "energy efficiency" has been the focus of specialists as a solution to the continuous increase in energy consumption, implicitly postulating that the decrease in energy consumption cannot be done if the price is a backward step in comfort. The result is a polarisation on the technical dimension of consumption, which carries a paradigm reported by B. MARESCA et al.: there is "an ambiguous approach of the energy consumer. On one hand he is considered like an active and rational agent (rationalist approach) seeing that, for an equal comfort level, he makes the choice to make financial gains. On the other hand, he only is the recipient of practices and uses that are predetermined and imbedded in technical systems. This approach suffers therefore from important limitations on the sociological side which renders it unreliable to be the foundation of behaviour transformation. […] Present comprehension of energy consumption is characterized by the flaws of both approaches: on one hand, techno-centrism bets

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[4] L. LUTZENHISER, 1993. *Social and behavioural aspects of energy use*. Annual Review of Energy and Environment, 18, 247–289., p. 284.

[5] L. LUTZENHISER, L. CESAFSKY, H. CHAPPELLS, M. GOSSARD, M. MOEZZI, D. MORAN, H. WHILHITE, 2009. *Behavioural assumptions underlying California residential sector energy efficiency programs,* report for the California Institute for Energy and Environment. University of California. (p. II)

on technological structure to orientate consumption downwards without questioning the uses of this technology, nor their signification. On the other hand, putting the individual in responsibility makes him the foundation of dynamics for change, without questioning the framework in which his arbitrations form."[6]

Reasons for the difficulties encountered in behaviour modification (and in attaining the policies objectives) are easily pointed: imperfect information of consumers, who are not aware of potential financial gains residing in ecologically virtuous choices, or the "stowaway" phenomenon (an individual who relies on others to lead the virtuous movement, without endorsing investments or constraints[7]), limit the individual behaviours' harmonization towards collective optimum. Solutions to implement to overcome these difficulties are also consensual: increase personalised information, develop incentive measures, lean on the increasing ecological sensibility, promote it through educational actions… The implementation of financial incentive tools and the policies targeting structural factors (such as building thermal regulations) are privileged devices in this perspective.

This rationalistic framework that is so often used in current public policies, however, stumbles over the most basic observations of the little impact shown by this kind of intervention. Rationalistic models seem incapable to account for the wide spectrum of residential energy behaviours that can be very different from the engineering standardised assumptions. Studies from sociological, psychological or economic fields have shown for a long time now that consumers are not as rational as the policymakers think they are, following their purchase habits more than new information, ignoring profitable investments[8], showing no discernible logic of use and more coherent speeches than practices.[9]

The energy-saving policies highlight an important contradiction, which does not escape from people's notice. Our economies lean on one fundamental postulate: the economic growth. Therefore, consumers are encouraged to consume ever more in order to support economic growth. In this context, it is difficult to impose limitations on energy consumption. This is why some policies have stressed less on "consume less", and more on "consume differently", although gains due to the improved efficiency of resources are often compensated by higher consumption levels.[10] This phenomenon will later be called "rebound effect" (see further in chapter 3.7).

Since the 1970s, field studies have highlighted that comfort is a goal, a quest for optimal well-being at home. Moreover, there is a great diversity of comfortable conditions which can lead to different energy consumptions in different social groups, cultures or countries. They act under a sociotechnical sphere of influence that accounts for the household's composition, education, age or lifestyle, the type of dwelling and ownership situation, heating or ventilation habits and routines…

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[6] B. MARESCA, et al, 2009. *La consommation d'énergie dans l'habitat : entre recherche de confort et impératif écologique*, Cahier de Recherche n° 264 du Centre de recherche pour l'étude et l'observation des conditions de vie (CREDOC), Paris, 87 p.

[7] B. MARESCA, et al, 2009. *Ibid*

[8] A.B. JAFFE and STAVINS' "paradox of energy efficiency" defines the gap between optimal investment and effective investment in energy efficient technologies (in A. B. JAFFE, R.N. STAVINS, 1994. *The energy-efficiency gap: What does it mean?*, Energy Policy, 22, 804-810)

[9] G. WALLENBORN, et al. (2006), PADDII (Plan d'Appui scientifique pour une politique de Développement Durable): « *Détermination de profils de ménages pour une utilisation plus rationnelle de l'énergie. Partie 1: Modes de production et de consommation durables* », Politique scientifique fédérale, Bruxelles, 106 p.

[10] CRIOC, 2007. *Consommation Durable: quel rôle pour le consommateur?*, synthèse des recherches menées dans PADDII (Plan d'Appui scientifique pour une politique de Développement Durable), Politique scientifique fédérale, Bruxelles.

As a result, studies (see further in section 3.8) observed considerable variations in energy consumption between buildings with the same physical characteristics, and concluded that bottom-up models were unable to explain the consumption dynamics.

Inside a household however, and in "normal circumstances" (that do not include the renovation periods that could induce rebound effects), works that analyse consumption practices and their evolution observe a relative inertia in behaviours. This is even more accurate for energy, which consumption is not directly visible and, as a simple mean to accomplish different tasks, is not an emotional topic. Energy is used routinely, according to domestic activity sectors: lighting, heating, cooking, washing… In each domain, households make choices and adopt behaviours according to criteria and constraints, among which energy savings or money savings can be less important than other personal criteria.

Some economists[11] modified the "classical rational choice" model by integrating people's tendency to not always follow the logic of maximising benefits and minimising effort based on available information, and referred to it as "bounded rationality". An example from D. KAHNEMAN and A. TVERSKY's *Prospects Theory*, is that human beings fear loss more than they are motivated by potential gain. "Save" has more influence than "waste". Hence, the 'behavioural economics', which seeks to combine the lessons from psychology and those from economics, has moved from a fringe activity to one that is increasingly accepted, and is used nowadays in public policies.

Psychology theories and models make a distinction "between reasoned and habitual behaviours and between individually and socially driven behaviours. These models assume that behaviour is, for the main part, the result of deliberate, cognitive processes. But many of our ordinary, everyday behaviours are carried out with very little conscious deliberation[12]. Therefore the transformation of environmental consciousness into action is obstructed, in part, by the fact that energy use is often bound up with more comprehensive behavioural patterns and habits.[13] This explains, to some extent, the fact that despite good intentions, people are locked into automatic and unsustainable behaviours."[14] Psychologists "seek to explain behaviours by attitudes. They award a certain power to the spirit (or psyche), conscious or unconscious, which allows to assume a hold on individuals: by changing attitudes, one can change behaviours. Some even claim that by changing a behaviour, one can change an attitude."[15] Of course they acknowledge the social factors, but their main focus is the relation between attitude and behaviour, singular. "Energy use can be affected by stimulus-response mechanisms and by engaging attention. People will respond to information regarding their energy usage, such as Home Energy Displays, or billing information that provide them with salient information in a manner that allows, and encourages, them to reduce their usage."[16]

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[11] D. KAHNEMAN, A. TVERSKY, 1979. *Prospect theory: An analysis of decision under risk*. Econometrica, Vol. 47, No. 2, S.263–291.

[12] T. JACKSON, 2005. *Motivating Sustainable Consumption. A review of evidence on consumer behaviour and behavioural change*. Surrey: Centre for environmental strategy.

[13] W. J. HEIJS, 2006. *Household energy consumption. Habitual behavior and technology*. In: *User Behavior and Technology Development. Shaping Sustainable Relations Between Consumers and Technologies*, Eds P. VERBEEK and A. SLOB, Springer, The Netherlands, 2006.

[14] A. HUBER, J. KORTMAN, A. M. BENITO, M. SCHARP, 2010. *BewareE: Développer et mettre en œuvre des services efficaces de sensibilisation à l'utilisation de l'énergie domestique*. Intelligent Energy Europe Program

[15] G. WALLENBORN, et al. (2006), *ibid*.

[16] T. CHATTERTON, 2011, *An Introduction to Thinking about 'Energy Behaviour': a multi-model approach*. Edited by Oliver ANDERSON, Customer Insight Manager, Department of Energy and Climate Change.

In those models, though, energy demand management is based on individual consumption behaviours, postulating that the quest for individual interest will meet collective optimum. By doing so, they leave the collective dimension of energy consumption behind, such as the incidence of social structure that influence behaviours[17]. The second, structuralist framework is now highlighted, considering behaviours in their collective dimension, as social construct, which structure and determiners can be highlighted and objectified. In such a perspective, energy consumption behaviours relate less to individual choices than the analysis of the conditions in which they form.

3.3 Sociology of energy

The educational theories consider energy use as a skill to be learnt through experience, thereby differentiating consumers as a heterogeneous set of individuals with different world-views and levels of skills, understanding and motives when it comes to their use of energy. Sociological models put much more emphasis on the context and structures that determine, interact with and are created by the ways that people behave. Sociological theories globally acknowledge the complexity of energy systems, the infinite possibilities in which technology and infrastructure can be used, the significance of daily practices and the weight of social constructs on the ways we consume energy[18]. While psychologists tend to analyse energy-related *behaviours* as autonomous individual processes, sociologists analyse energy consuming *practices* as actions embedded in larger "socio-technical systems". Whereas the economic model approach establishes a series of simplifying hypotheses that flatten spatial variations, implying the existence of an optimal use of an object, as defined by technicians in laboratories, sociologists developed the notion of "domestication" or "appropriation", in order to understand how technologies' users appropriate an object and use it in their own way[19].

According to T. CHATTERTON, "there is a wide array of actors and objects that are involved in the processes determining how energy is used: families, households, energy supply companies, other companies involved in making, promoting, selling and installing energy efficiency products, other companies involved in 'home improvements' and building work, 'communities', NGOs [Non-Governmental Organisations] and the government, as well as physical infrastructures and hardware. Each of these interacts with each other and can influence energy behaviour in different ways." Taking thermal insulation as an example, he illustrates the psychological issues ("how people are made aware of insulation opportunities so that they see it as being relevant to them"), social,

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[17] G. POQUET, A. DUJIN, 2008. *Pour les ménages, la recherche du confort prime encore sur les économies d'énergie*, "Consommation et Lifestyle" n°210 du Centre de recherche pour l'étude et l'observation des conditions de vie (CREDOC), Paris.

[18] E. SHOVE, 2009. *Behaviour Technology Practice. Transitions in practice, climate change and everyday life.* In: Conference Proceedings "First European Conference Energy Efficiency and Behaviour", 18.10.2009, Maastricht.

F. BARTIAUX, 2008. *Changing energy-related practices and behaviours in the residential sector: Sociological approaches*. Paper presented at the Efonet workshop "Behavioural changes – backcasting and future trends". Madrid, 6./7.

F. BARTIAUX, G. VEKEMANS, K. GRAM-HANSSEN, D. MAES, M. CANTAERT, B. SPIES, J. DESMEDT, 2006. *Socio-technical factors influencing Residential Energy Consumption*.

H. WILHITE, E. SHOVE, L. LUTZENHEISER, W. KEMPTON, 2000. *The Legacy of Twenty Years of Demand Side Management: We Know More about Individual Behavior But next to Nothing About Demand*. In: E. JOCHEM, J. STATHAYE, D. BOUILLE, (eds), *Sociey, Behaviour and Climate Change Mitigation*. Netherlands.

K. GRAM-HANSSEN, 2008. *Energy in Homes: An Historical Approach to Understanding New Routines*, In M. RÜDIGER, (ed.), *The Culture of Energy*, Cambridge Scholars Publishing, Newcastle, s. 180–199.

[19] G. WALLENBORN, et al., 2006. *ibid*.

institutional or organisational factors ("how all the different parties – homeowners, suppliers, installers etc. – relate to each other, as well as concepts regarding home improvements, adding value to property and more generally how people relate to having work done on their house") and educational concerns ("the extent to which people might understand whether they should be considering cavity or solid-wall insulation, or even why insulation might be desirable").

Energy consumption is not a practice in itself, but all the different things that people do at home which consume energy, such as cooking or washing, are practices guided by different determiners. From a social-science perspective, there are yet considerable differences between:

- The "behavioural approach", which focuses on the individual and on the relation between attitudes, norms, intentions and behaviour (assuming that individuals behave consistently);
- The "lifestyle" approach, which studies the patterns behind energy consumption and how consumption relates to socio-economics (assuming that the type of people living in a specific type of building is not random[20]);
- Or the "practice theoretical approach", focusing on what guides and forms the collective structures of the practices that people perform in their everyday lives. The main difference between the behavioural and the practice theoretical approach is thus the question of how individualised and how conscious people's actions should be understood. Practice theory will emphasise the collective structures and the unconscious habits.[21]

The lay public seems to view the supply of energy, energy conservation and the management of GHG emissions as the responsibility of others (the society, economic and public authorities, transport and industry sectors), and energy consumption as a problem rooted in industry, transportation and persistent inefficiency of installations[22], and deny the responsibility of personal behaviours and social construct. In Wallonia, 60% of people interviewed in a 2006 survey believed that climate change fight is first and foremost technological[23]. According to B. FAHRAR, "the public seems to view 'business and industry priorities' and 'decisions by governments' as 'the greatest obstacles to the country using energy more efficiently'."[24] But the impact of their domestic energy consumption on environment is generally underestimated, so that they feel less concerned[25]. This is eased, furthermore, by the "total" invisibility of energy[26], though it must be acknowledged that perception of energy consumption varies from one use to the next[27]. In car transportation, for example, a tank is to be filled regularly, for which you perceive limitations, efficiency, and direct costs which eases the apprehension of consumption. Fuel consumption for heating or DHW production follows a similar path, although with larger timespan between tank refills. Natural gas, electricity and hot water are delivered continuously and invisibly however, and the link between

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[20] K. GRAM-HANSSEN, C. BECH-DANIELSEN, 2004. *House, home and identity from a consumption perspective.* Housing, Theory and Society, 21(1), 17 – 26.

[21] K. GRAM-HANSSEN, 2014. *New needs for better understanding of household's energy consumption – behaviour, lifestyle or practices?* Journal of Architectural Engineering and Design Management, Taylor&Francis.

[22] L. LUTZENHISER, 1993. *ibid*

[23] G. WALLENBORN, et al., 2006. *ibid*

[24] B. FARHAR, 1993. *Trends in Public Perceptions and Preferences on Energy and Environmental Policy*. Washington, DC: Nat!. Renewable Energy Lab., p. XVII in LUTZENHISER, L., 1993. *ibid*

[25] H. WILHITE, et al., *A cross-cultural analysis of household energy use behaviour in Japan and Norway*, in Elsevier Energy Policy 24 (1996), pp. 795-803, Great Britain

[26] J. BURGESS, M. NYE, 2008. *Rematerialising energy use through transparent monitoring systems*. Energy Policy 36, 4454–4459.

[27] J. VITERBO, 2011. *ibid*

activity and energy consumption is not always made: sometimes, energy is seen as a commodity[28], a mean to reach the real target that is comfort at home (through light, heat, entertainment, food, hot water…). The user intentions are mainly directed towards the practices, not the amount of energy consumed[29]. Energy is omnipresent in the diversity of everyday practices and some of those energy-consuming practices are so deeply rooted in habits that they became a lifestyle which costs are no longer questioned. Most users are not able to estimate the consumption or cost of any particular end-use[30], especially when it comes to routines.[31] Households are rather in search of an equilibrium between the satisfactions of their needs and the preservation of their purchasing power, more or less impacted by their energy bill[32]. The feedback information that is an energy bill does not allow any deconstruction of the total energy consumption, and comes too late to make users aware of energy wasting behaviours and opportunities for change.[33]

Those use of energy are conditioned by social norms and technical standards that continuously (and jointly) evolve. They consume energy for comfort, hygiene (cleanliness), consumption *stricto sensu* (entertainment equipment, food preparation…), protection, membership or distinction. Comfort, in this case, refers to the basic answer to physiological needs in heat, light, hygiene and entertainment needs. Two explanations can be given for breaches in these norms: fuel poverty (economic constraint in precarious public) or ideology, which belief justifies a different behavior in voluntary sobriety[34]. But apart from militant attitudes, an individual's ecologic convictions usually do not automatically translate into economical practices. Most authors even postulate that "energy-aware" households are bigger energy consumers, explaining this paradox by the direct correlation between ecological sensitivity and education or income levels, directly related to energy consumption[35]. This is known as the "value-action gap", whereby people's behaviour does not seem to relate closely to their expressed values[36]. This phenomenon can arise for many different reasons referring to individuality (laziness, lack of interest), responsibility (lack of trust in the efficacy of individual behavioural change) or practicality (lack of time or money to engage in pro-environmental behaviour).[37] This does not necessarily imply that values do not relate to actions, but that they are not the only determining factor (social norms, facilitating conditions or habits form another set).

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[28] T. Hargreaves, M. Nye, J. Burgess, 2010. *Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors*, Elsevier, Energy Policy 38, 6111-6119

[29] K. Gram-Hanssen, 2014. *ibid*.

[30] W. F. Van Raaij, T. M. M. Verhallen, 1982. *A behavioural model of residential energy use*. Journal of Economic Psychology 3 (1983) 39-63. North Holland Publishing Company.

[31] E. Shove, 2003. *Comfort, Cleanliness and Convenience: The Social Organization of Normality*. Berg, Oxford.

[32] G. Brisepierre, 2013. *Analyse sociologique de la consommation d'énergie dans les bâtiments résidentiels et tertiaires. Bilan et perspectives*, ADEME, Paris.

[33] G. Brisepierre, 2013. *ibid*.

[34] Sobriety refers to gestures and changes in daily behaviours in a context of climatic and energy crises. It differs from the efficiency, which is linked to technical aspects of energy (La Branche, 2015)

[35] P. M. Boulanger, J. Couder, Y. Marenne, S. Nemoz, J. Vanhaverbeke, A. Verbruggen, G. Wallenborn, 2013. *Household Energy Consumption and Rebound Effect, Final Report*. Brussels: Belgian Science Policy – 100 p. (Research Programme Science for a Sustainable Development)

[36] T. Chatterton, 2011. *Ibid*.

[37] R. Mourik, S. Rotmann, 2013, *Most of the time, what we do is what we do most of the time. And sometimes we do something new*. Analysis of case studies IEA DSM Task 24 Closing the Loop - Behaviour Change in DSM: From Theory to Practice. Deliverable 2 for IEA Implementing Agreement DSM Task 24

In 2011, T. CHATTERTON referred to an *individualist model of behaviour* based around TRIANDIS' Theory of Interpersonal Behaviour.[38] "Individualist models of behaviour focus on different components of people's decision making processes, and how these then lead to actions. These models are very instrumental in their view of behaviour. They treat people as more-or-less rational, independent individuals who decide what they want to do, and then are free to act on this intention, give-or-take sets of identifiable constraints or barriers. Because of their strong grounding in traditional economically rational views of behaviour, these types of models have been extensively adopted by governments. Gradually, this very simple view of decision making has been expanded to take into account a number of other factors that have been demonstrated to be important in forming behaviours."[39] In this model, the behaviour is the aggregated response of a person, consequence of a complex interaction between several determiners. Behaviours are first defined by our habits and intentions, under the influence (help or hindrance) of external facilitating conditions (and knowledge about these factors is also likely to influence the formation of intention…).

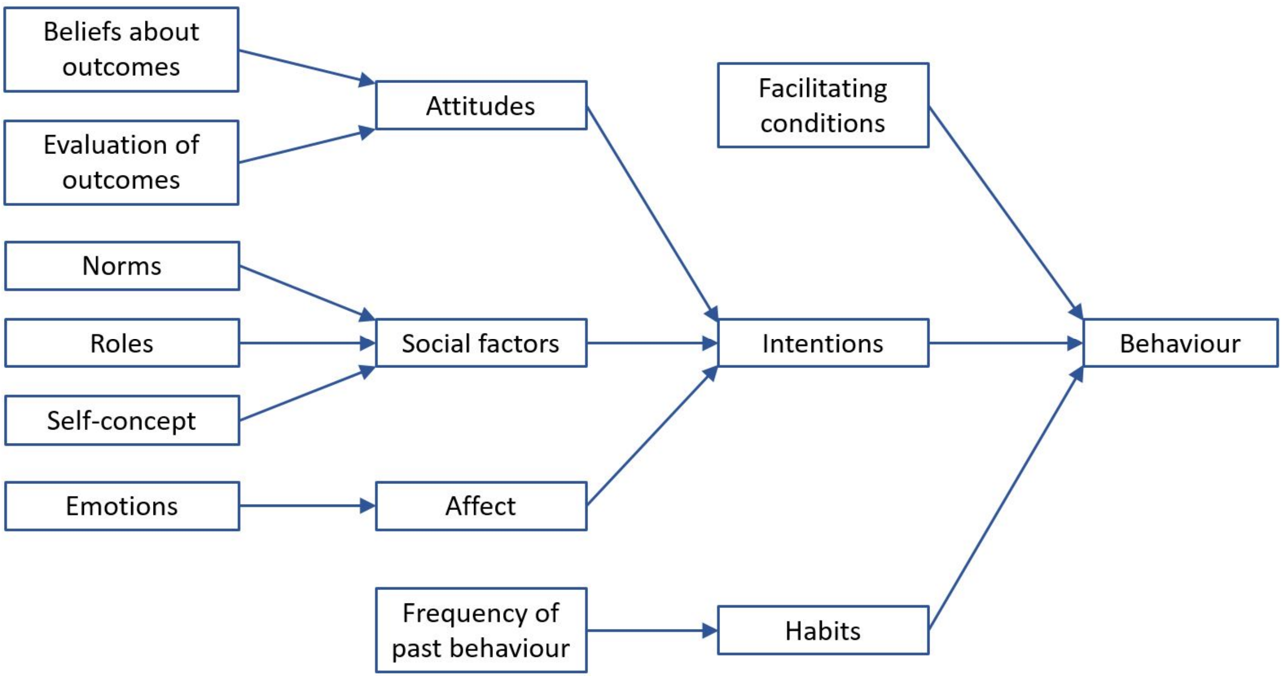

Fig. 3.3.1. Triandis 'Theory of Interpersonal Behaviour', 1977, reproduced from CHATTERTON, 2011.

Habits play a significant role in influencing behaviours; but for behaviours to become habits (or "routines": those practices are enacted without the need for conscious processes), they need frequency and automaticity[40]. Intentions represent the individual's decision-making process, a product of the interrelation of attitudes, social factors and affect. The latter is made of mainly subconscious, emotional factors, from the mood at the time of making the decision to the set of values that underline our attitudes.[41] Social factors refer to the perceptions of social norms and representations[42], relating to how people see themselves and their actions in relation to wider

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[38] H. TRIANDIS, 1977. *Interpersonal behaviour*. Monterey, CA: Brookds/Cole
[39] T. CHATTERTON, 2011, *Ibid*.
[40] A. HUBER, J. KORTMAN, A. M. BENITO, M. SCHARP, 2010. *BewareE: Développer et mettre en œuvre des services efficaces de sensibilisation à l'utilisation de l'énergie domestique*. Intelligent Energy Europe Program
[41] T. CHATTERTON, 2011, *Ibid*.
[42] In G. BRISEPIERRE, 2015: "The notion of social representation refers to the collective nature of our mental images which are shared by a group of individuals. This ordinary knowledge is the product of history; socially structured, it governs our

society. Roles, in this scheme, are defined by TRIANDIS as "sets of behaviours that are considered appropriate for persons holding particular positions in a group" and self-concept as "one's perceived identity"; and both are "important factors in determining whether action to promote certain behaviours may have a "spill-over" effect."[43]

Attitudes held by the individual themselves are defined by TRIANDIS as a combination of beliefs about the outcome (like the acceptance of one's responsibility, the perceived effectiveness of one's contribution or the desirability of benefits), an evaluation of the outcomes of the behaviour (how likely is it to succeed, and whether the desired benefits are worth any associated risks or constraints, for examples), and an arbitration between advantages and constraints. Attitudes are shaped by our values (which are acquired in the childhood, based on parental and societal models, and generally remain quite constant[44]), but also by our knowledge of internal and external factors and beliefs about expected cost-benefit trade-offs (which are more fluctuating), indicating the ability for an individual to change attitudes in time.

According to W.F. VAN RAAIJ and T.M.M. VERHALLEN, "attitudes are related to behaviour but do not necessarily cause behaviour. If we change behaviours in a more energy-conserving direction, we may expect that people develop energy-conscious attitudes. The reverse is not always true. Energy-conscious attitudes do not always lead to energy-conserving behaviour. Attitudes may lead to good intentions but social norms, lack of knowledge on the energy use of certain behaviours and on the energy-conservation effects of behavioural change, and situational factors, may block the intention to be realized in actual behaviour."[45]

3.4 Public policies

The next section is based on the following sources:

- F. BARTIAUX, 2011. *A qualitative study of home energy-related renovation in five European countries: homeowners' practices and opinions*, IDEAL EPBD Project, Louvain-la-Neuve, 251p.
- B. MARESCA, A. DUJIN, R. PICARD, 2009. *La consommation d'énergie dans l'habitat : entre recherche de confort et impératif écologique*, in Cahier de Recherche n° 264 du Centre de recherche pour l'étude et l'observation des conditions de vie (CREDOC), Paris, 87p.
- CRIOC, 2007. *Consommation Durable: quel rôle pour le consommateur?*, Synthèse des recherches du PADDII (Plan d'Appui scientifique pour une politique de Développement Durable), Politique scientifique fédérale, Bruxelles.
- A.-L. LINDEN, A. CARLSSON-KANYAMA, B. ERIKSSON, 2006. *Efficient and inefficient aspects of residential energy behaviour: what are the policy instruments for change?* In Elsevier Energy Policy 34, pp. 1918-1927.
- G. WALLENBORN, et al., 2006. *Détermination de profils de ménages pour une utilisation plus rationnelle de l'énergie. Partie 1: Modes de production et de consommation durables*, Synthèse des

relationship with the world. These are complex objects, with several dimensions: perception, opinion, imaginary. Distinct from practices, they define an action field and intervene in our interactions."

[43] T. CHATTERTON, 2011. *Ibid*.

[44] CRIOC, 2007. *Ibid*

[45] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.

recherches du PADDII (Plan d'Appui scientifique pour une politique de Développement Durable), Politique scientifique fédérale, Bruxelles, 106 p.
- D. ÜRGE-VORSATZ, S. KOEPPEL, S. MIRASGEDIS, 2007. *Appraisal of policy instruments for reducing buildings' CO2 emissions*, Building Research & Information, 35:4, 458-477

Although there may be conflicts at a theoretical level, in practice, taking a range of theories into account when designing policies is likely to help reduce conflicts between the approaches and ensure that much broader strategies can be developed, for example "learning from psychological approaches that it is not just about getting the pricing right, but also from sociological approaches that neither is just about getting sub-conscious triggers correct."[46] Under those considerations, it seems logic that only a good "policy mix" or combination of instruments can be effective[47], since it is necessary to simultaneously overcome several barriers of different kind (lack of social support, motivation, knowledge, information, perceived efficiency or money, defiance towards experts and public authorities, difficulties to act…). Policies generally share a top-down perspective and are formulated, established, controlled, and evaluated by an authority on behalf of national policy decisions[48]. The tools that are chosen by a public authority in order to implement its action convey the views and theories of the governing body, on the regulation modes over the governed body. "Public action tools are not axiologically neutral tools, and equally available. Quite the contrary, they convey values, nourished from an interpretation of the social [context] and precise conceptions of the envisaged regulation mode. A public action tool constitutes a technical and social device which organises specific social relationships between the public authority and its recipients, depending on representations and significations it conveys."[49]

Belgium seems to have developed a balanced array of diverse instruments, to be one of the most active countries on informative tools, and to have long preferred that kind of instrument. According to G. WALLENBORN, et al., in 2006, "the target is mainly the 'lay public', notably via vast information campaigns, and owners who are ready to invest in energy-efficient equipment and structures. Some measures are also specifically designed for households with low income and social housing. We bet a lot on households' spontaneity, and the existence of strong motivations for energy savings. It seems however that measures favouring investments are globally better accepted than those seeking behaviour change. Generally speaking, consumers do not adopt all behaviours of one profile or behaviour category, but only those they know, judge useful, trust, can implement…"[50]

Since 2006, some public policies have remained the same, although there has been some efforts into "triggering" the "household's spontaneity" mentioned above, especially via financial tools (tax rebates, zero-interest loans, subventions for the acquisition of energy-efficient equipment or insulation works) and informative instruments. The rapidity with which the number of measures destined to households has grown during the last two decades shows that they are now a prime target for public authorities, which action mainly seeks the modification of a) a household's living frame and b) individual attitudes and representations, in order to create new behaviours and

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[46] T. CHATTERTON, 2011. *Ibid*.
[47] G. WALLENBORN, et al., 2006. *Ibid*.
[48] A.-L. LINDEN, A. CARLSSON-KANYAMA, B. ERIKSSON, *Efficient and inefficient aspects of residential energy behaviour: what are the policy instruments for change?* In Elsevier Energy Policy 34 (2006), pp. 1918-1927
[49] P. LASCOUMES, P. LE GALES, 2004. *Gouverner par les instruments*, Paris, Presses de Sciences Po, p.14 (personal translation)
[50] G. WALLENBORN, et al., 2006. *Ibid*. (personal translation)

practices.[51] This goal is translated by the four main families of tools that are commonly used in public action: information (under many forms), regulations, technology or economic instruments.

3.4.1. Information policies

Also called "sociocultural" instruments, or "sermon"-type policies, they aim to persuade or dissuade the users to adopt certain behaviours related to energy consumption. They strive to overcome motivational "barriers" in human actions by connecting sustainable behaviours with desirable goals through "mobilisation messages". Therefore, those instruments have evolved along with the messages they carried, from "save money!" after the oil and economy crises of the 70s, to the current "save the planet!", as public authorities now call for responsible behaviours and civic engagement.

The informative instruments are of four types: communication (diffusion of information), awareness campaigns (drawing attention to the stakes), education (training, new knowledge, new behaviours…) and citizen participation. Some are based on emotions, others on behavioural options and their impacts, others yet on the display of good practices examples for inspiration, mimicry, and possible ripple effect. They have taken different forms in the past: brochures, flyers, advertisement, exhibitions, events, media campaigns, labels and labelling processes… More recently, home energy audits and EPCs, which in spite of their regulatory origin, are designed to address the imperfect information of homeowners on their dwelling.

Awareness and information campaigns destined to consumers have progressed the most. The development of this intervention axis leans on the idea that, though several surveys agree in recognizing the growing households' sensibility to climate change[52], it is still not enough, by far. Media campaigns generally target people's attitudes but tend to have limited effects.[53] An example can be given by the "Rational Use of Energy" campaign that has been present in Wallonia for years, seeking to inform energy users of small gestures to implement in order to save energy "easily" and without important nor expensive energy-saving measures. This rhetoric tends to underestimate the magnitude of changes to operate, which target the evolution of all domestic practices.[54] Energy-conscious behaviour asks for some effort in thermostat settings, closing curtains, turning off radiators. This means additional concerns and efforts, which is quite opposed to the quest for comfort that drives most households.[55]

Labelling consists in supplying consumers with an indicator for the appreciation and comparison of products (or dwellings in the EPC case), concerning quality attributes they cannot assess by themselves, such as the respect of environmental or social criteria all along the life cycle of the product. Labels are one form feedback information can take to make energy visible to householders. Other forms include more informative bills or, most recently, in-home real time displays and monitors for feedback campaigns. Studies show that clear, immediate and user-specific feedback can result in

[51] B. Maresca, A. Dujin, R. Picard, 2009. *ibid*.
[52] B. Maresca, A. Dujin, R. Picard, 2009. *ibid*.
[53] W. Abrahamse, L. Steg, C. Vlek, J.A. Rothengatter, 2005. *A review of intervention studies aimed at household energy conservation*, Journal of Environmental Psychology 25 (2005), pp. 273–291.
[54] G. Brisepierre, 2013. *Analyse sociologique de la consommation d'énergie dans les bâtiments résidentiels et tertiaires. Bilan et perspectives*, ADEME, Paris.
[55] W. F. Van Raaij, T. M. M. Verhallen, 1982. *ibid*.

savings of between 5% and 15%[56], but also that consumers generally misunderstand labels and the environmental information they displayed, and that product labelling alone (or general information alone) is not enough to correctly inform the public on sustainable consumption choices.

The conclusion of most studies on information tools is that they, alone, do not allow the expected long-term behaviour changes in sustainable consumption and should therefore always be used to complement other kind of instruments.[57] It does not mean that the information is not necessary or useful, they do play an influential role in consumers' choices. But being less binding than regulatory or economic tool, their success strongly depends on the will they manage to develop or reveal in consumers to adopt a particular behaviour.[58] The impact of an information can vary a lot depending on the message conveyed, the target public, the means (intellectual and financial) dedicated to the delivering, or the trust consumers place in the message or the emitter.[59] The diversity of messages (among which some are guilt-inducing), the multiplicity of issuers (like three different, regional, EPCs in Belgium), the lack of strategy, and consumers' "irrationality", diversity (even among a single household), laziness, lack of concern or sense of urgency, are possible explanations of the longer than expected time span needed to register global, effective and sustainable changes.

3.4.2. Regulation measures

They are legislative or regulatory instruments that impose the compliance to new standards and norms that can only be implemented by a public authority wishing to establish a constraint on the governed body. In the field of buildings' energy consumption, they are, for example, the legislated thermal regulations defined by the EU, permits, labelling obligations of products and buildings, appliance efficiency standards, environment quality norms, emission limits for CO_2, restrictions of trade.… They can act on producers of goods, materials and appliances, on installers, on buyers and sellers. They can act directly on homeowners by imposing limitations (complete or partial) on the purchase or the use of some products, or by imposing regulatory constraints on any construction or (important) renovation work. Direct regulation of households' practices is somewhat rare, however, because it is difficult to implement and apply, and is relatively intrusive, whereas the technical and financial side is easier managed uphill.

Those instruments are usually intimately linked with the economic tools: literature sometimes refer to regulatory instruments as the "stick"-type policies, to the "carrot"-type policies that are the economic instruments usually used to reward compliance (incentives) or punish disobedience (with sanctions known to the deviators in advance). Their cost-effectiveness is sometimes limited because of high enforcement costs. Like informative tools, they too have to be revised regularly in accordance with technological developments and market trends in order to remain effective, which means that they have to be monitored and honestly evaluated from times to times.

It is viewed as the most efficient form of energy management so far. Its impact depends on the balance of constraint and benefits they generate, but it is worth noticing that "during surveys

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[56] S. DARBY, 2006. *The Effectiveness of Feedback on Energy Consumption: A Review for Defra of the Literature on Metering, Billing and Direct Displays*. Environmental Change Institute, University of Oxford. In T. HARGREAVES, et al., 2010. *Ibid*
[57] CRIOC, 2007. *Ibid*.
[58] A.-L. LINDEN, et al., 2006. *Ibid*
[59] G. WALLENBORN, et al., 2006. *Ibid*.

directed in Belgium relative to sustainable consumption expectations[60], consumers have expressed the wish to see constraining measures adopted, that do not pertain to personal implication"[61]. There is, according to CRIOC, a wish that market products be respectful of the environment and that public authorities should regulate to help consumers who feel incompetent to assess the sustainable quality of a product. There is also a wish to be reassured on global participation, and regulation is the guarantee that everyone is subjected to the same requirements. It can also wake defiance in others, who doubt the fairness of the regulation (or its application). Doubt also rises in front of the mass of labels, highlighting the need for the authority to use information tools with caution. The elaboration (and harmonisation) of standards is problematic. In Europe, Directives dictate main directions, and countries are left to implement locally, regionally or nationally.

3.4.3. Technology tools

Technology improvements, their availability on the market, and specific incentives that target them are intended to facilitate new patterns of behaviour. Examples can be given in the field of energy performance of buildings with heat pumps and controlled mechanical ventilation systems, for the installation of which financial incentives are currently available in Wallonia. Another example is the impressive development of glazing in the last decades that now leads to a wide range of available products with different characteristics that influence different behaviours in shading, cooling, or even heating. Yet another example is illustrated by the new feedback techniques mentioned above in the information tools: making energy visible necessarily involves the need for a physical interface, and new technologies of information and communication have certainly jumped on the opportunity. "Control your home temperature from your phone!" is a new trend that illustrates the behavioural modification induced, if only for the technological fun.

The entertainment dimension that is found in new technologies is not to be neglected, as it can be related to social representations and our (wished or expected) relation with our social environment or wider society[62]. As an illustration, Fig. 3.4.1 displays a Facebook® publication of a 'friend' who installed photovoltaic panels on his roof: "I can almost hear my electric meter rotate backwards. I like the sun!" / "A little bit more sun and your meter will turn into a fan".

Fig. 3.4.1. Facebook publication (source: Facebook®)

[60] C. Rousseau, C. Bontinckx, 2007 *Testing propositions towards sustainable consumption among consumers* in E. Zaccai, 2007. *Sustainable consumption, Ecology and Fair Trade*, Taylor & Francis Publishers, UK.
[61] CRIOC, 2007. *Ibid.*
[62] N. Kalampalikis, M. W. Bauer, T. Apostolidis, 2013. *International review of social psychology*, Presses universitaires de Grenoble, France, 232 p.

When technology penetrates the market, it sometimes takes time to reach maturity and gain momentum[63]. But after the momentum often appears decline[64], and systems are replaced by other ones, generally improved. It is sometimes difficult to envision what the market will need, so that regulatory bodies rely on the industry to provide it with new technology, give it a direction, targets, improvements, with the implied necessity to induce some energy consumption reduction.

3.4.4. Economic instruments

The "carrot"-like policies aim to introduce virtuous energy consumption behaviours, in concordance with the rationalistic logic of users' interests maximisation.[65] They can carry a positive message, such as the financial incentives for renovation works targeting energy efficiency, public subsidies for the completion of an energy home audit, low-interest rates loans for energy-saving investments or "Green certificates" (tradable certificates for energy savings). They can also appear more negatively to the public (although a part of the revenues from those are typically reinvested in energy efficiency through "public benefit charges") by constraining them with fines, taxes or high energy prices.

Because it is often advertised through information campaigns (especially the 'positive' measures), another rationalistic characteristic of these policies is their assumption that the whole public is now well informed and has all the tools at its (easy) disposal to assess its possibilities and foresee the benefits of potential improvements to be made.[66] According to CRIOC[67], there is a necessity for an active attitude on the user part because they are less intrusive, which is why they are often preferred to regulatory instruments, although they often come along. The global impact will depend on the magnitude and design of the policy: low efficiencies can be explained by situations where the price does not hold a high place in the consumer's decision-making criteria list, or where the incentive is too low to constitute a signal (see further on price elasticity). The effectiveness of a "tax" instrument depends on the strength of the signal given, but also the availability of substitution options or alternative actions for the population affected. Economic measures, therefore, need to be well studied to not introduce social inequalities (as there is no available substitution option to energy, see further on fuel poverty) and to limit the number of "free-riders" (those who would have made the investment without the grant).

3.4.4.1 Price signal and elasticity

Though it depends on many other determiners that do not pertain to the public authority or the policies implemented in the region where it is used, the price of energy can be considered as an instrument on which the authority can exert an influence through taxes, VAT and added grid fees. As an instrument, energy price is supposed to constitute a signal to homeowners and householders, as witnessed by post-oil crisis energy adaptations. The influence of that signal however should not

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[63] G. WALLENBORN, et al., 2006. *Ibid.*

[64] T. P. HUGHES, 1987. *The evolution of large technical systems*, In T. BIJKER, T. HUGHES and T. PINCH, (editors) *The social construction of technological systems*, MIT Press, pp. 51 - 82.

[65] B. MARESCA, et al., 2009. *ibid.*

[66] K. GRAM-HANSEN, F. BARTIAUX, O. M. JENSEN, M. CANTAERT, 2007. *Do homeowners use energy labels? A comparison between Denmark and Belgium*, Elsevier Energy Policy 35 (2007), 2879-2888

[67] CRIOC, 2007. *Ibid.*

be overestimated[68], as it seems that sudden and large increases in energy prices tend to reduce the demand at least temporarily, while consumers adapt more easily to small price increases.[69] These different reactions to energy prices evolutions (which are watched permanently worldwide) are symptomatic of the "price-elasticity" that measures the sensitivity of demand to price changes and is defined as the percentage change in demand associated with an increase in price by 1%[70].

All households have different reactions to price increases in energy because of the above-mentioned invisibility of energy and blurred feedback information through energy bills, mainly, and because energy consumption does not only depends on economic constraint, but also on socially structured concepts of comfort and behaviours that are deeply rooted in routines and habits. As reported by B. MARESCA, et al.[71]: "The first result is that consumption/price elasticity is weak, and energy savings are temporary. When asked [during a 1975 survey in France] about their effective reaction to the increase of oil prices, respondents declared trying to reduce heating expenses in different ways: 15% by insulating their dwellings, 17% by better regulation of the heating installation, 3% by using less expensive fuel and 63% by heating less their dwellings. The majority reaction, among those who have indeed transformed their behaviours, is to lower the temperature of the dwelling. It is a short-term reaction to a strong price signal which, contrary to investments in different heating modes or better insulation, does not show a desire for long-term adaptation to a change of situation, and does not translate in sustainable consumption choices. It is an immediate reaction, susceptible to disappear as quickly as it has come, when prices drop." D. A. DILLMAN, et al., showed that lower-income households responded to energy price increases with cutbacks across nearly all end-uses of their life-style, while higher-income households maintained their consumption or took advantage of tax credits and incentive programs to invest in building and equipment energy-efficiency[72].

3.4.4.2 Fuel poverty

In energy consumption, a distinction first needs to be made between discretionary and non-discretionary uses. The first describes the uses that could be delayed, reduced or shortened like the heating of some less used rooms or the use of some electrical equipment. The second refers to the uses that are considered essential for answering basic physiological needs like cooking or heating the living room, and are less sensitive to the evolution of energy prices, even for low-income households.[73] This definition of numbered thresholds delimits a "socially acceptable" zone below which situations of discomfort or precariousness can exist[74] and are referred to as "fuel poverty". A definition has been proposed in 2010[75]: "is in fuel poverty an individual or household who expresses particular domestic difficulties in disposing of the necessary energy to satisfy basic needs, notably due to the maladaptation of their income and living conditions. It combines three factors: low

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[68] G. WALLENBORN, et al., 2006. *Ibid*.
[69] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.
[70] D. MAXWELL, P. OWEN, L. MCANDREW, K. MUEHMEL, A. NEUBAUER, 2011. *Addressing the Rebound Effect*, a report for the European Commission DG Environment
[71] B. MARESCA, et al., 2009. *Ibid*.
[72] D. A. DILLMAN, E. A. ROSA, J. J. DILLMAN, 1983. *Life-style and home energy conservation in the U.S.* 1. Econ. Psychol. 3:299-315 in L. LUTZENHISER, 1993. *Ibid*.
[73] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.
[74] B. MARESCA, et al., 2009. *Ibid*.
[75] S. La BRANCHE, 2015. *Brève introduction à la sociologie de l'énergie, Encyclopédie de l'énergie*, France

income, low quality of the dwelling and difficulties to pay energy bills." Although there is a clear link between fuel insecurity and plain economic distress, it is important to stress that it is not *only* linked to their income: "more generally, fuel poverty results from economic factors (energy prices, income level, employment), structural factors (dwelling quality, electrical appliances, climate) and social factors (lifecycle phases, socio-professional group, household composition) which, when added, can aggravate or reduce a fall in poverty."[76] Economic instruments are, obviously, important levers in that respect.

Low-income households are to some extent prepared to tighten their arbitrations and "accept lower temperatures, intermittent and/or partial heating regimes, lower hot water consumption and lower use of energy for other uses (lighting, cooking and appliances), in order to have lower energy bills"[77]. Besides, households that most need to improve the energy efficiency of their dwelling generally do not dispose of the financial capacity (nor the competences) to initiate necessary processes, cease opportunities, compare prices and services, and make necessary investments.[78] Households living in fuel poverty generally experience poor quality of life and increased health risk from prolonged exposure to cold temperature[79]: there is a clear greater concern for affordable warmth and health than for global warming in their attitudes and behaviours, so that it must be expected that energy efficiency measures would first allow those households to increase their comfort, before monitoring any energy savings[80] (see rebound effect further).

In the UK, "A household is said to be in fuel poverty if its occupants need to spend more than 10% of their income to afford adequate energy services, for heating, lighting, cooking in their home"[81]. According to P. JONES, et al.[82], up to 25% of UK households lived in fuel poverty in 2013.

According to J. COENE, et al.[83], in 2014, around 14.6% of Belgian households devoted too much of their available income to energy expenses. To those precarious households who show measured energy insecurity, they added hidden energy poverty (self-restrain in energy consumption when compared to similar households) and perceived energy poverty (people declaring having financial difficulties to heat sufficiently) and subtracted overlaps between categories to reach 18.7% of households that, in 2014, showed some objectified form of energy insecurity. (see Figure 3.4.2)

Low income households are obviously more concerned by this situation than high income households (although middle income households are not spared), but there are more influences on that insecurity barometer. For example, tenants are more concerned by this situation than owners, as are single-parents families and isolated households (especially among the elderly), Walloon more

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[76] S. La BRANCHE, 2015. *Ibid*

[77] J. P. CLINCH, J. D. HEALY, 2003. *Valuing improvements in comfort from domestic energy efficiency retrofits using a trade-off simulation model*, Energy Economics, 25, pp. 565583.

[78] J.-A. POULEUR, et al., 2012. *Ibid*.

[79] S. H. HONG, J. GILBERTSON, T. ORESZCZYN, G. GREEN, I. RIDLEY, 2009. *The Warm Front Study Group, A field study of thermal comfort in low-income dwellings in England before and after energy efficient refurbishment*, in Elsevier Building and Environment 44, pp. 1228-1236.

[80] P. JONES, S. LANNON, J. PATTERSON, 2013. *Retrofitting existing housing: how far, how much?*, Building Research & Information, 41:5, 532-550

[81] M. DOWSON, A. POOLE, D. HARRISON, G. SUSMAN, 2012. *Domestic UK retrofit challenge: barriers, incentives and current performance leading into the Green Deal*, in Elsevier Energy Policy 50 (2012), pp. 294-305

[82] P. JONES, et al., 2013. *Ibid.*

[83] J. COENE, B. DELBEKE, S. MEYER, 2016. *Baromètre de la précarité énergétique (2009-2014)*, Fondation Roi Baudouin, Bruxelles.

than Flemish populations (due to lower average income, bigger and less efficient homes and slightly colder climate), urban centres more than less dense regions…

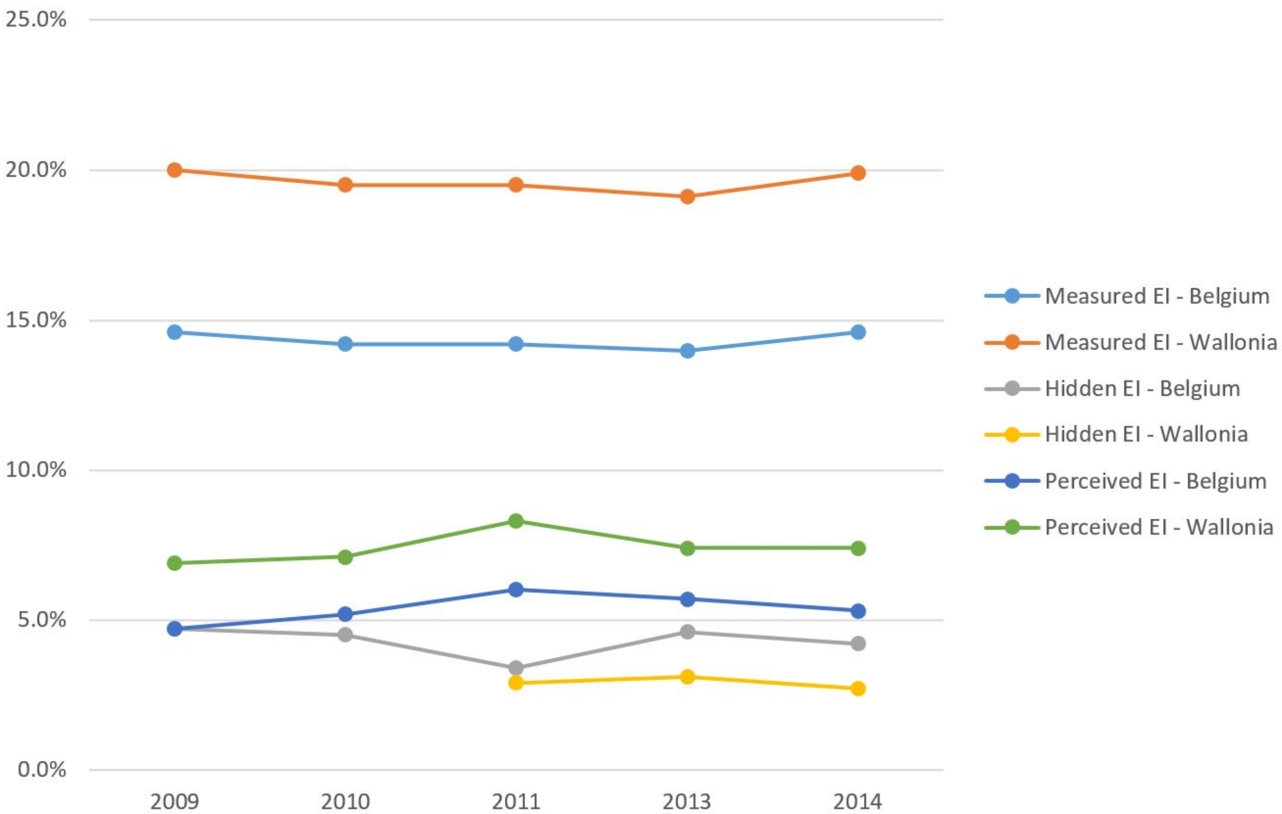

Fig. 3.4.2 Measured, hidden and perceived forms of Energy Insecurity (EI) in Belgium and Wallonia, 2009-2014 (2012 not available). Total fuel poverty rates are less than basic addition of energy insecurities rates. (Source: COENE et al., 2016)

In their 2011 territorial diagnosis of Wallonia[84], the CPDT warns of the potential segmentation of the housing markets, and the problems that could be brought to impoverished neighbourhoods by the EPC and, more broadly, EPB regulations. This view is also expressed by F. GREVISSE published in a 2012 report on the social impacts of the new EPB regulations in Belgium: "On one hand, 'financially disadvantaged' households cannot afford to take the EPC into account in their dwelling choice, because of the low availability of affordable-rent dwellings, and because of the lack of information and understanding of the stakes; they are pushed towards the least efficient and least expensive dwellings, which are not renovated since nothing obliges their owners. On the other hand, the other households opt for more efficient homes, therefore inducing a rise in these dwellings' prices and an incentive for owners to renovate."[85] He concludes that, in order for the EPC to influence the prices in real-estate (by incorporating energy costs), the requirements are:

- The EPC must be reliable and trusted;
- The low-rent dwelling segment has to be sensible to the "global cost" argument;
- The very poor has to be able to understand the interest of the EPC, to interpret it and consider it appropriately;
- The very poor has to have means of pressure on the market. The low availability of low-rent dwellings takes their negotiation capacity away.

[84] CPDT, 2012. *Ibid*

[85] F. GREVISSE, 2012, *Les impacts sociaux des nouvelles réglementations relatives à la Performance Energétique des Bâtiments (PEB) en Belgique*. Etude exploratoire Sustainable Energy Services, Fondation Roi Baudouin, Bruxelles.

3.5 Analysis of the EPC scheme

Studies have been led in neighbouring countries which can give interesting insights on acceptation and understanding of EPCs across Europe. The following section is based on studies from:

- Germany
    - H. AMECKE, 2012. *The Impact of Energy Performance Certificate: A Survey of German Home Owners*, Elsevier – Energy Policy 46 pp. 4 – 14
    - H. AMECKE, 2011, *The Effectiveness of Energy Performance certificates – evidence from Germany*, Climate Policy Initiative Report, Berlin, 24 p.
- The United Kingdom:
    - L. LAINE, 2011. *As easy as EPC? Consumer views on the content and format of the energy performance certificate*, in Consumer Focus, June 2011
- The Netherlands:
    - L. MURPHY, 2013, *The influence of the Energy Performance Certificate: The Dutch case*, in Elsevier Energy Policy 67 (2014) pp. 664-672
    - D. BROUNEN, N. KOK, 2011. *On the economics of energy labels in the housing market*, Elsevier Journal of Environmental Economics and Management 62, 166-179.
- Denmark:
    - T. H. CHRISTENSEN, K. GRAM-HANSSEN, M. DE BEST-WALDHOBER, A. ADJEI, 2014. *Energy retrofits of Danish homes: is the Energy Performance Certificate useful?*, Building Research & Information, 42:4, 489-500
    - K. GRAM-HANSSEN, F. BARTIAUX, O. M. JENSEN, M. CANTAERT, 2007. *Do homeowners use energy labels? A comparison between Denmark and Belgium*. Energy Policy, 35, 2879–88.
- International:
    - EPBD Concerted Action, 2011. *Implementing the Energy Performance of Buildings Directive (EPBD), Featuring Country reports (2010)*, EU Publications Office.
    - EPBD Concerted Action, 2015. *Implementing the Energy Performance of Buildings Directive (EPBD), Featuring Country reports (2016)*, EU Publications Office.
    - Bio Intelligence Service, R. LYONS, IEEP, 2013. *Energy performance certificates in buildings and their impact on transaction prices and rents in selected EU countries*, Final report prepared for European Commission (DG Energy)
    - J. BACKHAUS, C. TIGCHELAAR, M. DE BEST-WALDHOBER, 2011. *Key findings & policy recommendations to improve effectiveness of Energy Performance Certificates & the Energy Performance of Buildings Directive*, IDEAL EPBD Research Project, Netherlands.
    - V. TARANU, G. VERBEECK, 2016. *Qualitative analysis of energy performance certificates across EU countries under the lenses of behavioural insights*, Paper presented at the 4th European Conference on Behaviour and Energy Efficiency, Coimbra.

As discussed above in chapter 2.3, the EPC has been introduced as a way to break a frequent barrier for investments in energy efficiency that is imperfect information on the dwelling and its "invisible" energy efficiency (which can only be experienced after the actual purchase). The choice of house in itself carries technical characteristics (type of dwelling, age, size, environment, thermal insulation qualities and systems efficiencies…) that will influence energy consumption. People progressively appropriate their living space, slowly domesticate the technical framework of their dwelling. Therefore, the period just before moving into a new dwelling is fitting to raise awareness on energy performance and bring appropriate modifications.

Overall, the introduction of the EPC into the real-estate landscape has been met by a degree of indifference and is not the overwhelming success it was hoped to be. The negative publicity that surrounded the energy performance certification process hindered the market uptake, and the resulting lack of confidence in the energy label is costly and difficult to repair.

Most respondents to the researches indicated that the EPC has largely been treated as part of the paperwork that must be handed over on contract completion, so that energy efficiency played a minor role (if at all) on the purchasing decision. They made a clear distinction between energy efficiency in the context of a new build – when it is considered a valuable selling point – and older properties where it is considered almost in conflict with the search for period features and character. Several studies[86] confirmed that purchasers seem to care significantly less about energy efficiency when they are purchasing a home than about selling price (which is perfectly visible), location, outdoor space, comfort and other factors like home conditions issues (such as the age, character and structure of the property). Financial implications of energy efficiency are limited to relatable energy bills, the most important (only?) reason for buyers to consider energy efficiency in their purchasing decisions, followed by the comfort of dwelling.

An important specificity of the real-estate market is highlighted by H. AMECKE in 2011[87] to better apprehend the limitations of the EPC: "while information programs can potentially work in other markets, such as the household appliance market, the housing market is structurally different[88]. The housing market […] is demarked by scarcity and heterogeneity, which implies that households rarely choose between similar objects[89]. As a result, energy efficiency as a criterion of minor importance cannot play the same role for buildings as for electronic appliances even if energy efficiency is perfectly visible to the purchaser."

In 2013 however, the Bio Intelligence Service observed[90] "a clear relationship between a property's energy efficiency – as measured by its EPC – and its advertised price or rent" in several European countries, Belgium included. The results are in line (almost) everywhere: homebuyers are willing to pay a premium (which varies with the label category of the EPC) for homes that have been labelled as more energy efficient, or ''green''. The energy performance certificate is even qualified by D. BROUNEN and N. KOK[91] as "an effective signalling device that is capitalized into home prices". The results for Belgium were based on a more detailed analysis on the Flanders market, which implemented the EPC sooner (since November 2008), whereas the Walloon sample size was smaller

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[86] L. LAINE, 2011. *As easy as EPC? Consumer views on the content and format of the energy performance certificate*, in Consumer Focus, London, UK

[87] H. AMECKE, 2011, *The Effectiveness of Energy Performance certificates – evidence from Germany*, Climate Policy Initiative Report, Berlin, 24 p.

[88] W. BEEREPOOT, 2007. *Energy Policy Instruments and Technical Change in the Residential Building Sector,* Delft University Press; Technische Universiteit Delft. p. 240 p.

[89] A. O'SULLIVAN, 2007. *Urban economics*. Boston, Massachusetts; London: McGraw-Hill.

[90] BIO INTELLIGENCE SERVICE, R. LYONS and IEEP, 2013. *Ibid*

[91] D. BROUNEN, N. KOK, 2011. *On the economics of energy labels in the housing market*, Elsevier Journal of Environmental Economics and Management 62, 166-179.

(1,043 sales). The results for Wallonia were in line: a major improvement in energy efficiency (= -100 points on the EPC scale) is associated with a 5.4% higher price in Wallonia (see Fig. 3.5.1).

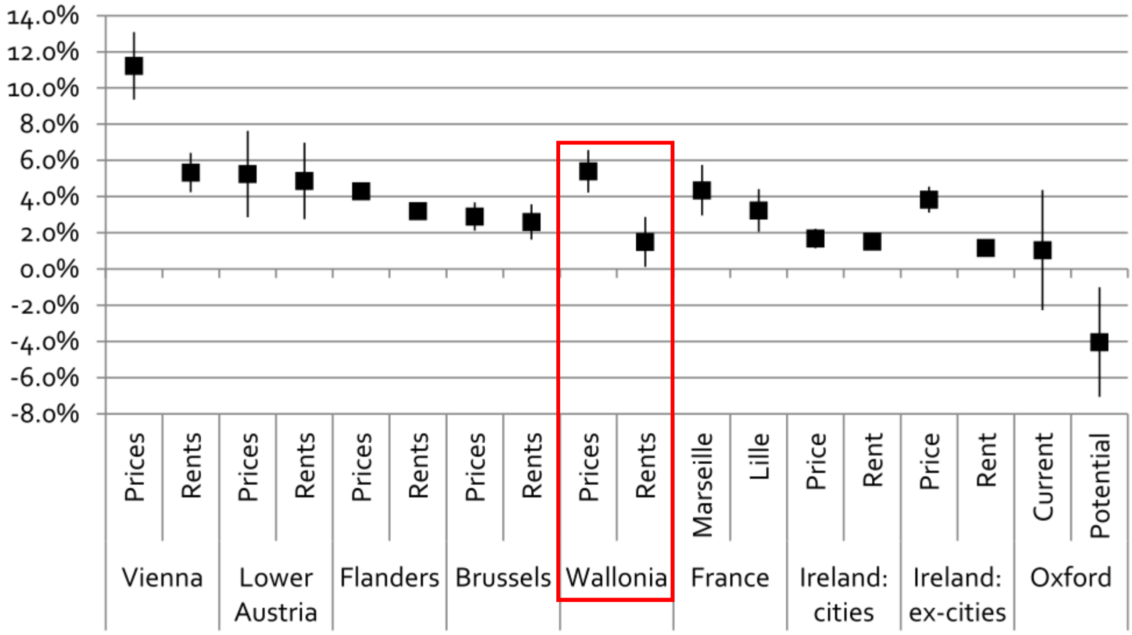

Fig. 3.5.1. Effect of one-letter or equivalent improvement in EPC rating across European property markets (95% confidence interval shown) (Source: Bio Intelligence Service, 2013).

It seems, therefore, that though still of little importance, energy efficiency influences global real-estate market and its prices, but it also seems like a single, isolated sale is still seen by the seller and the buyer as independent from energy considerations.

It is widely believed that the relevance of the EPC and the trust in its results would significantly increase from the moment it is made available and visible for all dwellings. The obligation of publication that was applied to EPCs by the recast EPB Directive is an important step in the introduction of the EPC to the lay public. Several studies published before reported, for example, that few EPC were available or presented unless it displayed positive information and results, or if it was requested by the potential purchaser, which only happened when they had a high a priori interest in an EPC[92] and were globally already "energy-aware"[93]. German respondents even mentioned that they were "hesitant to actively ask for the EPC, because they are afraid it could alienate the selling party". The same situation arose in the United Kingdom, where respondents declared themselves "unlikely to negotiate on the basis of the EPC's contents as once they have found the home they want, they do not want to 'appear difficult' and 'risk losing out'. Some participants even started thinking like sellers instead of buyers, and considered that the displayed estimation of the annual bill (and, in the UK, of the corresponding council tax band) could be "a threat to an easy sale"[94]. A seller would value the risk much more highly than the buyer/tenant would value the benefit.

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[92] H. AMECKE, 2012. *The Impact of Energy Performance Certificate: A Survey of German Home Owners*, Elsevier – Energy Policy 46 pp. 4 – 14
[93] H. AMECKE, 2011, *Ibid*.
[94] L. LAINE, 2011. *Ibid*

Why can't energy efficiency break the market barriers (yet) to occupy a stronger place in a household's selection criteria for a dwelling? The EU project IDEAL EPBD[95] showed that two main parameters, intelligibility and trust, are in tension in how people approach the EPC: in the UK and the Netherlands, the EPCs are easy to understand and the recommendations are easy to remember, while at the same time, there is little trust in the information. In Germany, however, the EPC has extensive technical information that is not easy to process, but it is globally perceived as a reliable source of information.

Intelligibility refers to the possibility for the lay public to understand the contents of the document, the results and perspectives that are presented in it; lack of understanding has been identified as a reason for the EPC's lack of impact on decision-making. It seems that the significance of the EPC remains blurry to many users, who generally only read and sometimes understand the A-to-G energy efficiency rating. One solution would be to provide the kind of information that is most meaningful and relevant to people.

"The current EPC was designed to present an energy expert's view,
not what the buyer or tenant needs to know"[96]

This is mentioned in many studies: the EPC does not display the information that the purchaser wants to see. Technical profiles will often understand enough of the contents to be able to compare the theoretical results with their real consumption, but also find that the information provided by the EPC is too general and trivial, the recommendations hackneyed; overall, that it is interesting but certainly not ground-breaking. Non-technical profiles will not understand all the contents and have difficulties converting the information into expected utility costs, which requires an expertise that most purchasers do not have. They will, however, welcome recommendations, especially "What can I do today?" tips for a rational use of energy (which are "common sense" to technical profiles, although they do not necessarily implement them).

Intelligibility can also refer to the look of the EPC, and there appears to be confusion towards the document in itself, which can seem too long, unattractive or too technical. Colour is important – in terms of readability, giving emphasis to key pieces of information, and reinforcing notions of 'good' and 'bad'. Respondents found reliant the scales which appear really close to other labels displayed on appliances, and credible the graphs that inferred a sense of standardisation and regulation behind the calculation that the figures alone did not. Credibility, however, is also reliant on the accuracy of the document and the method, so that the impossibility for the user to relate to the outputs (appropriation of results) leads to a lack of trust or understanding.

"It says 'calculated on standardised running conditions...
they are unlikely to match an occupier's actual fuel bills'.
So you're very confused again... it's not actually telling you much.
The more you look at it, the more you lack faith in it"[97]

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[95] F. BARTIAUX, 2011. *A qualitative study of home energy-related renovation in five European countries: homeowners' practices and opinions*, IDEAL EPBD Project, Louvain-la-Neuve, 251p.
J. BACKHAUS, C. TIGCHELAAR, M. DE BEST-WALDHOBER, 2011. *Key findings & policy recommendations to improve effectiveness of Energy Performance Certificates & the Energy Performance of Buildings Directive*, IDEAL EPBD Research Project, Netherlands.
[96] L. LAINE, 2011. *Ibid*
[97] L. LAINE, 2011. *Ibid*

Trust is central. Assets ratings are criticised by owners and landlords for their prices (related to the length of the process), strictness and inaccurate inputs (and outputs). Measured ratings are criticised by purchasers and tenants for their dependence on past behaviour and favourable ratings. When both are present, like in Germany, users are even more suspicious of having two different assessments of the same building giving different results, which translates into a low reliability for all EPCs. In Denmark, one of the first country to have implemented an energy identity passport of buildings in 2005, the EPC is ranked in 2014 as the second most trusted source of information, cited by 55% of respondents ("friends and family" is the most trusted source of information cited in many countries including Denmark). Their highest level of trust in the EPC might be related to the longer history of the certification scheme, making it more widespread there. As for any new policy, particularly when it is supposed to affect your behaviour or attitudes, it seems like time is the most influential parameter for the acceptation.

3.6 Home energy audits and motivations to renovate

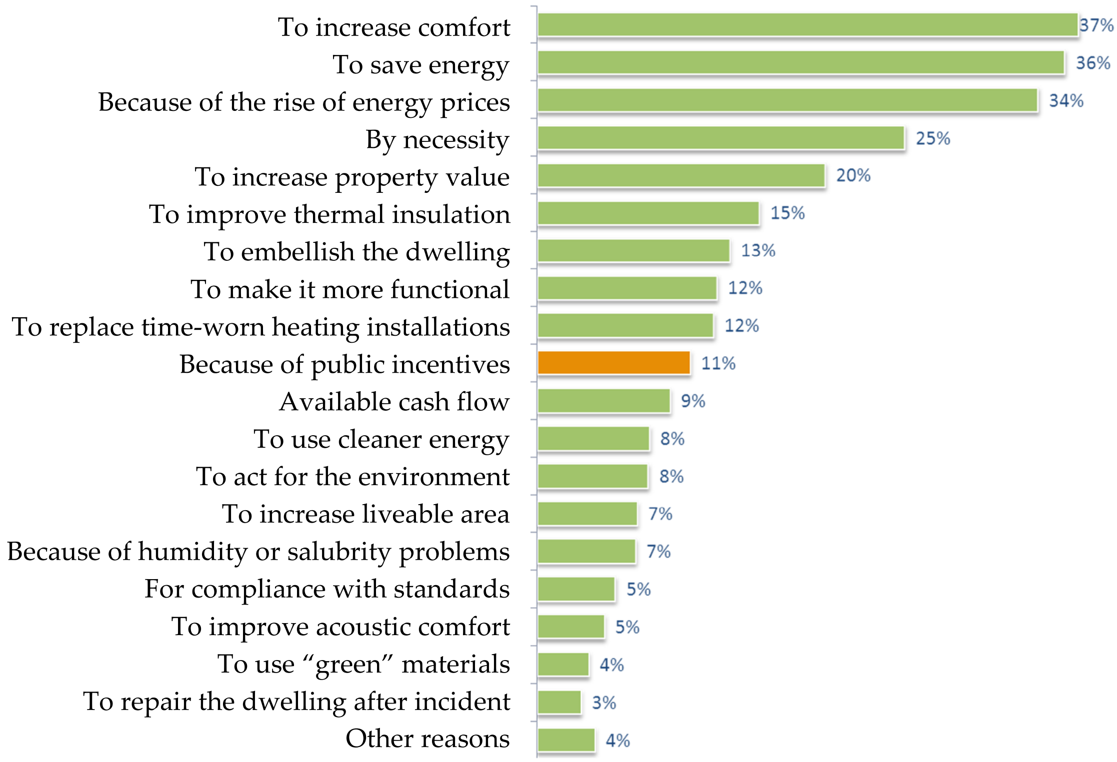

Fig.3.6.1. Motivations of respondents for further renovation works (n=929). (Source: POULEUR, et al., 2012)

By delivering what is supposed to be useful information and accurate recommendations to homeowners, the EPC seeks to inject some dynamism into the renovation sector. It seems however that the role it plays there is as influential as the role it plays in purchase decisions. J.-A. POULEUR et al.[98] presented in the Fig. 3.6.1 above their survey respondents' motivations to start renovating their home. Comfort and economic or financial concerns are first cited by Walloon homeowners, confirming rationalistic theories (although this list was designed by surveyors and could therefore

[98] J.-A. POULEUR et al., 2012. *Enquête sur la motivation des Wallons à rénover ou isoler leur logement, résumé non technique*. Espace Environnement, Charleroi.

be biased in that way). 'Irrational' motivations, such as the embellishment of the building, appear rapidly, however. Most motivations match the results of the international studies on the subject. When analysing the (non) adopted energy efficiency recommendations by the Dutch population, L. MURPHY reported that a significant portion of those recommendations (close to 50%) are ignored, and that a large number of adopted or planned measures were not recommended in the EPC. Overall, there is very little difference between the energy efficiency measures adopted by EPC recipients and non-recipients[99]. Another survey among 455 Dutch households which investigated the acceptability of energy-saving measures, concluded that "different socio-demographic groups and people with different environmental concerns preferred different types of energy-saving measures"[100], a personalisation the EPC is not able to offer.

Many studies have inquired among the European population about their motivations and incentives to renovate their homes. The lists of motivations and obstacles to renovation that are presented under regroup the conclusions of the following sources:

- S. LA BRANCHE, 2015. *Brève introduction à la sociologie de l'énergie, Encyclopédie de l'énergie*, France
- V. HAINES, V. MITCHELL, 2014. *A persona-based approach to domestic energy retrofit*, Building Research & Information, 42:4, 462-476
- M. DOWSON, A. POOLE, D. HARRISON, G. SUSMAN, 2012. *Domestic UK retrofit challenge: barriers, incentives and current performance leading into the Green Deal*, in Elsevier Energy Policy 50, pp. 294-305
- G. WALLENBORN, et al. (2006), PADDII (Plan d'Appui scientifique pour une politique de Développement Durable): « *Détermination de profils de ménages pour une utilisation plus rationnelle de l'énergie. Partie 1: Modes de production et de consommation durables* », Politique scientifique fédérale, Bruxelles, 106 p.
- B. ALLIBE, 2012. *Modélisation des consommations d'énergie du secteur résidentiel français à long terme. Amélioration du réalisme comportemental et scénarios volontaristes*. Thèse défendue à l'Ecole des Hautes Etudes en Sciences Sociales, CIRED - Centre International de Recherche sur l'Environnement et le Développement, Nogent-sur-Marne, France
- P. IMBS, J. BIARD, 2013. *Comment renforcer la performance énergétique immobilière avec le comportement vertueux des usagers ?*, Congres de l'ADERSE, Brest
- F. MEIJER, L. ITARD, M. SUNIKKA-BLANK, 2009. *Comparing European residential building stocks: performance, renovation and policy opportunities*, Building Research & Information, 37:5-6, 533-551
- V. TARANU, G. VERBEECK, 2016. *Qualitative analysis of energy performance certificates across EU countries under the lenses of behavioural insights*, Paper presented at the 4th European Conference on Behaviour and Energy Efficiency, Coimbra, 8-9 September 2016
- F. BARTIAUX, 2011. *A qualitative study of home energy-related renovation in five European countries: homeowners' practices and opinions*, IDEAL EPBD Project, Louvain-la-Neuve, 251 p.
- K. GRAM-HANSSEN, 2014. *Retrofitting owner-occupied housing: remember the people*, Building Research & Information, 42:4, 393-397

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[99] L. MURPHY, 2013, *The influence of the Energy Performance Certificate: The Dutch case*, in Elsevier Energy Policy 67 (2014) pp. 664-672

[100] O. GUERRA SANTIN, 2011. *Behavioural Patterns and User Profiles related to energy consumption for heating*, Elsevier Energy and Buildings 43 2662-2672

- D. ÜRGE-VORSATZ, S. KOEPPEL, S. MIRASGEDIS, 2007. *Appraisal of policy instruments for reducing buildings' CO2 emissions*, Building Research & Information, 35:4, 458-477
- H. AMECKE, 2011, *The Effectiveness of Energy Performance certificates – evidence from Germany*, Climate Policy Initiative Report, Berlin, 24 p.
- J. BACKHAUS, et al., 2011. *Key findings & policy recommendations to improve effectiveness of Energy Performance Certificates & the Energy Performance of Buildings Directive*, IDEAL EPBD Research Project, Netherlands.
- G. BRISEPIERRE, 2016. *Les dynamiques sociales de la "rénovation énergétique" dans l'habitat privé*, Plan bâtiment durable – « Nouvelles dynamiques de rénovation des logements »
- K. GRAM-HANSEN, F. BARTIAUX, O. M. JENSEN, M. CANTAERT, 2007. *Do homeowners use energy labels? A comparison between Denmark and Belgium*, Elsevier Energy Policy 35, 2879-2888
- R. GALVIN, 2014. *Why German homeowners are reluctant to retrofit*, Building Research & Information, 42:4, 398-408
- K. GRAM-HANSSEN, 2014. *Existing buildings – Users, renovations and energy policy*. Renewable Energy, 61, 136–140.

These studies do not all mention all the motivations hereunder, but these are the main that found themselves repeated more than once in the literature. All studies, however, mention that it usually needs a mixture of those incentives to trigger the will of homeowners into renovating their dwellings, for they are faced with numerous and various barriers. These incentives are listed under different types of motors, in random order:

- **Financial / economic**. The energy prices are going up, and there is little hope for them to go down; therefore, the reduction of the energy budget concerns all, privates and industries. Motivations are driven by the available income which represents potential investments, available incentives that could alleviate them, and the knowledge of energy costs and potential savings. Related, but not always mentioned by respondents, is the increase in property value. Several studies mention that the profitability (payback time) of the renovation is not always the main, and never the only motivation, requalified by the 'irrational' owner for taste or ecological reasons.
- **Comfort**. It has been mentioned already for low-income households in fuel poverty: the main concern is first and foremost to raise their comfort, which can take many forms for different households, but there are common indicators like the interior temperature, the light, the hygiene of the place when it comes to humidity problems, or even the silence (acoustic insulation is prized in Walloon urban dwellings).
- **Environment**. As main driver or nice second-hand advantage, ecological arguments are growing among the population. They register in the collective interests, but are more often mentioned among people from middle class and above, better educated and better informed of energy stakes. As for energy consumption, though, it is important to notice that ecological convictions are not always linked with energy-saving investments.
- **Technology**. As mentioned above, some find elements of fun and social representation in the acquisition and mastering of technological appliances and systems. It is linked with a wish to increase tacit knowledge on energy saving issues, solve a problem and master one's home. Related to that are the "Do-It-Yourself" renovation works, where householders manage part of the works themselves, get equals with professionals and coordinate the project, take control of quality control and results.

- **Retrofit**. Some motivations might simply find their origins in the qualitative state of the house. Some buy ruins with a potential to be revealed through renovation. Some reach thresholds of tolerance regarding the quality or salubrity of the house, obsolete systems and broken items, and are faced with the necessity to replace (sometimes due to procrastination or lack of due maintenance). Some seek the preservation of a heritage.
- **Aesthetics**. These motivations are by essence subjective, as they are related to the wish that homeowners have to develop a personal connection to the house and "feel at home", although these works do not always imply (but always accompany) an improvement in energy efficiency. The objectives rather refer to the wish to increase the functionality of the old house in order to ease new lifestyles; to redecorate to one's taste, change the kitchen or the bathroom; to "level up" the quality of the home to better social standards.
- **Competence**. Having experience in renovation projects eases the process of searching for information or professionals, although this might be linked to self-confidence in some literature. Competence in informants (often friends and relatives, or neighbours, colleagues, installers, sellers, technicians, architects, engineers…) and renovation professionals engenders trust, which is also an important boost in owners' motivations.
- **Timing**. Owners acknowledge that there are "natural" renovation moments, in particular those rare periods where the house is empty from any inhabitants, so that the works will not cause hassle. Those periods often coincide with a moment when people are already investing into the purchase of the house, so that "time pressure" may either boost or prevent renovation works. If financial burden is crucial, another good time to renovate is at the end of the initial loan reimbursement, when funds are available again.

Once again, motivations are cumulative, especially when it comes to energy efficiency. There are numerous benefits to gain from energy renovation works, and it shows that homeowners are aware of some of them, at least. For them, it is, after all, mainly about getting satisfaction more that optimum. Households' choices do not necessarily tend to global efficiency, or rational technical and economic choices. To each households, its equilibrium of "will" and "won't".

In the same way that those studies have collected the first, here is a summary of the barriers and obstacles that people may find (or sometimes, just feel) between them and the accomplished renovation works. They are often the negative side of the above-mentioned incentives, and are here also given in random order:

- **Financial / economic**. The absence or lack of available revenues are a major barrier to renovation, mentioned in every study, especially when the renovation costs have to be invested upfront (autonomous investment is the most frequent situation). Getting financial support can be very difficult and time consuming. High interest rates loans, delayed gains and long payback times (especially for landlords) can be some hindrance, although it must be reminded that profitability is not always a goal per se, or rather profitability can take many other forms than financial. An example can be given for low-income households, who will first seek to increase the average interior temperature before monitoring energy savings (see rebound effect).
- **Comfort**. As mentioned before, comfort is a quest for homeowners, a quest that may face saturation effects when inhabitants feel comfortable enough. Comfort is also progressively acquired, which makes owners reluctant to lower its level during the works. The perceived hassle of installation is a powerful brake for some.

- **Decision-making context**. Besides the availability of a capital, timing and contextual circumstances can help or prevent a decision. Timing is as influential in preventing works as it can be in motivating owners: there are sensible time-frames in life during which people have greater sensitivity towards making changes in daily routines. Procrastination, lack of time, or cognitive and administrative burden are known to slow processes down. Co-ownership in multi-family dwellings is a particularly complex case when it comes to build a renovation project. Families and elderly people who do not consider long-term occupation of a dwelling might avoid any important investment. A retrofit might only be triggered by failing systems and installations, a refurbishment before installation could only target paints and amenities (kitchen, bathroom)…
- Surveys find that owners often **overestimate** the energy performance of their dwellings before retrofit, which does not incite to improve it. Linked to this are the crucial interest and **information** issues, like the necessary knowledge about energy costs and potential savings, the experience about refurbishment priorities and possible technical choices, or the recurrent uncertainties about results (energy savings, costs and benefits, improvements in health and comfort…) and hidden costs (loss of well-being during works, efforts to provide, weight of uncertainties and engagement). Homeowners usually want to foresee all possible constraints before engaging important amounts of money, so that they have to search before renovation for trusted informants, competent professionals and good contractors. Expert professionals might be harder to find in rural areas, lack of trusted partners can stop renovation projects.
- Tight **regulations** and severe city centres urban planning obligations may prevent some external wall insulation or some sought improvement in natural lighting. Regulations have often been mentioned as obstacles to the respondents' will for a personalised renovation. This can be associated with what is sometimes called in literature "market failures", which "prevent the consistent translation of specific energy-efficient investments into energy-saving benefits (e.g. imperfect information, fragmented market structure, misplaced incentives, etc.)".[101]
- **Historical value**, character and aesthetic appearance can be brakes to energy efficiency, as some literature sources consider homeowners might want to maintain a building envelope due to historic value or personal taste. Agreed-upon historical buildings apart, the notion of "important architectural characteristics" of a house is blurry and subjective, and can be powerful motivations to not alter the exterior appearance of the building, therefore limiting energy improvement possibilities.

To these lists can be added other incentives and barriers, less often mentioned, but important to explain some rates in renovation. The EAP and EPC procedures, for example, provided a new gateway in renovation projects, through the eye of an energy expert. Owners are supposed to feel encouraged by the document, but studies show that the personal contact with the assessor, the optimal understanding of the delivered information (which implies the need for a communication strategy), the technicity of the discussion between owner and energy adviser, or the professionalism, punctuality, perceived objectivity, competence and enthusiasm of the contractor (or architect) are influential. Another example: according to K. GRAM-HANSSEN, "people's practices are, to some

[101] D. ÜRGE-VORSATZ, S. KOEPPEL, S. MIRASGEDIS, 2007. *Appraisal of policy instruments for reducing buildings' CO_2 emissions*, Building Research & Information, 35:4, 458-477

extent, guided by what could be understood as action and reward: you carry through activities because you get something in return."[102] LAINE exemplified this, as most participants in her UK survey "preferred the word 'save' to 'waste' because it is more positive, whereas 'waste' was taken by some to imply that they are a wasteful person and thus perceived more as a 'lecture'."[103]

3.7 Comfort and (p)rebound effect

3.7.1 Comfort

Results in energy-management research and studies show that the notion of comfort is central. In the 1970s, P. O. FANGER[104] defined comfort as the ideal result of the complex equilibrium of different parameters such as heat, humidity, air speed, etc., corresponding to a neutral sensation for the greater number. In his objectivist approach, comfort relates to a state, a product provided by building services, always susceptible to evolve, but only with rational and objective indicators of comfort that can be diffused and exported[105]. Since then some serious reassessment of the theories that govern energy use and management implied an evolution of the notion of comfort.

From the strict point of view of the occupant, thermal well-being cannot be reduced to the regulation of a thermostat. Its daily management includes a more sensitive approach, mobilising different means and practices that participate in the comfort without directly consuming energy: clothes, housecoats, plaids, the management of "ventilation", the circulation of air inside, the air tightening of sources of uncomfortable draughts, or the (in)direct use of additional heat sources like the sun, cooking activities or electrical appliances.[106] First improvements in the definition of comfort lays therefore in the refining of the parameters that are used to define the state of thermal well-being such as the activities performed and the clothes that are worn. It seems that householders know how to achieve the best comfort level they can, under duress of physical and economic possibilities. "Householders are capable of developing sophisticated intuitive knowledge about how their homes behave thermally and to use that knowledge to achieve the thermal conditions they want in a range of circumstances."[107] In this respect, the notion of adaptive comfort has been studied and improved in the last decades, arguing that contextual factors and recent thermal history influence the expectations and preferences of a building's occupants. According to J. F. NICOL and M. A. HUMPHREYS, "if a change occurs such as to produce discomfort, people react in ways which tend to restore their comfort"[108], which defines the adaptive principle. C. TWEED et al. add that "one of the key postulates of the adaptive comfort theory is that satisfaction with a given thermal environment is not solely a matter of physics and physiology. It recognises three categories of adaptation:

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[102] K. GRAM-HANSEN, F. BARTIAUX, O. M. JENSEN, M. CANTAERT, 2007. *Ibid*

[103] L. LAINE, 2011. *Ibid*

[104] P. O. FANGER, 1977. *Human comfort and energy consumption in residential buildings*, proceedings of the international Energy use management conference, Tucson, Arizona.

[105] B. MARESCA, et al., 2009. *Ibid*.

[106] G. BRISEPIERRE, 2013 *Ibid*.

[107] C. TWEED, N. HUMES, G. ZAPATA-LANCASTER, 2015. *The changing landscape of thermal experience and warmth in older people's dwellings*, in Elsevier Energy Policy 84, pp. 223-232

[108] J.F. NICOL, M.A. HUMPHREYS, 2002. *Adaptive thermal comfort and sustainable thermal standards for buildings*. Energy Build. 34, 563–572.

physiological adaptation, psychological adaptation and behavioural adaptation. Behavioural adaptation comprises a range of actions occupants may undertake to create and maintain their own comfort. Typically this refers to changing the levels of clothing or activity, but it can include other forms of adaptive behaviour — opening and closing windows, switching on fans, adjusting thermostats, consuming hot drinks, etc."[109]

The historian J. E. CROWLEY proposed a definition for comfort in 2001[110]: "a self-conscious satisfaction with the relationship between one's body and its immediate physical environment". By doing so, he acknowledges the physiological dimension in comfort which relates to the interactions between the body and its physical environment, which characteristics can be objectified. But comfort is first and foremost defined as a personal appreciation, the expression of a judgement, which engages representations that might be subjected to evolutions. "Cosiness" becomes "a cultural energy service, which we define as a set of energy use behaviours deeply rooted in the social, cultural and symbolic representation of the home."[111] That process of comfort quest fundamentally goes through energy spending mechanism, and institutes therefore an ideal living room temperature and a certain energy consumption level as social norm.[112] If we also consider the strong affective bond between dwelling and dweller, this renders behaviour modification (or evolution) very difficult in the refuge that is the home.[113].

3.7.2 Rebound effect

The following list is a summary of different literature inputs on the rebound effect studies:

- L. F. CHIU, et al., 2014. *A socio-technical approach to post-occupancy evaluation: interactive adaptability in domestic retrofit*, Building Research & Information, 42:5, 574-590
- P. M. BOULANGER, J. COUDER, Y. MARENNE, S. NEMOZ, J. VANHAVERBEKE, A. VERBRUGGEN, G. WALLENBORN, 2013. *Household Energy Consumption and Rebound Effect, Final Report*. Brussels: Belgian Science Policy – 100 p. (Research Programme Science for a Sustainable Development)
- C. TWEED, N. HUMES, G. ZAPATA-LANCASTER, *The changing landscape of thermal experience and warmth in older people's dwellings*, in Elsevier Energy Policy 84 (2015), pp. 223-232
- O. GUERRA SANTIN, 2010, *Actual energy consumption in dwellings, The effect of energy performance regulations and occupant behaviour*. Series Sustainable Urban Areas, IOS Press, under the imprint Delft University Press
- Z. BROWN, R. J. COLE, 2009. *Influence of occupants' knowledge on comfort expectations and behaviour*, Building Research & Information, 37:3, 227-245
- S. LA BRANCHE, 2015. *Brève introduction à la sociologie de l'énergie, Encyclopédie de l'énergie*, France

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109 C. TWEED, et al., 2015. *Ibid*

110 J. E. CROWLEY, *The Invention of Comfort: Sensibilities & Design in Early Modern Britain & Early America*, Baltimore, Johns Hopkins University Press, 2001

111 H. WILHITE, et al., 1996. *A cross-cultural analysis of household energy use behaviour in Japan and Norway*, in Elsevier Energy Policy 24 (1996), pp. 795-803, Great Britain

112 B. MARESCA, A. DUJIN, R. PICARD, 2009. *Ibid*

113 P. IMBS, J. BIARD, 2013. *Comment renforcer la performance énergétique immobilière avec le comportement vertueux des usagers ?*, Congres de l'ADERSE, Brest

- K. GRAM-HANSSEN, 2014. *New needs for better understanding of household's energy consumption – behaviour, lifestyle or practices?* Journal of Architectural Engineering and Design Management, Taylor&Francis.
- M. SUNIKKA-BLANK, R. GALVIN, (2012) *Introducing the prebound effect: the gap between performance and actual energy consumption*, Building Research & Information, 40:3, 260-273
- S. SORRELL, J. DIMITROPOULOS, M. SOMMERVILLE, 2009. *Empirical estimates of the direct rebound effect: a review*, in Elsevier Energy Policy 37 (2009), pp. 1356-1371
- B. ALLIBE, 2012. *Modélisation des consommations d'énergie du secteur résidentiel français à long terme. Amélioration du réalisme comportemental et scénarios volontaristes*. Thèse défendue à l'Ecole des Hautes Etudes en Sciences Sociales, CIRED - Centre International de Recherche sur l'Environnement et le Développement, Nogent-sur-Marne, France
- M. DEURINCK, D. SAELENS, S. ROELS, 2012. *Assessment of the physical part of the temperature takeback for residential retrofits*, Elsevier Energy and Buildings 52: 112-121
- D. MAXWELL, P. OWEN, L MCANDREW, K. MUEHMEL, A. NEUBAUER, 2011. *Addressing the Rebound Effect*, a report for the European Commission DG Environment

First observations of this paradox date back to W. S. JEVONS in 1865[114]: "It is wholly a confusion of ideas to suppose that the economical use of fuel is equivalent to diminished consumption. The very contrary is the truth […]; the reduction of the consumption of coal, per ton of iron, to less than one third of its former amount, was followed, in Scotland, by a tenfold increase in total consumption, between the years 1830 and 1863, not to speak of the indirect effect of cheap iron in accelerating other coal-consuming branches of industry". Another interesting example of this phenomenon is the apparition of central heating[115], now fully integrated into our daily lives. There was a time when "the ignition of glowing embers in a unique room was an opportunity to bring together all the members of family around only one seat and to share together different practices in everyday life. The introduction of gas boiler, or electric radiator, deeply disrupted our connections with domestic space and time, leading to the dispersal of energy-related practices at home. Cooking, showering, washing, all these practices revolved around the same device, but are now compartmentalised in different household activities, segmented by everyday life and domestic spaces"[116], resulting in a (serious) increase in energy consumption at the time.

The rise in internal temperature that follows the energy-efficiency improvement of one's home is commonly called the "temperature take-back". It is one of the forms that the rebound effect can take, particularly in low-income groups and in households with low internal temperatures prior to the efficiency measures[117]. "In these dwellings, financial constraints, in combination with a poor thermal insulation level of the dwelling, often force the inhabitants to maintain their house at very low indoor temperatures. When an energy efficient retrofit is carried out, these households are particularly susceptible for taking back a large part of the benefit of the retrofit in enhanced comfort."[118]

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[114] W. S. JEVONS, 1865. *The coal Question: An inquiry Concerning the Progress of the Nation and the Probable Exhaustion of Our Coal Mines*, London: Macmillian and Co.
[115] S. LA BRANCHE, 2015. *Ibid*
[116] P. M. BOULANGER, et al., 2013. *Ibid*
[117] S. SORRELL, J. DIMITROPOULOS, M. SOMMERVILLE, 2009. *Ibid*
[118] M. DEURINCK, D. SAELENS, S. ROELS, 2012. *Assessment of the physical part of the temperature takeback for residential retrofits*, Elsevier Energy and Buildings 52: 112-121

The rebound effect is defined by the observation that, when the technical system of a dwelling (its envelope and installations) are improved in energy efficiency, the expected energy and financial savings are somewhat overestimated. In the reality of the post-renovation occupation of the dwelling, the energy costs being substantially decreased, the financial savings allow for some adjustments in comfort and, consequently, in energy consumption. This effect can take three forms.

It is called "**direct**" when the decrease in energy consumption due to energy improvements is (partially) offset by an increase in energy consumption due to ulterior adaptations. The first example is the above-mentioned temperature take-back that appears "when occupants negate some or all of the energy savings by heating their homes to a higher temperature, thus, promoting greater heat losses through a higher temperature difference between outside and inside"[119]. Another way of increasing the energy consumptions is by "spatial rebound", which appears when the retrofitting allows to use more rooms that the owners could or would previously not afford to heat, thus expanding the liveable volume. Yet another is the stretching of the heating hours to previously unheated periods.

In his "*Brief introduction to sociology of energy*"[120], S. LA BRANCHE stresses that "it is the consciousness about the savings that trigger the counter-productive behaviour". Several authors, however, mention that this direct rebound is not always, or entirely, behavioural. M. DEURINCK et al., for example, mention a physical component of the temperature take-back: "Apart from the behavioural aspect, there is also a physical aspect that determines this temperature rise. After insulating and air tightening the building envelope, the temperature distribution in the dwelling changes: the temperature in the unheated zones is unintentionally higher and the temperature drop between two heating periods is lower. As a result, if the thermostat control is kept at the same setting before and after the efficiency measure, one might expect that the overall averaged house temperature will be higher for the renovated, energy efficient house."[121] This physical component of the temperature takeback has been mentioned by different authors.[122] Balanced ventilation system with heat recovery tend to favour this phenomenon, so that another direct rebound effect might be found in the necessary different operation of the improved dwelling. Low-temperature heaters and underfloor heating that requires the inertia of a heavy slab, for example, are systems that work better without too much intermittence, and owners are sometimes "required" to keep the heating on if they leave the house for the afternoon, something they would not have done with the previous system and regulation.

Following the definitions from G. HENDERSON, et al.[123], the 'shortfall' is defined as the "overall difference between the actual savings in energy consumption and those expected on the basis of engineering estimates." The definition of the direct rebound effect "is not consistent between studies

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[119] C. TWEED, et al., 2015. *Ibid.*
[120] S. LA BRANCHE, 2015. *Ibid*
[121] M. DEURINCK, et al., 2012. *Ibid*
[122] C. SANDERS, M. PHILLIPSON, 2006. *Review of Differences between Measured and Theoretical Energy Savings for insulation Measures*, Report by Centre for Research on Indoor Climate and Health, Glasgow Caledonian University, 2006.
G. MILNE, B. BOARDMAN, 2000. *Making cold homes warmer: the effect of energy efficiency improvements in low-income homes*, Elsevier Energy Policy 28 (6-7) (2000): 411-424
S. SORRELL, et al., 2009. *Ibid*
[123] G. HENDERSON, D. STANIASZEK, B. ANDERSON, M. PHILLIPSON, 2003. *Energy Savings from insulation improvements in electrically heated dwellings in the UK*, in: ECEEE 2003 Summer Study – Time to Turn Down Energy Demand, pp. 325-334

and the behavioural response appears to vary widely between different households. Nevertheless, the econometric evidence broadly supports the conclusions of the quasi-experimental studies, suggesting a mean value for the household heating shortfall of around 20%."[124] Other researchers suggest that the same proportion of 20 to 30% of the expected energy savings is not achieved, and that the distribution of shortfalls can vary a lot between different households[125]. When the shortfall exceeds 100% of the energy gains, it is called a "backfire" (this was the case when the central heating was introduced in London).

"Despite growing research activity, the evidence of the direct rebound effect remains sparse, inconsistent and largely confined to a limited number of consumer energy services. The main reason for this is the lack of suitable data sources."[126] But as the energy consumption for heating increases with the level of comfort, there should be a point where the whole-house indoor temperatures approach the maximum level for thermal comfort, and the "direct" rebound effect stabilises. If comfort can be improved in another way, the effect can become "**indirect**", with remaining financial savings used to buy other goods and services that will induce direct or indirect energy consumption. This generally translates into the acquisition of appliances and electrical equipment for the household (for example, a household that would invest money saved on heating bills thanks to insulation or installation change, in a new and bigger TV flat screen). Some research also refer to the industrial increase in energy consumption as a result of an increased demand in insulation and efficient installations. Another example can be found in the reinvestment of energy-related financial savings into long-haul flights to overseas holidays.

The third effect relates to **macroeconomics**: "the large diffusion of an improved energy efficiency could lead to a decrease of the global energy consumption. This would lead to a relax of the demand on energy markets, and consequently a decrease of energy prices, which would encourage to consume more, due to negative elasticity of energy demand to its price." Some literature mention the rebound effect in relation with other kinds of benefits: we use some goods or services because it makes us gain time (and "time is money")[127], or we consume more green products because they are labelled "green", encouraged by a feel good perception of being "green"[128].

There is another important reason that could explain the overestimation of financial savings after an important energy retrofit (besides too optimistic economical hypotheses on energy prices or discount rates): the overestimation of energy consumptions by the PTEM (Physical–Techno–Economic Models) that are used to assess the energy performance of buildings.

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[124] M. DEURINCK, et al., 2012. *Ibid*

[125] K. GRAM-HANSSEN, T. H. CHRISTENSEN, P. E. PETERSEN, 2012. *Air-to-air heat pumps in real-life use: Are potential savings achieved or are they transformed into increased comfort*. Energy and Buildings, 53, 64–73.
B. ALLIBE, 2012. *Ibid*
S. SORRELL, et al., 2009. *Ibid*
P. M. BOULANGER, et al., 2013. *Ibid*

[126] S. SORRELL, et al., 2009. *Ibid.*

[127] C. GOSSART, 2010. *Quand les technologies vertes poussent à la consommation*, Journal « Le monde diplomatique », July 2010, Paris

[128] D. MAXWELL, P. OWEN, L. MCANDREW, K. MUEHMEL, A. NEUBAUER, 2011. *Addressing the Rebound Effect*, a report for the European Commission DG Environment

3.8 Determiners of energy use

Many studies have reported having important differences in energy consumptions between households living in similar dwellings, with identical technical systems. These differences can, for the highest, reach 600%, meaning that one particularly energy-hungry household can sometimes consumes 6 times as much (final) energy than a particularly thrifty households:

- A. DE MEYER, V. FELDHEIM, 2011. *Le point sur la consommation d'énergie pour le chauffage*, Étude réalisée dans le cadre de l'action "Construire avec l'énergie" pour le compte de la Région wallonne, SPW-DGO4, Namur, Belgique
- M. DELGHUST, W. ROELENS, T. TANGHE, Y. DE WEERDT, A. JANSSENS, 2015. *Regulatory energy calculations versus real energy use in high-performance houses*, Building Research & Information, 43:6, 675-690
- L. LUTZENHISER, *Social and behavioral aspects of energy use*, Annu. Rev. Energy Environ., 1993, 18 :247-89, Washington State University, Pullman, Washington
- B. HACKETT, L. LUTZENHISER, 1991. *Social structures and economic conduct: Interpreting variations in household energy consumption*. Sociol. Forum 6: 449-70.
- R. H. SOCOLOW, R. C. SONDEREGGER, 1976. *The Twin Rivers Program on Energy Conservation in Housing: Four Year Summary Report*. Rep. No. 32. Princeton, NJ: Princeton Univ., Cent. Energy Environ. Stud.
- R. SONDEREGGER, 1978. *Movers and stayers: The resident's contribution to variation across houses in energy consumption for space heating*. Energy Build. 1:313-24
- O. GUERRA SANTIN, 2010, *Actual energy consumption in dwellings, The effect of energy performance regulations and occupant behaviour*. Series Sustainable Urban Areas, IOS Press, under the imprint Delft University Press
- Z. BROWN, R. J. COLE, 2009. *Influence of occupants' knowledge on comfort expectations and behaviour*, Building Research & Information, 37:3, 227-245
- K. GRAM-HANSSEN, 2014. *New needs for better understanding of household's energy consumption – behaviour, lifestyle or practices?* Journal of Architectural Engineering and Design Management, Taylor&Francis.
- M. SUNIKKA-BLANK, R. GALVIN, 2012. *Introducing the prebound effect: the gap between performance and actual energy consumption*, Building Research & Information, 40:3, 260-273
- E. CAYRE, B. ALLIBE, M-H. LAURENT, D. OSSO, 2011. *There are people in the house! How the results of purely technical analysis of residential energy consumption are misleading for energy policies*, in Proceedings of the ECEEE 2011 Summer Study on Energy Efficiency First: The Foundation of a Low-Carbon Society, pp. 1675–1683.
- J.-M. CAYLA, 2010. *From practices to behaviours: estimating the impact of household behaviour on space heating energy consumption*, in Proceedings of the ACEEE Summer Study on Energy Efficiency in Buildings, Pacific Grove, CA, US, 15–20 August 2010.
- K. ROTH, P. ENGELMAN, 2010. *Impact of user behavior on energy consumption in high-performance buildings* – results from two case studies, in Paper presented at the Fraunhofer Center for Sustainable Energy Studies, Denver, CO, US.
- C. TIGHELAAR, M. MENKVELD, 2011. *Obligations in the existing housing stock: who pays the bill?*, in Proceedings of the ECEEE 2011 Summer Study on Energy Efficiency First: The Foundation of a Low-Carbon Society, pp. 353–363.

- H. HENS, W. PARIJS, M. DEURINCK, 2010. *Energy consumption for heating and rebound effects*, Elsevier Energy and Buildings 42: 105-110
- P. JONES, S. LANNON, J. PATTERSON, 2013. *Retrofitting existing housing: how far, how much?*, Building Research & Information, 41:5, 532-550

The large variety of studies mentioned here shows that this phenomenon is quite common. It takes several names, such as "credibility gap" for W. BORDASS et al.[129], alluding to "the loss of credibility that occurs when wide gaps are observed between design expectations of energy efficiency and actual fuel consumption outcomes". It was labelled "performance gap" by Z. BROWN and J. COLE[130], although it is mainly related to gaps between behavioural assumptions and reality. It is also called "prebound effect", in relation to the above-mentioned "rebound effect" by M. SUNIKKA-BLANK and R. GALVIN[131]: "by contrast, the 'prebound' effect refers to the situation before a retrofit, and indicates how much less energy is consumed than expected. As retrofits cannot save energy that is not actually being consumed, this has implications for the economic viability of thermal retrofits." In their paper, they suggest a trend: "In general, the higher the EPR[132], the lower the measured energy consumption seems to be in proportion to the EPR. For example, the average measured consumption of a home with an EPR of 300 kWh/m².year is around 40% below its calculated value, while dwellings with an average EPR of 150 kWh/m².year can have an actual energy consumption around 17% below their calculated value."

In the results and conclusions of their analysis of 964 Belgian dwellings with known building characteristics and heating consumptions, H. HENS, et al.[133], suggested a similar pattern:

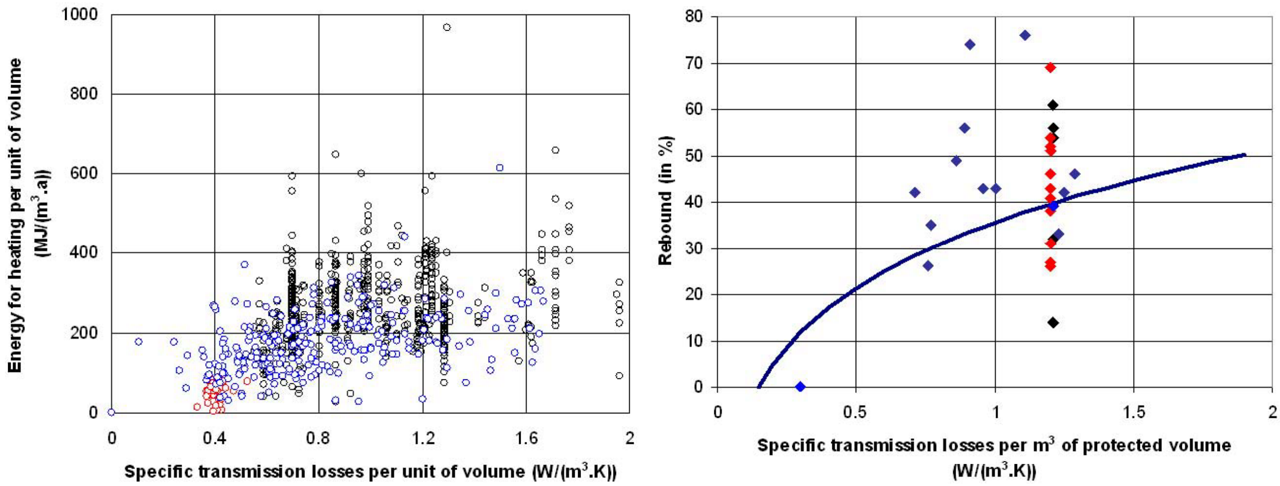

Fig. 3.8.1 LEFT: Normalized measured annual heating consumption for 964 dwellings as a function of the specific transmission losses, both per m³ of protected volume. **RIGHT**: Rebound factor in % as a function of the specific transmission losses per m³ of protected volume. The dots give individual rebound factors measured over time in different dwellings. (Source of both graphs: HENS et al., 2010)

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[129] W. BORDASS, R. COHEN, J. FIELD, 2004. *Energy performance in non-domestic buildings: closing the credibility gap*, Paper presented at the Building Performance Congress 2004, Frankfurt, Germany.

[130] Z. BROWN, R. J. COLE, 2009. *Influence of occupants' knowledge on comfort expectations and behaviour*, Building Research & Information, 37:3, 227-245

[131] M. SUNIKKA-BLANK, R. GALVIN, 2012. *Introducing the prebound effect: the gap between performance and actual energy consumption*, Building Research & Information, 40:3, 260-273

[132] Energy Performance Rating, the equivalent of the Espec rating in Walloon EPCs.

[133] H. HENS, W. PARIJS, M. DEURINCK, 2010. *Energy consumption for heating and rebound effects*, Elsevier Energy and Buildings 42: 105-110

Their rebound factor is, in this case, proportional to the "specific transmission losses per m³ of protected volume" (STV), expressed in W/m³K, equal to the average U-value of the building envelope, divided by its "compactness" (= protected volume/total thermal loss area). The higher the specific transmission losses per m³, the larger seems the proportionate gap. The results also "extend into the low transmission loss (= high energy efficiency) area where the 'prebound' effect becomes negative, i.e. the rebound effect becomes dominant"[134].

Benoît ALLIBE[135], in his modelling of the energy consumption of the French residential sector, uses two indicators extracted from the literature:

- $I_{obs} = C_{obs}/C_{th}$, where
  - C_{obs} is the observed consumption, and
  - C_{th} is the consumption calculated by a model of thermal calculations and its array of hypotheses on performances and climate.
- $I_{declared} = C_{sim}/C_{norm}$, where
  - C_{sim} is the calculated consumption, considering the households' declared behaviours;
  - C_{norm} is the calculated consumption, considering the "normal" behaviour of the thermal model.

Mentioning the first indicator, I_{obs}, he adds: "this indicator was introduced in 1998 by F. WIRL[136] and was since taken up under several appellations: "intensity factor"[137], "utilisation rate"[138] or "heating factor"[139], which all refer to the interpretation of the differences between observed and theoretical consumptions." There are many reasons invoked to explain this phenomenon, and most of them are related to uncertainties in the hypotheses used in the calculation method, which will be detailed for the Walloon method in chapter 4. It has been exposed previously that there can be a pretty wide array of determiners of energy use, which can be summarized in W. F. VAN RAAIJ and T. M. M. VERHALLEN "behavioural model of residential energy use"[140] in the Figure 3.8.2 below. In the PTEM models, most of these determiners are standardised for the understandable motive to "assess the building, not its users". This is mainly true for behavioural components of the methods, such as set temperatures and heating periods, which are replaced in engineering models by assumptions that may be simply wrong, or inaccurate in many "real" situations. Those determiners are generally divided among three families: physical (related to the technical system, the building and its energy characteristics, the climate, the model…), sociodemographic (related to the socioeconomic characteristics of the households) and behavioural (related to the energy attitudes and practices of the occupants). The main determiners, as found in the literature, are summarized in the last part of this present contextual section, as they will be used to build the questionnaire that has been elaborated, as explained in the second part of this thesis.

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[134] M. SUNIKKA-BLANK, R. GALVIN, (2012) *Ibid*
[135] B. ALLIBE, 2012. *Ibid*
[136] F. WIRL, 1988. *Thermal comfort, energy conservation and fuel substitution: an economic-engineering approach*, Energy Systems and Policy, 11, 311-328
[137] A. SCHULER, C. WEBER, U. FAHL, 2000. *Energy consumption for space heating of West-German households: empirical evidence, scenario projections and policy implications*, Energy Policy, 28, 2000, 877-894
[138] L.-G. GIRAUDET, 2011. *Les instruments économiques de maitrise de l'énergie : Une évaluation multidimensionnelle,* Thèse de doctorat soutenue le 28 mars 2011, 283 p
[139] C. TIGCHELAAR, B. DANIELS, M. MENKVELD, 2011. *Obligations in the existing housing stock: who pays the bill?*, Proceedings of the 2011 ECEEE Summer Study, France
[140] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.

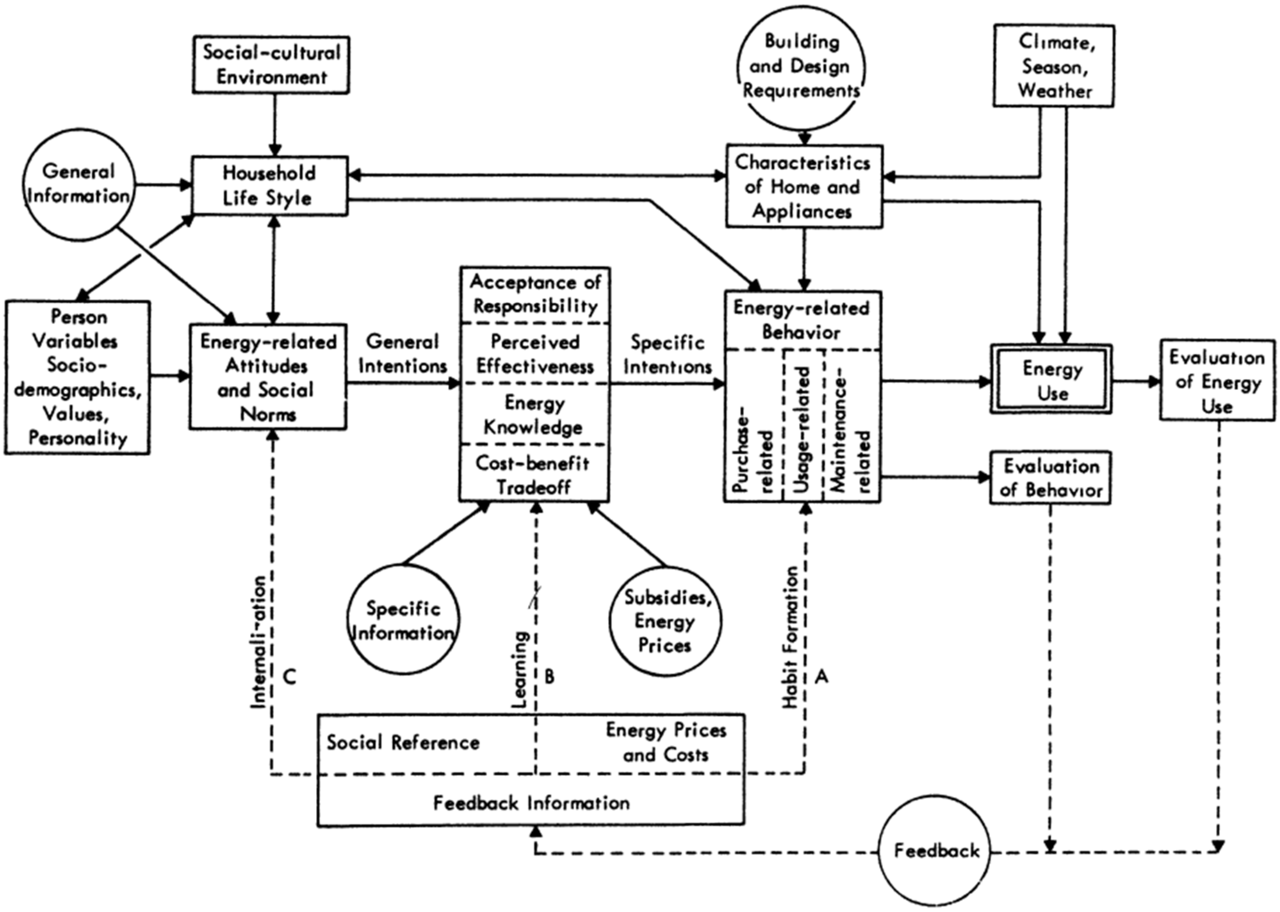

Fig. 3.8.2. Behavioural model of residential energy use (source: W. F. VAN RAAIJ and T. M. M. VERHALLEN, 1982)

3.8.1 Physical influences

If there is a side of energy management that has been largely known and used until now in all models, it is the energy characteristics of the energy system that lead to the evaluation of energy needs and consumptions. Climatic data is still acknowledged as "the most significant parameter that determines energy use" by K. STEEMERS and G. Y. YUN[141] who rightfully add that it is "not surprising for a housing stock that contains approximately 75% of buildings that predate energy-efficiency regulations." Although they were assessing the US residential stock, this conclusion is accurate for the Walloon stock. Heating degree-days, therefore, would be the single most significant variable influencing heating energy use for the whole residential stock. However, when the envelope of a building is insulated and its energy performances increase, the influence of the climate on its heating consumption decreases: climate, therefore, does not sufficiently explain energy demand.

The "energy efficiency" of a building is generally composed of an ensemble of numerical parameters that define the quality of the thermal envelope and the systems that are used to provide heat and general comfort to the living space. Usual parameters include liveable areas and volumes, thermal resistances and areas of envelope walls for transmission losses, air flow rates due to ventilation and in- or exfiltration, solar gains through glazed surfaces, heating and DHW installations efficiencies in producing, storing, distributing and emitting the heat or water, additional consumptions due to

[141] K. STEEMERS, G. Y. YUN, 2009. *Household energy consumption: a study of the role of occupants*, Building Research & Information, 37:5-6, 625-637

auxiliaries, fans and pumps needed in the processes. In those models, behavioural determiners of the consumption, such as the internal gains, are usually translated in standardised parameters which evaluation depends on determiners that can be objectivized (such as the protected volume), or a default value in the case of the set temperature for heating.

According to A. INGLE et al, "by focusing on technical home characteristics, home energy audit models generate energy-use estimates, retrofit designs and savings potential estimates in line with building stock efficiency and decoupled from any particular occupants. This approach contrasts with the importance to home energy use and energy use reduction of household occupants and their behaviours, suggesting the presence of a divide between the technical and behavioural aspects of home energy use in the home energy audit context. This 'techno-behavioural divide' is reflected, for example, when audit data collection is limited to the energy efficiency characteristics of the home and equipment, using standardized assumptions about occupants and equipment efficiency to perform the analysis. The divide is propagated from building energy modelling through to design and recommendation of retrofits to homeowners based on economic cost-effectiveness criteria. […] Technology–behaviour dynamics, such as rebound, are treated largely as externalities."[142]

Therefore, gaps between theoretical assessments and real consumption data are generally explained by technical failure or bad workmanship[143] that introduce uncertainties in the hypotheses mentioned above. "Overly complex or non-intuitive control interfaces" that render high-technology buildings or systems too complex to operate[144] and require dedicated management to achieve optimal performance are also sometimes cited.[145] This might for example be the case after renovation works that implied a change of heating installations and the replacement of a simple yet inefficient regulation system of thermostatic valves. The presence of a (programmable[146]) thermostat in the dwelling has been reported by several studies as influential in the energy use, although generally related to higher number of heated bedrooms and higher energy consumptions.[147]

O. GUERRA-SANTIN's study of the Dutch residential stock also correlates higher consumptions with the presence of a basement, a garage or a shed in the single-family building, "probably because they affect the behaviour of the users, for example, in their use of rooms or heating in these areas", whereas the presence of an open kitchen usually decreases consumption, "probably because of the heat generated by cooking and the use of appliances"[148].

Some authors also stress that the energy characteristics of the building can have an important influence on the way they use the building and its systems[149]. This was approached above by the observations on the rebound effect, from the generalisation of central heating in London to the later low-temperature systems that loose efficiency in intermittence. Part of the heating behaviour is linked with the possibilities that exist in the energy technical system, and the adaptability of

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142 A. INGLE, M. MOEZZI, L. LUTZENHISER, R. DIAMOND, 2014. *Ibid*
143 M. DEURINCK, et al., 2012. *Ibid*
144 Z. BROWN, R. J. COLE, 2009. *Ibid*
145 W. BORDASS, A. LEAMAN, 1997. *Future buildings and their services: strategic considerations for designers and clients*. Building Research & Information, 25(4), 190–195.
146 O. GUERRA SANTIN, 2011. *Ibid*
147 O. GUERRA SANTIN, L. ITARD, H. VISSCHER, 2009. *The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock*, in Elsevier Energy and Buildings 41 (), pp. 1223-1232
148 O. GUERRA SANTIN, et al., 2009. *Ibid*
149 C. TWEED, et al., 2015. *Ibid*.

inhabitants who move, modify and operate their homes to achieve the thermal conditions they want. Inhabitants adjust their habits to the efficiency or standard of the building in which they are living; some behaviours are "connected with certain types of building characteristics and heating and ventilation systems."[150] For example, they keep lower temperatures in inefficient houses and higher temperatures in efficient ones[151]. This has an enormous importance, especially when dealing with the renovation of an existing house: dwellers adapted their behaviours to their old system, and will adapt in their own ways to the new system. To cite S. SORRELL et al.[152], "it may be misleading to interpret [direct rebound effect] solely as a rational response to lower heating costs, partly because energy-efficiency improvements may change other variables (e.g. airflow) that also encourage behavioural responses."

Another conclusion might be that in a retrofit, it must be possible to foresee some adaptability issues to the new system that could be resolved by an accurate choice of installation (from the production to the emission, via regulation) that is chosen adequately with the users abilities and needs. In other words, not all systems are suitable for all envelopes and patterns of energy demand, but neither are they all suitable for all users.

3.8.2 Sociodemographic and-economic influences

According to O. GUERRA-SANTIN, the household characteristics that influenced energy consumption were size, age of respondent, type of ownership, and income[153].

Income is acknowledged by many studies as an important influential factor[154] in energy consumption because it allows both energy consuming practices and energy-saving investments, and income level seems to influence upwards both energy consumption and energy-saving behaviours.[155] As F. BARTIAUX says, "practices and representations in energy consumption are also socially constructed by our society of consumerism, which access is stratified, based on households' income level".[156] L. LUTZENHEISER specified that income is strongly associated with the consumption of resources, such as water[157], as well as with housing characteristics[158] (wealthy people tend to live in more spacious homes and heat more rooms through centralised systems piloted by thermostat[159]), electricity use and rate structure preferences[160], and attitudes toward and access to conservation[161].

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[150] O. GUERRA SANTIN, 2011. *Ibid*
[151] K. GRAM-HANSSEN, 2014. *Ibid*
[152] S. SORRELL, et al. 2009. *ibid*
[153] O. GUERRA SANTIN, 2010, *Ibid*
[154] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.
L. LUTZENHISER, 1993. *Ibid*
[155] G. WALLENBORN, et al., 2006. *Ibid*.
[156] F. BARTIAUX, et al., 2006., *La consommation d'énergie dans le secteur résidentiel : facteurs socio-techniques (SEREC)*, Scientific Support Plan for a Sustainable Development Policy (SPSDII)
[157] I. A. SPAULDING, 1972. *Social class and household water consumption. In Social Behavior. Natural Resources, and the Environment*, ed. N. CHEEK BURCH, L. TAYLOR. New York: Harper & Row
[158] L. LUTZENHISER, B. HACKETT, 1993. *Social stratification and environmental degradation: Understanding household C02 production*. Soc. Prohl. 40:50-73
[159] K. STEEMERS, G. Y. YUN, 2009. *Ibid*
[160] J. T. BLOCKER, P. R. KOSKI, 1984. *Household income, electricity use, and rate-structure preferences*. Environ. Behav. 16:551-72
[161] D. A. DILLMAN, et al., 1983. *Ibid*

In relation with the rebound effect and the fuel poverty, the "price-elasticity" has been defined above by D. MAXWELL, et al.[162] "Income elasticity", therefore, relates to the percentage change in energy demand associated with an increase in income by 1%, measuring the sensitivity of the energy demand to income changes. Income influence, however, is limited by the "non-discretionary" (or "constraint"[163]) status of energy consumption for heating needs, which means that basic essential physiological needs have to be answered "whatever the costs". "Low-income households conserve energy as much as they can, but their poorly insulated home is energy-wasting and they cannot easily reduce their energy use any further, while high-income consumers are unwilling to reduce their energy use. Middle-income consumers are the most likely conservers."[164] Furthermore, there seems to be a correlation between the level of income and the duration of acceptable payback periods in renovation works. High income households accept more easily the strategies and investments proposed by energy assessors (if they trust them), as long as they do not lose comfort (which might indicate that their energy consumption could be lower). Modest households will more preferably turn to restriction practices through "good domestic management", and are less likely to take advantage of the recent technical improvements in energy performance of buildings. It has been noted however that increase in income level in low-income households are often followed by an increase in appliances and equipment that offer immediate comfort (notably in social representation) but induce more energy consumptions[165].

Income level is variable in a household's lifecycle (the evolution of a family size, composition and age). According to L. LUTZENHEISER[166], the influence on the energy consumption of "household life-cycle differences have been reported in heating, housing needs and electricity use[167], overall energy-efficiency[168], building and appliance characteristics[169], and carbon dioxide pollution rates[170]. Age-related differences (primarily those involving older persons) have also been reported in relation to knowledge of energy-using equipment and building functioning[171], as well as in behavioural response to energy price and billing changes[172]."

Energy saving investments or behaviours are more the fact of higher or middle-class social groups, beneficiary of better average income and education levels.[173] The income level is usually dependent on other important sociodemographic characteristics of the household, such as the education level and the employment status. The education level informs, notably, on the level of competence to

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162 D. MAXWELL, et al., 2011. *Ibid*

163 G. BRISEPIERRE, 2013. *Ibid*

164 W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.

165 G. BRISEPIERRE, 2013. *Ibid*

166 L. LUTZENHISER, 1993. *Ibid*

167 V. C. LANGSTON, M. WILLIAMS, 1988. *Changing housing needs with age: Life-style and attitude implications for electricity use and management*. Proc. Am. Coune. Energy Effie. Econ., pp. 67-70. Washington, DC: ACEEE Press

168 L. W. BAXTER, S. L. FELDMAN, A. P. SCHINNAR, R. M. WIRTSHAFTER, 1986. *An efficiency analysis of household energy use*. Energy Econ. 8:62-73

169 L. A. SKUMATZ, 1988. *Energy-related differences in residential target-group customers: Analysis of energy usage, appliance holdings, housing, and demographic characteristics of residential customers*. Proc. Am. Counc. Energy E ffie. Eeon., pp. 11.131-43. Washington, DC: ACEEE Press

170 L. LUTZENHISER, 1993. *Ibid*

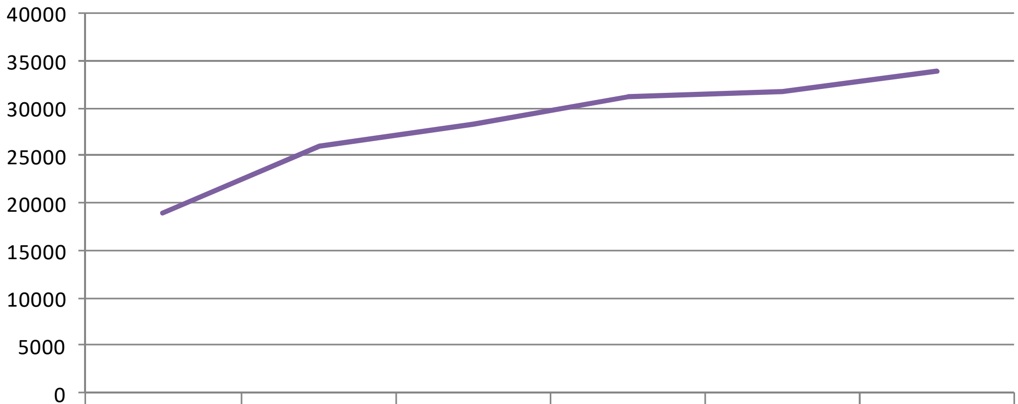
171 R. C. DIAMOND, 1984. *Energy use among the low-income elderly: A closer look*. Proc: Am. Counc. Energy Effic. Econ., Summer Study, pp. F52F67. Washington, DC: ACEEE Press

172 M. MARGANUS, S. BADENHOP, 1984. *Energy expenditures and family well-being by stage in the family lifecycle*. See Ref. 45, pp. 391-404

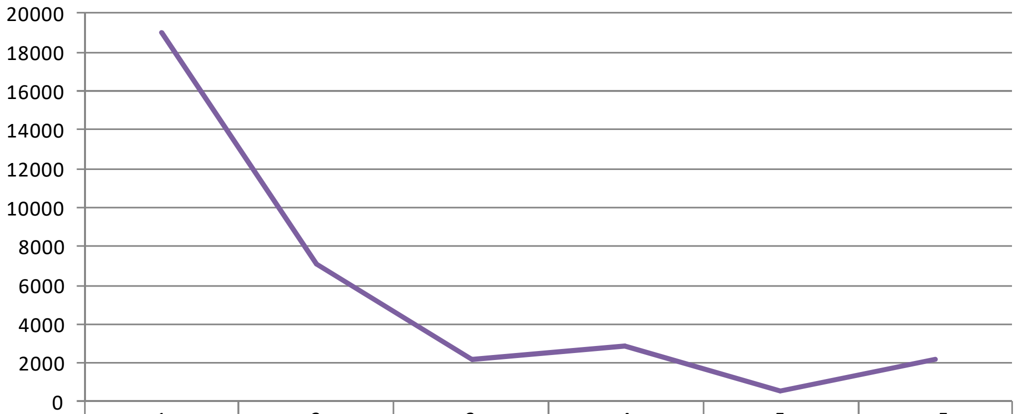
173 G. WALLENBORN, et al., 2006. *Ibid*.

understand energy consumption aspects. Education and profession relate to an ensemble of cultural resources, but first and foremost to an income level. Interestingly, higher education is related to less energy consumption[174] while higher income is correlated to more energy consumption[175]. Education and profession certainly have links with access to information in broader circles.

The Federal Public Service (FPS) Economy of Belgium released in 2012 a survey of energy consumptions in Belgian households[176], in which the Fig. 3.8.3 hereunder can be found, showing the different energy needs of households, depending on the number of members. The first graph gives the average energy consumption (in kWh/year) per number of occupants in the household in 2010. The second graph gives an estimate of additional energy consumption per occupant. Clearly, multiplying the number of a household's members does not translate in the same basic multiplication of energy consumption. Total consumptions increase with the size of households, but consumptions per capita decrease, due to economies of scale. Every added member to a family asks for less and less additional energy consumption, so that energy consumption per capita decreases in large households. Therefore, the increasing number of households that decrease in size should translate in global increase in energy consumption.



	1	2	3	4	5	> 5
Belgium	18972	26022	28243	31137	31727	33892



	1	2	3	4	5	> 5
Belgium	18972	7050	2221	2895	589	2165

Fig. 3.8.3. Belgium, 2010: average energy consumption (in kWh/year) per number of occupants in the household (first graph) and additional energy consumption per occupant (second graph). (Source: Eurostat, 2012)

[174] O. GUERRA-SANTIN, L. ITARD, 2010. *Occupants' behaviour: determinants and effects on residential heating consumption*. Building Research & Information, 38(3), 318–338.
[175] O. GUERRA-SANTIN, et al., 2009. *Ibid*.
[176] EUROSTAT, 2012. *Energy Consumption Survey for Belgian Households*, Federal Public Service (FPS) Economy, Belgium.

Age is also an important insight into energy consumption for several studies, as environmental awareness or motivations in changing behaviour for more energy-efficient practices are known to change with age. Older people also tend to stay more at home, and heat at higher temperatures, resulting in higher average consumption for space heating[177] for older households, when compared to younger households.

French sociologist G. BRISEPIERRE postulates that households' energy consumptions are product of interactions within the family, so that a household cannot only be seen as a unique entity. Energy consumption is caught in a battle for command when it relates to the repartition of domestic work within the couple, or to the practice of parental authority (set temperatures, duration of showers…). Energy related practices are to be differentiated between householders, when there is always one inhabitant who is thriftier, or more sensitive to the cold… G. WALLENBORN[178] mentions that in Belgium, the needs of the most demanding member of the household determine the temperature levels in the dwelling, and that the proposition to put on a sweater instead of increasing heating faces low success. There is also a possible differentiation by gender, as women seem more concerned by environment and more engaged in energy thrifty behaviours than men, or because "the masculine side more often takes charge of maintenance and purchase decisions, and the feminine side is more focused on daily use."[179]

G. BRISEPIERRE[180] also specifies that the age influence of a householder is dual, as it plays:

- First on the belonging to a generation, for people remain marked, life-long, by the historical context of energy use in which they have been raised. People born in the 30s/40s remember the times of restriction after war. Born in the 50s/60s, they knew the abundancy of the post-war economic boom. Born in the 70s and 80s, they knew the energy and economic crises which led to an education in moderation. Young generations from the 90s and 2000s saw the emergence of environmental problems and the critiques of the society of consumerism.
- Second, on their position in the cycle of life, which usually translates into an alternation between periods of higher and lower energy consumptions. Childhood is a period where we adhere to the family model, which might change in the teenager years. First bills (paid with first salaries) usually lead to thriftier behaviours, whereas adulthood is marked by a search for equilibrium, sometimes disrupted by the arrival of a child. According to W.F. VAN RAAIJ and T. M. M. VERHALLEN, "young households without children and both partners working outside the home tend to have a low level of energy use. Households with children at home have a higher use of energy."[181] After the children have left home, the energy use decreases, but gradually increases with age.

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[177] H.C. LIAO, T.F. CHANG, 2002. *Space-heating and water-heating energy demands of the aged in the U.S.*, Energy Economics 24, pp. 267-284.
A.-L.LINDEN, et al., 2006. *Ibid*
O. GUERRA SANTIN, 2010, *Ibid*
[178] G. WALLENBORN, et al., (2006), *Ibid*
[179] G. BRISEPIERRE, *Analyse sociologique de la consommation d'énergie dans les bâtiments résidentiels et tertiaires. Bilan et perspectives*, ADEME, 2013.
[180] G. BRISEPIERRE, *Analyse sociologique de la consommation d'énergie dans les bâtiments résidentiels et tertiaires. Bilan et perspectives*, ADEME, 2013.
[181] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1983, *A behavioural model of residential energy use*, Journal of Economic Psychology 3, pp. 39-63, North-Holland Publishing Company

3.8.3 Attitudinal and behavioural influences

The next section is an overview of the following literature, mentioned about the observation of important discrepancies in energy consumptions between similar dwellings:

- O. GUERRA SANTIN, 2010. *Actual energy consumption in dwellings: The effect of energy performance regulations and occupant behaviour*. Amsterdam: IOS Press.
- H. HENS, W. PARIJS, M. DEURINCK, 2010. *Energy consumption for heating and rebound effects*. Energy and Buildings, 42(1), 105–110
- M. SUNIKKA-BLANK, R. GALVIN, 2012. *Introducing the prebound effect: The gap between performance and actual energy consumption*. Building Research & Information, 40(3), 260–273
- D. BROUNEN, N. KOK, J. M. QUIGLEY, 2012. *Residential energy use and conservation: Economics and demographics*. European Economic Review, 56(5), 931–945
- O. GUERRA-SANTIN, L. ITARD, 2010. *Occupants' behaviour: determinants and effects on residential heating consumption*. Building Research & Information, 38(3), 318–338.
- O. GUERRA SANTIN, L. ITARD, H. VISSCHER, 2009. *The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock*. Energy and Buildings, 41(11), 1223–1232.
- K. STEEMERS, G. Y. YUN, 2009. *Household energy consumption: A study of the role of occupants*. Building Research & Information, 37(5–6), 625–637.
- H. WILHITE, et al., *A cross-cultural analysis of household energy use behaviour in Japan and Norway*, in Elsevier Energy Policy 24 (1996), pp. 795-803, Great Britain
- G. WALLENBORN, et al. (2006), PADDII (Plan d'Appui scientifique pour une politique de Développement Durable): « *Détermination de profils de ménages pour une utilisation plus rationnelle de l'énergie. Partie 1: Modes de production et de consommation durables* », Politique scientifique fédérale, Bruxelles, 106 p.

The observed array of real consumptions is partially explained in these studies by the occupancy and heating patterns and energy-consuming practices that differentiate the households. Most of these studies even state that "as buildings become more energy efficient, the occupants' behaviour plays an increasingly important role in energy consumption". It seems that an energy intensive lifestyle in a very energy efficient residence can lead to a higher energy use than an energy extensive lifestyle in a less energy efficient residence[182]. It might be more accurate to say that in all kinds of buildings, user behaviour has a comparably significant influence on the real heating energy use than energy characteristics. These findings, therefore, conflict with the simplifying assumption of a single, average and standardised user profile, as defined in the calculation methods.[183] The behaviour component is frequently underestimated or ignored in analyses of dwelling end use, partly because of its complexity.[184]

Energy-consuming practices can be of various sorts, such as:

- Habits in heating: set temperature in spaces directly heated, number of heated rooms, length of heating periods… Energy use increases when more rooms are heated with higher

[182] E. DE GROOT, M. SPIEKMAN, I. OPSTELTEN, 2008. *Dutch Research into User Behaviour in Relation to Energy Use of Residences*, PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin.
[183] M. DELGHUST, W. ROELENS, T. TANGHE, Y. DE WEERDT, A. JANSSENS, 2015. *Ibid*
[184] H. WILHITE, et al., 1996. *Ibid*

temperature settings.[185] The behaviours in temperature setbacks during night periods or absence are also of importance. Those habits are sometimes greatly influenced by the quality of the building, as explained above. The occupancy pattern generally determines the heating pattern in winters (especially in inefficient dwellings), so that the hours of presence at home are known to have a great influence: continuous presence increases energy use in comparison to cases when the users are almost never home or their presence is very variable. Occupancy patterns may be determined by lifestyle, preferences, and attitudes, perceptions of comfort, personal background, or household characteristics[186].

- Habits in ventilation: frequency and lengths of time during which the volume is ventilated, naturally or mechanically, manually or automatically, with or without particular practices in closing natural supply vents during cold periods, for example. Although the air tightness of the envelope is a parameter that mainly depends on the built quality, it is possible for users to airtight some elements (windows or doors) during winters and therefore diminish those losses. In highly efficient dwellings, the air flow rate becomes a significant (if not dominant) part of thermal losses, rendering this particular behaviour more and more influential.[187]
- Habits in cooling, when applicable. This is rarely the case in Walloon residential stock, and never the case in this research. Overheating in Walloon summertime is generally dealt with patience, shading devices and nightly ventilation.
- Habits in hygiene, which influence the ventilation habits, the frequency and lengths of baths and showers, or the number of appliances used weekly to wash dishes and clothes.
- Habits in lighting, which depend on the quality of the natural lighting provided by the architecture of the dwellings, its situation in the block, the presence of physical obstructions to sunlight… The energy consumption that ensues depends on the installation (number of lighting appliances, lighting power and periods…) and habits of the occupants (need for lit spaces, suitable comfort for different occupations, habits in shutting off the lights when leaving a space…).[188]
- Generally, habits in using appliances and equipment for entertainment or other domestic activities that may induce direct energy consumption and indirect consumption (TV times are sometimes linked with higher living room temperatures due to inactivity, for example).

These uses are defined by W. F. VAN RAAIJ and T. M. M. VERHALLEN as "usage-related behaviour", referring to the frequency, duration, and intensity of the day-to-day use[189] of the home and the appliances it contains. "Household lifestyle", on the other hand, is defined by enduring overall patterns of activities, such as leisure and hobbies, and is determined by social-cultural factors and a number of person variables that may influence energy-related attitudes and behaviours, such as personality values, related to interests and opinion. "A lifestyle is developed as a consequence of housing, family composition, and income conditions, and partly as a way of self-expression and self-realization."

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[185] O. GUERRA SANTIN, et al., 2009. *Ibid.*

[186] R.V. ANDERSEN, J. TOFTUM, K.K. ANDERSEN, B.W. OLESSEN, (2009) *Survey of occupant behaviour and control of indoor environment in Danish dwellings*. Energy and Buildings, 41, 11–16.
O. GUERRA SANTIN, 2010, *Ibid*

[187] O. GUERRA SANTIN, 2010, *Ibid*

[188] H. WILHITE, et al., 1996. *Ibid*.

[189] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.

There is, therefore, a second angle at which the influence of attitudes and behaviour on energy consumption might be observed. As developed above, the energy consumption is determined by social constructs (such as norms and representations), but also by "energy knowledge and illiteracy". Energy knowledge is the knowledge of energy costs, energy conservation behaviours, and the energy consequences of these behaviours. Perhaps the most striking gap in consumer information on the energy problem is which behaviours have which effect on the use of energy[190]. Energy illiteracy refers to the lack of information regarding the severity and scale of energy problems, relative energy prices, and consumption alternatives.[191] Energy-related attitudes, therefore, can be as various as price concern, environmental concern, energy concern, health concern, attitudes toward personal comfort and personal sense of responsibility in the global stakes. Relations between information, knowledge, awareness and behaviours obey complex schemes.[192] Ecological sensibility plays no role on the general equipment level, when it comes to diminishing the number of energy-consuming appliances. Quite the contrary, being associated to higher income and educational level, it is more often correlated to a high equipment level.[193] There is no direct and positive correlation between an environment-friendly attitude and consumption practices with low impact on the environment[194].

The insight into energy consumers' psychology is difficult to assess, and not the topic of this research. Besides, too much or too detailed data can be difficult to process and analyse and might, therefore, compromise the quality of the data, since important information could be lost. Data collection, in this study, focuses on aspects of behaviour that tend to vary more widely across the population and that seem to have a stronger influence on energy use.[195]

3.8.4 Patterns and profiles

Some authors have been focusing on those limited influential parameters and defined "profiles" as ensembles of relations that are more determining than others. At the centre is the household and its dwelling's energy characteristics, with on one hand what constitutes the framework (heating system, building envelope, electric appliances) and on the other hand what creates the ambiance within (energy consumption uses and behaviours, ways to inhabit the volume, relationships between households' members…).[196] User profiles can be defined as groups of households with similar characteristics that behave in a similar fashion, so that behavioural factors have to be correlated to household and building characteristics.

In the 80s, W. F. VAN RAAIJ and T. M. M. VERHALLEN[197] found five behavioural patterns. They could be partly crossed with the patterns developed later by E. DE GROOT, et al.[198]:

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[190] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.
[191] G. WALLENBORN, et al., 2006. *Ibid*.
[192] G. WALLENBORN, et al., 2006. *Ibid*.
[193] B. MARESCA, et al., 2009. *Ibid*
[194] M. VIKLUND, 2004. *Energy policy options - from the perspective of public attitudes and risk perceptions*, Energy Policy 32: 1159-1171.
[195] O. GUERRA-SANTIN, L. Itard, 2010. *Ibid*.
[196] G. WALLENBORN, et al., 2006. *Ibid*.
[197] W. F. VAN RAAIJ, T. M. M. VERHALLEN, 1982. *Ibid*.
[198] E. DE GROOT, et al., 2008. *Ibid*.

- 'Conservers': low temperature, low ventilation, higher education, small household size, working life, less energy consumption.
- 'Spenders': high temperature, high ventilation, low education, more often at home, more energy consumption. Adding in this pattern a greater use of space and electronics, E. DE GROOT et al. mention low energy concerns.
- 'Cool' ("affluent-cool" for E. DE GROOT et al.): moderate temperature, high ventilation, medium energy consumption, attitude does not explain energy consumption.
- 'Warm': high temperature, low ventilation, comfort quest, older people. Greater use of space and electronics does not prevent energy-saving concerns for E. DE GROOT et al.
- 'Average': moderate in temperature and ventilation.

The "conservers" and "average" behavioural patterns are not present in the study by E. DE GROOT et al., replaced by patterns of "comfort" (more use of electronics, of heating, of ventilation, which makes this pattern similar to "spenders") and "convenience-cool" (more use of electronics, of ventilation, which resembles the 'cool' pattern).

These studies were based on the analysis of different profiles of households, namely 'single', 'two adults below 60', 'single-parent families', 'two-parent families', and 'seniors above 60'. In addition, the 'two adults below 60' category was split into high-income and low-income, to highlight its importance as behaviour determiner. The 'low-income couples' category were merged with the 'singles', since the range of income was similar and no notable differences in behaviour were found between 'singles' and 'low-income couples'.[199] In singles and couples households, the behaviour was less related to temperature comfort or intensive use of appliances and space. High-income couples were less concerned about saving energy and sought a more convenient use of the dwelling. Families needed more space and made more use of heavy appliances. Seniors clearly preferred more comfort given that they scored high for 'ventilation' and 'temperature comfort'. Energy consumption turned out to be lower in senior households and higher in family households.[200]

As a result, four profiles were defined:
- 'Ease': people in this profile act to create comfort and have no real sense or interest in energy use, costs or environment;
- 'Conscious' households choose for comfort, but take into account costs and environment;
- 'Costs' people are aware of costs and save energy to reduce costs;
- 'Environment' category regroups households acting mainly for the environment.

Each profile is expected to act differently, as far as energy consumption is concerned, but also in renovation projects and investments in energy-savings. In 2014, V. HAINES and V. MITCHELL[201] developed the notion of "personas", which are "archetypal users who embody the goals and aspirations of real users in an easy-to-assimilate and personable form". In particular the personas represent the attitudes and motivations of homeowners related to making improvements to their homes, the difficulties and processes related, and how these attitudes, motivations and behaviours result in opportunities and barriers to retrofit. Based on qualitative interviews with real homeowners, the definition of the personas does not claim to represent all possible profiles of

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[199] O. GUERRA-SANTIN, 2011. *Ibid*
[200] O. GUERRA-SANTIN, 2011. *Ibid*
[201] V. HAINES, V. MITCHELL, 2014. *Ibid*

homeowners, but to help "visualize and communicate how differences in social background, available resources and competences together with differences in views (e.g. what constitutes a nice home) can have a huge impact on the ways and extent that homeowners retrofit their homes."[202] They are defined by using illustrative concepts to which their dwellings are assimilated, for householders define their idealised and personal relationship to their home. As G. WALLENBORN postulates: "People who wish to manage their dwelling in order for it to work rationally, without flaws, envision energy like a tool to be managed and are ready to make investments. People who envision their dwelling like a protective or resourcing space, and those who envision it like a convivial life space are not particular thrifty profiles. They mainly pursue goals linked to personal well-being, comfort. They could be more willing to invest than modify daily practices. People who do not own their dwelling, or do not envision to stay a long time are less disposed to invest. People who adopt energy-saving behaviours are also those for whom energy savings have most meaning, significations. There is a social influence: energy savings has less meaning for people in lower social groups."[203]

Table 1 Key information from the set of home improvement personas

Persona (including subtype)	Key features	Opportunities for retrofit
The Idealist Restorer: *The property is a project*	Motivated to live in an older property because of the character and the opportunity it provides for restoration and improvement. Values the aesthetic period features and space afforded by older homes	Very open to retrofitting energy efficiency measures and in an optimal order if the aesthetics of the home are respected
	Wants to restore as many original features within the home as possible but not at the expense of aesthetics, comfort and convenience. Although they wish to keep the sash windows, they have replaced the quarry tile floor in the hallway with laminate flooring	Interested in 'clever' energy saving technologies but only if the character of the home can be maintained
	Motivated to learn new DIY skills and wants to do things thoroughly	
	Energy efficiency is perceived as a construct of quality but aesthetics and comfort are valued more highly	
The Affluent Service Seeker: *The property is a pleasure*	Motivated to live in an older property because of the character, idyllic rural location large garden and useful outbuildings. Accepts that older properties are expensive to maintain and views spending on the property as a way to preserve and add value to the investment in the property	Open to incentive schemes and polices that generate income for the homeowner or add value to the property
	Seeks luxury and quality but also value for money. Known to be financially savvy. Values comfort over financial saving	Will choose to use specialist professionals to ensure a quality job
	Carries out very little DIY through choice but likely to be less physically able than when they were younger	
	Energy efficiency is perceived as difficult to achieve in a large old property but this persona is keen to take advantage of any grants or incentive schemes available	
The Property Ladder Climber: *The property is a step up*	Motivated to live in an older property by the potential it offers to add value to its resale value through renovation	Open to the use of finance schemes if these are cost-effective within the context of 'improving to sell'
	Happy to borrow money in the short-term to finance home improvements, paying these back when the property is sold	Unlikely to consider technologies with long payback times unless the cost of installation is passed on
	Enjoys developing their DIY skills as the projects get bigger with each property they buy	
	Open to consequential improvements as they are thinking at a whole-house level but these improvements must lead to financial gain at the point of resale	
	Energy saving beyond current building regulations is not a priority	

202 K. GRAM-HANSSEN, 2014. *Ibid*

203 G. WALLENBORN, et al., 2006. *Ibid*.

The Pragmatist: Subtype - Functional *The property is a place to live*	Motivated to live in an older property because of the layout and room size that accommodates a full and active family life Home improvements are seen as a hassle rather than a hobby; they take time away from more important things – hobbies and family time Not particularly interested in keeping older features of the property, but places greater value on convenience Concerned about the environment and climate change, as a result of their family values.	When things wear out or go wrong At the time of purchasing the property When re-purposing a space or extending the home When finance becomes available.
The Pragmatist: Subtype - Aesthetic *The property is a home*	Motivated to live in an older property because of the character and space it offers Enjoy having a project on the go but improving or updating the decor, furniture and appliances within the home will be of higher priority than repurposing of space or non-essential maintenance Likely to cover up some issues like damp through frequent redecoration rather than fix the underlying cause Values 'off the shelf' solutions, preferring to finance these from savings or windfalls rather than loans. Want a neat and tidy job to be done, with a good-quality finish	When they first purchase the property or within the regular cycle of decorating and refurbishment The order of retrofit will be driven by aesthetic priorities, *e.g.* the desire for new kitchen may lead to a new boiler
The Stalled: Subtype - Lack of Finance *The property is a shelter*	Wants a warm, comfortable home, but is not extravagant in their requirements Wants to feel safe and secure in their home and be assured that any work undertaken by tradespeople is not exploiting them financially or putting them in danger Frugal and interested in saving energy primarily to save money. They are positive towards opportunities to improve the warmth and security of their home Leaves parts of the property unheated through the winter, but uses draughtproofing to increase comfort	Limited to when grants are available Will undertake consequential improvements if dictated by grant scheme
The Stalled: Subtype - Pressures of Life *The property is a necessity*	Does not have the time, emotional energy or financial resource to undertake home improvements at present Will use a trusted, known professional to help with any essential jobs around the property but won't undertake any major projects May consider taking a loan to fund essential maintenance but they prefer to wait and use savings when they can afford	Almost none at present

Fig. 3.8.4. Key information from the set of home improvement personas (Source: HAINES and MITCHELL, 2014)

Chapter 4: Uncertainties and standardisation

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4.1 Research description

This study is based on the hypotheses that people do not act on energy-related decision because they cannot appropriate the message brought by the EPC. Not all people understand that an EPC is an asset rating and not an operational rating, nor can they all appreciate the consequences on the information they are given. Not all people know to what relates a kWh of primary energy per square meter of "heated floor area". It is believed, however, that by incorporating the user in the process, a solution to the lack of knowledge and appropriation of the EPCs could be found in the improvement of the communication around it. By considering complementary (and more accurately close to reality) results that integrate users' behaviours in the calculation method, the EPC could become the helpful tool it was designed to be *IF* it allows appropriation of results from the owners, and end-users of the EPC.

> *APPROPRIATION* "Individuals do not merely 'internalize' socially-derived knowledge. Rather, they engage in a transformative and constructive process referred to as 'appropriation'[1] in which both the source of the knowledge and learner are reciprocally transferred through individuals' engagement in goal-directed activity"[2]. In this context, appropriation is defined as the ability for the user to understand and adopt the EPC message and results. Awareness (of their influence on consumption) and perceived usefulness of results and advice are important in order to mobilize this new personal knowledge and to act upon it[3].

In this study, we acknowledge, of course, the necessity to maintain the current standardized approach in order to allow building comparisons, but also share the opinion of the EPBD Concerted Action that acknowledges the flaws and disadvantages, but also potentialities of the certification scheme and the calculation method it uses. "The EPC rates the building and not the way it is used. Elements in the calculation, such as payback time, cost-optimality, and cost-effectiveness of recommendations, depend on the actual energy performance in which the users play a significant role. In many countries […], calculation is based on a standard climate, standard user behaviour, and other default values, which might deviate more or less from the actual situation, depending on each specific case/building. While for the first purpose of the EPC, […] it is appropriate to use default values to achieve comparable calculation results, this might result in the calculation of seemingly distorted energy savings and thus compromise the second purpose of the EPC, which is to inform about the energy savings potential. As a result, it is necessary to strike a balance between these two objectives. One of the challenges is how to obtain realistic values rather than simply using possibly unrealistic default values without increasing the cost of data collection, bearing in mind that building documentation is not available for the majority of the building stock in need of renovation.

The aim of this study is to analyse the uncertainties in the Walloon EPC procedure that may explain the observed gaps between theoretical evaluations and real consumptions. The same kind of exercise has been realised in Belgium in the past, focusing more on the results of the EPB calculation method for new and efficient buildings. In 2011, for example, A. DE MEYER and V. FELDHEIM presented the

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[1] B. ROGOFF, 1995. *Observing sociocultural activities on three planes: Participatory appropriation, guided appropriation and apprenticeship*. In *Sociocultural Studies of the Mind*; WERTSCH, J.V., DEL RIO, P., ALVEREZ, A., Eds.; Cambridge University Press: Cambridge, UK; pp. 139–164.

[2] S.R. BILLETT, 1998. *Situation, social systems and learning*. Journal of Educational Work, 11, 255–274.

[3] P. SERFATY-GARZON, 2003. *L'Appropriation*. In *Dictionnaire Critique de L'habitat et du Logement*; M. SEGAUD, J. BRUN, J.-C. DRIANT, Eds.; Editions Armand Colin: Paris, France; pp. 27–30.

results of their energy consumption monitoring of 16 dwellings that received the “CALE” certificate (“Construire Avec L’Energie… naturellement” - “Build with energy… naturally”).

The EPB thermal regulations have been implemented progressively since September 2008. In order to help and train the sector into apprehending the new method and achieving the future requirements, Wallonia implemented in 2004 the CALE action. With still 4 years to wait for the official software to be developed, a slightly simplified method was implemented to allow complete assessments of new residential units’ energy performances in an Excel® spreadsheet developed by G. DUPONT (ULiege, Energy and Sustainable Development research team, directed by Prof. J.-M. HAUGLUSTAINE) and S. NOURRICIER (UMons, Department of Thermal Engineering and Combustion, directed by Prof. V. FELDHEIM). This tool was used by architects to assess the energy performances of their projects. For a subsidy of 750€ for the owner and 500€ for the architect, the CALE action asked architects to be compliant with future EPB regulation requirements, which were tougher than those imposed by the regulations in force at the time. Results were already delivered as a specific annual primary energy consumption per square meter (E_{spec} level).

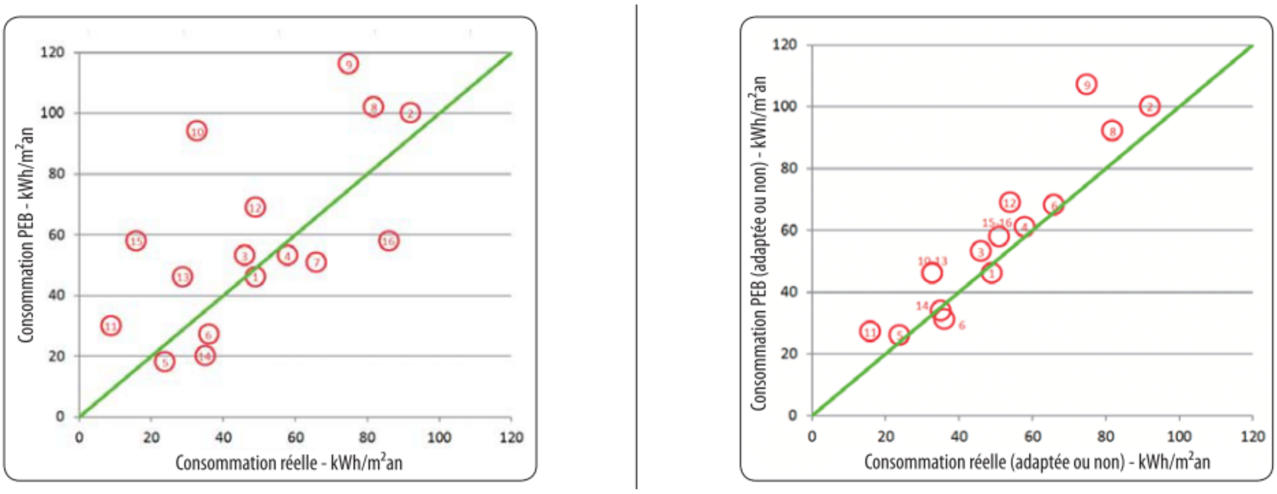

Fig. 4.1.1. Results of the comparisons, before (**left**) after (**right**) corrections. On the vertical axes, the final consumption as estimated by the EPB method (corrected or not). On the horizontal axes, real consumptions (both in kWh/m².year) (Source: DE MEYER, 2011)

In the report[4], A. DE MEYER and V. FELDHEIM compared the real data of final energy consumptions (for the period of May 2009 to April 2010) to those estimated by the EPB method. Raw results show gaps between -43% and +263% (a negative gap indicates that real consumption is higher than theoretical; positive gap indicates that the real consumption is lower than estimated by the EPB). However, when some corrections were applied to the “real consumption data”, these gaps decreased significantly (from -14% to +69%). Those corrections took into account:

- Real climatic data, measured on site.
- Real interior temperatures, measured on site.
- Particularly thrifty behaviours (appliances).
- More realistic calorific value for wood pellets.
- Particular behaviour in ventilation (partial or permanent closing of vents in natural supplies, intermittent use of mechanical systems).

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[4] A. DE MEYER, V. FELDHEIM, 2011. *Le point sur la consommation d’énergie pour le chauffage*, Étude réalisée dans le cadre de l'action " Construire avec l'énergie " pour le compte de la Région wallonne, SPW-DGO4, Namur, Belgique

- A very particular case of two joined houses, one being only heated around 20°C when occupied (evenings and weekends), and the other being permanently occupied by a retired person who heats at 22.7°C.

In 2015, M. DELGHUST et al. selected 1,850 high-performance Flemish houses to analyse the gaps between real and theoretical consumptions, calculated by their EPC. They found that "the EPB calculation underestimates the electricity use because it does not take the unregulated end-uses into account (cooking, lighting and domestic electrical appliances). On the other hand, it overestimates the heating energy use by on average 25%."[5] A previous study, published in 2013 by M. DELGHUST et al., incorporated older dwellings in their comparisons between calculated and measured energy consumptions, resulting in wider gaps (superior to 100% of the real energy consumption), concluding that "the variation in user behaviours has a large impact on the real energy use in old and new houses, adding an important uncertainty to the predicted energy use"[6]

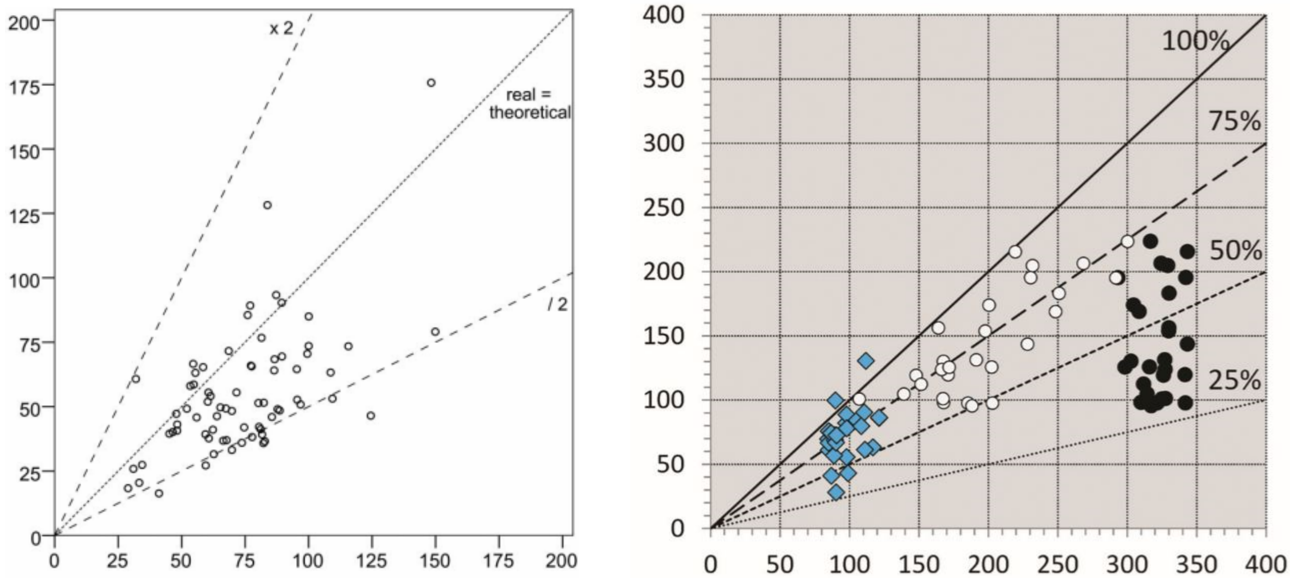

Fig. 4.1.2. LEFT: Annual primary energy use for space heating and DHW (subsample S2), per gross floor area: real and theoretical values (Source: DELGHUST et al., 2015). **RIGHT**: Annual heating energy demand, normalized per unit of floor area: real vs calculated values (Source: DELGHUST et al., 2013). In both graphs, real (measured) data is on the vertical axis [in kWh/m².year], and theoretical (calculated) data on the horizontal axis [in kWh/m².year].

The first two studies (A. DE MEYER and V. FELDHEIM, 2011 and M. DELGHUST et al., 2015) focus on new and efficient buildings, rather than old and inefficient ones subject to much more hypotheses that are included in this research. In the old housing, the many hypotheses taken to describe it are as much uncertainties on the result. There is, therefore, interest in the better defined gaps of efficient cases, as they mark the influence of remaining default values (such as the return temperature of the water to the heater) and standardisation (of behaviours, notably) on final results. Standardisation apparently suits the use of highly energy efficient buildings better than energy-inefficient housing, the standardized parameters of the method becoming accurately closer to reality.

[5] M. DELGHUST, W. ROELENS, T. TANGHE, Y. DE WEERDT, A. JANSSENS, 2015. *Regulatory energy calculations versus real energy use in **high-performance houses***, Building Research & Information, 43:6, 675-690

[6] M. DELGHUST, J. LAVERGE, A. JANSSENS, E. CNOCKAERT, T. DAVIDSON, 2013. *The influence of energy performance levels on the heating demand in dwellings: case-study analyses on neighbourhoods*. Proceedings – thermal performance of the exterior envelopes of whole buildings (Vol. 12). Florida, USA: ASHRAE (American Society of Heating, Refrigerating and Air-Conditioning Engineers).

The calculation method used in assessing the newly built stock is not very different from the one used in assessing the old stock, but it does contain less default values in the description of the energy characteristics. These studies on new buildings, therefore, lack of an insight on other uncertainties that affect the results in Walloon EPCs. This study will rather focus on old dwellings, the comparison of their energy consumptions and the evaluations made by the EPC calculation method, and the ways to close this gap through the use of a questionnaire that describes their energy consumption behaviours, attitudes and determiners described in chapter 3.

This chapter will focus on targeting the uncertainties of the EPC procedure (related to the description of the building and the definition of net heat demands and electricity consumptions) and the ways to lift them (through a questionnaire and the modification of the calculation method). The next chapter will describe the 16 case studies used to assess the methodology, the official and modified results. A sensitivity study will follow, in order to assess the importance and significance of the modifications and behavioural parameters into the modified method.

4.2 Uncertainties of the EPC

The uncertainties that appear in the Walloon EPC procedure might be distinguished between two categories: the ones related to the procedure in itself, the protocol that might bring simplifications and shortcuts by design; and the uncertainties related to the standardisation of the calculation method in itself. The first includes the behavioural influence of the assessor and the strict framework of acceptable proofs, while the second category relates to default values that remove the behavioural influence of the building's occupants in the calculation outputs.

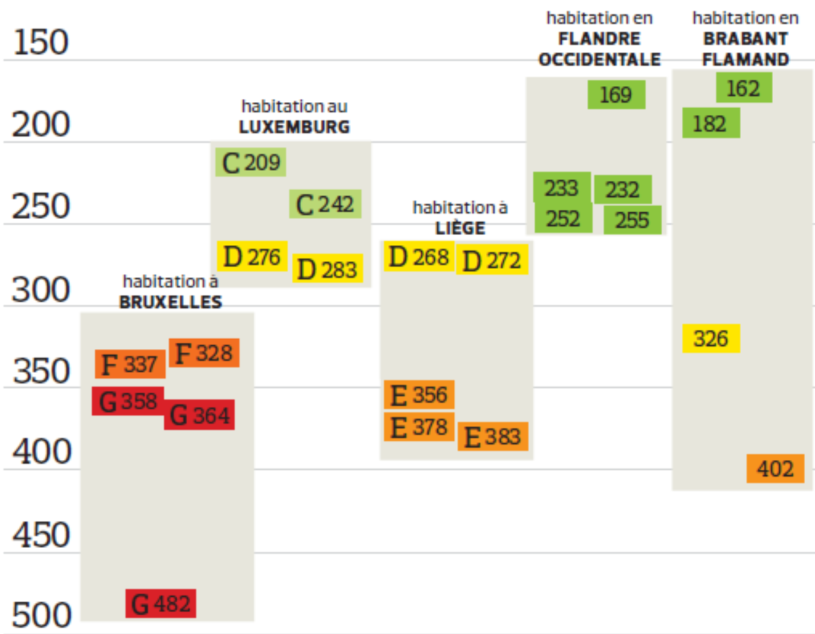

Fig. 4.2.1. Repartition of EPC results [kWh/m².year] for the five houses (Source: VANPARYS, 2012).

Although this is not directly linked to the results of this study, reservations should be mentioned towards the certification process in itself and the assessor's skills and professionalism. It is said by the administration that the process has been developed so that different assessors should obtain the same results for the same dwelling (another kind of "behavioural standardization"). In March 2012, however, a consumer-focused magazine[7] selected five houses (two in Wallonia, in the provinces of Liege and Luxemburg, one in Brussels and two in Flanders, in the West Flanders and Flemish Brabant provinces). Five assessors were asked to establish the EPC for each house. The Figure 4.2.1 displays the results; for a single dwelling, the greatest range of estimated consumption spanned between 162 and 402kWh/m².year, witnessing important divergences in the process.

L. LAINE, in her 2011 publication, put the same observation forward, as exemplified by the statement of one of her interviewees: "*We have had three different energy performance assessors to look at the same property within a very short space of time... and they came up with wildly different ratings... it shouldn't be subjective.*"[8]

There is few scientific validation (yet) to these results in Wallonia, but they highlight an important fact: the methodology always lends itself to the interpretation of the assessor, and the human error. It is quite consensual to state that the information gathered very much depends on the expert. The human nature of the assessor will taint the process by uncertainties on input precision, accuracy or plain correctness, however tight the protocol. Differences in data investigation and interpretation are bound to arise. But more than that, the deliverance of an EPC is a professional procedure, where someone pays someone else to get the job done, which implies a notion of profitability, on both sides. Owners play the concurrence to get lower prices, and their notion of "*maximal* acceptable price" depends on the interest they place in the EPC and its result. Owners want all they can get from the investment, but their investments are limited by what they hope to get. Assessors have to accept the concurrence influence, and their notion of "*minimal* acceptable prices" depends on the distance to the building and its complexity, and on the level of professionalism they are wishing to place into delivering the EPC. The globally low price-level in the market generally limits the possibilities to include an in-depth discussion with the owner on the method, the protocol or the EPC conclusions and recommendations.

Some inaccuracies can be honest mistakes, which is why the regular mandatory training for EPC assessors is acknowledged as one of the most effective methods to ensure EPC quality.[9] But in the early years of the EPC, some situations arose that were not foreseen by the rationalistic framework in which the EPC is implemented: unscrupulous assessors who propose EPCs under 100€, for dwellings they have never visited, leaning on the simplifications offered by the multiple default values of the method and the owners' complete lack of care in the results. The development of Quality Assessment measures by the Administration has, of course, limited those possibilities, but those situations greatly hurt the image of the EPC in its early years and are now costly to repair.

While studying high performance dwellings' consumptions data and assessments, M. DELGHUST et al., hinted in 2015 that "assessors who used measured air tightness levels were also much more likely to apply measured values instead of default values in other parts of the calculation, for example for the lengths of the hot water tubes and the window shading angles. […] Indeed, better reported performance levels are not only the consequence of better buildings but also of more thorough EPB

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[7] N. VANPARYS, E. NICLAES, O. LESAGE, *Certificat énergie, la base d'un véritable audit ?*, magazine Test-Achats n°562, March 2012, pp. 10-16.
[8] L. LAINE, 2011. *As easy as EPC? Consumer views on the content and format of the energy performance certificate*, in Consumer Focus, London, UK.
[9] EPBD Concerted Action, 2015. *Ibid*.

assessors"[10] This is still to be proven for EPC assessors, but this uncertainty has been somewhat lifted in this research, as all EPCs were either made by the author or by trust-worthy research colleagues who stuck to the protocol. Nevertheless, visits and interviews operated at the case studies' houses and the production of the EPCs, have brought about a reflexion on the protocol and list of accepted sources of accurate data in the dwelling description ("acceptable proofs") that have been developed to impose a rigid EPC assessment method, leaving few liberties to the assessors in the process.

The short list of acceptable proofs includes the following:

- Previous energy assessments can be used if they have been made through official procedures, such as an EPB declaration[11], a CALE (Construire Avec L'Energie, see above) attestation, or a previous certificate. The first two documents, however, mainly concern new buildings (or the newly built or renovated part of existing buildings for the EPB declaration).
- "Official" (as in "certified by the administration") documents are evidently allowed, which includes incentives application files for attributed grants or tax reductions for implemented energy-saving works, or the official labels acknowledged by the authority (in Wallonia, they are, for example, the EPBD database, the technical "ATG" agreements[12] and CE labels). These labels obviously can only be used to replace particular default values. Other official documents are listed, such as urban planning permits or notarized acts, but only to testify on the date of construction or renovation. Quite surprisingly, a delivered permit does not authorize the assessor to use the regulatory requirements in thermal insulation that were applicable at the time as default values, for those buildings built or renovated after the implementation of the first thermal regulations.[13]
- Other documents might be used that are certified, not by the administration but by trusted sources. This is, for example, the case of complete project building files provided directly by the architect, author of the construction or renovation project on the house (with conditions), reports from infiltration test operators… Those experts then become responsible for finding and delivering the documents that prove their statements.
- "Eye witnessing" is a possibility that is left to the assessor, implying that the assessor will have to use default values for some parameters that cannot be observed visually, such as the thermal conductivity of the insulation material (provided he can testify of the type and layer thickness). Photos could be used in that sense, but they have to be localizable and layer thicknesses can be difficult to prove. Provided he is authorized by the owner (and willing to), the assessor could also proceed to "dismantling or destructive tests".

In many case studies of this research, few acceptable proofs were available. This does not mean that default values were used everywhere, as there are several ways of defining the energy characteristics of the dwellings. In the description of the envelope, for example, the U-value of a wall, when known

[10] M. DELGHUST, et al., 2015. *Ibid*

[11] The official description of the energy characteristics that has to be made of new buildings, or new or renovated part of existing buildings, when a permit is asked for their construction / renovation.

[12] ATG (for Agréments Techniques – Technische Goedkeuring) are technical agreements delivered by the official Belgian Union for Technical Agreements in construction (UBATc - http://www.ubatc.be, last visited on April 27th, 2018).

[13] When mentioned, this observation raised some eyebrows from the occupants of the first case study that will be presented in the next chapter, owners of a house that could not present any "acceptable proof" but hoped that the 2007-permit could be used ("…so, you are telling me that the administration does not acknowledge their own delivering of a permit as an acceptable proof?").

with precision, is the most accurate description that could be given, but it mainly concerns new buildings or, at least, new walls. In the 16 case studies of this research, this possibility will be used twice, for buildings that have been retrofitted recently to really high energy standards in the frame of the BATEX[14] Programme, and dispose therefore of complete files of acceptable proofs. In the absence of such proofs, however, the assessor has to rely on less accurate description methods.

A wall will be mainly constituted of 3 types of possible layers: a structure, an air layer, and an insulation layer. The structure is described by the choice of a material (and its thickness) in a drop-down menu that hides default thermal conductivity values. The insulation layer can be either absent (when the assessor is sure about it), present or unknown. If present (with proof), it can be described by its thermal resistance (with proof), or its type (via a drop-down menu that hides default thermal conductivity values) and layer thickness (with proof, even if only visual). If unknown, a thermal resistance could still be attributed to a hypothetical insulation layer, depending on the building's age (or the renovation period).

The description of the systems is even more so dominated by default values, most of which have however different possible values depending on the description. For example, the efficiencies that characterize the distribution, emission and storage parts of heating and DHW supply, cannot be directly defined and encoded by the assessor, but their values depend on the presence and insulation of distribution pipes outside the protected volume, of storage tanks, and on the type of heat emitters (radiators, convectors, surface heating). The production efficiency value could be encoded, provided the owner disposes of the right acceptable proof, or defined by default. Both values will be eroded by multiplicative factors inferior to 1, depending on details of the installation such as the presence of a label, the type of regulation and the presence in or out of the protected volume.

One can see that there are different levels of accuracy in the description, and with each step downwards, the number of default values increases. It is, furthermore, an admitted principle in EPB procedures in Wallonia, that the use of default values should be disadvantageous for the results, so as to encourage the search (for the assessor) or collection (for the owner) of accurate acceptable data. M. DELGHUST et al., rightfully reminded in 2015 that "choosing more realistic default values can help bridging the prediction gap. However, this would oppose itself to the role of conservative default values, namely to admonish building teams to perform better and to verify their results, by rewarding these efforts through better energy labels based on measured values." Additionally, "more positive default values could even result in some kind of impunity for those buildings that really do perform badly."[15]

Nevertheless, this policy seemingly blames the vast majority for "not knowing" or "not caring". In order to tame this pessimistic view, it must be reminded that there are also very good reasons to the use of default values. They, first, allow a simplification of the protocol, so that the certification procedure can remain affordable for the owner, and worthwhile (never really lucrative) for the assessor. Furthermore, the collection of acceptable proofs is not the assessor's job, but the applicant's,

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[14] BATEX ("BATiments EXemplaires") is an incentive action initiated in Wallonia in order to promote remarkable examples of sustainable construction and renovation projects, in the wake of the "Construire Avec L'Energie… naturellement" action mentioned in A. DE MEYER and V. FELDHEIM study. BATEX projects were followed by assessors during the duration of the works, and received an incentive of 100€/m², built or renovated (first half allocated before works, second half after).

[15] M. DELGHUST, et al., 2015. *Ibid*

which implies that all assessors should start their EPC with the same information, use the same default values when there are no information, and therefore reach similar results. Although they were normally sent a "prepare the visit of the assessor" document prior to the actual visit, owners most often do not have most of these documents. They, in general, have little objective knowledge of the required characteristics, but most of them can give subjective information on the energy efficiency of their dwellings, or precise the "known" presence of insulation layers which will unfortunately have to be ignored due to the absence of acceptable proofs (untraceable or personal renovation) or ways to visually validate the information. Some will offer some documents that will have to be turned down, even if the information they contain might be valuable, such as "as-built plans", which cannot be used but for the date of the document. EAP reports (see chapter 2) cannot be used neither, because the EAP procedure allows assessors to consider "unacceptable" data in their description of the building, leaving the responsibility for the provided information to the owner. It is down to the assessor to explain with conviction why those information cannot be used, a perilous exercise in which the necessary trust in the results and recommendations is at stakes.

This will be considered in this study. For each case studies, the EPC has been realised first with respect to the protocol and the list of acceptable proofs. Variants have then been defined for each case, to reach more accurate definitions of the envelope and energy systems, in order to lift (part of) some uncertainties that are not related to occupants' behaviour. Some information given by "unacceptable" proofs were therefore considered in the assessments, such as EAP reports, as-built plans or insulation layers that were placed by the owners. It might be worthwhile to note that the owners interviewed for the case studies were made aware of the study design and intentions, and were willing to be as accurate as possible in the description of their dwellings, given that there was no regulatory or financial or other stake to this assessment, as far as they were concerned.

Furthermore, it must be acknowledged that the fact that the thermal characteristics of an insulation layer are known does not necessarily imply that the performance of the wall is accurately described. Many studies, among which the QUALICHECK programme[16], are currently assessing whether the savings obtained through energy efficient implemented works are compliant with estimations made beforehand by exploring the angle of the quality of works in highly efficient buildings. M. DOWSON et al. exemplify this observation by a sample of 72 dwellings which thermal imaging "showed that 20% of cavity wall areas and 13% of the loft areas lacked insulation", and that "U-values are often found to be higher than expected when measured in-situ, due to errors in the quality of construction, as well as thermal bridges and gaps in insulation."[17] The EPC calculation method, on the other hand, does not consider the state or visible quality of the envelope as a relevant parameter.

Wallonia uses a standardized consumption calculation method (asset rating), described in a Walloon Government Decision[18] and adapted in its Annex D[19] for the assessment of existing residential

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[16] http://qualicheck-platform.eu/, last visited on April 27th, 2018. This programme, completed in February 2018, gathered several countries and, in interaction with the EPBD Concerted Action, sought to identify compliance issues, highlight best practices, raise awareness and engage stakeholders into more reliable EPCs (mainly for new buildings).

[17] M. DOWSON, A. POOLE, D. HARRISON, G. SUSMAN, 2012. *Domestic UK retrofit challenge: barriers, incentives and current performance leading into the Green Deal*, in Elsevier Energy Policy 50, pp. 294-305

[18] SPW, SERVICE PUBLIC DE WALLONIE, 2014. *Arrêté du Gouvernement Wallon du 30 Juillet 2014 Portant Exécution du Décret du 28 Novembre 2013 Relatif à la Performance Énergétique des Bâtiments*; Belgian Monitor: Namur, Belgium; pp. 56172–56294.

[19] SPW, SERVICE PUBLIC DE WALLONIE, 2014. *Annexe D: Méthode de Détermination de la Consommation Spécifique des Bâtiments Résidentiels dans le Cadre de la Certification PEB*; Belgian Monitor: Namur, Belgium ; pp. 61636–61767.

buildings. The standardization aims to take the human factor out of the equations, by using objective parameters and statistical values as a replacement. For example, the protected volume (V_P) is a crucial parameter in the Walloon EPB calculation method, as it is the sole parameter used in the evaluation of Domestic Hot Water demand, heat losses by ventilation, internal gains, effective thermal capacity, or auxiliaries' consumptions. The clear advantage is to objectify the assessments, but on the down side, it denies all known influences on energy consumption from the building state and condition, its age and typologies characteristics, its dwellers and their characteristics.

The protected volume (V_P) is not the only marker of standardisation in the calculation method. The use of a stationary method is another one that implies the need to average the parameters and flatten spatial and time variations. This is valid for climatic data, solar and internal gains, or ventilation heat losses, for example. Standardisation usually means that the targeted parameters cannot be replaced by other values, even if they are known with precision. This is the case of several default values used in the Walloon calculation method, such as the definition of the set temperature (constant all year long at 18°C) or the heated volume (equal to 100% of the V_P, all year long). Other default values that are used can be replaced by accurate values when they are known; in their absence, another kind of standardisation occurs, when all buildings are given identical values for in/exfiltration rates or systems efficiencies.

4.3 De-standardisation

This research focuses on the reassessment of the final energy consumptions[20] of 16 case studies, and compare these results with real consumption data obtained from energy bills. Chapter 2 defined the main typologies and building characteristics that were sought in this research, targeting mainly the great share in the residential stock that represent the single-family urban brick houses. Given that this step in the research seeks to test the modified method, it seemed appropriate to target a variety of situations, typologies and energy performances, in order to better assess the accuracy of the hypotheses, and analyse the reaction of the calculation method to similar modifications applied to different (physical, technical, climatic) situations.

This research globally seeks a better appropriation of the EPC results by the owners, by considering the inclusion of behavioural parametrization into the calculation method in order to get additional, de-standardized and hopefully more accurate results. Chapter 3 defined typologies of residents to interview, practices to consider and attitudes to look for, acknowledging the occupants' influence on energy consumption. A variety of households in size, income level or occupation pattern were searched for among owners, considering their better knowledge of their home and energy consumptions as well as their higher interest in improving both of them. It must be acknowledged that this sample of 16 case studies can hardly be considered representative of the Walloon residential urban building stock. The next step would obviously be to broaden the research and lead a large-scale survey on heating habits among the population, and this research precisely aims to seek the necessary questions to ask for, once the link with the calculation method has been made.

[20] The conversion factors in primary energy, although necessary to standardize the comparison of buildings using different energy vectors, add to the mystery of results for most end-users, who have no idea what this might relate to.

In all 16 case studies, the real consumption data were collected by the interviewer (=author), based on energy bills for different periods of time, in order to serve as comparison points with theoretical revaluations. The energy meters, read once a year by the occupant, constitute his only reality of consumption; although they might be flawed, monitoring-based data are considered in this research the most (only?) reliant source of information on the household's energy consumption. This is the main reason for the absence of households that use oil fuel to prepare domestic hot water, or heat their homes, in this sample: they have been excluded for lack of accurately precise data on their real consumption, due to the impossibility to monitor the remaining levels of oil at each filling of the tank. A description of those 16 case studies can be found in the descriptive cards in the Annex 2 of the present dissertation[21], including their answers to the questionnaire described in the next section (4.3.1) and filled during the interviews. The case studies will start to appear in this chapter, as intermediary revaluation steps are needed for the global consumption revaluations in the chapter 5 presenting each case study, its protected volume variants, and energy characteristics.

This framework implies the need to consider all end-uses that influence natural gas and electricity annual consumptions. The revaluation of energy consumptions related to heating, for example, will mainly focus on the revaluation of net heat demands, through redefinitions of set temperatures and heated volumes, and revaluation of internal loads and heat losses. The evaluation of DHW demand is standardised in the calculation method but as it should be considered influenced by dwellers' behaviour and comfort standards, it will be revaluated in the realistic approach. By being mainly dominated by systems efficiencies that do not pertain to sociology of energy, the transformation of needs into consumptions will only be mentioned, although it is clear that default values there might also bring uncertainties on the results.

The use of a quasi-stationary single-zone calculation method imposes to keep a monthly approach on the evaluation of heating demands and consumptions, implying the use of average monthly climatic data. One monthly value has then to define each parameter of the calculation, such as the set temperature, heat losses by transmission and air renewal, internal and solar gains… It is the uncertainty on these monthly values that is questioned in this research. While leaning on this existing calculation method (one of the constraints of the research remains to prove the potentialities of the EPC scheme without the need for too deep a change in the calculation method), there is a clear need to inquire about the heating patterns and energy consuming habits of the households that were interviewed, in order to allow a revaluation of the net heat demand. It appears possible, therefore, to discretize inputs and, by doing so, replace a big uncertainty on monthly averages inputs by a string of smaller uncertainties on periods of time that are better described in occupancy and heating. This method has the merit to enter a detailed behavioural factor in the method and results, but remains subjected to averages and default values, on which the uncertainty should be lowered, either by a better description of the building, of the household, or their energy consuming habits.

In the current calculation method, the "t_m" parameter refers to the length of the months, in Ms (10^6 seconds). The discretizing process consists in splitting monthly t_m factors into sub-periods of time, and recalculating the global temperature of the building for each of those periods, depending on heating patterns (see Fig. 4.3.1 hereunder). The first case studies were approached without any

[21] The reader is invited to keep those descriptive cards at hand to better analyse and understand the results that will be presented in this chapter and the next, without having to resort to a tedious back-and-forth with these pages.

preconception of those patterns. Contrary to the regulatory calculation method hypotheses that consider the whole protected volume as heated, all year round, at the same set temperature of 18 °C (20 °C during daytime, 16 °C during night time), different heating schemes for four main spaces (living room, kitchen, bathroom and bedrooms) were enlightened by the interviews. It became apparent, for example, that the daytime and night-time zones of the dwellings are often managed differently in terms of set temperatures and heating schedules, depending on occupation patterns (and, therefore, the professional and/or scholarly situation of the occupants). The kitchen's heating scheme generally follows the living room pattern, except when both spaces are separated by doors, walls or hallways. Bathrooms are often heated only when needed, and at a higher temperature (often, even, boosted with an electrical device in addition to the central heating system); children's bedrooms are more often heated than parental bedrooms. As a consequence, equations considered 6 spaces: living room, kitchen, unheated bedrooms, heated bedrooms, bathroom and "others". The latter includes an additional heated room in some cases, used by one householder to work during the day, or opened on main heated rooms.

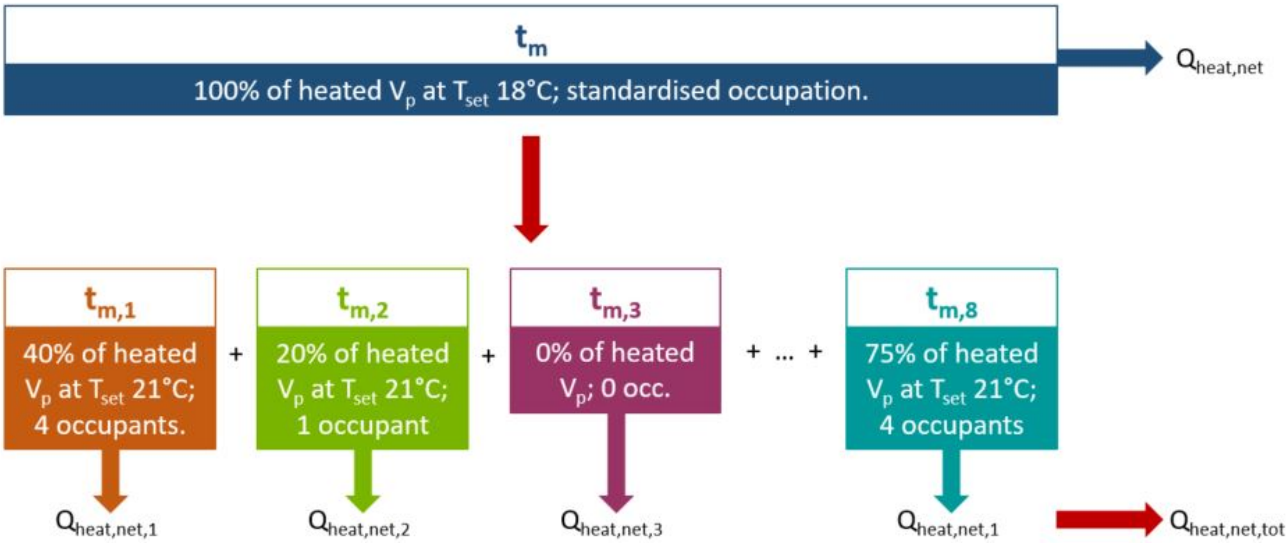

Fig. 4.3.1. Discretising pattern proposed in the modified method

Progressively, a similar division of the 24 hours of ordinary weekdays could soon be defined:

- Night-time periods, defined by the setback in temperature regulation that is usually included in the thermostat settings used in most households, are often around 8 hours long (23h – 7h for example).
- "Bathroom" times are either in the mornings or in the evenings, or both, depending on hygiene preferences and on the number of inhabitants of the dwelling. In all cases, a morning period to "wake up and get ready", and/or an evening period to "get ready for bed and turn off", are discernible. The total length of bathroom time is approached here by considering 30 minutes per occupant, split between mornings and evenings, and by subtracting those periods with added bathroom heating from the total morning and evening periods.
- Mornings periods, including variable bathroom periods, are considered lasting 5 hours (7h – 12h, for example); the evenings are considered lasting 4 hours (19h – 23h, for example).
- The rest of the day (12h – 19h) is divided between noon periods of 1 hour (Wednesdays are mentioned in households with children, for example), and afternoons of 6 hours, which can yet be divided between school periods (13h – 16h) and after-school periods (16h – 19h).

In the end, there are 8 periods of time discernible in most cases that brought the discretisation pattern shown in Fig. 4.3.1, in which the monthly calculations of the Net Heat Demands (=$Q_{heat,net}$) are revised in periodic NHDs ($Q_{heat,net,i}$) corresponding to better defined periods. The use of a quasi-stationary single-zone calculation method implies that there were no relations between the 96 revaluated and summed up NHDs (12 months times 8 periods). Night periods are an enlightening example of this observation: the definition of a temperature setback means that, in winter, there is a demand for minimal heating during the nights. In the discretised method, the night starts at 11PM with the house to be heated to reach the nocturnal set temperature. In reality, the house was likely to be heated at 21°C, for example, until 11PM, and the night would start by a period of no-heating, which length depends on the daily and nocturnal set temperatures, or the thermal quality and inertia of the envelope… The heating system only starts when the internal temperature would have progressively lowered and gone under the night setback settings. This observation is probably also accurate for the succession of daytime periods, or the passage from one month to the other, but with smaller influences on the end result. Another example that can be given is that during unheated periods, the internal and solar gains were considered lost for good in this modified method; in reality, they usually help limit the decrease in temperature that the heating system will have to compensate when it is turned on again. It appeared therefore that it was necessary to keep the quasi-stationary single-zone calculation method for as much calculations as possible, and to use the discretisation only to reassess the global internal temperature that translates the influence of the directly heated proportion of V_P and the demanded comfort temperatures in those parts. A step back was therefore formalised in a third modified calculation method, described in the next section and used in chapters 5 and 6.

Most case studies revealed quite clearly that the heated volume is limited, especially in poorly insulated houses, to a selection of most lived-in rooms such as the living room, the kitchen and the bathroom. Bedrooms are part of a more personal approach to heating, depending more on personal preferences than households' heating strategy. Nevertheless, when it came to reassess the net heat demand for this reduced volume, the possibility arose to focus on the sub-volume containing only directly heated rooms and revaluate their own heat losses and internal gains. This idea, however, was rapidly abandoned, as it meant the necessity to:

- Describe internal walls and floors that were not part of the envelope detailed in the EPC;
- Consider ventilation air flows between heated and unheated spaces and balance the energy flows in unheated spaces in order to obtain accurate environment temperatures to define heat losses from occupied spaces;
- Envision a reduction factor for the internal and solar gains available in the heated spaces, etc.

Besides, the need to keep the quasi-stationary single-zone calculation method for as much calculations as possible has been acknowledged above. The definitive calculation method, therefore, also keeps the single-zone model and its important parameters, such as the protected volume (V_P), heated floor area (A_{ch}), total heat loss area (A_T), etc. and uses the discretisation only to reassess the global internal temperature that translates the influence of the proportion of V_P that is directly heated and the comfort temperatures demanded in those parts. As a consequence, Net Heat Demands (NHDs) have to be revaluated for the whole dwelling, heated and unheated spaces alike.

4.3.1 Questionnaire

In order to gain additional data on inhabitants' behaviour and energy consumption habits, a questionnaire has been built (see Annex 1 for full copy), submitted by the author to the respondents during in-depth, open-ended interview in which questions are worked into a conversational flow. "Informants are encouraged to give their own explanations. Interviewers have the opportunity to ask follow up questions. The depth of information attained allows for an analysis and interpretation of complex culture-based household behaviours, something very difficult to achieve in a closed format interview or from survey questionnaire responses."[22] It also permitted witnessing some habits and behaviours that were not yet considered or not verbalized by respondents.

The ultimate goal of further research would be to get quantitative data from a wide survey that would allow the definition of patterns and profiles of users, and to refine the description of buildings based on typologies. Some questions integrated in the questionnaire for statistical purposes, therefore, were not directly used in the following step that is the incorporation of answers in the calculation method. This is the case of sociodemographic variables of the households and typology characteristics of the house.

4.3.1.1 Socio-Demographic Variables

The socio-demographic variables that have been identified by previous recent studies (see chapter 3) as important determiners in the analysis of a household's energy consumption have been considered in this study, as the questionnaire included questions on:

- The household's characteristics: size of the family, presence of toddlers, presence of children aged 15 or less (school age), presence of people aged 65 or more; and overall income category;
- The description of the responder to the interview (head of house) through their gender, age category, highest diploma, and daily occupation.

4.3.1.2 Building

An EPC assessor only gathers information on the building that is needed for the EPC calculation method; the questionnaire enquires about additional data expected to be of importance in this study:

- The age of the building, its typology category, number of exterior facades, position in the block, number of levels in the heated volume;
- The existence (and use) of an extension (quite commonly built at the back of the building, after the original building and often of lower quality);
- The disposition of the kitchen (open on the living room, its heating pattern will be copied; located in a separate room, closable by a door, it will have its own heating pattern) and the stairways to the upper floors (its characteristics of isolation from heated spaces will influence the resulting temperature in unheated spaces in the modified calculation method);
- The use of the upper floor area (liveable area for dwelling or for storage purposes, part of the heated volume or not, etc.);

[22] H. WILHITE, et al., 1996. *A cross-cultural analysis of household energy use behaviour in Japan and Norway*, in Elsevier Energy Policy 24, pp. 795-803, Great Britain

- The energy improvement investments that have been made since the EPC assessment, in order to upgrade it to better match the reality;
- The physical presence of means to regulate the heating installation, such as thermostatic valves, thermostats and exterior probes.

4.3.1.3 Heating Habits

The questionnaire displays questions that are used to describe the household's heating pattern and temperature management profile for those main spaces. A "normal" winter week (work or school week) has to be described as follows:
- Number of "all-day heating" days a week, during which the whole volume or the daytime zones only are fully heated all day (14h/day by hypothesis);
- Number of "partial heating" hours: average number of hours during which the main spaces are heated on "other days" (not "all-day" heating days);
- Spaces heated during winter nights;
- Set temperatures (when known; default values will have to be used otherwise, based on the favourite position of the thermostatic valves) for daytime and night-time (when necessary);
- Heating devices (for the repartition of real consumption data);
- Global temperature management systems (the presence of a regulation system).

Respondents are also questioned on "rational use of energy" habits that are bound to influence general temperature management hypotheses:
- Air tightening of windows and air draughts in winter, which will influence the heat losses by in/exfiltration. This influence is limited however, as the air flows mainly depend on the quality of the envelope. Without any "blower door" pressurization test on the building, the leak-flow parameter for heating demand evaluation ($\dot{v}_{50,heat}$) remains a default value that cannot be changed easily.
- Closing or not closing doors between heated and non-heated spaces is expected to influence the temperature difference between those spaces.
- Habits in putting extra clothes before raising the heat can be translated in adjustments of the set temperatures during colder periods of the year.
- Avoiding active air conditioning: this question revealed useless in this research, as no case study was equipped with air conditioning.
- Shutting off the heat when opening windows is a behaviour that can be witnessed in most cases; some, however, reported that their low-temperature installation prevents them from doing so, so that the use of this line could be questionable.

4.3.1.4 Ventilation Habits

Due to their influence on energy consumption, ventilation habits are also investigated, despite their often unconscious, irregular and inconstant nature in old buildings where no complete system exists. The questionnaire displays a series of possible ventilation schemes for four main spaces (living room, bedrooms, kitchen and bathroom), from "we do not (or rarely) ventilate this room in winter" to "this space is equipped with complete ventilation system with heat recovery", passing by "there is enough draught as it is", "we ventilate punctually" or "daily", "there is a ventilation system but we shut it in winter", etc. To each answer corresponds an empirical air flow rate (see section 4.3.3.4).

4.3.1.5 Internal Gains

Internal loads can be gained from different sources. In this study, the overall internal load will be evaluated through metabolism, lighting of the spaces and electr(on)ic equipment and appliances (including cooking). Metabolism loads are approached through the heating (= occupation) schedule of the dwelling and the size of the household, and the international standard ISO 7730:2005 (see 4.3.3.5). Lighting loads depend on the power of the installation and the area to be lit; thus, the following questions are added to the questionnaire in order to refine the evaluation:

- "Do you use low-energy bulbs?" and "Is the lack of natural light quality in the day zone a problem in your dwelling?" which influence the lighting power hypotheses;
- "Do you switch off the lights in unoccupied spaces?" which influences the lit area.

Respondents are asked to define their level of equipment, in order to evaluate the associated electrical consumption. A thorough listing of equipment appears relatively long and invasive from the respondent's point of view; as a result, five levels of equipment are proposed to their choice:

- Light (basic equipment of fridge with freezer, washing machine, microwave or regular oven, extractor hood, television);
- Moderate ("light" + dishwasher + computer and router, etc.);
- Average ("moderate" + comfortable kitchen equipment + electric dryer, etc.);
- Important ("average" + independent freezer + second TV + second computer, etc.);
- Heavy ("important" + second fridge + high-tech media equipment, etc.).

Additional data allow some refinement in the estimation of internal loads:

- The number of household members (part of the consumption for some equipment is fixed; part of some equipment varies according to the size of the household, including cooking equipment, small appliances and sleep mode consumptions);
- The number of weekly uses of their dishwasher, washing machine and electric dryer (open questions in the questionnaire);
- The daily use of their television(s) and computer(s), with 6 possible answers: "N.A.", "Less than 2 h a day", "2 to 4 h a day", "4 to 6 h a day", "6 to 8 h a day" and "more than 8 h a day";
- The evaluation of sleep mode-associated consumptions, approached thanks to the question "Do you switch off or disconnect appliances, instead of letting them in sleep mode?"

4.3.1.6 DHW Needs

The actual consumption in *hot* water was not accessible easily. Most owners were keen to release their water bills, which could not precise the quantity of water that went through the DHW preparation system. DHW needs are approached in the questionnaire with a single question: "Do you tend to prefer showers to baths, in order to save time and/or water consumption?" The answers to this question calibrate the new DHW need evaluation between 25 and 45l of hot water (50°C) needed daily per occupant. Although this single "Rational Use of Energy" question might seem insufficient to define the global water needs, it must be mentioned that another question, "How many baths/showers are taken per week for the entire household?" was initially included in the questionnaire, and seemed to raise intimacy issue among the first households to be interviewed. This might be explained by the "personal" connection between the interviewer and the respondents (friends, colleagues…). During the conversations, owners mentioned notably their own difficulty to quantify the "baths and showers": "*It depends if [my daughter] is here or not which, believe me, makes* *quite a difference"*; *"How do you quantify a bath? Like, when you just pour 5 or 10cm of water, just to rinse yourself, or when you draw long and bubbly baths?"*; *"We used to shower, but the kid arrived mid-year, and now baths are more common"*. Not only is the volume of water uncertain, but so is the temperature to which it is used. Given those unknown parameters, the reduction of the DHW needs to a single question did not seem too approximate.

4.3.1.7 Consumption Data

The questionnaire enquires about the respondents' real consumption data for energy vectors (including wood, natural gas and electricity) and the corresponding period, so that climatic data can be chosen consequently.

Electricity consumptions are always given in kWh on invoices, so that these data were easily accessible. All houses used natural gas as the main energy vector, and data are also available in kWh on annual invoices. When necessary, data were translated into kWh, considering a calorific power of 11.5 kWh/m^3 for natural gas[23] and 3.5 kWh/kg of dry wood[24] (RH < 25%).

4.3.2 Revaluation of electricity consumptions

In this research, the electricity consumption could be divided into seven different uses:

- Lighting, depending on natural light quality and installed lighting devices.
- Cooking, with electrical hobs (some households used natural gas, which consumption was therefore evaluated in the same way).
- Appliances and equipment for cooking (ovens, microwaves ovens, extractor hoods), cleaning (dishwasher, washing machine, dryer, iron, vacuum cleaner), entertaining (computers and routers, TVs and decoders) and others (including occasional uses and sleep modes).
- Heating with electric heaters, either a room (used in bathroom for a boost when it is used, for example) or a complete zone.
- Auxiliaries for heating and ventilation systems.
- Domestic Hot Water when it is provided by an electric device.
- Air-conditioning, often provided by electric systems. No such systems were present in the case studies however.

4.3.2.1 Lighting

Lighting is not evaluated in residential EPB calculation, as it is believed to be rather insignificant with regards to other energy uses. It is, however, part of electricity bills; it has been decided to include it in the calculated results in order to ease comparisons between measured and calculated consumptions. The default installed power, used in non-residential calculations, is 20W/m^2, which seems far above real installations. A more realistic approach has been inspired by (CSTC, 2011)[25] and

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[23] Official Website of the Walloon Commission for Energy. Available online: http://www.cwape.be/ (accessed on 26 September 2016).

[24] Website of the Belgian Association for the Promotion of Renewable Energies. Available online: http://www.apere.org (accessed on 26 September 2016).

[25] BBRI - Belgian Building Research institute, 2011, *Guide pratique et technique de l'éclairage résidentiel*, Programme de recherche ECLOS, Bruxelles, 62 p.

(SPW, 2013)[26], considering several installations efficiencies and average rooms areas. This allowed to reduce the lighting power between 3 and 8 W/m², depending on the installation's efficiency of and the quality of natural light. Electricity consumption due to lighting results from the installed power and the duration of use. In Liege, the year is shared between 4474 hours and 15 minutes of daylight, and 4285 hours and 45 minutes of night[27]. Considering 3 annual weeks of absence and sleep hours (8 hours a night for the remaining 344 days), this leads to 1377.34 annual hours of artificial lighting, shared between the months of the year according to Figure 4.3.2.

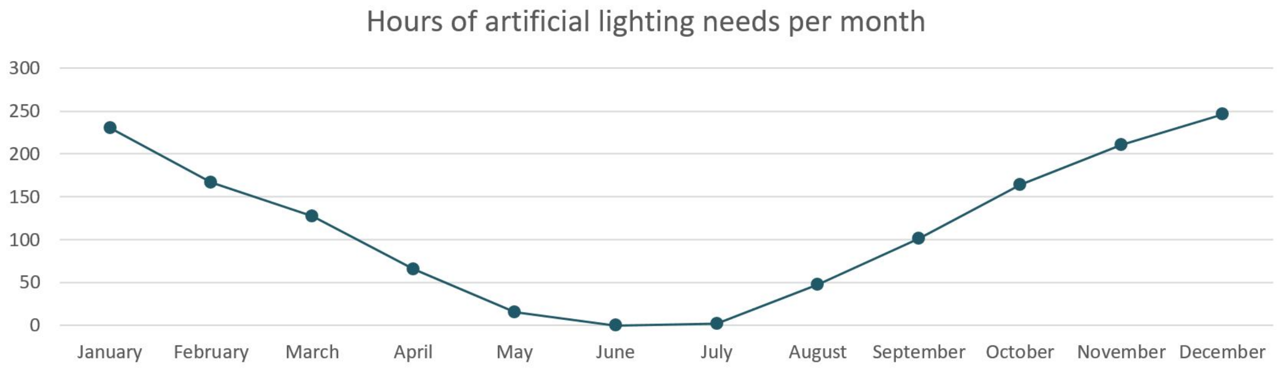

Fig. 4.3.2. Artificial lighting hours per month

Monthly electricity consumption for lighting is therefore evaluated thus:

$$W_{light,m} = t_{m,light} \times P_L \times 0.8 \times A_{ch} \times f_{occ} \times f_L \times f_{qual,light} \quad (1)$$

where:

- $W_{light,m}$ = monthly electricity consumption for lighting [kWh/month].
- $t_{m,light}$ = monthly number of lit hours (see Fig. 4.3.2).
- P_L = installed lighting power, varying between 4 and 6 W/m², depending on the answer to the question "do you have a tendency to use low-energy lightbulbs?" in the questionnaire (5 possible answers between "not at all!" and "yes, of course!").
- 0.8 is a factor reducing the A_{ch}, the heated floor area evaluated in the EPC to define the E_{spec} value (see chapter 2). Being evaluated by considering outside dimensions of the building, the 0.8 factor reduces the A_{ch} to the usable area, without walls.
- f_{occ} is a reducing factor considering only the used and occupied spaces of the protected volume, depending on the declared occupation pattern.
- f_L is a reducing factor related to the question of the survey "do you have a tendency to switch off lights in unoccupied spaces", and varies consequently between 0.5 and 0.7 depending on the given answer (5 possible answers between "not at all!" and "yes, of course!").
- $f_{qual,light}$ is a multiplicative factor related to the question "do you have a tendency to make use of good natural light quality?". Here also, 5 possible answers (between "not at all!" and "yes, of course!") were related to 5 values between 0.8 and 1.2.

The values given to the f_L and $f_{qual,light}$ factors were defined empirically and adjusted during the course of the research through comparisons between global electricity consumption estimations and real data. The graph hereunder shows the lighting electricity consumptions for the 16 case studies,

[26] SPW - SERVICE PUBLIC DE WALLONIE), 2013. *L'éclairage efficace des logements, Guide pratique à destination du particulier*, Programme de Recherche ECLOS, Namur, 36 p.
[27] www.ephemeride.com, last visited in May 2016.

where "level 1" is the lowest consumption possible under the equation (1), and level 5 is the highest. 3 of the 123 possible intermediate levels are displayed; the green columns mark the case studies evaluated consumption, depending on their characteristics and answers to the questionnaire.

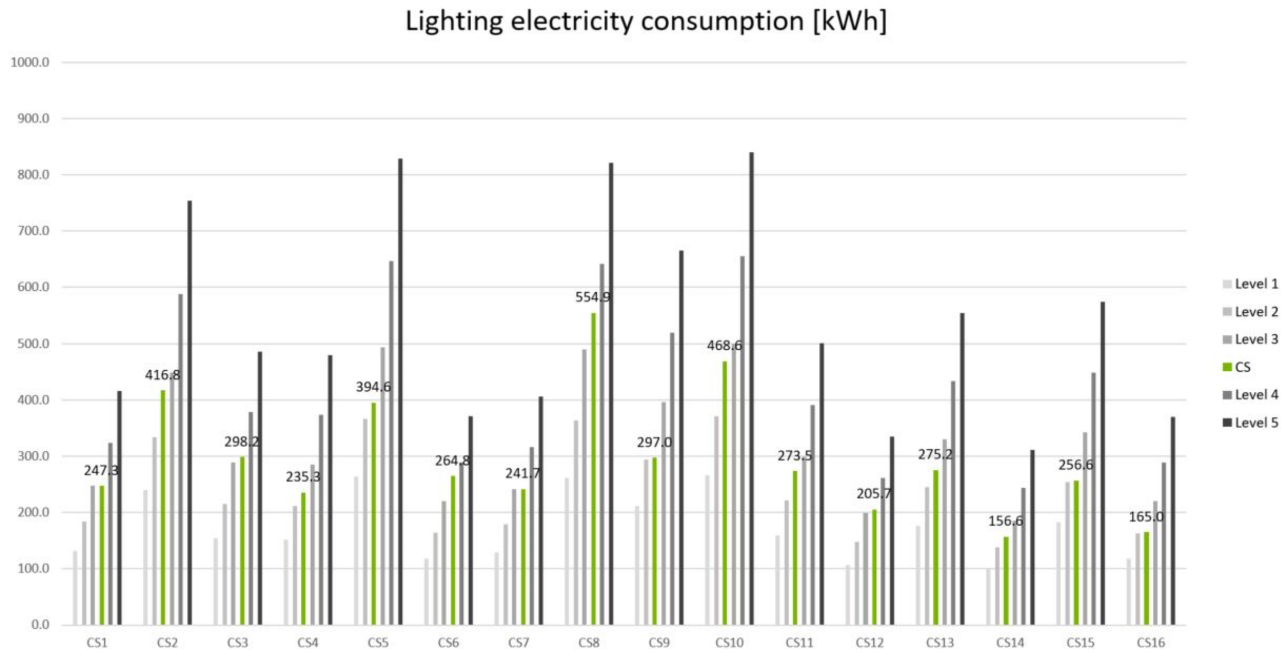

Fig. 4.3.3. Electricity consumptions for lighting in the 16 case studies

4.3.2.2 Appliances and equipment

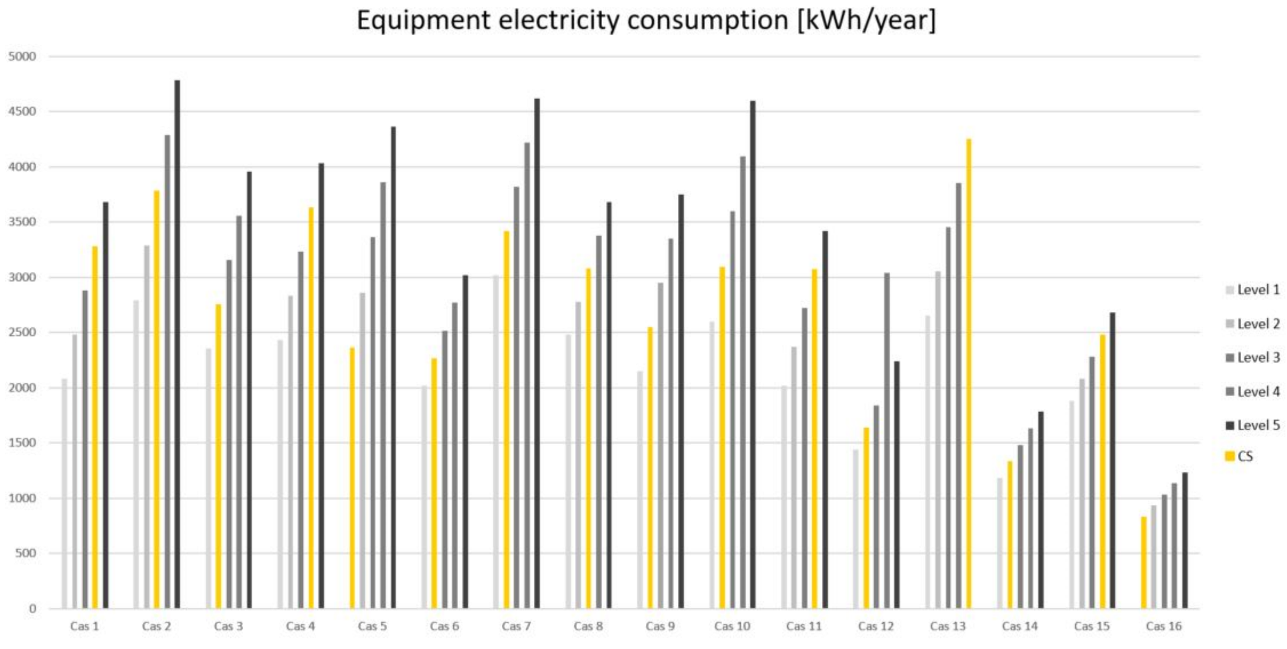

Fig. 4.3.4 Electricity consumption due to equipment levels in each case study. Yellow bars represent the estimated consumption level according to the answers to the questionnaire.

First evaluations of the electricity consumption for electr(on)ical equipment and appliances listed the hypothetical equipment, researched standard consumptions or appliances power and assessed the time or pattern of use. Adding up all these particular consumptions led to an overestimated total consumption in all the first cases where it was tried, and the real consumptions data were used to reduce those hypotheses. The realisation of such an exercise on a large number of comparisons (after a quantitative survey, for example) would allow to better clarify those hypotheses. Although it means that another and probably less detailed approach was needed, this first approach still allowed to make some observations and consider more accurate hypotheses:

- The presence and use of a dishwasher, a washing machine (for clothes) and/or an electric dryer are three important parameters of the overall consumption.
- Their consumptions depend therefore on much needed estimates of use from the owners; on average, dryers are expected to use 2kWh per cycle, dishwashers and washing machine, 0.8kWh per cycle. Other consumptions depend on the number of inhabitants (oven, traditional and microwave, kitchen extractor hood and iron, for a total of 110kWh/year + 135kWh/year.pers), or on the size of the usable area (0.8*A_{ch}, as in lighting), such as the vacuum cleaner (1kWh/m².week).
- The remaining of the equipment, labelled under "others", is dependent on the level of overall equipment (estimation made by both the owner and the interviewer) described in 4.3.1. They add 100 to 500 kWh/pers. to the total, according to the level. All 5 levels were encountered in the 16 case studies: the number 16, for example, was not equipped with a dishwasher, a freezer, a television nor a dryer, whereas the number 13 was equipped with no less than 10 different screens (used every day).

4.3.2.3 Cooking

The energy consumption used by the hobs (whether powered by electricity or natural gas) depends mainly, in this study, on the number of occupants. It is evaluated at around 100kWh/year in fix consumption, and an additional 50kWh/year per occupant. The Fig. 4.3.5 hereunder shows the corresponding consumptions (yellow columns mark the case studies where natural gas is used).

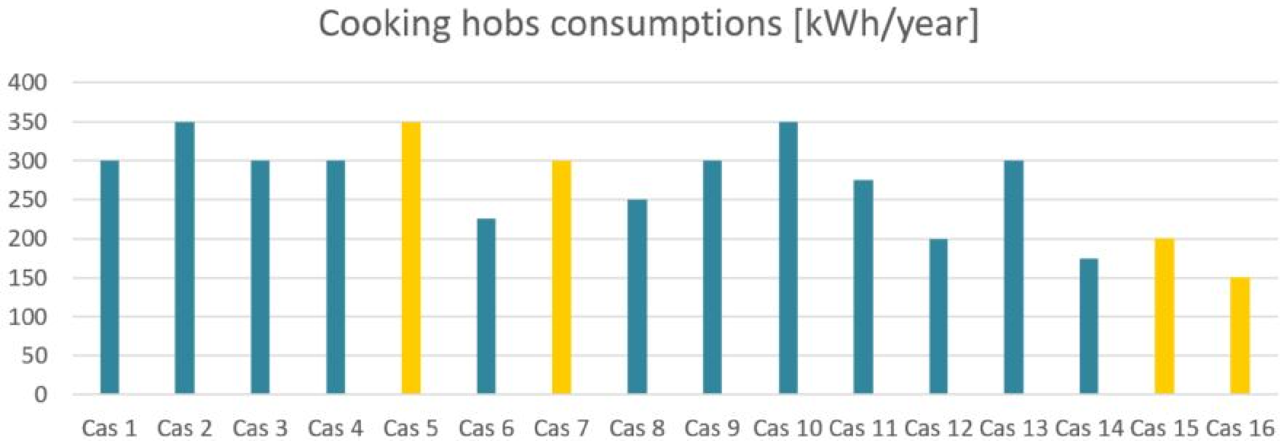

Fig. 4.3.5. Energy consumption for use of cooking hobs in case studies (electricity in blue, natural gas in yellow)

4.3.2.4 Extra heating

When a whole sector is considered heated by electricity, the quite straightforward assessment is realised in the same way than other heating consumption assessments (see 4.3.3). In the cases where electricity is used as an additional heating source (used to power the quicker supply of extra heat in bathroom when used, for example), the evaluation considers 1 electric heater, with an average power in use of 1kW, during the whole period of time when the room is used (30 min/pers in the bathroom, for example, or the announced heating pattern for any other room) during the coldest month of the year (often January). This consumption is reduced during the other months, by a reducing factor equal to the ratio of the Net Heat Demand (NHD) for the assessed month to the NHD of the reference coldest month. The Fig. 4.3.6 hereunder shows the resulting electricity consumptions for the case studies using it as extra heating for a single room (other case studies results including whole-zone heating will be shown in the next chapter), for the EPB climate. In the CS10, the heater is used for an "office" room. In the CS14, this consumption corresponds to the boost in heat that is demanded during bathroom time, not the overall consumption (this case study only consumes electricity).

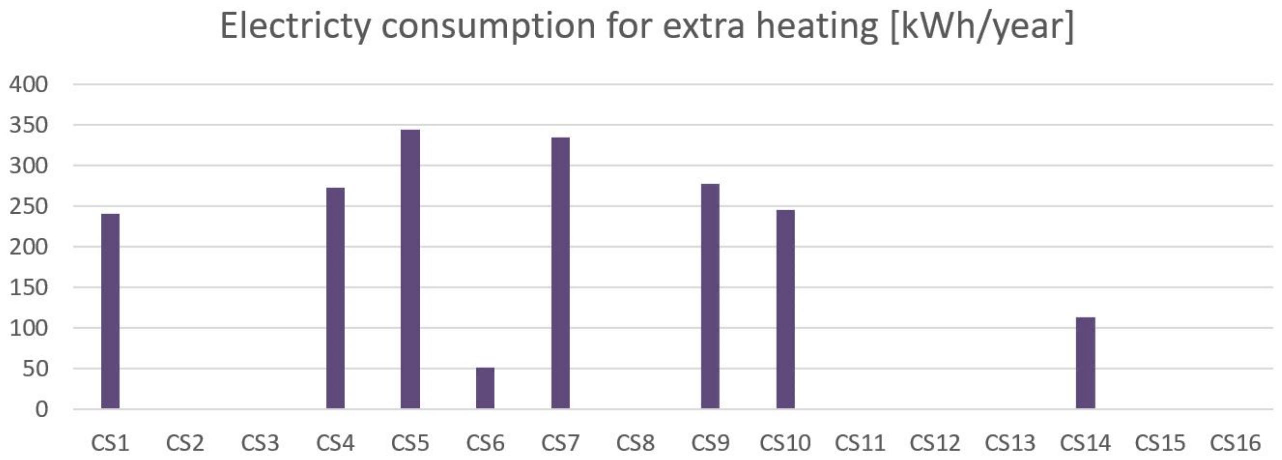

Fig. 4.3.6. Electricity consumption for extra heating in the case studies, for the EPB climate and base calculations before sensitivity testing

4.3.2.5 Auxiliaries

In the regulatory EPB calculation method, the energy used by the auxiliaries for heating systems is evaluated with the protected volume as sole parameter[28]:

$$W_{aux,heat,m} = \sum_j \left(\frac{\sum_i Q_{heat,gross,sec\ i,m}}{\sum_i Q_{heat,gross,sec\ i,a}} \right) \times W_{aux,heat,j} \quad (2)$$

$$Q_{heat,gross,sec\ i,a} = \sum_{m=1}^{12} Q_{heat,gross,sec\ i,m} \quad (3)$$

where:

- $W_{aux,heat,m}$ is the monthly electricity consumption of the auxiliaries functions [kWh];
- $Q_{heat,gross,sec\ i,m}$ is the monthly Net Heat Demand for the energy sector "i" [MJ];
- $Q_{heat,gross,sec\ i,a}$ is the annual NHD for the energy sector "i" [MJ];
- $W_{aux,heat,j}$ is the electricity consumption of the auxiliary function "j", defined thus:

$$W_{aux,heat,j} = \alpha_j \times \sum_i V_{sec\ i} \quad (4)$$

where:

- α_j is a multiplicative factor that depends on the auxiliary function "j", varying between 0.1 and 0.7;
- $V_{sec\ i}$ is the protected volume of the energy sector "i" [m^3].

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[28] SPW, SERVICE PUBLIC DE WALLONIE, 2014. *Annexe D: Méthode de Détermination de la Consommation Spécifique des Bâtiments Résidentiels dans le Cadre de la Certification PEB*; Belgian Monitor: Namur, Belgium ; pp. 61636–61767.

Ventilation fans' electricity consumption is evaluated in the same way described above, with α_j parameters varying between 0.085 and 0.235. In this research, auxiliaries' electricity consumptions will be evaluated in the same way, but considering the volume heated directly, not the entire protected volume.

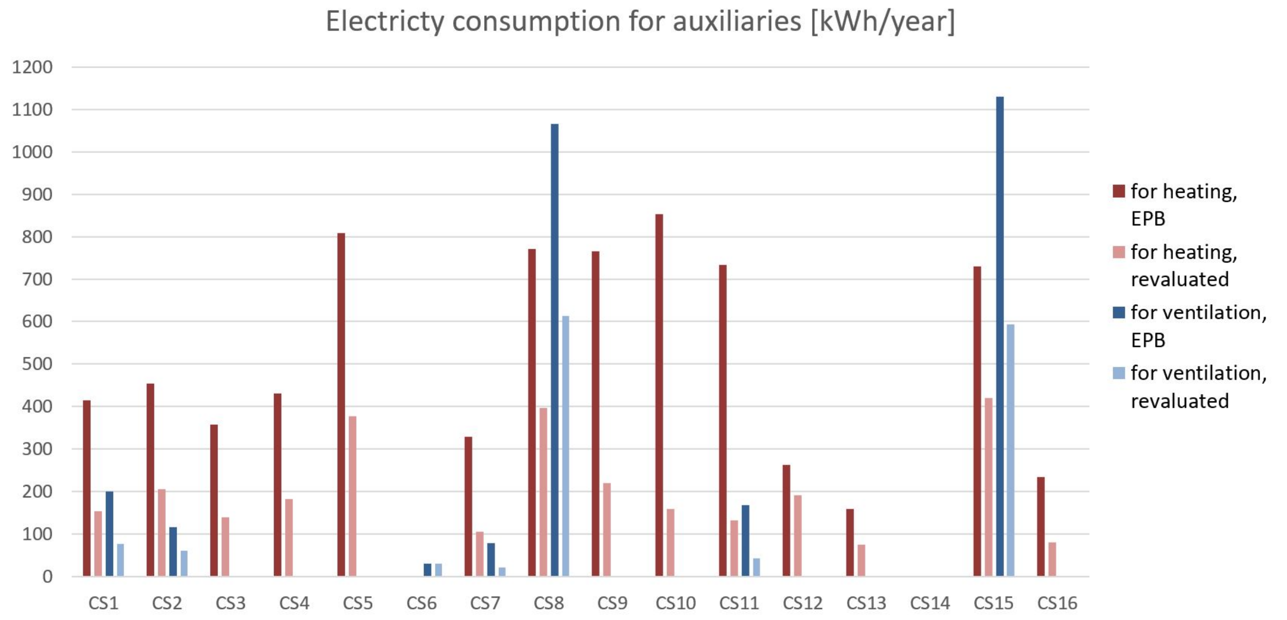

Fig. 4.3.7. Auxiliaries' electricity consumption for heating supply (red) and mechanised ventilation (blue), as calculated by the EPB regulatory calculation method (darker) and the modified method (lighter) for the 16 case studies

Results from the EPB regulatory calculation method were added in the Fig. 4.3.7 above because they are the only comparison possible between both methods. The previous steps in the revaluation of electricity consumptions (lighting, cooking, appliances and equipment) are simply negated by the regulatory method, either because they are considered negligible or influenced by occupants.

All case studies benefit from a reduction of the estimated consumption by considering the reduced volume that is heated or the shorter length of time these auxiliaries are needed, compared to the EPB hypotheses of constant and whole-dwelling heating. The case studies 8 and 15 (see next chapter) are old houses recently renovated to very high energy standards in the "exemplary buildings" frame. They are the only cases equipped with complete mechanical ventilation systems with heat recovery, and high-tech heating systems that explain the much higher auxiliary consumptions. Similarly to the case studies 5, 9, 10 and 11, the higher electricity consumptions for heating auxiliaries are a consequence of much bigger protected volumes. In some cases, the important reduction is an image of the small share of actually heated volume, compared to the whole protected volume.

The last post of electricity consumption (in some case studies) concerns the production of Domestic Hot Water, but this particular part of energy consumption will be addressed later in the revaluation of net DHW demand (see 4.3.4). The comparisons being made in final energy, there is little difference between energy vectors, although electricity systems usually benefit from better efficiencies (and consequent lower consumptions).

The next graph exposes, for each case study, the summary of the electricity consumptions so far. They will be compared to real consumptions in next chapter, when those consumptions will be added to heating and DHW related consumptions. The lowest consumptions are those of smaller households (1 or 2 occupants) in smaller houses (CS6, 16). The CS14 is an exception: completely heated and provided in DHW by electric means, this consumption is bound to increase consequently in the next steps.

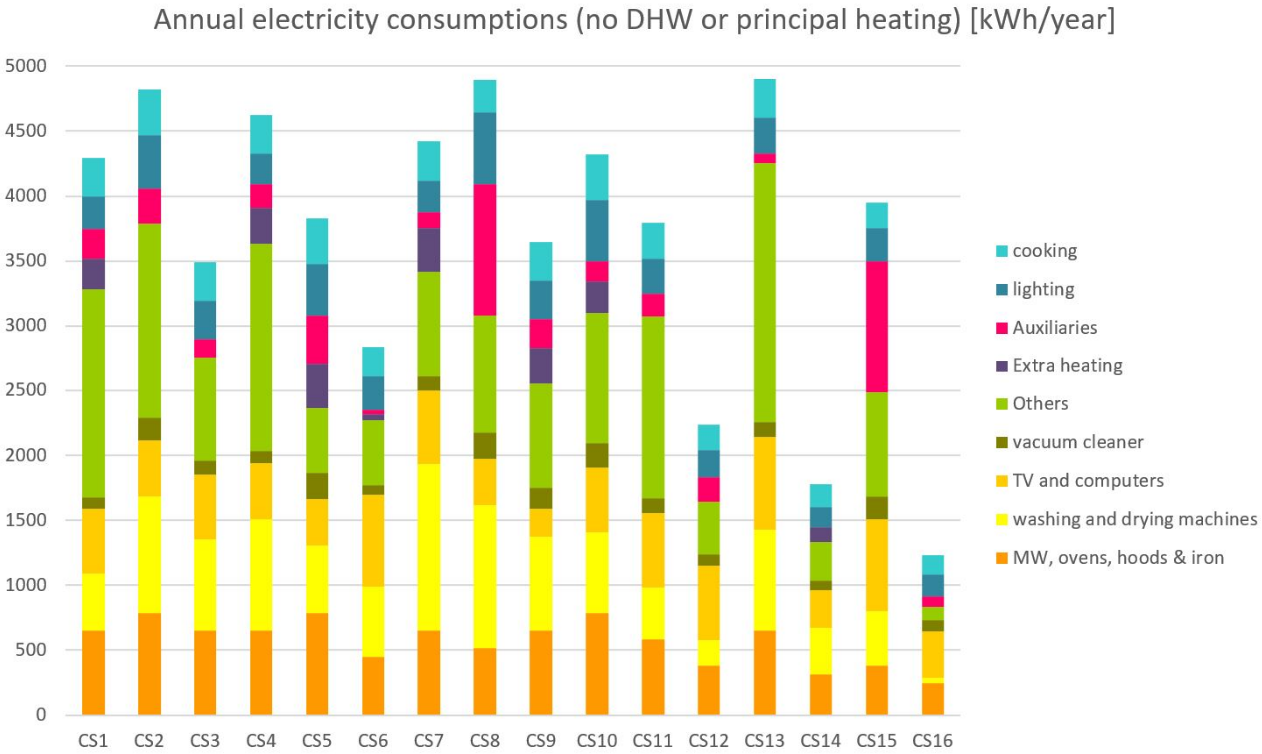

Fig. 4.3.8. Total electricity consumptions revaluated for all end-uses and all case studies

4.3.3 Revaluation of Net Heat Demand

4.3.3.1 Simulator

It was necessary to find a software that would allow alterations on the calculation method, which was obviously not the case of the software developed for the regulatory EPC assessment of existing dwellings, PACE (for "Procédure d'Avis et de Certification Energétique" – "Energy Certification and Audit Procedure"). The opportunity was found in the Excel® spreadsheet developed by G. DUPONT (ULiege) and S. NOURRICIER (UMons) for the CALE Action mentioned in chapter 4.1. When this Action was implemented in 2004, with still four to six years to wait for the official software to be developed, the Administration asked for a simplified method allowing complete assessments of new residential units, built on a list of inputs that was defined for the first calculation method. Since its implementation, the regulatory calculation method describing the energy performance of new residential dwellings (EPB) has been gradually detailed, specified and improved, which translated in a longer list of necessary inputs. The first and simplified method used in this early CALE tool, however, was closer to the certification calculation method which relies heavily on limited – but crucial – input, including default values. The calculation method for the assessment of existing dwellings' energy performance[29] is not different from the method for new dwellings[30] in its general

[29] SPW, SERVICE PUBLIC DE WALLONIE, 2014. *Annexe D: Méthode de Détermination de la Consommation Spécifique des Bâtiments Résidentiels dans le Cadre de la Certification PEB*; Belgian Monitor: Namur, Belgium ; pp. 61636–61767.

[30] SPW, SERVICE PUBLIC DE WALLONIE, 2014. *Arrêté du Gouvernement Wallon du 30 Juillet 2014 Portant Exécution du Décret du 28 Novembre 2013 Relatif à la Performance Énergétique des Bâtiments*; Belgian Monitor: Namur, Belgium; pp. 56172–56294.

structure, but it introduces several simplifications, standardization and default values to ease the description of the building. It is the input description that mainly differentiates both methods, not the calculation method in itself. A series of input parameter, therefore, were gathered from the PACE software then directly introduced in the modified CALE spreadsheet: such was the case of U_m, the average thermal transmission coefficient; $Q_{s,m}$, the solar gains; or the efficiencies for the technical systems. Other limited alterations were possible in accordance with the regulatory calculation method to ensure that all parameters of the EPC calculation method were implemented in the CALE spreadsheet. Tests have been run, between the PACE software and modified spreadsheet to ensure the correspondence of results, before implementing any other modification made necessary by the objectives of this research and integrate the (coded) answers to the questionnaire.

This step of the project required a back-and-forth movement between both tools: progressive modifications have thus been made to the regulatory calculation method and to the questionnaire. The short description of it that has been made above relates to the latest version of the questionnaire, as the description of the revaluation of net heat demands hereunder relates to its latest version.

4.3.3.2 Net Heat Demand

The official calculation method estimates the NHD thusly:

$$Q_{heat,net,m} = Q_{T,heat,m} + Q_{V,heat,m} - \eta_{util,heat,m} \times (Q_{i,m} + Q_{s,m}) \quad (5)$$

where:

- $Q_{heat,net,m}$ = monthly NHD [MJ];
- $Q_{T,heat,m}$ = monthly heat losses due to transmission [MJ];
- $Q_{V,heat,m}$ = monthly heat losses due to airtightness and ventilation [MJ];
- $\eta_{util,heat,m}$ = monthly heat gains application rate; a factor inferior or equal to 1 taming internal and solar gains when they are less needed (depending on monthly heat losses/gains ratios);
- $Q_{i,m}$ = monthly internal gains [MJ]; see further for the proposed evaluation method;
- $Q_{s,m}$ = monthly solar gains [MJ]. Their evaluation is not changed in this method, although an uncertainty, even small, should be acknowledged there: by offering 16 orientation choices in the windows description, the method implies a possible 11.25° difference with the actual orientation, leading to (small) discrepancies in the evaluations of the solar gains.

4.3.3.3 Heat Losses by Transmission

They are evaluated as follows in the regulatory method:

$$Q_{T,heat,m} = H_{T,heat} \times \left(18 - \theta_{e,m}\right) \times t_m \quad (6)$$

where:

- $Q_{T,heat,m}$ = monthly heat losses through the envelope [MJ];
- $H_{T,heat}$ = transmission heat losses coefficient [W/K], sum of the heat losses through the all walls of the envelope. This parameter is mainly ruled by default values that are difficult to change (when there is no more accurate data available) and uninfluenced by inhabitants behaviour and habits;
- $\theta_{e,m}$ = monthly average exterior temperature [°C];
- t_m = length of the month [10^6 s].

The transmission heat loss coefficient is defined as follows:

$$H_{T,heat} = \sum_j b_j \times A_j \times U_j \tag{7}$$

where:

- b_j = weighing factor that considers the environment of the heat loss area "j" and the average temperature considered in the neighbouring space [-]; in the regulatory calculation method, it is equal to 1 for most heat losses areas, except for those adjacent to an out-of-V_P basement (for which b = 2/3) or the floors laid on the ground (for which b = 1/(1+U_j));
- A_j= area of the heat loss surface "j", evaluated on its external dimensions [m²];
- U_j = thermal transmission coefficient, U-value of the heat loss surface "j", as determined by the regulatory calculation method.

Without modification of the $H_{T,heat}$ coefficient (this will come with the variants described in chapter 5), the introduction of different periods of the heating schedule in the evaluation of transmission heat losses was implemented by the subdivision of the time term (t_m, in Ms), first between heated and non-heated periods ($t_{m,heat}$ and $t_{m,noheat}$), then by dividing the $t_{m,heat}$ into a sum of n $t_{m,heat,i}$ terms that represent the lengths of the n different periods of heating time "i":

$$t_m = t_{m,heat} + t_{m,noheat} = t_{m,noheat} + \sum_{i=1}^{i=n} t_{m,heat,i} \tag{8}$$

This means that for each $t_{m,heat,i}$ period, the set temperature has to be redefined to better fit the reality of the households' comfort conditions. It is approached based on the respondent's answers to the questionnaire about the set temperatures of the different main heated spaces, and the volumetric proportions that were deduced from that. This way, a big uncertainty on an standardised annual average (T_{set} = 18°C in the regulatory calculation method) is replaced by smaller uncertainties on tailored average temperatures for the different periods of heating time "i" ($T_{set,i}$).

The mono-zone model needs a hypothesis on the temperature of unheated (or indirectly heated) spaces in order to estimate the global average internal temperature of the dwelling. This is another uncertainty on the result that must be acknowledged, although it could be lifted by monitoring the actual set temperatures , which has been realised on two of the case studies included in this study in that prospect. This ΔT between heated and unheated spaces is considered in this research to depend logically on several determiners such as:

- The actual ΔT between heated spaces and the exterior, as those unheated spaces are usually between both environments;
- The volume ratio between heated and unheated spaces is another important influence (the EPB regulatory calculation method considers that ratio to be 100%, all the time).
- The quality of the envelope and the ventilation air flow rate that provide more or less uniform temperatures throughout the volume. This principle was described by M. DEURINCK et al.[31] as the "physical component of the temperature take-back" in the rebound effect: "When improving the insulation quality of the building envelope, the transmission and ventilation heat losses decrease, not only in the heated zones but also in the unheated zones. Under equal

[31] M. DEURINCK, D. SAELENS, S. ROELS, 2012. *Assessment of the physical part of the temperature takeback for residential retrofits*, Elsevier Energy and Buildings 52: 112-121

thermostat settings, the utilisation of the solar and free gains increases, leading to less energy demand in the heated zones and higher temperatures in the unheated zones. A better insulation and air-tightness level also leads to smaller temperature drops between two heating periods. As a result, both dwelling and time averaged indoor temperatures increase after improvement of the insulation level, even if the inhabitants do not alter their heating pattern." It is thus necessary to integrate in Equation (9) hereunder a factor f_{pct} (for "Physical Component of the Temperature") translating this observation in the calculation method.

- A behavioural response to discomfort should influence the temperature differences between spaces, which is approached by the Responsible Use of Energy questions "Do you close doors of non-heated spaces, in order to isolate them from the heated volume?" and "Does the member of the household who is most sensitive to cold have a tendency to put on an extra sweater instead of increasing the heating?". Answers to both questions have been coded to relate to 5 possible values for the $f_{\Delta T,uhs}$ and ΔT_{set} factors in the Equation (9). The ΔT_{set} can be translated either in increased set temperature during the coldest heating months (+1°C if the respondents checked "1", +0.5°C if they checked "2"), or in lowered set temperature during the warmer heating months (-0.5°C if they checked "4", -1°C if they checked "5"). Both situations cannot arise simultaneously, and the threshold between "coldest" and "warmer" heating months is defined by the arithmetical average monthly exterior temperature during the months where the NHD is > 1% of the annual NHD. The 1% threshold has been chosen to avoid remnant NHDs due to the method that would wrongfully influence that average.
- There is also an architectural component that has to be taken into account: the presence of a stairway which, if open on heated rooms, could influence the air flows and temperature homogenization in the dwelling. "Is the stairway between liveable levels of the protected volume open on living spaces, or separated (in a closable hallway, for example)?" is the question added in the "building description" section of the questionnaire which serves that purpose. Open stairways volume is added to the heated volume. Temperature in a separate stairway (and other unheated spaces) depends on the tendency to close doors.

The final equation for calculating the resulting temperature in unheated spaces is the following:

$$T_{uhs,m} = \left(T_{set,hs} + \Delta T_{tset}\right) - \left[\left(\frac{\left(\left(T_{set,hs} + \Delta T_{tset}\right) - \theta_{e,m}\right)}{2}\right) \times \left(1 - f_{Vp,hs}\right) \times f_{\Delta T,uhs} \times f_{pct}\right] \qquad (9)$$

where:

- $T_{uhs,m}$ = monthly average temperature in unheated spaces during heating periods [°C];
- $T_{set,hs}$ = set temperature in heated spaces [°C];
- ΔT_{tset} = positive or negative increment in set temperature according to sensitivity to cold [°C];
- $\theta_{e,m}$ = monthly average exterior temperature [°C];
- $f_{Vp,hs}$ = ratio of the heated spaces' volumes on the total protected volume, during the heating period considered.
- $f_{\Delta T,uhs}$ = empirical factor (0.8 to 1.2) affecting the temperature difference between heated and unheated spaces, which value depends on the tendency to close doors between them.
- f_{pct} = multiplicative factor considering the quality of the envelope as influence on temperature homogenization.

Afterwards, the average periodic temperature $T_{set,i}$, and the resulting global monthly internal temperature $T_{set,m}$ can be defined thusly:

$$T_{set,i} = T_{set,hs} \times f_{Vp,hs} + T_{uhs} \times (1 - f_{Vp,hs}) \quad (10)$$

$$T_{set,m} = \sum_{i=1}^{i=8} \frac{(T_{set,i} * t_{m,heat,i})}{t_{m,heat}} \quad (11)$$

And, finally, the heat losses by transmission can be revaluated thus:

$$Q_{T,heat,m} = H_{T,heat} \times (T_{set,m} - \theta_{e,m}) \times t_{m,heat,m} \quad (12)$$

The revaluation of $Q_{T,heat}$ is difficult to present here without giving more details about the envelope quality and composition, and the variants that will be used for the case studies. Consequently, these results will be shown in chapter 5.

4.3.3.4 Heat Losses by Ventilation

Their evaluation ($Q_{V,heat}$) in the regulatory method is very similar to Equation (6), but the $H_{V,heat}$ coefficient includes heat losses caused by both air tightness and hygienic ventilation:

$$H_{V,heat} = 0.34 \times (\dot{V}_{in/exfilt,heat} + r_{preh,heat} \times \dot{V}_{hyg,heat}) \quad (13)$$

where:

- $H_{V,heat}$ = heat losses coefficient due to air tightness and ventilation [W/K];
- $\dot{V}_{in/exfilt,heat}$= air tightness ventilation air flow for heating calculations [m³/h];
- $r_{preh,heat}$ = taming factor considering the pre-heating of ventilation air (when applicable) [-];
- $\dot{V}_{hyg,heat}$ = hygienic ventilation air flow for heating calculations [m³/h];

In the modified method, the total air change rate (due to ventilation and air tightness) is revaluated following respondents' answers to their ventilation and weather-stripping habits.

As far as air tightness is concerned, the answer of the respondent to the question "Do you weather-strip the doors and windows in winter, to avoid air leakages?" defines the value of an empirical multiplicative factor (f_{v50}, which ranges from 0.8 to 1) that eventually reduces the air change rate through the envelope.

$$\dot{v}_{50,bmod} = \dot{v}_{50,heat} \times f_{v50} \quad (14)$$

$$\dot{V}_{in/exfilt,heat} = 0.04 \times \dot{v}_{50,bmod} \times A_T \quad (1)$$

where:

- $\dot{v}_{50,bmod}$ = air flow due to airtightness, under 50 Pa pressure difference, by square meter of the heat loss area, tamed by inhabitants' behaviour ($m^3/h\ m^2$);
- $\dot{v}_{50,heat}$ = air flow value, due to airtightness, under 50 Pa pressure, by square meter of the heat loss area. The default value for heating calculations in the absence of an airtightness testing is 12 $m^3/h\ m^2$;
- f_{v50} = multiplicative factor taming the air flow to consider behaviour [-];
- A_T = total heat loss area of the V_P envelope [m²].

In the regulatory method, the hygienic ventilation air flow rates are estimated with the protected volume as the only parameter:

$$\dot{V}_{\mathrm{hyg,heat}} = \left[0.2 + 0.5 \times e^{\left(\frac{-V_p}{500}\right)}\right] \times m_{\mathrm{heat}} \times V_p \qquad (2)$$

where m_{heat} is a multiplicative factor dependant on the quality of execution of the ventilation system, taking air leakages into consideration, for example; the default value in the regulatory calculation method is 1.5; in this research however, when no system is present, this parameter is set to 1.

In most case studies, the actual air change rates were unobtainable, in the absence of any complete standard ventilation system. Assumptions were made by questions on the behavioural management of the ventilation during winter, in the main spaces of the house (living room, kitchen, bedrooms and bathroom):

- When the space is declared "non-ventilated", or "only ventilated through air leakages", or occasionally ventilated by "punctual window opening" (no regular or daily opening), the air change is considered null;
- When dwellers declare "daily window opening" in a space, its volume (or, rather, the corresponding share in V_P) is considered renewed once a day;
- When supply vents are present in window frames, but the dwellers report obstructing them in the winter, the air change is fixed at 15% of the regulatory air supply [m³/h] required for the space. 15% of the nominal air flow is the maximum allowed by the Belgian residential ventilation standard (NBN D50-001) when vents are closed;
- When the kitchen extractor hood evacuates the air outside (no recycling) and is declared as ventilation unit when cooking, it is considered used for 20 min/day + 10 min/day per person at an air flow of 400m³/h;
- When a mechanical temporised air extractor is used in the bathroom, it is considered used for 30 min/day per person at an air flow of 100m³/h;
- When a complete ventilation system could be considered present, the regulatory air flow for hygienic ventilation of the protected volume were considered, based on usable areas (0.8^*A_{ch}) for the different dry spaces.

These air change rates, for each types of spaces, deduced from the answers of the owners to the questionnaire, were added and averaged in m³/h for the whole occupied volume. The Figure 4.3.9 hereunder gives an overview of the $H_{V,heat}$ coefficient as evaluated by the EPB regulatory calculation method (Equation (13)) and revaluated by these hypotheses, which validation was unfortunately not possible. In most cases, the coefficient evaluated by the EPB is a rather good indicator of the size of the building (represented by the protected volume, V_P, in Fig. 4.3.9). Two exceptions are clearly to be considered when observing the graph: the two newly-and-highly-renovated case studies 8 and 15. In those cases, the BATEX files contained the necessary documentation to consider the real ventilation air flows supported by the systems put in place (467m³/h and 353m³/h respectively, with respective $r_{preh,heat}$ factors in Equation (13) of 0.3 and 0.17). These are also the only two cases where the airtightness of the envelope had been tested previously to the research, and reach respective $\dot{v}_{50,\mathrm{heat}}$ factors (see Equation (14)) of 1.6 and 3.7 m³/h per square meter of the total heat loss area (A_T). In both cases, the ventilation systems are equipped with heat recovery and recycling units for the supply of air in the living room, allowing to reduce the total air flow supported by the system, to recover part of the exhaust heat… CS15 has also resorted to a "ventilation on demand" regulation, which allows to reduce the air change rate (by a factor of 0.53 in this case) depending on the actual needs in ventilation, determined by two CO_2 sensors (placed in the living room and the parents' bedroom). This explains why those buildings of respectable sizes (812 and 860m³ of V_p, respectively) present much lower $H_{V,heat}$ coefficient, according to the EPB. This also explains why the revaluation did not have the same effect on both case studies: in CS8, the hygienic ventilation air flow rate estimated by the regulatory method ($\dot{V}_{hyg,heat}$ in Equation (14)) is 363.67m³/h, and the installed rate is 467m³/h; in CS15, these values are respectively 373.56m³/h and 353m³/h. Added with the other influences, this revaluation increased the $H_{V,heat}$ coefficient for CS8 (+12.6%), and decreased it for CS15 (-32.2%). For the other case studies, the revaluation decreased the H_{Vheat} coefficient in average by 72.9% (min -64.1%, max -83.1%).

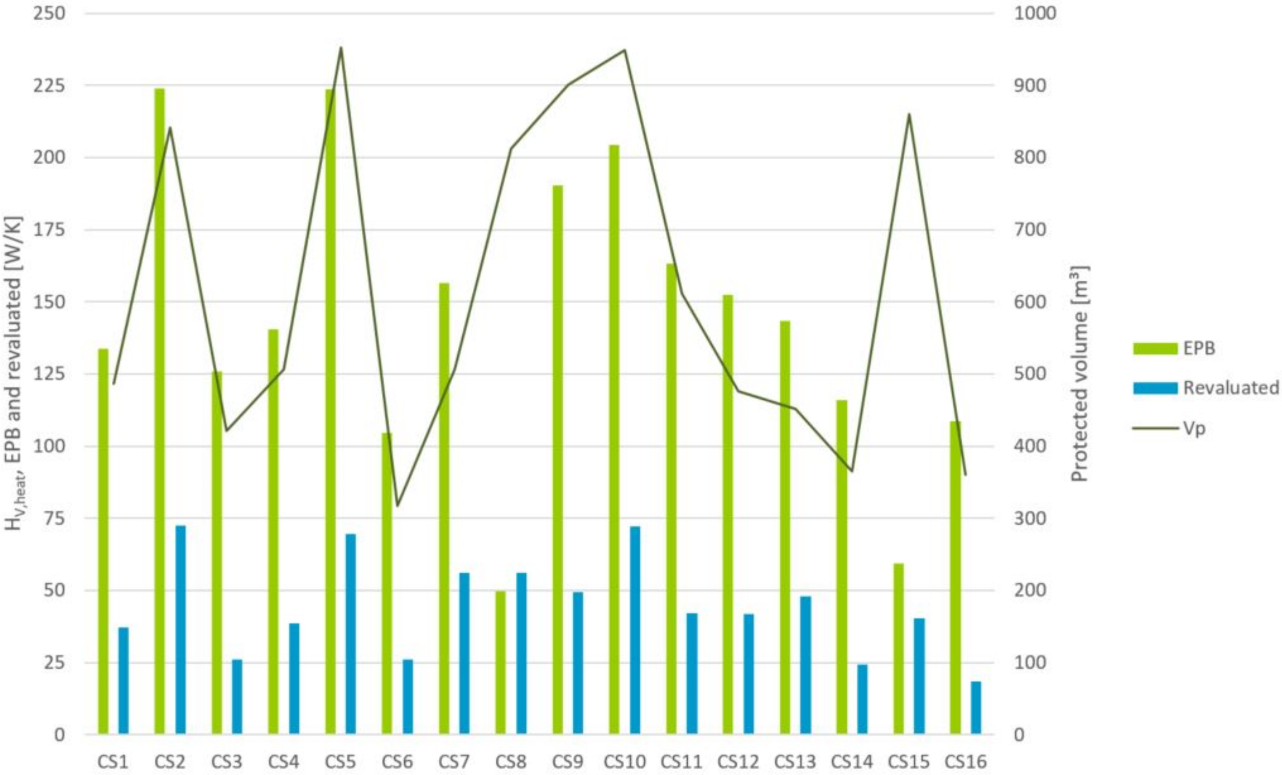

Fig. 4.3.9. $H_{V,heat}$ coefficients for the 16 case studies, evaluated by the EPB and the modified methods, and protected volume of the case studies for comparison

4.3.3.5 Internal gains

In the official calculation method, they vary linearly with the protected volume:

$$Q_{i,m} = (0.67 \times V_p + 220) \times t_m \quad (17)$$

In this proposition, however, internal gains are revaluated as the sum of power delivered by:

- The use of lights, appliances and equipment, as evaluated above. It is considered in this method that 100% of the electricity from those consumption posts bring internal gains in the dwellings. Exceptions to this rule have been integrated, however: electricity consumptions for washing machines, dishwashers and electric dryers, for example, are negated in this calculation of internal gains, as their heat effect is generally literally sent down the drain. Besides, in many case studies, these machines are located in basements that are outside of the heated volume. Similarly, the heat that could be gained from filled-up baths or lengthy showers could also be accounted for, but are neglected for the same reasons.

These internal gains used to be split between the different periods of the day in the first modifications of the method, with attention to the times they were used (gains due to lighting, for example, were reserved for the first and last 3 periods of the day). After taking a step back in the discretisation of the calculations, this step became unnecessary, although a monthly differentiation is kept. Gains due to lighting depend on monthly ephemerides, as explained in 4.3.2.1. Gains due to cooking and using appliances are distributed according to the length of each month.

- The presence of inhabitants (depending on the size of the household, the occupation pattern of the building and the loads defined by the ISO 7730: 2005 standard):

$$Q_{met,a} = \left(\frac{\sum_{i=1}^{i=a} N_{occ} \times P_{met,i} \times t_{m,occ}}{3600} \right) \tag{18}$$

where:

- $Q_{met,a}$ = annual internal loads due to metabolism (occupation pattern) [MJ];
- N_{occ} = number of occupants, size of the household [-];
- $P_{met,i}$ = metabolism load of one person present during the period 'i'. The hypotheses are taken from the standard ISO 7730:2005, in which the metabolic loads are 80W/person asleep, 100W/person awake without activity (evenings), or 120W/person awake doing an activity during daytime;
- $t_{m,occ}$ = length of the occupation periods [10^6 s].

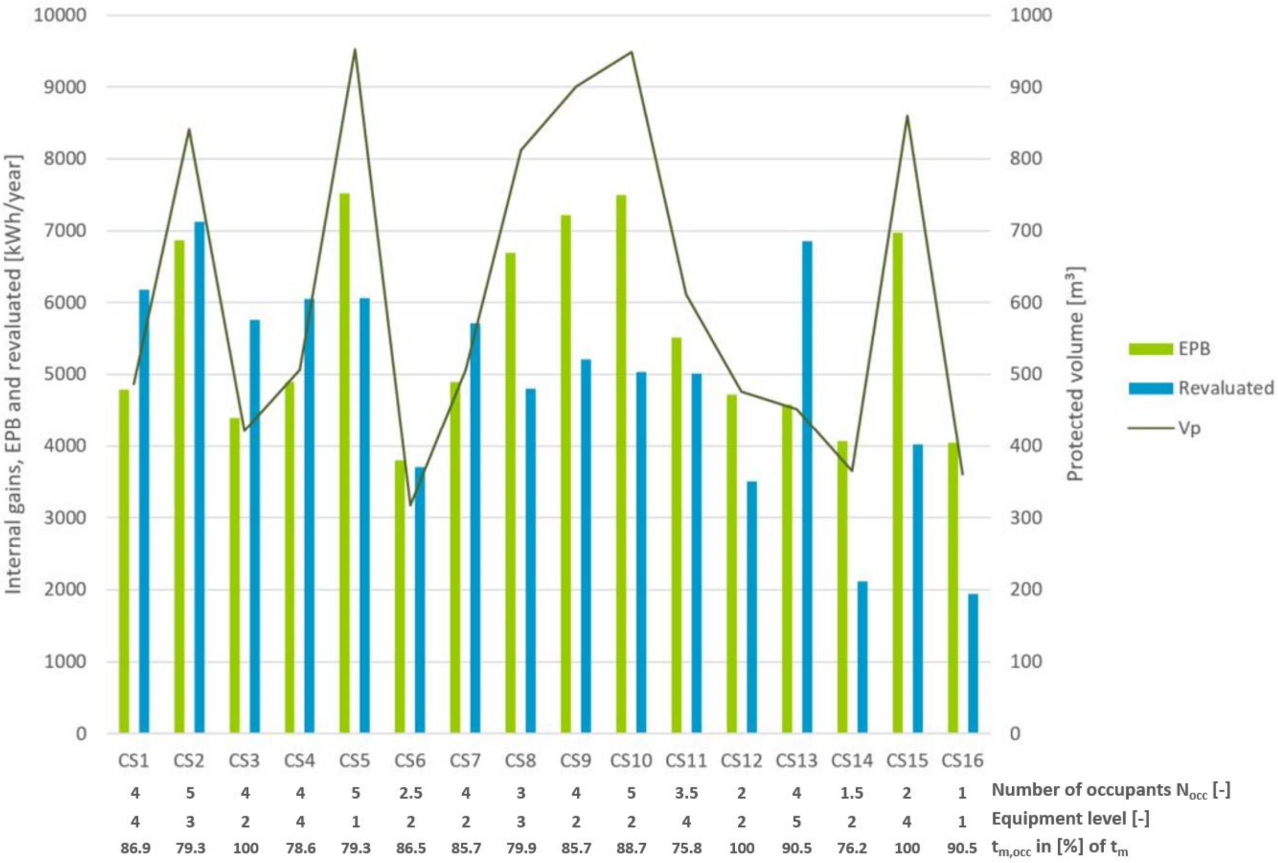

Fig. 4.3.10. Internal gains ($Q_{i,a}$), for the 16 case studies, evaluated by the EPB and the modified method, and protected volume of the case studies for comparison

The Figure 4.3.10 presents the results of the evaluation of internal gains, according to the EPB regulatory calculation method and the modified method based on the respondents' answers to the questionnaire. Regulatory evaluation is proportional to the protected volume, as visible, and considers a constant presence at home (in Equation (18), $t_{m,occ}$ = 100% of t_m), whereas the revaluation considers the real number of occupants and realistic pattern of presence ($t_{m,occ}$ defined by the answers to the questionnaire) and equipment levels, described in 4.3.2. As a result, in average, the revaluated internal gains are lower than the gains evaluated by the EPB method (-8.4% on average), but the graph displays a wide range of discrepancies (min -49.6%, max +52.1%).

The "2.5" number of occupants in CS6 relates to the part-time presence of a child, who spends the other half of her time at her mother's house. The "3.5" and "1.5" numbers of occupants in CS11 and 14 relate to the partial presence of a grown-up child who spends weekdays in another place to study, but comes back home for the weekends, even sometimes during the week.

The $t_{m,occ}$ parameter, reflecting the proportion of time that the dwelling is considered occupied by at least one person, includes the night period (33.3% by hypothesis). Without considering those periods, there is someone present in those houses on average 79% of ordinary week daytimes (the respective values vary from 64%, in dwellings occupied by working adults, to 100% in dwellings occupied continuously). In the revaluation, the influence of a low number of occupants (regarding the size of the house) can be seen in case studies 8, 12, 14, 15 and 16, for example, which implies that the EPB regulatory calculation considers an average number of occupant per m³ of V_P that is not as conservative as one could have thought. Case study 2, for example, with 5 occupants and an average equipment level, is revaluated quite close to the regulatory evaluation; CS15, however, with only 2 inhabitants in the same kind of volume and a higher equipment level, is revaluated much lower than the regulatory evaluation. Levels of equipment influence greatly the revaluation also, as examples of low levels can be found in CS5, 9, 10, 12, 14 and 16 and examples of high equipment levels in CS1, 4 and 13. CS13 has in common with CS3 a high number of television or (fix) computer hours that explain higher revaluated internal gains.

4.3.3.6 Solar gains

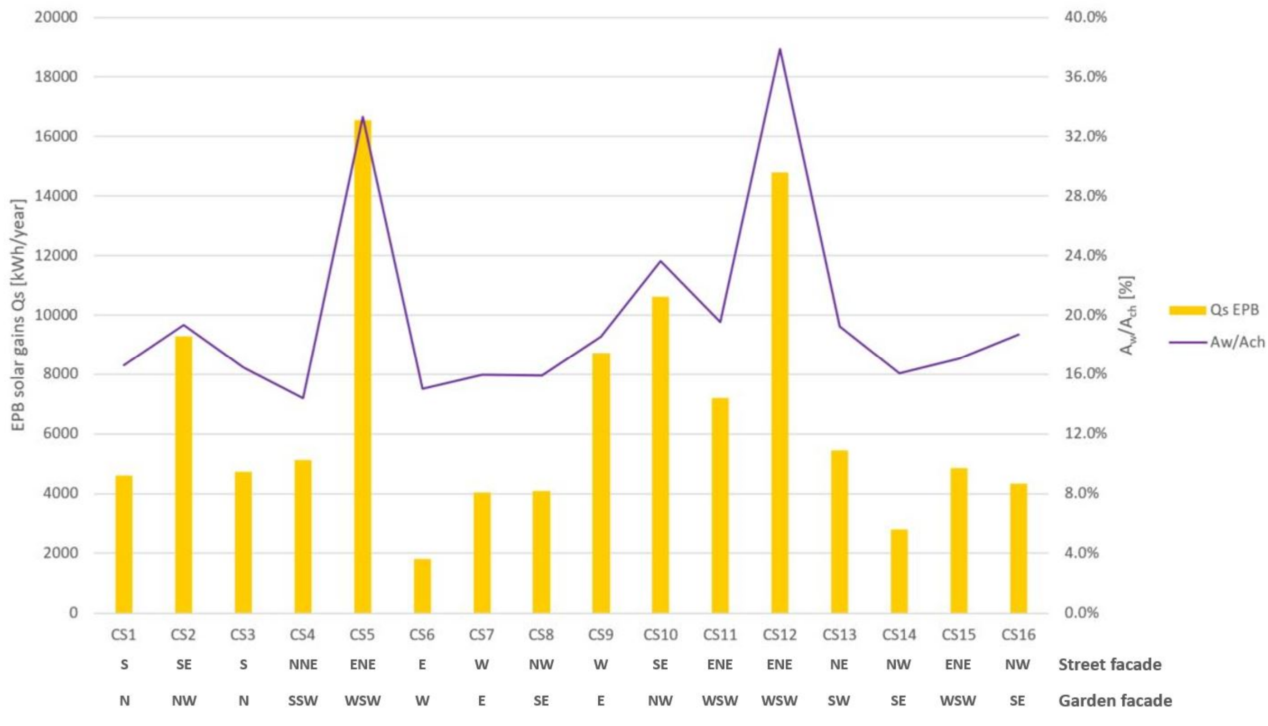

Fig. 4.3.11. Annual solar gains, Aw/Ach ratio and main façade orientations in the 16 case studies

Although they might not be changed in the modified method (by lack of data from the climatic stations used to gather real climatic data, see 4.3.5), it seemed important to consider their influence on the evaluations presented here. They depend, obviously, on the dwellings' orientations and glazing characteristics (surfaces, solar factor, tilt…), so that the graph also presents the ratio between windows area (A_w) and the total heated floor area (A_{ch}), as well as the orientation of the main facades (street and garden). The presence of verandas in the CS5 and CS12 is quite visible.

4.3.3.6 Heat Gain Application Rate

The Equation (5) above presents the monthly heat gains application rate ($\eta_{util,heat,m}$), a factor inferior or equal to 1 that tames the internal and solar gains when they are less needed, depending therefore on the ratio between monthly heat gains ($Q_{g,heat,m}$ in the Equation (19)) and losses ($Q_{L,heat,m}$).

$$\gamma_{heat,m} = \frac{Q_{g,heat,m}}{Q_{L,heat,m}} \tag{19}$$

$$\text{if } \gamma_{heat,m} \geq 2.5, \eta_{util,heat,m} = \frac{1}{\gamma_{heat,m}} \tag{20}$$

$$\text{if } \gamma_{heat,m} = 1, \eta_{util,heat,m} = \frac{a}{a+1} \tag{21}$$

$$\text{if } \gamma_{heat,m} < 2.5 \text{ and } \neq 1, \eta_{util,heat,m} = \frac{1-\gamma_{heat,m}^{a}}{1-\gamma_{heat,m}^{a+1}} \tag{22}$$

$$a = 1 + \frac{T_{heat}}{54000} \tag{23}$$

$$T_{heat} = \frac{C}{H_{T,heat} + H_{V,heat}} \tag{24}$$

where:

- T_{heat} = time constant [s]
- C = effective thermal capacity of the protected volume, in [J/K].

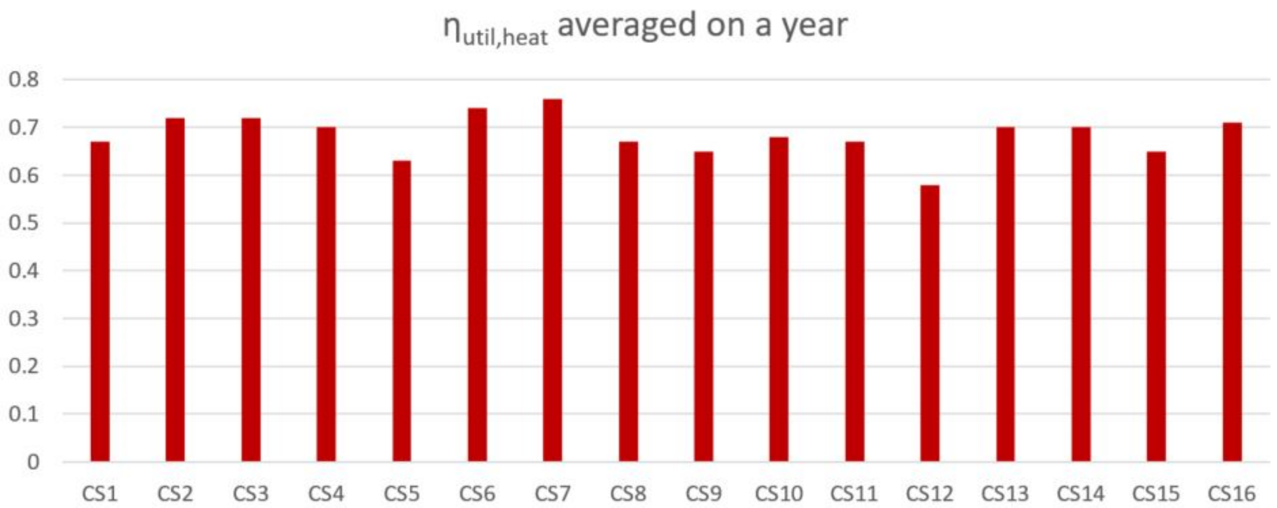

Fig. 4.3.12. Heat Gains Application Rate ($\eta_{util,heat}$), averaged on an EPB climatic year, used to tame the internal gains in the regulatory NHD calculation method for the 16 case studies

Surprisingly for a method that describes the whole envelope, there is no detailed calculation of the thermal capacity. It is based on three possible description of the thermal inertia ("light", "heavy" and "in-between"), depending on the ratio of "massive" surfaces. The protected volume is the only parameter in the evaluation of the thermal capacity:

$$C = c \times V_P \tag{25}$$

Where c = 27,000 [J/Km³] in light houses, 217,000 [J/Km³] in heavy houses and 67,000 [J/Km³] in-between (which concerns most houses, and all those included in this research).

There is an interesting paradigm about that Heat Gain Application Rate (HGAR) in the evaluation of old dwellings. Influenced by the thermal inertia, it should represent an effect of heat conservation and rendition. It concerns the whole energy balance inside the dwelling, not only the internal and solar gains. By considering values inferior to 1, this parameter considers that, even in winter periods, inhabitants of a dwelling will only use part of those internal gains to help heat the house. This HGAR factor implies a strategy of limitation on those gains that could be considered accurate in new and efficient dwellings, but seems at odds with the way people use old dwellings. Furthermore, in all cases (even the highly performant dwellings), results from the regulatory calculation method show heating needs and consumptions in summer periods as a result of low HGAR factors, which is quite contrary to the respondents views. In many cases, the respondents to these interviews indicated their will to maximise the solar gains at all times, when available, except in overheating periods. This factor may be highly needed in the evaluation of overheating risk and cooling consumptions, but does not seem to give an accurate view of the evaluation of heating needs. It has been decided, therefore, to consider a factor $\eta_{util,heat,m}$ equal to 1 in these calculations that only target heating consumptions (see next chapter for more details). If there were cooling consumptions to be evaluated, this assumption would not be acceptable; as it is, no case study declared any kind of cooling system which consumption should have been revaluated.

4.3.3.7 Extra heating integration

When electric devices are used to boost the heating power during relatively short periods, the consumption evaluated in 4.3.2.4 is simply deducted from the NHD, each month, considering a global efficiency for this heating system equal to 1 (net heat demand = final consumption).

4.3.4 Revaluation of DHW demand

DHW consumption normally depends on the number of inhabitants. In the official method however, it is calculated with the building's protected volume as the only parameter, considering three types of drawing: baths, showers and kitchen sinks (the others are either using the same plumbing or negligible):

$$Q_{water,bathi,net,m} = f_{bath,i} \times \max\left(64;\ 64 + 0.22 \times \left(V_p - 192\right)\right) \times t_m \tag{26}$$

$$Q_{water,sinki,net,m} = f_{sink,i} \times \max\left(16;\ 16 + 0.055 \times \left(V_p - 192\right)\right) \times t_m \tag{27}$$

where:

- $Q_{water,bathi,net,m}$, $Q_{water,sinki,net,m}$ = net energy demand for the preparation of DHW drawn for a bath (or shower) or a kitchen sink [MJ];
- f_{bathi}, f_{sinki}: share of the bath, shower or kitchen sink in the total DHW net energy demand [-].

In this study, a realistic demand in DHW was estimated as the first approach by the number of baths and showers taken weekly by the household and their tendency to prefer showers (rational use of energy) to baths. By hypothesis, respondents are given a "water consumption level" (from 'light' to 'heavy') and attributed a daily use of 30 to 50 litres of water per occupant according to the level granted[32]. This water supplied comes out of the public network at an average temperature of 10°C and has to be heated to a minimal temperature of 50°C, so that the monthly net energy demand for DHW becomes:

$$Q_{water,net,m} = \frac{\left(N_{lt} \times N_{occ} \times N_{d,m} \times 4.1855 \times 10^3 \times \left(\theta_{water,out} - \theta_{water,in}\right)\right)}{10^6} \quad (20)$$

where:
- $Q_{water,net,m}$: the net energy demand for domestic hot water production [MJ];
- N_{lt}: the number of litres per occupant and per day, to be heated [l];
- N_{occ} = the number of occupants in the dwelling [-];
- $N_{d,m}$: the number of days in the month [-];
- $4.1855 \text{ X } 10^3$: the energy needed to raise by 1°C the temperature of 1 litre of water [J/kg.K];
- $\theta_{water,out}$: the temperature of the heated water = 50°C;
- $\theta_{water,in}$: the temperature of the supplied water = 10°C.

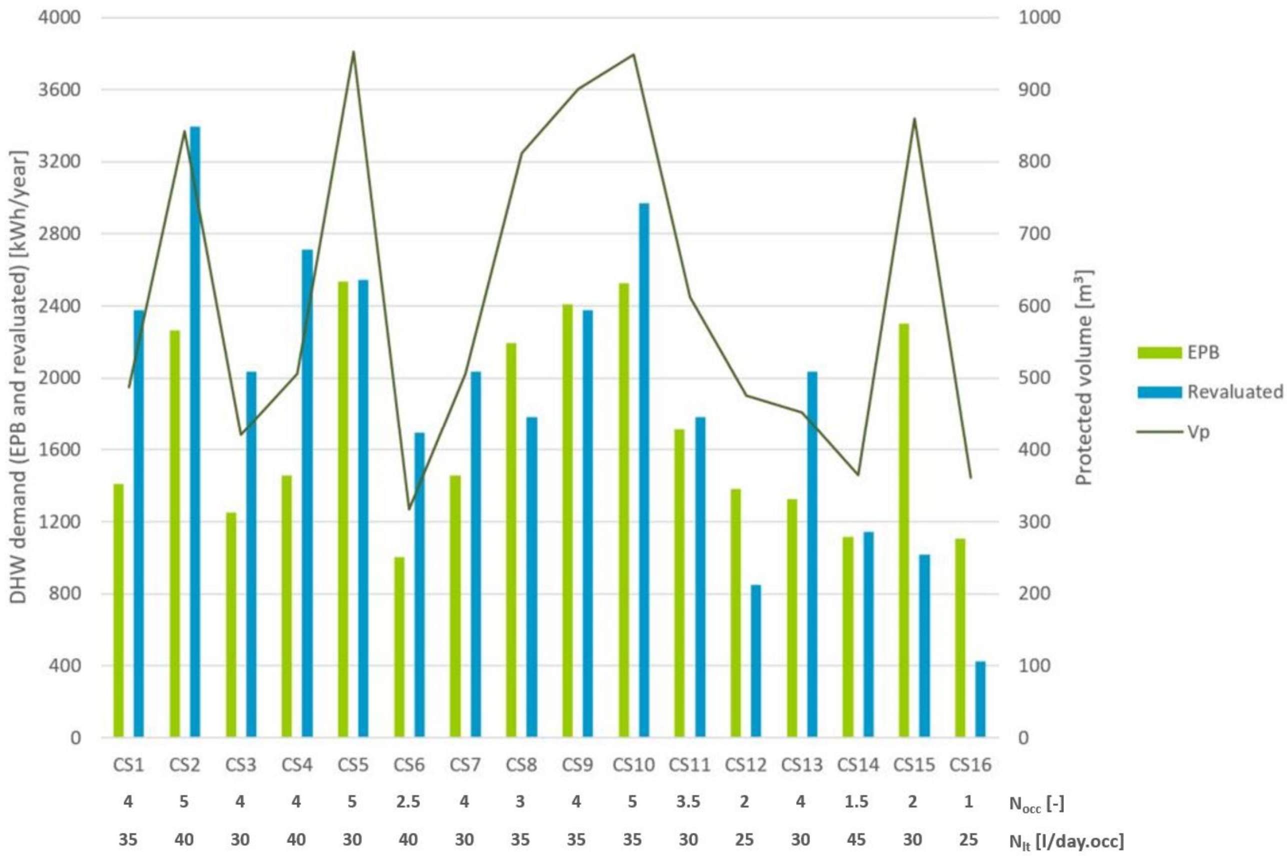

Fig. 4.3.13. Domestic Hot Water demand for the 16 case studies, evaluated by the EPB regulatory calculation method and the modified method, and the protected volume for comparison.

[32] J.-M. HAUGLUSTAINE, 1979. *Incidences du Comportement Humain sur la Consommation D'énergie dans les Habitations Sociales.* Master's Thesis, University of Liege, Liege, Belgium.
E. DAVIN, P. ANDRÉ, 2014. *Rapport Smart Micro Cogen WP2: Identification des Profils Caractéristiques de Consommations (Chauffage, Consommations Électriques) dans les Bâtiments*; University of Liege: Arlon, Belgium; p. 25.

This Figure 4.3.13 displays the comparison between the DHW needs evaluated by both the EPB and the modified methods, based on the Equation (20) above. The number of occupants in the dwellings, as well as the number of litres to be heated for each of them (according to their answers to the questionnaire), are indicated below the graph. On average, the revaluated DHW needs are 17.4% higher than those estimated by the EPB method, which is quite surprising considering the opposite tendency in the estimation of heating demands (see next chapter). The global overestimation could either come from the hypotheses presented above, of course, but also from the respondents' answers (who could overestimate themselves the level of water used daily) or, simply, from EPB hypotheses. The discrepancies range between a minimal -61.6% (in CS16, a single woman showing thrifty behaviour and great environmental consciousness) to +86.4% (in CS4, a couple living with their two children). The low discrepancy in CS14 is explained by a combination of a low number of occupants and a high demand level (45l/day.occ). In the CS5, 9 and 11, however, the low discrepancies could be explained by the proximity with the EPB hypotheses, which can globally be considered not that far off reality.

4.3.5 Climate

Standardisation can be exemplified by the climatic data which are still of major importance in the assessment of the residential energy consumption[33]. The graph hereunder shows the average climatic data that are used in the EPB Walloon calculation method for the evaluation of heating demands (in blue), and the comparative climatic normal data for the years 1981 – 2010, as published by the Royal Meteorological Institute of Belgium (IRM)[34] for the reference city of Uccle, near Brussels.

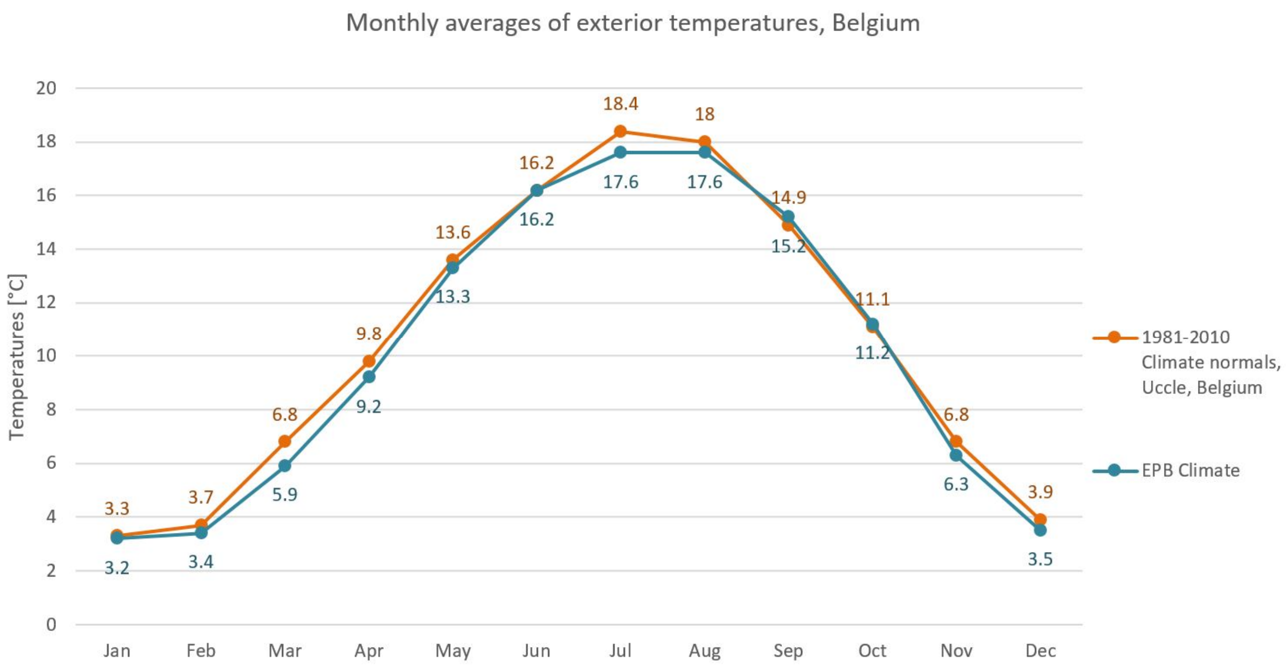

Fig. 4.3.14. Average climatic data for Belgium, according to the IRM (orange) and the EPB (blue)

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33 K. STEEMERS, G. Y. YUN, 2009. *Household energy consumption: a study of the role of occupants*, Building Research & Information, 37:5-6, 625-637

34 https://www.meteo.be/meteo/view/fr/360955-Normales+mensuelles.html#ppt_5238240, last visited on March 3rd, 2018.

The next graph (Fig. 4.3.15) shows data from another website, meteobelgique.be[35], for 10 different cities in Belgium. It is interesting to notice that the EPB climate, with 1,935 annual degree-days 15/15, is on average warmer than most of the presented cities climates (2,329 DD 15/15 on average). EPB climate is comparable to the climate by the seaside (Oostende with 2,029 DD15/15, and Veurne with 1,987 DD15/15).

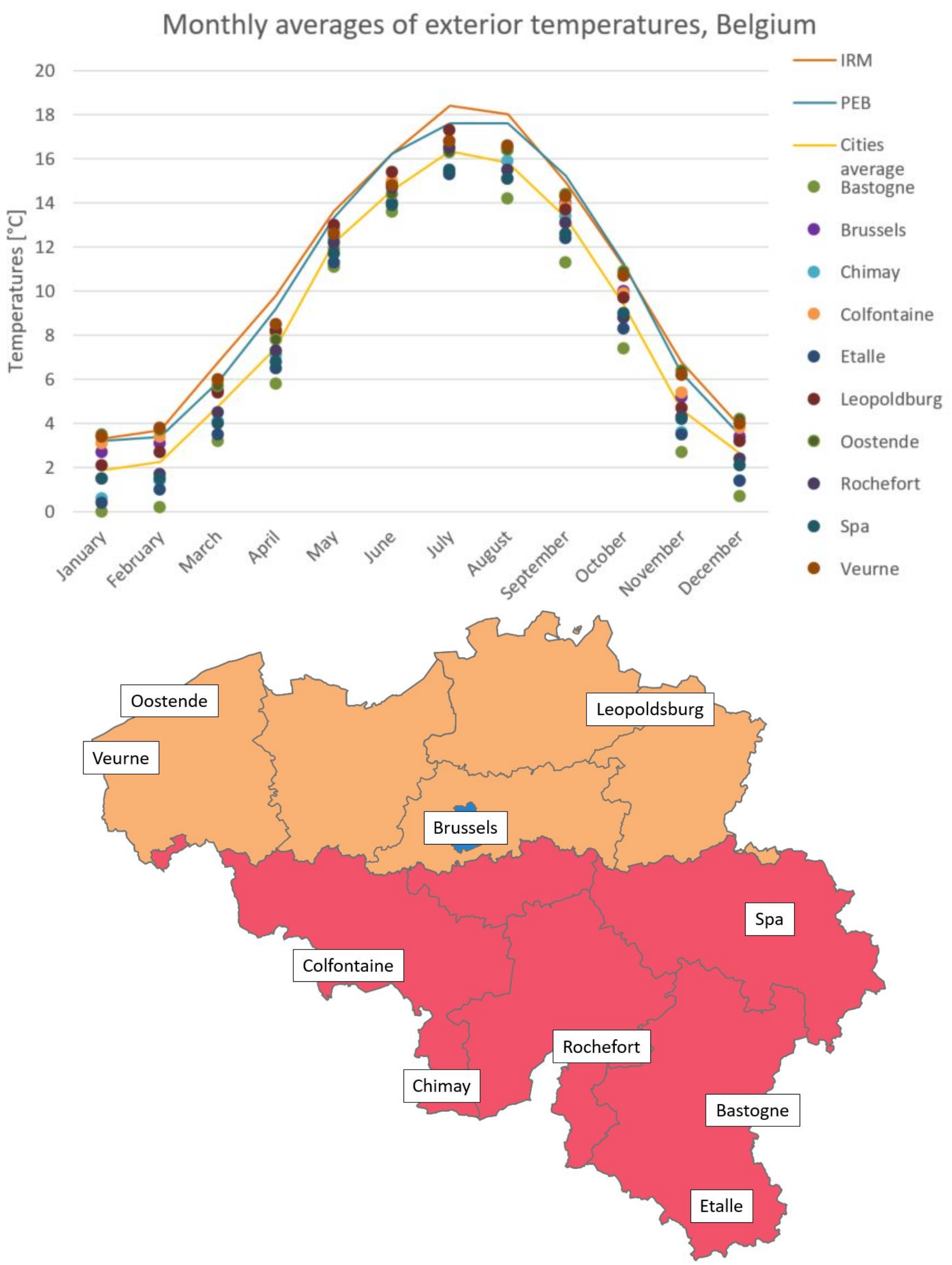

Fig. 4.3.15. Average climatic data for Belgium, according to the IRM (orange), the EPB (blue), and the meteobelgique.be website for other cities (shown on map) averages

[35] https://www.meteobelgique.be/article/donnees-statistiques/climatogramme.html, last visited on March, 3rd, 2018.

The case studies included in this research are localised around the city of Liege, in the East part of Wallonia. Privacy protection necessities forbid to reveal the exact location of those buildings, but the website providing the meteorological data did include climatic stations around Liege that were helpful to model more accurate data for the case studies and allow to highlight the uncertainties that might be included in assessments based only on the average EPB climate. The next Figure shows roughly the localisation of Liege, the case studies (blue dots) and the climatic stations (green dots) that were available and used in this research:

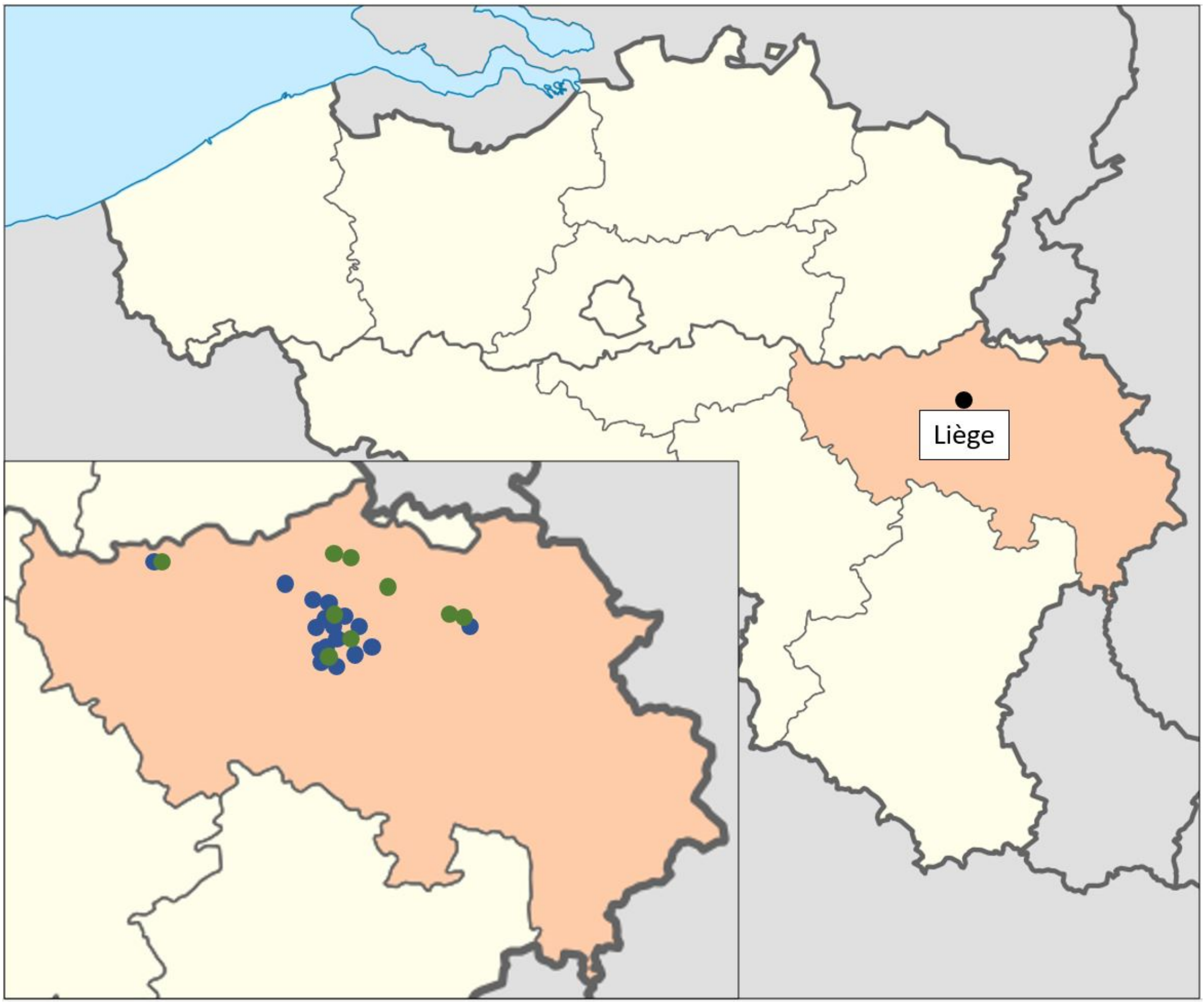

Fig. 4.3.16. Rough position of the case studies (blue dots) and climatic stations (green dots) used in this research, on a map of Belgium and of the Province of Liege

The climatic data for all those stations were not available for each year, however, as they have been implemented progressively over the last few years (last one in April 2014). The graph hereunder (Fig. 4.3.17) shows the collected data for those climatic stations around Liege that were used for the revaluations of heating consumptions. In each case studies, the climatic data that were considered were obtained from the stations nearest or, in some cases, by the average values of the equidistant stations (especially in cases located in the outskirts of Liege, who benefited from different conditions than dwellers from the city centre). In the Fig. 4.3.17, the EPB climate has been added in order to allow comparisons. It is interesting to notice that, contrary to Figure 4.3.15, temperatures are generally above the EPB data, indicating that those regulatory hypotheses might have been chosen conservatively for urban cases; or, defined by the average data from the last fifty years or so in Uccle, that the following graph might be an indication that the weather is warming up…

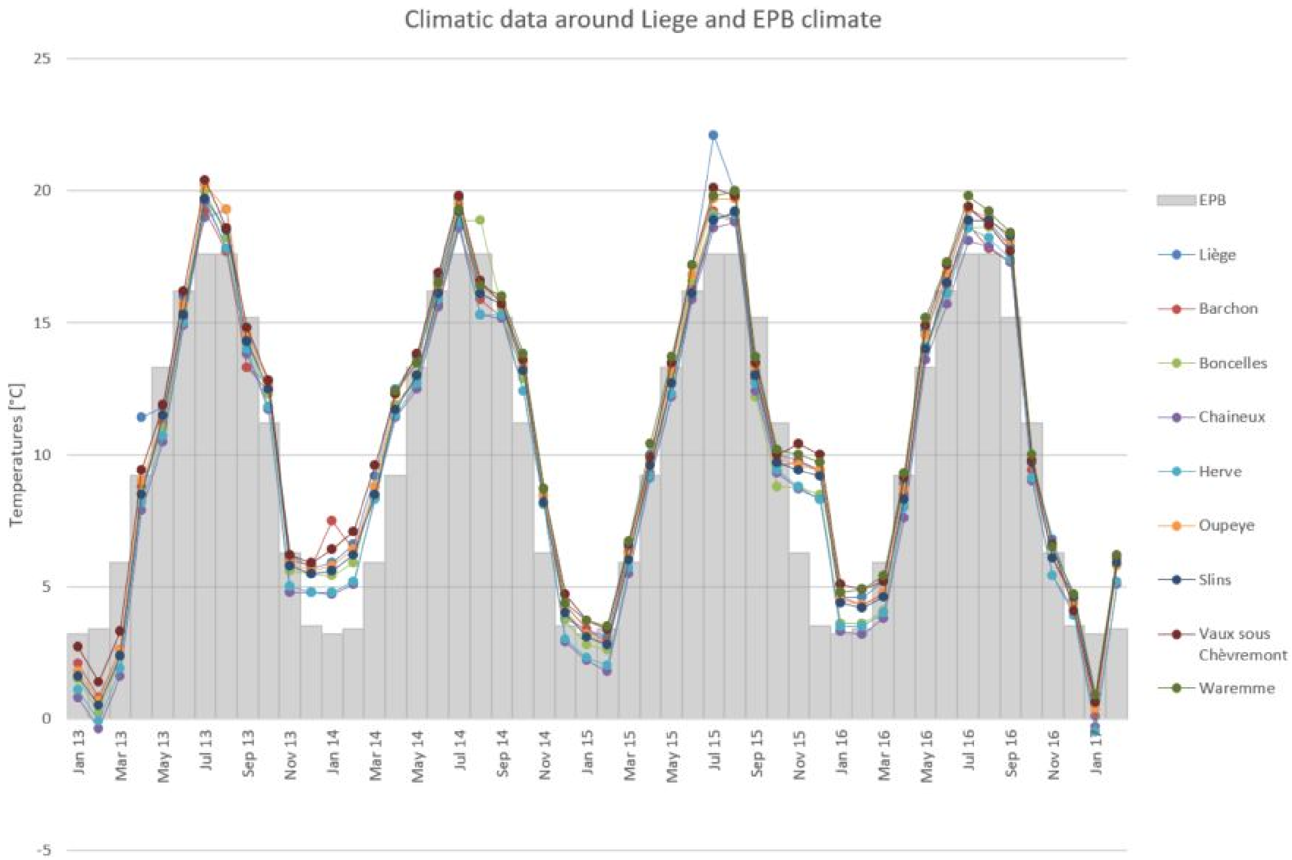

Fig. 4.3.17 Climatic data of stations around Liege between January 2013 and February 2017 (curves, source: meteobelgique.be) and EPB climate for comparison (grey columns, source: SPW, 2014)

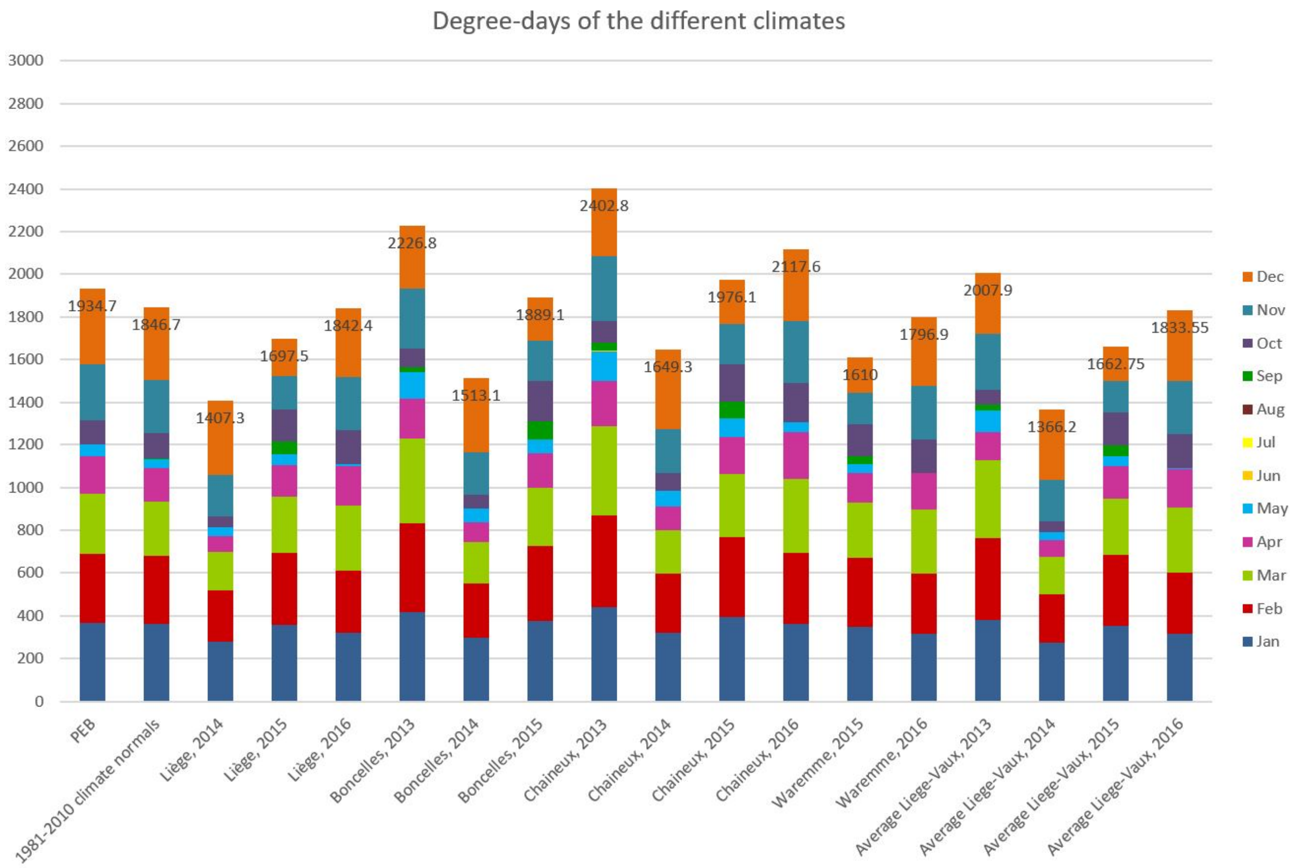

Fig. 4.3.18. Degree-days for the different climates: EPB (source: SPW, 2014), IRM (source: www.meteo.be) and local climates used for the case studies (source: www.meteobelgique.be)

Chapter 5: Case studies

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5.1 Introduction

This chapter will present the preliminary results for each of these case studies, in the form of comparisons between the real consumption data given by the respondents and the official and revaluated results given by the methods described in chapter 4.

While searching for a variety of dwellings with different typologies and energy characteristics, the definition of the sample started to include a search for “acceptable proofs” that could be used in the definition of the EPC. As mentioned in chapter 4.2.1, few of them were found, although the owners were keen on giving any information and documentation they had to help in the process. Variants were therefore defined for each of these case studies, on a common foundation that is the “official” EPC, a priori completed with respect to the protocol. Some of the case studies’ owners presented “unacceptable” documents that were used nevertheless, in order to better define the envelope; some presented “acceptable” proofs that were “ignored” to assess the depth of the uncertainty they leave in their absence. Not all variants that will be described in this chapter are based on the quest for “acceptable proofs”: in CS2 and 6, for example, they are about the subdivision of the building in energy sectors because of the presence (or, rather, use) of different heating systems. In CS5, 9, 11 and 16, they are about the inclusion of some spaces in, or their exclusion from the protected volume in the EPC description (mainly basements or attics). In CS8 and 15, the newly-and-highly-efficiently-renovated dwellings, the interest was mainly to compare the results from both calculation methods: EPC for existing buildings and EPB for new ones.

Simulations were run with both the Real Climate (RC) data gathered from local climatic stations and the Average Climate (AC) of the EPB regulatory calculation method, on the basis that discrepancies created by an average climate on local situations are to be acknowledged, if it is to be used for realistic foresight evaluations. In each case, the revaluated results will be presented for each variant, considering 4 progressive alterations to the method which are, in order:

- The first simulation, labelled “BASE”, considers the basic modifications that are detailed in chapter 4, but a ΔT_{tset} factor (see Equation (9), chapter 4.3.3.3) equal to zero, and conserves the Heat Gain Application Rate (HGAR) coefficient (see chapter 4.3.3.6) as evaluated by the EPB regulatory calculation method.
- The second simulation, labelled “TSL”, built on the previous one, introduces the ΔT_{tset} factor, based on the respondents’ answers to the questionnaire and the hypotheses described in chapter 4.3.3.3, applicable on the coldest OR the warmer heating months’ set temperatures. Heating months are those which Net Heat Demands are superior to 1% of the annual total. The threshold between coldest and warmer months is marked by the average monthly exterior temperatures ($\theta_{e,m}$ in Equations (6) and (9)) of heating months.
- Third and next-to-last simulation, labelled “HGAR1_HS”, is based on the same hypotheses as the latter one, only the HGAR coefficient is considered equal to 1 during the coldest months of the year, the ones which average exterior temperature is below the average threshold of the previous simulation.
- The last simulation, labelled in graphs “HGAR1_AY” considers the whole ensemble of modifications proposed in chapter 4, and a HGAR coefficient equal to 1 all year round for the evaluation of heating demand.

The last step in the presentation of these case studies was to analyse thoroughly and reflect on these preliminary results to assess the different modifications presented here, to choose the variants and steps in the modified method that will be submitted to the sensitivity testing in the next chapter, and to improve the evaluation of electricity consumptions, in particular, as they influence indirectly the evaluation of heating consumptions. It shouldn't be a surprise, therefore, if most revaluations of electricity consumptions are accurate in the end.

For each case study, the chosen variant will be characterized in a description sheet that can be found in the Annex 2 of this work. These cards regroup:

- A description of the household (H) and the respondent (R) based on the questionnaire (see chapter 4.3.1 or Annex 1).
- A photograph of the street façade of the house.
- Two images of a 3D modelling of the protected volume that helped make the measurements and appreciate the volumetric ratios. Those 3D-models have all been harmonized in colours (all living rooms are red, all kitchen spaces yellow, all bedrooms green, all bathrooms blue…) in order to grasp the internal subdivision in functional spaces, helped by an added legend. The windows are represented in white, and the spaces out of the protected volume are only defined by their boundaries (in transparency). Walls against the ground are lined, and shared walls are represented covered by a grid.

Fig. 5.1.1. Example of 3D modelling images used in the descriptive sheets, for the CS3. On the left, a low-angle shot of the West and South (street) facades; on the right, a high-angle shot of the East and North (garden) facades.

- An added description of the building, containing:
  - General data, which should be specified by the assessor himself to better characterize the architectural or functional specificities that might explain (part of) the energy consumption, such as the number of levels in the volume, the opening characteristics of the stairways, the kitchen or the dining room on the living room, or the typology. The Table also presents important thermal characteristics of the variant's envelope, and its heating and DHW systems efficiencies. Added information on the description of the envelope can be found in this chapter, often explaining the variants description. This Table on the descriptive sheet also includes the results of the official EPC (level on the scale and E_{spec} indicator of specific primary annual energy consumption per square meter of heated floor area), and the real consumption data delivered by the respondents (for natural gas, electricity and wood) with the periods of time covered by these data.

Protected volume V_P [m³]	487
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	228
Compactness $C = V_P/A_T$ [m]	2.13
Global envelope thermal transmittance U_m [W/m²K]	0.64
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	71
Global DHW installation efficiency η_{dhw} [%]	51
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	181
Level on the official EPC certification scale	C
Annual natural gas consumption according to the official EPC [kWh/an]	27,563
Real natural gas consumption [kWh/an]	8,300
Period(s) covered	2015
Real wood consumption [kWh/an]	0
Period(s) covered	-
Real electricity consumption [kWh/an]	3,989
Period(s) covered	2015

Fig. 5.1.2. Example of descriptive energy characteristics for the CS1.

- The back of the cards is dedicated to the behavioural side of the survey. It includes important determiners of the electricity consumption revaluation for the appliances and equipment as well as their answers to inquiries about ventilation and heating related behaviours. A table gathers their attitudes towards Rational Use of Energy behaviours that influence their energy consumption as explained in chapter 4, using a 5-level scale of agreement of assertions:

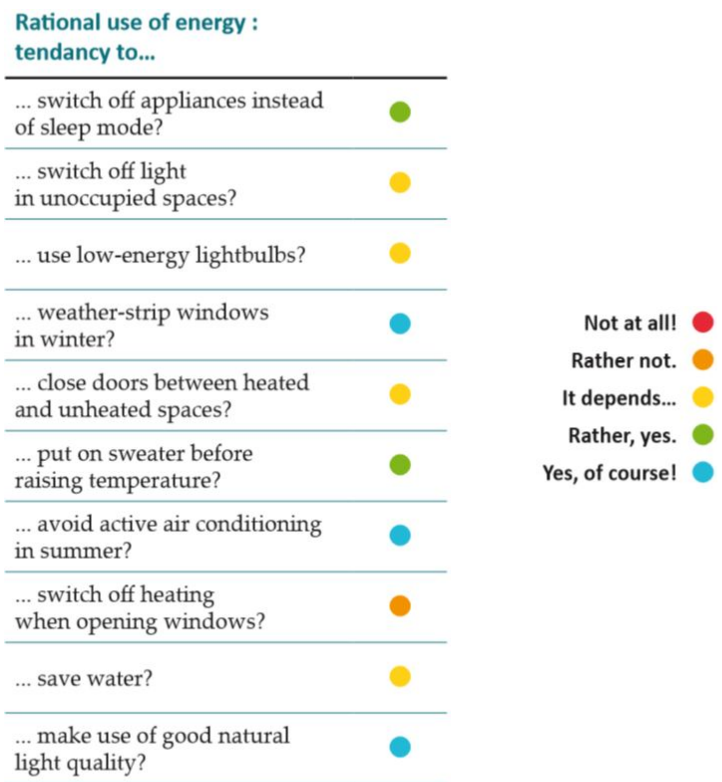

Fig. 5.1.3 Example of RUE behaviours table, for CS1.

- Lastly, the sheet displays the heating pattern deduced from the answers to the questionnaire. The Figure 5.1.4 hereunder exemplifies the subdivision in 8 daily periods for the CS1. Blue-green periods represent daytime heating, whereas the grey periods represent the nightly temperature setback, and blank periods are unheated. The set temperatures specified in this table refer to the directly heated spaces, eventually averaged with volume proportions as weighing factors when several rooms are heated at different temperatures, which explains spread values. The temperature in unheated spaces being part of the results, they are not displayed in these tables. The percentage of V_P (protected volume; energy sectors in CS2 and 6) displayed refers to the directly heated proportion which contains the rooms indicated (LR = Living Room; DR = Dining Room: K = Kitchen; MBDR = Main BeDRoom; OBDR = Other BeDRooms; BTR = BaThRoom; oth. = others). This fVp,hs ratio of Equation (9) is evaluated precisely in theses case studies, using the actual volumetric repartition of functions. When the database of case studies is larger, it could be possible to ease its evaluation with averages in proportions, based on the typologies or the number of bedrooms, for example.

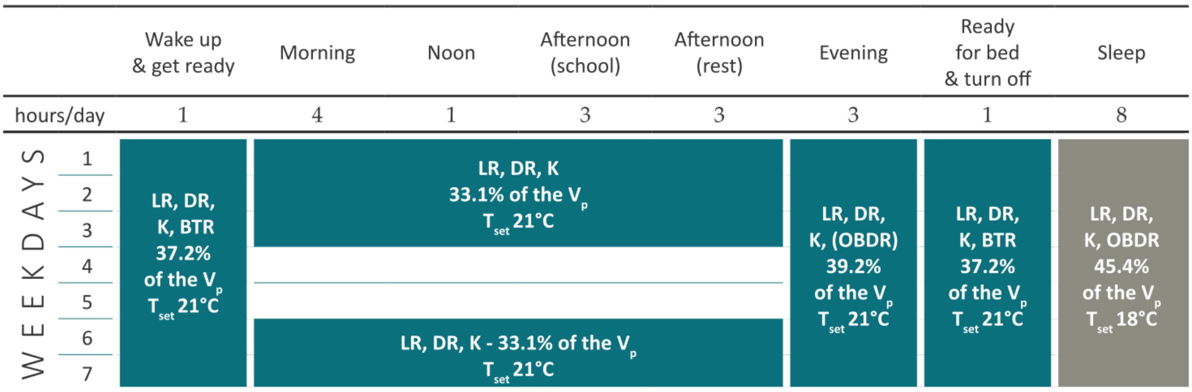

Fig. 5.1.4. Example of heating pattern table, for CS1.

5.2 Description and preliminary results

The order in which the case studies below are presented relates only to the chronological order in which the interviews were led.

5.2.1 Case Study 1 – CS1

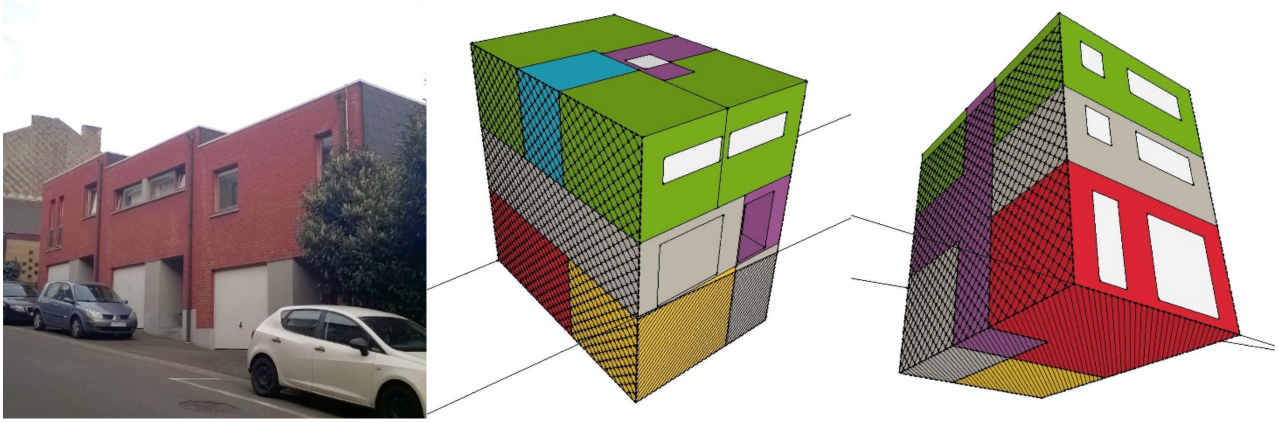

Fig. 5.2.1. CS1 – **Left**: street facade; **centre**: high-angle shot of the West (shared) and South (street) facades; **right**: low-angle shot of the East (shared) and North (garden) facades

This first case study is a recent buildings (2007) from the suburbs of Liege, inhabited by a family of four. The owners are in their thirties, and they had two toddlers at the time of their interview, led on March 31st, 2016. Mr and Mrs A. are independent University graduates, who work part-time at home. During the period covered by the consumption data (2015), Mrs A. was also more at home due to her maternity leave for their second child. The heating pattern (see Figure 5.2.2 hereunder) shows that during the day, between 33% and 39% of the house is heated.

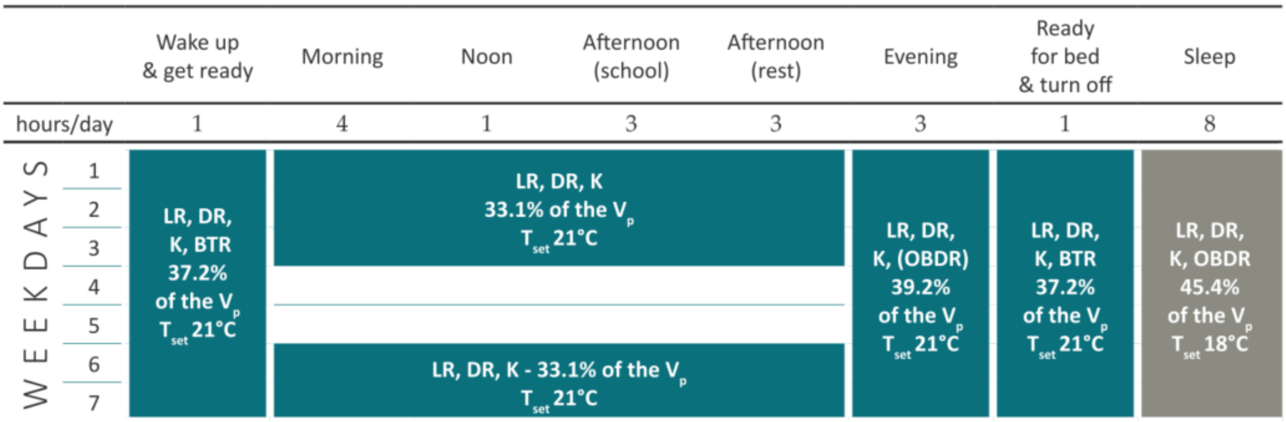

Fig. 5.2.2. Heating pattern of the CS1, according to owners' answers to the questionnaire.

Living room, adjoining dining room and kitchen are heated most of the time. The bathroom is heated only when needed and used, and the children bedrooms (OBDR) are mainly heated in the evenings during the coldest winter months. Living room, dining room, kitchen and children bedrooms are submitted to a temperature setback at night (18°C) to avoid too cold situations (which rarely happen, according to the owners). Their global Rational Use of Energy score is 3.7 out of 5 (average answer to RUE questions used in the modified method).

They are the first owners of this dwelling, but did not follow the construction in itself and bought it "to be equipped". Mr and Mrs A. did not have much acceptable proofs to offer for their dwelling, although they were keen on giving as much information as possible. They mentioned, for example, having added an insulation layer (10cm of bio-sourced material) to the flat roof, and 4cm of polyurethane to the garage door (garage which is used for storage, DIY… park bicycles instead of a car). They were also in possession of "as-built plans" that indicated the presence of insulation in all the construction walls, even in the walls against the ground or shared between adjacent buildings, sometimes in small thicknesses. According to the protocol, the "as-built plans" could not be used in the making of the official EPC, for anything else than the construction date. Mr and Mrs A. having no other proof to offer, documented or visual, to the presence of the insulation layers, 3 variants have been defined here:

- The first is the "official" one, completed with respect to the protocol and list of acceptable proofs. There were few in this case, but it benefitted from the default values attributed to the probable (albeit reported "unknown") presence of insulation in the walls, according to the age of the building. The resulting important parameters are a mean U-value (U_m) of 0.9W/m^{2}K and a $H_{T,heat}$ coefficient of 191.85W/K. The EPC displays the official results as a specific annual primary energy consumption of 181kWh/m^2.year, and a "C" level on the certification scale.
- The second variant, labelled "UAP" (for "UnAcceptable Proofs"), took into consideration the information supplied by the owners, such as the presence of insulation layers they placed

themselves under the roof and against the garage door. The "as-built plans" were considered too, and the indication of types of insulation materials and layers thicknesses were introduced in the software for all the walls where an insulation layer was reported. This still implied the use of default values for the thermal conductivities of materials, for example. As a result of these hypotheses, the U_m value dropped to 0.78W/m²K, the $H_{T,heat}$ coefficient to 170.1W/K, the specific annual primary energy consumption to 155kWh/m².year, and the certification label, to "B".

- The third variant, labelled "Umax" considered that, by having been built in 2007, this building should respect the regulatory requirements that were in force when the permit was introduced. Maximal U-values were already imposed to every walls of the protected volume, albeit they had not yet been modified and reinforced by the EPB regulations: 0.6W/m²K for the exterior walls, or 0.4W/m²K for the roof, for example. This hypothesis could be seen as an optimistic or naïve confidence that buildings indeed respect the minimal energy requirements imposed when they are built or renovated; in this case, the plausibility of these performance levels was somewhat "guaranteed" by the data found in the as-built plans. This operation reduced the U_m value to 0.69W/m²K, the $H_{T,heat}$ coefficient to 147.1W/K (see Figure 5.2.3 below), and the specific annual primary energy consumption to 142kWh/m².year, the certification label remaining to "B".

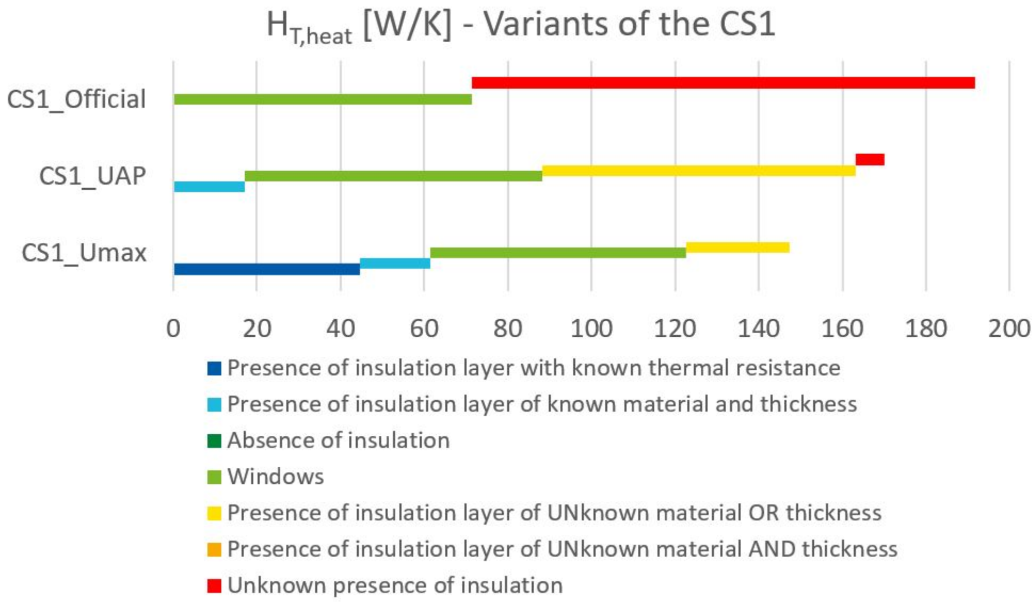

Fig. 5.2.3. Coefficients $H_{T,heat}$ [W/K] for the 3 variants of the CS1

More than the $H_{T,heat}$ coefficients, the Figure 5.2.3 above shows the description behind. Chapter 4.2.1 described the different levels of (un)certainty that can exist in the evaluation of a heat loss wall's thermal resistance, between the minimal information supported by default values, and the complete knowledge of every layer. This is translated in the graph above in the selection and progression of colours representing different levels of accuracy in the knowledge, from the red lowest level, to the blue highest levels of knowledge. An indicator of accuracy on the description of the envelope could originate in such a comparison, although it must be reminded that the description that is made depends on the assessor, and that the theoretical knowledge of the components does not necessarily corresponds to the practical characteristics that could be monitored in reality (depending on the age of the components, the quality of the works, the maintenance…).

In Figure 5.2.3 above:

- The remnant heat losses due to "unknown presence of insulation" in the second variant concern a (small) part of the first floor that is situated above the entrance niche. No section of that zone was visible in any plans.
- The slight improvement in the windows heat losses in the third variant (around 10W/K) is due to the application of maximal U-values on doors (entrance and garage).
- In the third variant still, the remnant heat losses due to "presence of insulation layer of unknown material or thickness" are related to heat loss surfaces which description in variant 2 resulted in U-values that were already better than the U_{max} values required at the time. This is notably the case of the flat roof, re-insulated by the owners, or the walls against the ground which benefitted from the default values and the simplified calculation method, notably the b_j coefficient, for those walls (see chapter 4.3.3.3, Equation (7)). These heat losses, therefore, could be considered as accurate as those defined by the U_{max} values.

No testing of the air tightness had been made, so that the default value of 12m³/h.m² was considered for the $\dot{v}_{50,heat}$ factor (see Equation (15)). The house is equipped with a partial ventilation system, composed of air grids in the window frames of the living room and all the bedrooms, and mechanical exhausts in the bathroom and toilets. The kitchen, open on the living room but placed against the ground, under the garage, is not equipped with any exhaust (other than the hood when cooking), neither is the adjacent laundry room. The owners admitted that in winter, they are used to close the ventilation grids in the windows frames to avoid draughts, and proceeded to ventilate by punctual or daily opening of windows. The extractor in the bathroom being timed on its use, they keep using it normally. As a result, the heat losses coefficient due to air change ($H_{V,heat}$) is revaluated at 37.1W/K, 27.7% of the EPB regulatory hypotheses (133.8W/K).

The house is equipped with a boiler, using natural gas for fuel, located inside the V_P, which provides heat through radiators, and domestic hot water to the bathroom and kitchen. The installations are characterized thus:

- For heating, the global efficiency is 71%, determined by:
  - Production: 82% (low-temperature boiler, placed after 1990, regulation in "sliding temperature" with external sensor)
  - Distribution: 100% (all pipes are in the V_P)
  - Storage: 100% (no storage, direct supply)
  - Emission: 87%. The EPC protocol defines it, for radiators, depending on the type of valves, type of regulation, presence of a thermostat, and on the kind of heal loss wall that can be found behind the devices.
  - Solar fraction: 0% (no solar installation)
- For DHW, the global efficacy of the system is evaluated at 51%:
  - Production: 75%
  - Distribution: 68%
  - Circulation loop: 100% (absent)
  - Solar fraction: 0% (no solar installation)

The results of the revaluation of the final energy consumptions for the three variants of the CS1 are visible in Fig. 5.2.4 hereunder. This graph, which will present in a similar way the preliminary results for each case study, presents many information to look for. They gather the consumption results for all the variants of the case study (3 in this case; "V1_official", "V2_UAP" and "V3_Umax"), both climates (average, in grey columns, and real, in yellow to red columns), all energy vectors (electricity and natural gas in this case), and the different steps of the revaluation mentioned in 5.1 ("BASE", "TSL", "HGAR1_HS" and "HGAR1_AY"). The blue lines represent the EPC results in final energy consumption (which differ for each variant, at least for natural gas consumptions), and the green lines represent the real energy consumptions delivered by the owners.

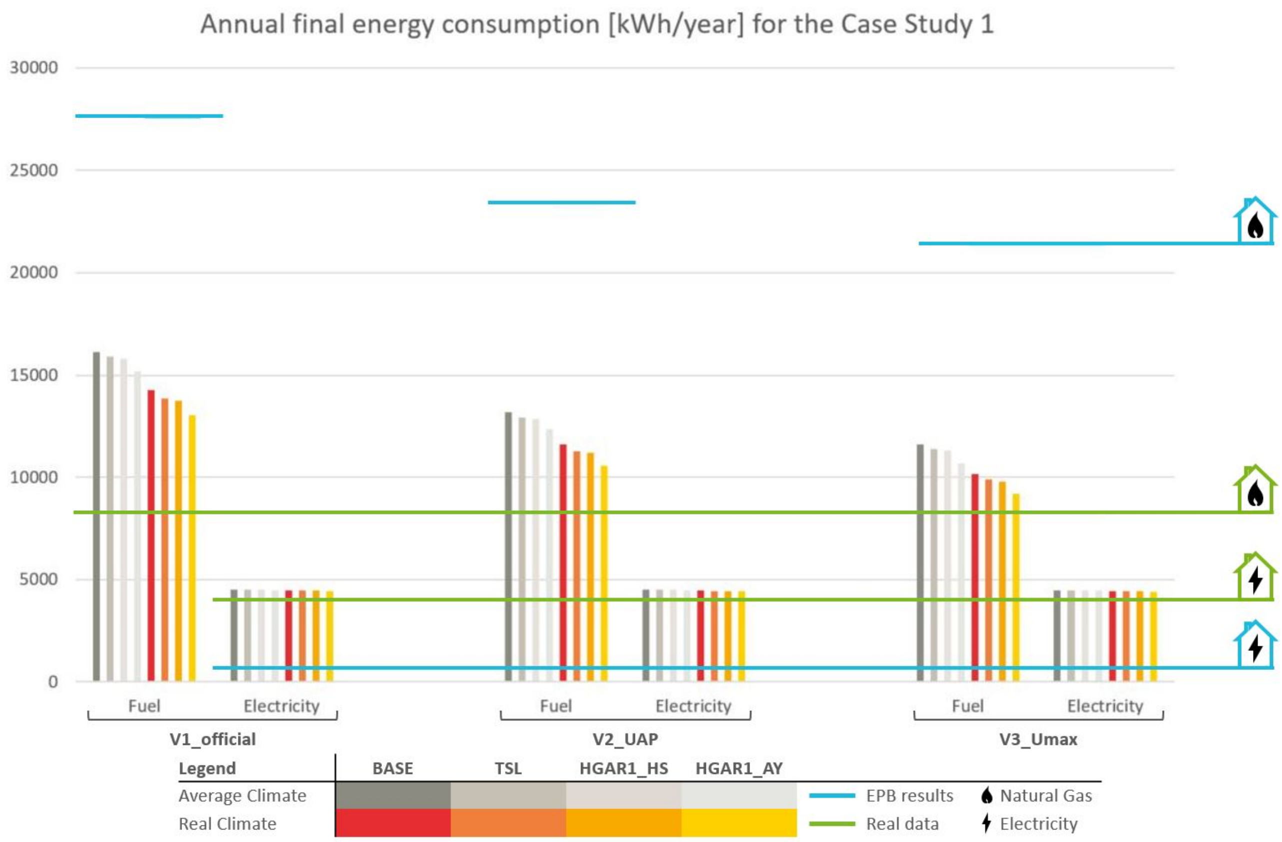

Fig. 5.2.4. Results of revaluated energy consumptions for the three variants of the CS1, for different steps in the method

Real consumption data are only 30.1% of the first variant's EPC theoretical final consumption, 35.5% of the second, and 38.9% of the third. There is, therefore, a factor of 3 that has to be shrunk to next to 1 by the modifications. It is safe to say that in this case, the gap between the theoretical final energy consumption and the real consumptions (in green) has been nearly closed by the hypotheses: the lowest revaluation (third variant, real climate, HGAR1_AY) reaches the value of 1.11.

The use of the real climatic data allowed a reduction of the natural gas consumptions by 13.1% on average, closing the gap in doing so. There is a slight difference between the methods employed (BASE: -12.1%; TSL: -13%; HGAR1_HS: 13.1%; HGAR1_AY: 14.3%), and an ever smaller difference between the variants (12.9% for the V1, 13.2% for the V2 and 3). There is globally few differences however, as this reduction varies between 11.7% and 14.6%, considering all simulations.

Each successive step in the calculation method shown in the Figure 5.2.4 brings its own reduction in the revaluations. The "TSL" step, considering in this case a decrease of the set temperature of 0.5°C, during warmer heating months, brings a 2.1% reduction to the energy consumption simulations. The HGAR1_HS step brings the more timid reduction: 0.8%. The annihilation of this factor's influence in the HGAR1_AY step brings a more important 5.1% reduction to the revaluation in this case. Overall, the reduction between the "BASE" and the "HGAR1_AY" simulations reaches 7 to

9%, depending on the variant and on the climate. The main drop, however, is to be attributed to the introduction of the other behavioural input in the calculation method, described in chapter 4: "BASE" simulations registered reductions of the theoretical consumptions by 41.4% for the first variant in average climate, to 52.5% for the third variant in real climate.

The electricity consumptions are quite accurately evaluated, apparently, between 4,405 and 4,513kWh per year (10.4% to 13.1% higher than the real consumption). The climate influence on consumptions is negligible here, as the extra heating of the bathroom is the only end-use concerned.

The choice of the variant is important: the consideration of additional information on the house apparently helped close the gap, although this could be, by definition, an uncertainty. It is perfectly conceivable that present results for the third variant hide a convenient balance of overestimations and underestimations on different end-uses of the consumption that balance quite well in this case. The presentation of other case studies' results will allow some generalisation, but the results so far tend to choose the third variant for the sensitivity testing, and the detailing that follows.

The Figure 5.2.5 below, therefore, shows the repartition of the revaluated energy consumptions for the HGAR1_AY simulations in the definitive version of the calculation method, for the chosen third variant of the CS1. The upper part of the graph analyses the electricity consumptions, and delivers the remaining gaps between the theoretical evaluations and the real data given by the owners. The comparison with the EPC official results is knowingly impossible, given that the latter only considers heating and ventilation systems' auxiliaries, whereas the revaluations add the consumptions from appliances, lighting, cooking and other dominating end-uses. The lower part does the same with the natural gas (in this and most cases) consumptions. The red portions show that the net heat demands have been reduced from 20.8 to 27.4% of those estimated by the official EPC, thanks to the behavioural modifications. The DHW is given more importance in the total consumption after modification, as the net demand in this case is apparently underestimated by the EPB method (or overestimated by the modified method).

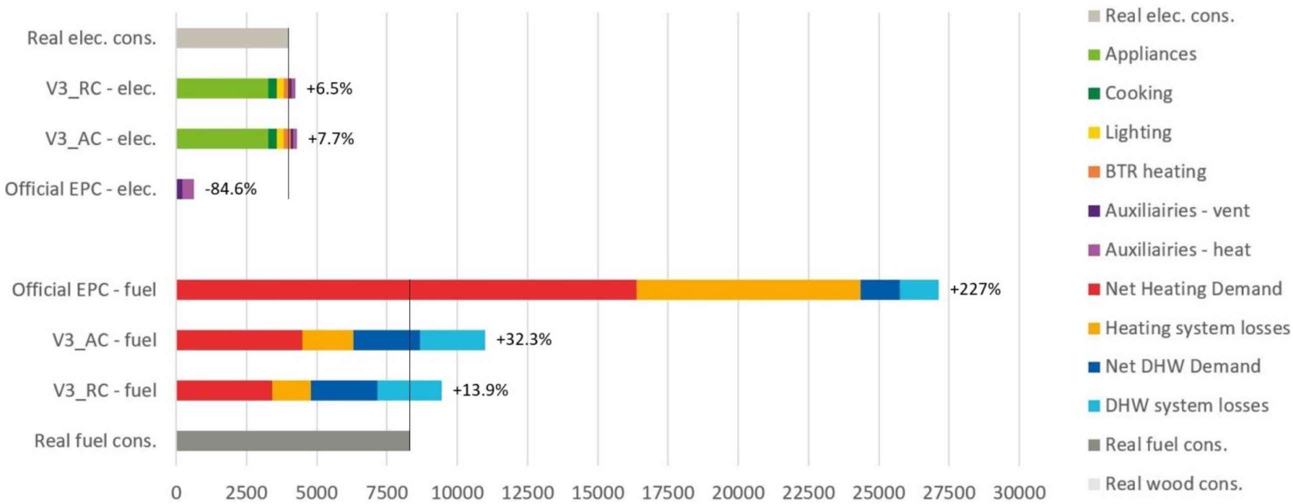

Fig. 5.2.5. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS1

Credibility of the results can also be analysed through the curves of temperatures inside the house. The next Figure 5.2.6 shows them for the chosen variant and terminal simulation step of the CS1 (HGAR1_AY). There are, in this graph, many information to look for as well. The curves, first, display the annual evolution of monthly average temperatures due to daytime settings (blue curves) and night time settings (grey curves). For each set, the upper, darker curve marks on the left axis of the graph, the temperature in directly heated spaces. Lower, lighter curves indicate the resulting temperature in unheated spaces, as evaluated by the Equation (9) of chapter 4. Intermediary curves are the average of both, weighed by the proportion of heated spaces in the V_P ($f_{V_{P,hs}}$ in Equation (9)). The red curve indicates the global resulting monthly average temperature in the whole V_P, the temperature that is evaluated to replace the standardised 18°C of the regulatory calculation method (yellow line). The green curve, finally, marks the exterior temperature (real climate data). Columns indicate the monthly final fuel consumption for heating only (right vertical axis of the graph), evaluated based on those temperature hypotheses. Darker columns mark "coldest heating months", whereas lighter columns mark "warmer heating months".

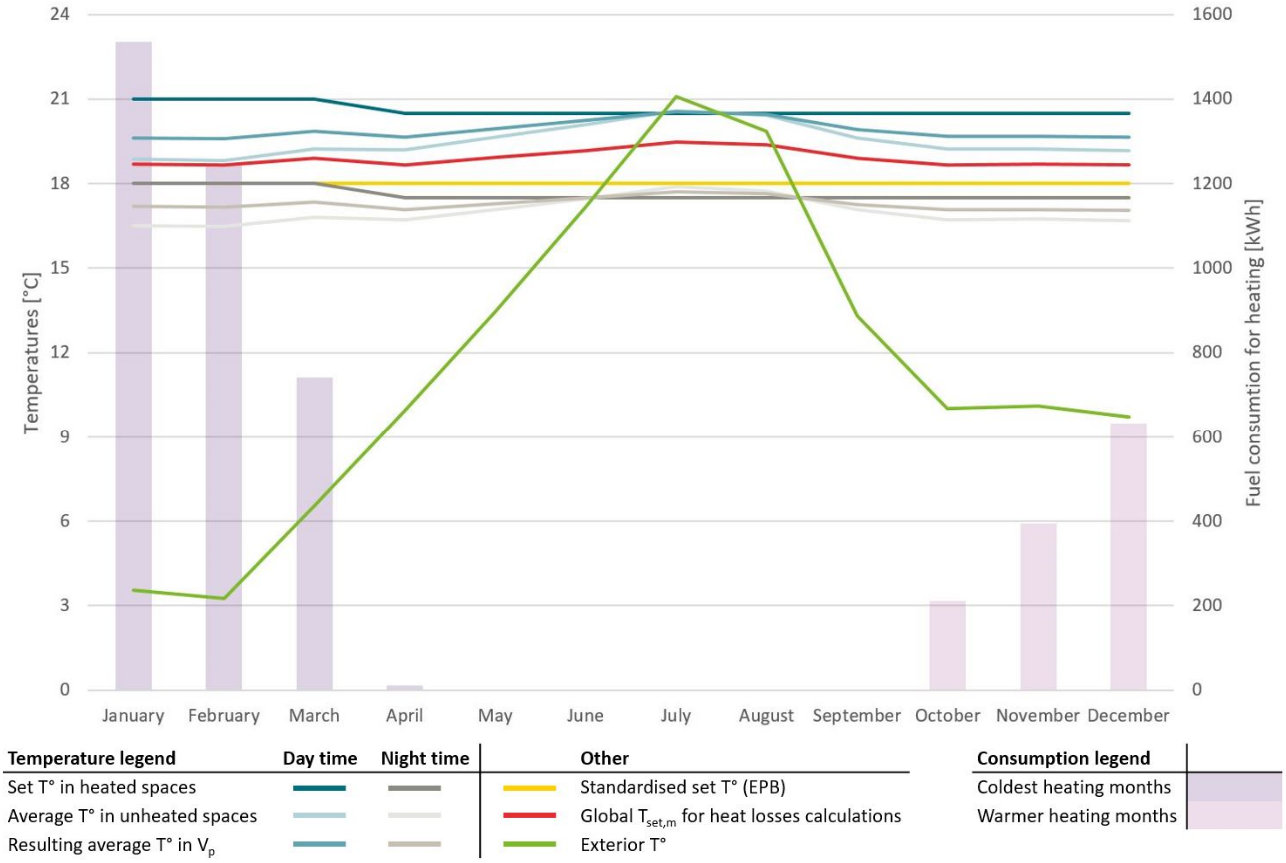

Fig. 5.2.6. CS1: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

It shows, notably, that the temperatures inside the V_P should be quite stable, and that the evaluated temperature in unheated spaces is quite close to the set temperatures in heated spaces (other case studies, lesser insulated or performant, will show greater differences).

The small consumption for the month of April being inferior to 1% of the total consumption (the same can be said about NHDs), its exterior temperature is not taken into account in the calculation of the threshold between coldest and warmer heating months. In this case, therefore, the heating period covers the first three coldest months of the year, and the three warmer last ones. It could seem odd that the consumption for October, November and December should increase progressively, when the exterior temperature was quite stable. This shows the influence of the solar gains on the results, as they progressively decrease during those three months.

5.2.2 Case Study 2 – CS2

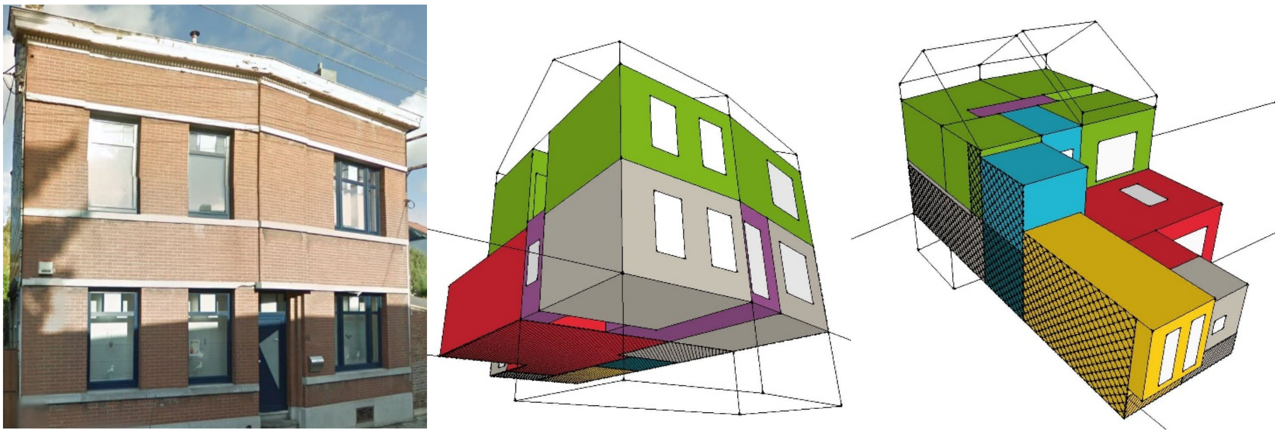

Fig. 5.2.7. CS2 – **Left**: street facade; **centre**: low-angle shot of the OSO (alleyway) and SSE and SE (street) facades; **right**: high-angle shot of the ENE (shared) and NNO (garden) facades

The second case study is a large (842m³) house, built and extended over the years in the suburbs of Liege. The house was recently renovated by works that mainly targeted the annex (extension and insulation) and the installation of 9.12kW$_P$ of photovoltaic panels on the roof. The acceptable proofs for the envelope, in this case, consisted on a complete file of the renovation works, notably bills that allowed to consider the presence of insulation in the roof, walls and floor of the extension, and in the flat roof of the older extension. The presence of insulation in the attic floor, visually witnessed by the assessor, allowed to exclude the attic from the protected volume. As far as the other walls and heat loss areas are concerned, no visible insulation, or suspicion of some, could define variants. The global $H_{T,heat}$ coefficient for the CS2's envelope is evaluated at 763.6W/K, its repartition, according to uncertainties on the input, visible in Figure 5.2.8.

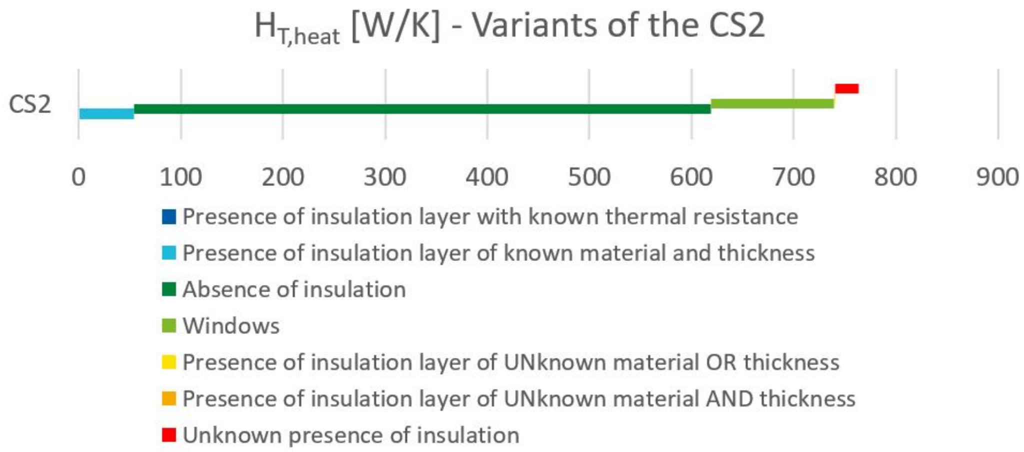

Fig. 5.2.8. Repartition of the $H_{T,heat}$ coefficient [W/K] for the CS2

The coefficient is dominated by the high share of uninsulated walls. The uncertainty on the description of these walls can be limited to the uncertainty on the default values used as thermal conductivity coefficient for the materials, and taming "b_j" coefficients. The default thermal resistances of floors could be considered a bit more suspicious however, as it is defined by a single choice of the type of structure: "standard" (thermal resistance of 0.26m²K/W, regrouping light floors made of a wooden structure as well as concrete floors, whether made of hollow-core slabs or cast-in-place decks) or "cellular concrete" (0.5m²K/W). The remaining wall with unknown presence of insulation is the roof of the first extension, which still covers the parents' bathroom.

The house is equipped with a central heating installation, connected to a condensing boiler using natural gas, situated in a basement considered outside of the protected volume:

- For heating, the global efficiency of the central heating system is 69%, determined by:
  - Production: 90%;
  - Distribution: 95% (uninsulated pipes in V_P);
  - Storage: 100% (no storage, direct supply);
  - Emission: 81%;
  - Solar fraction: 0% (no solar thermal installation).
- For DHW, the global efficacy of the system is evaluated at 39%, considering:
  - Production: 75%;
  - Distribution: 51% (default for lengthy pipes, due to great distances between DHW producer and bathrooms and kitchen end-uses);
  - Circulation loop: 100% (absent);
  - Solar fraction: 0% (no solar thermal installation).

The pipes allow the heat distribution in all the rooms of the protected volume. However, Mr and Mrs B. have acknowledged a change in their heating habits since the installation of the PV panels, encouraging the use of electric heaters in the bedrooms and bathrooms. "*We try to use the electricity from our panels*", as Mrs B. stated, and the data they delivered for three consecutive years certainly shows an equilibrium between production and consumption:

Table 5.2.1. Annual electricity production and consumption in the CS2

Year	Electricity produced by PV panels[1] [kWh]	Electricity consumed [kWh]
2013	9,135	10,243
2014	9,766	9,436
2015	10,154	9,983
Total	29,055	29,662

The efficiency of the local electric devices is evaluated at 96%, considering:

- Production: 100%;
- Distribution: 100% (local system, no distribution);
- Storage: 100% (no storage, direct supply);
- Emission: 96% (default value for direct electric radiators or convectors with electronic regulation).

In the certification protocol, when assessors find themselves in a situation where a central heating system and a local heating system are both present in a room, they are supposed to ignore the local system and only consider the central one. This leads to the definition of the "official" EPC, but seems at odds with the description of the heating habits, and could lead to unrealistic results. A solution appears in the notion of "energy sector" (ES) in the EPB and EPC calculation method: an energy sector is defined as a sum of rooms, included in the protected volume, considered heated by the same heating system and showing therefore identical efficiencies in terms of heat production and emission. The approach is quite different between both methods, however: for example, the EPB

[1] The EPC regulatory calculation method evaluates the annual production of 9.12kWp of PV panels, oriented SSE and inclined 30°, to 6,098kWh/year.

method for new and renovated buildings will require the consideration of the local system over the central one, if both are presents in a room, because of its less favourable efficiencies. The subdivision in ES, which only affects the evaluation of energy consumption for heating, is required by the EPC protocol; the EPB method imposes, if ES are not defined when they could be, to consider the most detrimental values for the system's efficiency. But the main difference between both methods lays in the description of those sectors:

- In the EPB method, the ES are defined at the very beginning of the description process, and the complete energy balance is made for each sector separately, which implies the necessary distinction in measuring and describing the heat loss surfaces beforehand. This process is, honestly, more time-consuming for assessors.
- In the EPC method, the protected volume is first defined and its global envelope, described as a whole. The definition of ES comes afterwards, at the description of the heating systems, when the assessor is asked to choose a volumetric repartition between the different ES among three possible choices: 100/0, 80/20 and 60/40. The Net Heat Demand will be basically divided according to this ratio, and to each part will be attributed systems efficiencies that will turn that demand into consumption.

As there was not much debate to be expected from the description of the envelope or the protected volume in this case, the CS2 variants are defined based on the description of the energy sector:

- The first and "official" EPC was completed with respect to the protocol and list of acceptable proofs. The protocol requires, in this case, to consider only one energy sector of rooms heated by the central installation, and to neglect the use of movable local electric heaters. For this variant, the revaluated electricity consumptions were approached as explained in chapter 4.3.2.4 for the bathroom extra heating end-use. For the bedrooms, the consumptions were approached by applying a volumetric ratio on the global NHDs (22.5% for the bedrooms and 77.5% for the rest, in this case) and different efficiencies to the corresponding shares. The result of this official EPC is a house characterized by an average U-value of 1.4W/m²K (for a total heat loss surface of 602m²), and a "D" level on the certification scale due to the specific annual primary energy consumption of 293kWh/m².year.
- The second variant, labelled "2ES_EPC", considers the use made of the heating systems, be it electric and movable, more than their presence. Two ES are therefore defined, and in this variant they are described according to the EPC protocol and method. The 60/40 repartition of the protected volume is chosen, which is not far from the 63.5/36.5 reality, and the same ratio is applied on the NHDs. Considering the efficiencies above, the result is an "E"-labelled house, characterized by the same average U-value and heat loss area than the first variant, but a specific annual primary energy consumption of 392kWh/m².year.
- The third variant, labelled "2ES_EPB", considers the description of the ES according to the EPB method for new and renovated buildings. The 63.5/36.5 ratio is applicable, although it is more a general information than a useful parameter in the method here, as each sector is described separately in terms of envelope and heating systems. The EPC software does not allow such a division, so that two files were created for evaluating the heating consumptions. The results evaluated on the total V_P, such as the DHW consumption, were collected from the second variant to insure correct global results: a specific annual primary energy consumption of 410kWh/m².year ("F" level on the EPC scale), defined by the differentiated average U-values of 1.43W/m²K for the first ES, and 1.34W/m²K for the second ES.

In this house dwells a family of 5, composed of the parents in their forties and 3 children in schooling age. Mr B. goes to work every day out of his home, and Mrs B. is a teacher: their occupation (and heating) pattern of the house, therefore, is very much defined by the school hours, as can be seen in Figure 5.2.9 (also visible in the descriptive card of the CS2 in the annexes). It is divided between two energy sectors, and the indicated volumetric proportions are related to the third variant definition. The first sector represents therefore 63.5% of the V_P, and the second, 36.5%.

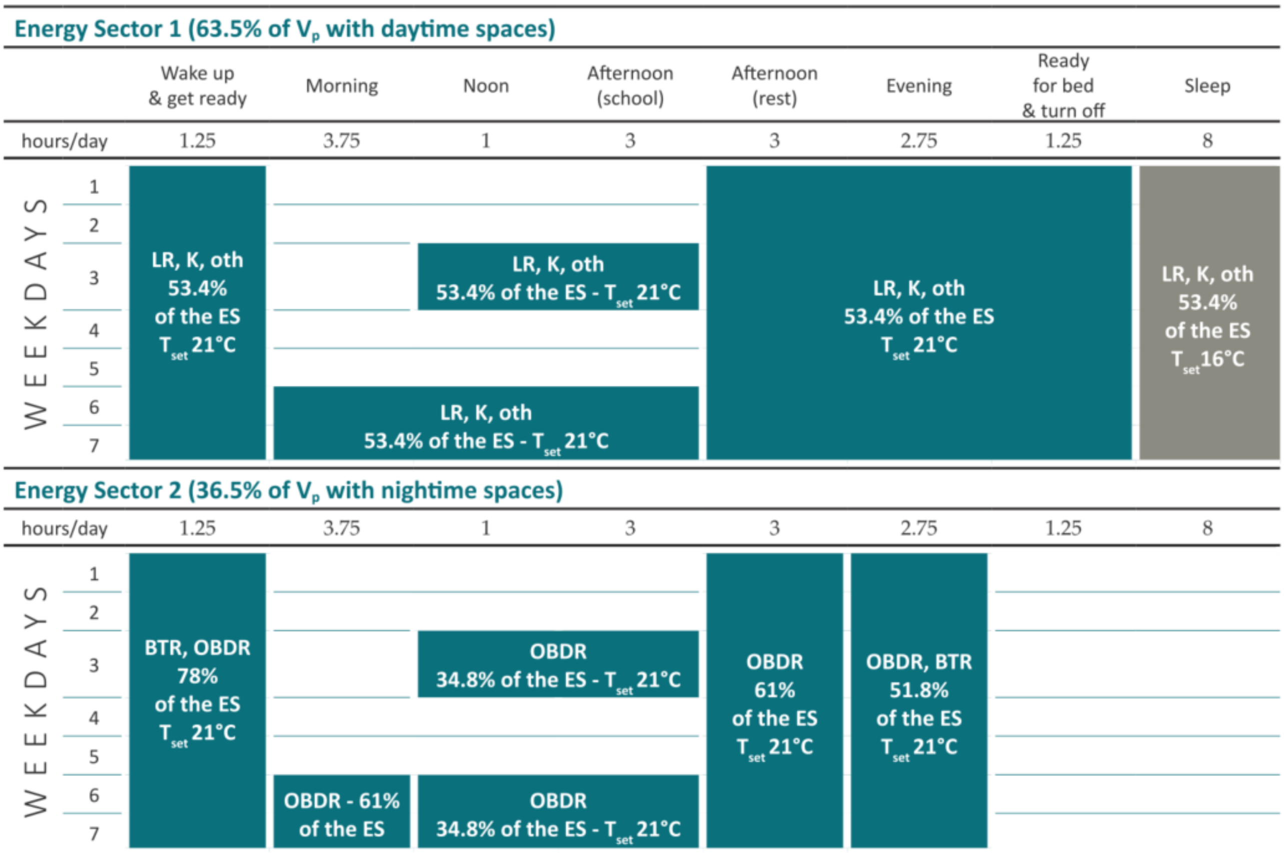

Fig. 5.2.9. Heating patterns of the first (above) and second (below) energy sectors of the CS2, according to owners' answers to the questionnaire.

The heating pattern of the first sector always concerns the same daytime rooms: living room, kitchen and "other", which relates to the cellar adjacent to the kitchen. All these rooms are in the extensions; the ground floor of the initial building (street block) includes an office, the entrance hall and a dining room (separate from the living room, rarely used), all of which are "rarely heated" according to the owners. In the heating pattern of the second energy sector, the children bedrooms represent 61% of the ES2, and the bathrooms, 17%. Other proportions that are shown in Figure 5.2.9 for the ES2 are the results of differentiated heating patterns between coldest and warmer heating months. For example, during warmer months, the children bedrooms are heated on mornings (until noon during weekends), and in the evenings, before bedtime. The proportion of 34.8% during afternoon periods considers in reality 61% heated during coldest months, and 0% during warmer months.

The owners gave real electricity and natural gas consumption data for 3 years. Unfortunately, real data were not available from the climatic station of Liege before April 2013, which means that only two years of consumption could be assessed hereunder. Climatic data, however, cannot alone explain the annual discrepancies in consumption. The set of data used for de-standardising the calculation method is the same, from one year to the other, which means that annual discrepancies that cannot be explained by the weather conditions probably have roots in behavioural "inconsistency" that cannot be taken into account in this method. B. ALLIBE's is partly right in suggesting that "bottom-up models cannot explain the dynamics of consumption"[2]. The accuracy of the modified results still have to be analysed with the different climates:

- The Figure 5.2.10 shows results for the period from April 2014 to March 2015 for natural gas, and January to December 2014 for electricity.
- The Figure 5.2.11 shows results for the period from April 2015 to March 2016 for natural gas, and January to December 2015 for electricity.

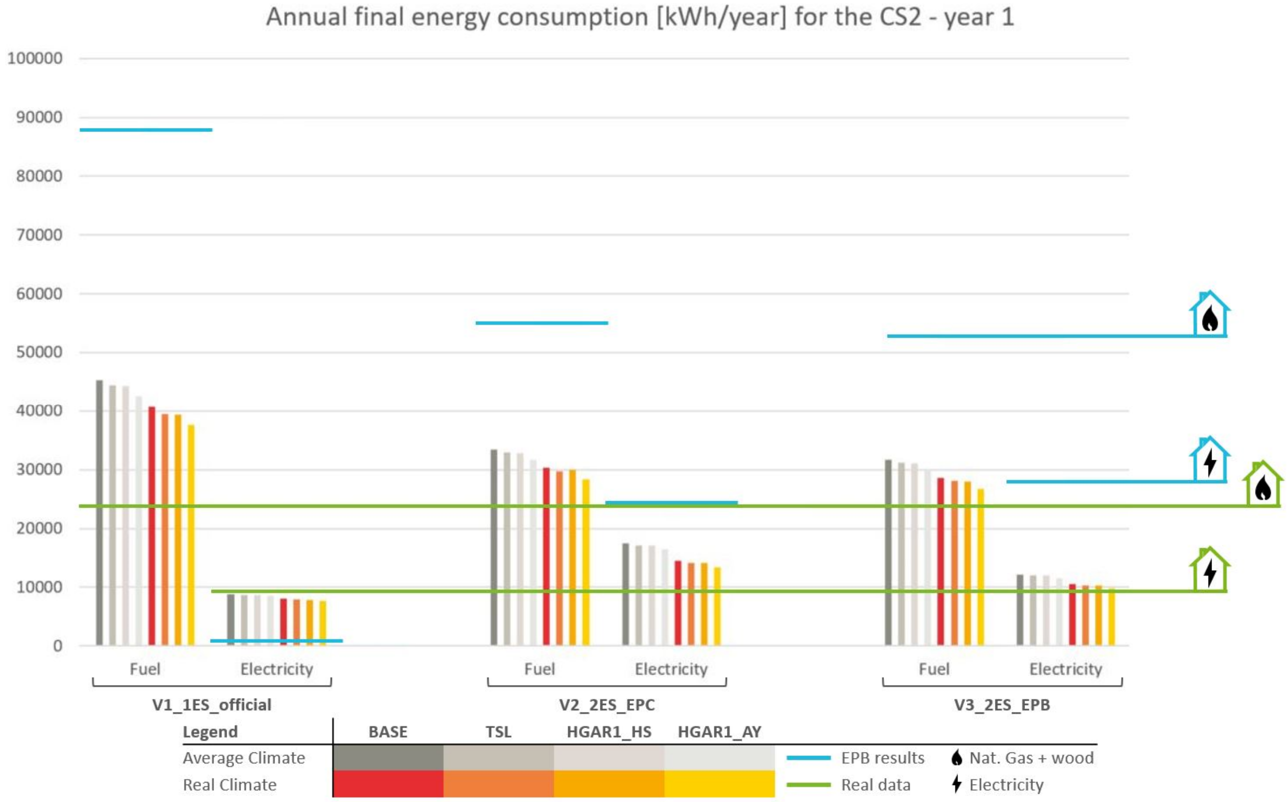

Fig. 5.2.10. Results of revaluated energy consumptions for the three variants of the CS2, for different steps in the method and the **first** climatic year.

The regulatory theoretical results are evaluated between, for the third variant, 2.2, and, for the first, 3.7 times the natural gas quantity consumed by the owners during the first year, 1.94 and 3.23 times the quantity consumed during the second year. The subdivision in energy sectors (variants 2 and 3) brings the necessary reduction of volume to which the central heating efficiencies have to be applied, the results are lower and consequently more accurate. The lowest revaluations, for the third variant, are 12% above the real data for the first year, 5% under them for the second, which are much more acceptable results. The use of real climatic data delivers the same kind of reduction than in the CS1: -10.2% in the first year, -12.9% in the second. Those reductions are relatively constant, whatever the method or the variant.

The choice of variant will mainly come from the electricity consumption revaluations results in this case. The first variant clearly underestimates the consumptions, both regulatory (EPC results in

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[2] B. ALLIBE, 2012. *Modélisation des consommations d'énergie du secteur résidentiel français à long terme. Amélioration du réalisme comportemental et scénarios volontaristes*. Thèse défendue à l'Ecole des Hautes Etudes en Sciences Sociales, CIRED - Centre International de Recherche sur l'Environnement et le Développement, Nogent-sur-Marne, France

electricity consumption ≈ 9% of the real data) and revaluated (81.8% for the lowest). The second variant overestimates the consumptions, both regulatory (EPC results ≈ 256% of the real data) and revaluated (142.1% for the lowest). The third variant indicates EPC results that are nearly thrice (296%) the real consumption data, but in this case the revaluation is more accurate (104.4% for the lowest revaluation). This can mainly be attributed to the more accurate description of both sectors, in terms of heat losses. In the second variant, the NHDs are simply divided by a 60/40 ratio, without consideration for the particular heat loss areas that define each sub-volume. This results in a higher share of NHDs for the energy sector 2 (the one heated by electricity) in the V2 than in the V3.

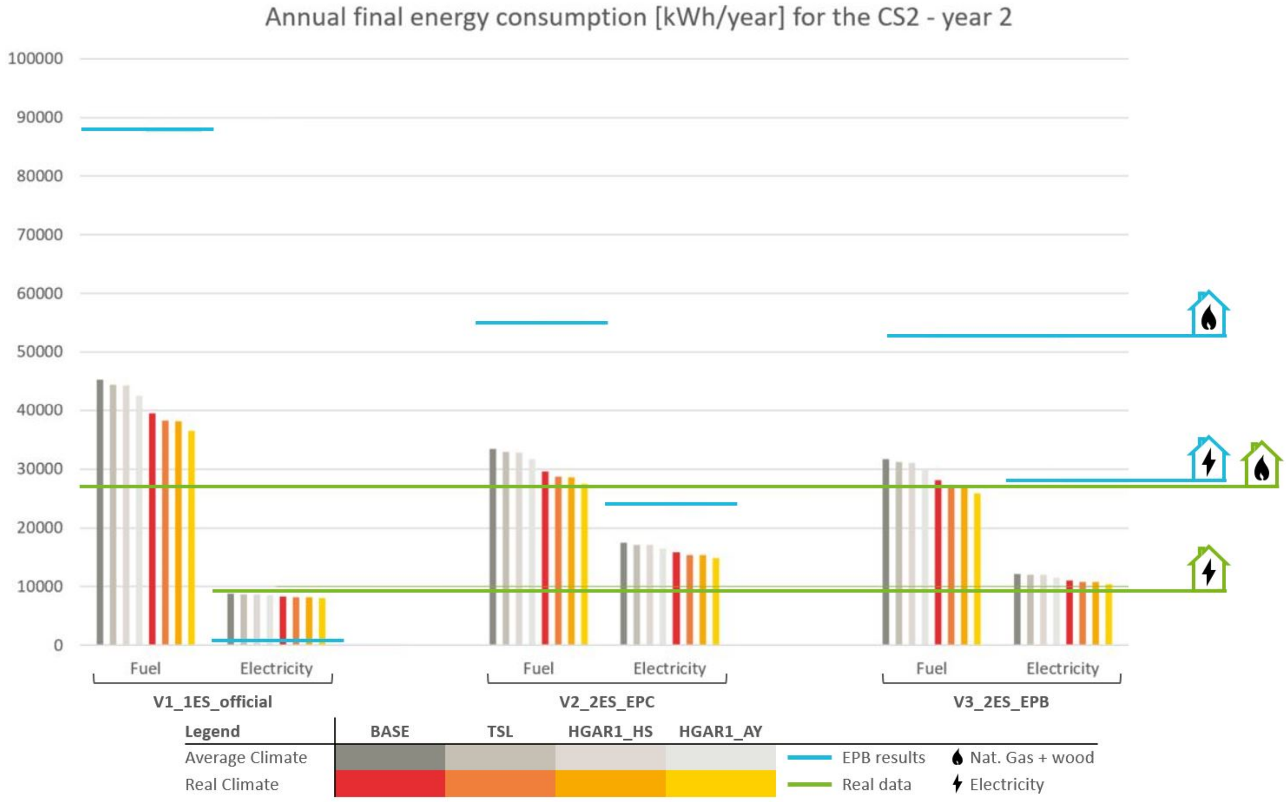

Fig. 5.2.11. Results of revaluated energy consumptions for the three variants of the CS2, for different steps in the method and the **second** climatic year.

Given the high share of uninsulated walls and the high influence of default values on the description of the envelope and the system, results so close to reality could be considered surprisingly accurate. The conclusion is similar to CS1: either the hypotheses are "spot-on", either overestimated consumptions, due to detrimental default values for example, are compensated by underestimations on other end-uses. The latter is the most probable situation, but other case studies have to feed this reflexion. The next Figure details the energy consumptions (revaluated with the last model version, especially for electricity consumptions) of both energy vectors, according to the official EPC, the real data and the chosen variant for the sensitivity testing, which in this case is the third variant (in its HGAR1_AY version). The declared consumption of wood logs, has been added to the natural gas consumption, as it is used to heat the same energy sector. It must be reminded, however, that, first, the efficiency of that fire pit is not known by the method, which only considers the settings of the thermostat, and the presence, alone, of the condensing boiler. If the efficiency of that particular system is difficult to determine, so are the related NHDs, as it is not used every day but on some cold winter evenings, and the temperature attained in the living room as a consequence of its use cannot be guessed easily. In this case, wood consumption is estimated at 1,970kWh, or around 5%

of the total final energy consumption of the household, and is mainly used for extra heat (above the set temperature used in the calculation method) during cold evenings.

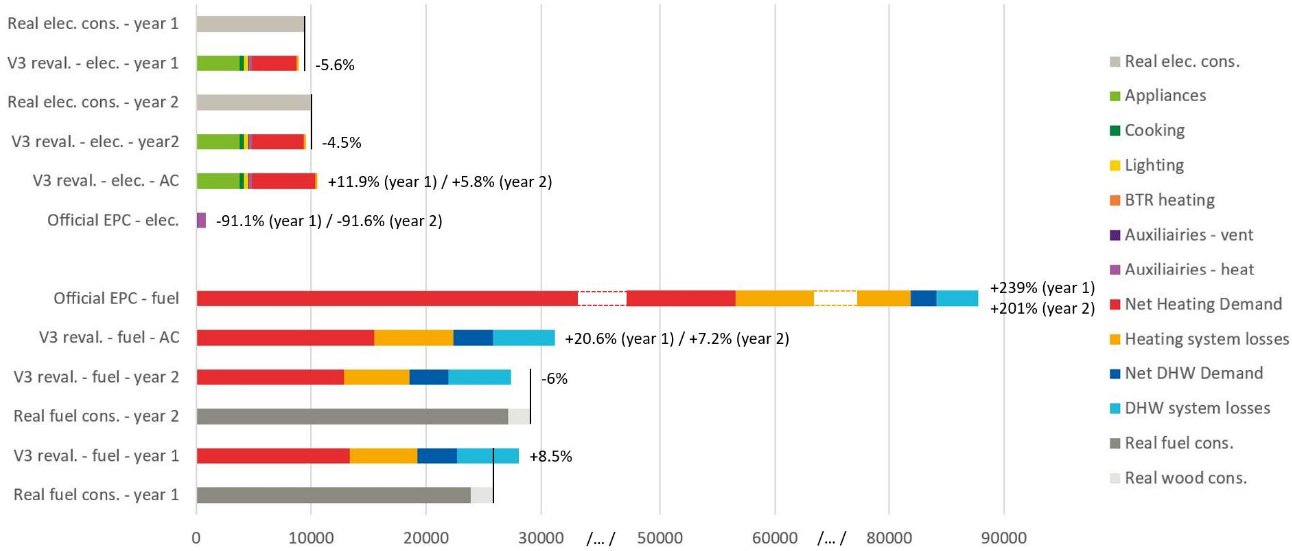

Fig. 5.2.12. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS2

The Figure 5.2.12 shows that the repartition of consumptions seems quite reasonable, although the importance of the DHW installation losses could be questioned here. The boiler is in the basement, but most of these "losses" do happen inside the protected volume, and might be considered useful as internal gains. Overall, the huge gaps of more than 200% of the real consumption data, brought by the official EPC, could be lowered to less than 10%, an ultimate goal.

The next Figure 5.2.13 shows the temperatures evaluated in the unheated spaces of the volume, and the overall temperature that is used to evaluate the heat losses, considered as replacement of the constant 18°C of the standardised method. This graph is a little bit more complicated than for the first case study, as it contains the information for both energy sectors of this case study. The set temperatures (darker blue and grey curves), for daytime and night time periods, are the same in both ES calculations. In this case study however, there is no demand in heating for the second energy sector (containing the bedrooms and bathrooms) during the nights, according to the owners' answers to the questionnaire. In consequence, the resulting average temperature (in red) is higher for the ES2 than for the ES1, as the night periods are affected with a null weight in the average.

Globally, the graph shows that, for coldest months (like January, which average outside temperature is around 3.5°C), the temperature in unheated spaces of the ground floor (ES1) are expected to lower to 17°C, and those on the first floor (ES2), to 15°C, when the rest of the V_P is heated at 21°C. The resulting average temperature is around 19°C for the ES1, and a little above 18°C for the ES2. As there is no night heating of the ES2, the curve of the "resulting average T° in ES2" (intermediary blue) is the same than the "Global $T_{set,m}$ for heat losses calculations" (red curve). For the ES1, on the other hand, the global $T_{set,m}$ is the result of the average "resulting average T° in ES1" for the daytime periods (intermediary blue curve) and the night time period (intermediary grey). The heating period here is partitioned between 4 coldest months and 3 warmer ones. The consumptions given in Figure 5.2.13 only concern the heating of the dwelling. The same exercise was done for the second climatic year, but does not bring much more information to the reader.

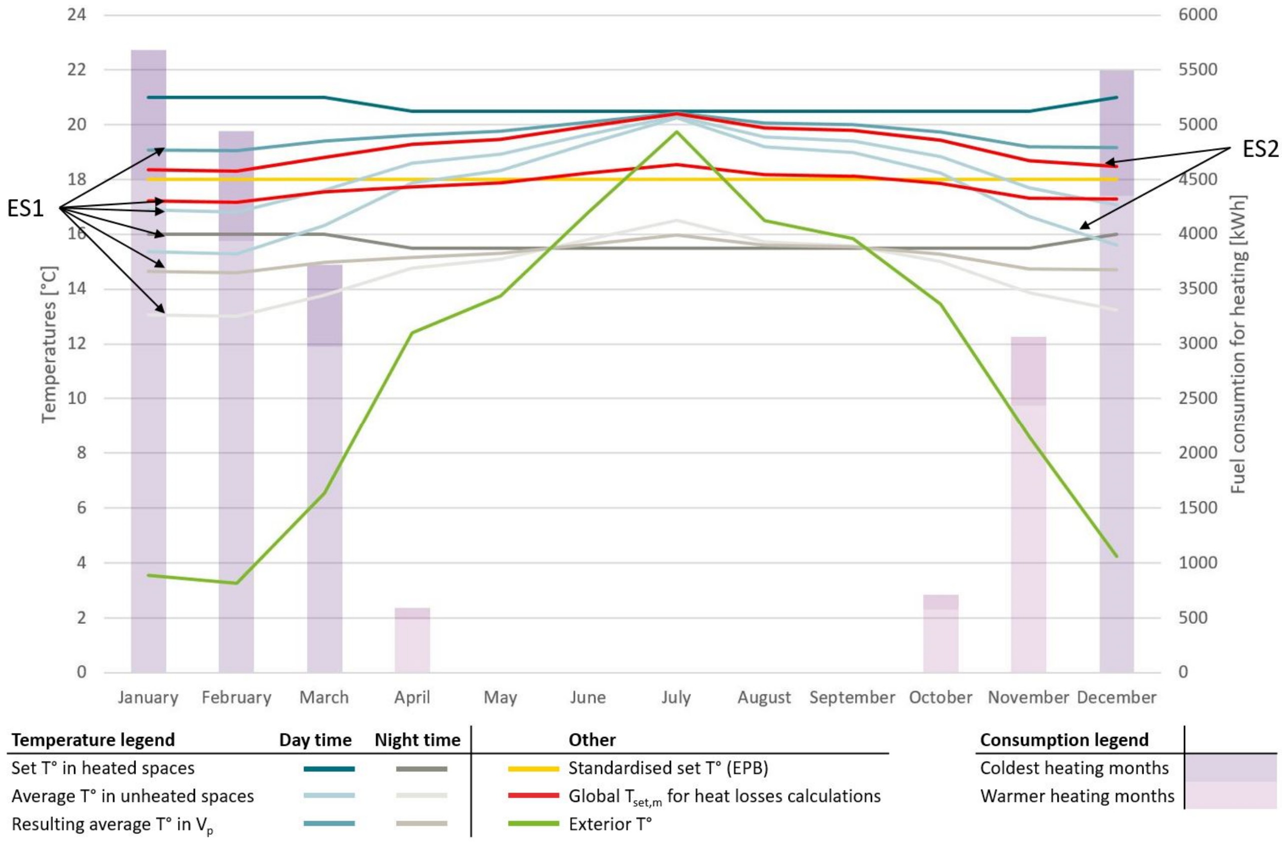

Fig. 5.2.13. CS2: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

5.2.3 Case Study 3 – CS3

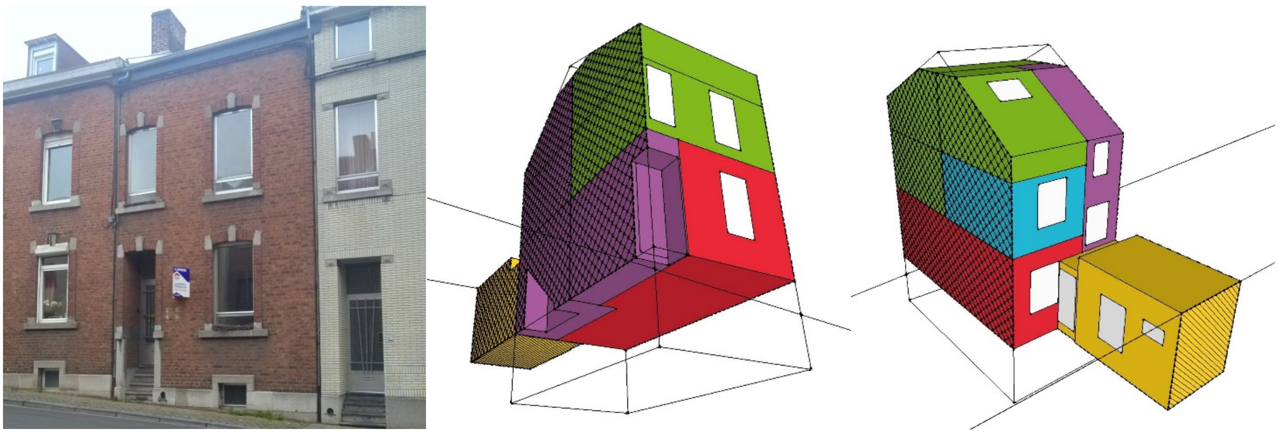

Fig. 5.2.14. CS3 – **Left**: street facade; **centre**: low-angle shot of the West (shared) and South (street) facades; **right**: high-angle shot of the East (shared) and North (garden) facades

The third case study is a row house built in the first half of the 20th century, very similar to the CS7 (see further) in typology, but in row position (whereas the CS7 is an end-of-row). Both houses are located on a hill side: in the case of the CS3, the hill goes up from the entrance. This means that the garden is at first-floor level, resulting in a bad quality of natural lighting and of ventilation of the ground floor. In the CS7, the hill goes down from entrance level, so that the whole dwelling is elevated from the ground at the back and benefits from better lighting and ventilation. It might be worth noting that the owners of this house, Mr and Mrs C., did not stay long in it: the bad comfort quality and lack of natural light drove them out of the dwelling a few months after the interview.

The C. family that lived in this dwelling is composed of four members: two parents in their thirties raising their two young children. At the time of the survey, the youngest boy was still a toddler, looked after by the Mrs C. who decided to be a stay-at-home parent for the time being. The pattern, therefore, shows continuous heating during the winter period. The proportion of constantly heated volume can be reduced to the only living room (and attached dining room) for large periods of time. Mrs C. explained that, because of the humidity and bad light in the kitchen, it was only used and heated when needed. It is also a bit more heated during the coldest months to "cut humidity", and during weekends when everybody is home. The children bedrooms were located on the last floor of the house, the only part that had been renovated prior to their moving in the house. New windows had been placed in the newly-insulated roof (part of that insulation was still visible when they moved in, but their retrofitting of the halls hid it). As a result, the upper floor benefitted from warmer temperatures in the house, and the children bedrooms rarely had to be heated, except before bedtime during the coldest months.

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3	1	8
WEEKDAYS 1–7	LR, DR, K 39% of the V_p T_{set} 21.38°C	LR, DR, (K) 30.4% of the V_p T_{set} 21.77°C	LR, DR, K 39% of the V_p T_{set} 21.38°C	LR, DR, (K) 30.4% of the V_p T_{set} 21.77°C	LR, DR, K 39% of the V_p T_{set} 21.38°C	LR, DR, K, (OBDR) 51.1% of the V_p T_{set} 21.09°C	LR, DR, K, BTR 47.8% of the V_p T_{set} 21.13°C	LR, DR 26.9% of the V_p T_{set} 18°C

Fig. 5.2.15. Heating pattern of the CS3, according to owners' answers to the questionnaire.

There seemed to be few possibilities for this family to maintain a constant and homogeneous comfort level in the house, which might explain the changing proportions of heated V_P and set temperatures in the Fig. 5.2.15 above. With only one income for the household, this low-earning family could probably fit the definition of "fuel poverty" as defined in chapter 3.4.4.2.

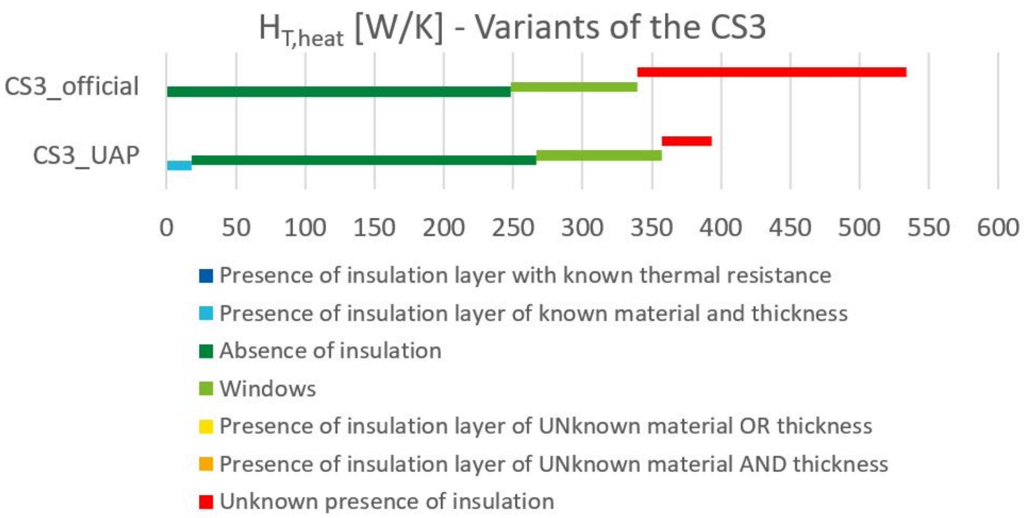

Fig. 5.2.16. Coefficients $H_{T,heat}$ [W/K] for the 2 variants of the CS3

The definition of the envelope is quite simple in this case, as there are few walls which description could be considered uncertain. The $H_{T,heat}$ coefficient (Figure 5.2.16) is dominated by a large share of walls with absent insulation (most vertical walls and floors) and the default values of the windows. In the first, "official" variant, the presence of insulation in the tilted roofs is considered unknown, resulting in a large share of heat losses by default. No acceptable proof could be used to indicate the date of renovation. In the second variant ("UAP"), the presence of 12cm of extruded polystyrene was considered, based on the owners' knowledge, marking the reduction of 158.27W/K of unknown heat losses into 17.96W/K of "better" defined ones. The presence of insulation in the flat roof of the annex remains unknown, however, and the owners could not bring more information on the subject.

As far as air change is concerned, this house has not been submitted to an airtightness testing, and the default value of 12m³/h.m² for the $\dot{v}_{50,heat}$ parameter in Equation (15) has been imposed. The C. family is also one of the few to have declared very rarely ventilating their living room, bedrooms or bathroom in the winter. The humidity of the kitchen seems to impose the daily opening of windows, and the resulting revaluated $H_{V,heat}$ coefficient stays low at 26.2W/K.

The house is equipped with an old boiler using natural gas, providing heat and DHW, situated in the basement (which has to be considered out of the protected volume, undoubtedly).

- For heating, the global efficiency is 60%, determined by:
  - Production: 77%, default efficiency for natural gas boilers that are neither condensing nor atmospheric, of unknown label or regulation, installed out of the V_P after 1990;
  - Distribution: 95% (uninsulated pipes out of the V_P);
  - Storage: 100% (no storage, direct supply);
  - Emission: 82%, due to the presence of several radiators in front of uninsulated walls;
  - Solar fraction: 0% (no solar thermal installation).
- For DHW, the global efficacy of the system is evaluated at 33%, considering:
  - Production: 65%, default efficiency for the same boiler that produces heat (installed after 1990, using natural gas, of unknown label), producing instantaneous DHW with an internal heat exchanger;
  - Distribution: 51% (minimal by default);
  - Circulation loop: 100% (absent);
  - Solar fraction: 0% (no solar thermal installation).

The Figure 5.2.17 below is showing the results of the revaluations for both variants and different steps in the method. The electricity consumption, in this case, does not include end-uses that could be dependent on the climate, and is revaluated constantly in all variants and methods at 3,915kWh, 21.1% higher than the declared consumption of 3,234kWh. The calibration of the evaluation of electricity consumptions after these preliminary results will reduce this discrepancy.

This case study presents a reduction of the theoretical natural gas consumptions as expected: the EPC results were 308% (V2) to 430% (V1) over the real declared consumption; those "prebound" gaps dropped to 116% and 166%. This remnant discrepancy remains superior to 100% of the declared natural gas consumptions in nearly all simulations run on this case study, and must be analysed.

The Figure 5.2.18 below gives an overview of the chosen second variant, for the HGAR1_AY step that includes the revaluation of electricity consumptions after calibration. The "prebound" gap in natural gas consumption has increased in consequence from 116% to 131.3%, in the "real climate" (RC) hypothesis, and 179.1% in the "average climate" (AC) hypothesis.

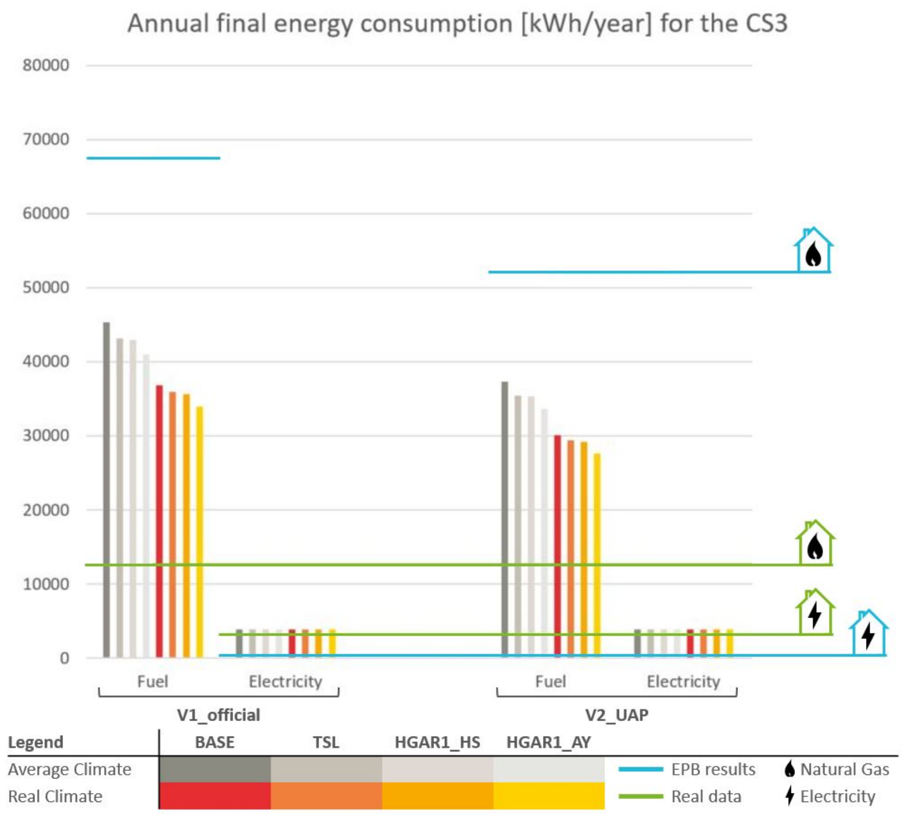

Fig. 5.2.17. Results of revaluated energy consumptions for the two variants of the CS3, for different steps in the method

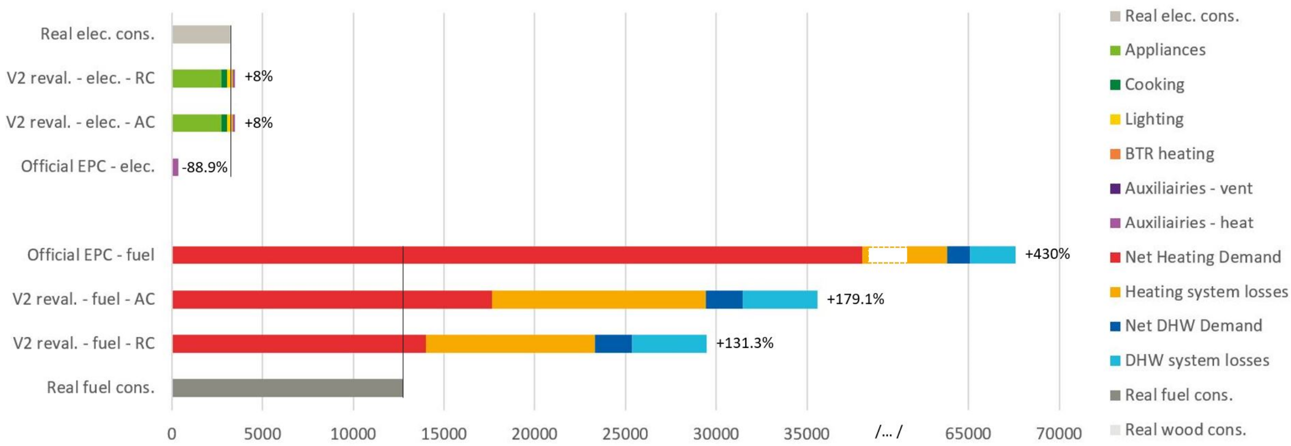

Fig. 5.2.18. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS3

In this case as in the previous one, the DHW needs (and subsequent consumptions) are evaluated above the EPB hypothesis. Given that the efficiencies have been kept in the revaluations, for lack of more accurate or realistic values, the related losses take more importance in the revaluations, compared to the official EPC calculations.

Another important observation is that the revaluations of the net demand for heating alone are superior to the total real natural gas consumption for the period covered, which means that major improvements still have to be brought to that side of calculations. The default values that dominate the description of the envelope could be debated: they appeared accurate in the CS2, but the greater age of this house as well as differences in quality of the works could explain some disparities. Internal gains could be underestimated, mainly their metabolic component, as the accuracy of the electricity consumptions renders this one quite difficult to modify. The period covered could also be much more sunny than expected, or than translated through the standardised hypotheses.

It must be observed that the total natural gas consumption of 12,743kWh that appeared on Mr C.'s energy bill, covering the period from June 2013 to May 2014, is inferior to the combined heating and DHW systems' losses for the same period. The demand for heating might be overestimated, so that more accurately lowered NHDs could be evaluated. Nevertheless, the default efficiencies attributed to the heating and DHW systems are questionable: if they are correctly estimated, the NHDs would have to be divided by 2, and the demand in DHW reduced by 30%, to approach the real consumption data with a gap that would be inferior to 10%.

When first results showed important gaps to be explained, the owners were met for a second time in order to clarify some needed information. They admitted that, during the period covered, their old boiler had stopped working), several times, which denied them access to heat and DHW for several days while waiting for technical assistance and could explain part of the gaps. Additionally, they mentioned being very thrifty in their everyday behaviours related to water-use, for example. This alone can hardly explain a 131.3% discrepancy, but might explain part of it; the gap that remains would have to be attributed to uncertain hypotheses. Unfortunately, the owners' decision to leave the house a few months after the interview rendered any monitoring impossible.

The Figure 5.2.19 below shows that the revaluation of internal temperatures in unheated spaces is noticeably lower for this case study than for the previous ones. In January, for example, the external temperature of 6°C brings the unheated spaces to a mere 13°C, while living spaces are heated at 21.5°C, which brings the global $T_{set,m}$ temperature for that month a little above 16.5°C. The heating period, in this case, spreads from September to May, which seems quite long.

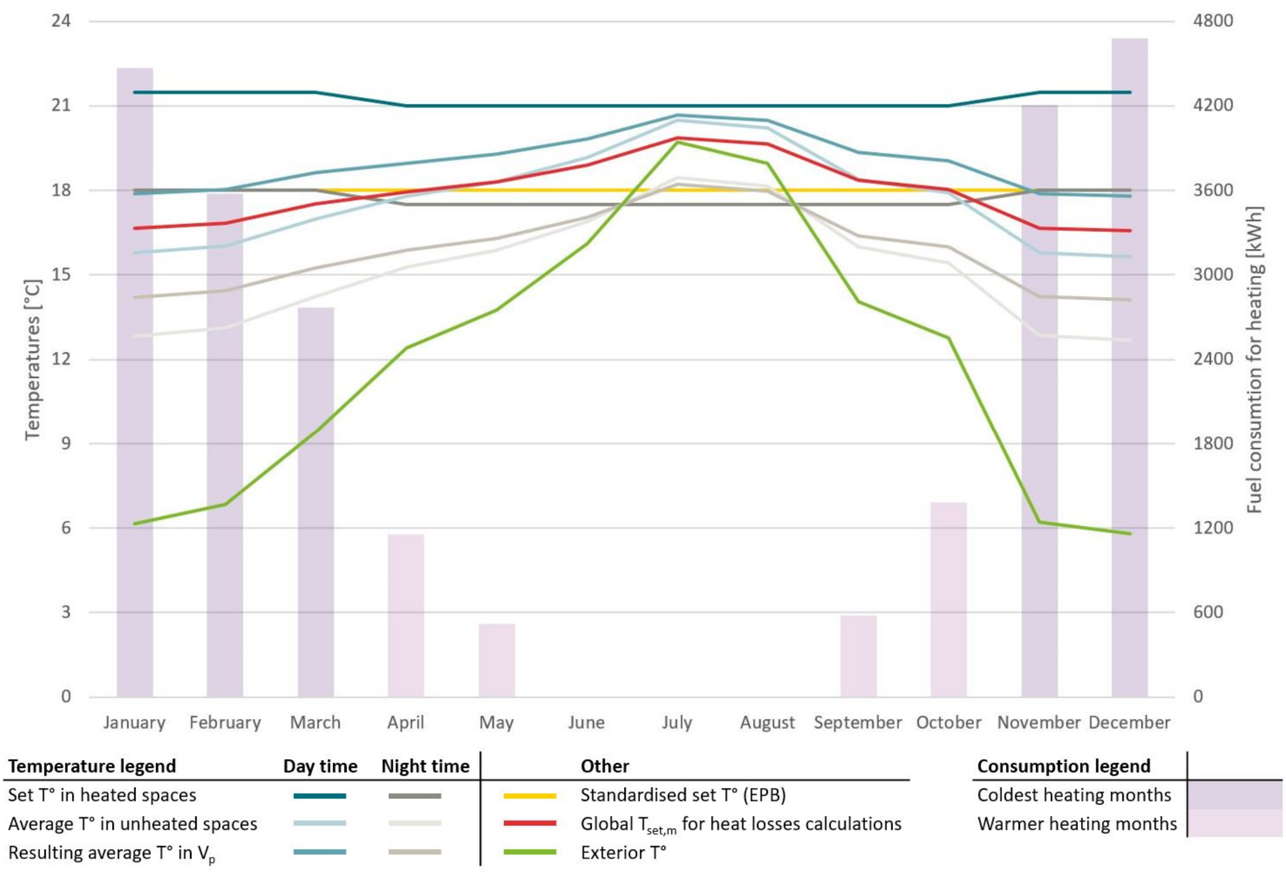

Fig. 5.2.19. CS3: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

A decrease in NHD would bring to the method a higher internal temperature in unheated spaces, given that it is directly influenced by the quality of the envelope, as described in Equation (9) (see section 4.3.3.3). This phenomenon, called previously in this work the "physical component of the temperature" sees the main decrease of the $H_{T,heat}$ coefficient accompanied by an increase in temperature in unheated spaces. The consequence on the result would still be a global decrease in consumption, but not as important as expected. Another effect must be considered here: by reducing the NHD, one would also reduce the heating period (for example to October to April, instead of September to May), and therefore modify the average parting the coldest and warmer months in the calculation method. The influence of this phenomenon in the calculation method is, however, relatively low, with changes in the results that barely reach a few hundred kWh for the months that would shift from one category to the other (the month of March in this case).

5.2.4 Case Study 4 – CS4

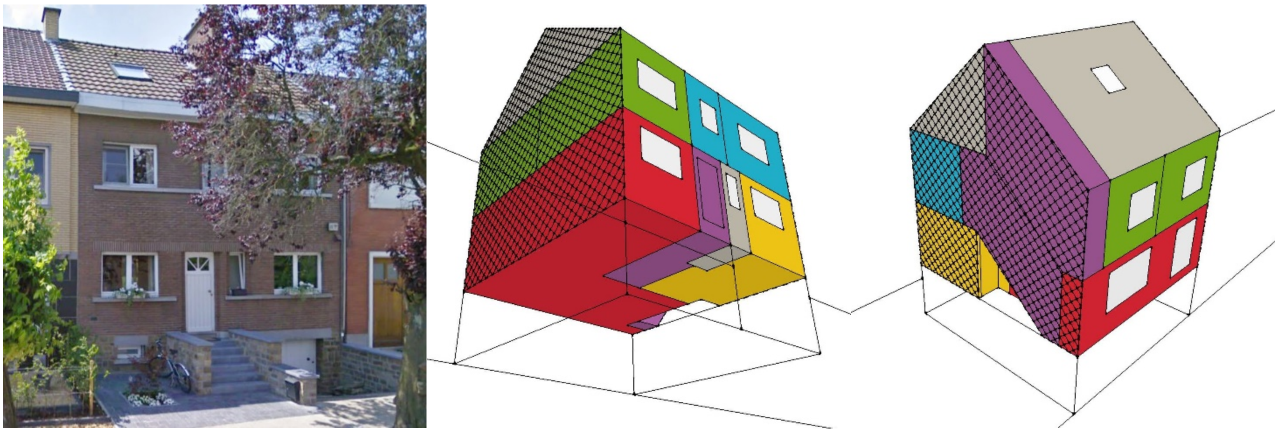

Fig. 5.2.20. CS4 – **Left**: street facade; **centre**: low-angle shot of the ESE (shared) and NNE (street) facades; **right**: high-angle shot of the WNW (shared) and SSW (garden) facades

This row house was built after the World War II during the urban extensions of city centres, in the town of Waremme, at 25km from Liege, equipped with its own climatic station. The EPC for this house was made by a trusted assessor who explained her hypotheses and showed all the acceptable proofs needed. The owners, Mr and Mrs D., are a couple of young parents, both University graduates and working full time (or nearly full time for the mother) outside of the house. As in CS3, the owners had a renovation project for this house, before finally deciding to leave the house for a better, bigger but less insulated house in the suburbs. The renovation project intended to occupy the upper floor, which was then only used for storage, with the night time zone (bedrooms and bathrooms) located right beneath. The living spaces for daytime are on street level, above the basement level, which is considered unheated and is excluded from the protected volume (V_P) without a doubt.

According to the official EPC delivered, none of the vertical or horizontal walls were insulated at all. The only heat loss surface that contained insulation (12cm of extruded polystyrene according to the assessor) was the tilted roof, one of the reasons why the upper floor is considered part of the V_P. The description of the envelope is not the subject of much debate, therefore, apart from the necessary use of the certification method's default values. The variant in this case (labelled "incomplete") considers therefore the uncertainty of an incomplete assessment that would oversee the presence of insulation in the tilted roof (if it was not visible anymore, for example). The figure 5.2.21 below displays the description of the resulting $H_{T,heat}$ coefficients: in the first variant, the 85m² of roof with "unknown presence" (meaning "absence", in this case) of insulation, are given a U- value of 4W/m²K, and contribute to the $H_{T,heat}$ coefficient by 340W/K; in the second variant, the characterization of the roof insulation layer lowered those to 25W/K (-93%), thus reducing the global $H_{T,heat}$ coefficient by a factor of two. The rest of the $H_{T,heat}$ coefficient, benefiting from 120m² of shared walls, is defined by the 75m² of cavity walls, 68m² of basement ceiling and 25m² of windows.

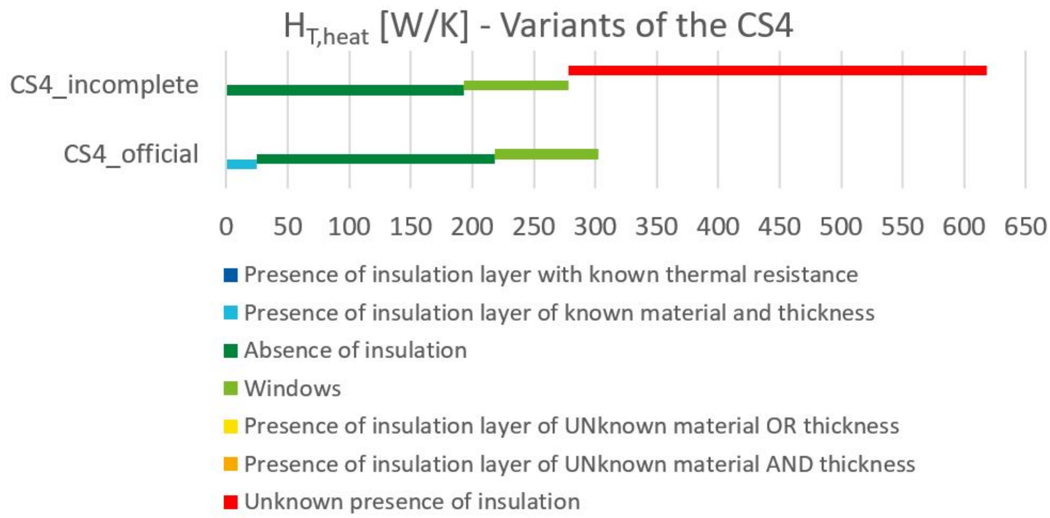

Fig. 5.2.21. Coefficients $H_{T,heat}$ [W/K] for the two variants of the CS4

Although it must be reminded that other losses and gains, as well as the systems' efficiencies, will influence the final result, the effect of those 12cm of polystyrene in the roof on the comparison between both variants here might highlight a tenacious discrepancy remaining in other case studies, such as the CS3, or the CS12. The first variant results in a house characterized by an average U-value of 2.38W/m²K, a specific annual primary energy consumption of 370kWh/m².year, and an "E" category on the certification scale. For the second variant, the average U-value drops to 1.16W/m²K, the specific annual primary energy consumption to 204kWh/m².year and, consequently, the certification scale level rises to "C".

The house was heated via a central installation, supplied by a condensing boiler using natural gas as fuel, located in the basement. The owners had the boiler's technical documentation, which they had installed, so that the "real" efficiency of the system was used as input:

- For heating, the global efficiency is 78%, determined by:
  - Production: 89% (107% theoretical efficiency evaluated for new systems according to norms and standards, degraded to 89% due to regulation and position out of the V_P);
  - Distribution: 98% (small length of uninsulated pipes in V_P);
  - Storage: 100% (no storage, direct supply);
  - Emission: 89%;
  - Solar fraction: 0% (no solar thermal installation).

Apart from the use of an extra electric heater in the bathroom, there is no other heating system to be included in the (modified) assessment. The production of domestic hot water is managed by the same boiler, and the global efficacy for the whole system is evaluated at 49%, determined by:

- Production: 65%;
- Distribution: 75%;
- Circulation loop: 100% (absent);
- Solar fraction: 0% (no solar thermal installation).

The heating pattern of the house below is very similar to the CS2's, which was very much defined by the school hours. Mr and Mrs D., in CS4, have two young children and their presence at home dictates the daily routines. The house is more globally heated than in previous cases: during most presence periods, 53% of the V_P, including the living room, dining room, kitchen (both open on the first), bathroom and children bedrooms, is heated at 21°C. The bathroom electric heater is only used as a booster during ablutions periods; its consumptions will be evaluated according to section 4.3.2.4. On warmer months, the heating is generally turned off sooner in the children bedrooms, which explains the 46.9% proportion of heated volume for the sixth and eighth periods. In the sixth one, the 20.23°C set temperature considers that the children bedroom is already submitted to the 16°C temperature setback that takes place at night, while the rest is still on daytime settings.

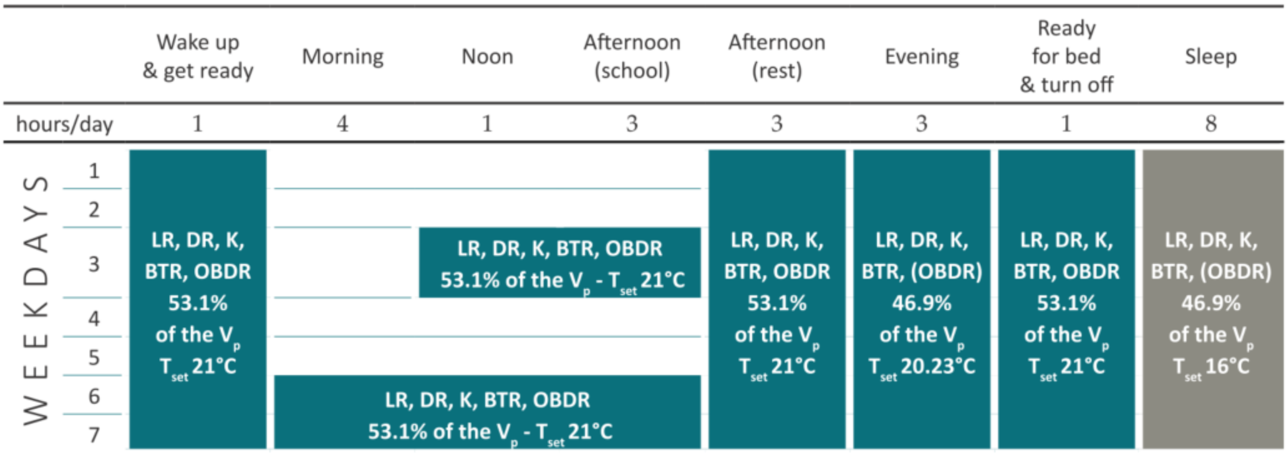

Fig. 5.2.22. Heating pattern of the CS4, according to owners' answers to the questionnaire.

The Figure 5.2.23 below indicates that the information in the roof insulation, if ignored, brings an added 81.5%, on average, on the theoretical consumption (for an increase of the $H_{T,heat}$ coefficient of 104%). This discrepancy is quite constant among methods and climate hypotheses, varying only between 77.8% and 83.6%. The influence of the EPB method is still very visible, as the comparison of the EPC results (obtained with the regulatory method, on the basis of the differentiated variants' descriptions) indicates the same increase (83.5%) in natural gas consumptions. The results of the first, "incomplete" variant, These results also hint that the "incomplete" results could be obtained due to a lack of data hunt, to the assessor's lack of professionalism, but also to the definition of an acceptable proof in the description of the dwelling. In this case, the insulation was visible and therefore normally considered in the description. The owners, when imagining the renovation project, estimated the roof insulated enough and planned to simply add an internal cladding to hide it and convert the "attic" into spacious bedrooms. They finally decided to sell the house as it is, and asked for an EPC to an assessor who could witness its presence. But would they have implemented their renovation plan, there would not have any proof anymore of the existence of the insulation hidden behind a plaster board. When asked, during the interview, if they would have thought about making photos of the insulation, to show potential ulterior assessors, to witness its presence, their answer was quite clear: "*Of course not. Who would have thought about that?*" Owners are expected to keep track of every information that could be used in an energy assessment, but it is not instinctive to most of them. There, the acceptable proofs concept appears as a construct that only seem obvious and suitable to the "informed" and "aware" public, not the lay citizen who expects the assessor to determine the performance of his house on his behalf. A trust issue appears, when the assessor does not look for the accurate information, nor considers "honest" data that is handed by the owners. The

EAP procedure could still have considered the presence of the insulation, if mentioned by the owners; This leads to wonder, therefore, how many "hidden" and neglected insulation layers (of all states and conditions) could partially explain the gap between the average residential energy consumptions defined in chapter 2.2.2.5.

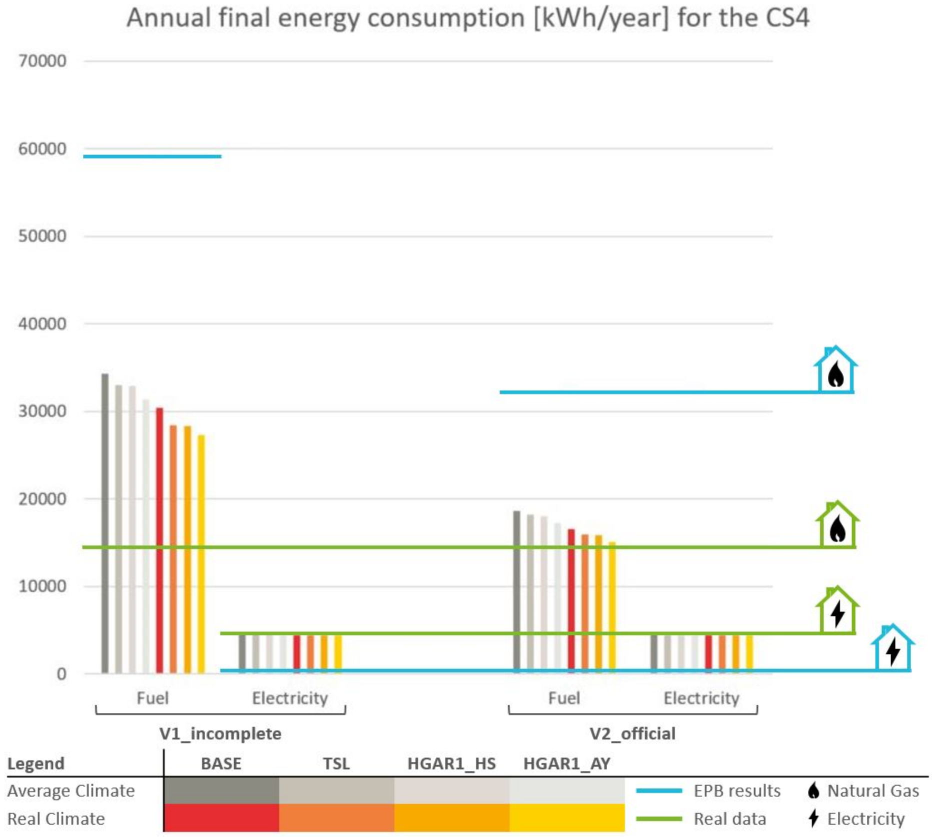

Fig. 5.2.23. Results of revaluated energy consumptions for the two variants of the CS4, for different steps in the method

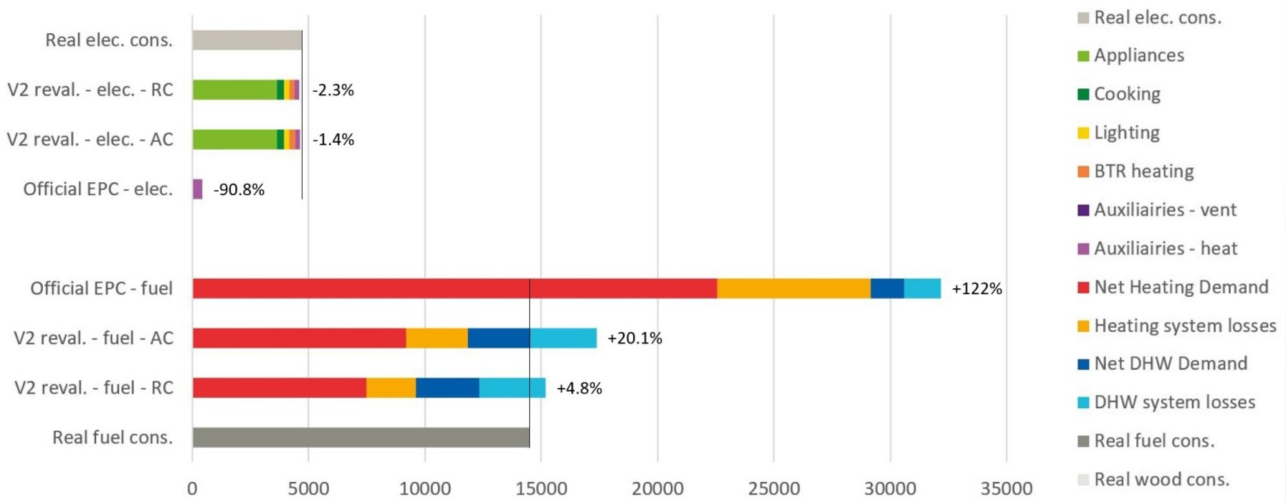

Fig. 5.2.24. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS4

Once again, the DHW needs are revaluated upwards, when compared to the EPC standardised method, which in the long run tends to contradict the belief that EPB approach is detrimental in every aspects. Given the 16 case studies' average global DHW installations efficiencies (just below 50%), it is suspected that underestimations of the DHW needs in the EPB method might still bring accurate consumptions. In the revaluations, those unchanged efficiencies, applied on increased needs, can only bring higher consumptions, as shown in Figure 5.2.24.

The use of the average climate dataset, as could be done for prospective evaluations, brings this case study, which can be considered satisfyingly accurate, 15% higher in natural gas consumptions; this gap may be small, but has to be considered as a possible unavoidable discrepancy on the results.

The difference in envelope quality between both variants is, in this case, quite marked, and the Figure 5.2.25 below, along with the corresponding figures for the other case studies so far, shows the influence of the f_{pct} factor included in the evaluation of the resulting temperature in unheated spaces. Continuous curves indicate the temperatures in the second, official variant of the building. The three doted lines display, for the first and "incomplete" variant, the resulting average temperatures in unheated spaces during daytime and night time periods, and global $T_{set,m}$ for heat losses calculations. For example, in January, the exterior temperature is on average 3.7°C and the set temperature during daytime is 21°C, 16°C at night. The average temperatures in unheated spaces are, for the first variant, respectively 14.31°C during the day, 10.9°C during the night; for the second and official variant, those average temperatures in unheated spaces rise to 17.43°C (+3.12°C) during the day, 13.3°C (+2.4°C) during the night. As a consequence, the global $T_{set,m}$ temperature, used to replace the standardised 18°C of the EPB regulatory hypothesis for the calculation of heat losses, is revaluated at 15.8°C in the first variant, 17.2°C in the second. The modified method does consider, therefore, that an increase in envelope performances influences upwards the average temperature in unheated spaces.

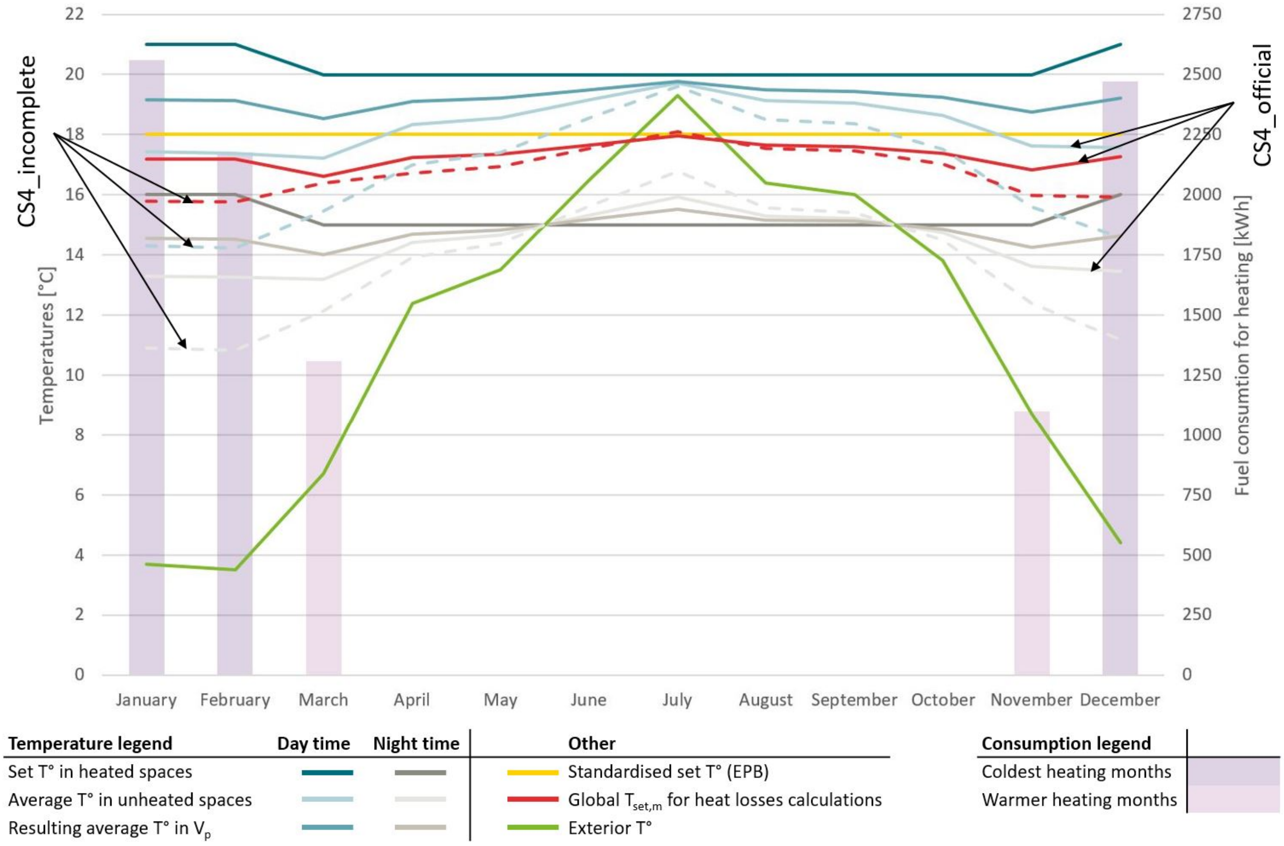

Fig. 5.2.25. CS4: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

In this case study, Mr and Mrs D. reported their regular use of added clothes before raising the heat, which in accordance to the hypotheses defined in section 4.3.3.3 means a value of -1°C for warmer months, for the ΔTset factor. This is visible in the inflexions in the curves in March and November, which will be addressed in the sensitivity testing on those factors in chapter 6.

5.2.5 Case Study 5 – CS5

The problematic about acceptable proofs finds a direct echo in the description of the fifth case study. Here is a house, located in the city centre of Liege, which belongs to the typology of "masters" houses described in chapter 2.2.2.3, characterized by larger facades, higher volumes and better natural light than their "blue-collar" or "modest" counterparts. These old houses are not well insulated to start with, mainly composed of bricks for the walls and basement ceiling, and wooden structures for the tilted roof and intermediate floors. The general EPC protocol approach is to consider it uninsulated before any acceptable proofs can allow the assessor to say otherwise. Mr E., the owner met for the interview, was very keen in describing what he knew of the composition of his house. He had an EAP made a few years before in order to get incentives for the placement of new windows and a new condensing boiler. As stated before, the EAP is not an acceptable proof in the EPC protocol, but contains information that could be valuable to this study. It indicated, notably, the presence of 6cm of an old mineral wool layer in the tilted roof, which was not visible (anymore), and therefore not to be considered in the official EPC assessment.

Fig. 5.2.26. CS5 – **Left**: street facade; **centre**: low-angle shot of the NNW (shared) and ENE (street) facades; **right**: high-angle shot of the SSE (shared) and WSW (garden) facades

When assessing an old, uninsulated house, it is not always easy to define the "protected volume", as it may or may not include some unheated spaces such as a basement, an attic, an annex… The will to standardise the procedure as much as the results has led the administration to deliver a diagnostic flow chart with a string of questions to be answered in order to decide whether a space should be included in or excluded from the V_P. For example, a room should be added to the V_P if it is directly heated (and the simple presence of a radiator is sufficient to conclude so), if it is open on the indisputable part of the V_P (no door, for example), if it is the only room containing one of the four fundamental functions (kitchen, bathroom, living room or bedroom, although the functions can be regrouped), if it is indirectly heated (though it is more debatable) or if there is a visible intention to insulate (presence of insulation, double glazing, even the finishing of the room can be decisive). The same room could be excluded from the V_P if, for example, it is not sufficiently waterproof or airtight (this targets particularly attics and basements), if it is only accessible from the outside or on occasions (via the use of a collapsible ladder to get to the attic, for example)… In case of a remaining doubt after answering the 8 levels of the flow chart, the flowchart advocates that the room should be excluded from the V_P.

In the CS5, if the insulation layer in the roof, mentioned only by the EAP, is neglected, there is no clear reason to include the attic inside the protected volume. Some wooden boards close the roof complex and therefore hide the insulation layer, but no other sign of occupation, such as indirect heating or fundamental function (other than storage) allowed to settle the argument. Therefore, the official EPC considers that insulation layer "unknown", and the attic out of the V_P. Should the presence of the insulation layer be acknowledged by the official EPC thanks to an acceptable proof, the attic would have been included in the V_P because of the clear "intention to insulate". This is the case in the EAP model, which acknowledges the insulation layer. Two different approaches on the same house differ even in the definition of the protected volume: if the goal of the administration is to bring both procedures (EPC and EAP) together, the definition of acceptable data will have to be harmonized in some ways (even if some data cannot be considered in the EPC version), at the risk of adding more confusion and distrust to the procedures and results…

The old insulation layer in the tilted roof is not the only one that had to be neglected in the regulatory procedure. The EAP also declares the presence of 12cm of polyurethane in the green roofs that cover the annexes at the back (confirmed by the owner), and around 16m² of walls insulated internally by the owner himself, with cellular concrete blocks, in the bathrooms. Four variants are created for this CS5, therefore:

- The first and "official" EPC, realised with respect to the protocol, considers the "unknown" (translated to "absent" in this case) presence of insulation in the roof, and excludes the attic from the protected volume, which is evaluated at 869m³ for a total heat loss area of 533m². The resulting EPC indicates an average U-value of 1.82W/m²K, and an "E" level on the certification scale, due to a specific annual primary energy consumption of 387kWh/m².year.
- The second variant, labelled "RedVp_UAP" (for "Reduced V_P" and "UnAcceptable Proofs) also excludes the attic from the V_P, but considers the presence of insulation in the tilted roof that covers the stairway, and the other insulation layers described above. The protected volume and heat loss area are the same than the first variant, but the average U-value drops to 1.5W/m²K, and the certification scale level to "D", due to the E_{spec} consumption indicator of 325kWh/m².year of primary energy.
- The third, "IncVp_AP" (for "Increased V_P" and "Acceptable Proofs") includes the attic but neglects the information from the EAP report. The protected volume increases to 953m³, the area of heat losses (A_T) to 553m². The average U-value is, in this case, the highest of the four variants, at 1.86W/m²K, and the E_{spec} indicator is 377kWh/m².year of primary energy ("E" level on the certification scale).
- The fourth variant, "IncVp_UAP", includes the attic and the EAP information on invisible insulation layers. With the same V_P and A_T than the third variant, the average U-value drops to 1.36W/m²K, the E_{spec} indicator to 287kWh/m².year and the certification level rises to "D".

Between the first and second variants, the use of "unacceptable" data allowed the transformation of 190W/K of heat losses due to "unknown presence of insulation", into 16.51W/K (-91.3%) defined by the information on the types of materials and thicknesses, and allowed thus an 18.1% reduction of the global coefficient. Between the third and fourth variants, 321.4W/K of heat losses are replaced by 47.11W/K (-85.3%), bringing a 26.9% reduction of the $H_{T,heat}$ coefficient. The remaining heat losses attributed to "unknown presence of insulation" in the fourth variant concerns the small surface of flat roof above the parents' bedroom overhang, at the back. In the second variant, it also includes the attic floor, described as any other boundary wall of the V_P.

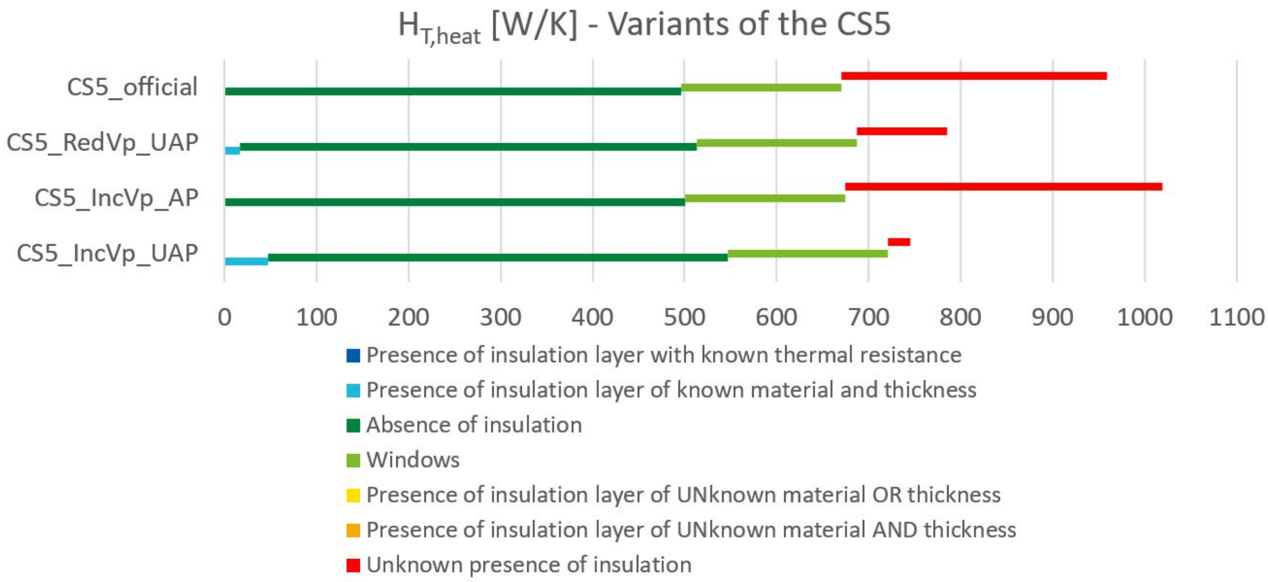

Fig. 5.2.27. Coefficients $H_{T,heat}$ [W/K] for the 4 variants of the CS5

The heat is supplied by a condensing boiler located in the basement (indubitably out of the V_P) that also provides the domestic hot water (instantaneously, via an internal heat exchanger). The heating efficiency is evaluated at 70% in the V2 and V4, and 68% in the V1 and V3. This is due to the position of radiators against walls that are considered insulated or not, changing the emission part of the efficiency from 82% in the V2 and V4, to 80% in the V1 and V3. In all cases, the distribution efficacy is evaluated at 95% (uninsulated pipes in the basement), the storage at 100% (no storage) and the production at 90% (default value for a variable temperature condensing boiler using natural gas, of unknown theoretical efficiency, located out of the V_P). The DHW installation's global efficiency is evaluated at 39%, due to a 75% efficiency for the production boiler (default efficiency for the same boiler that produces heat – using natural gas, variable temperature –, producing instantaneous DHW through an internal heat exchanger) and 51% by default for the distribution pipes' efficiency.

In terms of ventilation, Mr and Mrs E. are among the owners who ventilate most, despite the lack of any ventilation system. They declared daily opening of windows in all proposed rooms (living room, kitchen, bathroom and bedrooms), leading to an average estimated hygienic air change of 22.6m³/h. The $H_{V,heat}$ coefficient of 69.6W/K also includes the air change due to in- or exfiltration, characterized here by a $\dot{v}_{50,heat}$ factor by default of 12m³/h per square meter of the heat loss area, under a pressure difference of 50Pa.

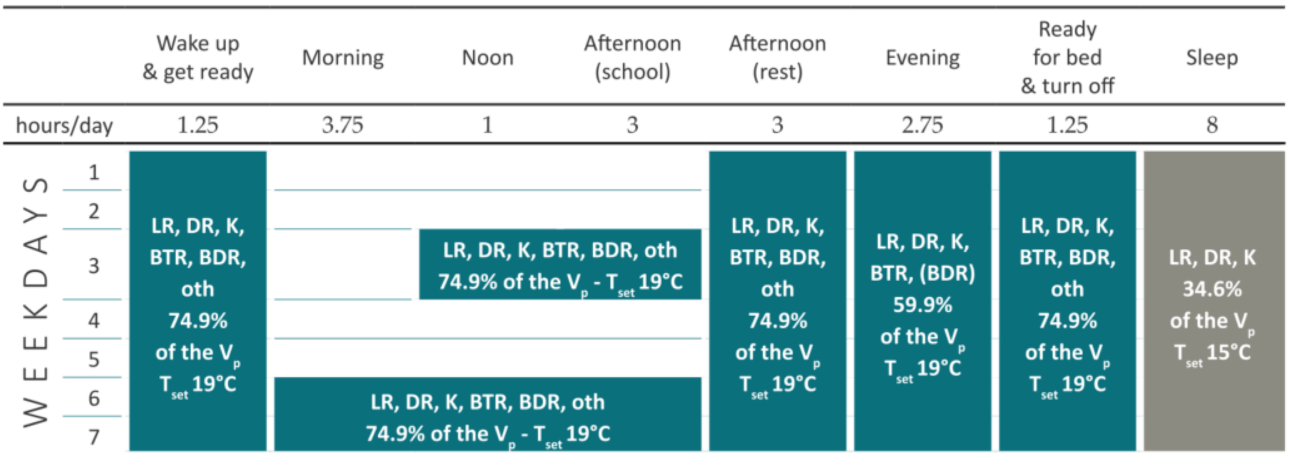

Fig. 5.2.28. Heating pattern of the CS5, according to owners' answers to the questionnaire.

Mr and Mrs E. live in this house with their three young children. Both owners, University graduates in their late thirties – early forties, are working parents, who indicated another heating pattern (see Figure 5.2.28 above) defined by school hours. Their profile defined by the interview could be defined as rather "environmental-friendly", notably through a rather high score to the RUE (Rational Use of Energy) questions of 4.0 out of 5, and a low equipment level (1 out of 5). This can partly explain their declared electricity consumption (less than 3,000kWh in 2014), one of the lowest when compared to the household size (although their last child was not born yet at the time). The same household, on the other hand, presented the highest natural gas consumption bills of this research sample (nearly 34,000kWh consumed in 2015), which could be explained before presenting any results by the size of the building (one of the biggest of the sample), the high $H_{T,heat}$ coefficients defined in Figure 5.2.27, and the occupants' tendency to heat a large part of the protected volume. The heating pattern above indicates that nearly 75% of their V_P (evaluated on the "IncVp" hypotheses with the attic in the V_P) is heated during winter occupancy hours, including the living room (and open-attached dining room and kitchen), bathroom, all bedrooms and the "other" space that is the home office. The temperature is kept low (set temperature declared at 19°C) but homogeneous during the day. Only the daytime zones (living room, dining room and kitchen, nearly 35% of the total) are submitted to a temperature setback at night (15°C), while the other rooms are unheated. The evening periods see the bedrooms and office heated only during the coldest months of the heating period. The Figure 5.2.29 hereunder displays the results for the four variants, and the progressive modifications steps of the method:

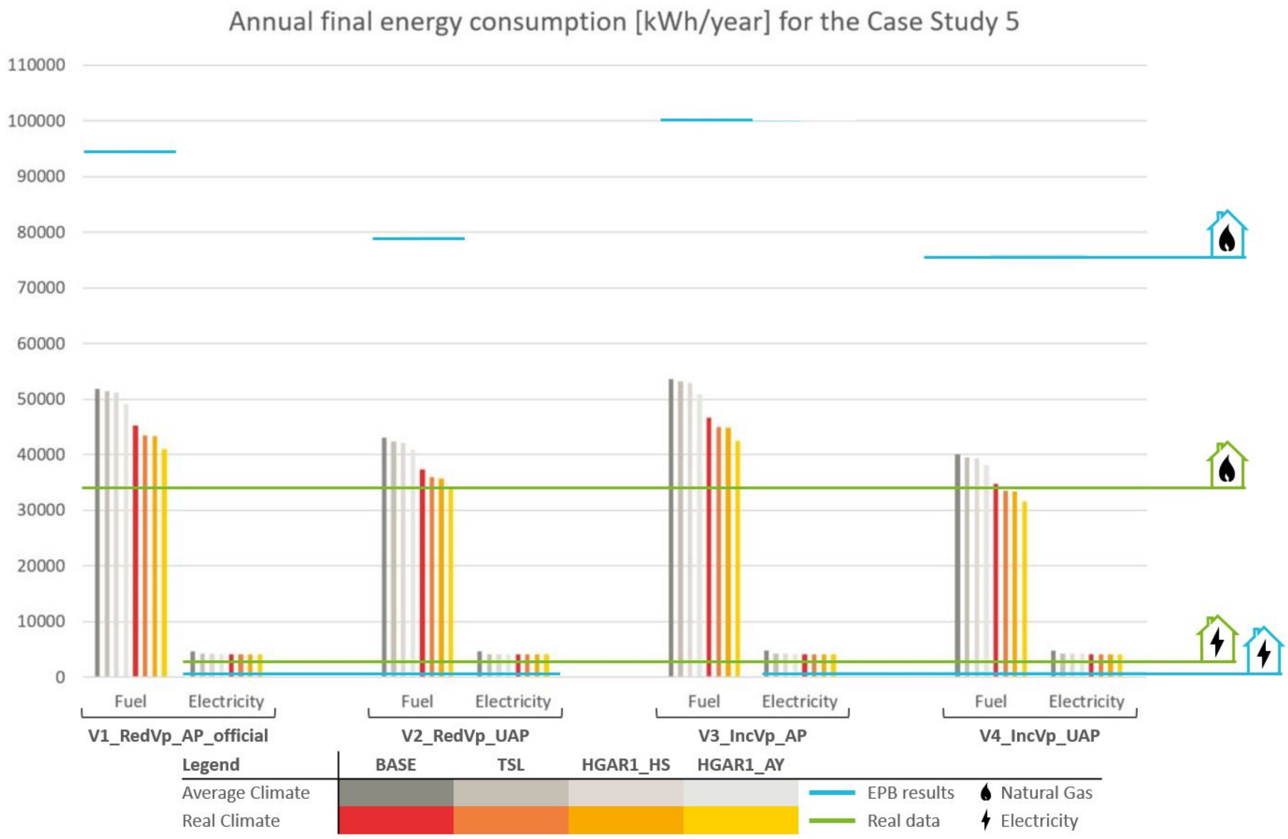

Fig. 5.2.29. Results of revaluated energy consumptions for the four variants of the CS5, for different steps in the method

Revaluated results are slightly underestimated for the second and fourth variants, both considering the invisible insulation layers, but remain overestimated in the first and third one. The inclusion of the attic in the protected volume is less influential on the results than the inclusion of "unacceptable" data. The underestimation of the natural gas consumption could be resolved by a more accurate revaluation of electricity consumption, which calibration after these preliminary results will lower the related internal gains and, therefore, increase slightly the natural gas consumption, as visible in the Figure 5.2.30 below. But a doubt subsists: is the inclusion of the attic in the V_P, when it is not heated at all, necessary? If the existence of the insulation in the roof is acknowledged, the question is mute: the attic has to be included, and the chosen variant would therefore be the fourth one. If it is not, the first and official variant excluding the attic brings slightly lower results than the third variant including it (uninsulated). Other case studies, where the same kind of questions is debated about basements, indicate that the inclusion of those "buffer zones" is necessary to bring accuracy to the results, probably in part because the reference temperature for the heat losses is the exterior.

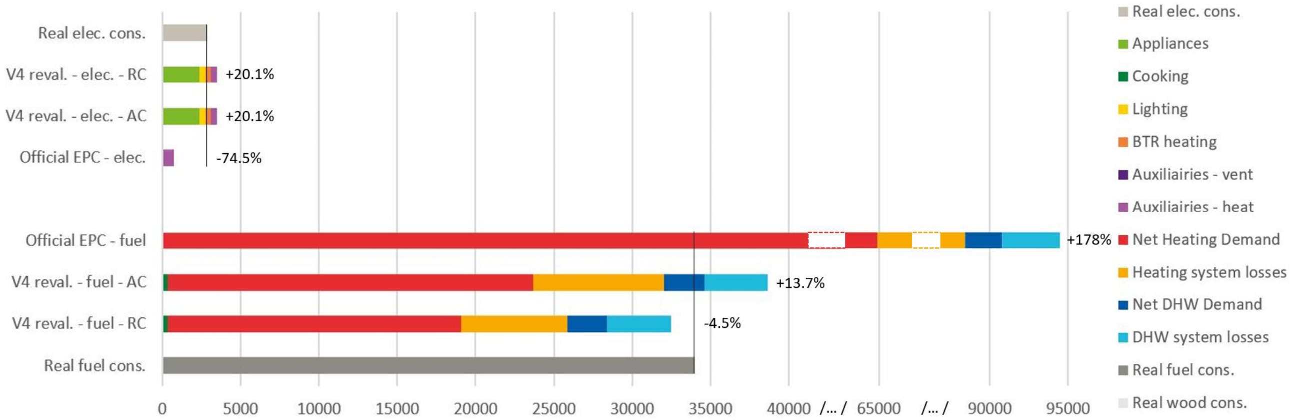

Fig. 5.2.30. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS5

As shown by the Figure 5.2.30 above, the electricity consumption is still overestimated by 20% in this case that declared one of the lowest consumption per inhabitant. It should be noted that the consumptions for cooking are in natural gas. As far as the DHW is concerned, the revaluations of the net demands are, in this case, a mere 200kWh above the EPB hypotheses. The EPB seems thus to consider that 5 inhabitants is the norm for a protected volume of around 900m^3. This correspondence between both methods on that particular evaluation means that, in this case, the reduction of the theoretical total natural gas consumption can only come from a reduction in net heat demand. Given the presence of the veranda oriented WSW, and the resulting importance of the solar gains in this case study, "real" insolation data could conceivably bring different results.

The temperature curves in this case study (Figure 5.2.31) highlight the influence of the ΔT_{set} factor which, brings a slight decrease in set temperature (max -0.5°C) for the warmer heating months, linked to the owners' tendency to "put on a sweater before raising the temperature in their home". This other important determiner of their "environmental-friendly" might explain, with the low temperature settings for heating (19°C during the day, 15°C at night), the lower revaluations in this case study. This hypothesis, which will be discussed in chapter 6, could reveal itself too influential to be determined by only one answer to a RUE question. Some respondents to the questionnaire, for example, understood the question literally (which after all do consider the possibility to raise the set temperature, not to lower it), so that by answering "not at all", they simply point out that they do not raise the temperature above mentioned settings (and probably, as in this case, do not consider the possibility to lower it). Others understood that, in answering "not at all", they indicate that the declared settings are already at their highest (the questionnaire does inquire about the settings for a cold winter week), and that they would lower the temperature rather than raise it, when the climate is milder.

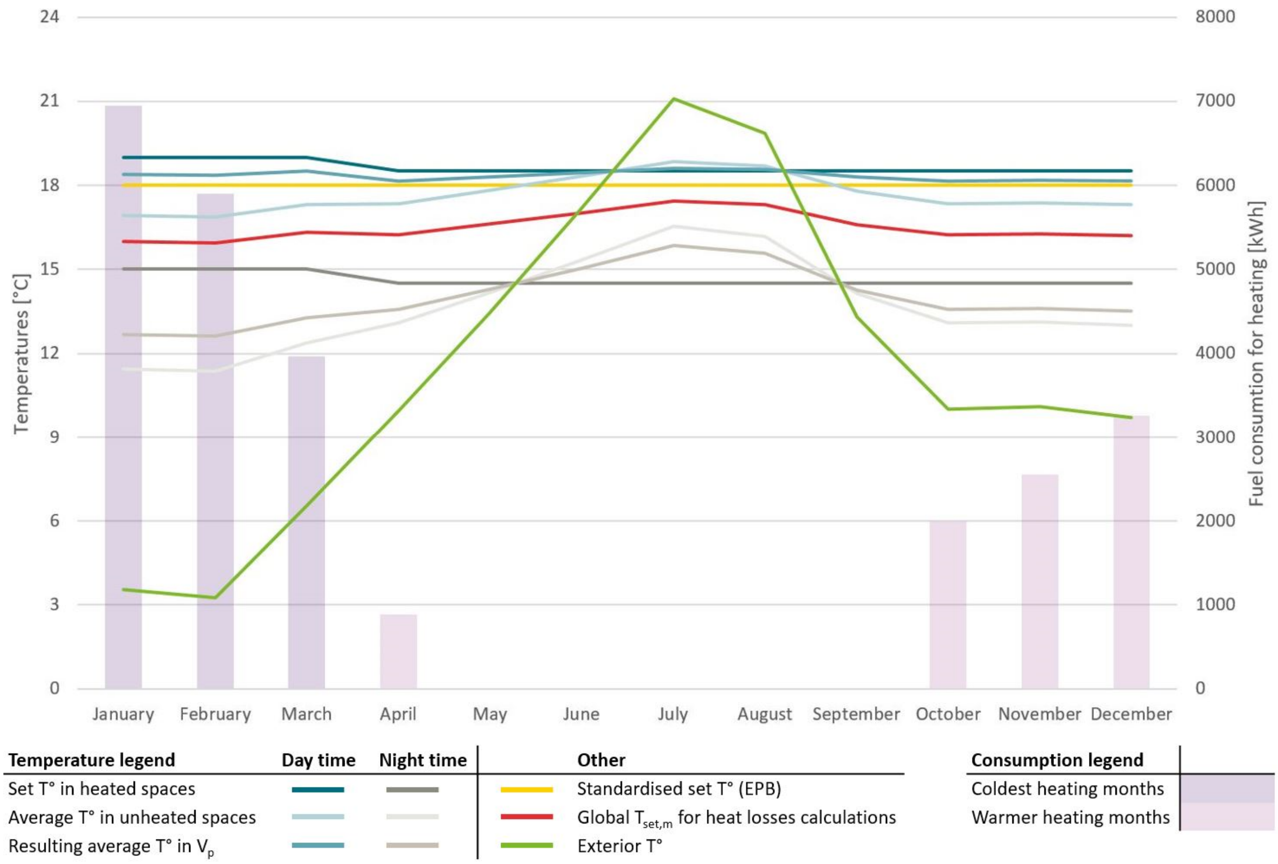

Fig. 5.2.31. CS5: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

5.2.6 Case Study 6 – CS6

In the sixth case study dwells a family with quite a different profile, presenting a RUE score of 3.1 out of 5 (one of the lowest score in the sample). They declared about temperature management in their living room: "*the one who feels coldest, wins. It's not when, it's who will turn the valve to its maximum*." Yet, they presented one of the lowest energy consumption bill in the sample, due to the combination of a small volume (318m³ of V_P, the smallest house in the sample, only half of which is being directly heated), and a relatively low $H_{T,heat}$ coefficient which, at 197W/K, is comparable to the CS1 built in 2007. This is mainly due to the insulation of all roofs, the high share of party-walls in the envelope description and the consequent reduced heat loss area (see Figure 5.2.32 hereunder).

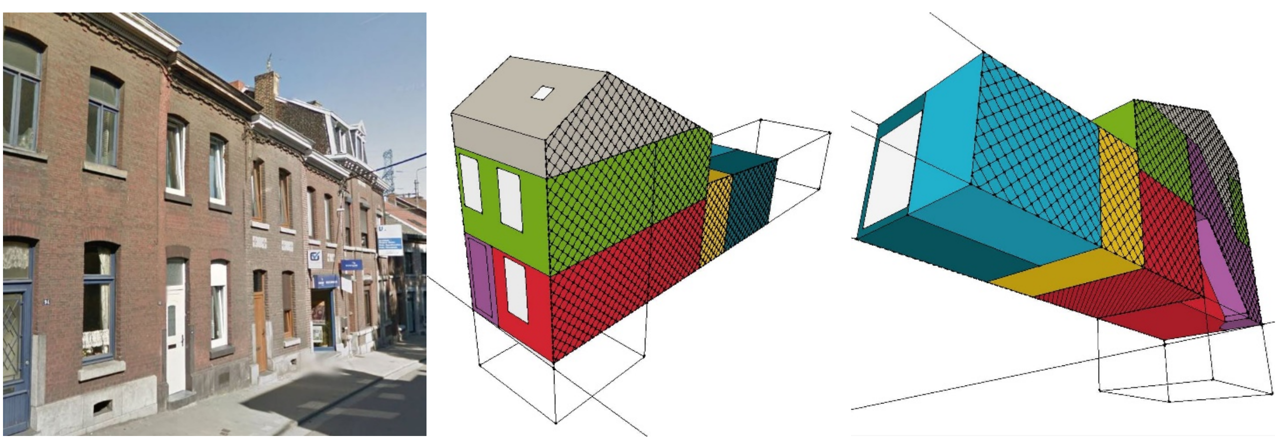

Fig. 5.2.32. CS6 – **Left**: street facade; **centre**: high-angle shot of the North (shared) and East (street) facades; **right**: low-angle shot of the South (shared) and West (backyard) facades

The house also has the specificity of being one of the few in the sample that is not equipped with central heating, and is only heated with local heaters. The stove in the living room is supplied in natural gas and provides heat to the majority of the space. The bathroom, located on the ground level at the end of the annex (see Figure 5.2.32-right: the bathroom is in light blue), is heated with an electric heater only. The EPC protocol would normally impose the definition of two energy sectors in this case.

"If it is not possible to access to any space that is directly heated on the same floor level, […] the certifier is required to regroup the indirectly heated space to the biggest ensemble of directly heated spaces that are accessible from the indirectly heated space considered."[3] The upstairs rooms, therefore, not being equipped with any fix heating system, would have to be joined to the downstairs rooms, because they largely benefit from their heat provided by the stove, and are only accessible from there. Therefore, the other sector is reduced to the bathroom alone. The protocol mentions that "If at least one heating system serves more than 10% of the V_P, the assessor is required to ignore the heating systems serving less than 10% of the V_P."[4] The bathroom, representing 8.5% of the total V_P, and should therefore be neglected and joined to the main, and now only, energy sector. As was the case with the CS2, the variants in this CS6 will consist in applying the energy sector subdivision:

- The first variant, the "official" one, has therefore to consider only one energy sector, heated by the local stove in the living room. In this case, the electricity consumption for the bathroom will be evaluated as described in section 4.3.2.4. The official results, therefore, are a "D" level on the certification scale, defined by a specific annual primary energy consumption of 304kWh/m².year. The average U-value of the building is evaluated at 1.1W/m²K.
- The second variant, labelled "2ES_EPC", considers two energy sectors, defined with as much respect to the EPC method as possible. The volumetric ratios proposed in the protocol are 100/0, 80/20 or 60/40. The bathroom alone, representing 8.5% of the V_P, will be attributed the 20% ratio, whereas the rest of the house, heated by the stove, represents 80% of the volume and heat losses. The average U-value of the building is the same as in the first variant (1.1W/m²K). The over-representation of the electric heating in this method translates into a higher specific annual primary energy consumption of 343kWh/m².year ("E" level, though very close to the D/E threshold, fixed at 340kWh/m².year).
- The third variant, labelled "2ES_EPB", considers two energy sectors defined by the EPB method for new and renovated buildings, the 91.5/8.5% volumetric ratio and the real heat loss repartition. The average U-value is 1.11W/m²K for the main sector, and 1W/m²K for the other. The Espec indicator is closer to the first variant, at 309kWh/m².year ("D" level too).

The three variants present the same $H_{T,heat}$ coefficient, which breakdown is presented in Figure 5.2.33 below. The known presence of insulation in the roofs is characterized by its material (polyurethane) and thickness (8cm). The remaining "unknown presence of insulation" refers to the floors laid on the ground (under part of the living room) and the floor on crawl space (under the annex).

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[3] BBRI, ICEDD, UCL, UMons, ULg, 2012. *Certification énergétique des logements existants en Région wallonne : manuel du certificateur. Partie II : Protocole de collecte des données*, version du 22/10/2012, DGO4, Namur, section 8.2.1.5 p.105. [author's translation]

[4] BBRI, et al., 2012. *Ibid*, section 8.2.1.3 p.104. [personal translation]

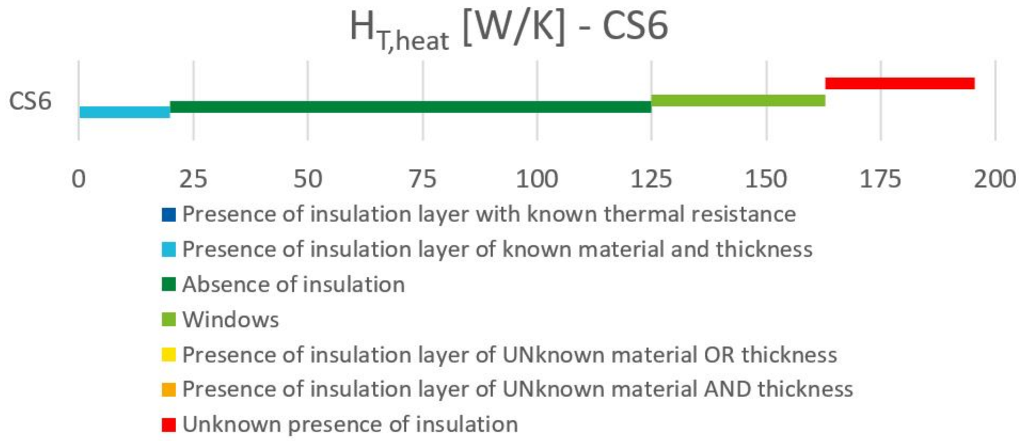

Fig. 5.2.33. Repartition of the $H_{T,heat}$ coefficient [W/K], identical for the three variant of the CS6

In terms of ventilation, a mechanical extractor has been found in the bathroom, timed on the lighting system (with an added ventilation time after switching the light off), bringing a hypothetical 100m³/h air change rate in the second energy sector. Mrs F., furthermore, mentioned opening windows daily in the living room and the bedrooms. The resulting revaluated $H_{V,heat}$ coefficients are 21.24W/K in the first sector, 4.92W/K in the second, considering the air tightness by default.

The EPC calculation method attributes default efficiencies to local heating systems, as it does with most of the efficiencies describing the overall performance of central heating systems. There are, in this case, less parameters to be considered, and no default value that could be replaced with a more accurate value, if it was known. The efficiency for the heating systems used in these variants are:

- The global efficiency of the living room stove is 63%:
  - Production: 72% (default value for a stove of unknown age, using natural gas);
  - Distribution: 100% (local system, no distribution);
  - Storage: 100% (no storage, direct supply);
  - Emission: 87% (default value).
- The efficiency of the local electric device in the bathroom is evaluated at 90%, considering:
  - Production: 100%;
  - Distribution: 100% (local system, no distribution);
  - Storage: 100% (no storage, direct supply);
  - Emission: 90% (default value for direct electric radiators or convectors with unknown presence of electronic regulation).

The Domestic Hot Water cannot be supplied by the same systems, and is produced in this case by an electric boiler located outside of the V_P, in the unheated space at the back of the house. Its efficiency is evaluated at 71%, one of the highest in the sample for this system, considering:

- Production: 80% (default value for electric production with internal storage);
- Distribution: 89% (small pipe lengths);
- Circulation loop: 100% (absent);
- Solar fraction: 0% (no solar thermal installation).

Mr and Mrs F. are both working outside of the house, but with very different schedules, as Mr F. is working the shift in an industry. His personal quest for thermal comfort implies that the kitchen, dining room and living room (all joined spaces, about half of the V_P) are heated "round-the-clock" at 22°C (increased to 23°C during coldest heating months). They estimated that there were no one at home for two days a week, during which the heater would naturally not be on. The second energy sector, composed of the bathroom alone, is heated only when used. The set temperature during those periods is the maximum indicated in the questionnaire: 24°C.

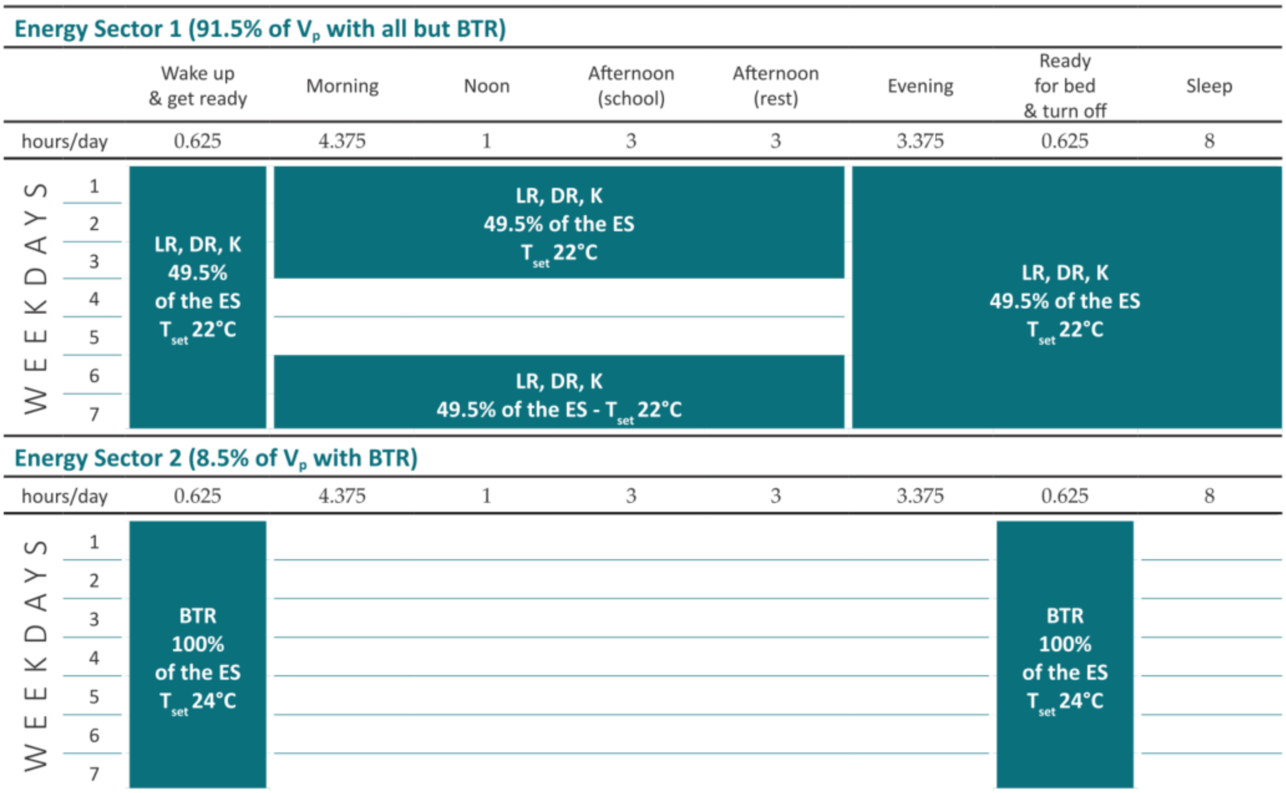

Fig. 5.2.34. Heating patterns of the first (above) and second (below) energy sectors of the CS6, according to owners' answers to the questionnaire.

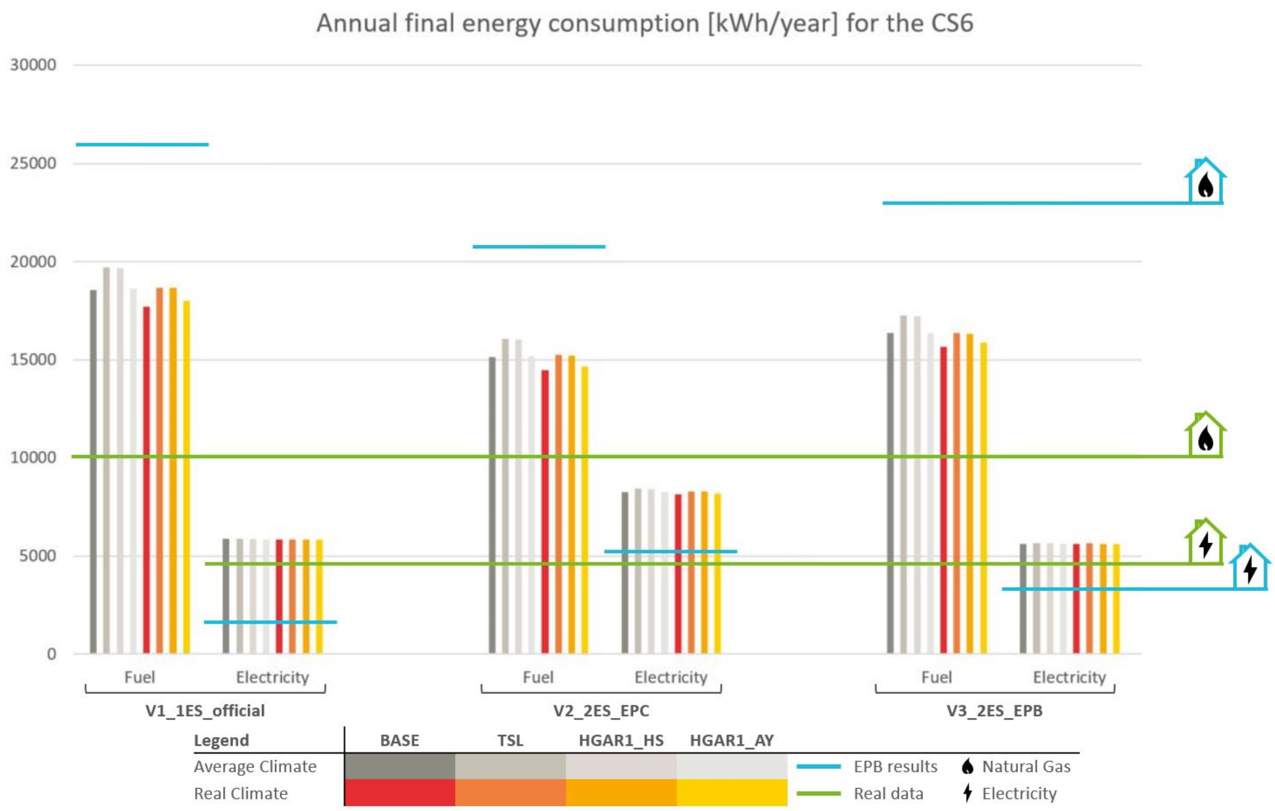

Fig. 5.2.35. Results of revaluated energy consumptions for the three variants of the CS6, for different steps in the method

The first variant, with a single energy sector, shows higher natural gas consumptions than the two others. The electricity consumptions are quite constant, revaluated 27% above the real data in these preliminary results. The second variant presents lower results in revaluation of natural gas consumptions, but overestimates the electricity consumptions by a factor 1.8, which can be explained by the 20% volumetric and heat loss ratio that was applied to the electric sector in this variant. If, for the sake of argument, the realistic ratio of 91.5%/8.5% was applied on this variant dominated by the EPC calculation method, the resulting electricity consumption would drop, in the RC_HGAR1_AY simulation (yellow bars), from 8,177kWh to 6,709kWh, still 45.5% above the real data. Considering a realistic repartition of volumes and heat losses, the third variant seems to approach the natural gas consumptions better than the first variant (yet remaining around 60% higher on average), and the electricity consumption better than both other variants (yet remaining 22% above the real data).

The influence of the ΔT_{set} factor is also visible in this graph, as it gives the "hill" shape to the natural gas results columns: Mr F., particularly sensitive to cold apparently, answered "Not at all!" when asked whether they tend to add layers of clothes on their back before raising the temperature in the living room. 1°C was therefore added to the set temperature for coldest heating months in the "TSL" and following simulation steps.

An interesting result is the repartition of electricity consumptions in these three variants. The figure 5.2.36 hereunder presents this repartition for the HGAR1_AY configuration in real climate (RC): the total consumptions are evaluated at 5,842kWh for the first variant, 8,177kWh for the second and 5,620kWh for the third. The appliances, lighting, cooking and DHW consumptions are the same in the three revaluations, and totalize 5,540kWh, which is, alone, above the declared consumptions. In the second variant, the heating electricity consumption is evaluated at the same level than the appliances or the DHW consumptions (around 30% of the total each). The results announce 2,554kWh of electricity consumed in order to heat a 27m³ bathroom alone (surrounded by three shared vertical walls and an insulated roof): considering this household's bathroom time (1.25 hour per day), this represents a heating power of 6kW, which seems largely overestimated. This is a clear example of the fact that "losses" due to the use of domestic hot water inside the V_P are neglected when they can be a sensible part of the energy balance (drawing a bath does help heat up the place). The 219kWh evaluated in the first variant, or even 72kWh in third, appear much more probable.

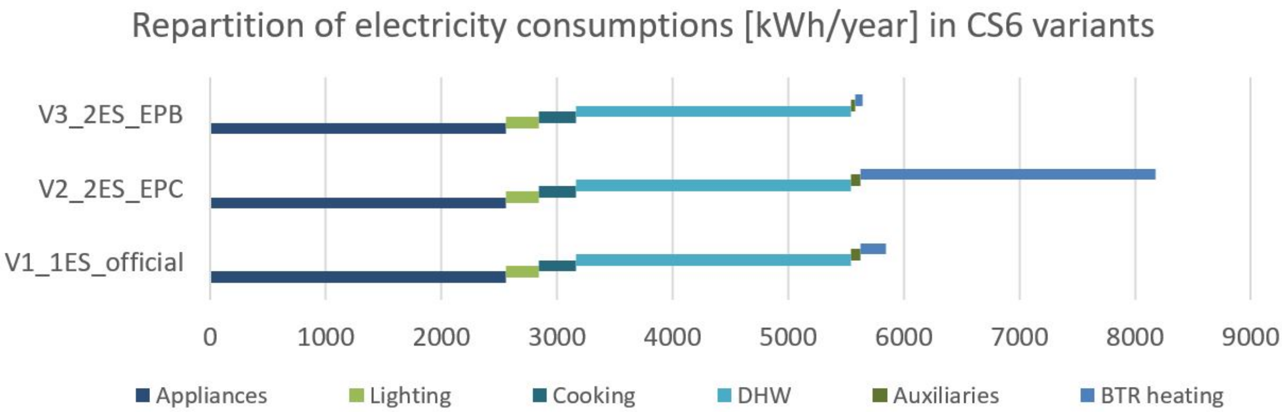

Fig. 5.2.36. Repartition of the electricity consumptions per end-use, revaluations results for the three variants of the CS6

The choice of the third variant, in this case, is motivated by the belief that a more precise description of energy sectors is necessary to bring more accurate results. After calibration, the results in electricity consumptions appear much closer to reality, overestimated by 13%.

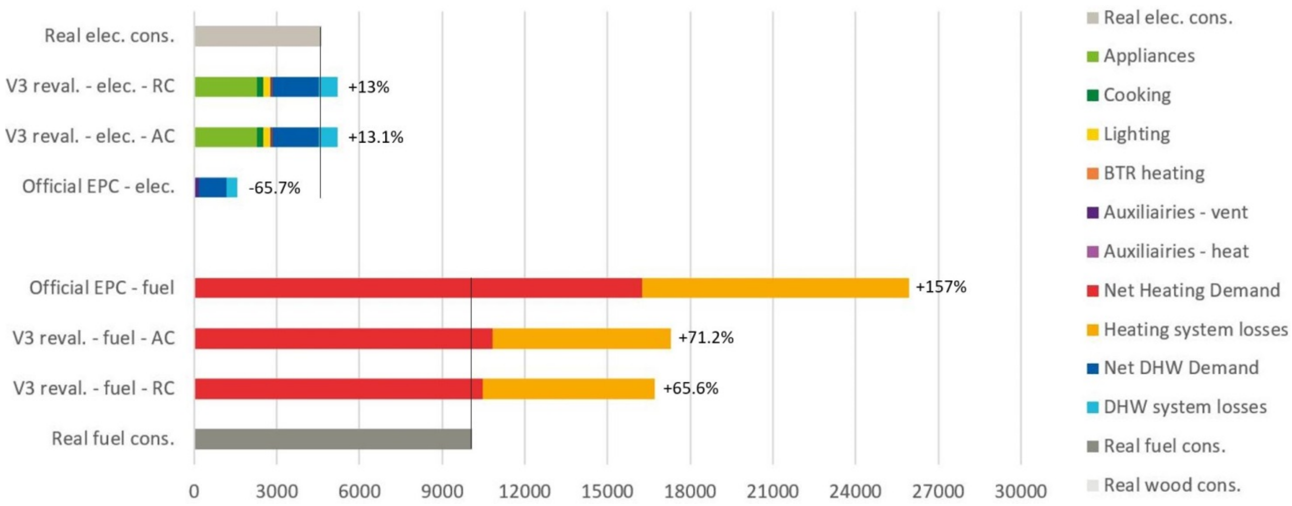

Fig. 5.2.37. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS6

The natural gas consumption being only influenced by the heating of spaces, the remaining gap between the revaluations and the real data can only be closed by either the reduction of the demand, or the improvement of the efficiencies hypotheses, and more probably by a combination of the two. The figure 5.2.38 hereunder displays the temperature curves for both energy sectors. In the ES2 with the bathroom, the set temperature for heating is set at 24°C, and 25°C during coldest months; there are no unheated spaces in the ES2, so that resulting temperature in the ES2 follows the same curve. The reduction of consumption for that sector, therefore, mainly comes from the reduction of the heated time period to 5% of the total. In the first sector heated by the gas stove, the set temperatures are the same for the daytime and night time periods, so that their curves of the temperatures in unheated spaces, and resulting $T_{set,m}$ for the ES1, are merging.

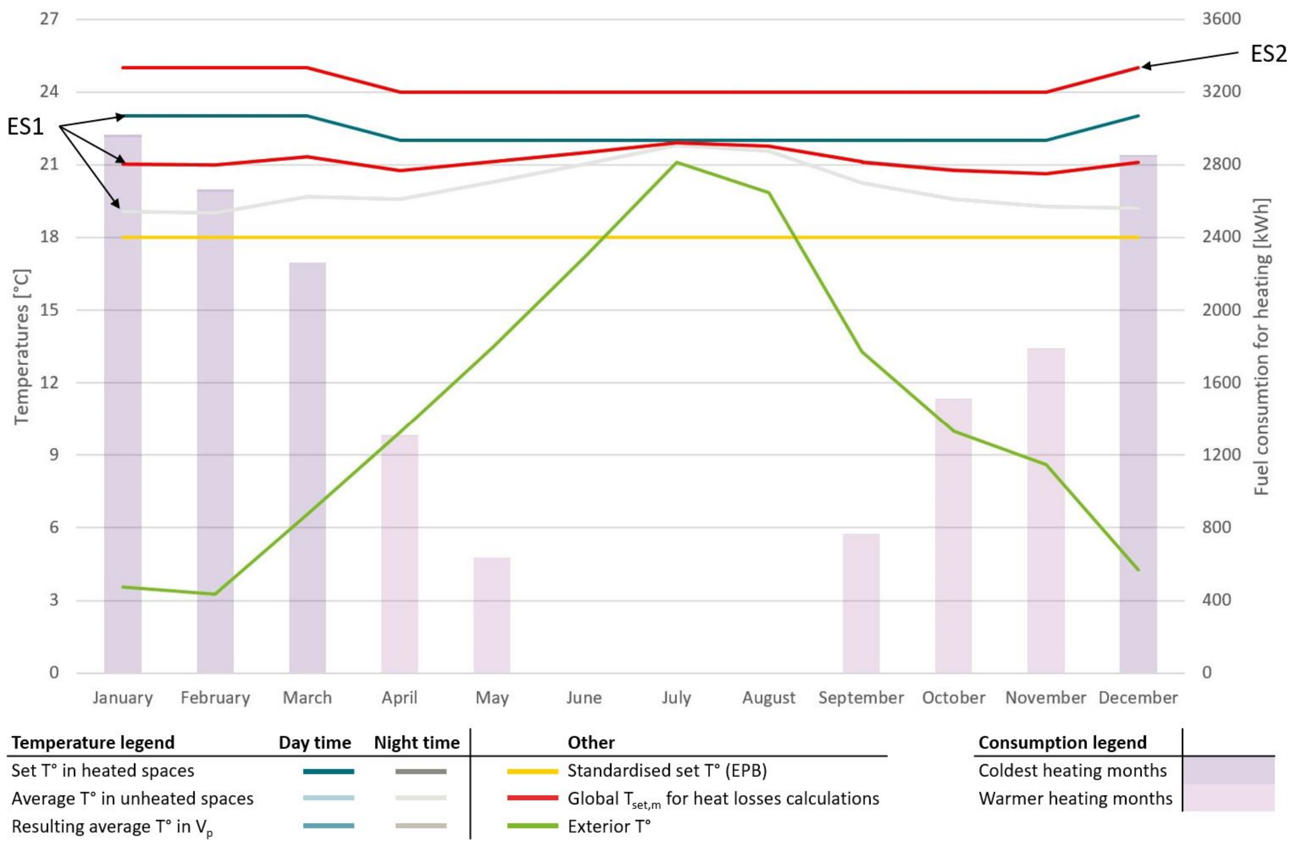

Fig. 5.2.38. CS6: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

In this case, the resulting $T_{set,m}$ temperature curve is largely above the average and standardised 18°C hypothesised by the EPB. The high set temperatures given by the owners, and the hypothesis on the ΔT_{set} factor (+1°C during coldest months), result in relatively high average temperature in unheated spaces. In January, for example, with an exterior temperature of 3.5°C and a set temperature of 23°C in daytime spaces, the bedrooms and attic's average temperature is expected to rise to 19°C, which is quite high, given the poor quality of the envelope, so that some adjustments might be needed.

5.2.7 Case Study 7 – CS7

This case study has notably been chosen because of the similarities it shares with, and the parameters that differentiate it from the CS3 described above. Both houses' typology can be qualified of "modest brick house", both are located on a hill side, with this CS7 benefitting in lighting and ventilation from its elevated position above the garden.

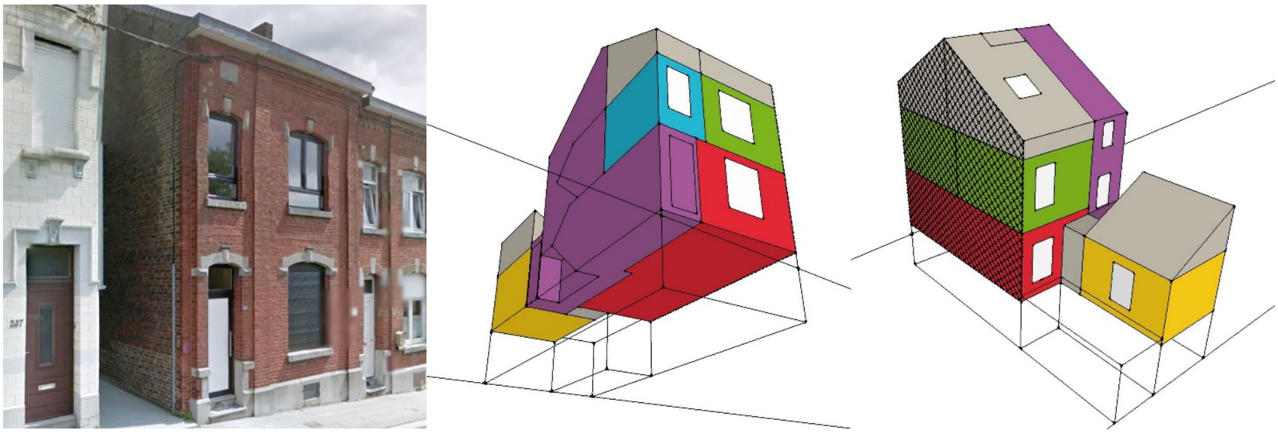

Fig. 5.2.39. CS7 – **Left**: street facade; **centre**: low-angle shot of the North (alleyway) and West (street) facades; **right**: high-angle shot of the South (shared) and East (garden) facades

Table 5.2.2. Comparison of CS3 and CS7 parameters

Parameter	CS3	CS7
Position	Row (2 exterior facades)	End-of-row (3 exterior facades)
Protected volume V_P [m³]	421	506 (+20.2%)
Heat loss area A_T [m²]	225.5	355.8 (+57.8%)
Compactness ($C = V_P/A_T$) [m]	1.87	1.42

The owners of the house, Mr and Mrs. G., had finished a series of renovation works which, on an energy point of view, mainly relates to the complete retrofit of the upper level, the change of the boiler and of all windows. The attic was, before work, not insulated, not airtight, not fit for living. It has been insulated, sealed, and naturally lit through roof windows. Those rooms had not been used nor heated at the time of the interview, however, as they were still gathering a budget to reinvest in the last step: radiators, bathroom equipment and general fitting out. Their two young children (5 and 3 years old at the time) were used to sleep in the same bedroom, on the first floor, since their early days, and were patiently waiting for these new rooms to be heated.

The insulation of the upper floor was incited by the ECOPACK regional framework, a 0% interest loan for renovation works that include a financial incentive that does not have to be reimbursed. A complete ECOPACK file for attributed incentives was therefore available as acceptable proofs for those heat loss surfaces and the newly installed condensing boiler. The description of the energy system, therefore, did not stir particular questioning: when defining variants, it appeared that the only improvement that could be brought to the description of the envelope was to consider the U-value of 1.1W/m²K for the new double glazing, instead of the default value of 1.4W/m²K attributed to "high efficiency double glazing installed after 2000" (the real value could not be found in the documentation of the ECOPACK). Given the negligible reduction this change in value brings to the $H_{T,heat}$ coefficient (from 604.9W/K for the "official" EPC to 600.7W/K for the variant labelled "Umax" in Figure 5.2.40 below), it was finally decided to consider only one variant in the envelope ("Umax"), and the 1.1W/m²K U-value for glazing.

In Figure 5.2.40, the 26.2W/K related to the known resistance of insulation layers (dark blue) relates to the upper floor heat loss surfaces. The unknown presence of insulation, in red, relates to the roof of the kitchen in the annex, mainly. The rest of the opaque envelope is considered uninsulated, so that the average U-value of the house is evaluated at 1.69W/m²K, and the specific annual primary energy consumption, to 436kWh/m².year (level "F" on the certification scale).

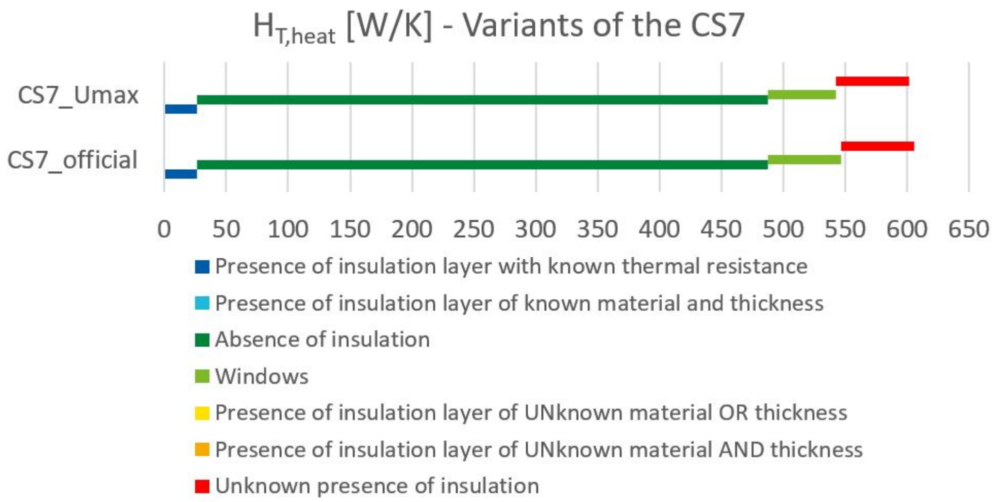

Fig. 5.2.40. Repartition of the $H_{T,heat}$ coefficient [W/K] for the two variants of the CS7

No real variant was really interesting based on the envelope, therefore, but neither were there any based on the systems, mainly represented by the condensing boiler mentioned above, using natural gas to supply heat and DHW to the whole dwelling. Its efficiencies are:

- For heating: global efficiency of 72%:
  - Production: 90% (108% of theoretical efficiency evaluated according to norms and standards, degraded due to variable temperature regulation, theoretical 30°C return water temperature and position out of the V_P);
  - Distribution: 95% (uninsulated pipes out of V_P);
  - Storage: 100% (no storage, direct supply);
  - Emission: 84%;
  - Solar fraction: 0% (no thermal solar installation).
- For DHW: global efficiency of 40%, considering:
  - Production: 65%, default efficiency for a production of DHW coupled to heat supply (variable temperature boiler using natural gas), with separate storage;
  - Distribution: 62% (production close to kitchen, far from bathroom);
  - Circulation loop: 100% (absent);
  - Solar fraction: 0% (no solar thermal installation).

Mr G. works every day out of his home, but Mrs G. shares her time between a half-time job and caring for her two young children, who attend the local kindergarten or school. The main daytime spaces (kitchen and living room, with its adjacent dining room) are therefore heated when the whole family is present at home (mornings and after school). The heating pattern of the household presents, on average, 3 days a week when the heating is completely shut off due to complete absence during the day. For the 4 remaining days, the presence of the mother at home is indicated by the heating of the daytime rooms alone (*"I spend my days going up and down those stairs for laundry, tidying, organising, cleaning, or else work in the living room… I don't need to heat the rest of the house, I'm hot enough as it is"*, says Mrs G.). The bathroom is heated by both the radiator and an electric boost, when in use. At night, a temperature setback of 16°C is left in the living room and dining room, and in the children's bedroom during the coldest months of winter.

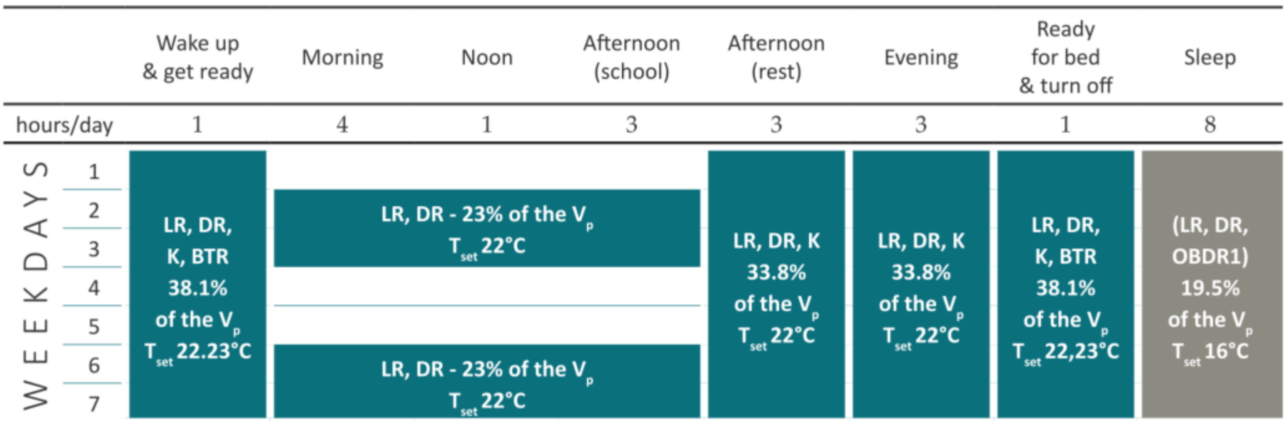

Fig. 5.2.41. Heating pattern of the CS7, according to owners' answers to the questionnaire.

In terms of ventilation, Mrs G. mentioned opening windows daily, in the kitchen and the bedrooms. The only ventilation device that was found in the house is a timed extractor in the toilets, on the first floor, which explains the electricity consumption for ventilation auxiliaries in the results. The global $H_{V,heat}$ coefficient was revaluated to 56W/K in this case study, which is more than twice the CS3 coefficient, due to a higher hygienic ventilation rate (the CS3 owners admitted rarely ventilating their dwelling) and a higher air change due to the lack of airtightness (the $\dot{v}_{50,heat}$ factor is imposed by default at 12m³/h.m² in both cases, but the bigger heat loss area of the CS7 brings more draughts).

The results shown below, in Figure 5.2.42, compare the dynamics of the modifications brought to the revaluations in the second variant of the CS3 ("UAP", the chosen variant), and the CS7. The real natural gas consumption given by Mr G., owner of the CS7, does not cover a whole year, but a little less than nine months (11/12/15 to 30/08/16), as the reader was restarted when the heating system was changed in December 2015. The results in the Figure 5.2.42 consider the same heating period (with a 20/31 ratio applied to December consumptions). The electricity consumption data, on the other hand, cover the whole year between September 2015 and August 2016.

The initial gap between the theoretical, regulatory results and the real consumption data is smaller for the CS7 (+230%) than it was for the CS3 (+430%), despite a higher $H_{T,heat}$ coefficient. This gap has been reduced to 78% at the highest, 43% at the lowest for the CS7, whereas the CS3 presented a remnant discrepancy in the theoretical consumptions superior to 100%. The envelope, in this case study, is a little bit more insulated (average U-value of 1.69W/m²K, compared to 1.76W/m²K in the CS3), but more important in area, so that a conclusion is difficult on this data alone. Both houses' walls, built at the same time, are similar in materials (bricks) and thickness, without insulation.

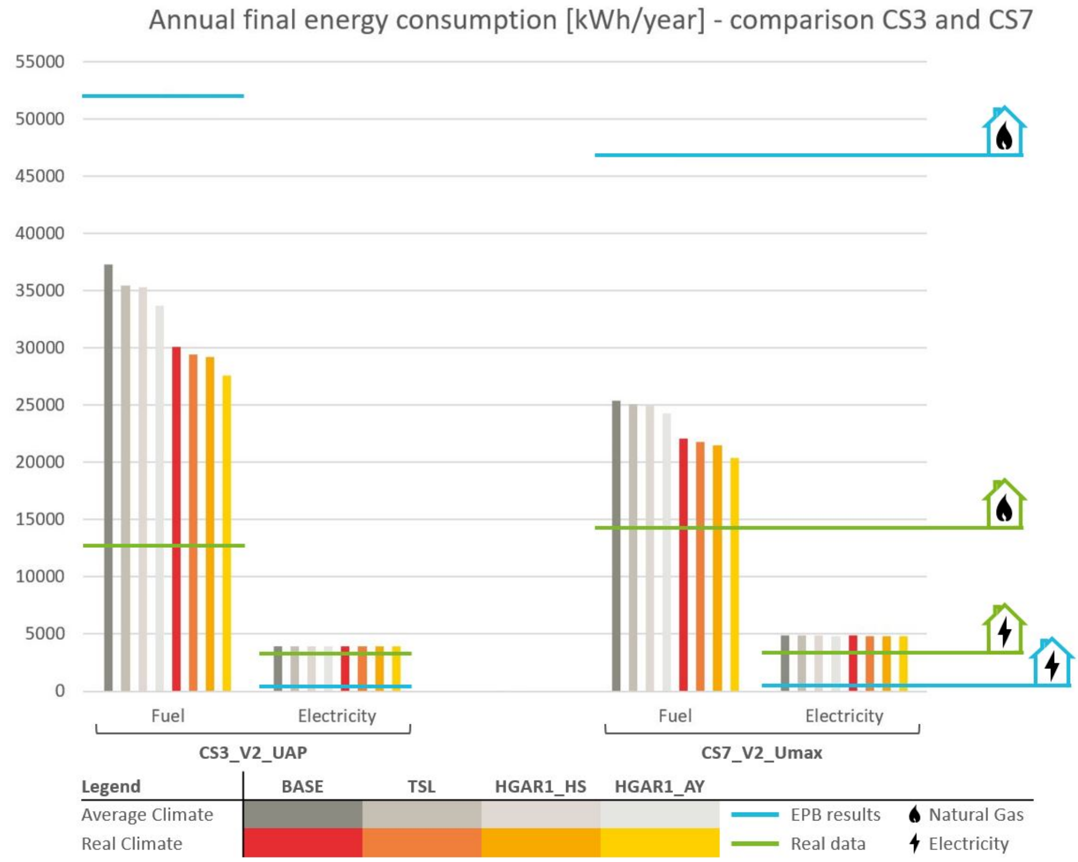

Fig. 5.2.42. Results of revaluated energy consumptions for the CS3 and CS7, for different steps in the method

The main difference between both houses is the precision in the description of the heating system's efficiency: in the CS3, the production was evaluated at 77%, mainly by default, and the global efficiency of the installation, at 60%. In the CS7, the production efficiency is evaluated at 90%, based on the theoretical efficiency at 30% of heating load (producer information), and the global efficiency at 72%. It is difficult to assess the real improvement in accuracy without monitoring campaigns or audits of both houses' heating installations, which is now impossible for the CS3, but it certainly shows the influence of acceptable data on the results.

The progressive steps in the modified method all bring, since the first case study with the exception of the CS6, progressive reductions in the estimated consumptions. Though of small importance separately (less than 5%, closer to 2% for each step), these progressive reductions bring together an important reduction in the results, as shown in Figure 5.2.42. The decrease is more important in CS3 than in CS7, however: as it is mainly due to the evaluation of NHDs, this phenomenon is attributed to the higher share of heated V_P in the CS3, and the longer period of heating (all day round), so that those factors (TSL, HGAR = 1) have more effect on the CS3, especially for daytime (mornings, noon periods and first part of afternoon).

The final revaluation of the CS7 variant before sensitivity study is shown in Figure 5.2.43 below. In this case also, the real natural gas consumption is more or less equal to the revaluated NHDs, which means that they are still largely overestimated. The higher and, probably, more accurate efficiencies characterising the heating system certainly reinforce this hypothesis. In a similar way, the revaluated total electricity consumption for appliances only is nearly equal to the total real data of electricity consumption for the covered period. The remaining discrepancy after this "final" revaluation is in the same proportions as in CS5: around 20%, from an overestimation of the equipment level.

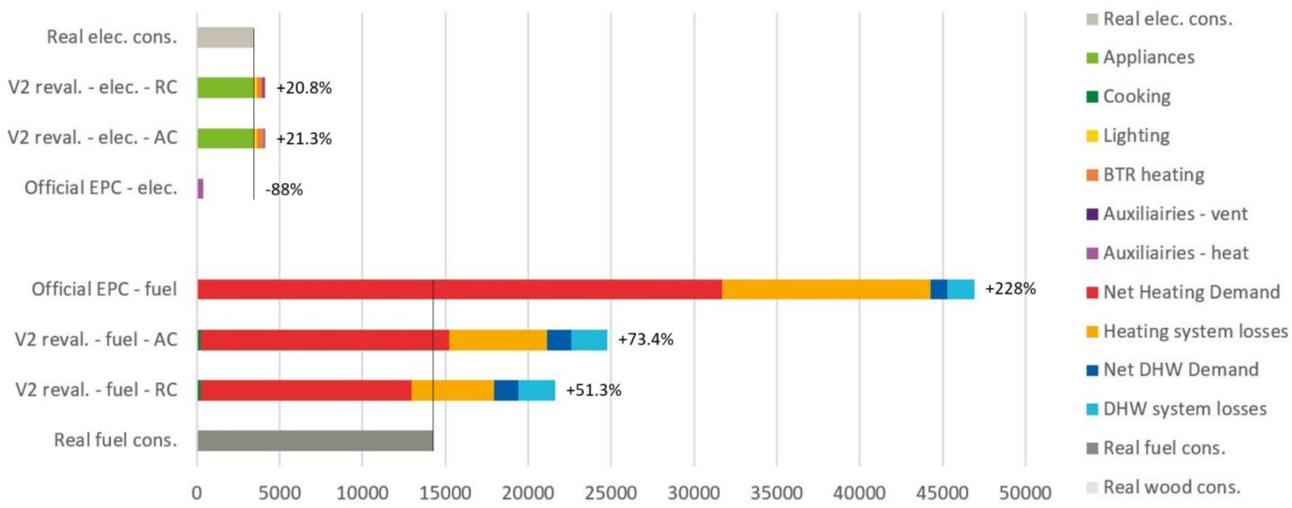

Fig. 5.2.43. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS7

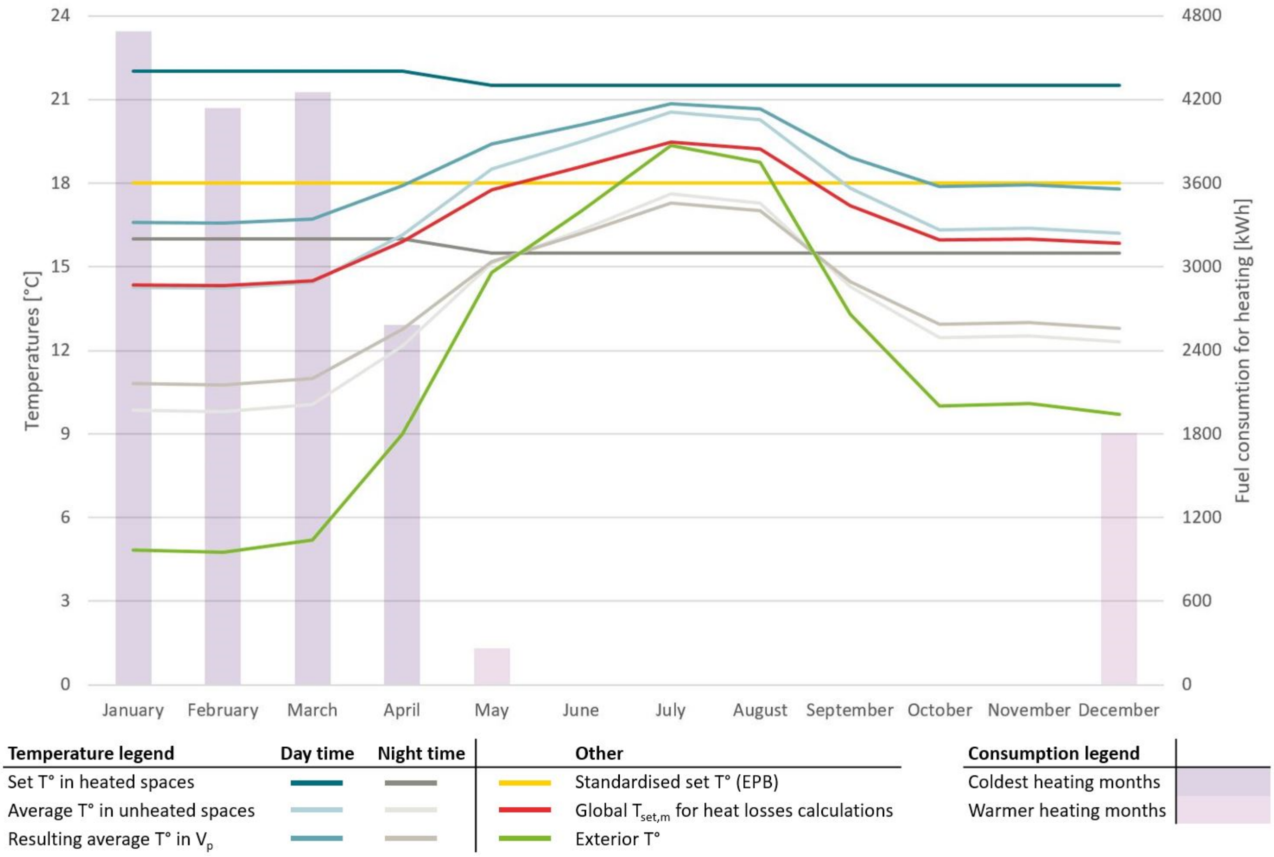

Fig. 5.2.44. CS7: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

The revaluations have been simulated on a complete year (for the electricity consumption, due to the heating of the bathroom), as shown by the temperature curves on Figure 5.2.44. The revaluations of heating consumption displayed on the same Figure, however, only cover the period of real natural gas consumption data given by the owner, between December 11th, 2015 and August 30th, 2016. The temperature, as revaluated in unheated spaces during daytime or night time periods, are very low when compared to the other case studies so far. This is due to the disadvantageous ratio between heated and unheated spaces, displayed in the heating pattern (Figure 5.2.41), and to the rather high f_{pct} factor, which integrates the influence of the envelope performance in heat homogeneity, and is evaluated to 1.3 [W/m³.K] in this case study. All other case studies so far had f_{pct} factors inferior to 1, a threshold that marks its importance in Equation (9). In this case, it is furthermore accentuated by the $f_{\Delta T,uhs}$ factor, a 1.2 factor that considers their habit to close doors between heated and unheated spaces (see section 4.3.3.3). There seems to be a slight exaggeration of those hypotheses, though no monitoring is possible in this house, as the upper level is now finished and occupied by the children, and the heating pattern of the house has changed.

5.2.8 Case Study 8 – CS8

The eighth house was initially built in the 1960's in the suburbs of Liege, and bought by a young couple of architects in their late twenties, who searched for a dwelling to renovate. Their initial project was largely upgraded when the BATEX scheme was implemented in Wallonia (see Fig.2.2.48 in section 2.2.3), searching for buildings with exemplary environmental and energy performances, to award them a subsidy of 100€ per built/renovated square meter. The street façade, visible in Figure 5.2.45 hereunder, is the façade after renovation, the situation described in the EPCs, in which the household has been interviewed and for which they described their heating habits.

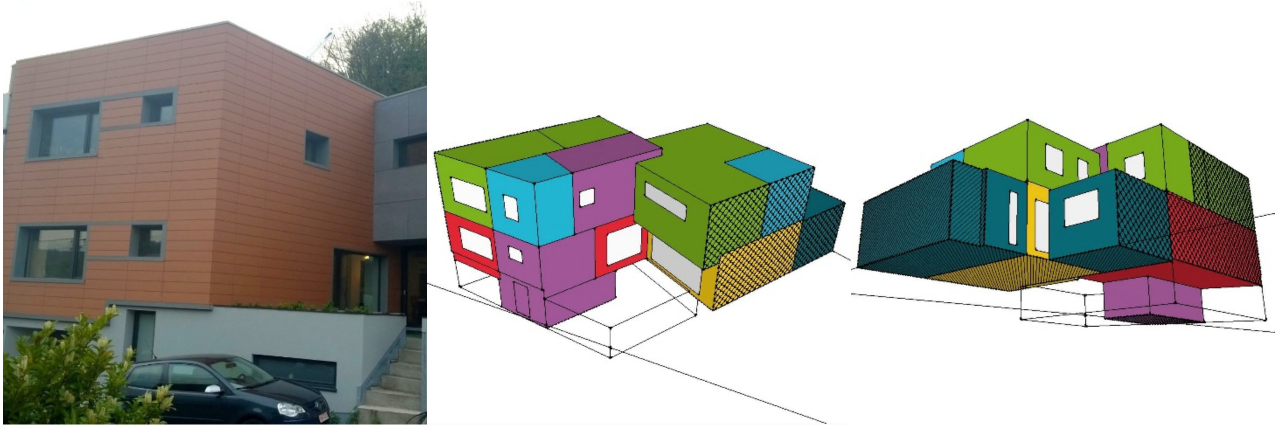

Fig. 5.2.45. CS8 – **Left**: street facade; **centre**: high-angle shot of the SW (shared) and NW (street) facades; **right**: low-angle shot of the NE (shared) and SE (backyard) facades

The particular architecture and volumetric of the building, displayed in Figure 5.2.45, is due to its typology (1960's concrete house, with a flat roof) and its particular position along a hillside road which rises quite rapidly in the general SSW direction. The plot of land, limited by the hill, does not include a garden but two small backyards delimited by the successive renovations and annexes that were built at the back, and a front yard visible on the picture above. The owners decided to keep the complete volume, insulate the whole envelope and use the flat roofs to create green exterior spaces.

The attributed BATEX subsidy means that there was a complete file of acceptable proofs to be used in the description of the envelope, up to the completed EPB declaration describing the renovated building as accurately as it would have been asked for a newly built dwelling. All the thermal resistances of the insulation layers were available, but better yet, the U-values of all heat loss surfaces were evaluated and could be used in the description. The three variants in this case study, therefore, are defined by three different ways to use this information in the description:

- The first variant, labelled "EPC_min", uses all the insulation types and thicknesses described in the BATEX file, leaving to the EPC method the responsibility to use its default values to deduce thermal resistances. The very important thicknesses of insulation are very influential in this comparison, as they nearly insure that the U-values obtained in this variant are very close to those of the EPB declaration, at least for opaque walls. This can be exemplified with the green roofs: the owner-architects mentioned the presence of two layers, one of 30cm of mineral wool with a thermal conductivity of 0.04W/mK, and the other of 24cm of mineral wool with a thermal conductivity of 0.035W/mK, filling the spaces of a wooden structure. The EPC calculation method separates the thermal resistances of the structure (0.2m²K/W for "standard" roof composition, making no distinction between wood or concrete structure), and the insulation in mineral wool, which is attributed a 0.044W/mK thermal conductivity by default. Both methods show identical end results: a U-value for the roof of 0.08W/m²K. Some walls, with thinner insulation layers, show bigger differences between methods, such as the street façade, which is given a U-value of 0.15W/m²K by the EPB, and 0.21W/m²K by the EPC method. The main difference is to be found in the description of the windows, as triple glazing in PVC frames is characterized by an average U-value of 1.65W/m²K using the default values of the EPC method, twice the value (0.81W/m²K) delivered by the EPB, used in the second and third variants. The EPC results, in this variant, are an average U-value for the building of 0.23W/m²K, a 52kWh/m².year specific annual primary energy consumption, making it an "A" building.

- The second and "official" variant considers the U-values and systems' efficiencies delivered by the EPB declaration, and translates them into the EPC software and calculation method. The resulting average U-value for the building is, in this case, 0.17W/m²K, and the resulting E_{spec} indicator, 41kWh/m².year, making this variant an "A+" building.
- The third variant considers the results given by the EPB declaration, using therefore the calculation method developed for new buildings. The interest here is quite straightforward: this case study (as well as the CS15), described to the last detail in terms of energy system's characteristics, can be used to assess the importance of variations on high-performance dwellings' certification due to EPC simplifications. The main results are quite comparable to the first variant: an "A" level on the certification scale due to a specific annual primary energy consumption of 52kWh/m².year, and an average U-value of 0.21W/m²K.

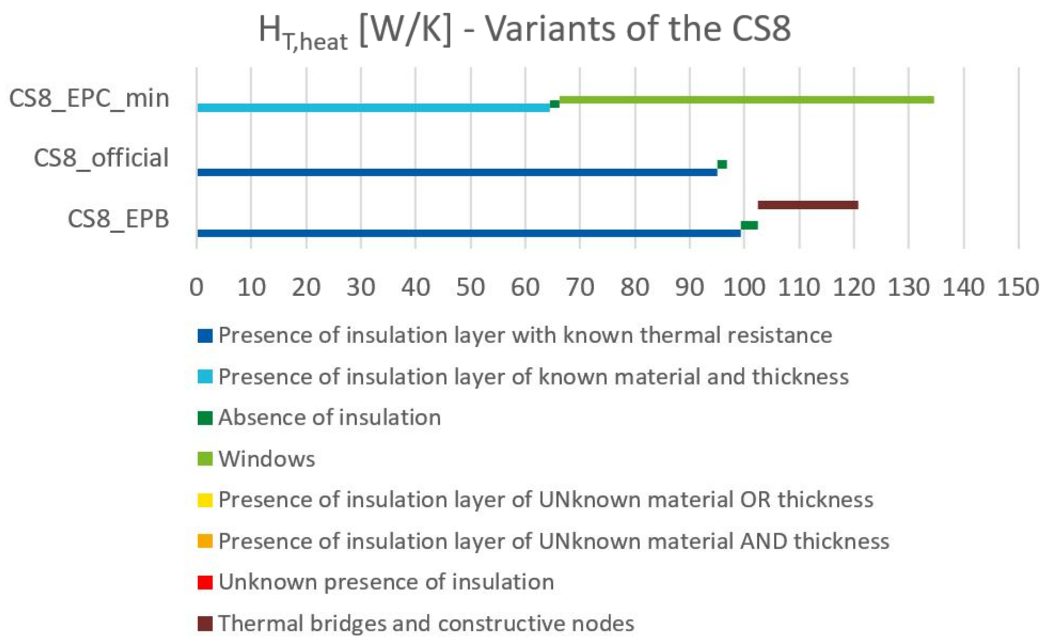

Fig. 5.2.46. Repartition of the $H_{T,heat}$ coefficient [W/K] for the three variants of the CS8

The Figure 5.2.46 above displays the $H_{T,heat}$ coefficients for those variants described above. The small portion of heat losses due to "absence of insulation" relates to 4m² (0.7% of the total heat loss area) of floor laid on the ground that could not be technically insulated by the owners. The real windows U-values, considered in the second and third variants, were encoded as "known thermal resistance" in the Figure above. The third variant displays an important difference: the consideration of thermal bridges and construction nodes in the definition of new and highly-efficient buildings. In theory, these added thermal losses should be defined for all cases, but are rightly considered negligible in the EPC method for most old and uninsulated buildings. However, when it comes to assess the performance of highly insulated buildings, the share of heat losses due to these weaknesses in the thermal insulation of the envelope becomes significant: in this CS8, the added 18.4W/K for thermal bridges represent 15% of the total 121W/K of heat losses by transmission. These added heat losses partly compensate the use of the default values in the first variant, explaining the greater similarities in the results between those variants, when compared to the second.

A wood stove, powered by pellets, located in the living room, supplies the household with heat and DHW. The heat is distributed in the different rooms of the house via the ventilation air, managed by a completely mechanical system with heat recovery. The evaluated efficiencies of the systems are:

- For heating: global efficiency of 77%:
    - Production: 87%. A stove should be indicated as a local system in the EPC software, characterized by a default value for the production and emission efficiencies. In this case however, the system has been described as a central heating installation supplied by a wood boiler (not stove), which allowed to consider the distribution of heat in the volume and the production of DHW by the same system. The partial load efficiency of the production device (as determined by the current norms and standards), which can only be used for central installations, is 94% in this case. This possibility was left to the owners-architects when filling the EPB declaration; the same hypothesis has been taken in the EPC method for consistency.
    - Distribution: 100% (all in V_P);
    - Storage: 100% (the storage is located in the protected volume, no loss considered);
    - Emission: 89%;
    - Solar fraction: 49 to 58%. This first CS presenting a solar installation is equipped with 10m² of thermal panels that feed the heating and DHW systems. The solar fraction for heating is evaluated at 48.9% of the NHD for the first variant, 58.3% in the second and 57.9% in the third. It is determined by the monthly average efficiency of the solar system (identical in all three variants), and the ratio between the monthly sunlight gains of the solar installation (depending on the orientation, slope and surface of the panels, identical for the three variants) and the global heat and DHW demand. This last determiner explains the variations in solar fraction between variants.
- For the DHW system, the global efficiency is evaluated at 40% in the EPC method and 29.5% in the EPB method. This difference is attributed to more detrimental default values used in the EPB method for new buildings: the production device was given a production efficiency of 45% in the EPB method, 65% in the EPC. Other contributing efficiencies are:
    - Distribution: 62% in EPC method, 65% in EPB (difference due to default values in EPC method that do not apply in EPB);
    - Circulation loop: 100% (absent);
    - Solar fraction: 49 to 58% (identical to the solar fraction in heat production).

The ventilation system in the EPB declaration manages a 467m³/h air flow, in supply and exhaust, with an 82% theoretical heat recovery efficiency, reduced to 70%, mainly due to the absence of continuous measuring of in- and out-flows. The $r_{preh,heat}$ coefficient (Equation (14), section 4.3.3.4) is therefore equal to 0.3. An airtightness testing of the envelope has been realised at the end of the renovation works, and the report given by the assessor presents a $\dot{v}_{50,heat}$coefficient (Equation (15), section 4.3.3.4) of 1.6m³/h per square meter of the heat loss envelope, for a pressure difference of 50Pa. The $H_{V,heat}$ coefficient in this case study is therefore revaluated at 56W/K (comparable to the CS7), when the regulatory calculation method had evaluated it at 49.8W/K.

When interviewed, Mr and Mrs H. had just welcomed their first child, which explains the presence of Mrs H. at home more often than usual. But more than the presence at home, in this case, the heating schedule is highly influenced by the quality of the envelope and the performance and characteristics of the heating system. When the owners were asked about the number of heating hours per day, their answer was different from all other interviewees: "*we hardly really stop the system… actually, the thermostat and exterior probe manage to have a constant internal temperature of 20°C downstairs, 18°C upstairs, but I cannot tell you how many hours a day of actual heating this represents. Plus it's low temperature, so that it would not be really advisable to shut the system off completely, except for several days… The inertia and airtightness of the building do the rest.*" Translated in terms of heating pattern, it will be considered thus:

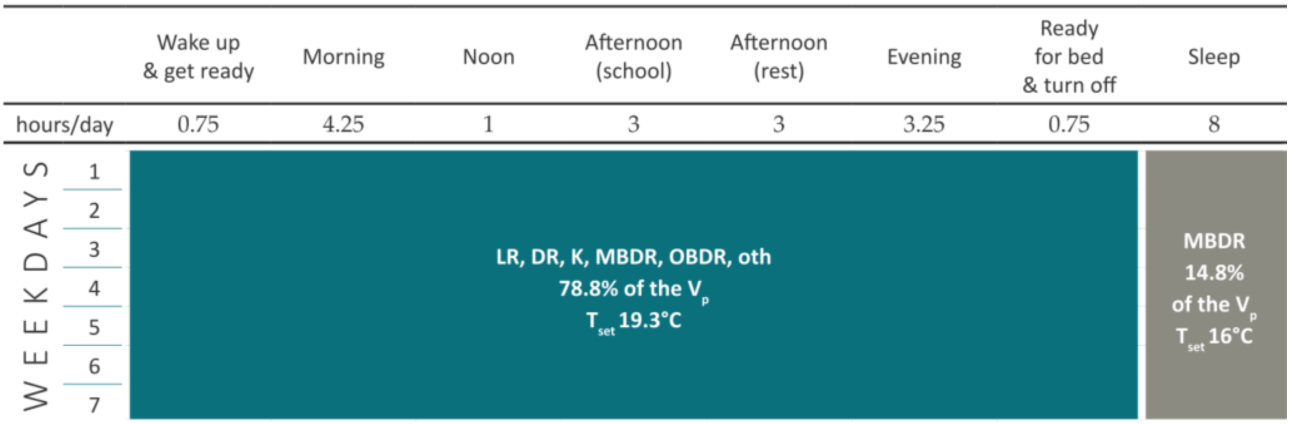

Fig. 5.2.47. Heating pattern of the CS8, according to owners' answers to the questionnaire.

Nearly the whole V_P is heated all day: the excluded rooms are the technical annex at the back, the circulations and… the bathroom ("*we let the hot water run for 10 seconds, and it is as hot as in a sauna in there*"). The set temperature of 19.3°C considers the differentiated settings between downstairs and upstairs. During the night, the owners mentioned a setback temperature in their bedroom, where their toddler was still sleeping at the time of the interview; but that "*it is rare when the temperature goes as low as 16°C during the night, given the quality of the envelope*". The production of the thermal solar panels is entirely consumed annually, so that the final energy consumptions of natural gas presented in the Figure 5.2.49 integrate the solar production and consumption. The Figure 5.2.48 below displays the solar productions for the CS8, theoretical and actual (3,100kWh from November 2015 to October 2016), in order to highlight that particular share of the consumptions. The results are similar between the average and real climates, given that the solar radiation hypotheses could not be replaced with local data. The small variations are due to the fact that the solar fraction is, as explained above, influenced by the total demand of the dwelling (for both heating and DHW production in this case). The first variant presents results closer to the EPB evaluation, whereas the second and third are closer to the real production data. Overall, the revaluations seem quite accurate, albeit the results from the regulatory calculation method are undeniably underestimated.

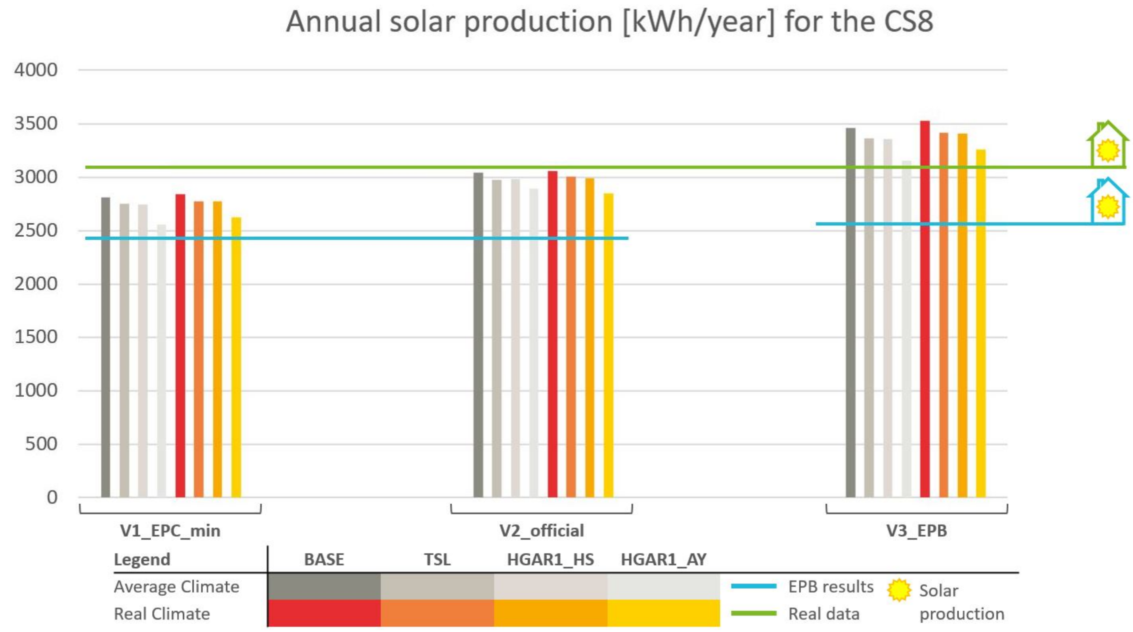

Fig. 5.2.48. Results of revaluated energy consumptions for the CS8, for different steps in the method

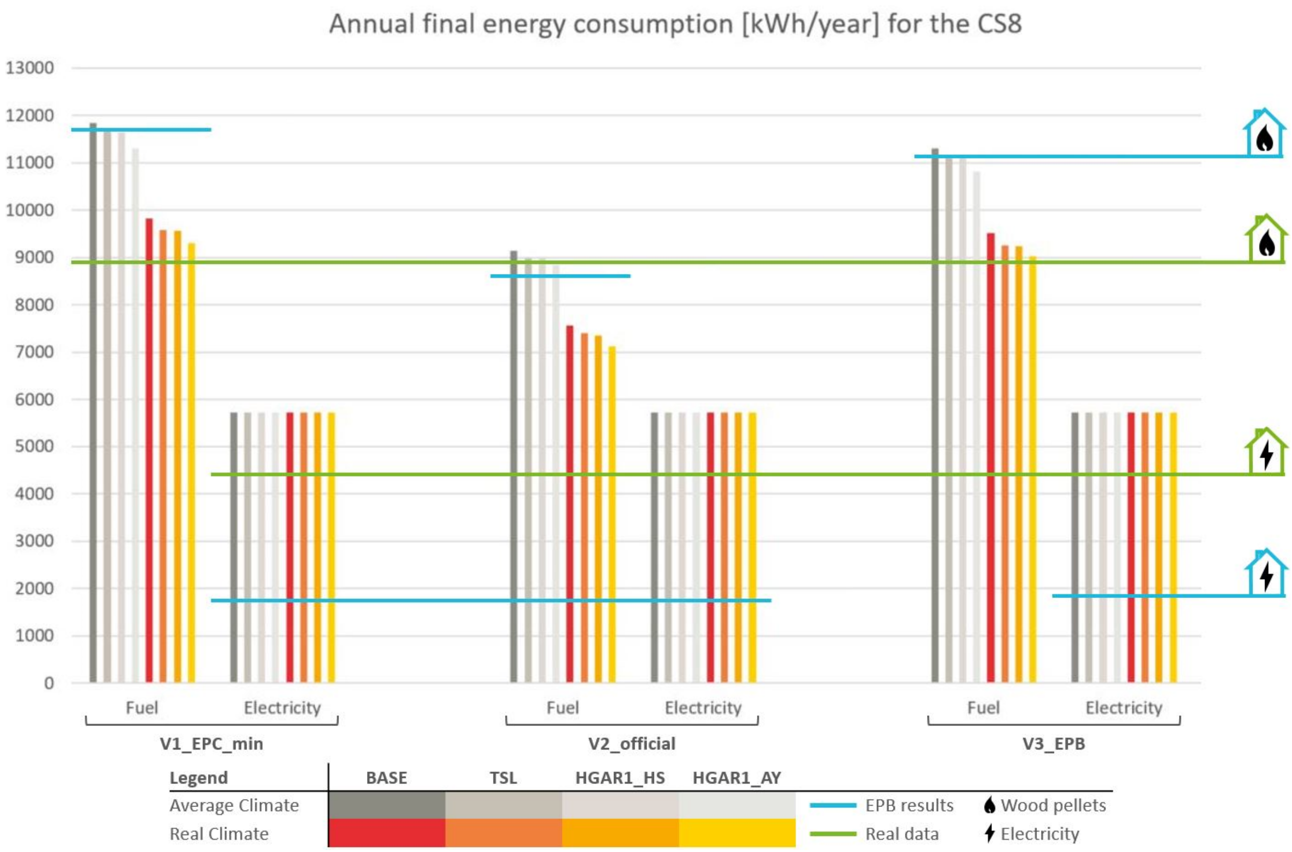

Fig. 5.2.49. Results of revaluated energy consumptions for the CS8, for different steps in the method

As expected, the results of the wood consumption revaluations are quite similar in the first and third variant, and lower in the second, significantly enough to dismiss that variant for the final step of the research, as it shows an underestimation of the consumption of around 20% (see Figure 5.2.49). The first variant's results are, on average, 4.1% higher than the third, which is due to the combination of a higher $H_{T,heat}$ coefficient (11% above the coefficient of the third variant – see Figure 5.2.46), lower share of the solar installation in the heating and DHW results, and a higher DHW system efficiency. It seems like the first and third variants combine higher $H_{T,heat}$ coefficients and milder realistic climate data to reach accurate evaluations, whereas the second variant combines lower $H_{T,heat}$ coefficient and colder climatic data to do the same (and, in this case, approach the theoretical results which are really close to the real data). The third variant however, more accurate as far as the inputs are related, is the obvious choice for the next step (see Figure 5.2.51 below).

The overestimation of electricity consumptions is quite important in this case: +30%. The analysis of its repartition (see Figure 5.2.50) enlightens the necessary adjustments in the calculation method. The consumptions for appliances is dominant, evaluated at 3,500kWh, nearly 80% of the declared 4,400kWh consumption. Lighting is also seemingly overestimated at 870kWh. Clearly, the size of the dwelling has too much weight in this case study's revaluations, as it also influences the auxiliaries' consumptions, which are particularly important in this case due to the presence of the mechanical ventilation with heat recovery (ventilation which additionally carries the heat towards the different rooms). The calibration of the electricity consumption revaluation, brought before the sensitivity study in order to match the description made in 4.3.2, sees these size-influenced consumptions tamed by the ratio of heated volume, for example, a modification that was not yet brought to the method at this point. After those modifications, the estimated electricity consumption were only overestimated by 11.2% (see Figure 5.2.51).

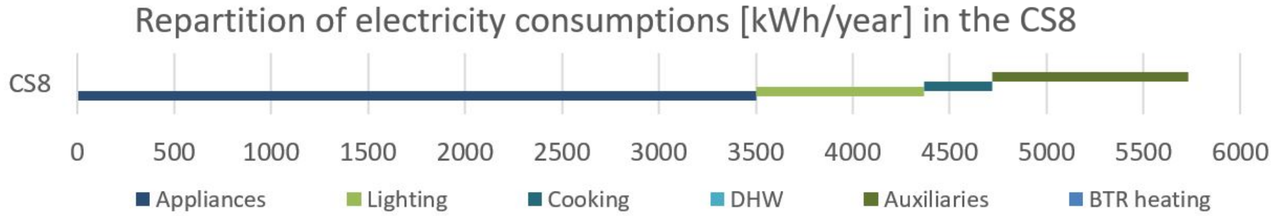

Fig. 5.2.50. Repartition of the electricity consumptions per end-use [kWh], results of the revaluations for the CS8

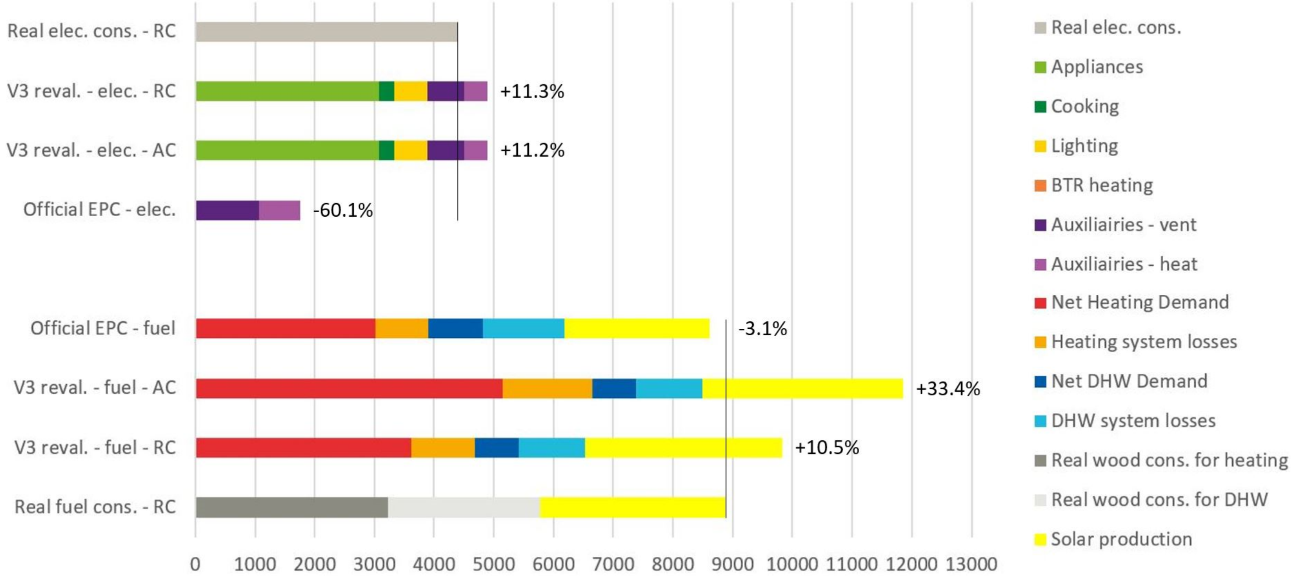

Fig. 5.2.51. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS8

Mr H. has followed closely the settings and parametrization of the systems in order to maximize their efficiencies and minimize their consumptions, showing validation of the observation that there is an element of fun, interest and intellectual stimulation that can lead to real savings, in a technology that can be appropriated by the owner. It also allowed him to give detailed consumptions, separating DHW and heating consumptions, as well as the solar production. The immediate observation is that the official EPC seems here more accurate, in terms of total consumption and repartitions, although it must be reminded that it uses the average climate. The use of the real climatic data, which brings to the revaluations in Figure 5.2.49, a significant average 17.4% reduction, would, here also, reduce the estimated consumption of the official EPC by at least 15%, underestimating therefore its results. Revaluated consumptions based on the third variant, made with both sets of climatic data, show more accurate solar production results. This is only due to the influence of the total (overestimated in the V3) net heating and DHW demand in the equation, as the solar radiation data and installation characteristics are the same in all models. These revaluations also display an imbalance between heating and DHW related consumptions. The arrival of their first child during the covered period explains part of the DHW needs (and consumptions) underestimation.

It is interesting to note that, in the Figure 5.2.49, the use of the average climate (grey columns) brings revaluated results really close to the EPC theoretical and standardised results (blue lines), especially for the "BASE" simulations, which are still the most "EPB-standardised". This can be explained by the fact that the EPB regulatory calculation method was initially developed for new and efficient buildings, and its standardisation, considering 100% of the V_P heated at 18°C, is closer to the CS8 reality, where around 80% of the V_P is heated at 19.3°C. This is clearly visible in Figure 5.2.52 hereunder, displaying the temperature curves for the CS8 revaluations: the red line marking the global $T_{set,m}$ used for revaluated heat losses is very close to the yellow line marking the EPB standardised 18°C $T_{set,m}$. The Figure also shows that, in this very performant case study, the f_{pct} factor plays its part in reducing the temperature gap between heated and unheated spaces.

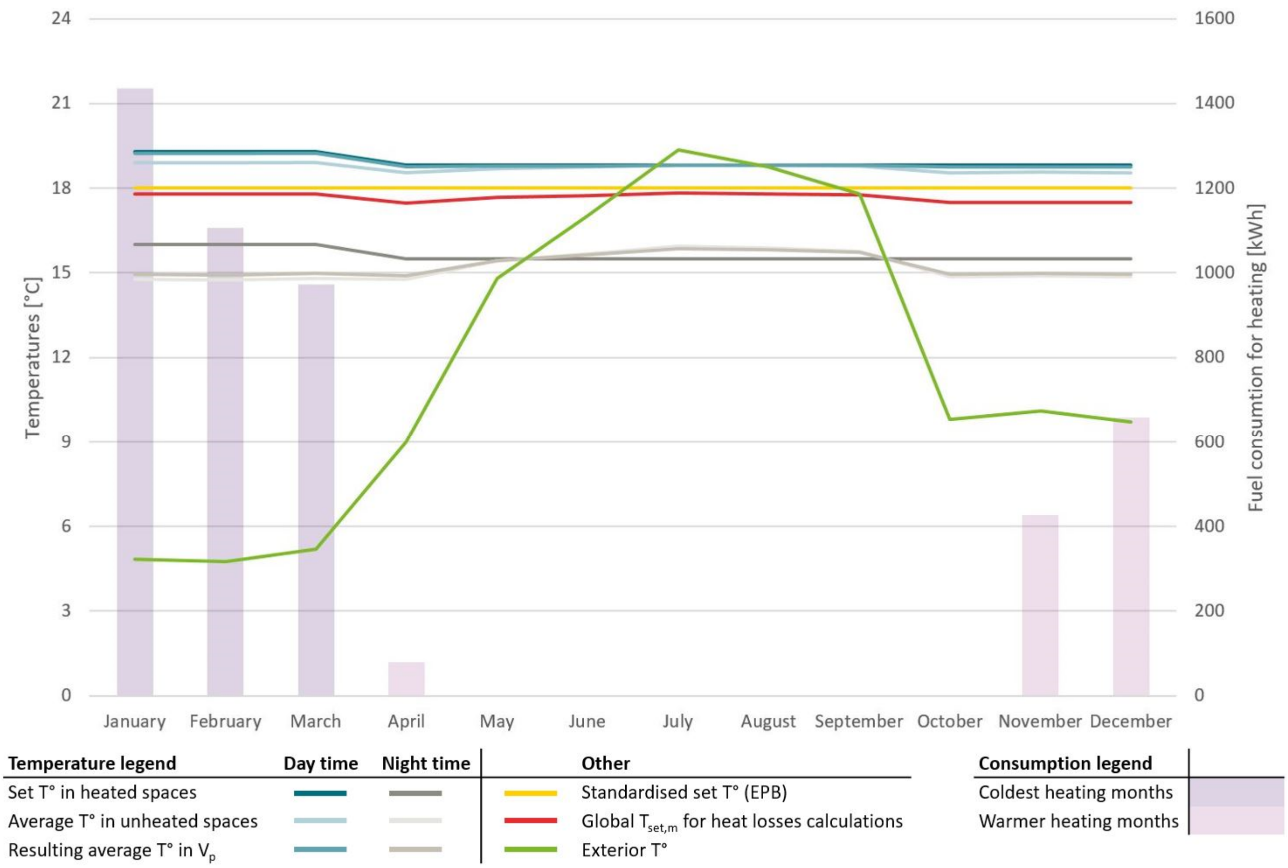

Fig. 5.2.52. CS8: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

5.2.9 Case Study 9 – CS9

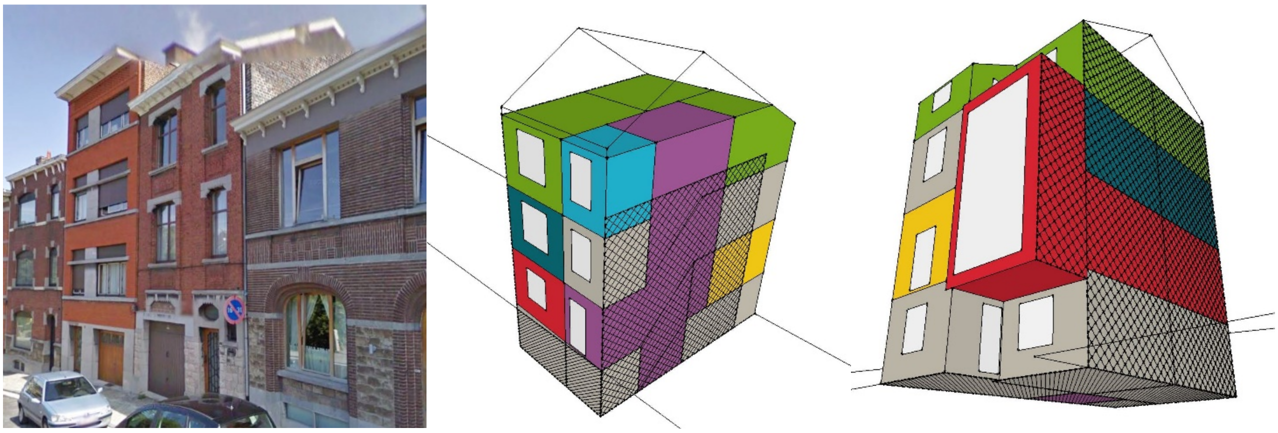

Fig. 5.2.53. CS9 – **Left**: street facade; **centre**: high-angle shot of the South (shared) and West (street) facades; **right**: low-angle shot of the North (shared) and East (garden) facades

At first sight, this house would have to be categorized in the typology of modest brick house, given the width and few architectural details of the façade, although it must be acknowledged that the size of the buildings (around 900m³ of complete V_P, distributed on four levels) is more characteristic of the master houses. In this case again, the house is located on a hill side, with the garden dominating the valley of Liege. The owners are Mr and Mrs I., who live in this house with their two small children. Mrs I. is the architect who developed the renovation project of their own house, which first step had been finished for some times, with insulation applied to the garden façade and annexes at the back, and to the attic floor. Garden-side windows had been changed for triple glazing, with the front façade still equipped with "old" double glazing), and the old boiler replaced by a condensing one. The family was preparing for a second step in renovation, which will see the remodelling of the upper floor in order to create an additional living space under the tilted roof. This upper level is currently still used as an attic, and is only accessible through a trap door in the third floor ceiling. The presence of an insulation layer on the attic floor clearly indicates that this space is to be considered out of the V_P for the time being. The architect of the project, Mrs I. was keen to give all available information under the form of an "attestation signed by the architect" in order to characterize the envelope and heating system accurately.

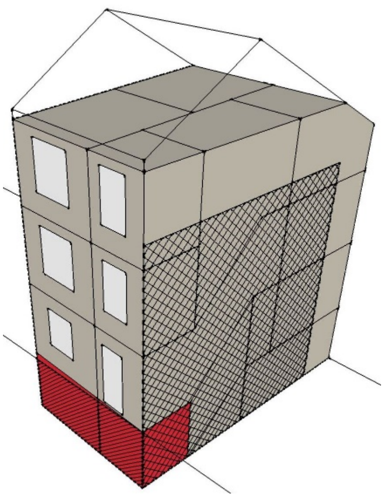

Fig. 5.2.54. Basements included or excluded of the V_P, according to the variant.

The lower level of the house is composed of unheated basements (front façade, underground, in red in Figure 5.2.54) and technical rooms, with a space for Mr I.'s DIY works and an access to the garden, below the living levels. The owners kept the old kitchen units found upstairs and installed them in the basements, to be used when eating in the garden in the summer. As it is a secondary kitchen, rarely used, its inclusion in the V_P is not obligatory. Given the decision flowchart that rules the definition of the V_P, these rooms should be included for the sole reason that there is a "visible intention to insulate": the insulation layer added to the back façade has been extended to the ground level, insulating therefore part of the basements. The only reasonable doubt concerns the basement rooms that are under the front façade, highlighted in Figure 5.2.54: there was no real necessity to add them to the V_P, but no real reason to exclude them either. The variants in this CS9 were therefore defined as in the CS5: either the basements are included ("IncVp_official") or excluded ("RedVp") from the envelope description. If those rooms are included, the envelope to describe includes more walls against the ground, which benefit from reduced "b_j" factors (see Equation (7), section 4.3.3.3) in the evaluation of heat losses by transmission. If they are excluded, those basements must be considered an "outside environment", and the walls separating it from the protected volume have to be described, and attributed a b_j factor equal to 1. Their position, visible in Figure 5.2.54, underground and surrounded by spaces that have to be included in the V_p for reasons exposed above, shades a doubt on that hypothesis, making their inclusion in the protected volume more accurate.

Initially, the variants included also the consideration of the U_{max} values that were applicable when the permit for the renovation was introduced, in 2012. The only heat loss surfaces that did not reach the U_{max} value of the time, however, are:

- 8.6m² of tilted roof above one of the bedrooms on the third level, where the declared presence of mineral wool resulted in a 0.48W/m²K U-value, while the U_{max} was imposed at 0.3W/m²K.
- 4.7m² of old garage door filling in the front façade, the garage becoming the living room after renovation. The declared presence of insulation (description of material type and thickness) resulted in a U-value of 0.57W/m²K whereas the U_{max} value was imposed at 0.4W/m²K.
- Only 2cm of expanded polystyrene could be placed behind the natural stones cladding 10.73m² of front façade. As the U_{max} value of 0.4W/m²K is unlikely in these circumstances, the value was not imposed.

These small improvements in U-values, and relative small portions of heat loss areas, did not bring influential modifications to the variants results: the $H_{T,heat}$ coefficient only decreased by 0.7% in the official variants ("IncVp", between the one labelled "Umax" and the other), 0.6% in the "reduced" one ("RedVp"), as can be seen in Figure 5.2.55 hereunder. The use of the U_{max} values only changes 6.81W/K due to walls with "presence of insulation layer of known material and thickness", into 4.61W/K of "known thermal resistance", which is considered negligible.

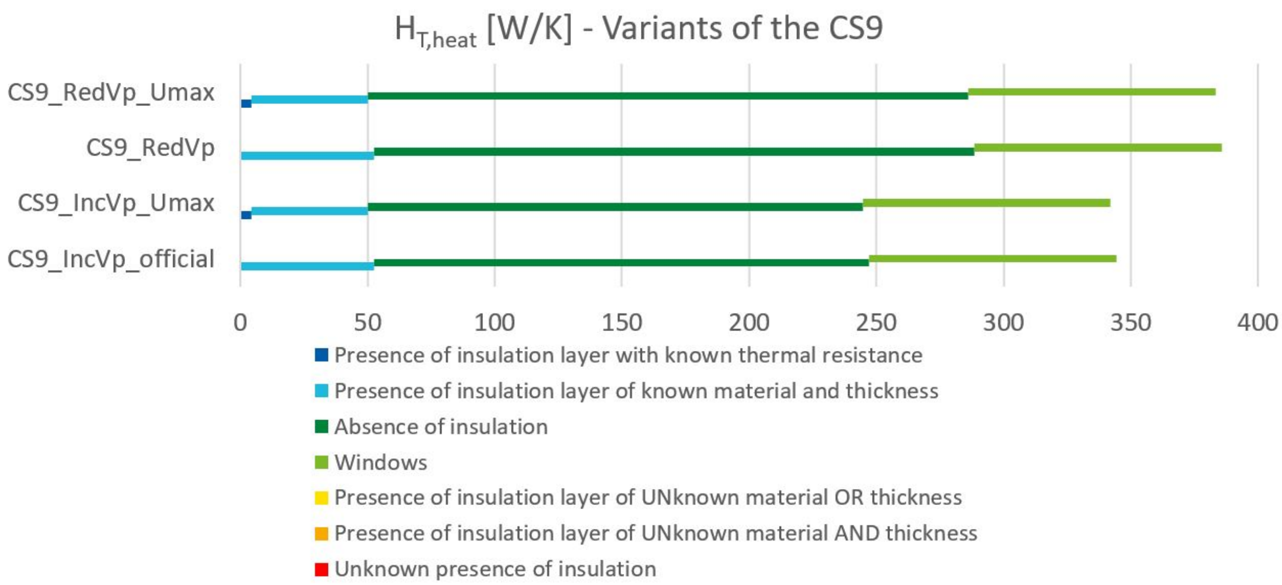

Fig. 5.2.55. Repartition of the $H_{T,heat}$ coefficient [W/K] for the four variants of the CS9

The first variant, therefore, labelled "IncVp_official", is characterized by 901m³ of protected volume, 371.2m² of total heat loss area, an average U-value of 0.97W/m²K, a specific annual primary energy consumption of 149kWh/m².year, and a resulting "B" label on the certification scale. The second variant, labelled "RedVp", is characterised by an average U-value of 1.04W/m²K, a protected volume of 837m³, a total heat loss area of 317.3m² and a "C" label on the certification scale due to a specific annual primary energy consumption of 170kWh/m².year.

There was no ventilation system installed, Mrs I. saying that it was not necessary yet, given that the envelope is very draughty, but that it would probably be installed with the last part of the renovation works. The air tightness of the envelope had not been tested at the time, but has been tested since, and the $\dot{v}_{50,heat}$ coefficient needed in Equation (15) (see section 4.3.3.4) has been evaluated at 11m³/h per square meter of heat loss area, for a pressure difference of 50Pa, which is close to the default value used in the regulatory calculation method (12m³/h.m²).

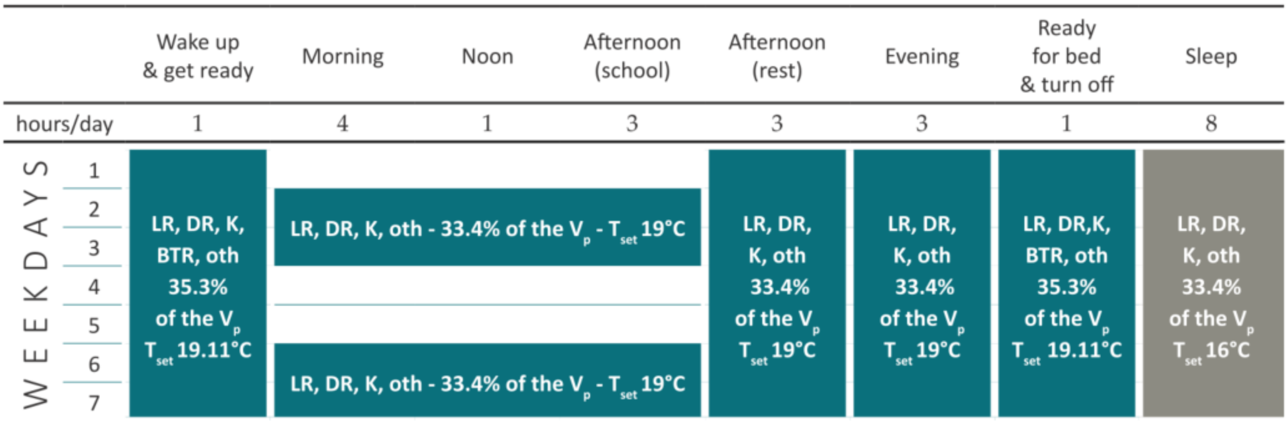

Fig. 5.2.56. Heating pattern of the CS9, according to owners' answers to the questionnaire.

Mr and Mrs I.'s first child was attending school, at the time of the interview, while their second child, still a toddler, was cared for in a local kindergarten three days a week, explaining the heating pattern above (Figure 5.2.56). There is a consistency in the volumetric proportions displayed in this graph: one third is always heated, containing the living room, dining room and kitchen and "other", which in this case is a room on the second floor, opened in mezzanine on the living room downstairs. The (small) bathroom is heated only when in use, with an added electric booster heater.

The heat is provided in the dwelling by a central installation, supplied by a condensing boiler that is powered by natural gas. Its global efficiency is evaluated at 78%, considering:

- Production: 92% (theoretical efficiency $\eta_{30\%}$ = 108%, according to norms and standards, degraded due to temperature regulation and theoretical 30°C return water temperature);
- Distribution: 95% (uninsulated pipes out of V_P);
- Storage: 100% (no storage, direct supply);
- Emission: 89%;
- Solar fraction: 0% (no thermal solar installation).

The Domestic Hot Water is supplied by the same boiler, and the global efficiency of the installation is evaluated at 40%, considering:

- Production: 65% (default efficiency for a production of DHW coupled to heat supply (variable temperature boiler using natural gas), with separate storage;
- Distribution: 62% (production close to kitchen, far from bathroom);
- Circulation loop: 100% (absent);
- Solar fraction: 0% (no solar thermal installation).

The influence of the different $H_{T,heat}$ coefficients displayed in Figure 5.2.55 is directly visible in Figure 5.2.57. Both variants are insulated, but the variant with the protected volume increased to include all basement rooms, presents lower results than the second variant which excludes those spaces. In this modified and de-standardised calculation method, a bigger volume does not mean bigger consumption anymore, as it only adds unheated spaces and therefore slightly modifies the ratio of heated vs unheated spaces. It does not impact the DHW needs or ventilation rates anymore: the main change is the definition of the surrounding heat loss walls, as explained above. The analysis of the CS8 showed that the EPC results were really close to real consumption data, due to a very high knowledge in the description of a highly performant energy system, and to accurate standardisation. The analysis of the CS9, on the other hand, along with previous case studies, shows that the EPC hypotheses overestimate the heat losses of those houses with lower performances. The $H_{T,heat}$, coefficient, mainly, would need to be reduced in order to gain realistic results, but in this case, it is unclear whether the reduction of that coefficient should really be attributed to the inclusion of the basement in the protected volume, or the description of the uninsulated walls. Improvements could be gained from less detrimental description hypotheses in this method.

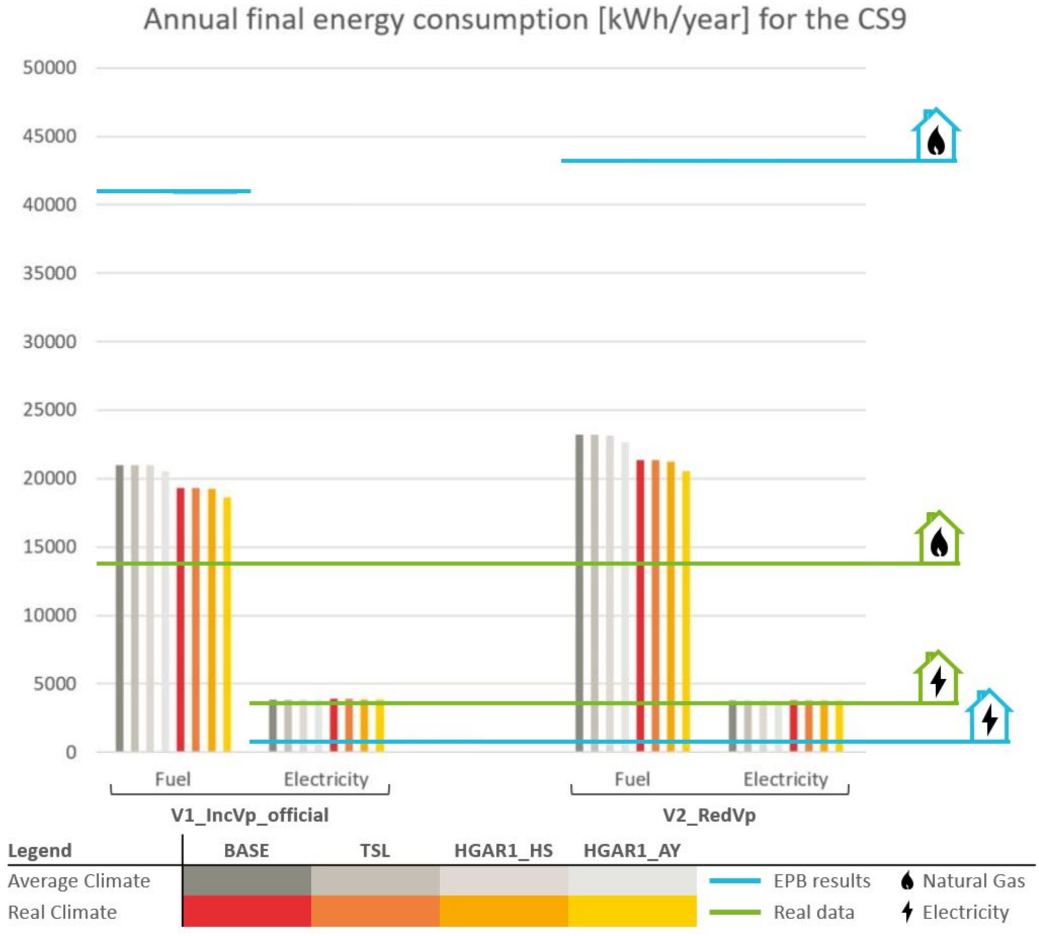

Fig. 5.2.57. Results of revaluated energy consumptions for the two variants of the CS9, for different steps in the method

The repartition of the revaluated consumptions in Figure 5.2.58 indicates that the EPB hypotheses in terms of DHW demand matches the revaluation that is made with "behavioural" parametrisation explained in section 4.3.4. It is the second time that the revaluation results present such a similarity, the first one being for the CS5 "master house". CS5 and 9 are similar in household size (4 inhabitants at the time of the interviews) and great protected volumes (over 900m³ for the chosen variants).

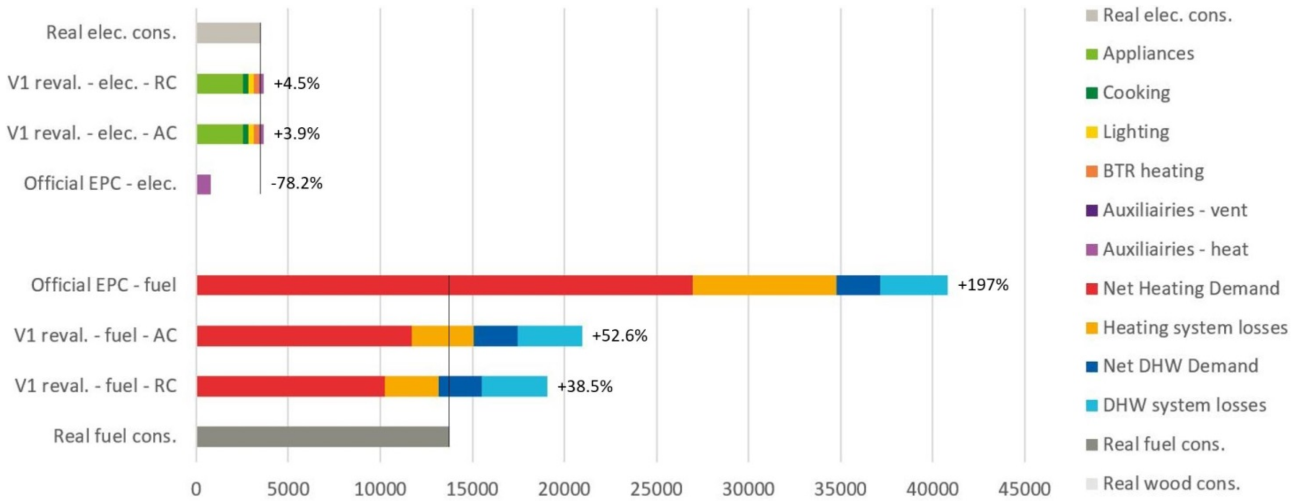

Fig. 5.2.58. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS9

It seems unlikely that an improvement on efficiencies' accuracy could ever close the remaining gap between revaluations and real data; the definition of the net heat demand is therefore carrying part of the blame, especially when considering the effect the climatic data has on results. Here again, as already witnessed in other case studies of similar location around Liege, the use of real data reduces the heating consumption results by around 15%.

The real consumption data given by Mr and Mrs I. covered the period between mid-September 2014 and mid-September 2015. September results in Figure 5.2.59 below are evaluated considering 55% of September 2014 results, and 45% of September 2015 results, which explains the slight inflexion in the curves.

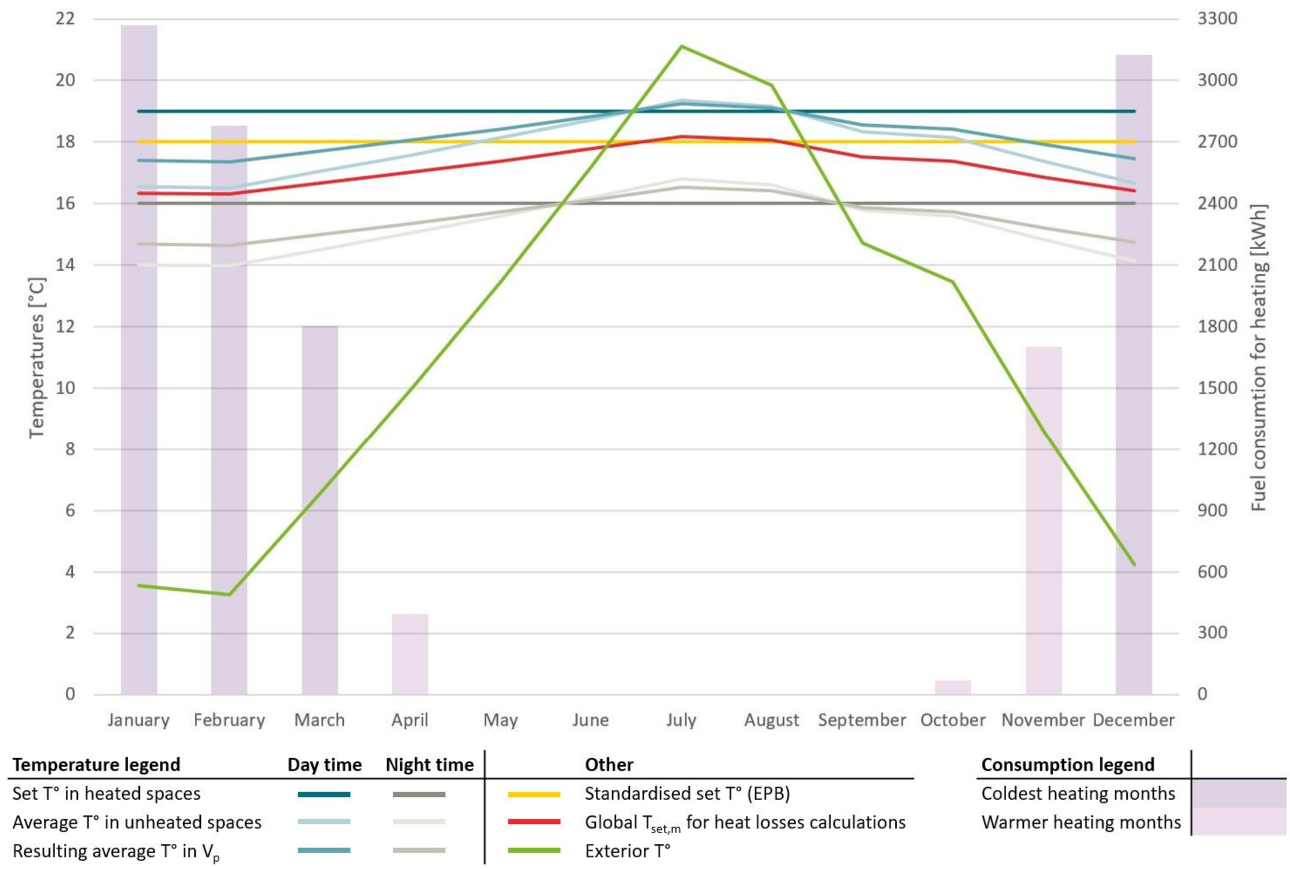

Fig. 5.2.59. CS9: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

5.2.10 Case Study 10 – CS10

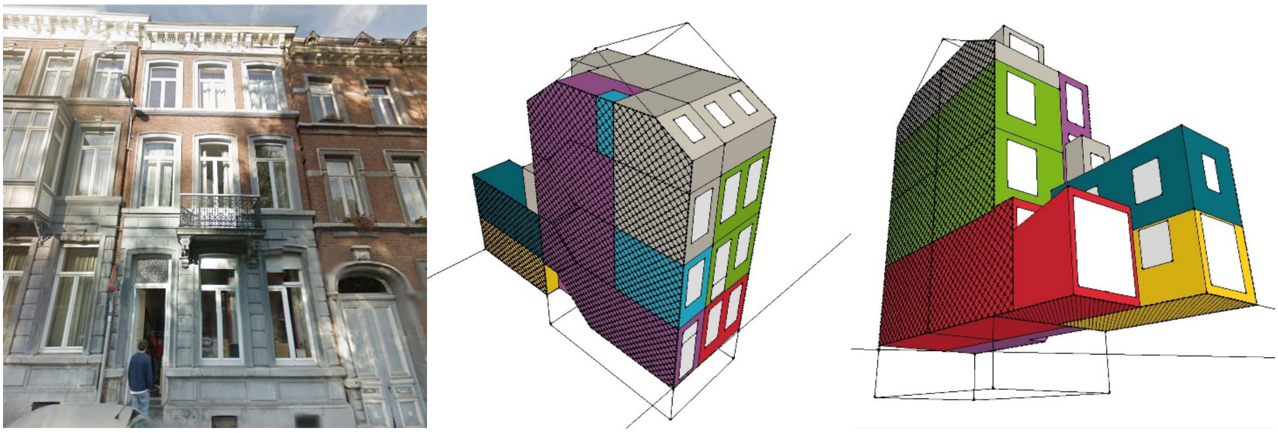

Fig. 5.2.60. CS10 – **Left**: street facade; **centre**: high-angle shot of the SW (shared) and SE (street) facades; **right**: low-angle shot of the NE (shared) and NW (garden) facades

The tenth case study is very similar to the fifth, at least in terms of typology, as both are "master" brick houses built before 1919, situated in a row, with total protected volumes around 950m^3. There are even similarities in the annexes that were built at the back and, in both cases, renovated. Those annexes are composed of a two-storey volume containing the kitchen and an office room upstairs ("other"), and a lower volume extending the living room in the garden. In this case however, the house benefits from higher areas of shared walls, and consequent smaller heat loss area (436m^2, compared to 553m^2 for the CS5). The owners of the house are Mr and Mrs J., who bought the house in the late 1990's, and immediately proceeded to make a few necessary restorations and retrofits, helped by an architect of their friends, given the condition of the house. A few years later, in 2004, they decided to change the windows on the back façade and, yet a few years later, had changed the windows on the front façade, and added some insulation in all roofs (and attic floor). The owner himself first declared that no insulation was added on vertical walls anywhere, then corrected this by mentioning the living room extension, made in 2008.

Here, the definition of variants did not depend on the inclusion or exclusion of rooms from the V_P: this house, built on a basement that had no reason to be included, contains four liveable levels. The fifth one is a low-height space separated from the rest by an insulated floor and no visible access, which legitimately exclude it from the V_P. The definition of variants rather depended on the accepted presence of that insulation layer on the "attic" floor, and other insulation layers, which the owner knew about but could not "prove" for an official EPC. In this, the CS10 is closer to the CS1 and CS3 definition of variants, and challenges the uncertainty brought by the short-list of acceptable proofs on the description of the energy system:

- The first variant, labelled "official", considers the lack of acceptable proofs (even to attest the date of renovation) and the impossibility to visually witness the presence of insulation in those walls. The resulting average U-value is evaluated at 2.24W/m^2K, and this official EPC would categorise this house "F", given its 452kWh/m^2.year specific annual primary energy consumption E_{spec} indicator.
- The second variant, labelled "UAP", takes the declarations of the owner into consideration, and introduced the presence of insulation layers for the roofs and attic floor, and the living room extension. The owner could add the type of insulation, but seemed unsure on the thickness. The default values of the certification method were therefore still partially used in

this "UAP" variant that grants the house an average U-value of 1.68W/m²K, and an "E" level on the certification scale, thanks to its 351kWh/m².year E_{spec} indicator.

- The insulation was applied when the official U_{max} requirement was fixed at 0.4W/m²K for the roofs and 0.6W/m²K for exterior vertical walls, so that the third "Umax" variant considers those values that were applicable at the different steps of the renovation. The house, labelled "D" by the certification scale, would present an E_{spec} indicator of 334kWh/m².year due to an average U-value of 1.59W/m²K (which is a small 5.5% improvement over the second variant).

The Figure 5.2.61 below displays the definition of the $H_{T,heat}$ coefficient for the three variants. Heat losses due to the acknowledged absence of insulation (dark green) and those due to the windows (light green) are constant in the three evaluations. As far as the windows are concerned, dates could be found on the glazing that attested of the different periods of installation. In the graph hereunder, therefore, 329W/K of heat losses due to unknown presence of insulation (in red in the first variant), are replaced by 84.7W/K (-74.3%; -25.1% for the total $H_{T,heat}$ coefficient) of heat losses acknowledging the presence of insulation (in yellow in the second variant). They still rely heavily on default values of the certification method to attribute thermal resistance to the insulation layers. Those heat losses are replaced, in blue in the third variant, by 44.5W/K of heat losses due by "known thermal resistance" (or imposed U_{max} values, in this case). This smaller decrease (-47.5% when compared to the second variant, -86.5% when compared to the first) leads to a reduction of the total $H_{T,heat}$ coefficient by 5.5%, when compared to the second variant, 29.3% when compared to the first.

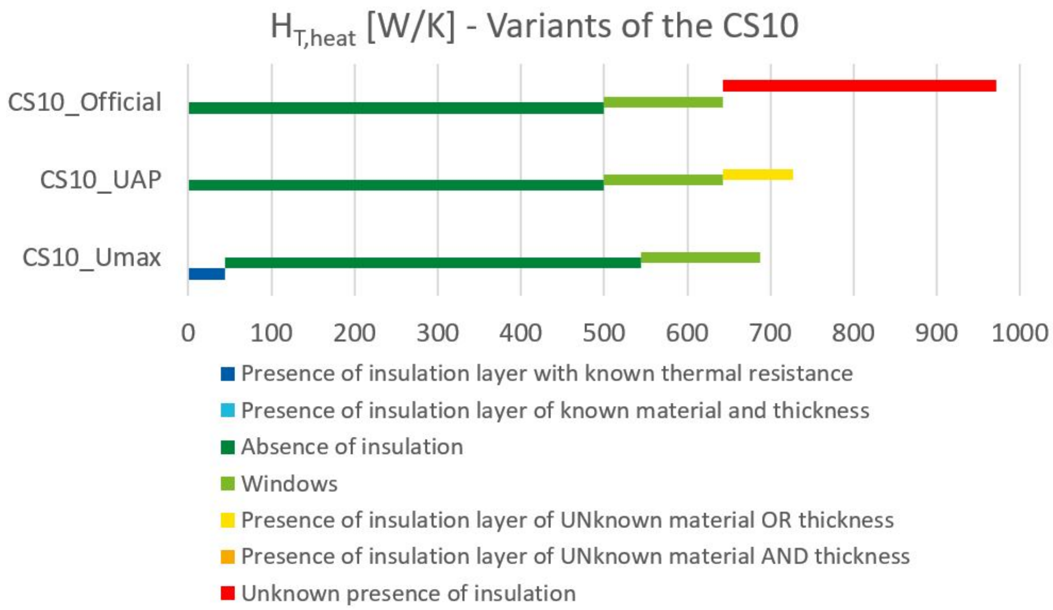

Fig. 5.2.61. Repartition of the $H_{T,heat}$ coefficient [W/K] for the three variants of the CS10

The use of the extractor hood when cooking, daily windows opening in the bedrooms and bathroom, and the absence of any testing of the airtightness, led to a revaluation of the $H_{V,heat}$ coefficient at 72.2W/K, one of the highest in the sample, which is due to the bigger volume of air to be changed.

The DHW is supplied by the boiler in the basement, fuelled by natural gas. The global efficiency attributed to the installation is, in this case, 43%, considering:

- Production: 70% (default for a variable temperature boiler with internal storage);
- Distribution: 62% (production close to kitchen, far from bathroom);
- Circulation loop: 100% (absent);
- Solar fraction: 0% (no solar thermal installation);

The heat is supplied by using natural gas for the same boiler located in the basement. The central heating installation has been granted a global efficiency of 59%, considering:

- Production: 77% (default for a low and variable temperature atmospheric boiler, installed after 1990 outside the protected volume, of unknown theoretical efficiency);
- Distribution: 98% (small length of uninsulated pipes out of V_P);
- Storage: 97% (storage out of V_P);
- Emission: 81%;
- Solar fraction: 0% (no thermal solar installation).

The owner mentioned the use of wood logs in the winter for an additional comfortable heat in the living room, dining room and kitchen area. Interestingly, a stove, installed after 2006, fuelled by wood logs, is attributed the same global efficiency of 59% in the certification method, defined by a production efficiency of 72% and an emission efficiency of 82%. This simplifies the calculation and the comparison: the annual consumptions of natural gas and wood logs will here be added, simply, considering a final energy consumption of 1,970kWh per cubic stacked meter (stere) of dry wood[5].

As often, the living room, dining room and kitchen are the main and more regularly heated spaces. The presence of children who attend school during the day is again visible in the heating pattern (Figure 5.2.62), and so is the occasional presence of Mrs J. at home on afternoons, where she works in the office room situated above the kitchen. When interviewed, the owner, a man in his late forties – early fifties, mentioned about the heating of the bedrooms: "*Very little, actually. Very, very, very little. But I think, there too, I would have given you a totally different answer last year […]: teenagers seem to like to have tropical heat in their room. Only a little shirt, a little short, and glued to the heater, which should be around 93°C. And I believe, only there they are comfortable. Totally incredible. So, now, my daughter heats to the max, when she's in her room.*" The small volumetric share of this room, heated at 24°C, compared to the rest of the heated volume (at 20°C) is translated in a slight increase in set temperature of 0.42°C in after school periods, visible in the table below. The increase of 0.58°C during morning and evening periods is also influenced by the bedroom heating, and by the heating of the bathroom at 22°C. The main specificity of this household is the total absence of heating at night. Up until now, and for all the remaining case studies, a temperature setback is always used at night, often in a reduced set of rooms, but not in this dwelling.

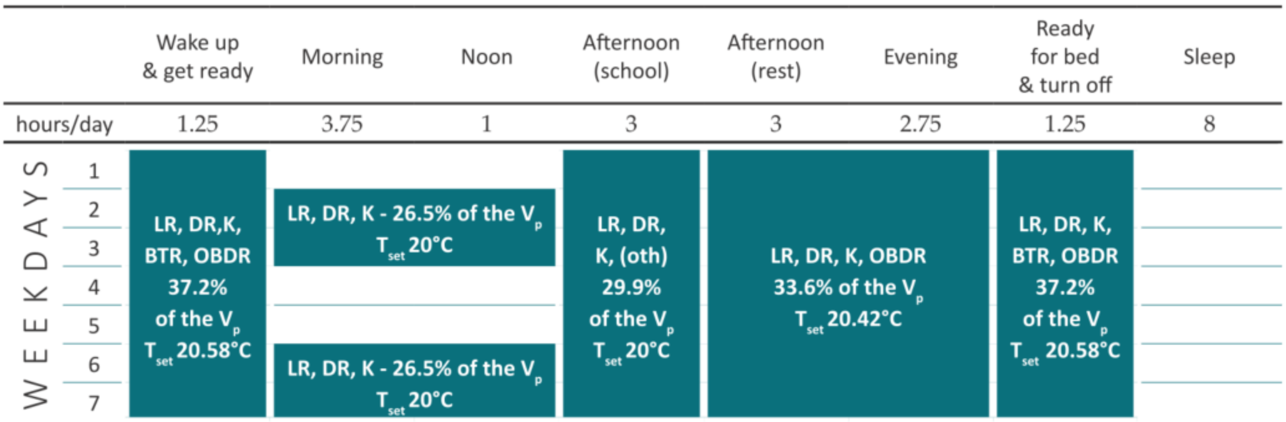

Fig. 5.2.62. Heating pattern of the CS10, according to owners' answers to the questionnaire.

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[5] Website of the Belgian Association for the Promotion of Renewable Energies. Available online: http://www.apere.org (accessed on 26 September 2016).

The first observation of the results in Figure 5.2.63 below is the important gap between the theoretical final energy consumption results of the regulatory EPC (118,646kWh of natural gas) and the actual consumption data (22,625kWh of natural gas in 2016 + 2 annual steres of dry wood): +346.6%.

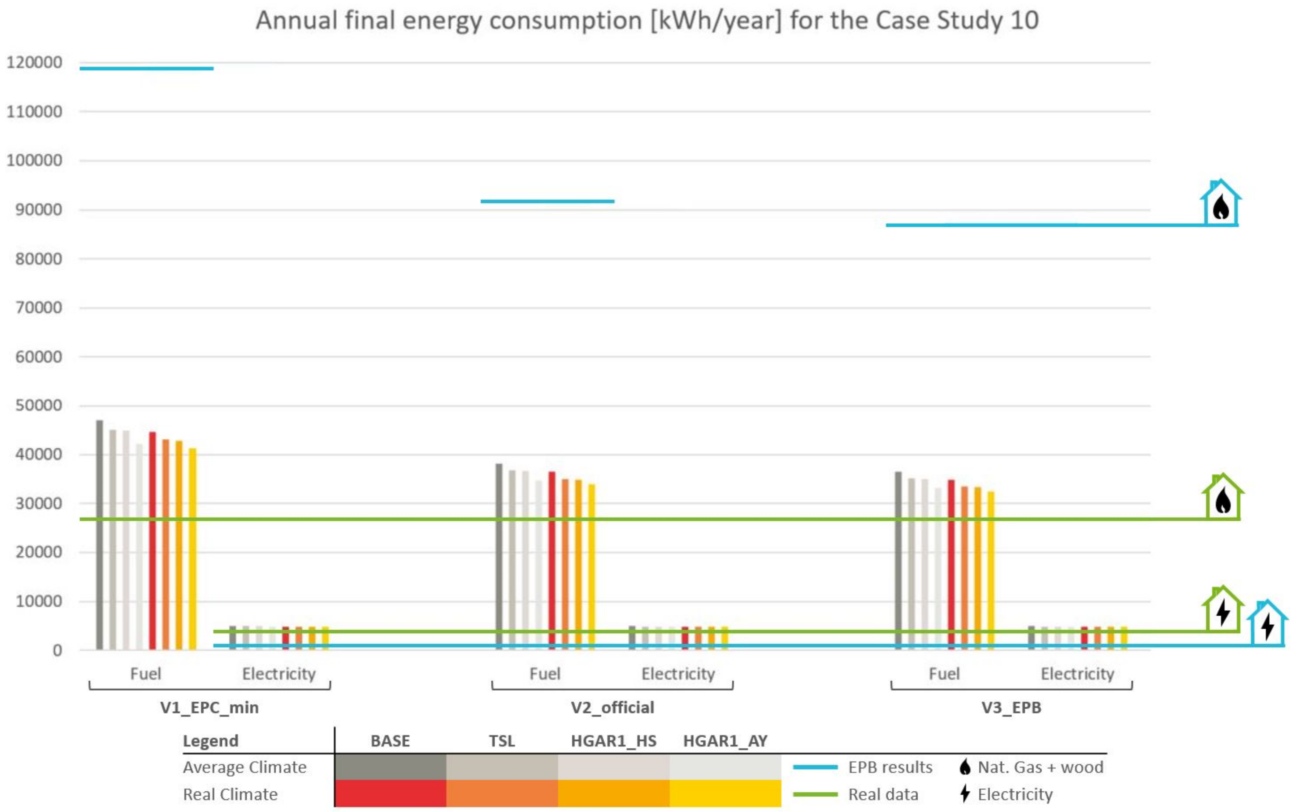


Fig. 5.2.63. Results of revaluated energy consumptions for the three variants of the CS10, for different steps in the method

Second observation: the modifications brought to the calculation method allow a bigger reduction of these theoretical evaluations than the choice of the variant, in this case. The main parameters are the low ratio of directly heated volume (around one third of the total V_P), and the complete lack of heating at night. In this case, the best evaluation for the first variant is still 55.3% above the real consumption, whereas the second variant is 27.7%, and the third, 22.3% above the real data. The fact that there is a remaining gap should not be surprising, however, given the high number of default values that still dominate the description of the energy system, as witnessed by the different case studies. The climatic data did not bring many differences in this case study, reducing the evaluations by less than 5%, on average.

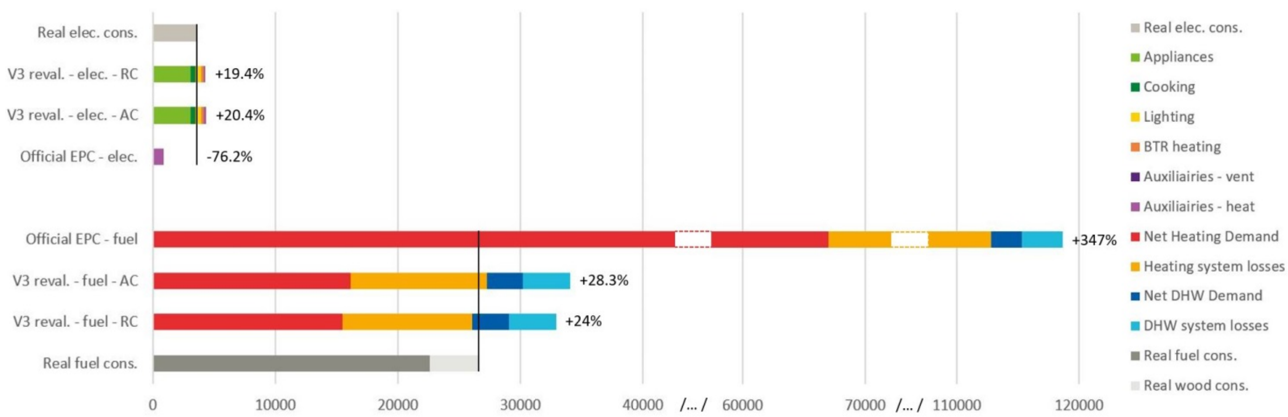


Fig. 5.2.64. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS10

The Figure 5.2.64 shows that the real consumption data barely covers the revaluated final energy consumption for heating alone. It seems therefore that the NHDs, already divided by three thanks to the modified method, could yet still be reduced to fit the real consumptions. This expected reduction could come from a more accurate approach on the description of the energy system, still dominated by default values. The third variant has been chosen here, for the simple reason that this one presented the lowest $H_{T,heat}$ coefficient. Whether the repartition of those heat losses is accurately described in Figure 5.2.61, it is difficult to say: it is plausible that the insulated walls do not reach the imposed U_{max} values, and that uninsulated walls are more thermally resistant than the default values would suggest. The results of the CS3, CS5, CS7, and CS9 tend to back this latter hypothesis. The choice of the third variant has been made in coherence with the single-zone, complete volume hypotheses of the calculation method: the accuracy of the $H_{T,heat}$ coefficient is more important, in the end, than its repartition, which is mainly necessary when assessing renovations' improvements.

The Figure 5.2.65 hereunder does not display the temperature curves for the night time heating, as there is none in this case study. The calculation method, when a period is declared unheated, does not consider those periods at all in the calculations, or rather lists them in the $t_{m,noheat}$ period of time (see Equation (8)). In the Equation (12) of the section 4.3.3.3, those periods of time are therefore not integrated in the definition of the $T_{set,m}$ curve (in red hereunder). This graph indicates that, during coldest months, a 5°C difference in temperature is to be expected between heated and unheated spaces, which seems quite reasonable.

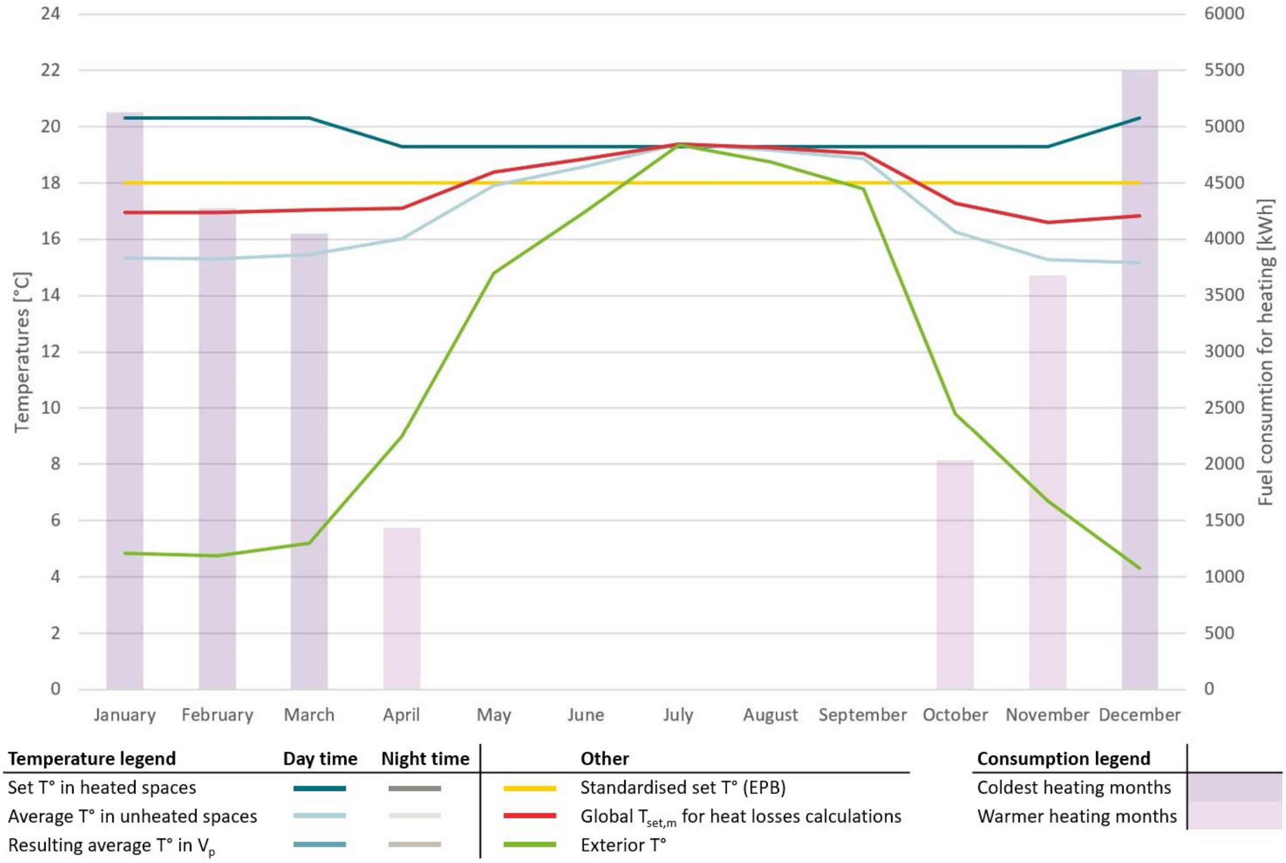


Fig. 5.2.65. CS10: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

5.2.11 Case Study 11 – CS11

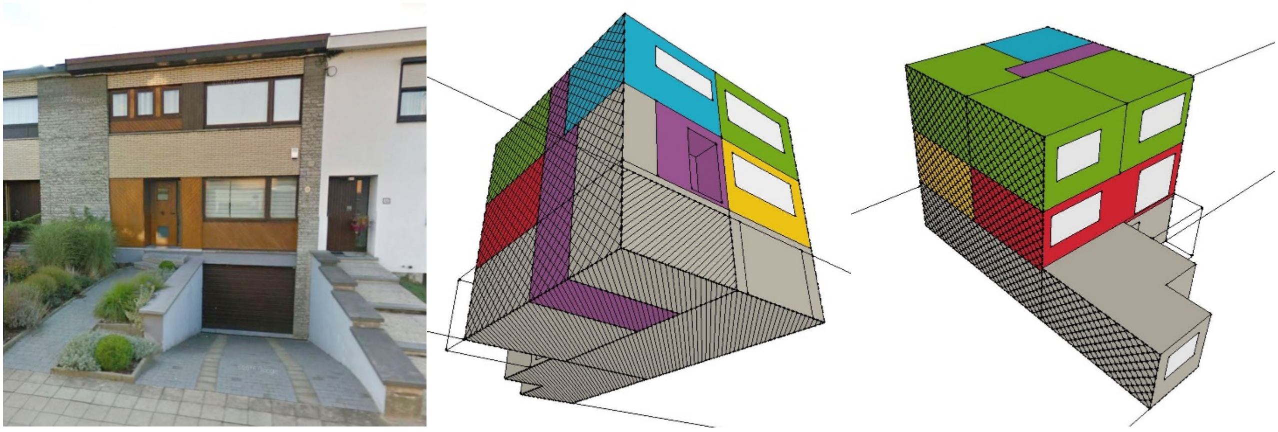


Fig. 5.2.66. CS11 – **Left**: street facade; **centre**: low-angle shot of the SSE (shared) and ENE (street) facades; **right**: high-angle shot of the NNW (shared) and WSW (garden) facades

This next case study is a house built in the 1970's during the urban extensions, examples of which can now be found in the suburbs of many city centres; this one being a little further from Liege than others (around 30km), a different set of real climatic data were used here. These houses were often built in rows, which tend to reduce their heat loss area, and with a concrete structure that allows flat roofs, which tends to reduce the liveable volume per square meter of heated floor area. The owner, Mr K., architect, has lived in this house with his wife since the arrival of his now grown-up children. The energy performance of buildings being a great interest of his, he has insulated several walls of his house during the decades he spent there and was able to deliver all necessary information to consider those insulation layers in the EPC (the acceptable proof being an attestation of the architect, therefore). Such insulation can be found, in small thicknesses, in the flat roofs of the principal and secondary volumes, in the walls of the office downstairs or in some front-façade walls (the wood panels visible in Figure 5.2.66 above, for example).

This house is composed of three levels; on the middle level, the entrance hall opens on the stairway and on the main liveable daytime spaces (living room and attached dining room and kitchen). The upper level, accessible by the open stairway, has three bedrooms and one bathroom. The stairway is also open on the lower level, landing in a storeroom, leading to technical rooms (garage, boiler room) and to a rarely used office room contained in an annex at garden level (visible in grey on Figure 5.2.66-right). Comparably to CS5 and CS9, it is the definition of the protected volume that is central in the definition of variants for this case study. The difference is that, in this case, the volume that could be excluded from the V_P is bigger and contains the garage and the rarely-used office that extends it. Given that these rooms are airtight and waterproof, directly accessible, permanently, from the protected volume and could be directly heated, or that they display a clear "intention of insulation" in the presence of… insulation and double glazing, those rooms should in theory be included in the protected volume, no questions asked, as far as the protocol and flowcharts are concerned. The owner himself indicated that there was a "frost-free" setting that was constantly required in there in order to conserve the files it contains, but that the presence of the boiler in the next room usually was enough (at least when the house was equipped by an old boiler), during heating period. The choice of the first variant, considering the inclusion of all the building and its heat loss areas in the protected volume, as official EPC, is evident. The second variant (labelled "RedVp") considers the garage and the office excluded from the protected volume, which imposes to ignore some insulated areas and windows (and garage door, in this case), visible in the repartition of the $H_{T,heat}$ coefficient displayed in the Figure 5.2.67 hereunder. The table below displays the main parameters for the variants:

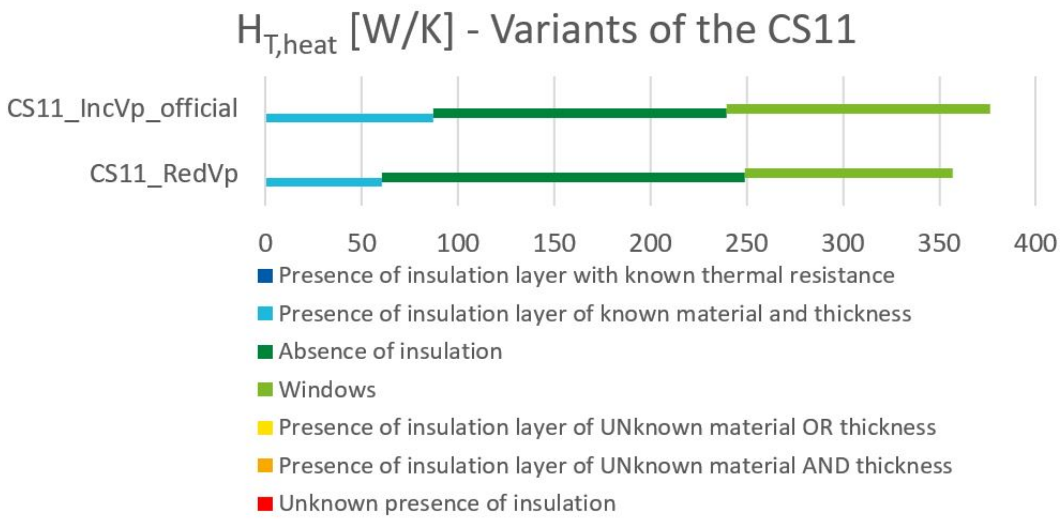


Fig. 5.2.67. Repartition of the $H_{T,heat}$ coefficient [W/K] for the two variants of the CS11

Table 5.2.3. Comparison of the CS11's V1 and V2 parameters

Parameter	V1_IncVp_official	V2_RedVp
Protected volume V_P [m³]	612	466 (-24%)
Heated floor area A_{ch} [m²]	224.3	168.6 (-25%)
Heat loss area A_T [m²]	336.2	273.9 (-19%)
Compactness ($C = V_P/A_T$) [m]	1.82	1.7
Average U-value U_m [W/m²K]	1.19	1.32

The house is equipped since 2013 with a condensing boiler that uses natural gas to produce heat and domestic hot water for the household:

- Its global efficiency for heating is evaluated at 80%, considering:
    - A theoretical efficiency ($\eta_{30\%}$, defined by the current European testing standards) of 107% was imposed, and degraded to 91% due to the regulation, water temperature…;
    - Distribution: 100% (the boiler room stays inside the V_P);
    - Storage: 100% (absent);
    - Emission: 88%;
    - Solar fraction: 0% (no thermal solar installation).
- The supply of DHW is afflicted by a 47% global efficiency, considering:
    - Production: 75% (default efficiency for instantaneous production by a natural gas boiler with internal storage and variable temperature);
    - Distribution: 63%;
    - Circulation loop: 100% (absent);
    - Solar fraction: 0% (no solar thermal installation).

The owner also indicated the annual use of one stacked cubic meter of dry wood per year, in a stove located in the living room. The presence of the central heating system does not permit to consider a subdivision in energy sectors here, so that efficiency of the wood log stove will have to be considered at the same value (80%) than the main system.

The K. family that dwells there is composed of four grown-ups. The mother and father both work full time out of the house during the week. The eldest son spends most of his weeks in a boarding school but spends his weekends at home. The younger daughter is attending the university nearby, and still lives at home. The heating pattern of the family is the following:

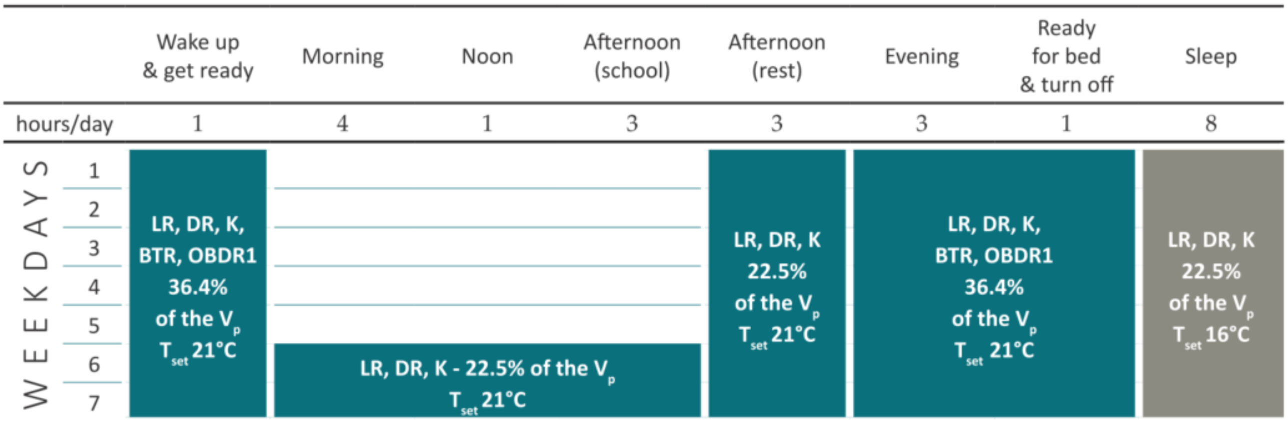


Fig. 5.2.68. Heating pattern of the CS11, according to owners' answers to the questionnaire.

Here again, the heating of the living room, dining room and kitchen is the constant minimum when there is someone present at home. Heating during daytime is only requested during the weekends. The only bedroom that is heated, in winter times, is the daughter's bedroom. The bathroom is heated when in use, but no use of an electric boost was mentioned here. It is one of the first households to mention the presence of a ventilation exhaust mechanical system in the bathroom, timed on the bathroom use. Other means of ventilation are mentioned, such as the use of the kitchen extractor hood when cooking (as often), and the regular half-opening of the main bedroom, which led to an average air change revaluation of 16.5m^3/h due to ventilation alone (whereas the EPC regulatory method considers 318.57m^3/h, based on Equation (17), section 4.3.3.4). No airtightness testing of the envelope had been made before the first assessment, so that the default value of 12m^3/h.m^2 was used for the $\dot{v}_{50,heat}$ coefficient, leading to a $H_{V,heat}$ coefficient revaluated at 42.24W/K.

The preliminary results are presented hereunder for the three years of real data given by the owner (from January 7th, 2013, to January 13th, 2016). For the first time, all revaluations are beneath the real data. Theoretical regulatory results using the average EPB climate are 63% ("RedVp" variant, year 1) to 116% ("IncVp" variant, year 2) above real consumptions. After revaluation, the results using the average EPB climate fell between 4.2% and 24.6% below the real data. When considering real climatic hypotheses, these gaps are yet slightly reduced (6.3% to 20.4% below the real consumption). The three graphs displayed (Figures 5.2.69, 70 and 71) indicate clearly that the use of real climatic data allows to explain the annual variations. The first one is a rare example of an increase in the revaluations due to the use of real climatic data, when compared to the average EPB climate, considering that this CS11 is located outside of city centres, in a colder climatic region.

The differences between both variants (see table above) are believed to bring visible discrepancies in the results, such as those displayed between the results from the regulatory calculation method (Δ = 4,173kWh/year); the graphs hereunder, however, indicate that the discrepancy between both variants was reduced between 88 and 360kWh: the first variant, with the basement, benefits from a lower average U-value and higher gains, from both internal and solar sources, whereas the second variant mainly benefits from reduced heat loss area and heat losses by ventilation (smaller volume and exfiltration area).

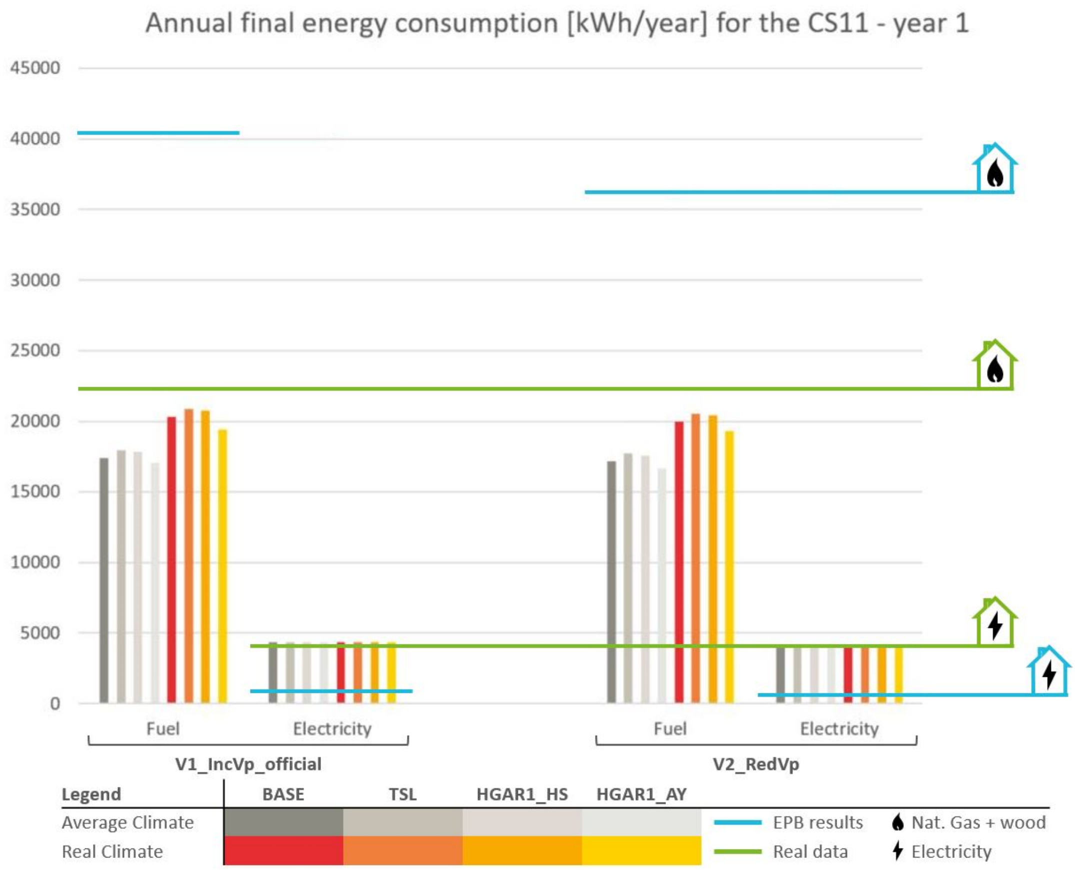


Fig. 5.2.69. Results of revaluated energy consumptions for the two variants of the CS11, for different steps in the method and the **first** climatic year.

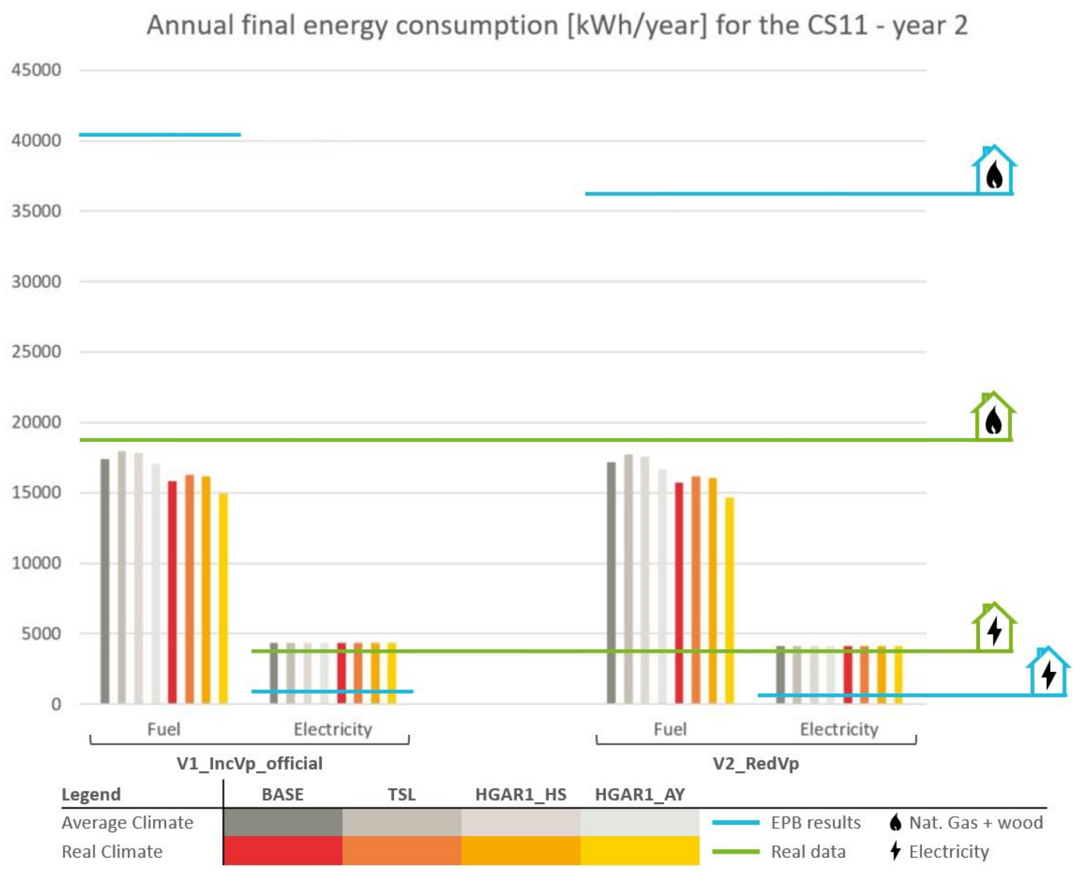


Fig. 5.2.70. Results of revaluated energy consumptions for the two variants of the CS11, for different steps in the method and the **second** climatic year.

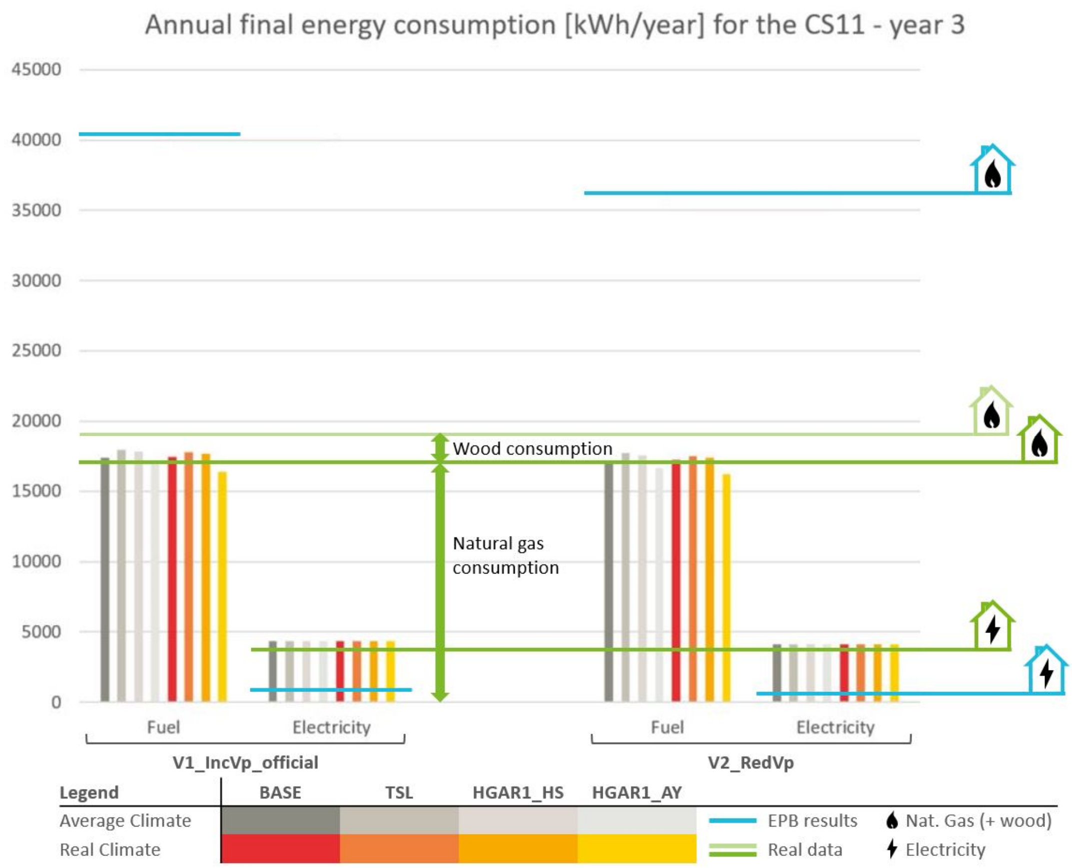


Fig. 5.2.71. Results of revaluated energy consumptions for the two variants of the CS11, for different steps in the method and the **third** climatic year, with and without including the real wood consumption.

This last graph shows another interesting observation, illustrated by the faded green line marking the real consumption level including wood, the brighter green line marking the consumption level without it. The observation stands for the three years of real consumption data given by the owner: the results of revaluations would be much closer to reality without considering the annual consumption of dry wood (estimated in this case at 1,970kWh). This would mean, however, that the wood consumption is considered "extra", a bonus, a boost in comfort only wood warmth can bring. It is true that the hypotheses of the revaluations did not consider any particular setting to integrate the consumption of wood in the calculation method, any raise in temperature coming from the burning of the wood in the living room stove during cold winter evenings, for example. The settings that were considered are only those of the thermostat that regulates the natural gas boiler, and under that particularly convenient light, the results are not far from reality. The hypothesis of an 80% efficiency for the wood stove, imposed by the single energy sector configuration explained above, might also explain part of the discrepancy. As a reminder, a similar wood stove was given in the CS2 the 59% efficiency of the central heating installation, which was much closer to the method default value for this type of stove than this one.

Slightly closer to the real consumption data, the first and official variant seems to be the right choice here. The Figure 5.2.72 hereunder displays the repartition of the consumptions after the calibration of the electricity part, which has barely changed the results, or the conclusions drawn above. The second year, clearly warmer, shows a greater gap in the revaluations than both others, which tends to incriminate the calculation of the internal temperatures in the unheated spaces, and the average $T_{set,m}$ that replace the standardised 18°C of the regulatory method. The second graph below, Figure 5.2.73, tends to validate this observation: the $T_{set,m}$ for January, defining the global temperature at which the whole protected volume is considered heated, is quite low, at 15.5°C, due to unheated spaces which temperature is evaluated at 16°C during the day and 12°C during the night.

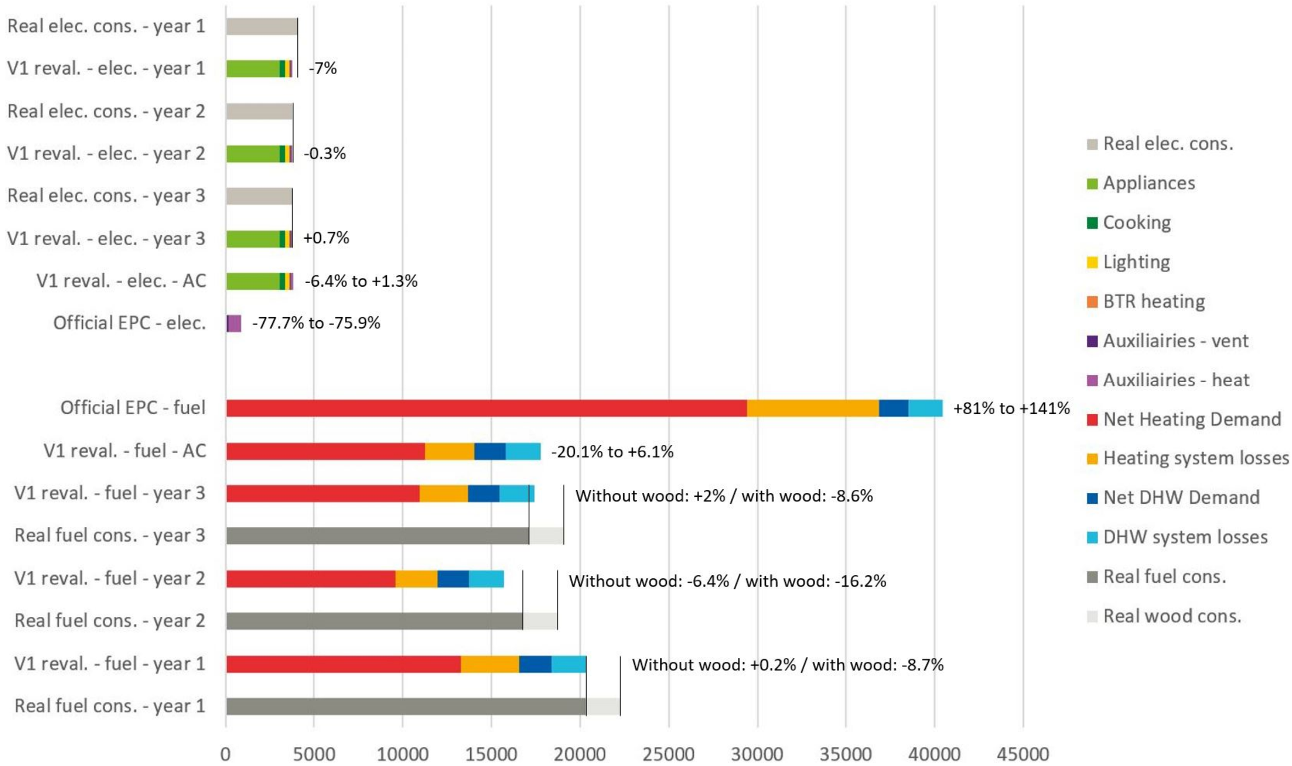


Fig. 5.2.72. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS11

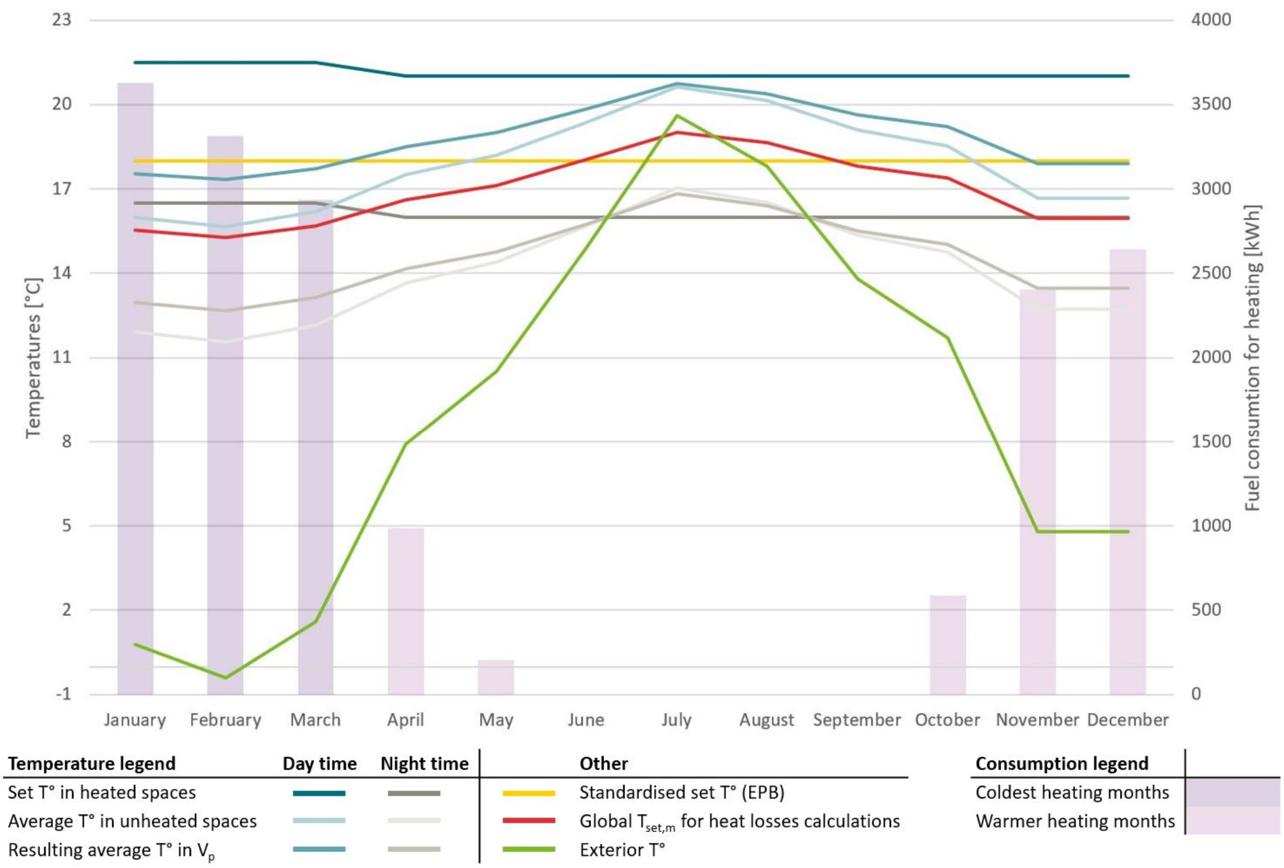
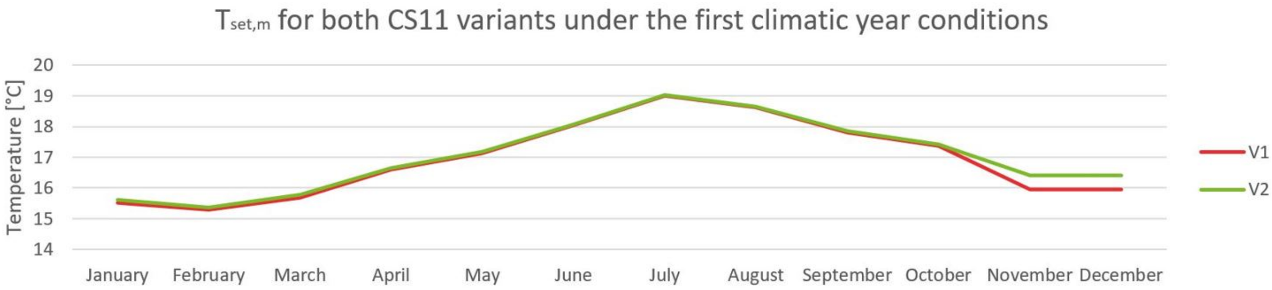


Fig. 5.2.73. CS11: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

One could easily suspect that the choice of the variant is crucial in that matter: the "full" protected volume, as described in this first and official variant, contains a bigger ratio of unheated spaces, which influence in the calculation of the resulting temperature for heat losses therefore increases. It appears that the second variant counterbalances this effect by a higher f_{pct} factor (see Equation (10), section 4.3.3.3), which considers the influence of the envelope's performance in the determination of the temperature in unheated spaces. Figure 5.2.74 below displays the $T_{set,m}$ curves for both variants:



	Average proportion of heated spaces ($f_{Vp,hs}$)	f_{pct} factor	$(1 - f_{Vp,hs}) * f_{pct}$
First variant – full Vp	0.253	0.684	0.511
Second variant – reduced Vp	0.334	0.849	0.565

Fig. 5.2.74. CS11: Evolution of the revaluated consumption for heating, for both CS11 variants, under first climatic year conditions

There is an observation that starts to take shape after several case studies: the results seem to grow closer to reality when the proportion of heated spaces increase. In older and less efficient buildings, households have a tendency to limit the heated volume to the living spaces mainly, and count on internal heat and air flow to maintain a temperature that is not too low in the rest of the house. The lower the ratio of heated spaces, the further from EPB standardised hypotheses that dominate the single volume calculation method that is still used here. The f_{pct} coefficient, in particular, should probably be defined based on monitoring campaigns that would help assessing the real influence of the energy system performances on the resulting temperature. This CS11 has been subjected to a small temperature monitoring campaign, which will be discussed in next chapter.

5.2.12 Case Study 12 – CS12

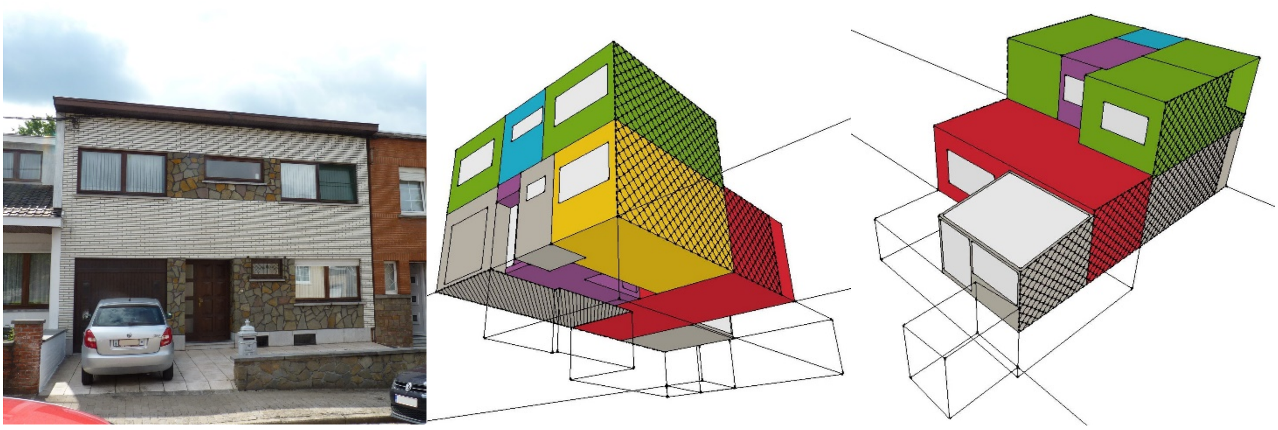


Fig. 5.2.75. CS12 – **Left**: street facade; **centre**: low-angle shot of the NNW (shared) and ENE (street) facades; **right**: high-angle shot of the SSE (shared) and WSW (garden) facades

The next house is very similar in architecture to the previous CS11, though built a little bit before, in the 1950's, and located on a hill overlooking the valley of Liege. The building is composed of three levels, the lower one (at garden level) containing basements, boiler room, a storage and a cellar. The middle street level, contains the garage, the entrance, the main daytime living spaces and a veranda overlooking the garden. The upper floor, covered by a flat roof, contains three bedrooms (or, in this case, two bedrooms and an office) and a bathroom. An important difference with CS11, however, is that the stairway leading to the basement is closed, and that the lowest level could be excluded from the protected volume without a doubt.

The owner of this house is Mrs L., a retired woman who lives with her partner. Although willing to help in giving all possible information, Mrs L. could not mention any presence of insulation in the house, nor could she give any acceptable proof to feed the description. The EPC had already been done by a trustworthy assessor, and has been checked at the time of the interview: no insulation was visible, suspected, or found in the walls of the house (without dismantling or destructive tests). Three categories of heat loss areas were defined here: those where no insulation is present (and the assessor is sure about it), those where the presence of insulation is unknown (and in this case, only the flat roof is concerned), and the doors and windows. The apparently unequivocal $H_{T,heat}$ coefficient is therefore the following:

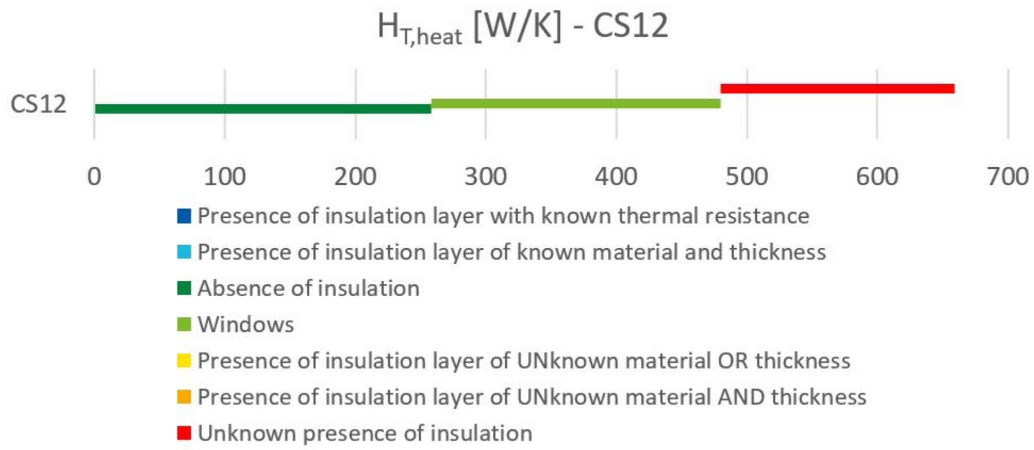


Fig. 5.2.76. Repartition of the $H_{T,heat}$ coefficient [W/K] for the CS12

No variants could be made on the description of the heating systems either. The heat is provided homogeneously by the low-temperature boiler located in the basement to the different rooms of the dwelling by the central installation, regulated by the thermostat in the living room. According to the EPC protocol, its global efficiency is 67%, considering:

- A theoretical efficiency ($\eta_{30\%}$, defined by the current European testing standards) of 92%, which has been degraded to 81% due to the regulation, the presence out of the V_P…;
- Distribution: 98% (small length of uninsulated pipes outside the V_P);
- Storage: 100% (absent);
- Emission: 84%;
- Solar fraction: 0% (no thermal solar installation).

The domestic hot water is provided by an electric boiler, also located in the basement, to which a global efficiency of 50% was attributed, considering:

- Production: 80% (default value for electric production with storage);
- Distribution: 62%;
- Circulation loop: 100% (absent);
- Solar fraction: 0% (no solar thermal installation).

As for the ventilation, no integrated system was registered, and the owner only mentioned a daily opening of her bedroom's windows. The kitchen extractor hood recycles the air; it does not exhaust it outside when cooking, so that it is not taken into consideration here. No air tightness testing had been done previously to this research, so that the default value of 12m³/h.m² was used for the $\dot{v}_{50,heat}$ parameter of Equation (15), resulting in a revaluated $H_{V,heat}$ coefficient at 42W/K.

The heating pattern is very constant: around 65% of the protected volume, containing the living room, dining room and kitchen, bedrooms and bathroom, is heated at all times. The circulations are indirectly heated by open doors, but the garage and the veranda are not heated at all (not directly, at least). During the night, the described volume is set back at 18°C; during the day, the "daytime" level is heated at 22.6°C (read on the thermostat), the "night time" level at 20°C, and the bathroom at 24°C during ablutions, resulting in the global set temperatures in Figure 5.2.77 below:

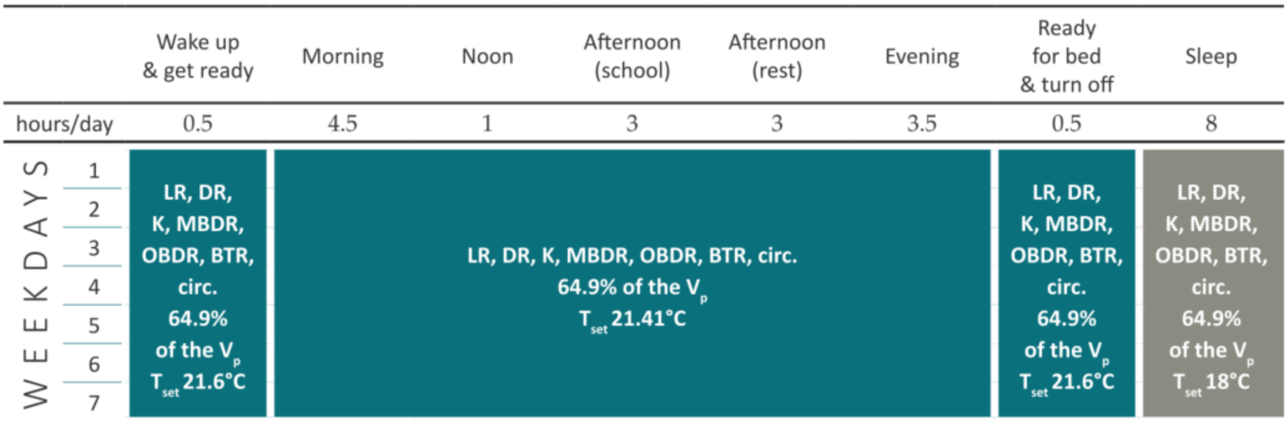


Fig. 5.2.77. Heating pattern of the CS12, according to the owner's answers to the questionnaire.

In Figure 5.2.78 hereunder, the preliminary results for the single variant of the CS12 are presented for the three periods (years) covering the data given by the owner. The natural gas consumption revaluation only concerns the heating part of the balance, the DHW being prepared via electricity. As far as the heating consumptions are concerned, therefore, there is for the second time, after the CS3, a discrepancy between the revaluations and the real natural gas consumption data that cannot be wiped away by the modifications proposed here. In the Figure 5.2. 78, the theoretical EPC results (65,637kWh of natural gas final consumption) were estimated 2.8 times higher than the average real consumption data (23,427kWh). The revaluations brought this ratio to a minimum of 2.1, by using all the modifications described in chapter 4 (simulation RC_HGAR1_AY in the Figure below). The sensitivity testing that will follow this preliminary chapter will show that the parametrization of the calculation method cannot be the only questionable determiner of this discrepancy.

The provision of DHW dominates (91.5%) the final electricity consumption evaluated by the EPC standardised method, which also includes in this case the auxiliaries. Quite interestingly, it is very close to the real consumption data delivered by the owner, which include in addition the necessary electricity consumption for lighting, cooking and using appliances and equipment. The first conclusion would be that the standardised method overestimates the DHW-related consumption, either by exaggerating the net demand (estimated at 1,385kWh/year by the EPC method, based on the size of the building, revaluated by this method to 850kWh/year) or underestimating the efficiencies of the installations.

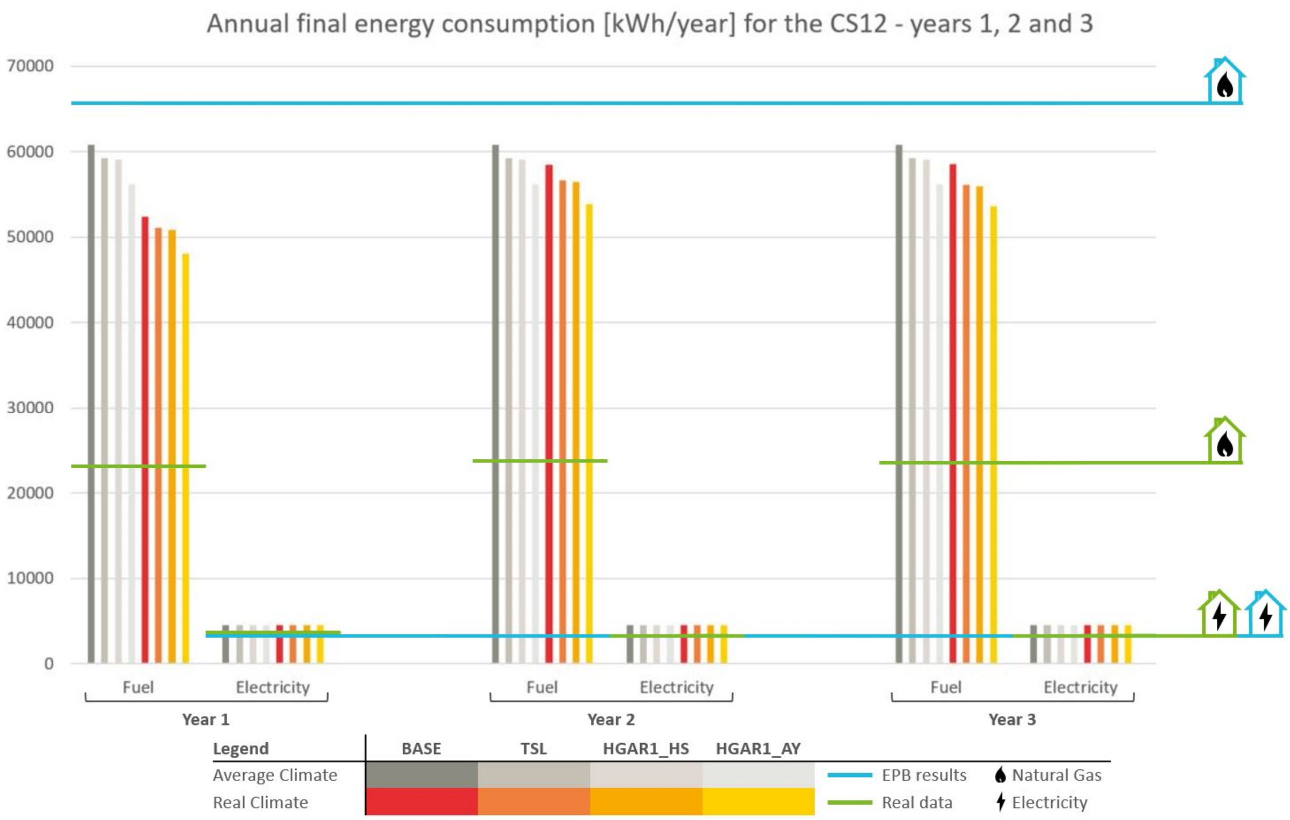


Fig. 5.2.78. Results of revaluated energy consumptions for three heating years of the single variant of the CS12, for different steps in the method

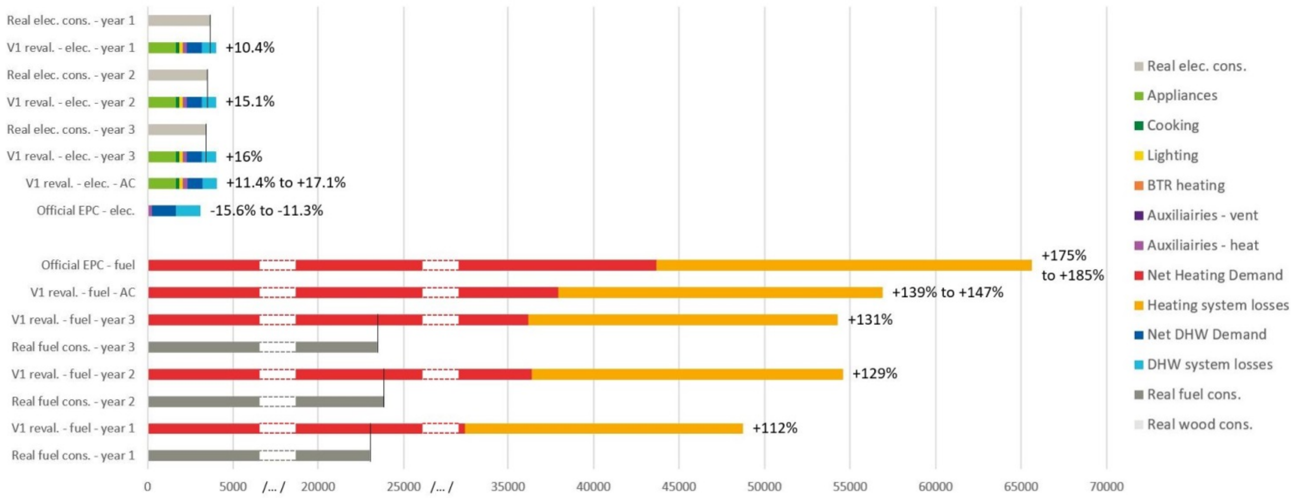


Fig. 5.2.79. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS12

Another observation is that the ratio between natural gas consumptions revaluations and real data shows a wider range of variation when using the real climatic data. This means that, in this case, the real consumptions data vary less, from one year to another (standard deviation of 421kWh), than the evaluations that were made using the real climatic data (standard deviation of 3,290kWh). In most other case studies, real climate tended to explain the annual variations better. As climate only influences the heating consumptions, it is more influential on the consumption of less efficient buildings. This would incriminate the characterization of the energy system in this case: should its envelope and heating installation be more accurately described, revaluations results would better follow the dynamics of real data. Looking closely, the first year's revaluations are "particularly low" (+112%), whereas the second and third year are both overestimated by 130%. A behavioural change in habits at that time, or in the energy system, might bring a better explanation; unfortunately, this kind of dynamics is not possible in a "one-shot" interview and description of the heating habits.

In this case, the important gap of theoretical consumptions that does not seem to be likely to shrink easily could be (partially, at least) explained by the actual presence of insulation material in the flat roof, when the impossibility to eye-witness its presence and the absence of acceptable proof imposed its description as "unknown" in the official EPC. A hypothetical insulation layer of 6cm of mineral wool in the roof brings the average U-value of the building from 1.86W/m²K to 1.49W/m²K. In the $H_{T,heat}$ coefficient, described for the official variant in Figure 5.2.76, and for this hypothesis in Figure 5.2.80, 177.24W/K of corresponding heat losses were reduced by 73% due to "known" insulation thickness and material in the roof. The coefficient is reduced by 19.6%, from 659.45 to 530.07W/K. The remaining 2.68W/K of "unknown" insulation concern a small portion of the walls surrounding the basement stairway.

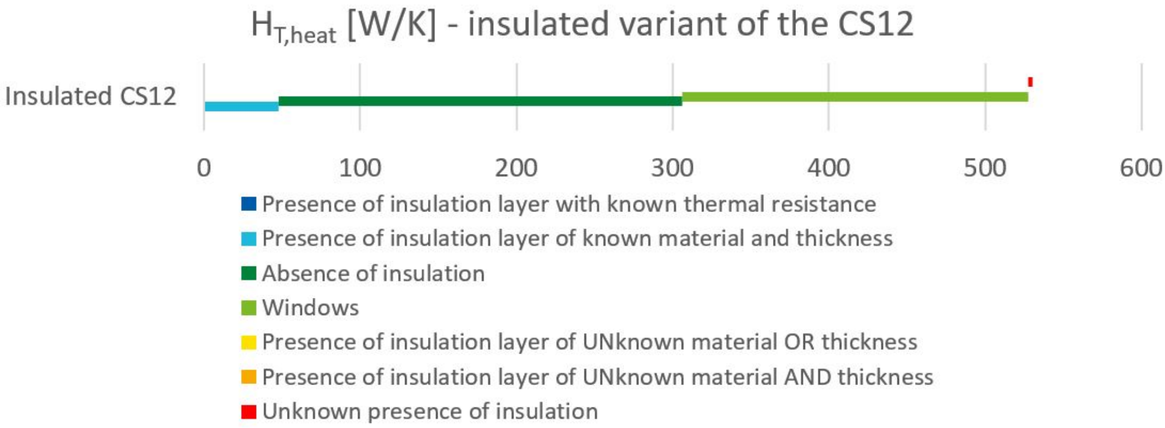


Fig. 5.2.80. Repartition of the $H_{T,heat}$ coefficient [W/K] for the CS12, considering 6cm of mineral wool in the roof

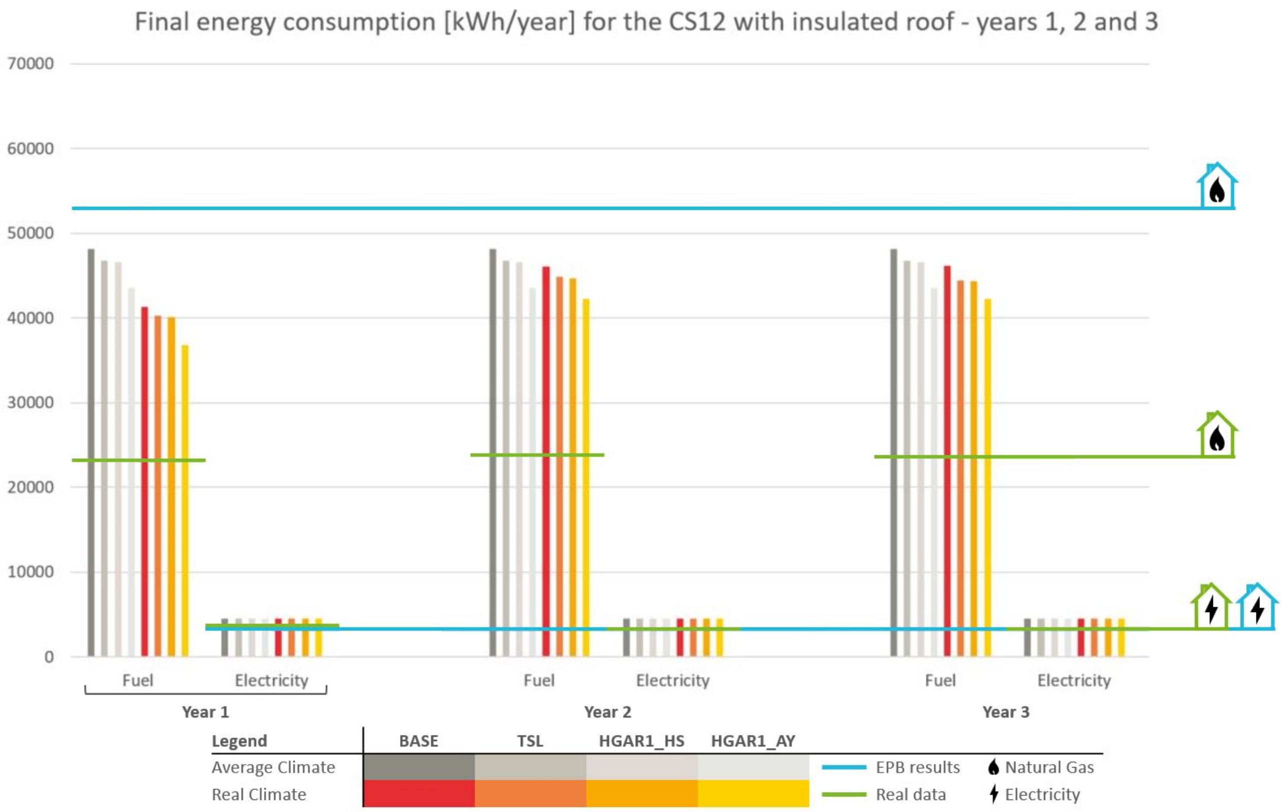


Fig. 5.2.81. Results of revaluated energy consumptions for three heating years of the CS12, considering the presence of 6cm of mineral wool in the roof, for different steps in the method

The equivalent to Figure 5.2.78, considering the insulated roof, is visible above. The scale has been kept identical to ease the comparison. In the simulations under the average EPC climate, the average resulting decrease in natural gas consumption is 12,600kWh (constant, from 12,470 to 12,684kWh). When using real climate data, the reduction is on average of 11,527kWh, and more variable between simulations (from 10,765 to 12,327kWh). The standard deviation mentioned above slightly decreased to 3,158kWh, but this improvement does not allow to better explain the consumption dynamics on the period covered, nor does it allow to close the "prebound" gap, which means that the behavioural change is more likely to explain the lower gap of the first year. At their lowest, these consumption revaluations are still on average 72.6% higher than the real consumption data. The hypothetical insulation layer in the roof could be thicker than 6cm, but the reduction of the $H_{T,heat}$ coefficient by that mean has a limit, both in credibility and on the total heat losses by transmission. There are, after all, 480W/K of heat losses attributed to the other uninsulated walls and windows. If the mineral wool layer was 12cm thick, the average U-value would be lowered to 1.43W/m²K, the $H_{T,heat}$ coefficient to 502.24W/K, and the consumptions revaluations about 1,800kWh.

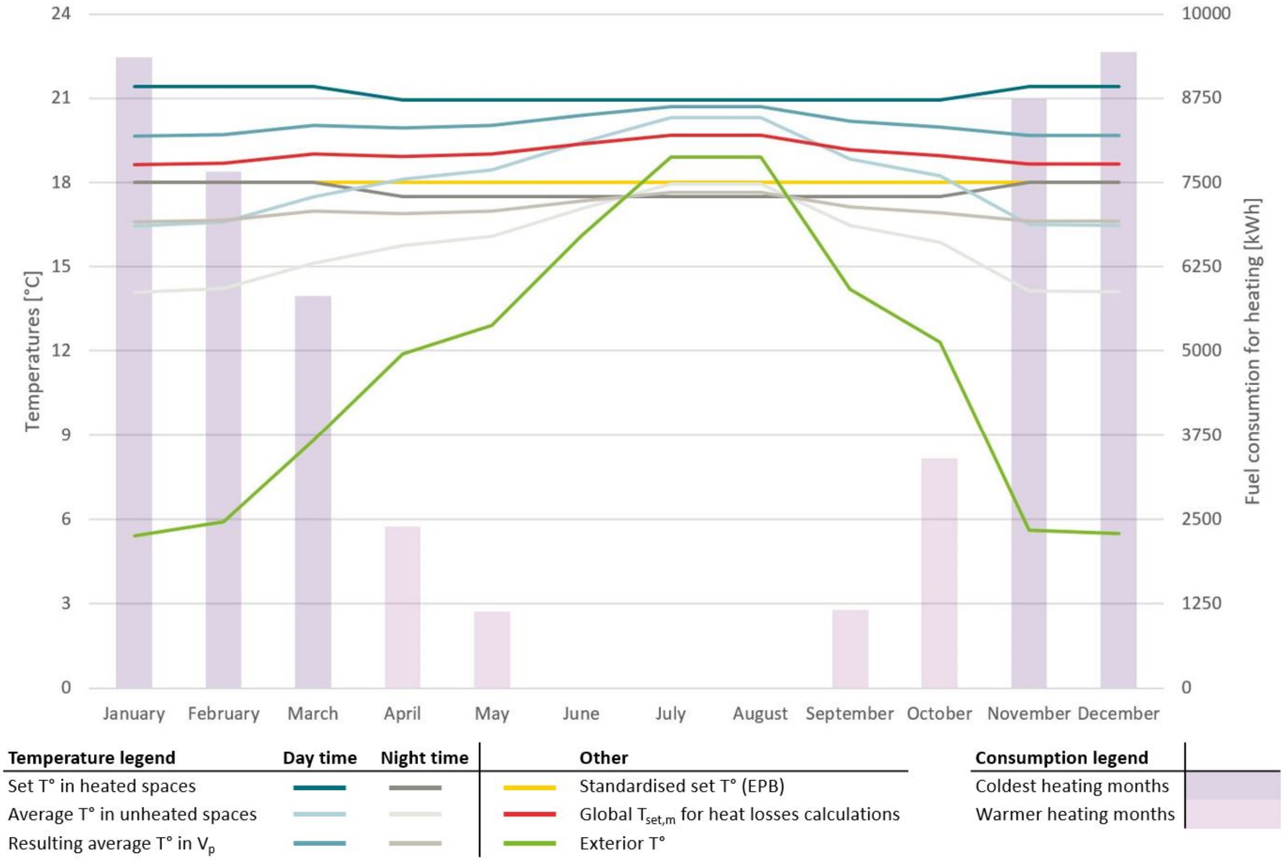


Fig. 5.2.82. CS12: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

An interesting comparison can be made between this case study and the CS3. Both are apparently uninsulated, although insulation layers might hide in the envelope that could explain part of the discrepancy between theoretical evaluations and real consumption data. The hypotheses describing both energy systems are still dominated by many default values, especially those characterizing the envelope. Both sets of results show important remaining gaps between revaluations and real data that do not seem to shrink enough under the influence of the modifications proposed here. Another common point between CS3 and CS12 is that both houses are heated all day long, according to the respondents' answers to the questionnaire, which is closer to the EPB standardised hypotheses of the regulatory calculation method. The set temperature is higher than the EPB's standardised 18°C, as visible on Figure 5.2.82 above, which partially explains the difficulty to lower the revaluations. A monitoring campaign of this case study's internal temperatures has been realised afterwards and will be discussed in the sensitivity testing described in next chapter.

In January, with an average 5.4°C outside, the temperatures of the unheated spaces (mainly the garage and veranda, on the middle floor) is expected to drop to 16.4°C during the day, 14.1°C at night. Intuitively, higher temperatures in those rooms would translate into a higher global $T_{set,m}$ temperature. In reality, the calculation method will indeed increase the consumptions if the raise of temperature in those rooms is due to open doors, or set temperatures. It will not, however, increase the consumptions if that resulting higher temperature is due to a better performance of the envelope, translated through a lower $H_{T,heat}$ and f_{pct} coefficients. The aforementioned hypothesis of 6cm of mineral wool in the roof gives the corresponding temperature curves, in Figure 5.2.83 below.

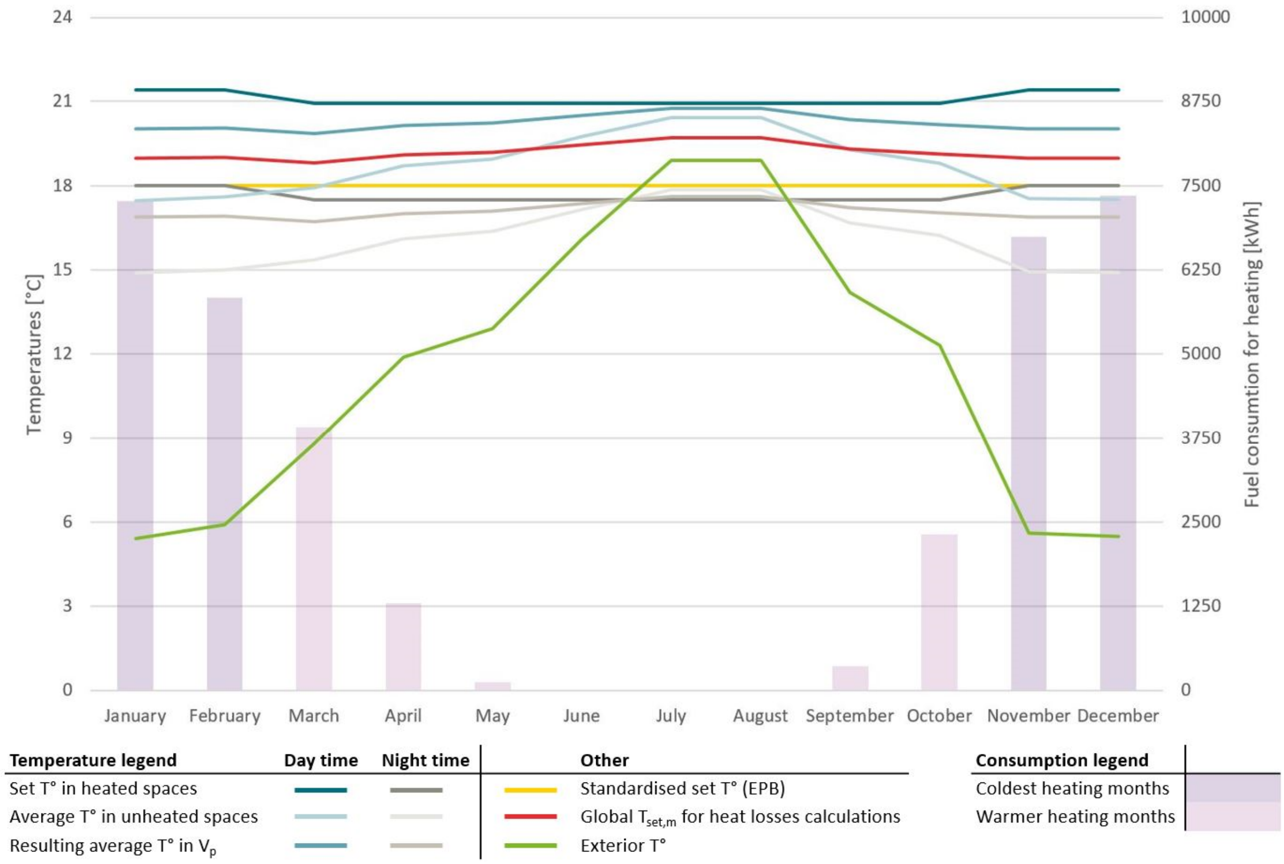


Fig. 5.2.83. CS12: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

The improvement is visible, but minimal. For the same month of January, the resulting temperature in unheated spaces rises to 17.5°C (+1.1°C) during day time, 14.9°C (+0.8°C) at night. The importance of the heated volume in this case study (when compared to unheated spaces) keeps an important domination on the results. The monitoring campaign should give another light on this observation.

Lastly, it must be noted that the improvement on the $H_{T,heat}$ coefficient has one other influence on the calculation method, besides directly lowering the heat losses, on the threshold between coldest and warmer heating months. The month of March, considered among the coldest in the official variant despite an average exterior temperature of 8.8°C, is considered among the warmer months in Figure 5.2.83, due to the fact that the month of May could be neglected in the calculation of the threshold.

5.2.13 Case Study 13 – CS13

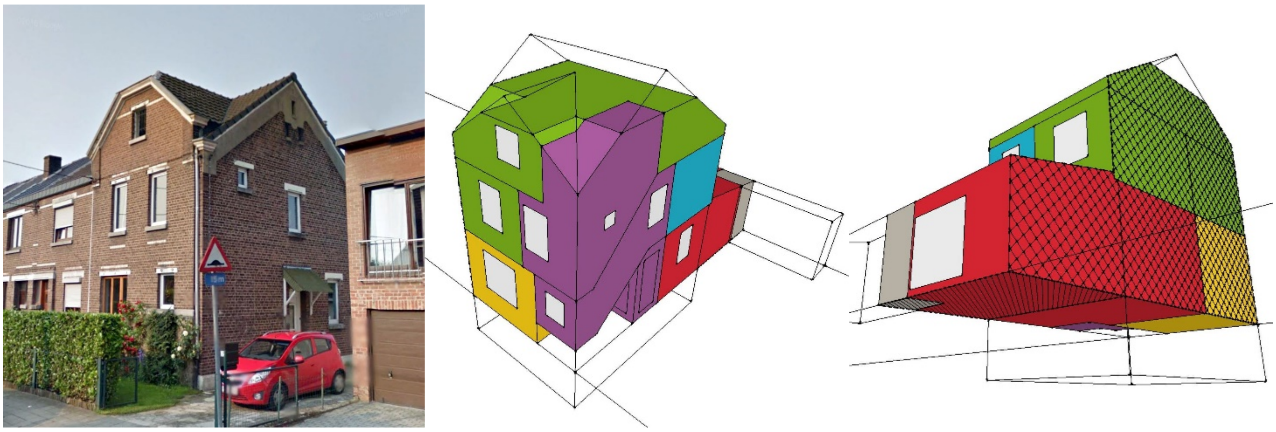


Fig. 5.2.84. CS13 – **Left**: street facade; **centre**: high-angle shot of the NW (entrance) and NE (street) facades; **right**: low-angle shot of the SE (shared) and SW (garden) facades

This house is a "modest" brick house (like CS3, CS7 and CS9), sitting at the end of a row (like CS2 and CS7) of blue collar houses. It has been built during the industrial development of the valley that preceded the Second World War, in a street of blue-collar houses punctuated by bigger houses that were reserved for managers and team supervisors. Those houses are larger and higher, and benefit from the third exterior façade to increase the parcel surface and the quality of natural lighting. When they were built, those houses were not equipped with any insulation layer. The approach in this case is to consider any wall uninsulated, unless acceptable proofs can say otherwise. The definition of the protected volume is straightforward, as there was no real doubt over the inclusion of the spaces. The total heat loss area stays the same for both variants, therefore, at 309.9m², and its protected volume at 452m³, for 145m² of heated floor area.

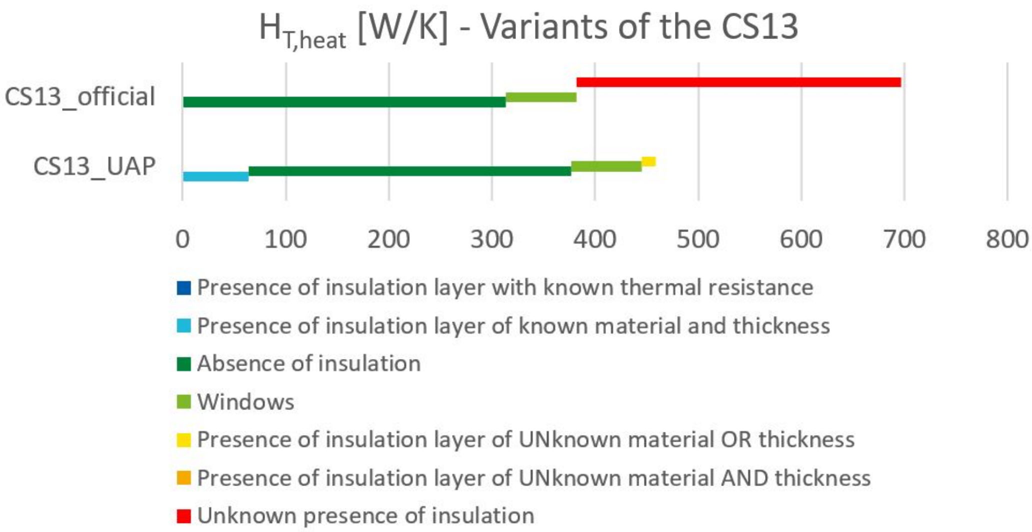


Fig. 5.2.85. Repartition of the $H_{T,heat}$ coefficient [W/K] for the two variants of the CS13

The official EPC leaned on the very thin list of given acceptable proofs to provide the first variant of this case study, characterized by heat loss areas described either as clearly uninsulated, or with the unknown presence of insulation. The EPC results are an average U-value of 2.26W/m²K, a specific annual primary energy consumption of 573kWh/m².year, and the corresponding "G" level on the certification scale.

The definition of the second variant takes into consideration the supposed presence of insulation layers, placed and mentioned by the owners themselves: 4cm of mineral wool in the tilted roofs of the main and secondary volumes, as well as in vertical walls of the annex; 8cm of mineral wool in the ceiling of the upper floor, and an unknown (without dismantling) thickness of mineral wool in a small, wooden part of the basement ceiling. As a result, this second variant labelled "UAP" (for UnAcceptable Proofs) is characterized by an average U-value of 1.5W/m²K, and an "E" level on the certification scale attributed by a specific annual primary energy consumption of 398kWh/m².year (-30%, when compared to the first variant).

The house is heated by a rather old boiler located in the basement, via the central distribution system. The global efficiency of the system has been evaluated at 62%, considering:

- Production: 77% (default efficiency for a low and variable temperature, atmospheric boiler of unknown efficiency, using natural gas and placed after 1990 outside of a V_P);
- Distribution: 98% (small length of uninsulated pipes out of V_P);
- Storage: 100% (no storage);
- Emission: 82%;
- Solar fraction: 0% (no thermal solar installation).

The owner has mentioned the annual consumption of three stacked cubic meter of dry logs in the wood stove located in the living room. Their use of the system is quite different than in the CS2, the CS10 or the CS11. In the winter, the wood stove is lit quite early, and clearly participates in getting the required comfort. It replaces the use of the central heating system (at least for the living room, dining room and kitchen) for complete periods and evenings, and is not used only as a complement. As in those other case studies, the presence (and use) of the central heating system in the living room imposes its consideration in a single energy sector, and the oversight of the stove. Therefore, the stove is given the same 62% efficiency than the central heating installation, which is quite close to the 59% efficiency the stove would have been given in its own energy sector.

Domestic Hot Water is, in this case, provided by two distinct installations:

- The first one is an electric boiler located under the kitchen sink, characterized by an efficiency of 90%, considering:
  - Production: 95% (default efficiency for instantaneous electric production);
  - Distribution: 95% (production very close to the kitchen end-use);
  - Circulation loop: 100% (absent);
  - Solar fraction: 0% (no solar thermal installation).
- The second one is a boiler located in the bathroom, characterized by an efficiency of 66%:
  - Production: 80% (default for instantaneous DHW boilers using natural gas);
  - Distribution: 83% (production close to the bathroom end-use);
  - Circulation loop: 100% (absent);
  - Solar fraction: 0% (no solar thermal installation).

This household declared ventilating their house more than others households living in similar buildings of the sample (poorly uninsulated, draughty, without ventilation systems), by opening windows daily in the living room, the kitchen and the bedrooms. No test of the air tightness allowed to consider another value for the $\dot{v}_{50,\text{heat}}$ parameter of Equation (15) than the default 12m³/h.m². As a result, the $H_{V,heat}$ coefficient is, in this case, revaluated at 48.08W/K.

Mr M. works out of his home every day, and Mrs M. is a housewife who spends about half her days at home (due to the presence of her grown-up sons, at school or university), the other half outside. As a result, the heating pattern hereunder is partially defined by school hours. The living room, dining room and kitchen (as one space) as well as the bathroom are heated at all times when present. When he is at home, their second son also has the habit to heat his bedroom, except at night. The set temperature defined by the thermostat in all the house is kept low, at 19°C (although the use of the wood stove in the living room sometimes brings the temperature higher), and 16°C at night.

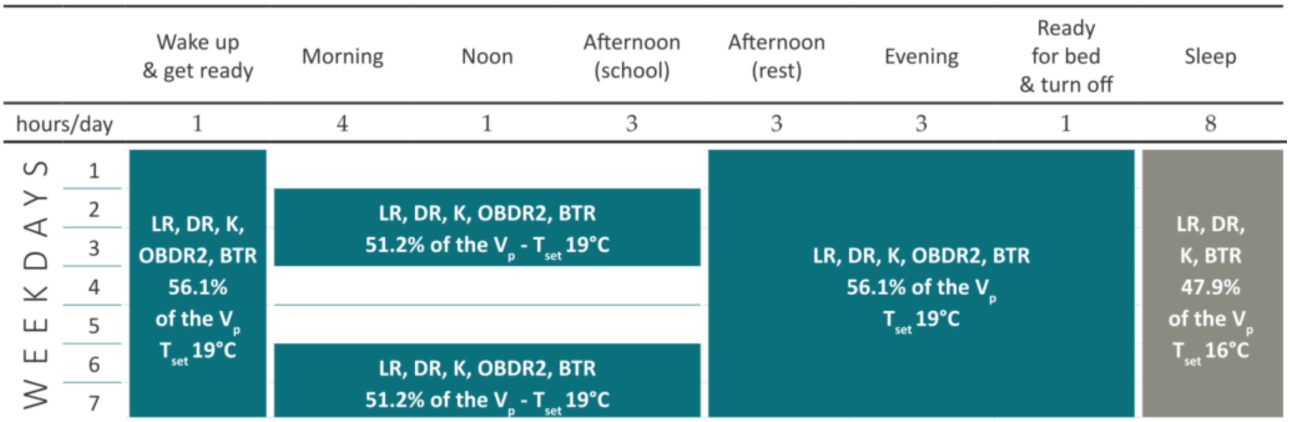


Fig. 5.2.86. Heating pattern of the CS13, according to the owner's answers to the questionnaire.

The real consumption data declared by the owner is 8,458kWh of natural gas consumed between August 13th, 2015 and July 26th, 2016 and three annual steres of dry wood (evaluated at 5,910kWh), which have been summed up in the graph below (see the results in Figure 5.2.87). He also declared 3,641kWh of electricity consumption between March 12th, 2016 and December 1st, 2016. In this case, the electricity consumption is mainly revaluated by the appliances and equipment (78%), cooking (8%) and DHW for the kitchen (8%), all end-uses that are considered constant during the year. Over a whole year, the real electricity consumption is therefore evaluated to be around 5,054kWh.

The initial EPC regulatory results were 5.7 times the real data, for the first variant, 3.93 times for the second. The de-standardisation of the method decreased the theoretical consumption by 43 to 57% for the first variant, 42 to 58% for the second. As expected given the previous case studies, the variant that lowers the $H_{T,heat}$ coefficient most, approaches real consumption data better. However, the lower revaluation (real climate, HGAR1_AY) is still 65% above the real consumption data.

Adding the consumption of dry wood is certainly considering the behaviour of the owners, who declared using their stove as much as possible. However, the temperature attained in the living spaces due to the use of the stove, expected to be higher than the 19°C of the thermostat that regulates the boiler and was considered in the inputs, has not been taken into consideration here. This is the limitations of this calculation method that cannot consider both systems and their settings in one energy sector. It cannot, either, integrate the dynamics of the practice that consists, for an individual, to fuel a stove with wood logs occasionally to gain an additional, indescribable comfort.

Here is, along with the CS3 and the CS12, another example of inefficient house (or described as much, at least) which still displays gaps superior to 50% after the modifications brought to the calculation method. These case studies have in common that the description of their energy system (mainly the envelope) is still very much dominated by default values, but other case studies (such as the CS11, or the CS4, which are more recent houses than the CS3, CS12 or CS13) also show important share of heat losses due to "absence of insulation", and still present accurate values. It seems as though the default values, chosen at their most detrimental level, do not consider the fact that pre-war houses envelopes are more thermally efficient than post-war envelopes. This advocates for the creation of a more subtle and accurate database of values that could be used in the EPC to characterize the envelope.

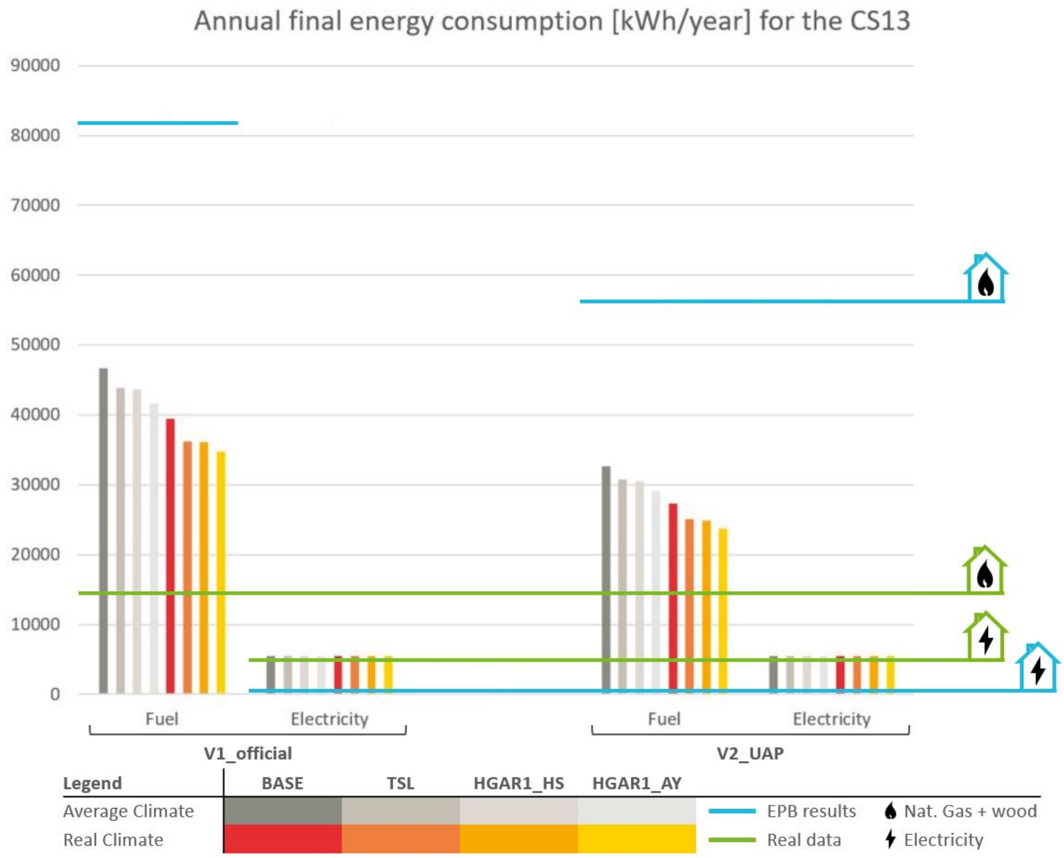


Fig. 5.2.87. Results of revaluated energy consumptions for the two variants of the CS13, for different steps in the method

In this case again, the real consumption data covers the net heat demands alone in the revaluations. DHW can hardly been considered problematic here; the problem lays in the heating net demand and system's efficiencies. The description of the envelope is again the focus of the main suspicions.

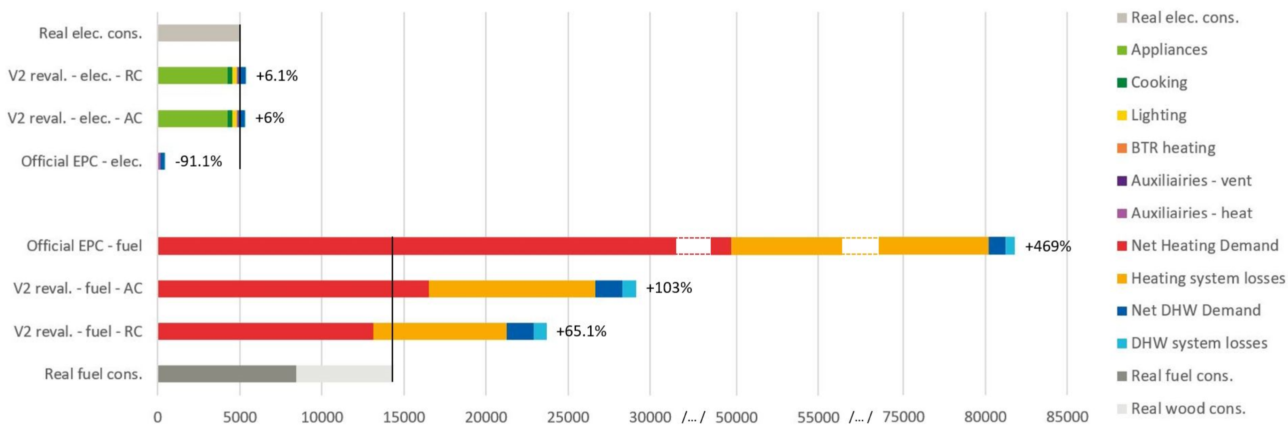


Fig. 5.2.88. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS13.

The temperature curves above indicate that the global revaluated $T_{set,m}$ is quite lower than the EPB standardised 18°C, as it even lowers beneath 16°C for the month of… April, for an average exterior temperature of 9°C. This type of graph also indicates where the hypotheses related to the threshold between coldest and warmer heating months are slightly mistaken: in this case, the curves would be more realistic if the month of April had been considered “coldest”, in terms of temperature settings.

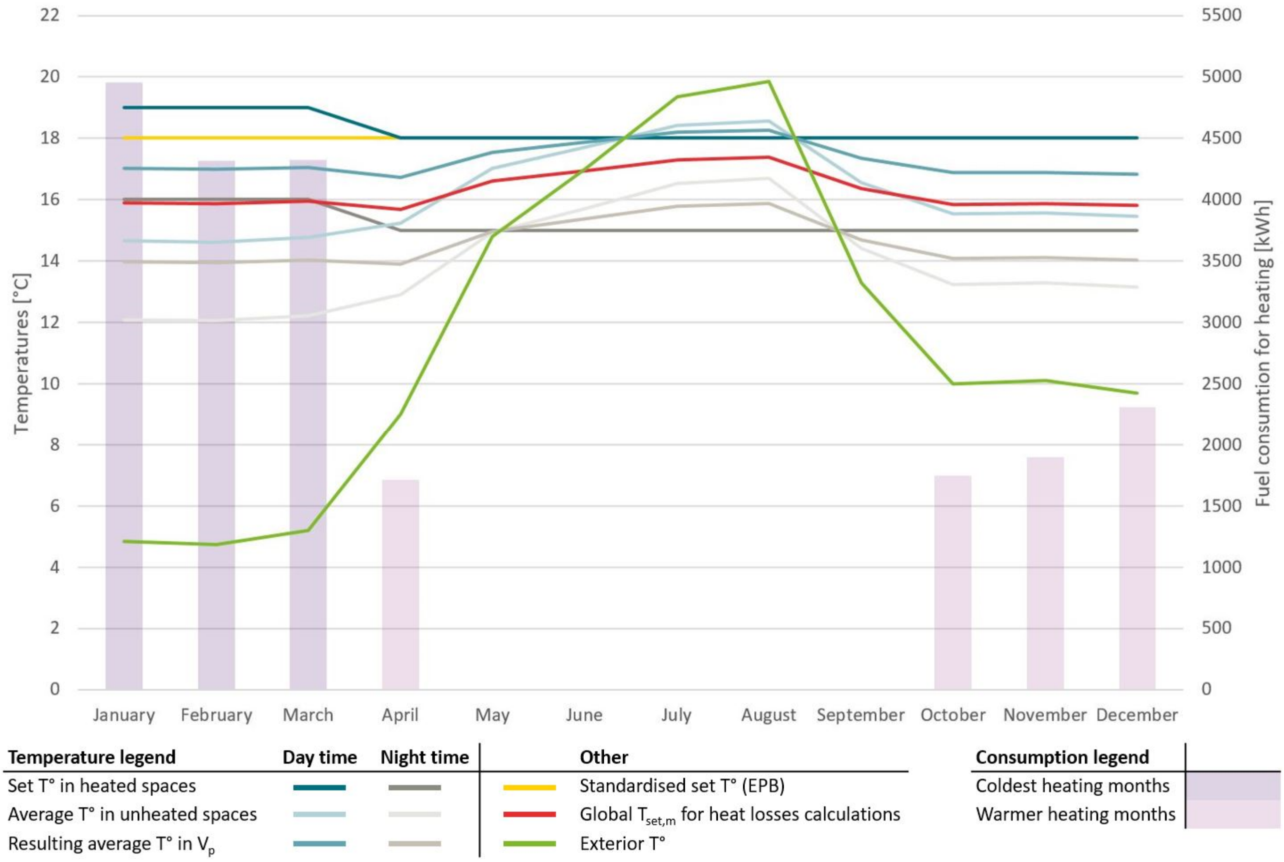


Fig. 5.2.89. CS13: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

5.2.14 Case Study 14 – CS14

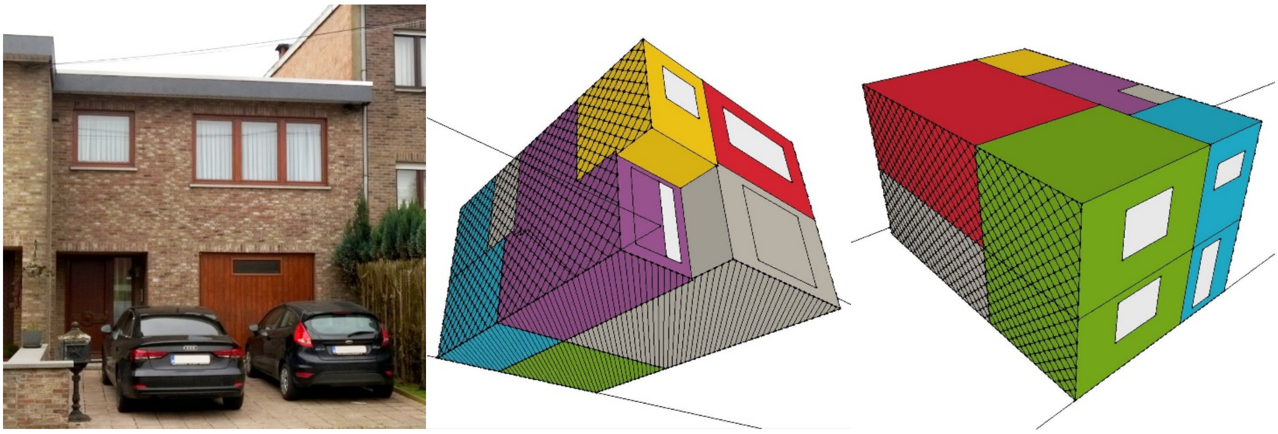


Fig. 5.2.90. CS14 – **Left**: street facade; **centre**: low-angle shot of the NE (shared) and NW (street) facades; **right**: high-angle shot of the SW (shared) and SE (garden) facades

The fourteenth case study is one of the most recent houses in the sample, built in the suburbs of Liege in 1987, under the first thermal regulations. It is a very simple volume composed of two levels covered by a flat roof, with a garage on the lower level and no basements. The owner is Mrs N., a middle-aged divorced woman who works full time. Her daughter is attending university, and lives during the week in a small house shared by students in the city centre, but still comes home every weekend, where she occupies the bedroom on the lower floor. Most of the week, therefore, Mrs N. mainly uses the upstairs rooms, containing the living and dining room, the kitchen, a bedroom and a bathroom. No variants could be defined based on the definition of the protected volume, which encompasses all the rooms of the dwelling and therefore totalises 364.7m³ of protected volume (V_P), for 207.2m² of total heat loss area (A_T).

The owner could provide some information, among which the permit that was granted to the first owner in 1987. The EPC protocol dictates however that, as an "official document", it can only be used to attest of the date of construction or renovation, or the date of the glazing. Mrs N. was also in possession of the necessary documents to attest of the presence of an added layer of 10cm of polyurethane in the flat roof during works she has commanded a few years sooner.

- The first and "official" variant relies mainly on the default values proposed in the calculation method when 1987 is introduced as date of construction. The flat roof is mainly defined by the only accountable insulation layer (U_{roof} = 0.21W/m²K), while the presence of insulation in the rest of the heat loss surfaces facades is declared "unknown"; consequently, the method gives the exterior facades a U-value of 0.78W/m²K (default thermal resistance of insulation: 0.333m²K/W), and the on-ground floor, 0.63W/m²K (default thermal resistance of insulation: 0.167m²K/W; the b_j coefficient for ground as environment explains the lower U-value). As a result, the house is characterized by an average U-value of 0.82W/m²K, and, given the house compactness ($C = A_T/V_P$) of 1.75, a resulting K-level[6] of 65, indicating that the requirements of 1987 were achieved (thanks to the polyurethane in the roof and the default values of the EPC method for the other walls). Brought into today's PACE software for the certification, this house is labelled "E" on the certification scale, due to a specific annual primary energy consumption of 376kWh/m².year.
- The second variant ("UAP"), was built on the information contained in the permit document: the presence, types and thicknesses of insulation layers in the facades (extruded polystyrene, 4cm) and in the flat roof, which contained 15cm of mineral wool, which according to the owner were left in place when the polyurethane was added. There was no indication that could be used of insulation in the on-ground floor, the "unknown" presence of insulation was left. The average U-value is therefore revaluated at 0.7W/m²K, for the same dwelling which K-level is revaluated at 56, its certification scale level to "D", and its E_{spec} indicator to 340kWh/m².year (right above the D/E threshold).

The Figure 5.2.91 hereunder displays the $H_{T,heat}$ coefficients for both variants defined in the CS14. The reduction of heat losses due to "presence of an insulation layer with known resistance" (in dark blue) is due to the flat roof: the first variant only considered the polyurethane, whereas the second added the layers mentioned by the permit, which reduced the roof's heat losses. As stated above, the remaining heat losses due to the "unknown presence of insulation" (24.1W/K) relate to the floor laid on the ground.

[6] The K-level, indicating the global insulation level of the house, is a regulatory requirement since the first thermal regulations for all buildings newly constructed or importantly renovated (if a change is made from unheated to heated affectation). In 1987, when the permit was introduced, there was not yet any maximal U-values required for any particular wall, but a maximal K70 requirement was imposed for the whole dwelling. Its calculation method can be found in [Région Wallonne, 1984. *Arrêté de l'Exécutif fixant les conditions générales d'isolation thermique pour les bâtiments à construire destinés au logement ou destinés en ordre principal au logement*, extrait du Moniteur Belge du 31 Octobre 1984 – N. 1606].

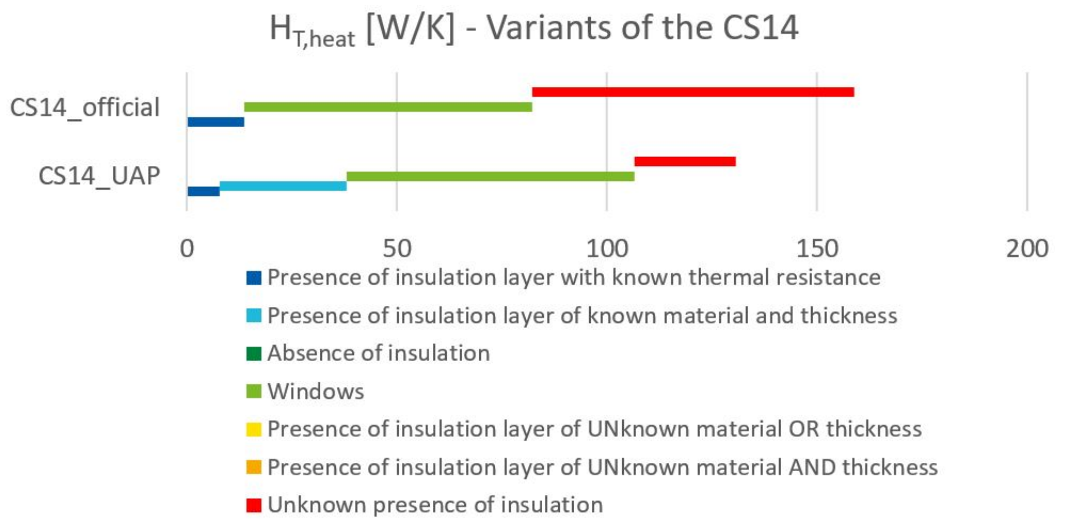


Fig. 5.2.91. Repartition of the $H_{T,heat}$ coefficient [W/K] for the two variants of the CS14

The heating pattern of the house is not, for once, defined by the occupancy schedule of the house, but by the heating system. The house is only supplied in electricity, there is no use of natural gas or wood in this case study. Each room of the dwelling is equipped with electric storage heaters and emitters, considered as local heating installation in the EPC protocol. These devices, upon demand, store the heat at night, and release it the next day, depending on the regulation system. In this case, as visible in the Figure 5.2.92 below, Mrs N. demands that the main daytime spaces (living and dining room, kitchen) are heated at 20°C during the day, so that the house could be warm when she gets back from work. Her daughter's bedroom is also often heated in the evenings, either because she is present or because the owner wishes to "cut the chill" in the rest of the house, especially during "bathroom time". She acknowledges the use of an extra electric booster heater in the bathroom when she uses it, partly because she likes having 24°C in there, partly because the accumulators, storing the heat at night, are often nearly unloaded when evenings come.

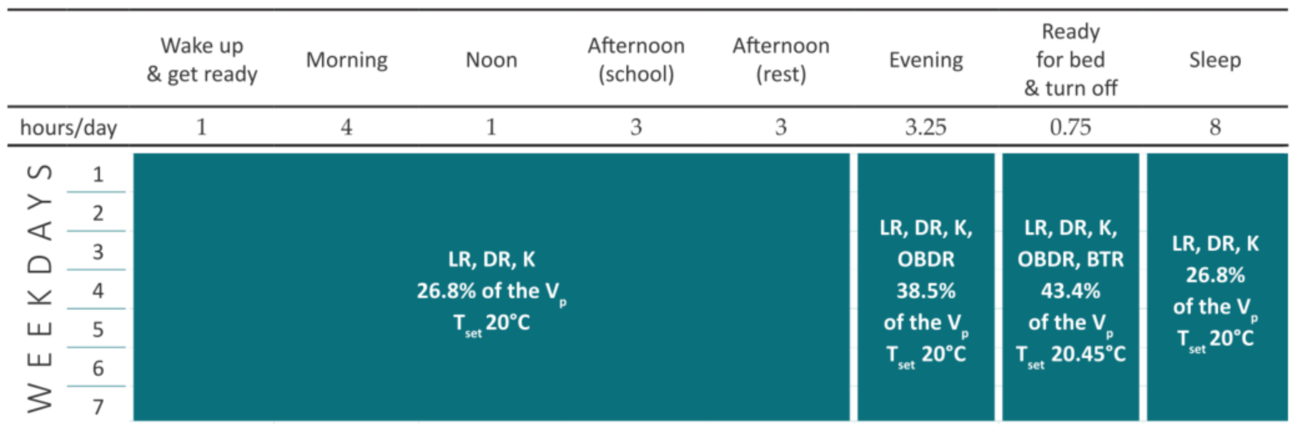


Fig. 5.2.92. Heating pattern of the CS14, according to the owner's answers to the questionnaire.

In this calculation method, the heating installation is given an 85% global efficiency, considering:

- Production: 100% (default for local electric system)
- Distribution: 100% (local system, no distribution)
- Storage: 100% (the storage is 100% inside the protected volume, there are no losses there)
- Emission: 85% (due to the accumulation system, and the absence of external sensor)

DHW is prepared by an electric boiler situated in the garage. It is quite new, replaced recently by the owner, although this had no impact on the global efficiency, evaluated at 52% considering:

- Production: 80% (default for electric production with internal storage);
- Distribution: 65% (72% for the upstairs bathroom, 83% for the downstairs bathroom, and 39% for the kitchen sink);
- Circulation loop: 100% (absent);
- Solar fraction: 0% (no solar thermal installation).

Mrs N. gave her electricity bills: 8,311kWh between October 2014 and October 2015, and 9,282kWh for the following year. It is interesting to notice, first, that the first period covered (2014-2015) is colder than the next (2015-2016), with 1,770 degree-days 15/15 versus 1,558 DD15/15. If the annual variations in consumption were only influenced by the climate, as is the case in this calculation method, then the real data should have been lower during the second period. Electric accumulators are, by essence, devices of a heating system that is less influenced by climate than others. Mrs N. has to foresee her heating needs for the next day when she demands for heat storage at night, and the heat will be released on the next day anyway. The lack of any exterior sensor could explain these differences, as could annual variations in solar gains, or behavioural changes in temperature regulation or comfort settings, which can be linked to the energy prices for example. Therefore, in the Figure 5.2.93 below which displays the results for both variants and both years of real data consumption, the revaluations made by the modified method tend to decrease the second period consumptions, when compared to the first, contrary to the owner's data.

In this relatively insulated case study, the real consumption given by the owner is about half of the standardised theoretical consumptions delivered by the EPC regulatory method (43 to 49% for the first variant, 48 to 54% for the second), which is not a bad initial score in this research sample. The lowest revaluations (real climate – HGAR1_AY) are 56.8% above the first year's real consumptions, 30.3% above the second year's for the first variant, 40% and 17% respectively for the second variant.

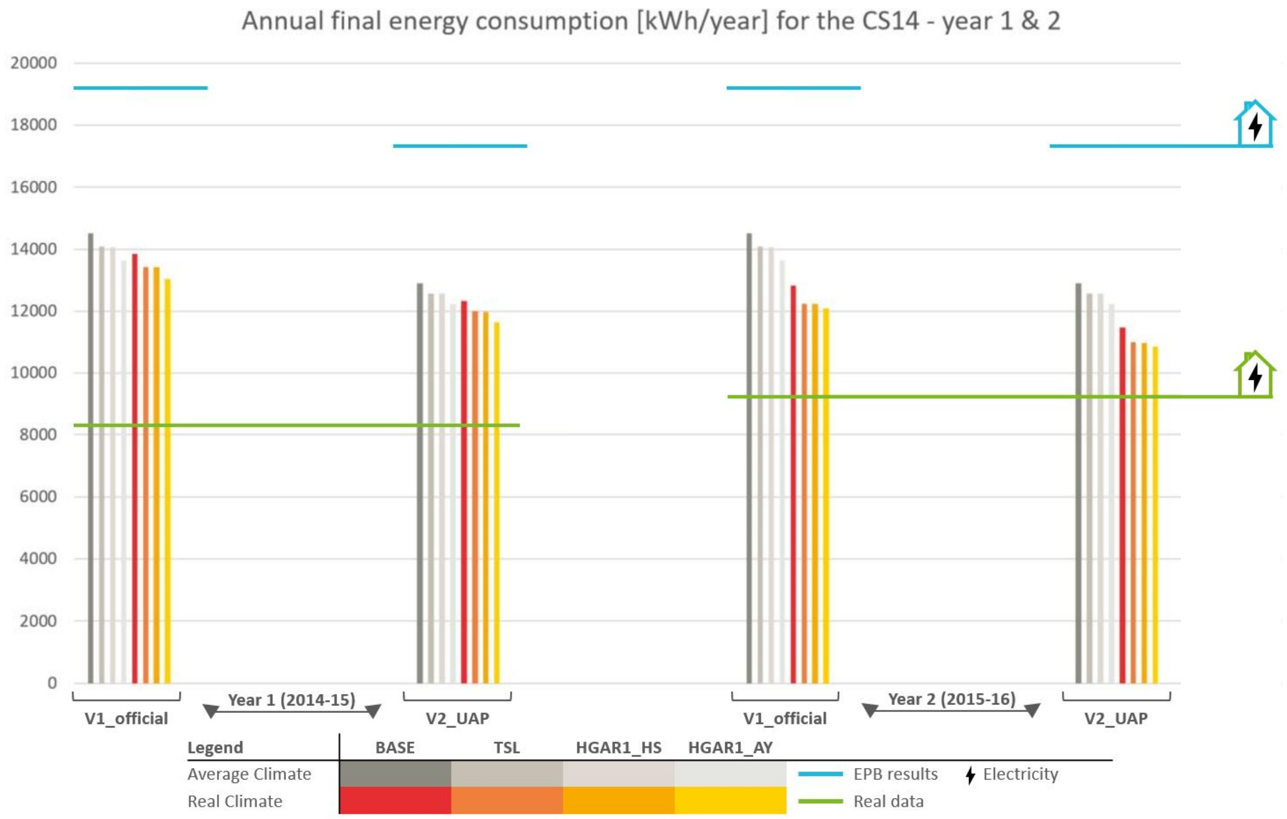


Fig. 5.2.93. Results of revaluated energy consumptions for the two variants of the CS14 and two years of consumption, for different steps in the method

No case study so far could provide any indication as to the repartition of their consumptions, in order to assess clearly the accuracy of this modified method. All results presented so far have been mainly used to assess the plausibility of the method. This case study is even more difficult to assess, as there is only one energy vector, and two energy bills, to investigate. Results add the consumption revaluations (and uncertainties) for appliances, lighting, cooking, auxiliaries, DHW and heating end-uses. This case study was left out of the calibration scheme, as it was integrating the unknown (but probably high) share of consumptions for heating and DHW supply. It has benefited from the calibration afterwards, as did the other case studies that presented electricity consumptions for the supply of DHW, which explains why those case studies might still present greater discrepancies in electricity consumption results (+13% for the CS6, see Figure 5.2.37; + 10 to 16% for the CS12, see Figure 5.2.79, for examples). The results of the calibration are visible in the Figure 5.2.94 below that displays the repartition of electricity consumptions for both years of consumptions of the second variant, before and after final calibration.

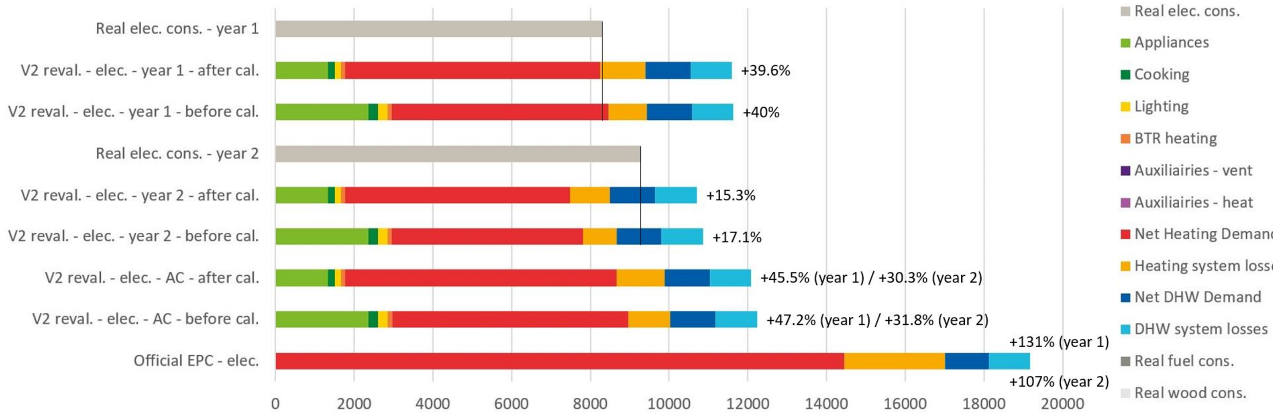


Fig. 5.2.94. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS14

Globally, the calibration brought very little change (less than 2% reduction) to the consumptions. The main modification stands in the reduction of consumptions attributed to appliances, cooking and lighting. As these particular consumptions are partially used as internal gains in the modified calculation method (see section 4.3.3.5), their reduction led to an increase in heating consumptions. In order to close the gap, the internal gains do not seem influential enough in this case study: the definition of the heat losses and efficiencies might again be more accurate targets.

The Figure 5.2.95 below displays the temperature curves for this CS14 during the first year of consumption (October 2014 to October 2015). The settings in temperature are identical during day and night times (20°C), with the exception that daytime averages include ablutions times when the set temperature in the bathroom is raised to 24°C. The graph below displays, therefore, very little differences between the day and night periods in terms of resulting temperature in unheated spaces, and global "set" temperature curve in the protected volume.

Globally, the $T_{set,m}$ revaluated by this modified method is very close to the standardised 18°C, at least during the heating months. This tends to validate the EPB hypothesis, although it is important to specify that other determiners, such as solar gains and systems' efficiencies, also play a crucial role in reducing the revaluated energy consumptions for heating. This case study, however, presents high efficiencies for the systems, which is characteristic of the electric systems in the EPC protocol.

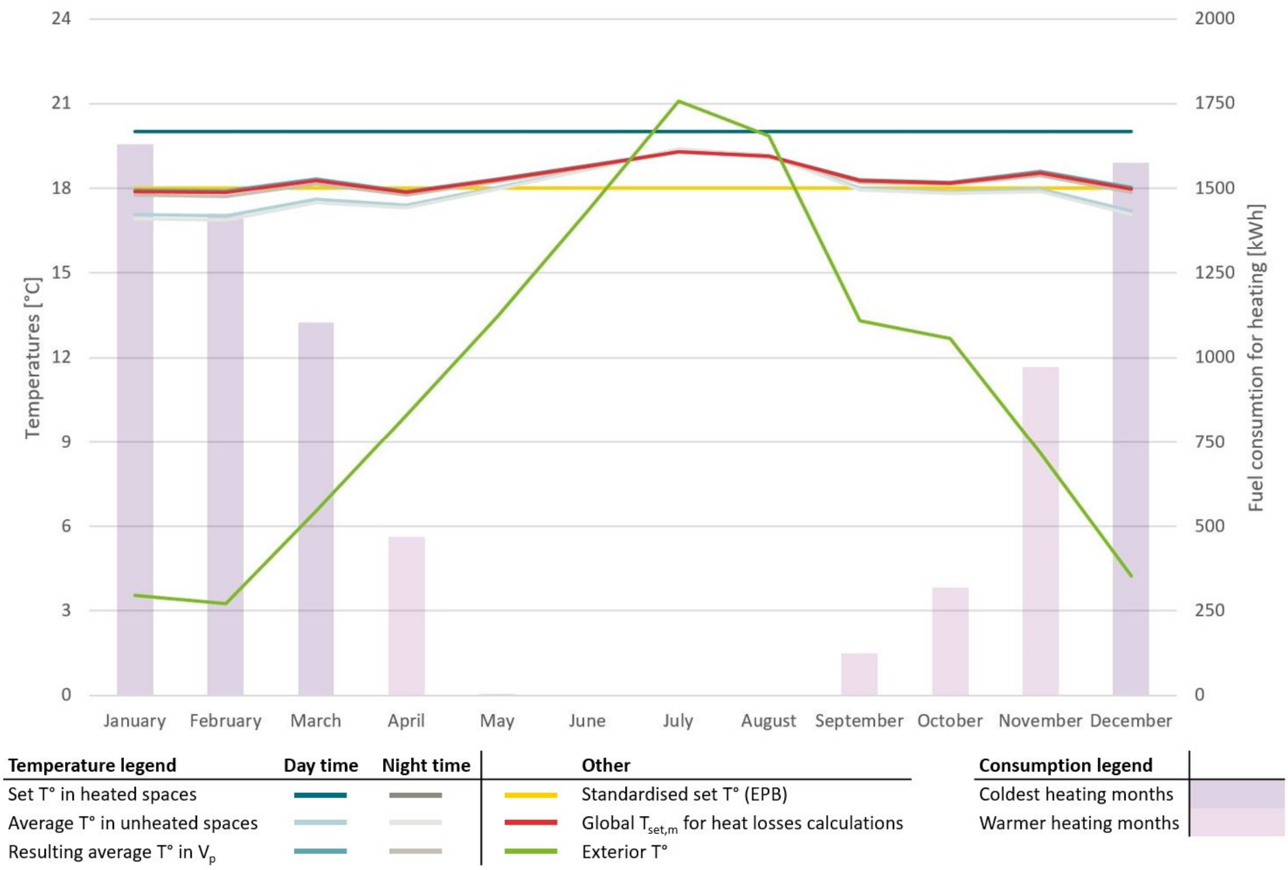


Fig. 5.2.95. CS14: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

5.2.15 Case Study 15 – CS15

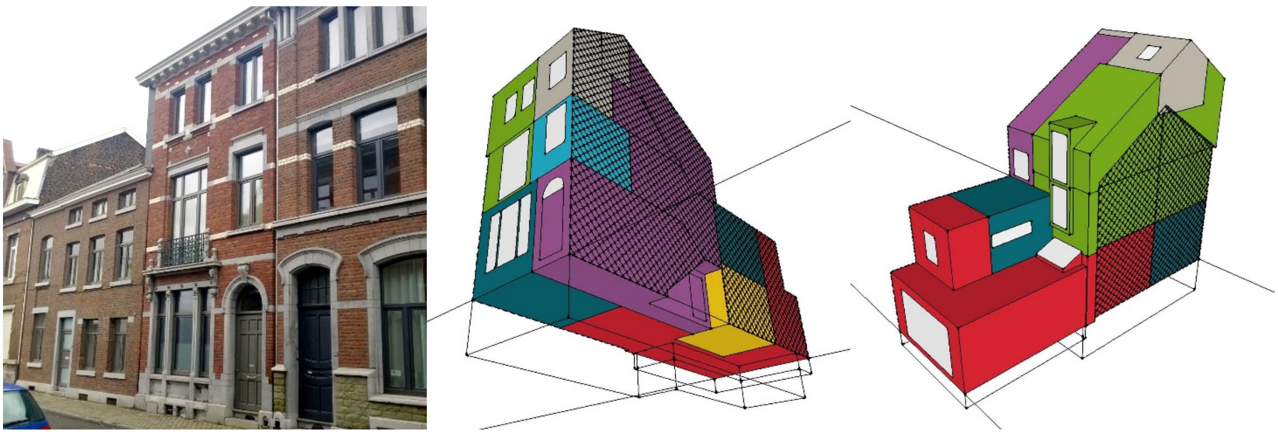


Fig. 5.2.96. CS15 – **Left**: street facade; **centre**: low-angle shot of the NNW (shared) and ENE (street) facades; **right**: high-angle shot of the SSE (shared) and WSW (garden) facades

Although of a very different typology, the next case study presents some important similarities with the CS8, as it is another old house renovated to very high standards under the BATEX framework. In this case too, therefore, a complete file of acceptable proofs was given to the assessor in order to deliver the EPC and proceed to this research. A complete EPB declaration had also been completed, describing the renovated building as accurately as if it was newly built. All the thermal resistances of the insulation layers were available, but better yet, the U-values of all heat loss areas were given and usable in the EPC description. The definition of the protected volume, in efficiently insulated buildings, cannot be subjected to variants. Efficiencies were hardly debatable either, so that the variants in this case study were defined like in the CS8, on the level of accuracy in the description of the envelope:

- The first variant, labelled "EPC_min", describes all the insulation types and thicknesses from the BATEX file, leaving to the EPC method the responsibility to use its default values to deduce thermal resistances. As a result, the average U-value of the envelope is evaluated at 0.37W/m².K. The differences with the U-values delivered by the EPB declaration are minimal when it comes to assessing the roofs (+0.01W/m²K on average), a little bit more important for floors and vertical walls (up to +0.08W/m²K), but the main differences are in the description of the windows. Triple glazing in wood window frames is attributed a U-value of 1.69W/m²K by the default values of the EPC method. The U-values delivered by the EPB declaration ranged between 0.84 and 1.36W/m²K, with an average of 1W/m²K, values which are used in the second and third variants. The building, described thus, is labelled "A" on the EPC scale (E_{spec} = 62kWh/m².year).
- The second and "official" variant considers the U-values delivered by the EPB declaration, and translates them into the EPC software and calculation method according to the protocol. The resulting average U-value, for the total 425m² of heat loss area, is 0.29W/m²K. The EPC scale label does not change (A), given the specific annual primary energy consumption of 54kWh/m².year.
- The third variant considers the results given by the EPB declaration, using therefore the calculation method developed for new buildings. The interest here is quite straightforward: use this case study (as well as the CS8), which energy system's characteristics are described in detail, to assess whether the EPC simplifications bring important or small variations on high-performance dwellings' certification. The EPB calculation method for new buildings takes the constructive nodes and thermal bridges' additional heat losses into account, where the EPC method does not, even for efficient buildings: in this case study, these additional heat losses are evaluated by the EPB at 16W/K (11.2% of the total heat losses). As a result, the average U-value in this third variant is evaluated at 0.34W/m²K, and its E_{spec} indicator at 57kWh/m².year (still an "A" label).

As said before, the typology of this building is quite different than the CS8, as this brick "master house" presents architectural features which the owners wanted to save from the beginning, despite their ambitious renovation project. In order to preserve the front façade, it was insulated using interior systems, whereas the back façade, which had no real interest in preservation, was externally covered by insulation and roughcast or wood cladding. It was also quite rare to find sanitary crawl spaces under the annex, which are usually built after the main volume, directly onto the ground. This allowed for a complete insulation of the floors (with 11cm of polyurethane, in this case). The renovation works also brought a remodelling of spaces and functionalities. The ground floor living area has been extended on the garden to bring light and space. The upstairs levels have been redistributed, and the upper floor slightly lowered, in order to create one more bedroom. The roofs have all been insulated, with 16 to 24cm of polyurethane and/or mineral wool.

The Figure 5.2.97 below shows the repartition of the $H_{T,heat}$ coefficients. In the "EPB" and "official" variants, the 13.2W/K of heat losses due to "absence of insulation" (dark green) refer to the entrance door of the building, which had not been changed (yet) and is composed of uninsulated wood panels and single glazing, hold together by a wood frame. In the "EPCmin" variant, those heat losses are hidden in the "windows" category. The very small difference (2W/K) of heat losses due to "presence of insulation layer with known resistance" (dark blue), between the second and third variants, is due to rounding errors.

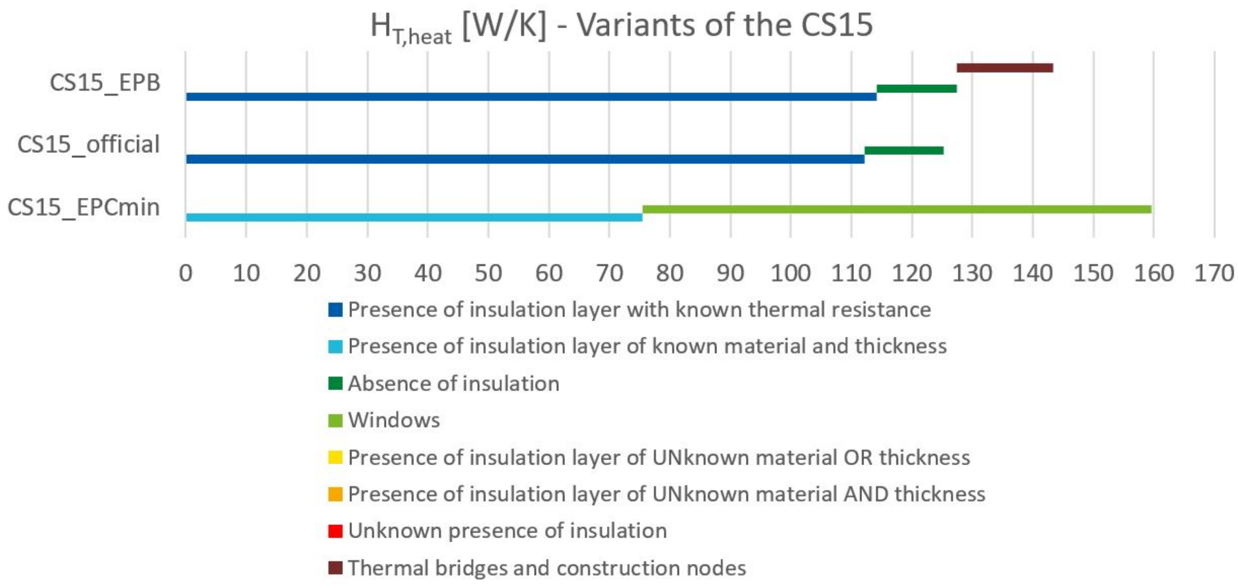


Fig. 5.2.97. Repartition of the $H_{T,heat}$ coefficient [W/K] for the three variants of the CS15

The envelope's air tightness had been tested, and the official report indicated a $\dot{v}_{50,heat}$ coefficient used in Equation (15) of 3.7m³/h.m² under a difference in pressure of 50Pa, which is slightly higher than expected, due to the old entrance door. A completely controlled ventilation system is installed in the upper level of the building, supplying mechanically 353m³/h of fresh air to living room, office and bedrooms, and retrieving it from bathrooms, kitchen and toilets. The heat exchanger present has a theoretical efficiency of 87%, reduced to 83% by the method. The $r_{preh,heat}$ coefficient mentioned in Equation (14) (section 4.3.3.4), therefore, is equal to 0.17. Globally, the $H_{V,heat}$ coefficient for this case study has been revaluated at 40.33W/K.

Heat is provided by a condensing boiler, supplied in natural gas and located in the protected volume on the upper floor. The global efficiency of 80% is explained in the EPC protocol by:
- A theoretical efficiency ($\eta_{30\%}$, standard efficiency at 30% of load, according to standards) of 108%, degraded to 92% due to the regulation and the temperature of return water ($\theta_{30\%}$);
- Distribution: 98% (very small portion of pipes outside the V_P);
- Storage: 100% (absent);
- Emission: 89%;
- Solar fraction: 0% (the thermal solar installation only feeds the DHW installation).

It is interesting to note that the efficiencies given in the EPB method (for the third variant) are slightly different. The global efficiency is evaluated at 84% in that variant, considering:
- The same theoretical efficiency ($\eta_{30\%}$) of 108%, degraded in this case to 90% due to the design return water temperature θ_{return} of 50°C;
- Distribution: 99% (very small portion of pipes outside the V_P);
- Storage: 100% (absent);
- Emission: 94%.

No other type of heating device is necessary in this house, including the occasional electric heater in the bathroom. DHW is provided by two different circuits, described in the EPC method thus:

- The first one is the condensing boiler situated on the upper floor that provides the heat to the dwelling, characterized by an efficiency of 50%, considering:
    - Production: 65%, default for coupled heat/DHW variable temperature production with separate storage;
    - Distribution: 77% (production relatively close to the bathrooms);
    - Circulation loop: 100% (absent);
    - Solar fraction: 60%. This is the only installation to which the 7.05m² of thermal solar panels, oriented SW on the 30° tilted roof, are connected.
- The second is an electric water heater located in the kitchen (which is far from the condensing boiler on the upper floor), characterized by an efficiency of 76%, considering:
    - Production: 80%;
    - Distribution: 95% (the purpose of decentralised systems);
    - Circulation loop: 100% (absent);
    - Solar fraction: 0% (the solar thermal installation does not feed this installation).

Here also, the different EPB hypotheses have to be mentioned to assess the third variant. The first installation connected to the boiler was granted a very-low 37.5% global efficiency, mainly because the default value for the production was surprisingly fixed at 45% for a boiler with separate storage[7]. The distribution efficiency is a little bit higher, at 83%, and so is the solar fraction, averaged here at 67% over the year (the difference is mainly due to higher demand, as explained in the CS8). The second DHW installation, connected to the electric boiler, is granted a 67% efficiency; the difference with the EPC method is in the production efficiency, fixed at 70% in the EPB method (for 80% in the EPC method).

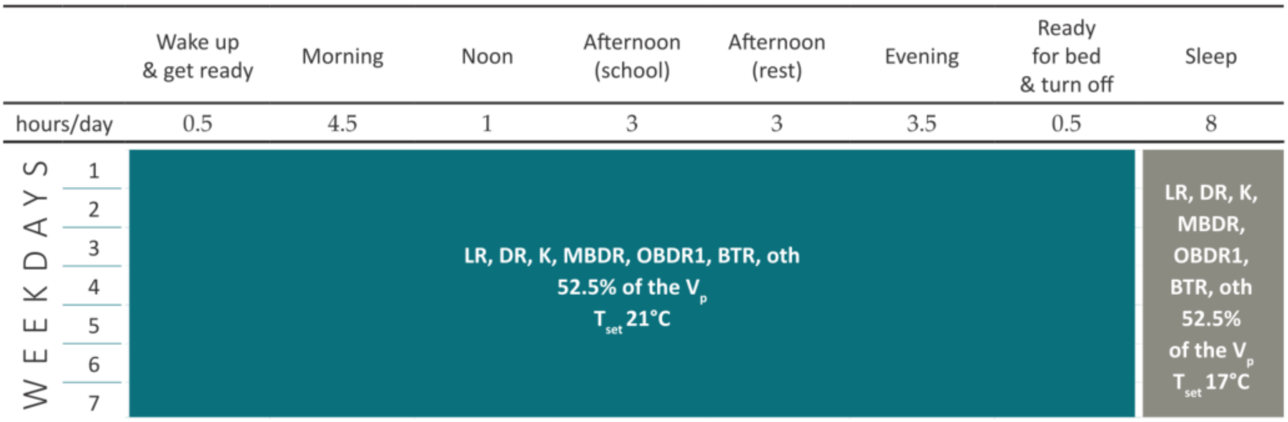


Fig. 5.2.98. Heating pattern of the CS15, according to the owner's answers to the questionnaire.

As was the case for the CS8, the definition of the heating pattern is somewhat different here. The very high performance level of the envelope (in transmission and exfiltration) and systems (heat recovery on the ventilation, low-temperature settings) favour the constant and homogeneous heating of the chosen rooms (in this case, the living room, dining room, kitchen, first-floor bedrooms and bathroom, and office) over the day. As the owner, Mrs O., declared: "*we have a low-temperature heating installation, so the heating engineer told us it would be best to let it heat continuously, that we would consume less like this than if we have to "stop and start" the system each time…*" To this declaration must

[7] The EPB calculation method for the evaluation of DHW-related consumptions has been changed since this case study's final declaration, after the introduction of the ECODESIGN standard. The data collected in this declaration are the only "acceptable" for this boiler, however.

be added the fact that Mr O. was working as an independent architect in his home and was therefore often present during the day. Mrs O. was working full time out of the house. The resulting heating pattern, in Figure 5.2.98, shows a constant heating of just above half of the V_P, at 21°C during the day and 17°C at night.

The results in Figure 5.2.99 show that the electricity consumption revaluations, which do not include any end-uses influenced by the climate, are quite constant. For appliances, lighting, cooking, DHW production and heating auxiliaries, these consumptions are evaluated at 4,073kWh for the first two variants, 4,111kWh for the third (the difference is due to the evaluation of auxiliaries consumption), slightly underestimated therefore at 92.1 to 92.9% of the real consumption data (4,423kWh).

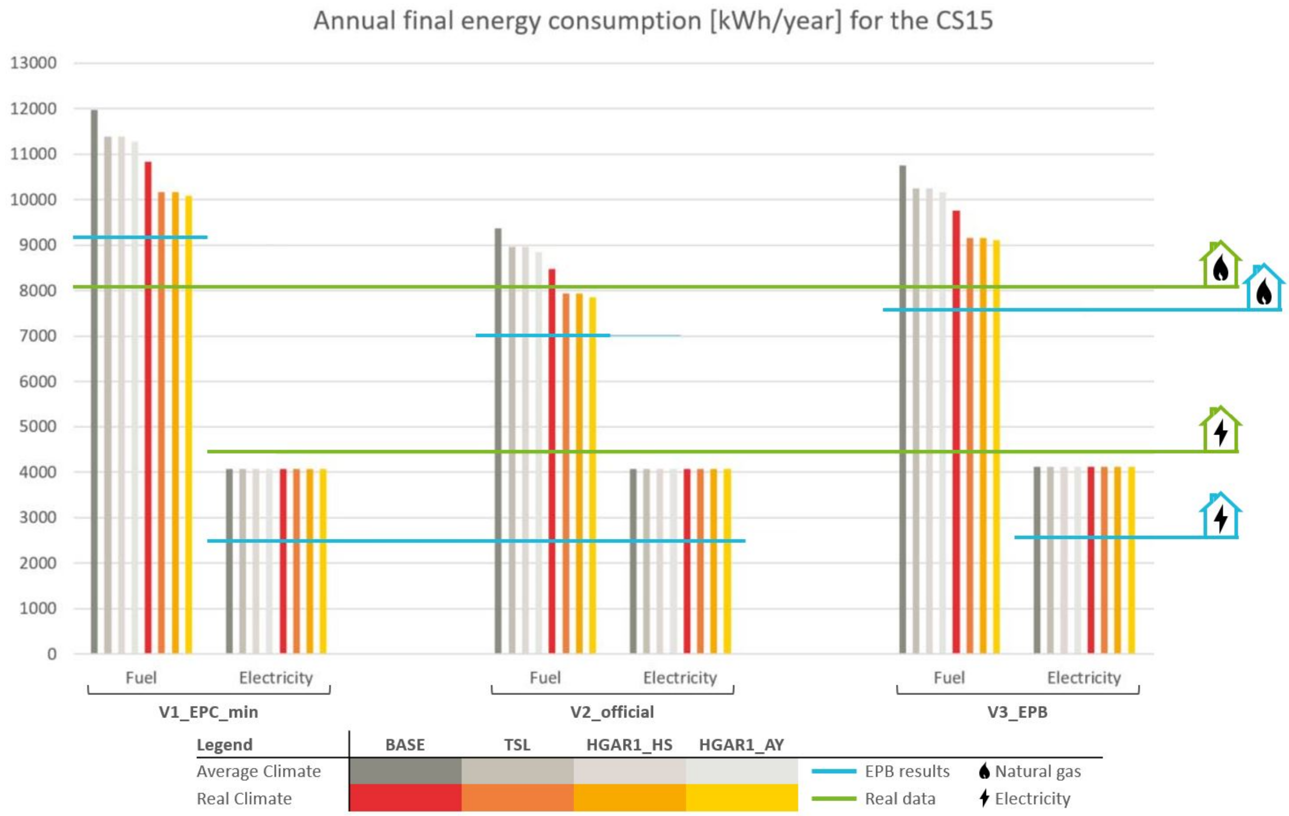


Fig. 5.2.99. Results of revaluated energy consumptions for the three variants of the CS15, for different steps in the method

For the first time, all revaluations of natural gas final consumption are above the standardised EPC results, which seem quite accurate in their prediction of consumptions. The same kind of observation could have been made of the CS8 results, although in that case, the lower set temperatures (19.3°C during the day, 16°C during the night) revaluated most consumptions under the EPC standardised results. This CS15 shares another common point with the CS8: the results of the second variant are revaluated too low, mainly due to the lower $H_{T,heat}$ coefficient, whereas the first and third variants are very similar. The proximity of the results for the V1 and the V3 can be explained by the heat losses due to constructive nodes and thermal bridges in V3, which make the total nearly equal to the heat losses from the first variant's "less precise" description of the envelope. The slightly detrimental default conductivity coefficients for insulation materials compensate the imperfect insulation. This is once again specific to high-performance buildings; the conductivity coefficients are "detrimental", when compared to the new types available today on the market, to integrate the fact that in old buildings, the insulation is often old itself, and in less efficient condition. Whatever the reason attributed to these added heat losses, however, they seem to be accurate.

The differences between the systems' efficiencies in both method (EPC and EPB) redistribute the heating and DHW consumptions; the lower DHW installation's efficiency only results in an increase of 100kWh in consumption for the third variant (considering the solar fraction of the production), whereas the higher heating efficiency explains a decrease in consumption of more than 1,000kWh, compared to the first variant. As in the CS8, the third variant is here chosen to show the repartition of the revaluated consumptions:

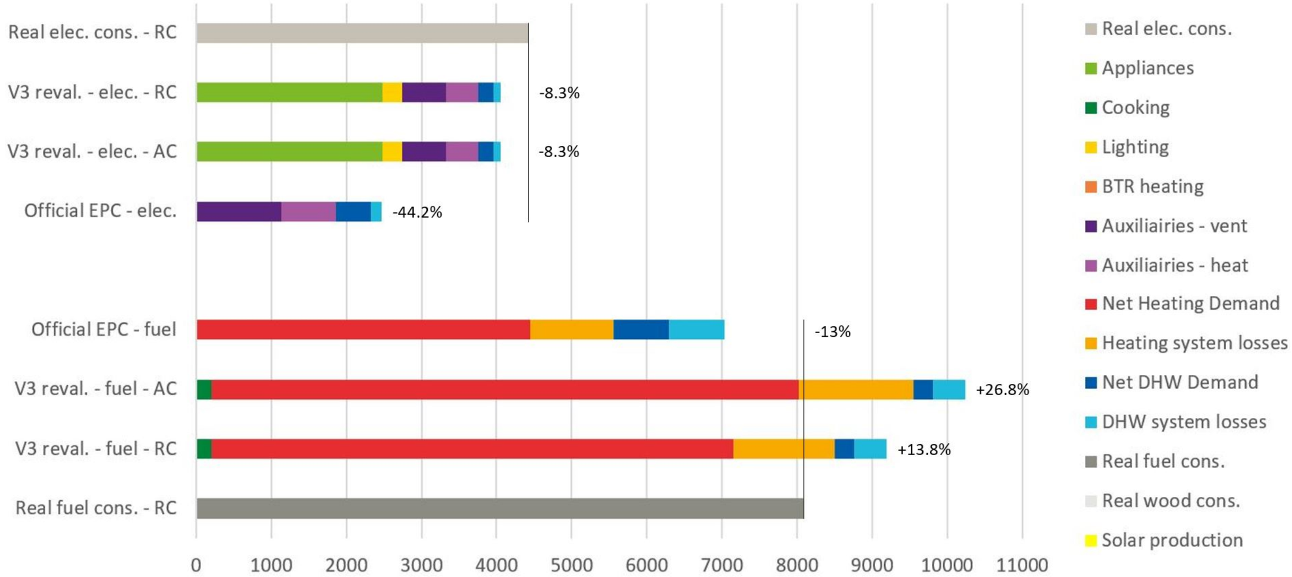


Fig. 5.2.100. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS15

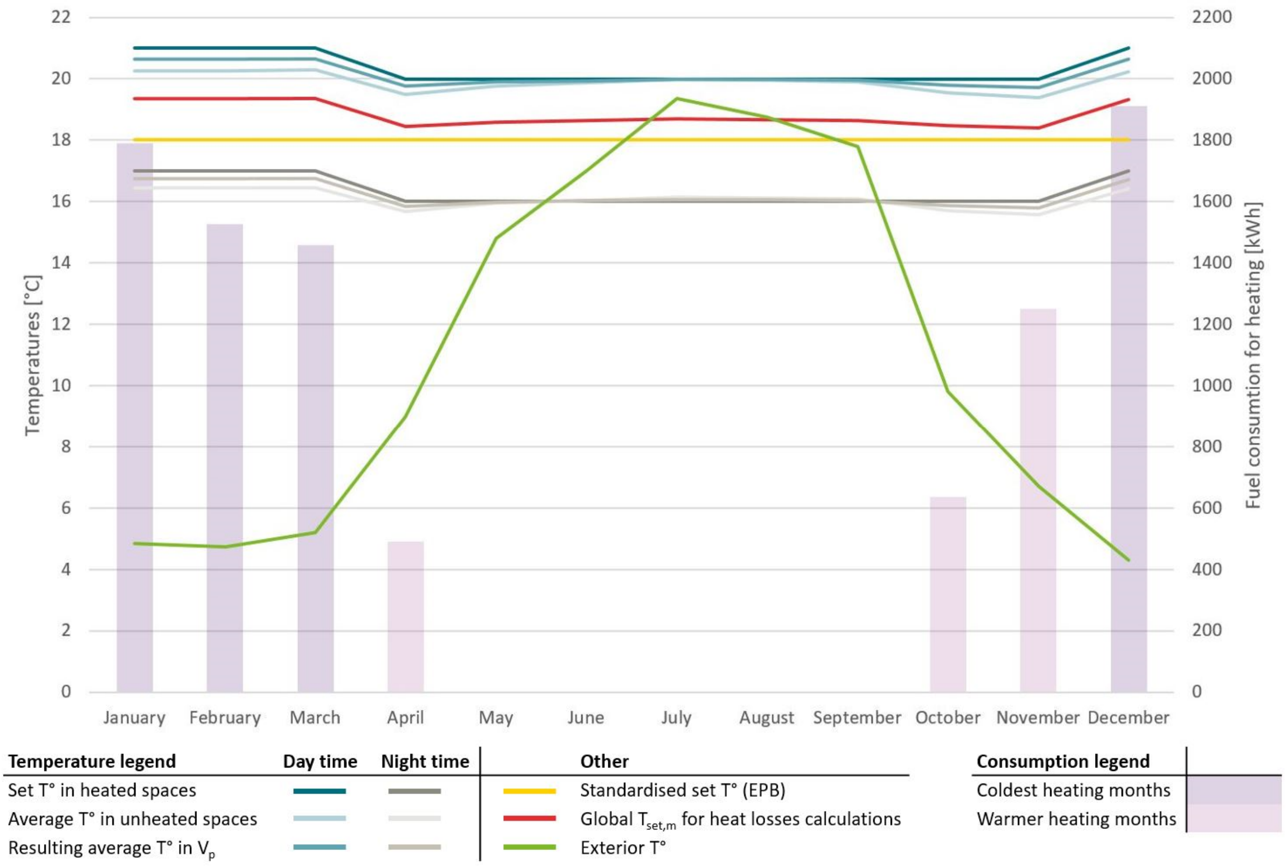


Fig. 5.2.101. CS15: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

The DHW part of the consumptions needs a little explanation. This house being quite big, the EPB standardised method tends to overestimate the DHW needs of this two-members household by more than 100% (those 2,302kWh have been revaluated at 1,017kWh, annually). The solar fraction is also slightly different: around 60% for the EPC, and 67% for the EPB method which parameters were used in this V3 revaluation. The data on solar energy production for that year could not be given by the owners, so that no comparison of results is possible in this case. The EPC evaluates the annual production to 1,689kWh, the EPB method to 1,486kWh, and the revaluations between 961kWh and 1,081kWh per year.

The temperature curves in Figure 5.2.101 above are quite similar to those displayed in Figure 5.2.52 for the CS8. In this case, the f_{pct} factor introducing the influence of the envelope performance in the evaluation of the resulting temperature in unheated spaces is the lowest of the sample at 0.214, and is yet reduced by the $f_{\Delta T,uhs}$ factor of 0.9 (see section 4.3.3.3) considering that the owners are not used to close the doors between heated and unheated spaces. The ΔT between both space categories is therefore supposed to be quite low.

5.2.16 Case Study 16 – CS16

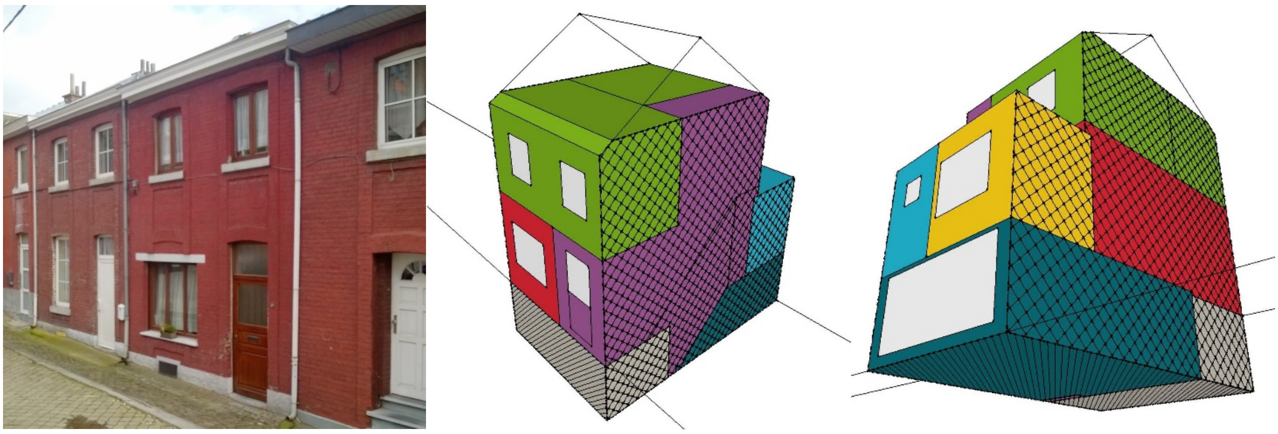


Fig. 5.2.102. CS16 – **Left**: street facade; **centre**: high-angle shot of the SW (shared) and NW (street) facades; **right**: high-angle shot of the NE (shared) and SE (garden) facades

The sixteenth and final case study has been chosen for two particularities under-represented in this sample: the size of its household (it is owned and occupied by a single woman who lives alone) and its typology of "blue-collar" brick house (only represented by the CS6 so far), characterised by small sizes and volumes, poor quality and energy performances. This house is composed of three levels, the lower two being extended in a more recent (but not of better quality) extension at the back. As often in this kind of typology, the bathroom is on street level, in the extension. Two bedrooms compose the upper level, covered by a flat ceiling under the tilted roof. On the lower level, the owner had installed an artist studio, at garden level, and a basement completes the volume. This basement, in grey in Figure 5.2.102 (centre and right), which contains the boiler that provides heat and DHW to the dwelling, is the subject of the variants definition for this case study, as there are few other aspects of its performances (related to the envelope or the systems) that could be debated.

The inclusion of this basement in the V_P is honestly debatable: it could be expected that different assessors reach different conclusions. The boiler cannot be considered as an emitter, therefore the basement cannot be considered "directly heated", however important the boiler losses are to its direct environment. It is accessible from the studio, through a simple and uninsulated door. Nothing in the room could be qualified as an "intention to insulate", so that as there are no tangible reasons to include the room in the V_P; the protocol flowchart recommends that the assessors, "in case of a doubt, exclude the room from the protected volume". The "official" EPC, labelled "official_RedVp" (for Reduced protected volume), therefore excludes the basement, whereas it is included in the second one, labelled "IncVp" (for Increased V_P).

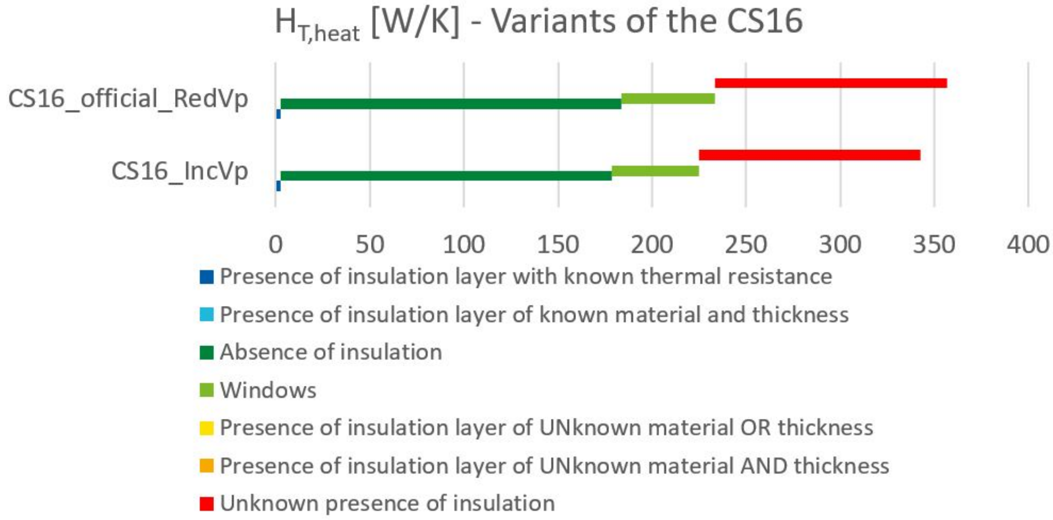


Fig. 5.2.103. Repartition of the $H_{T,heat}$ coefficient [W/K] for the two variants of the CS16

The repartition displayed in Figure 5.2.103 suggests that the reduction of the protected volume increased its heat losses. There are very few insulated surfaces in the building, as far as the owner is aware. The (very small, in dark blue) share of heat losses due to the known thermal resistance of "insulation layer" refers to 2.4m² of newly installed glazing, which U-value of 1.1W/m²K could be proven by the owner. Other variations between both variants' coefficients are explained simply:

- The first variant, with 331m³ of protected volume excluding the boiler room, includes the wall separating the boiler room from the artist studio, its door and the basement ceiling. The resulting average U-value is evaluated at 1.9W/m²K; the specific annual primary energy consumption, at 388kWh/m².year, labels this house "E".
- The second variant, with 361m³ of V_P including the boiler room, replaces those heat loss surfaces by the wall against the ground, and a greater surface of on-ground floor. The total heat loss area stays the same at 192.44m², the lateral walls not being accounted for, given that they are against a – supposedly – heated neighbouring space. The average U-value for this variant is close to the first one, at 1.87W/m²K. The EPC label is kept to "E" by the specific annual primary energy consumption indicator evaluated at 344kWh/m².year.

The boiler is connected to the urban network of natural gas supply, and provides heat to the dwelling with a hypothetical global efficiency of 64 to 68%, depending on the variant, considering:

- Production: 80% (default efficiency for a variable temperature boiler installed after 1990) for the first variant that considers the boiler out of the V_P. For the variant that includes the boiler room, that efficiency is increased to 81%;
- Distribution: 95% if the boiler is to be considered out of the V_P, 100% if it is included in;
- Storage: 100% (no storage);
- Emission: 84% (no differences between variants, as the boiler is not an emitter);
- Solar fraction: 0% (no thermal solar installation).

No other heater, of any kind, is used in this case study. The variable temperature boiler, however, also provides the DHW, with a global efficiency of 47%, considering:

- Production: 75% (default for instantaneous supply of DHW, coupled to heat production);
- Distribution: 62%;
- Circulation loop: 100% (absent);
- Solar fraction: 0% (no solar thermal installation).

The owner, Mrs P., has been out of work for some times now due to her health, and spends her days either in her home, notably in the studio she declared heating and using 2 to 3 hours a day, or outside of the house, helping local associations. Her answers to the interview showed a thrifty behaviour, exemplified by the heating pattern visible in Figure 5.2.104 below. Mrs P. only heats the necessary rooms at a low 19°C. The bathroom, being on the first floor and sheltering the only toilet of the house, is heated like the living room or the kitchen. The main bedroom is heated in the mornings and the evenings, to "cut the chill" before or after bedtime. The bad quality of the house require Mrs P. to maintain a temperature setback for the night, at the lowest temperature of the sample, 14°C. This settings were, to her words, used to be 1°C higher, a few years before; when asked why she lowered them, her answer was "*for environmental reasons. Economic, too, but mainly environmental.*" Mrs P. is also the only respondent of the sample to express such conviction at nearly all Rational Use of Energy questions, scoring an impressive 4.8 out of 5.

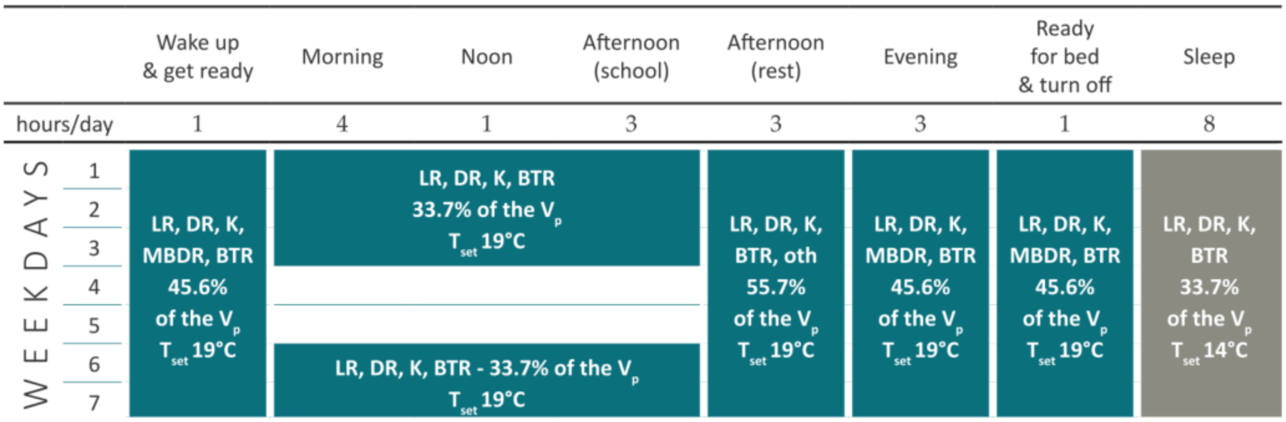


Fig. 5.2.104. Heating pattern of the CS16, according to the owner's answers to the questionnaire.

In terms of ventilation, Mrs P. mentioned some daily opening of windows, mainly in the bedroom. The bathroom is occasionally ventilated after showers, although when it is really cold, Mrs P. just opens the bathroom door to benefit from the added heat due to the hot water. The kitchen is not equipped with any extractor hood, and is open on the living room. Mrs P. mentioned opening the windows from times to times. The resulting air change rate is low: 1.8m³/h on average. Such a low ventilation rate can only mean that the air tightness of the house is quite bad, supplying therefore the necessary fresh air to the dwelling, which has been confirmed by Mrs P. who mentioned air draughts around the door, the kitchen and bathroom windows… The default value of 12m³/h.m² is kept for the $\dot{v}_{50,heat}$ coefficient of Equation (15).

The first observation is the very low electricity consumption (1,169kWh) declared by Mrs P. who does not have any television, dishwasher or electric dryer, another example of her thrifty behaviour. All revaluations of electricity consumptions were overestimated by 40 to 47%, which finally led to the final calibration mentioned before. These electricity consumptions being partly transformed or used into internal gains, the impact of those overestimations had to be toned down.

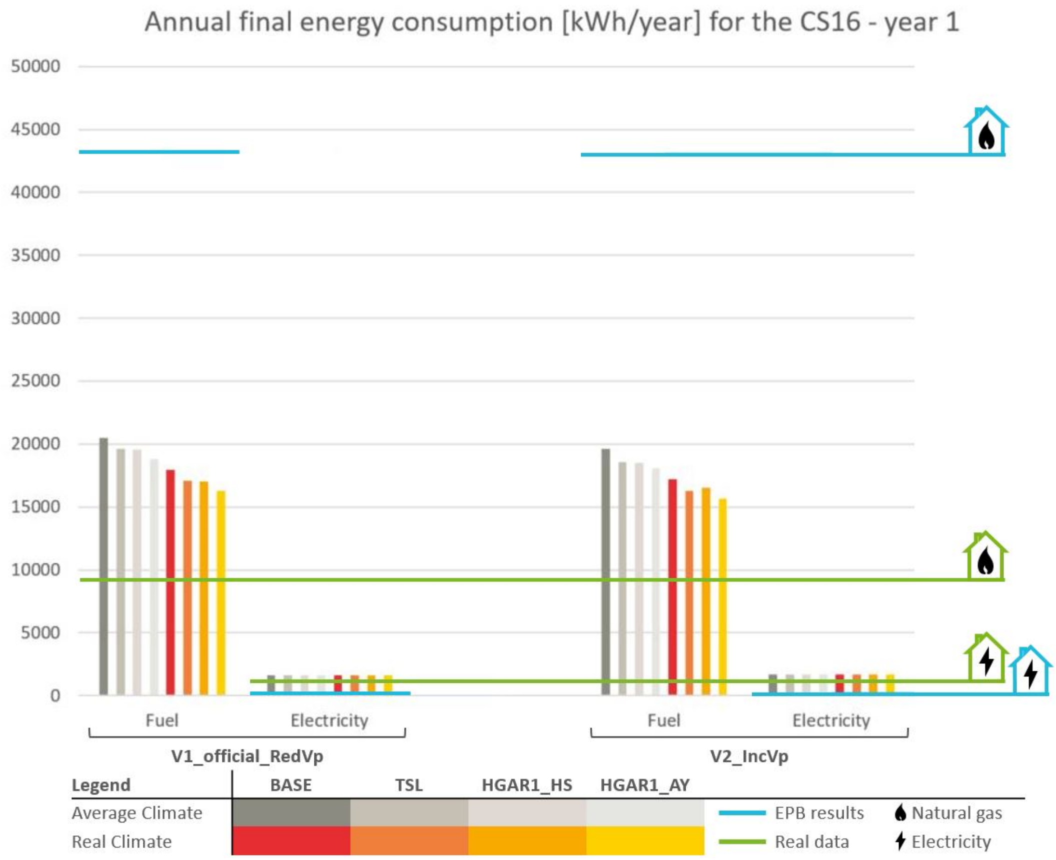


Fig. 5.2.105. Results of revaluated energy consumptions for the two variants of the CS16, for different steps in the method and the first climatic year.

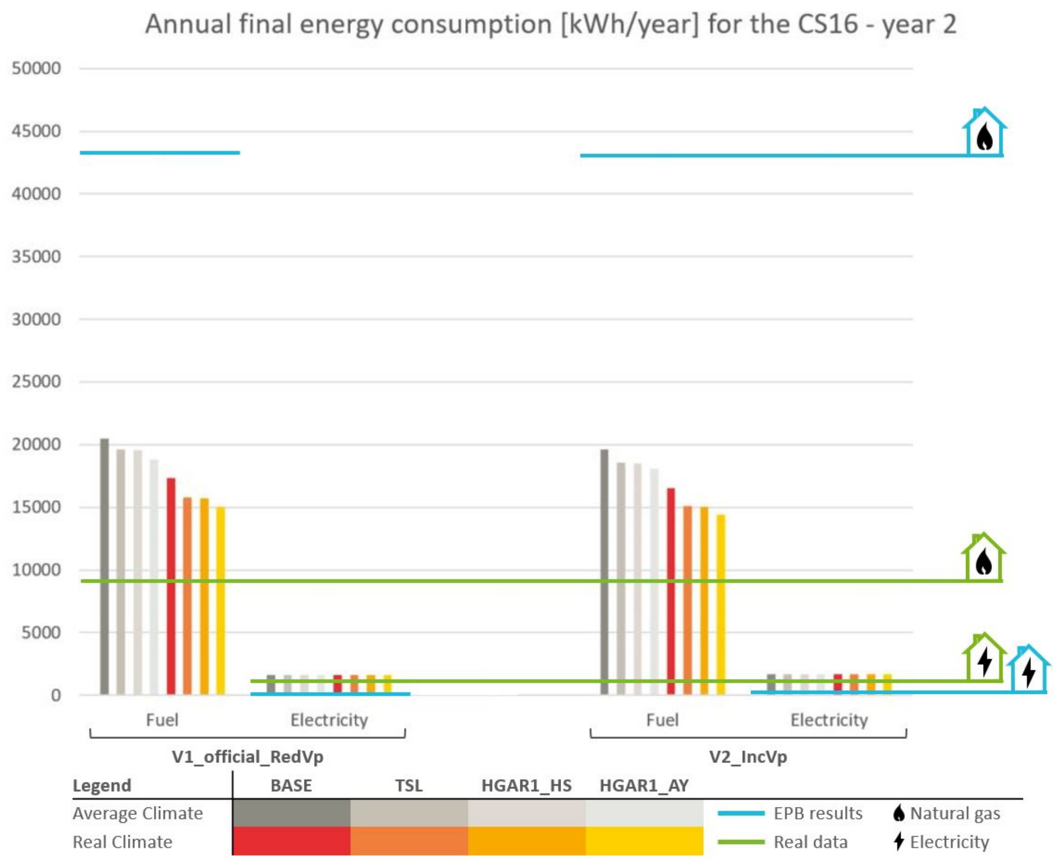


Fig. 5.2.106. Results of revaluated energy consumptions for the two variants of the CS16, for different steps in the method and the second climatic year.

The second observation is that all results, from the standardised or modified calculation methods, are quite similar between both variants. The second variant's EPC results are evaluated 0.5% below the first in final natural gas consumption. The difference is a little bit more marked between the revaluations of the modified method, with the second variant's revaluations 4.4% below the first variant's results in average. However, the lowest revaluations (real climate, HGAR1_AY) are still 69.3% to 76.4% above the real consumption data. Those results are a little bit better for the second year of real data consumption given by Mrs P., visible in Figure 5.2.106, where the lowest revaluations are 58.9% to 65.6% above the real data.

Reasons for those gaps are many, and it seems now quite normal to suspect the detrimental default values that can still be found in the description of the energy system. Following the example of the CS3 and CS12, the presence of hidden insulation could be suspected in the ceiling of the bedrooms, for example, or in the small portion of tilted roof that envelops the V_P. There was, in this case study, no possibility to replace the uncertainty in the definition of the $H_{T,heat}$ coefficient, by a certainty. No opening in the bedrooms' ceilings allowed to eye-witness the presence of insulation, and the owner seemed quite affirmative that there was none. There were no possibility, either, to determine whether part of these gaps might be explained by more accurate values for the systems' efficiencies, also dominated by default values. Another possibility to explain this overestimation could be found in the definition of the heating pattern. Her particularly thrifty behaviour could be seen as a "voluntary" fuel poverty, and is likely to be translated into shorter periods of heating, for example.

The Figure 5.2.107 hereunder displays the repartition of consumptions for the second variant and both consumption periods given by the owner. The first period, with 1,683 degree-days 15/15, was slightly colder than the second, with 1,639 DD15/15 (-2.6%). The revaluations follow that logic, and even amplifies it a little, according to those results. As far as the climate is concerned, if the exterior temperature has an important influence on the results, it must be reminded that the use of real insolation data (unavailable for the local climatic stations consulted here) could partly explain those additional discrepancies, given the glazed area in the workshop, for example. Her particular will to gain as much solar gains as possible is, to her own words, "*often enough to avoid heating the studio when I work there. I heat it one day a week, on laundry day, to avoid getting humidity problems, but other than that… it depends.*" The default EPC solar gains were maintained in this modified method and used in both periods revaluations.

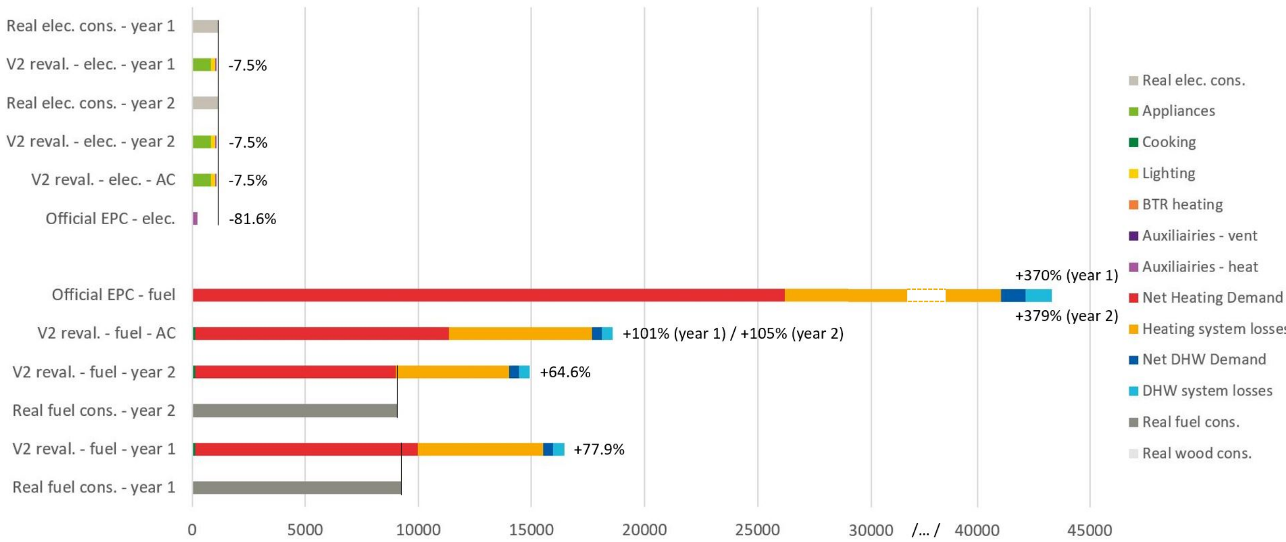


Fig. 5.2.107. Repartition of revaluated final energy consumptions [kWh/year] for the chosen variants of the CS16

The last calibration operated on electricity consumptions is visible in Figure 5.2.107, as those results now display a slight underestimation (-7.5%) where all revaluations overestimated the electricity consumptions by 40% before the calibration. This case study in particular was useful in defining consumptions for low levels of equipment, although the use of natural gas for cooking is responsible for this remaining 7.5% discrepancy: as most houses used electricity for cooking, the related consumption was included in the calibration process, but excluded from this case study's total.

The Domestic Hot Water production has also been reduced in the revaluations, due to the small size of the household and the owner's thrifty behaviour that also applied to water consumption. The main natural gas consumption end-use rightfully remains the heating of the dwelling. The real data given by the owner is equal to the NHD revaluations alone, which indicate their overestimation. As in previous cases, it is suspected that the heat losses of the buildings are still overestimated by the detrimental default values that dominate its description. The temperature curves in Figure 5.2.107 hereunder tend to confirm this: few other case studies displayed such important gaps in temperature between heated and unheated spaces, and this is due to the combination of high f_{pct} and $f_{\Delta T,uhs}$ factors, respectively equal to 1.01 and 1.2. In January, with an average 5°C outside, the temperature should drop to 14°C in unheated spaces during the day, and just above 10°C during the night, which still seems too low. As in CS12, a lower $H_{T,heat}$ coefficient would admittedly increase the temperature in unheated spaces, and is believed to lower the global consumption nevertheless. It is important to acknowledge also that the low temperature settings during the coldest heating months displayed by the same Figure (19°C during the day and 14°C at night) also partly explain the low level of the global revaluated $T_{set,m}$ (red curve).

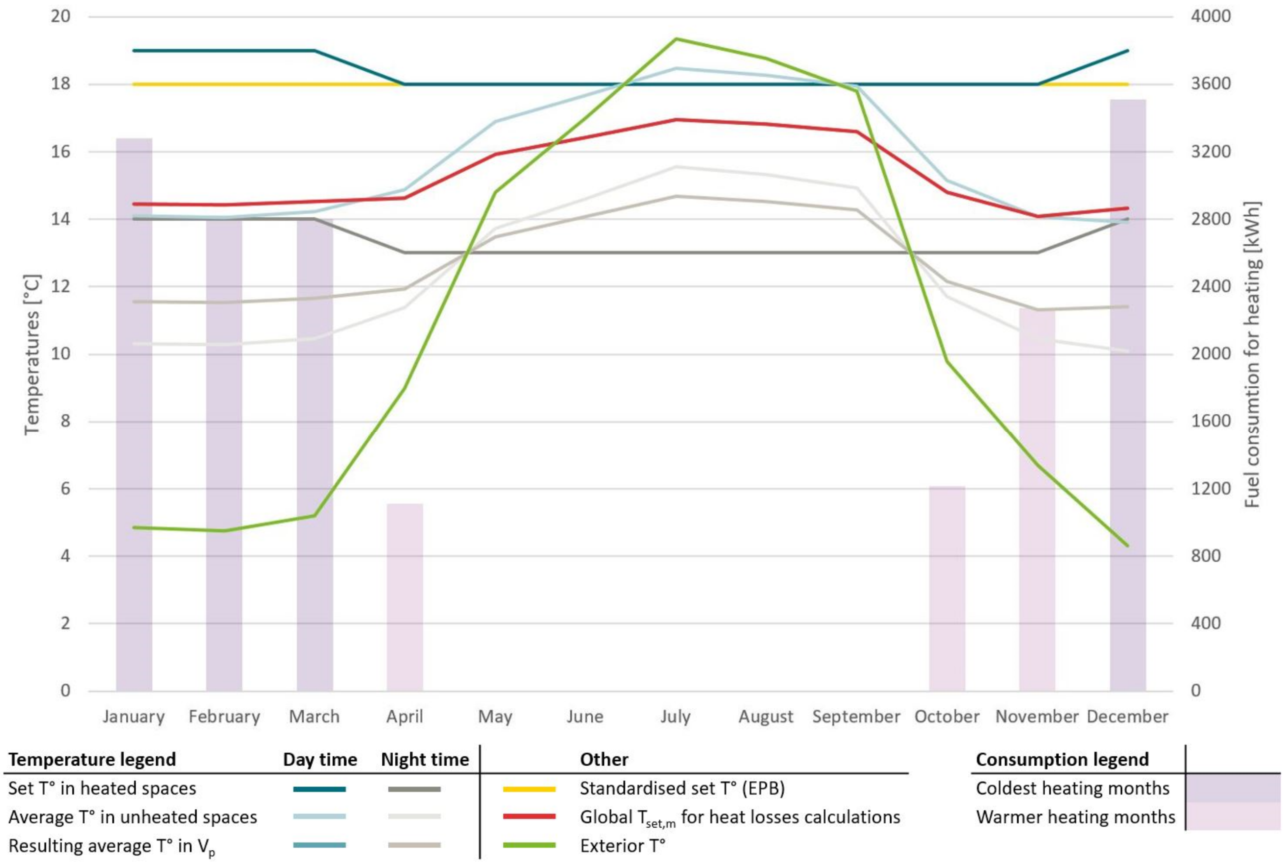


Fig. 5.2.108. CS16: Evolution of the real climatic data and internal temperatures evaluated for the calculation of the heat losses; evolution of the revaluated consumption for heating.

Chapter 6: Sensitivity Analysis

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6.1 Overview of the results

Chapter 5 presented the results separately for each case study in order to analyse their dynamics for each particular definition of variants. Preliminary results have proven that, in all cases, closest revaluations to the real data were obtained by the "HGAR1-AY" step, which considers the full modification of the method, including the use of the ΔT_{tset} factor (see Equation (9), chapter 4.3.3.3), the value of 1 imposed on the Heat Gain Application Rate (HGAR) during the whole heating period, and the final calibration of the electricity consumptions. This first section of chapter 6 will present an overview of those final results for the whole sample which will serve as a comparison point for the sensitivity analysis that will follow.

The first two graphs below (Figures 6.1.1 for the simulations under average climatic conditions, and 6.1.2 for those under real exterior temperatures) present the results of total (= natural gas + wood + electricity + thermal solar production if applicable) final energy consumption for all the case studies. All results are presented in the following order:

- First, the grey columns show the final energy consumptions results in kWh/year from the EPC regulatory and standardised calculation method. Results of the official EPC are always presented and, where necessary, a second grey column displays the results from the EPC of the chosen variant described in section 5.2, if different from the official one, marking the "improvement" that could be obtained by considering a higher accuracy in the description of the energy systems (envelope or systems), protected volume or energy sectors.

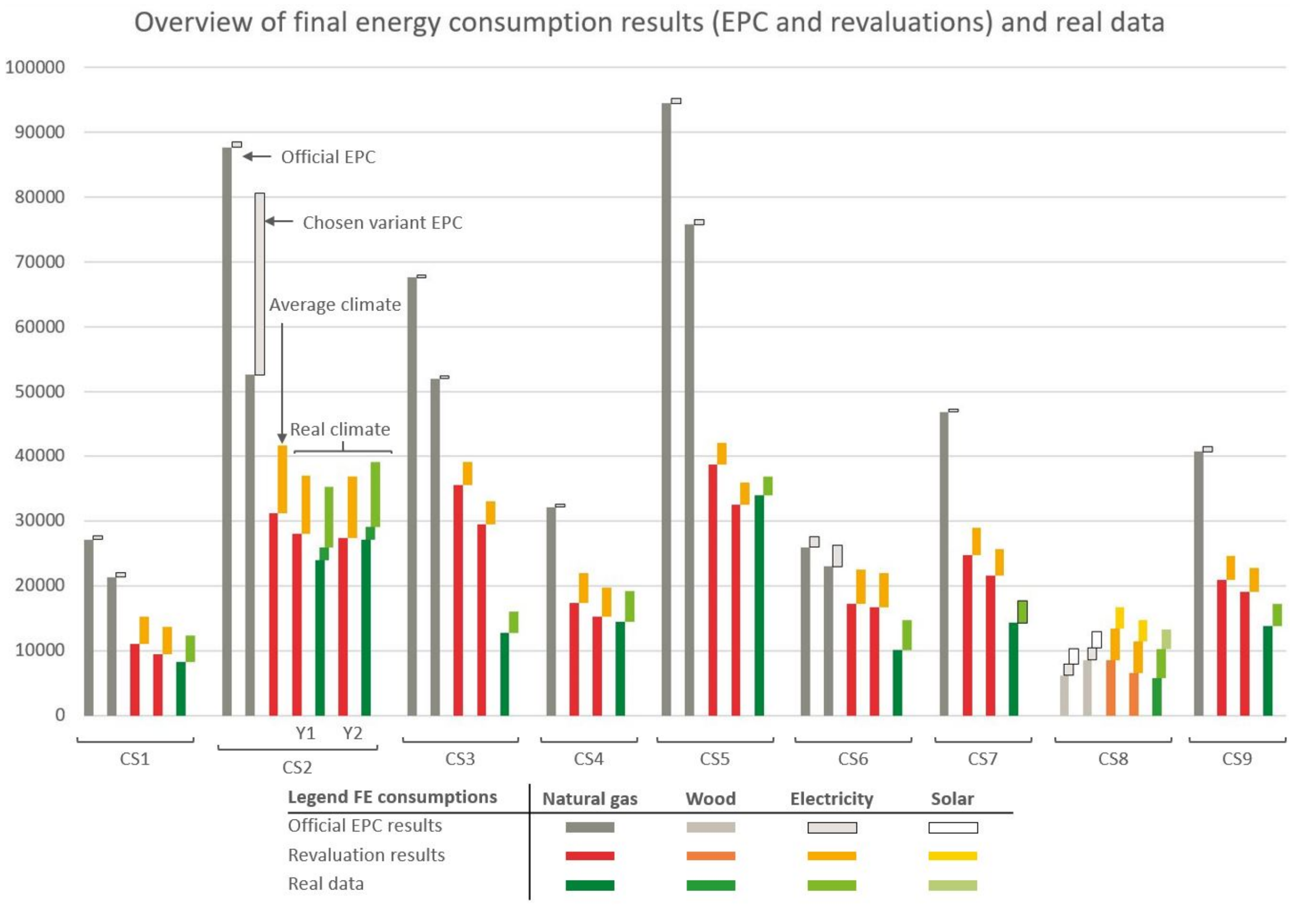

Fig. 6.1.1. Overview of the final energy consumption results for the chosen variants of the CS1 to CS9: official EPC results, revaluation results and real consumption data, by energy vectors

- Second, the results of the revaluations made with the modified method presented in chapters 4 and 5 are displayed by the columns in red, orange and yellow (each colour displaying a different energy vector). The first of those columns shows the results of the revaluations that used the average climate, the following one(s) display the results of revaluations using the real climate data.
- Lastly, the green columns show the real consumption data given by the case studies' owners, here also differentiated by energy vectors.

The reduction of the gap between the theoretical consumptions delivered by the official EPC and the real consumption data is undeniable and can even be considered encouragingly accurate in several cases (CS1, 2, 4, 5, 8, 10, 11, 14, 15). It is also undeniable that, in some cases, gaps are still of significant importance: CS3 and CS12, mainly; CS6, 7, 13 and 16, then CS9 or 10to a lesser degree.

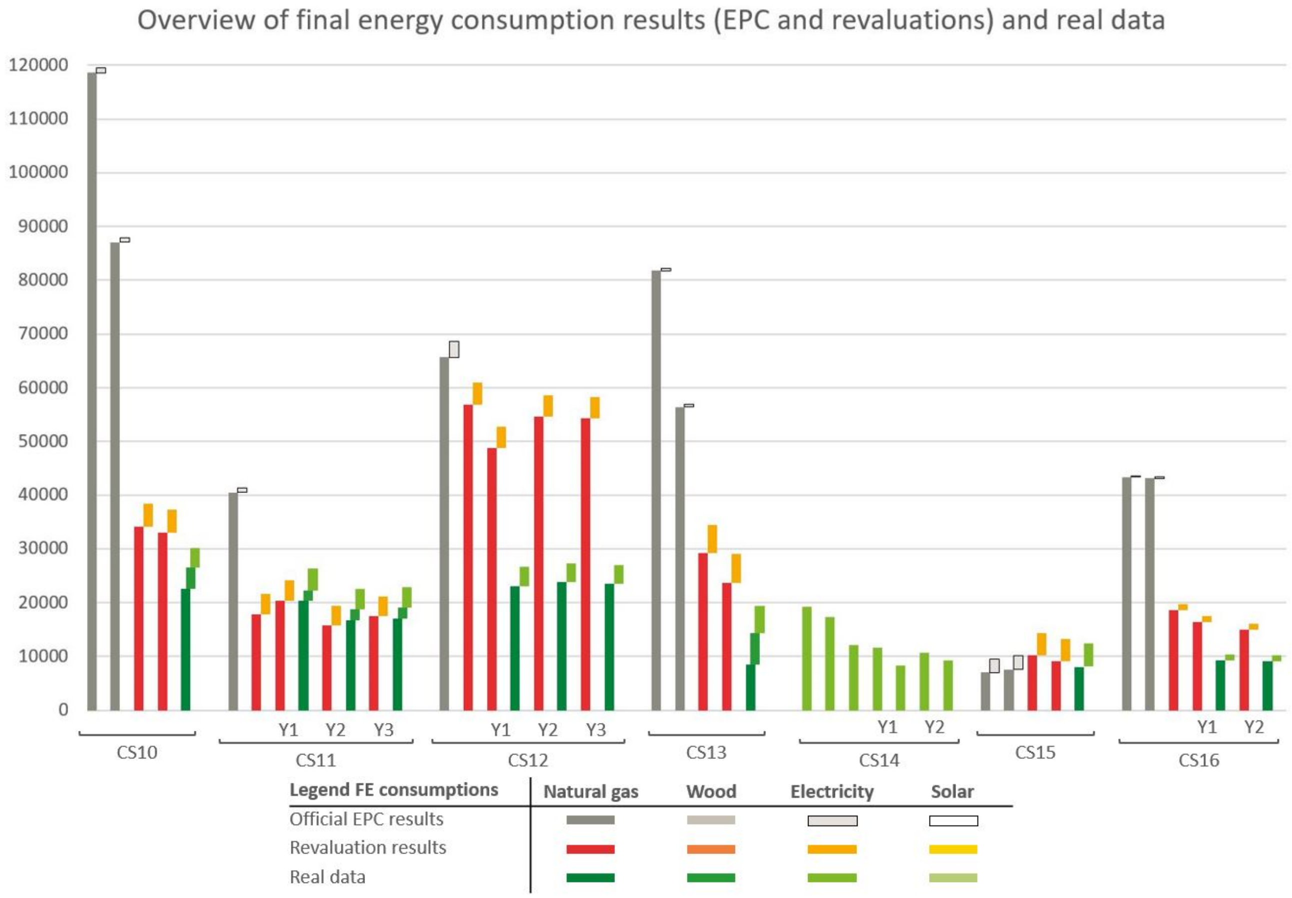

Fig. 6.1.2. Overview of the final energy consumption results for the chosen variants of the CS10 to CS16: official EPC results, revaluation results and real consumption data, by energy vectors

The definition of the case studies' variants had the declared objective to try and lift part of the uncertainty of the official EPC, related to the description of the protected volume (in all its definitions), before modifying the calculation method. The results from the official EPC are still important to keep as a comparison point for that reason. As stated before, it is important to keep in mind that those hypotheses on variants and reduction of set temperatures, heating periods or heat losses by transmission, defined in order to close the gap between theoretical and real results, do not seek to replace the official EPC nor its results. The use of a standardised regulatory calculation method fed by a strict protocol of data collection is necessary to allow the "unequivocal" certification of the building, not its users.

The Figure 6.1.3 below displays the ratios of the results above, when compared to the official EPC results. This ratio, an important indicator of the overestimation brought by the standardised method, is mentioned in chapter 3, introduced by B. ALLIBE[1] in his modelling of the energy consumption of the French residential sector, as the "$I_{declared}$" ratio:

$$I_{declared} = {C_{sim}}/{C_{norm}} \qquad (30)$$

where:

- C_{sim} is the calculated final energy consumption, based on the occupants' declared behaviour;
- C_{norm} is the calculated (final energy) consumption, considering the "normal" (standardised) behaviour of the thermal model (= the official EPC results, in this case).

Figure 6.1.3 shows those ratios, evaluated on the total consumption periods given by the owners:

- First, the grey columns display the ratios of the chosen variants EPC results on the official ones. A ratio equal to 1 means that the chosen variant is the official one.
- The red and orange columns show the $I_{declared}$ ratios for revaluated consumptions (of the chosen variant), first with the average climate, then with the real one. The average value of that ratio for this sample of 16 case studies is 0.69 for the revaluations made with the average climate, 0.63 for those made with real climatic data. Those ratios drop respectively to 0.57 and 0.52 if the CS8 and 15 (the highly performant buildings) are not taken into account.
- The green columns shows the ratios of the real data given by the owners, on the official ones. The average value of that ratio for this sample is 0.51, which means that the households really consumed, for the period covered, on average, half the energy expected by the official EPC. This ratio drops to 39% if the highly performant CS8 and 15 are not taken into account.

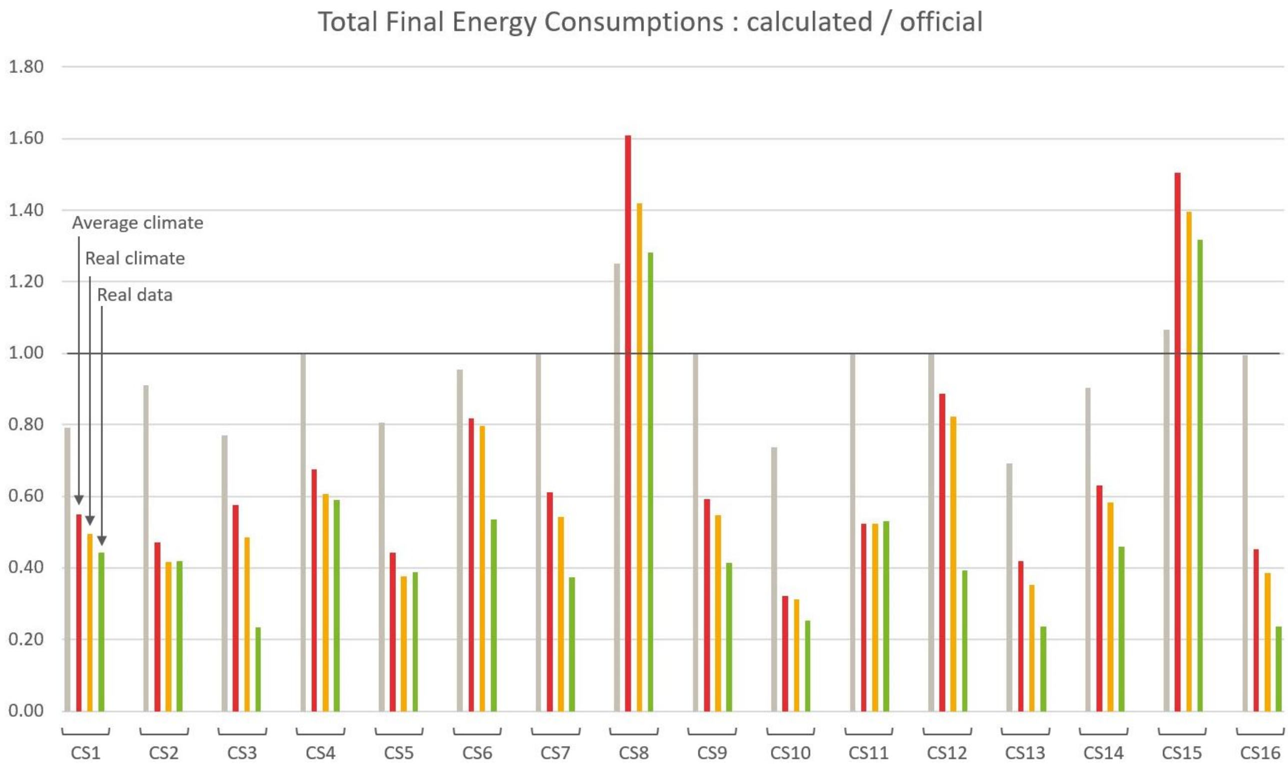

Fig. 6.1.3. Overview, for each case study and consumption period, of the $I_{declared}$ indicator (= calculated / official results of total final energy consumption)

[1] B. ALLIBE, 2012. *Ibid*

This leads to the next Figure 6.1.4, which presents the curves defined by those ratios, when they are sorted and ranked, depending on the E_{spec}, the specific annual primary energy consumption per square meter of heated floor area, main result of the official EPC. Here again, the ratios are evaluated on the final energy consumption results, and adapted to the total periods covered.

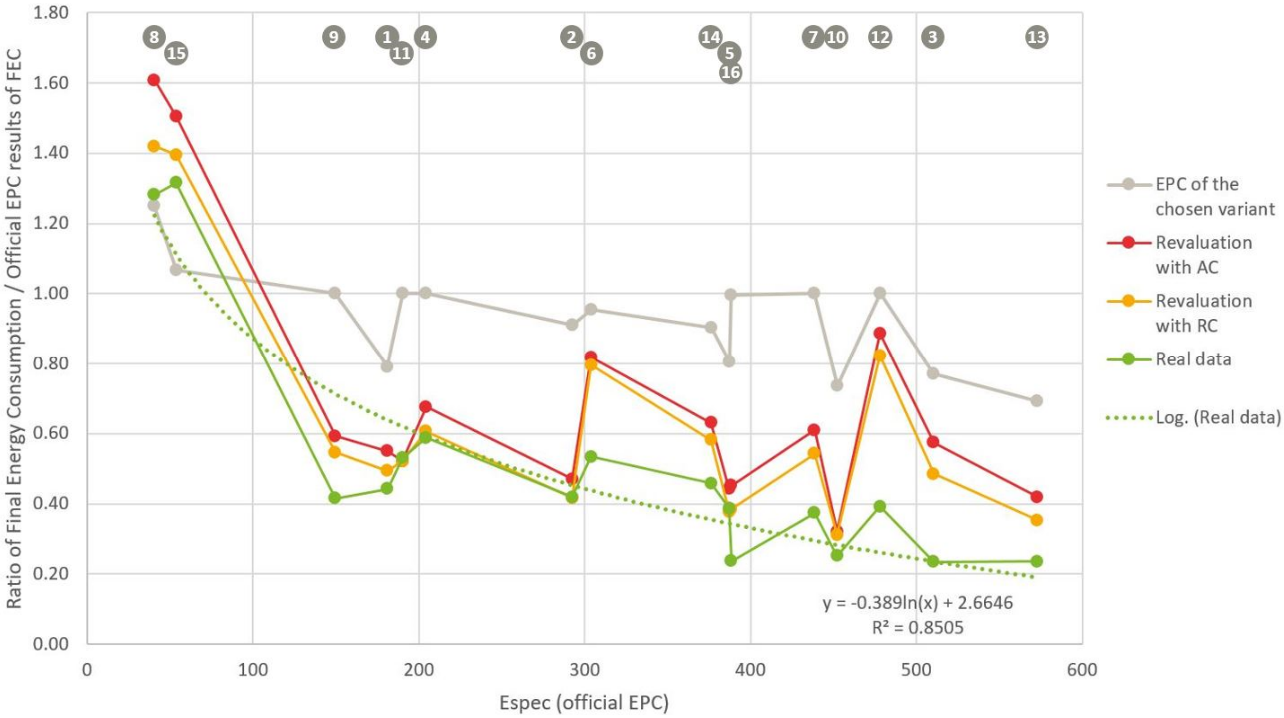

Fig. 6.1.4. Curves of the $I_{declared}$ indicator (= calculated / official results of total final energy consumption), ranked according to the official EPC result in [kWh/m².year] of primary energy consumption

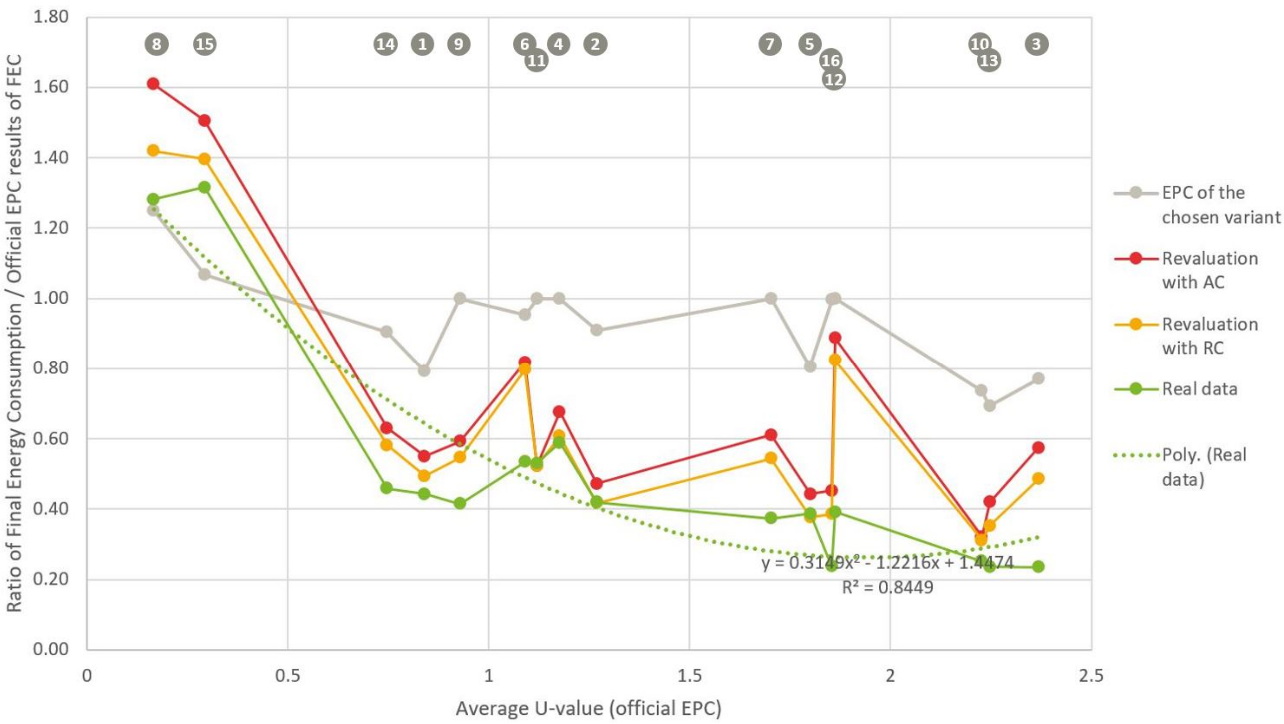

Fig. 6.1.5. Curves of the $I_{declared}$ indicator (= calculated / official results of total final energy consumption), ranked according to the average U-value from the official EPC [W/m².K]

The dotted trend curve in Figure 6.1.4 above indicates that the ratio of the real data on the official EPC results of final energy consumption is relatively well linked to the official E_{spec}. This seems like a nod to the coherence of the EPC calculation method: the overestimation of *final energy* consumption could be quite proportional to the official indicator *in primary energy*. The Figures 6.1.5 above and 6 below show that those ratios of the real data on the official EPC results of final energy consumption also show significant relationships with the average U-value [W/m²K] and the total final energy consumption [kWh/m² of heated floor area] from the official EPC. Relations have been sought with the same parameters of the variant EPC, but they showed slightly lower coefficients of determination R^2 (-0.05 on average). The difference is small enough however to consider that, globally, the real data of consumption can be accurately approached by using the results from the EPCs, official or variant. As far as the revaluations are concerned, the fact that their curve is getting closer to the "real data" curves is a comfort, although the case studies which revaluated consumptions could not be brought near the real data show visibly less accurate correlations like the one described between the real data and the official EPC results in this graph too (the CS12, for example).

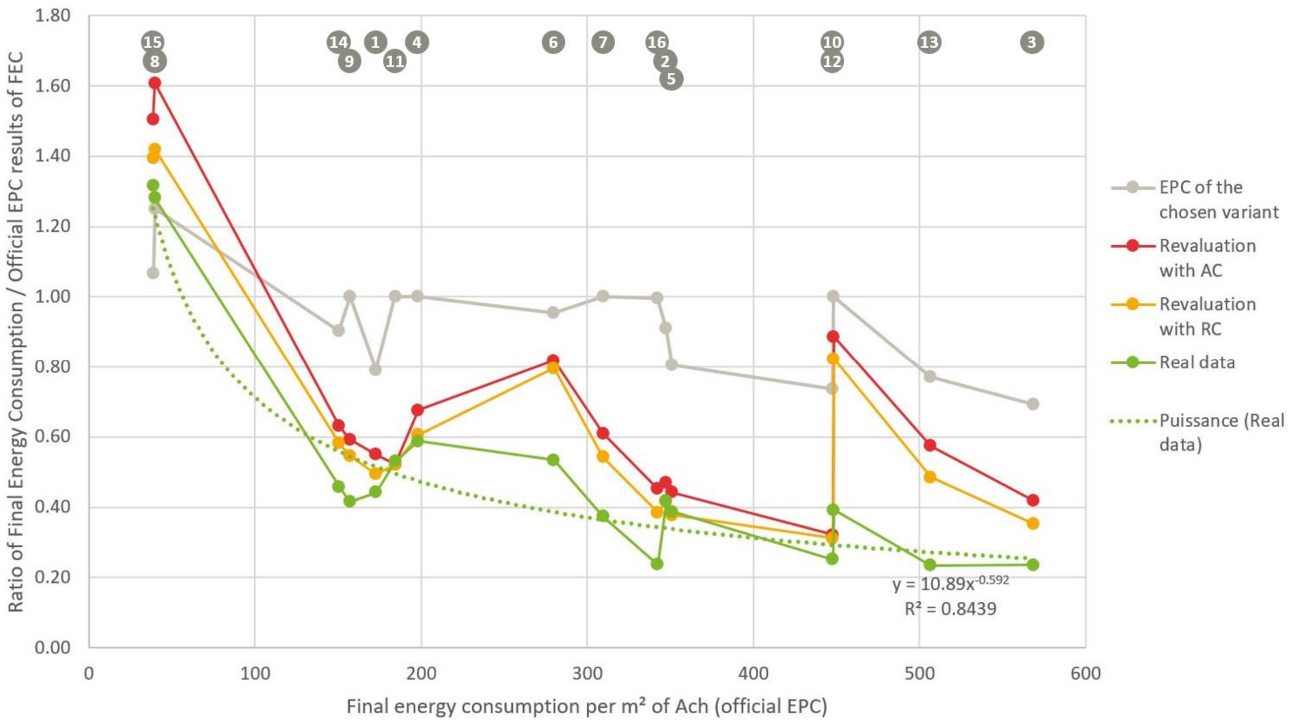

Fig. 6.1.6. Curves of the $I_{declared}$ indicator (= calculated / official results of total final energy consumption), ranked according to the total final energy consumption expected by the official EPC [kWh/m²]

The main target of this research, however, is not a comparison with the official results, but with the real data given by the owners. Benoît ALLIBE, in his research, compares the real data to the evaluated consumptions by this other ratio mentioned in chapter 3:

$$I_{obs} = {}^{C_{obs}}/_{C_{th}} \qquad (31)$$

where:

- C_{obs} is the observed consumption;
- C_{th} is the consumption calculated by a thermal model and its array of hypotheses on climate and performances (= the results of the official results as well as those of the revaluations).

From the beginning of this research, the inverse ratio has been used, labelled here "$I_{eval/obs}$":

$$I_{eval/obs} = {}^{C_{reval}}/_{C_{obs}} \qquad (32)$$

where C_{reval} is the consumption evaluated by the EPC model and its calculation method, whether regulatory and standardised (official EPC), or modified as described in chapter 4.

This indicator marks in a more direct and visual way the overestimation of the evaluated final energy consumptions, when compared to the real data. The Figure 6.1.7 below shows these ratios for the case studies, with a different display. For each period of real consumption data of case study, the sequence of ratios presented below is the same:

- First, the ratio [EPC theoretical final consumption results] / [Real data], in hollow columns;
- Second, the [Revaluated final consumption results in the average climate] / [Real data];
- Third, the [Revaluated final consumption results in the real climate] / [Real data].

The colour code used in Figure 6.1.7 has been defined early on to visualise the case studies that had reached satisfying results in the revaluation process. The first objective for an ideal acceptable gap of uncertainty on the results was defined at 10% of over- or under-estimation of the real consumption data, marked by the blue colour in the graph above. When it comes to appear satisfyingly accurate to any owner, in order for them to trust the results and use it wisely, therefore, a small margin seems necessary to achieve, and the results below indicate that it is possible for several case studies (CS1, 2, 4, 5, 8, 11, 15). The results from the chapter 5 related to the use of real climate data, and the behavioural dynamics of consumption, indicate that one might expect differences in annual real consumption greater than 10%. A second acceptable misestimating gap of 25% (green/yellow in the graph below) seems more realistic in some cases (CS10 and 14). Between 25 and 50%, the ratios are marked in yellow; in orange between 50% and 100%, and in red beyond 100% of total final energy consumption overestimation.

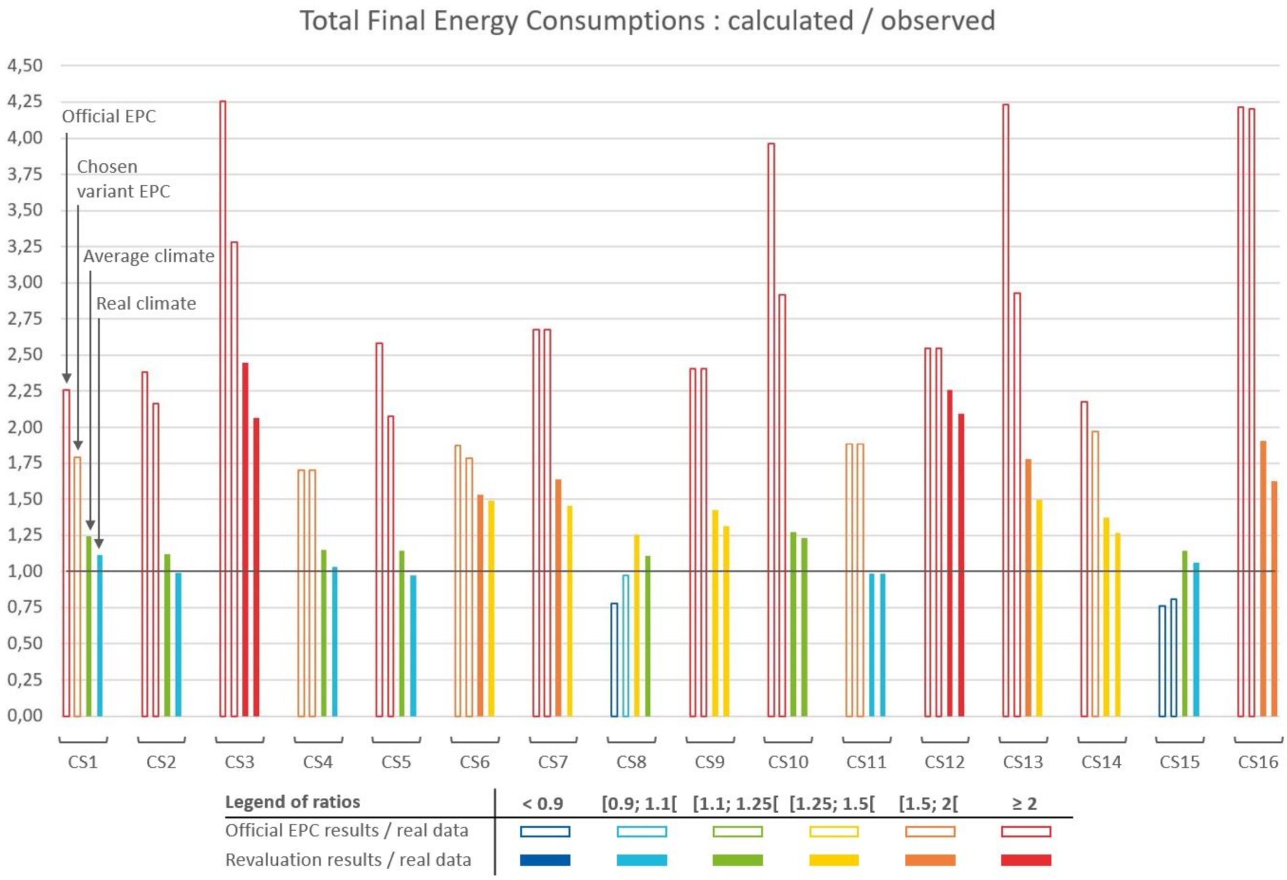

Fig. 6.1.7. Overview, for each case study and consumption period, of the ratio calculated results of total final energy consumption / real data (observed consumption)

The EPC results are translated in this graph by a forest of red, hollow columns. Some case studies are given by the regulatory method a final consumption level that is more than four times the real consumption data of the household. Only the highly efficient buildings (CS8 and 15) show a better initial result, due to the (better described) higher efficiency of their energy system.

The graph also emphasizes the remaining gaps in the revaluations of the CS3 and the CS12 (and, to a slightly lesser extent, the CS16, 6, 7, 13…). The CS3 and the CS12 share the particularities of being heated continuously. These case studies with remaining $I_{eval/obs}$ ratios superior to 1.5 are among the less insulated and efficient buildings in the sample. The Figure 6.1.8 below also shows that there is an interesting relation between the $I_{eval/obs}$ indicator described here and the E_{spec} indicator, result of the official EPC, despite a lower determination coefficient.

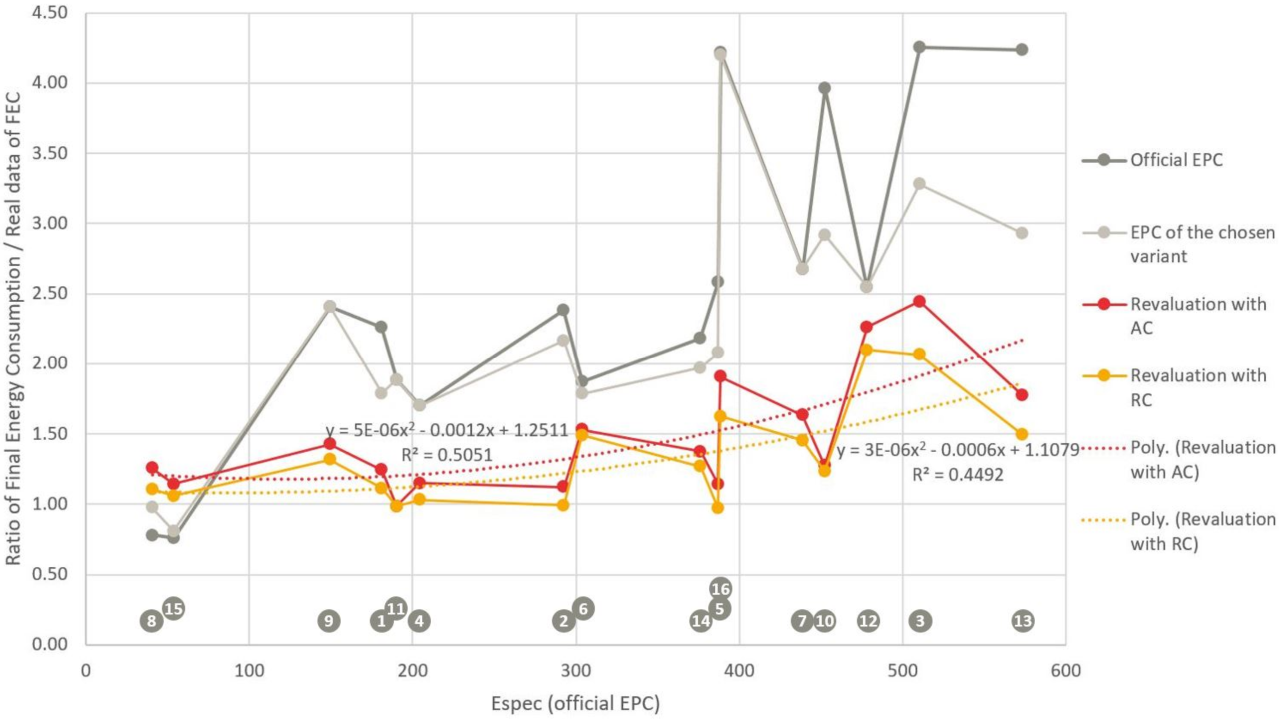

Fig. 6.1.8. Curves of the $I_{eval/obs}$ indicator (= calculated results of total final energy consumption / real data of observed consumption), ranked according to the official Espec result in [kWh/m².year] of primary energy consumption

In the search for correlations, the higher determination coefficient was found between the ratio of the revaluated final energy consumption on the real data, and the average U-value of the chosen variant, displayed in the Figure 6.1.9. Contrary to the observations on the $I_{declared}$ ratio, the coefficient R^2 was quite lower when ranking those ratios according to the average U-values of the official EPC (see Figure 6.1.10 below). Other rankings of those ratios, $I_{declared}$ and $I_{eval/obs}$, were attempted to deduce trend curves; relatively significant correlations exist between those ratios and, for example, the age of the building (considering the CS8 and CS15 as the newest buildings in the sample), or the $H_{T,heat}$ coefficient, but neither of those trends presented higher R^2 coefficient than those presented here.

Most of the results until now seem to indicate that the regulatory and standardised calculation method is much more accurate when it comes to assess the efficiency and predict the consumptions of high-performance dwellings. After all, this is exactly why the original EPB method has been created: to assess the energy performances of new and efficient dwellings, which globally better fits the “single-zone” and “homogeneity” implications of the standardised method than old dwellings. This proves the need to adjust the calculation method to the specificities of heating demand and management in inefficient dwellings, where the heating patterns are more complex, due to variable set temperatures in a selection of heated spaces, an intermittence in heating which cannot fit the standardised method, its hypotheses and parameters.

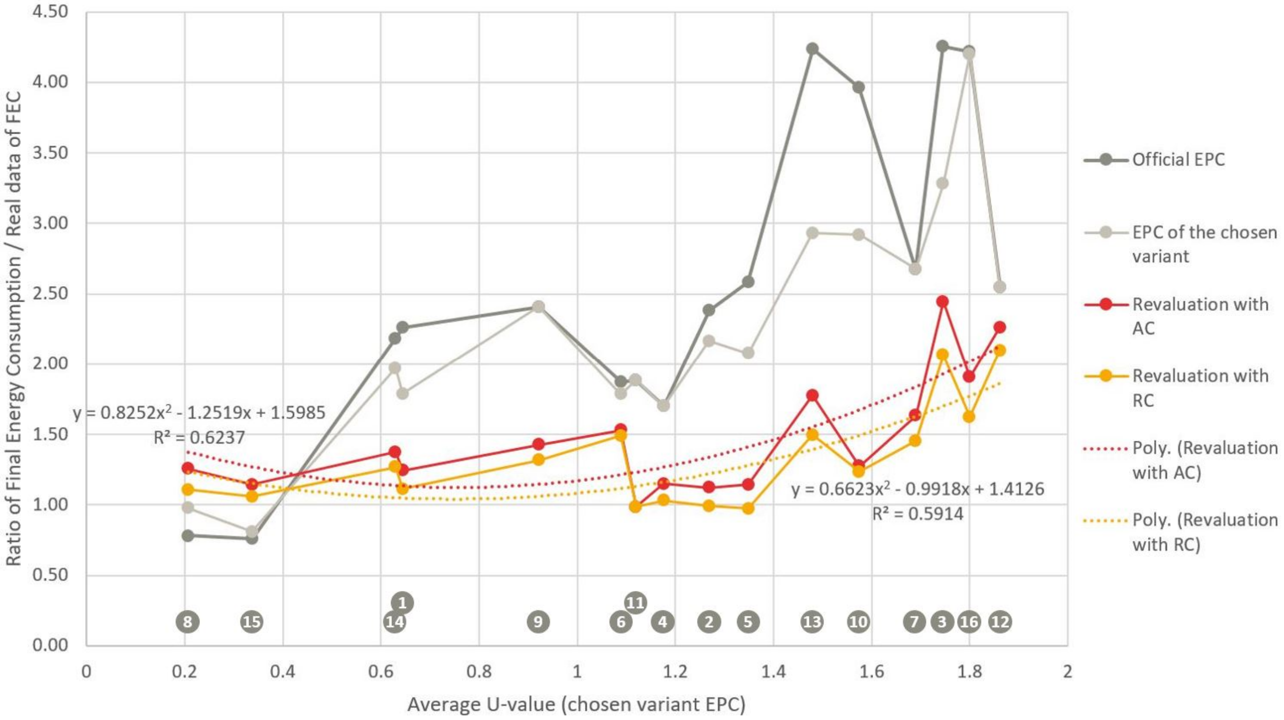

Fig. 6.1.9. Curves of the $I_{eval/obs}$ indicator (= calculated results of total final energy consumption / real data of observed consumption), ranked according to the average U-value from the chosen variant's EPC [W/m².K]

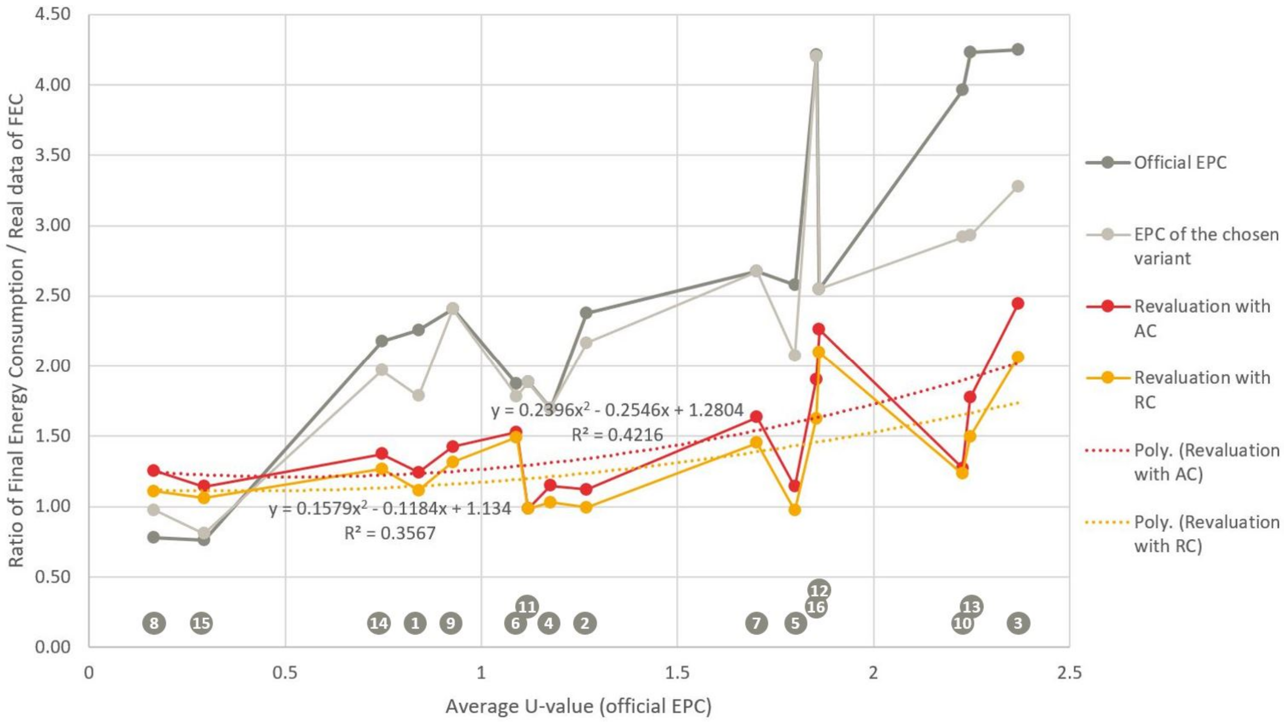

Fig. 6.1.10. Curves of the $I_{eval/obs}$ indicator (= calculated results of total final energy consumption / real data of observed consumption), ranked according to the average U-value from the official EPC [W/m².K]

6.2 Sensitivity analysis

In chapter 5, the assessment of the method has been approached for each case study separately, by the definition of variants that followed their specific coherence. This section will allow to take a step back and assess the results as a whole, by considering the parameters' influence and determine the discriminant ones. A sensitivity analysis tries to provide a comprehensive understanding of the influence of the different input parameters and their variations on the model outcomes. The objective is to identify the most significant parameters in the model, understand relationships between input parameters and outputs, test the robustness of the output, quantify uncertainty and its influence on the outcomes, and identify optimal parameter settings in the model[2]. A "global" sensitivity analysis, which "aims to evaluate the entire parameter space to determine the system's functionality"[3], is not suitable here. This section aims at analysing the influence of the newly implemented parameters in the method, not the regulatory calculation method that served as a basis for the modifications. This research will therefore be led as a "local" sensitivity analysis, implemented with a "one-factor-at-a-time" methodology that imposes all other factors to remain equal to the base set of parameters (*ceteris paribus*), when one of them is submitted to the sensitivity analysis. The "BASE" results, resumed in the first part of this chapter, include therefore the parameter translation of the owners' answers to the questionnaire.

All results in this section will be presented as a total of final energy consumptions, including all energy vectors and, in the case of the CS8, the solar production. When necessary, these results will be detailed. The electricity consumption will not be submitted to the sensitivity study *per se*, mainly because real consumption data have been used to calibrate their revaluations' calculation method. Electricity consumptions have been included in the $I_{eval/obs}$ ratio (which could have been limited to the natural gas consumptions in many cases) because some electricity consumptions are related to the partial or complete production of DHW, or to extra local space heating consumptions in many dwellings. The CS14, particularly, only consumes electricity for all end-uses.

Most revaluations have been realised considering both real and average climate data sets. Results in chapter 5 indicated that real exterior temperature data explained an important part of the remaining gaps in most case studies (without closing them). The average climate is to be used to continue the assessment of the uncertainty gap that can be attributed to these standardised data.

The first necessary observation, before the analysis in itself, is the following: the main inaccuracy in the results can be related to heating consumptions. As a result of the base hypotheses, the case studies present shares in energy consumption related to DHW that range between 3% of the total final energy consumption for the least efficient case studies (CS12), and 30 to 35% for better ones (e.g. CS1, in this case), depending on the climate. Those shares are visible in details in the repartition of consumptions graphs presented for each case study in chapter 5. The Figure 6.2.1 hereunder resumes the repartition between heating and DHW consumptions in all case studies (EPC results in grey, revaluations under different climates in red-orange).

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[2] M. Alam, V. Abedi, J. Bassaganya-Riera, K. Wendelsdorf, K. Bisset, X. Deng, S. Eubank, R. Hontecillas, S. Hoops, M. Marathe, 2016. *Computational Immunology. Models and tools. Chapter 6 – Agent-Based modeling and High Performance computing*. Academic Press, Elsevier.
[3] M. Alam, et al., 2016. *Ibid*

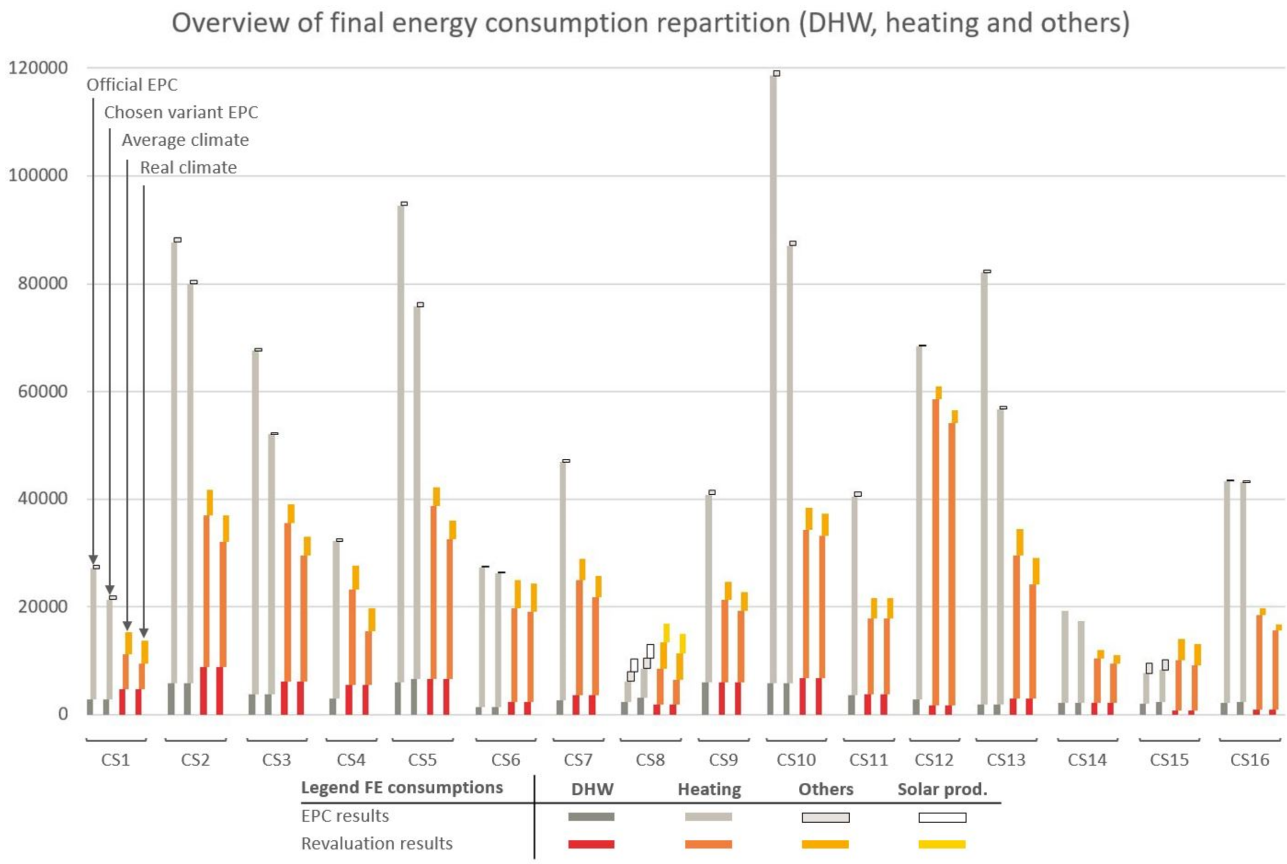

Fig. 6.2.1. Overview of the total final energy consumption evaluation results [kWh/year] for the 16 case studies, emphasizing the repartition between DHW, heating and "others" consumptions, and the solar production for CS8.

A more detailed comparison of DHW demand, evaluated under the standardised method and the modified method, can be seen in Figure 4.3.13 in section 4.3.4. In any case, the revaluations are quite close to the standardised calculations or, at least, do not seem to present variations that could explain the $I_{eval/obs}$ ratios of the CS3, 7, 12 or 16, for example. The DHW systems' efficiencies have been kept in the revaluated method for lack of more accurate information, and even though their low levels could be questioned, it is unlikely that more accurate efficiencies would reduce those case studies' ratios to 1. Heating consumptions are, besides electricity consumptions for appliances, lighting or cooking, the only other end-use revaluated in this research. Preliminary results from chapter 5 indicate quite clearly that they hide the main discrepancy on the revaluated results that cannot be explained at this point. As in DHW consumptions, the by default efficiencies characterising the heating installation, as detrimental as they may be, could not really explain the $I_{eval/obs}$ ratios either. The main "culprit" of the discrepancy, therefore, seems to be the evaluation of the net heat demand.

The sensitivity of the results to the variability of the emission, distribution, storage and production systems' efficiencies, has been realised and is visible in the Annex 3 of this thesis dissertation. It was necessary to assess their influence, the same way it has been done for all other parameters, notably because they are partly influenced by the assessor's human factor. Although the results are important, they are sensibly exterior to this research, which centres more on the definition of the net heat demands. The section 6.3 will first focus on heat gains influence, which is to be considered with more interest now that they have been increased (at least the internal gains). Solar gains are also important in this study, as they have been kept at standardised level due to a lack of available more accurate data. In section 6.4, heat losses by ventilation will be approached by the air change rates attributed to hygienic ventilation and infiltration. Section 6.5 studies the influence of heat losses by transmission. They will be first approached globally, by the $H_{T,heat}$ coefficient, which translates the direct influence of the heat loss area or the average U-value. Different accuracy determiners of the transmission heat loss coefficient, such as the description of the protected volume (precision on measurement, accuracy on inputs) or the heating pattern (time or space repartition, or set temperatures), will then be discussed. The definition of the global temperature in the house, which will be used to determine the heat losses of the global volume, is influenced by several parameters that are crucial to assess. The volumetric repartition of the heated and unheated spaces, the parametrization of the Equation (9) in section 4.3.3.3, and the basic set temperature in heated spaces, are among the most important influences on the end results. The last section of this chapter will therefore seek validation of the internal temperature calculation method that is developed in this work, by analysing two temperature monitoring campaigns that were led on CS11 and 12.

6.3 Heat gains

Heating the home to reach comfort remains the main residential energy consumption in most case studies, as evidenced by the Figure 6.2.1 above. Equation (5) in section 4.3.3.2, resumed hereunder, informs how the official calculation method estimates the NHD:

$$Q_{heat,net,m} = Q_{T,heat,m} + Q_{V,heat,m} - \eta_{util,heat,m} \times (Q_{i,m} + Q_{s,m}) \qquad (5)$$

where:

- $Q_{heat,net,m}$ = monthly NHD [MJ];
- $Q_{T,heat,m}$ = monthly heat losses due to transmission [MJ];
- $Q_{V,heat,m}$ = monthly heat losses due to airtightness and ventilation [MJ];
- $\eta_{util,heat,m}$ = monthly heat gains application rate, described in section 4.3.3.6 [-];
- $Q_{i,m}$ = monthly internal gains [MJ];
- $Q_{s,m}$ = monthly solar gains [MJ].

By considering a HGAR factor ($\eta_{util,heat,m}$, heat gains application rate) equal to 1 in all revaluations of heating consumptions, the full influence of internal and solar gains is visible on the results, whereas the official value of the ratio (≤ 1) would have lowered this impact. Equation (5) has therefore been modified into Equation (33) below. This section will enquire about the influence of each of these terms on the energy balance, and the eventual need for further precision in their definition.

$$Q_{heat,net,m} = Q_{T,heat,m} + Q_{V,heat,m} - Q_{i,m} - Q_{s,m} \qquad (33)$$

6.3.1 Internal gains

In this modified method, the internal gains are defined by the number of inhabitants (metabolic loads) and the heat gains from part of the electricity consumptions, related to the use of appliances and electr(on)ic equipment, lighting and cooking end-uses. The Figure 4.3.10 in section 4.3.3.5 shows the comparison of those global gains, estimated by both the standardised method and the modified method. As the de-standardisation process defined in chapter 4 reintroduced its influence, a change in the number of occupants would modify many parameters of the calculation method, besides the metabolic loads. One more person in the household changes also the DHW demand, the bathroom time, the cooking time, and the use of different appliances. The influence of the change in metabolic internal loads alone (as required by the "one-factor-at-a-time" methodology) would be impossible to assess. It has been decided therefore to analyse the influence of the internal gains, on the sole variation of electricity consumptions related to lighting and appliances, via 5 levels of consumption:

- Very low: minimum equipment, parsimonious lighting, high share of low-energy lightbulbs;
- Low: equipment level 2, higher lighting level with lower share of energy-saving lightbulbs;
- Average: level 3 for the equipment (more or doubled appliances), increasing lighting power;
- High: more duplicated appliances, in the kitchen or in DIY dedicated spaces. More rooms lit with less energy-saving lightbulbs;
- Very high: level 5 of equipment (e.g. CS13 with more than 10 screens). General lighting in the house, lightbulbs mainly "traditional".

The corresponding energy consumptions are visible in Figure 4.3.3 in section 4.3.2.1 for lighting, and Figure 4.3.4 in section 4.3.2.2 for the levels of equipment. Figures 6.3.1 and 2 below display, for all case studies, a visual repartition of global electricity consumptions under this part of the sensitivity analysis. These consumptions may include end-uses such as heating (extra local heaters, or complete energy sector heating as in CS2 and CS14) and DHW (in CS6, 12, 13, 14 and 15). The grey columns indicate the real electricity consumption declared by the owners. As a general rule, all results in this chapter integrate the global period covered by the revaluations (1 year in most case studies; 2 years for the CS2, 14 and 16; 3 years for the CS11 and 12). Figures 6.3.1 and 6.3.2 below, however, display the average annual real consumptions for those case studies, in order for the graphs to remain easy to read, especially for low-consuming case studies. CS2 and CS14 are particularly interesting as they clearly show the link between the increase in electricity consumption for appliances and lighting, and the decrease in electricity consumptions for heating. In the CS2, only the second energy sector (one third of the V_P) is heated using electricity, so that the compensation is less visible than in CS14.

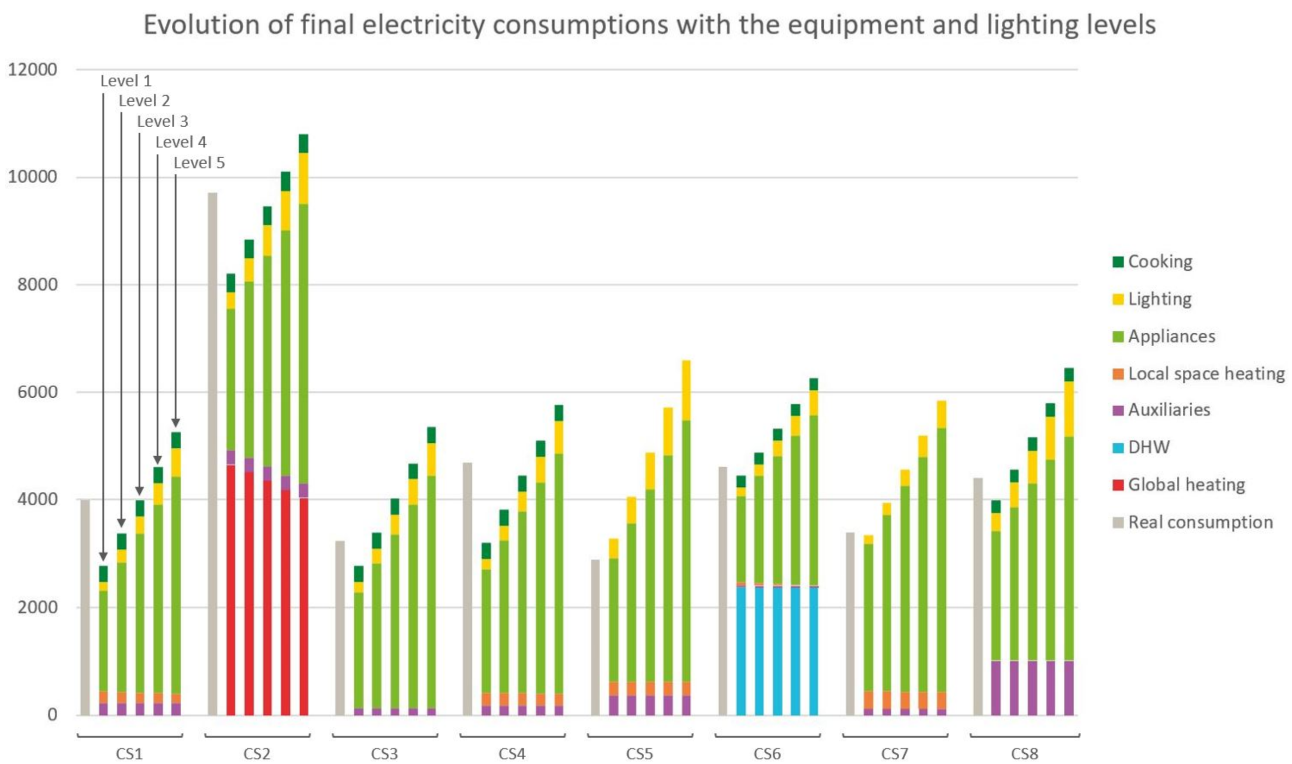

Fig. 6.3.1. Evolution, for each case study, of the global electricity consumptions [kWh/year] for the "$Q_{i,m}$ – internal gains" analysis under the real climate hypotheses.

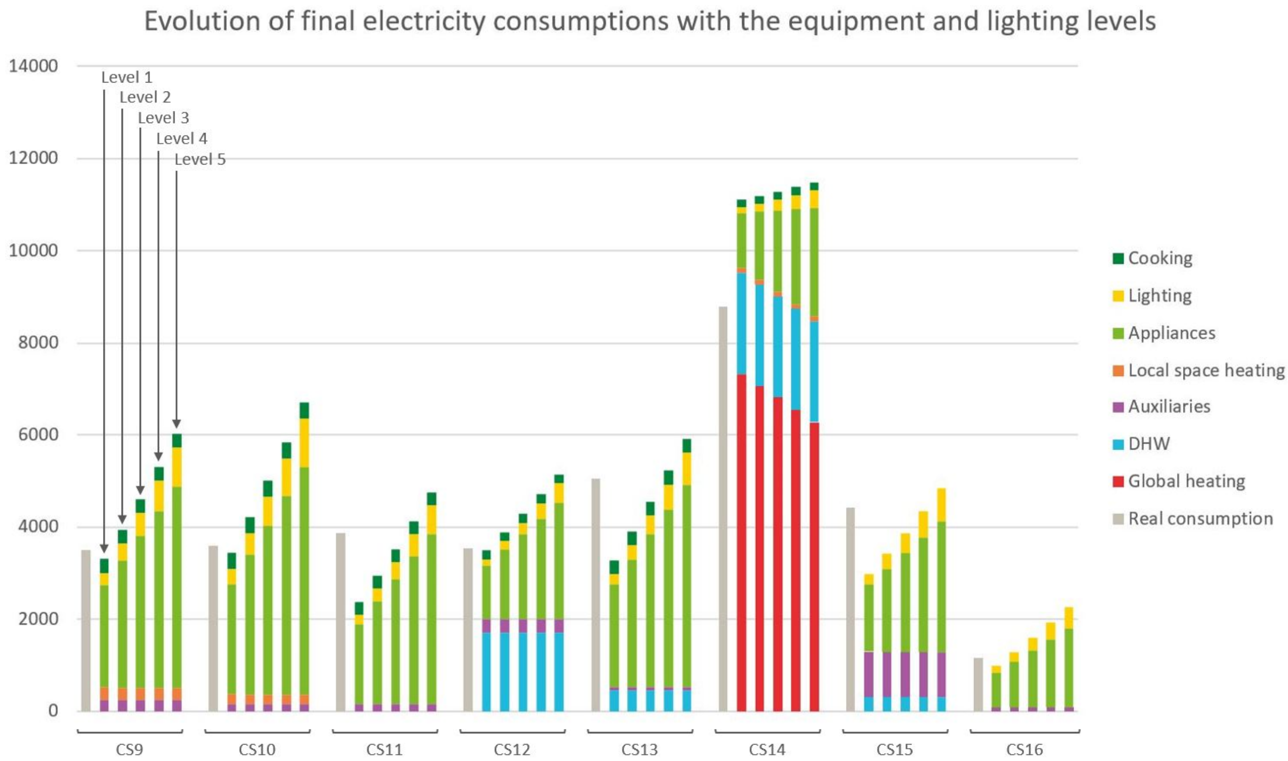

Fig. 6.3.2. Evolution, for each case study, of the global electricity consumptions [kWh/year] for the "$Q_{i,m}$ – internal gains" analysis under the real climate hypotheses.

Figures 6.3.3 and 6.3.4 below show the impact of those variation of the internal gains on the global $I_{eval/obs}$ ratios, first under average climate conditions, then under real exterior temperatures, for the total covered periods of consumption. The result is globally negligible, or so it would seem. Many case studies (most, one could say) see their final energy consumption vary by less than 1% per level increment in internal gains.

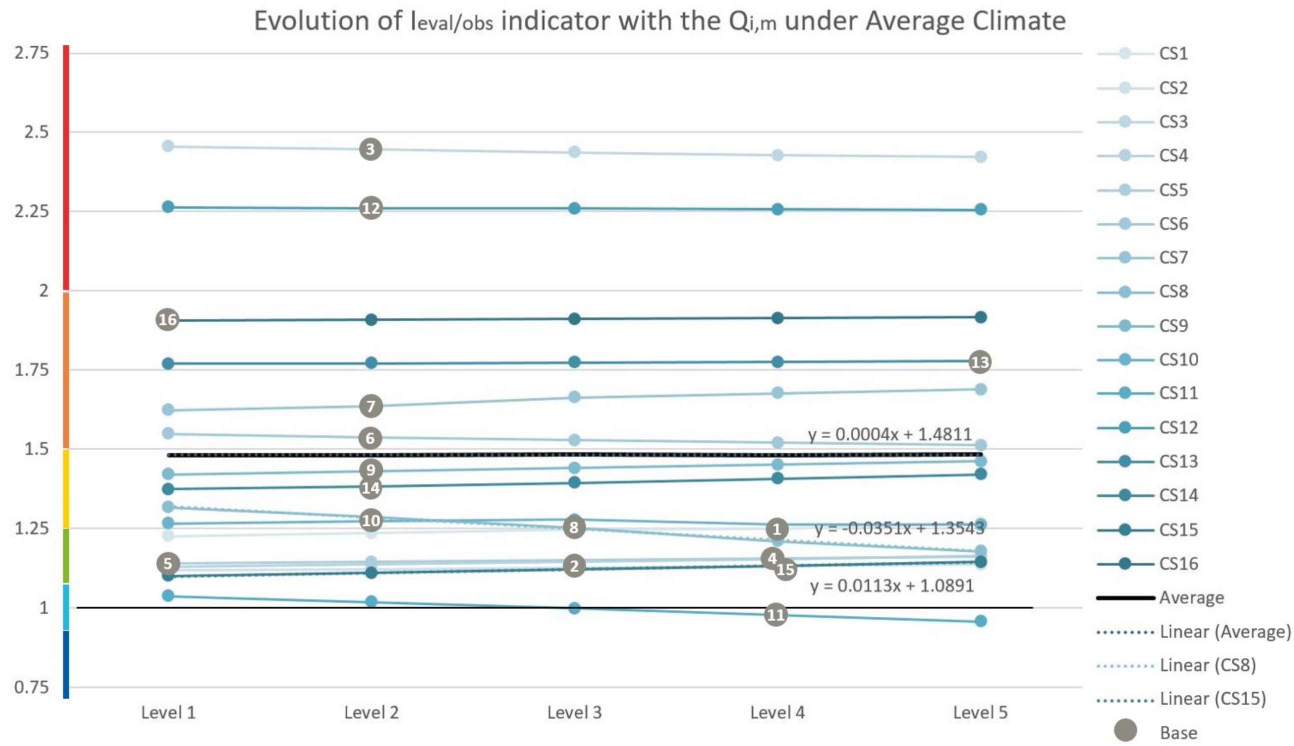

Fig. 6.3.3. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$Q_{i,m}$ – internal gains" analysis under the average climate hypotheses.

Some case studies present an increase in consumption, such as the CS14 which consumptions are described in Figure 6.3.2 above. The explanation is simple: the HGAR coefficient being equal to 1, an increase in electricity consumption, which implies an increase in internal gains, translates into a *nearly* equivalent decrease in NHD, according to Equation (33). However, not all equipment-related consumptions are recovered as internal gains, as consumptions for dishwashers, clothes washers and dryers are considered lost "down the drain". It is correct to say, however, that the share of those consumptions recovered as internal gains increases with the levels of this analysis, from 76% on average for level 1, to 88% on average for level 5. Figures 6.3.3 and 4 show that, when considering all fuels in the $I_{eval/obs}$ ratio definition, the increase is, also for the CS2, nearly negligible. The definition of levels in appliances and lighting consumptions is mainly important for the repartition of consumptions inside a nearly constant total.

The range of variations on the global energy consumptions per increment in equipment and lighting level, for all case studies, span between -2.6% (CS8) and +1% (CS7, 15) under the average climate, and -0.5% (CS3) and +1.55% (CS4) under real climate conditions. The focus being on the consumption for heating, it is logical to witness a more important influence of climate on the variation of results. The changes in the ranking is so different between both sets of simulations that it could only be attributed to climate; which is another proof that this variation on the global $I_{eval/obs}$ ratio is negligible.

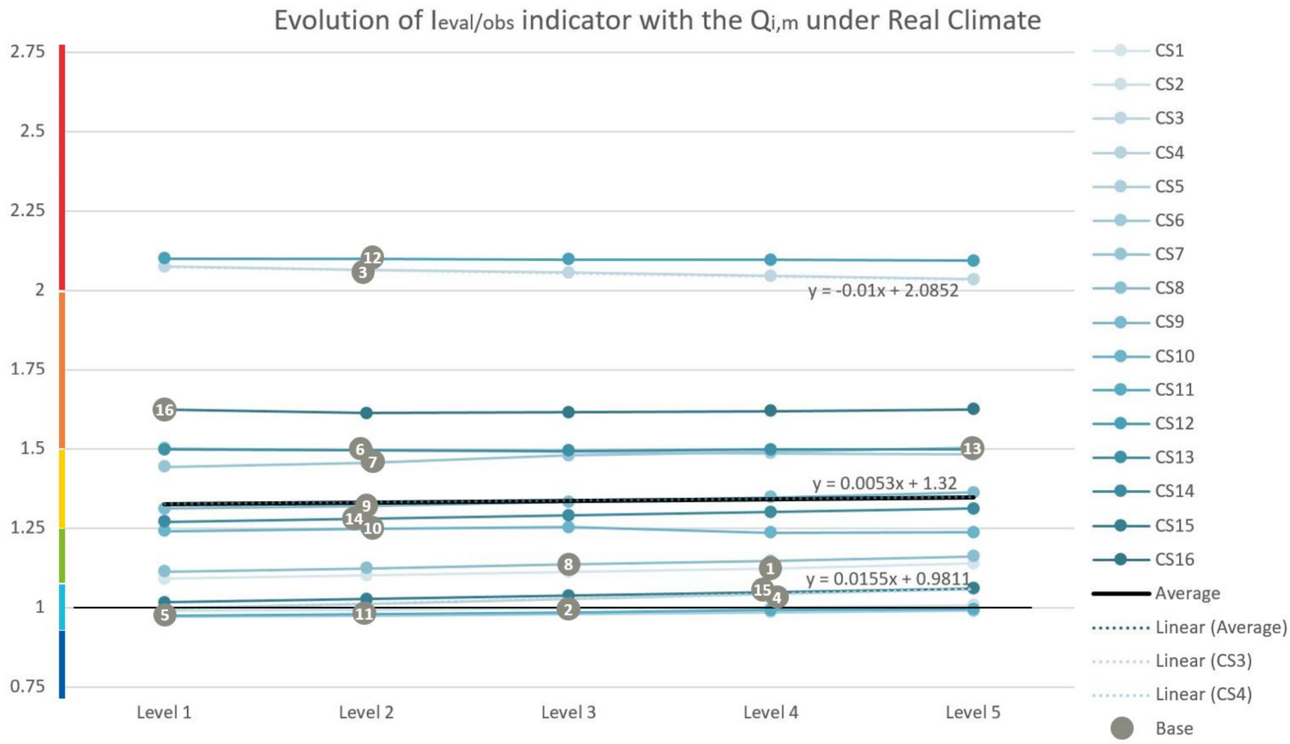

Fig. 6.3.4. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$Q_{i,m}$ – internal gains" analysis under the real climate hypotheses.

6.3.2 Solar gains

Solar radiation data were not available from the climatic stations (close to case studies) that delivered the exterior temperature data for the heat losses calculations. The evaluation of the solar gains has therefore not been changed in this method. A small uncertainty has been acknowledged in the "limited" 16 cardinal orientation choices in the windows description, implying a maximal possible 11.25° difference with the actual orientation. This set of simulations shows the variation of the global consumptions, should the solar radiation data be reduced or increased by increment or decrement of 5%, inside [-25%; +25%] limits. The influence of this variation is obviously more marked, as the solar gains directly reduce the heat losses in the net heat demand balance, without entailing any other kind of energy consumption. However, for such an important [-25%; +25%] variation spectrum of the solar radiation, the results could have been expected to be more impressive (Fig. 6.3.5 and 6):

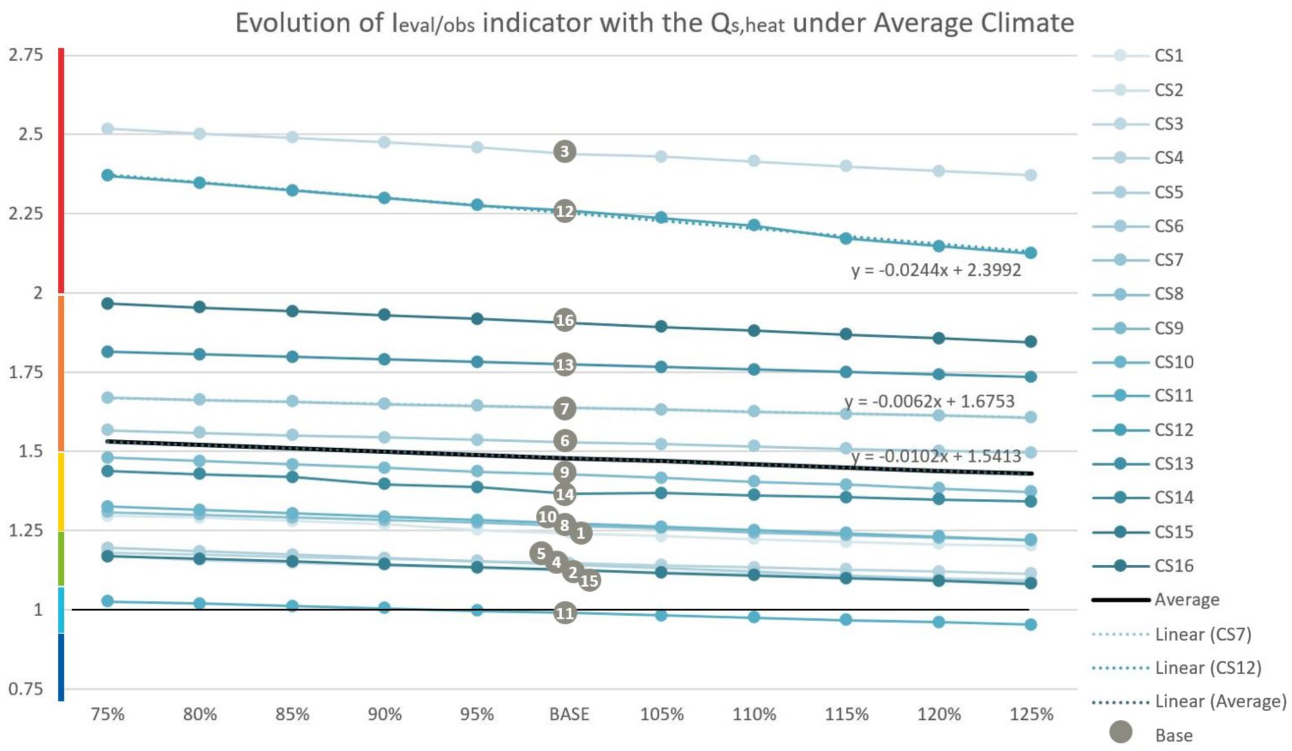

Fig. 6.3.5. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$Q_{s,heat}$ – solar gains" analysis under the average climate hypotheses.

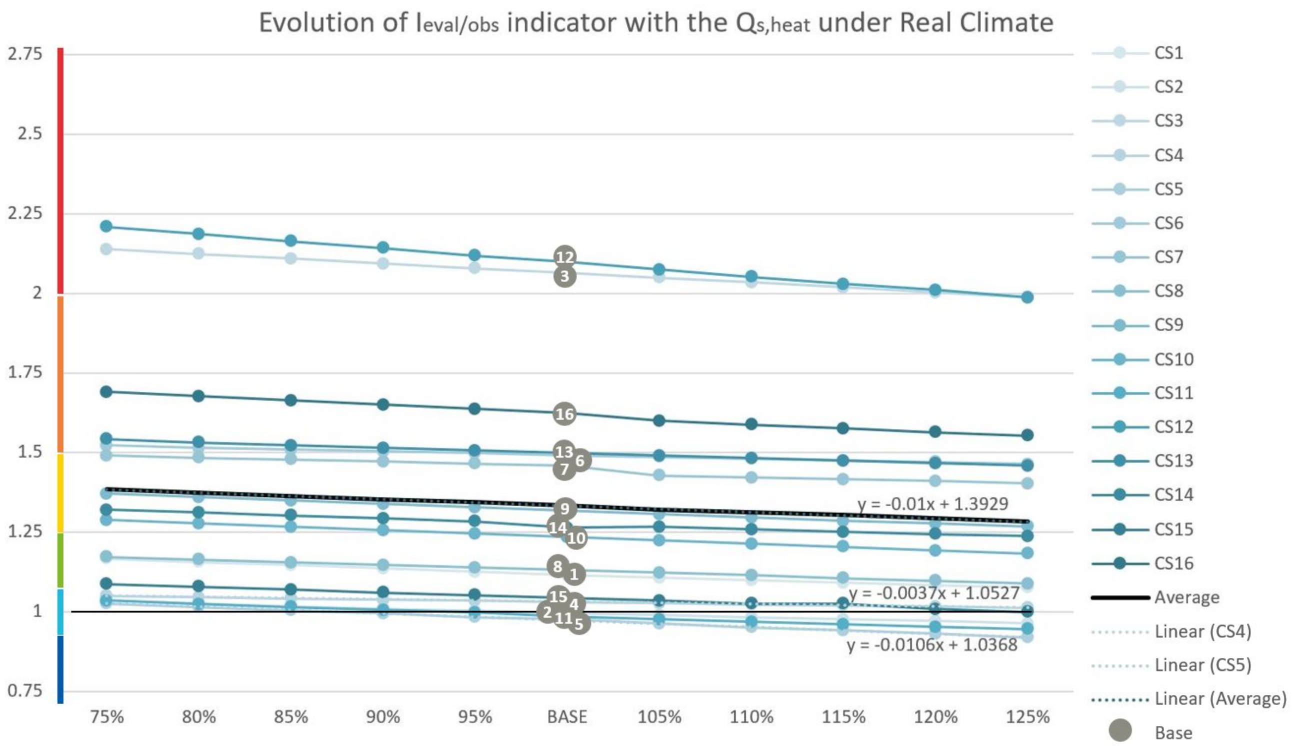

Fig. 6.3.6. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$Q_{s,heat}$ – solar gains" analysis under the real climate hypotheses.

Under the average climate hypotheses, a 5% increase in solar gains is responsible for an average 0.6% decrease in energy consumption, ranging between 0.4% for the CS7 and a little above 1% for the CS12. Reassuringly, the dwellings that display the higher glazed area, whether in absolute or relative terms (CS5, 10, 12, 15), are also those which show the higher influence of this variation on solar gains. The CS7 is at the low end of the influences because the reference period of the owners' real consumption data covers around 9 months, from December to August, whereas the other case studies consumptions are evaluated on, at least, a full year.

The use of real data modifies the ranking without changing fundamentally the results. The average reduction of consumption linked to an increase in solar gains of 5% is now at 0.7%, ranging between 0.4% (CS4, CS6) and a little bit over 1% (CS5, CS12). Globally, it seems that, even if the solar radiation in the regulatory method is underestimated, the way to get the $I_{eval/obs}$ ratio of the CS12, or the CS3, closer to 1, is not to be found in the solar hypotheses. For that, the insolation would have to be multiplied by 5 in the CS12, and by 7 in the CS3 which does not benefit from great natural lighting.

6.4 Air change heat losses

Heat losses in the EPC model, aside from the systems' losses, include on one hand the transmission of heat through walls, and on the other hand the losses due to the renewal of the air inside the dwelling. This air change can be caused either by hygienic ventilation, or by in- or exfiltration of air through the envelope. They are both represented in the Equation (13) of section 4.3.3.4, resumed hereafter, which defines the air change heat loss coefficient $H_{V,heat}$:

$$H_{V,heat} = 0.34 \times \left(\dot{V}_{in/exfilt,heat} + r_{preh,heat} \times \dot{V}_{hyg,heat}\right) \quad (13)$$

where:

- $H_{V,heat}$ = heat losses coefficient due to air tightness and ventilation [W/K];
- $\dot{V}_{in/exfilt,heat}$ = air tightness ventilation air flow for heating calculations [m³/h];
- $r_{preh,heat}$ = taming factor considering the pre-heating of ventilation air (when applicable) [-];
- $\dot{V}_{hyg,heat}$ = hygienic ventilation air flow for heating calculations [m³/h].

6.4.1 In-/exfiltration

The first set of simulations enquires about the real influence of the $\dot{V}_{in/exfilt,heat}$ parameter:

$$\dot{v}_{50,bmod} = \dot{v}_{50,heat} \times f_{v50} \quad (14)$$

$$\dot{V}_{in/exfilt,heat} = 0.04 \times \dot{v}_{50,bmod} \times A_T \quad (15)$$

where:

- $\dot{v}_{50,bmod}$ = air flow due to airtightness, under 50 Pa pressure difference, by square meter of the heat loss area, tamed by inhabitants' behaviour [m³/h.m²];
- $\dot{v}_{50,heat}$ = air flow due to airtightness, under 50 Pa pressure difference, by square meter of the heat loss area [m³/h.m²]. The default value for heating calculations in the absence of a testing is 12m³/h.m², attributed to 14 of the 16 case studies in the revaluations so far;
- f_{v50} = multiplicative factor taming the air flow to consider behaviour [-];
- A_T = total heat loss area [m²].

All case studies have been submitted to the variation of the $\dot{v}_{50,heat}$ parameter, between the values of 0m³/h.m², and 12m³/h.m², the default value. Only two houses had been submitted to an infiltration test previously, and were given an official report attesting the values of 1.6m³/h.m² for the CS8, and 3.7m³/h.m² for the CS15. During the course of this research, 4 other case studies have been tested in order to clarify their $\dot{v}_{50,heat}$ parameter:

- The CS7 has been submitted to a pressurization test on October 24th, 2017, under normal conditions according to the NBN EN13829 standard in force in Belgium, which resulted in a $\dot{v}_{50,heat}$ value of 7.26 m³/h.m² on average (6.7 m³/h.m² for the under-pressurization test, 7.79 m²/h.m² for the over-pressurization test). Important leakages have been identified all around the walls that "close" the stairs towards the basement.
- The CS9 has been submitted to a pressurization test on October 17th, 2017, under normal conditions according to the NBN EN13829 standard in force in Belgium, which resulted in a $\dot{v}_{50,heat}$ value of 11.02 m³/h.m² on average (8.78 m³/h.m² for the under-pressurization test, 13.2 m²/h.m² for the over-pressurization test). According to the owner, Mrs I., the reason for this difference between both tests is the presence of a trap door on the attic floor, which could have lifted easily under pressure.
- The CS11 has been submitted to a pressurization test on October 16th, 2017, under normal conditions according to the NBN EN13829 standard in force in Belgium, which resulted in a $\dot{v}_{50,heat}$ value of 5.81 m³/h.m² on average (5.84 m³/h.m² for the under-pressurization test, 5.75 m²/h.m² for the over-pressurization test).
- The CS12 has been submitted to a pressurization test on October 26th, 2017, under normal conditions according to the NBN EN13829 standard in force in Belgium, which resulted in a $\dot{v}_{50,heat}$ value of 9.11 m³/h.m² on average (9.06 m³/h.m² for the under-pressurization test, 9.16 m²/h.m² for the over-pressurization test). Important leakages have been identified all around the walls that "close" the stairs towards the basement.

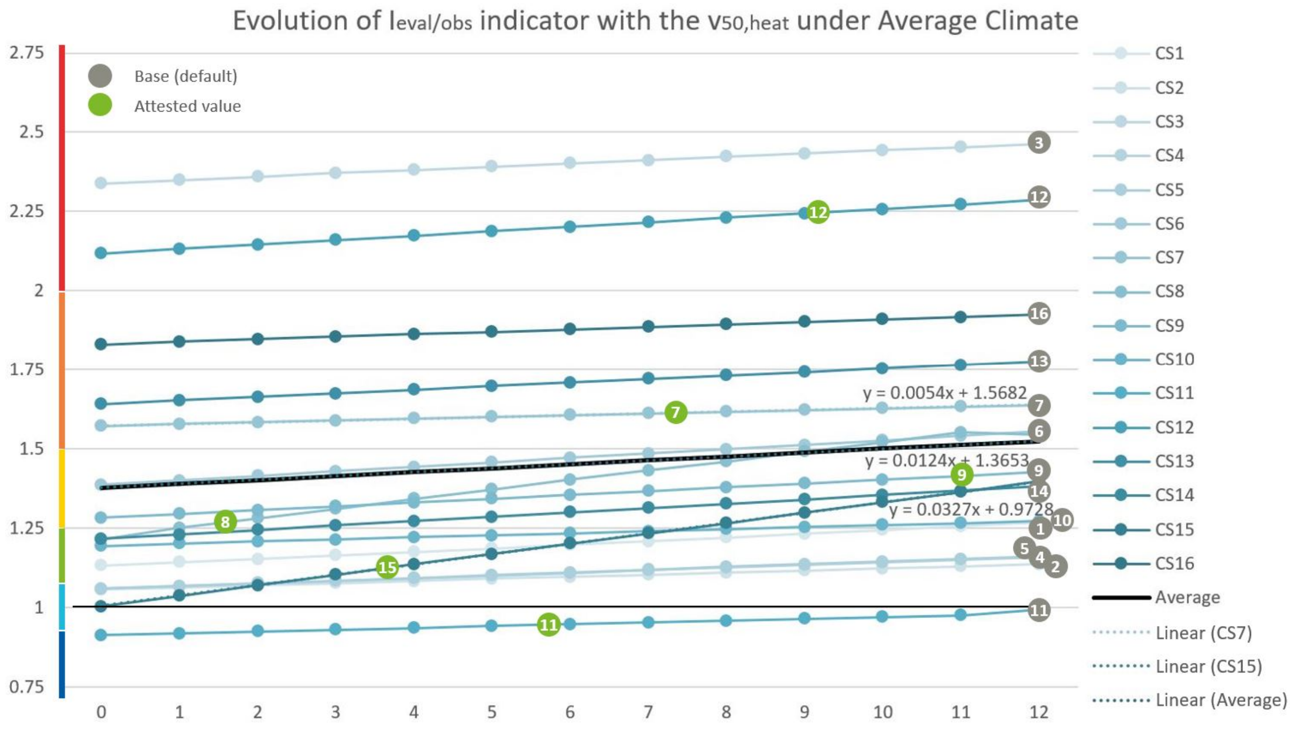

Fig. 6.4.1. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$v_{50,heat}$ – infiltration" analysis under the average climate hypotheses.

As one might expect, the most important impact is applied on the CS15, and the CS8. Their energy efficiency is such, and their energy consumption so low, that air tightness marks its influence on the balance. Each time the $\dot{v}_{50,heat}$ parameter increases by 1m³/h.m², the CS15 sees its theoretical energy consumption increase by 3.3%. In the case of the CS8, this increase brings a 2.3% raise on the global energy consumption under average climate, 2.4% under real climate. The average on the sample is around 1% under both climates. All "inefficient" cases indicate, with their very low variation, that the manner to reduce their $I_{eval/obs}$ ratio is not via the air tightness, which is not crucial to their energy consumption evaluation. As the influence on the case studies can be ranked according to the share of heating in the global consumptions, there is no reason for that ranking to change under real climatic conditions, as evidenced by the Figure 6.4.2.

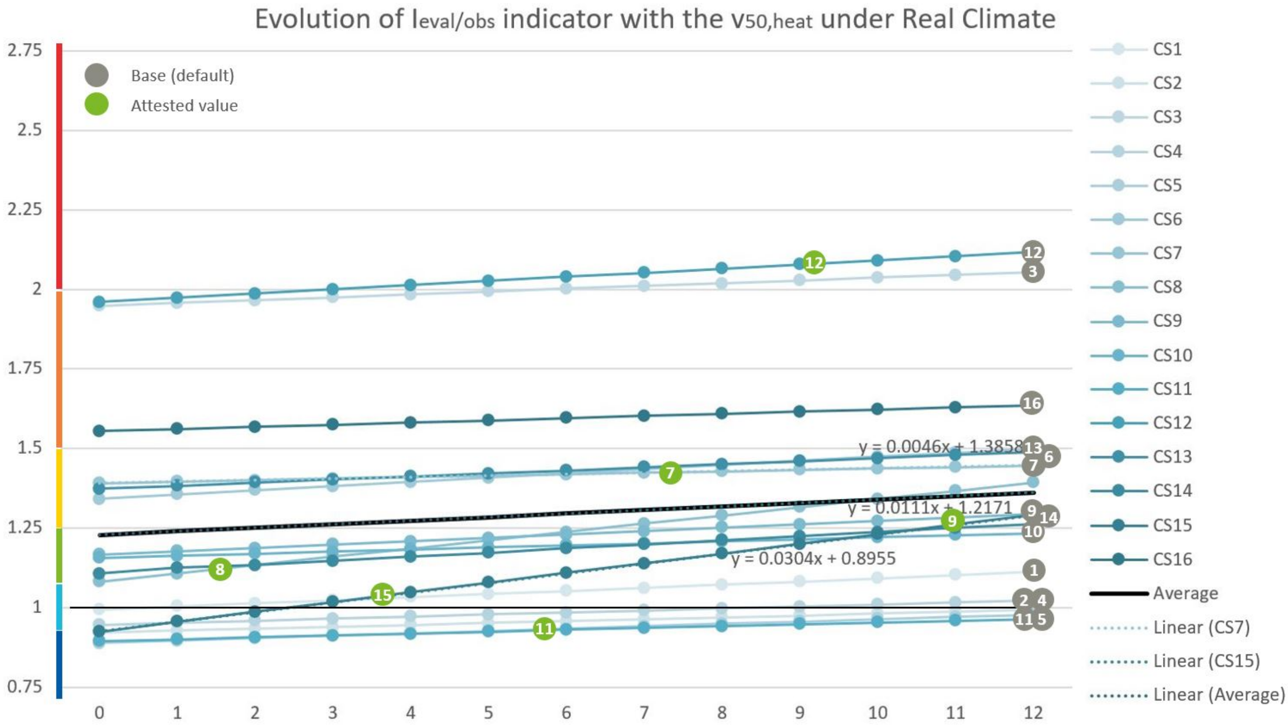

Fig. 6.4.2. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$v_{50,heat}$ – infiltration" analysis under the real climate hypotheses.

Other case studies were considered for testing. Some houses, such as the CS3, 4, or 6, have been sold or rented out, and were unavailable. Others, such as the CS2 or the CS5, have been renovated after the interview, their energy system did not fit the description made in this research anymore.

6.4.2 Ventilation

The other part of air change heat losses is due to the hygienic ventilation of the dwelling. In the regulatory calculation method, the air change rate is defined with the protected volume as only parameter, in an attempt to standardise the evaluation of heat losses that, in reality, depend a lot on dwellers' practices. Once again, one can see here the remnants of the initial EPB calculation method for new and efficient buildings, in which those heat losses are more accurate thanks to the obligatory installation of a complete ventilation system in compliance with standards in force. In this sample, only two houses were equipped with such ventilation systems: the CS8, and the CS15. Given their high energy efficiency and air tightness, the regulations in place and the requirements of the BATEX Program under which these houses were renovated, this was not even an option for the owners. In both cases, a complete mechanical system, with central heat exchanger, has been installed. The CS1, built in 2007, is a house that should be equipped with a complete ventilation system. Natural ventilation supply vents were present in the window frames of most "dry" spaces such as the living room and the bedrooms. Mechanical exhaust units existed in the bathroom and toilets, but lacked in the kitchen and "laundry room". Besides, the owners, Mr and Mrs A., admitted closing the supply vents in the winter, to avoid cold air draughts. All other case studies pre-date the inclusion of ventilation requirements in the thermal regulations, and were therefore not equipped with any kind of system initially. When the interview were led and the dwellings described, this was still the case for the CS2, 3, 4, 5, 9, 10, 12, 13, 14 and 16. Other case studies were equipped with, mainly, a natural or mechanical exhaust, in humid spaces such as the bathroom (CS6, CS11) or the toilets (CS7), in order to get rid of humidity or odour problems, rather than insure hygienic renewal of air.

In those 14 case studies, the absence of ventilation systems renders the evaluation of air change rates difficult. The rates have therefore been approached by a series of question enquiring about the dwellers' habits in ventilation during winter (heating) period, in the four kinds of spaces that are the living room, the kitchen, the bathroom and the bedrooms. Chapter 4, section 4.3.3.4, defined the parametrization behind the possible answers, and Figure 4.3.9 showed the differences in $H_{V,heat}$ coefficients these hypotheses brought.

The next set of simulations sees the air change rate [m³/h] due to hygienic ventilation vary between 0% and 100% of the V_P, in order to assess the importance of precision in this parameter. Figures 6.4.3 and 4 show the results of those simulations on the evolution of the $I_{eval/obs}$ ratio, first under average climate then real climate conditions.

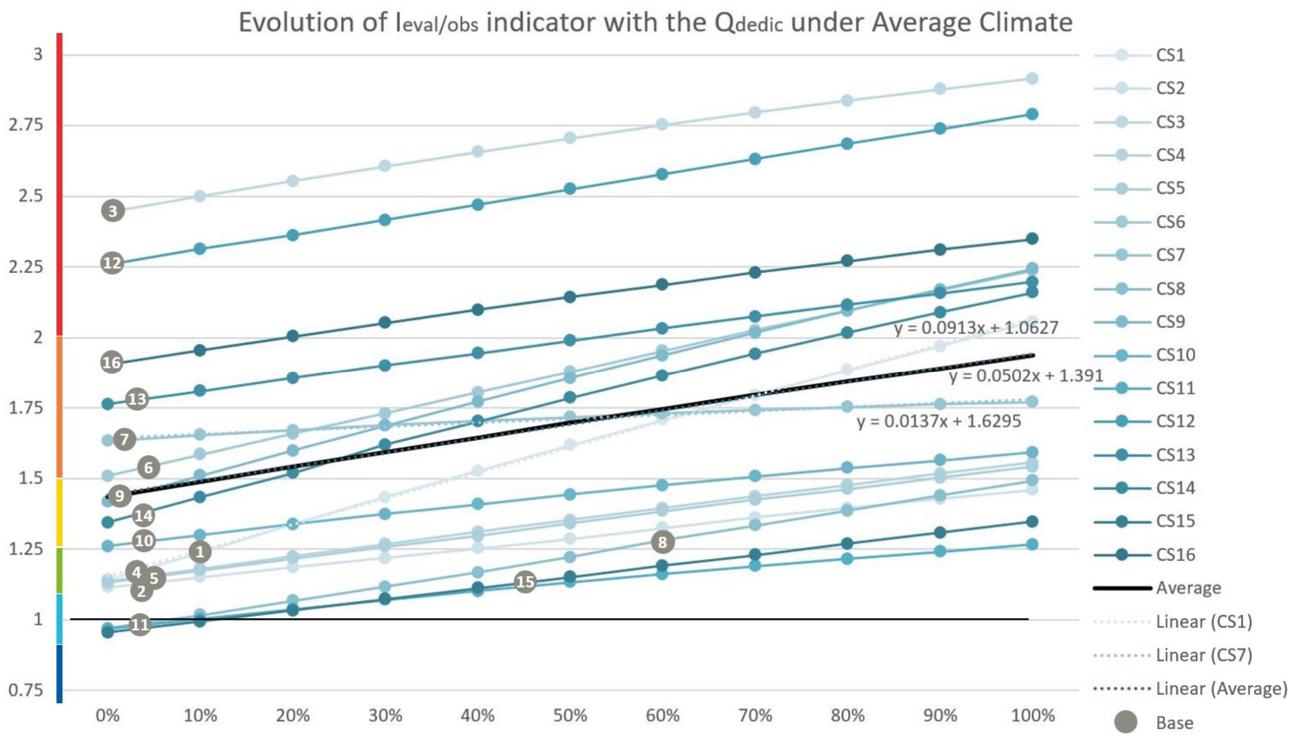

Fig. 6.4.3. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "Q_{dedic} – ventilation" analysis under the average climate hypotheses.

Some similarities with the "infiltration" analysis have to be mentioned. For example, buildings with low thermal envelope efficiency, such as the CS12, 3, 16, 7 or 13, are less influenced than insulated buildings such as the CS8, 15, 1 or 14. Some differences are noticeable, however. For example, the presence of the heat exchanger on the mechanical ventilation systems in CS8 and 15 is visible; the $r_{preh,heat}$ coefficient (see Equation (13) above) which defines the proportion of hygienic ventilation air change that remains to be heated by the heating system, has dropped from 1 in most cases, to 0.3 in the CS8, and 0.17 in the CS15. The most impacted houses in the sample are therefore the CS1 and 14, second most energy-efficient buildings in the sample after those exceptions but naturally ventilated. Another important difference is the superior impact of ventilation, when compared to infiltration. Per 10% increment in ventilation rate, the energy consumption increases between 2% for the CS3, 16 or 12, to 8% for the CS1, and 6% for the CS9 and 14. Even in CS8 and 15, with their low $r_{preh,heat}$ coefficient, ventilation rates influence results more than infiltration.

Figures 6.4.3 and 4 also show that initial ventilation rates in most dwellings are disturbingly low. This could be a reproach to the parametrization hypotheses brought to the questionnaire's answers, which could underestimate the rates. Most households declared that their ventilation practices were limited to opening a window for a few minutes a day (mostly in bedrooms), or using the extractor hood when cooking, which cannot be considered to generate high daily average rates of ventilation. Besides, higher rates would only increase the energy consumptions, which would not bring the $I_{eval/obs}$ ratio closer to 1 for the CS3 or 12. But the importance of the ventilation losses, according to this analysis, and their influence on the balance, is not to be neglected and should therefore be more closely evaluated. It is perfectly probable (if not downright certain) that in most cases, those underestimated heat losses due to ventilation went unnoticed, drowned in overestimated transmission heat losses. Here again, the question of the accurate distribution of determiners in a global estimation can be raised. As there might be compensations between DHW and heating consumptions revaluations, others might appear in NHD evaluations, where the underestimation of heat losses by ventilation could be offset by the overestimation of the heat losses by transmission.

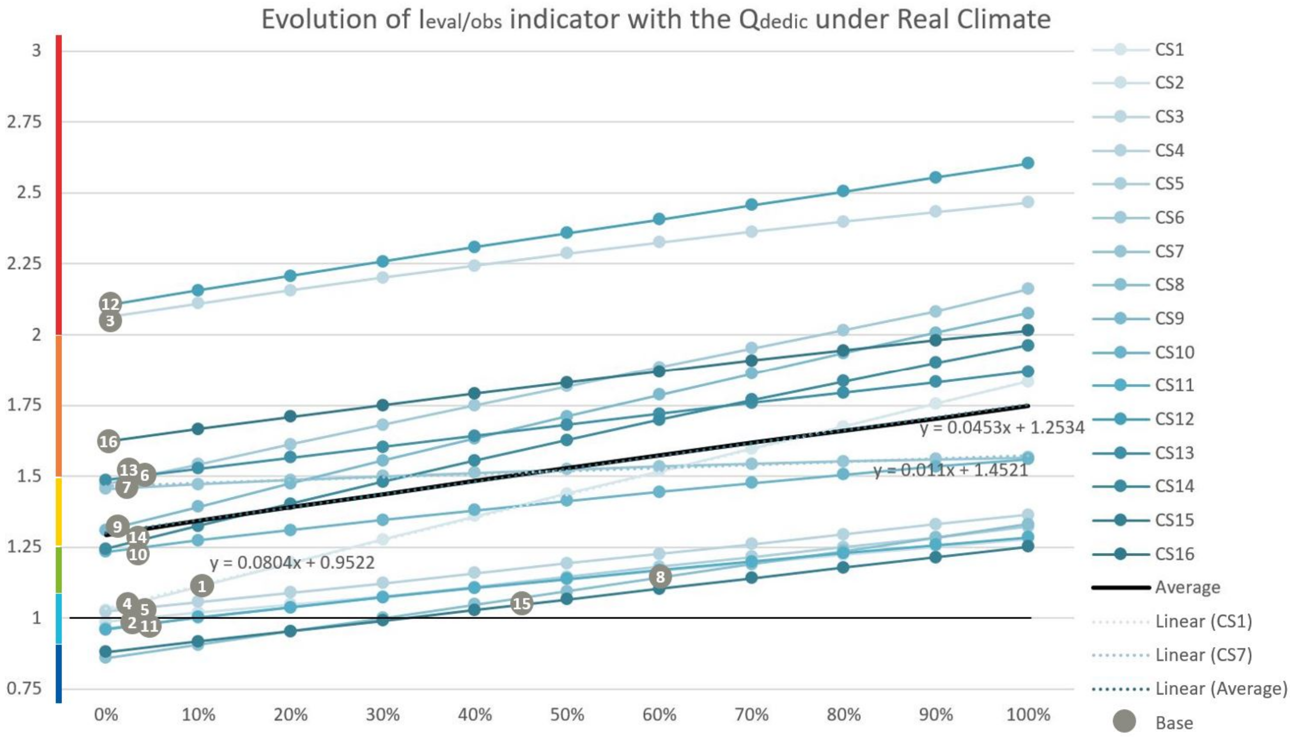

Fig. 6.4.4. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "Q_{dedic} – ventilation" analysis under the real climate hypotheses.

6.5 Transmission heat losses

6.5.1 Measurements

Measurements of the building are often tedious and time-consuming. They can be difficult in some situations, and represent a large share of the assessor's fee. Some simplification would certainly be welcome, if the price in accuracy is not too high. In some ways, the actual Walloon EPC protocol does propose some kind of simplifications on the description of annexes and secondary volumes: a calculation protocol has been implemented to evaluate all areas based on the smallest number of needed (and possible) measurements, with variants. In that case, the inaccuracy of calculated areas is nearly inexistent. This section will test the sensitivity of the results to the measurements of the heated floor area, protected volume, and total heat loss area, in order to assess the degree of precision that ought to be required in that prospect.

6.5.1.1 Heated Floor Area (A_{ch})

The heated floor area (A_{ch}) is considered a major parameter in the EPB framework in Wallonia. It is not used in the calculation method until the very last step, as it is the denominator in the equation defining the E_{spec} indicator:

$$E_{spec} = \frac{E_{char,ann,prim,en,cons}}{A_{ch} \times 3.6} \tag{32}$$

where:

- E_{spec} [kWh/m².year] is the specific annual primary energy consumption indicator per square meter of heated floor area;
- $E_{char,ann,prim,en,cons}$ [MJ] is the characteristic annual primary energy consumption of the protected volume, considering the consumptions for heating, DHW, cooling, auxiliaries and renewable supply of all kinds;
- A_{ch} [m²] is the heated floor area corresponding to the protected volume.

It is quite necessary to develop a precise, extensive and exhaustive definition of this single parameter when maximal E_{spec} values are imposed by the EPB thermal regulation for new residential buildings. A few square meters could make a difference in achieving required targets in primary consumption and therefore obtaining the legal permit to build. It might be argued that, in the case of the EPC, no such stakes depend on the precision of the A_{ch}, as the E_{spec} indicator is only used to rank the EPCs in a non-binding scale. Should the EPC ranking be used to grant incentives, impose taxes or regulate rental markets, the A_{ch} would be as important in the EPC as it is in the EPB calculation method.

This parameter does not have any other direct influence on the regulatory calculation method. In this modified method, however, this parameter has been introduced punctually in order to evaluate the ventilation air change in the CS1, 8 and 15, for example, which are the only houses equipped with ventilation systems compliant with the NBN D50-001 standard, a norm integrated in thermal regulations for all newly built dwellings since 1996 which evaluates the needed hygienic air change with the floor area as main parameter. It is another kind of standardisation, where the house needs to be equipped for any kind of household, independently from the number of inhabitants. The heated floor area is also used in all cases to evaluate the consumption for vacuum cleaning (included in "appliances" consumptions) and for lighting (with reduction factors). A variation in A_{ch} should therefore bring variations in electricity consumptions, and in fuel consumption via the heat gains evaluation. A test has been run on all case studies, with the A_{ch} parameter reduced of 10% (*ceteris paribus*), under the average climate conditions. Small houses (such as the CS6 or the CS16) and very efficient buildings (CS8 and CS15) showed the greatest variation in their consumption results, which were reduced by a mere 100kWh/year. In any case, this variation is small enough to be negligible, meaning that the precision on the A_{ch} parameter still does not influence the results in consumption.

6.5.1.2 Protected volume (V_p)

The protected volume was a central parameter in the evaluation of a building's performances in the regulatory framework. It can even be acknowledged as the main standardisation solution to many parts of the energy balance that are, in reality, very much influenced by the dwelling's occupants. It defined, alone, the heat losses by ventilation, the internal gains, the domestic hot water needs or the auxiliaries' electricity consumption. The de-standardisation process that was explained in chapter 4 mainly translated in the removal of this parameter's influence on the results, as often as can be. This section sees the V_p parameter varying in a range of [-10%; +10%] around the "base points" in order to assess its remaining influence. Although it conserves an impact on the auxiliaries' consumption, their global influence on the total final energy consumption is rather negligible. The biggest use of the V_p's value is in the definition of the f_{pct} ratio used in Equation (9) to evaluate the resulting temperature in unheated spaces:

$$f_{pct} = \left(\frac{H_{T,heat} + H_{V,heat}}{V_p}\right) \qquad (10)$$

where:

- f_{pct} = multiplicative factor considering the quality of the envelope as influence on temperature homogenization;
- $H_{T,heat}$ = transmission heat losses coefficient [W/K], sum of heat losses through the different walls of the envelope;
- $H_{V,heat}$ = heat losses coefficient due to air tightness and ventilation [W/K];
- V_p = protected volume [m^3].

The Figure 6.5.1 below indicates that the case studies that are most affected by this variation on the volume are those that combine low proportion of heated volume (such as the CS11, CS7 or CS10), and/or low global performances (such as the CS3, CS7, CS16, or CS10). The CS7 witnesses the biggest impact by seeing its consumption decreased by 2.35% each time the protected volume is decreased by 5% (see upper trend curve equation in Figure 6.5.1). Better performing buildings, such as the CS8, CS15 or CS1, witness very low variations of their results: the CS8, for example, sees its consumption decreased by less than 0.3% for the same 5% decrease of volume (see lower trend curve equation in Figure 6.5.1). The average, for this sample, witnesses a 1% decrease for each 5% decrease of the V_p value. The precision on this particular value is not of great importance in the modified method if the results are accurate, but remains influential for households that heat small shares of their relatively inefficient house.

The use of real climatic data does not change the results any more than it did in chapter 5 above: by generally approaching real data with more accuracy. $I_{eval/obs}$ curves get closer together as a result, and closer to the target of 1. The "curves" in Figure 6.5.2 show slightly increased slopes, meaning that the reductions in consumption associated to a reduction in volume are slightly superior to those evaluated under average climate. The 2.35% reduction, for each 5% reduction of CS7's V_P, becomes 2.5%, and the sample average stays at 1%: the difference is negligible.

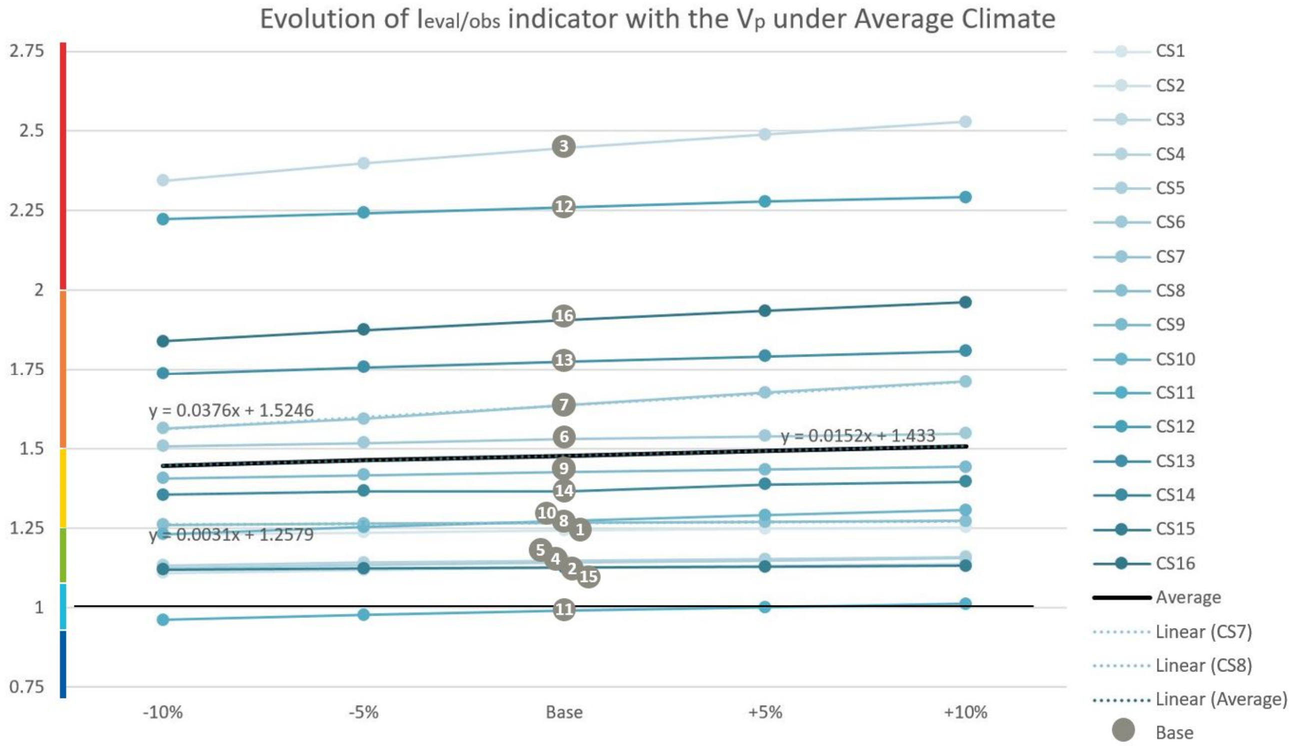

Fig. 6.5.1. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "V_P" analysis under the average climate hypotheses.

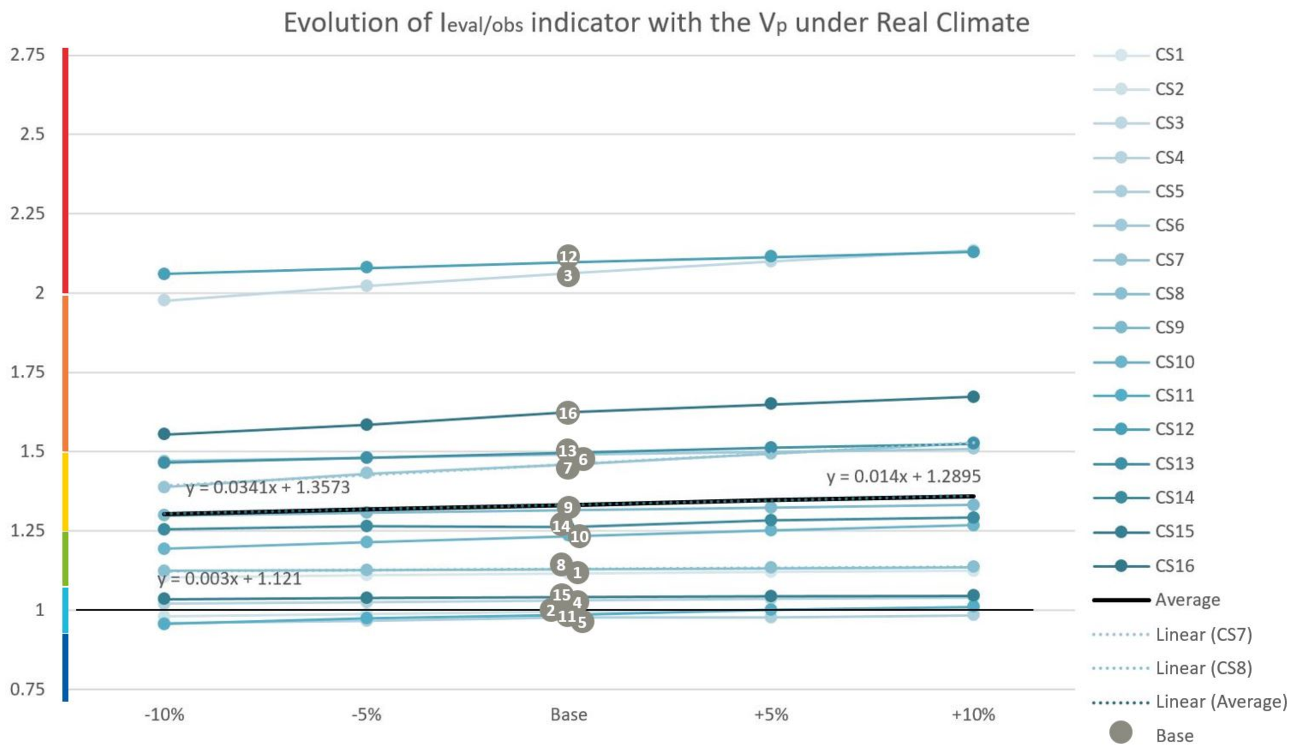

Fig. 6.5.2. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "V_P" analysis under the real climate hypotheses.

If the protected volume, as a parameter, has lost most of its influence on the results, its description remains an important influence, as evidenced by the chapter 5 and the variants' definition. In CS2 and 6, its subdivision was at stake; in CS1, 3, 4, 8, 10, 13, 14 and 15, its performances were dependent on the consideration of acceptable proofs. In the CS5, 9, 11 and 16 however, the variants were defined based on whether or not some parts of the building should be considered in or out of the V_P. Their inclusion were honestly debatable when considering the EPC protocol. In all cases however, their inclusion revealed to be the chosen variants, for they all showed higher heating systems' efficiencies (the boilers being included too in the V_P), lower average U-values and, in CS5, 9 and 16, lower $H_{T,heat}$ coefficients. In the CS5, the inclusion of the attic in the V_P translated in a 5% decrease in consumption, mainly due to the insulation in the roof that got considered in the process. In the CS9, the inclusion of a small basement located between the ground and heated spaces led to a consumption reduction of 7%. In the CS11, the inclusion of the lower ground floor led to a 2% increase in consumption, mainly due to the importance of those spaces volumes, and of their consequent influence on the evaluation of the resulting temperature in unheated spaces. In the CS16, as in the CS9, the inclusion of the similar basement led to a 3.4% reduction of revaluated total annual final energy consumption.

In other case studies, such as the CS2, CS3, CS4, CS6, CS7, CS10, CS12, or CS13, basements have been left out of the protected volume. The EPC protocol understandably excluded those basement from the V_P, and those previous results indicated that there is little to be expected from their inclusion, as far as the reduction of the $I_{eval/obs}$ ratio is concerned. The following Table 6.5.1 displays the hypotheses (which differ from the previously described CS3) and main results for an attempt made on the CS3:

Table 6.5.1 Hypotheses and results of the CS3, with or without the basement in the V_P

Data	Without basement	With basement
V_P [m³]	421.4	531.9
A_{ch} [m²]	134.16	178.36
A_T [m²]	225.5	242
U_m [W/m²K]	1.75	1.55
$H_{T,heat}$ [W/K]	393.6	375.2
Heated share of Vp ($f_{Vp,hs}$) [-]	0.343	0.265
f_{pct} factor [-]	0.996	0.747
Total annual final energy consumption under Average Climate [kWh/year]	39,061	37,768
$I_{eval/obs}$ factor under AC	2.44	2.36
Total annual final energy consumption under Real Climate [kWh/year]	32,972	31,898
$I_{eval/obs}$ factor under AC	2.06	2.00

The difference is noticeable (superior to 1,000kWh reduction in total final energy consumption), but not enough to close the overestimated gap in consumption: the $I_{eval/obs}$ ratio is reduced by a mere 3%. This case combines the heat loss reduction of the CS9 and 16, and the volumetric influence of the CS11's added spaces. The solution to this case's overestimated consumptions is not there, and it is believed that it is not there for the CS12's $I_{eval/obs}$ ratio either, for the same reasons. In the CS12, it is the veranda that might be inadequately included in the V_P, as will be discussed in section 6.6.1.

6.5.1.3 Scaling

The last step in this part of the sensitivity analysis considers the general scaling of the building. How would the results vary, if the whole dwelling was 5 or 10% smaller, or bigger? The set of simulations presented here impact therefore not only the protected volume (V_P), but also the heated floor area

(A_{ch}) and the total heat loss area (A_T), which remained unchanged in the "V_P analysis" section. The same boundaries of [-10%; +10%] have been applied in this set of simulations, as it is mainly designed to define regression trends.

The Figure 6.5.3 below displays the results for this "scaling" analysis under the Average Climate conditions. The multiple influence of this variation on the scale of the building is more visible than the variation on the protected volume alone, marking therefore the influence of the heat loss area. Linear regression lines are more inclined, translating the higher reductions brought by a 5% scaling-down of the building:

- -7.1% for the CS12, which shows the highest sensitivity to this hypothesis variation;
- -4.4% for the CS8, the highly efficient case study which shows the lowest sensitivity to the scaling down;
- -5.5% on average in this sample.

There seems to be a straightforward correlation between the global size of the building and its final energy consumption: scaling down the building by 5% reduces the consumptions by 5%. The added (expected) observation is that inefficient buildings see their consumption reduced by a bigger factor (steeper slopes of regression lines) than efficient dwellings, or relatively inefficient dwellings that were already accurately revaluated ($I_{eval/obs}$ ratios close to 1), such as the CS2 or 5.

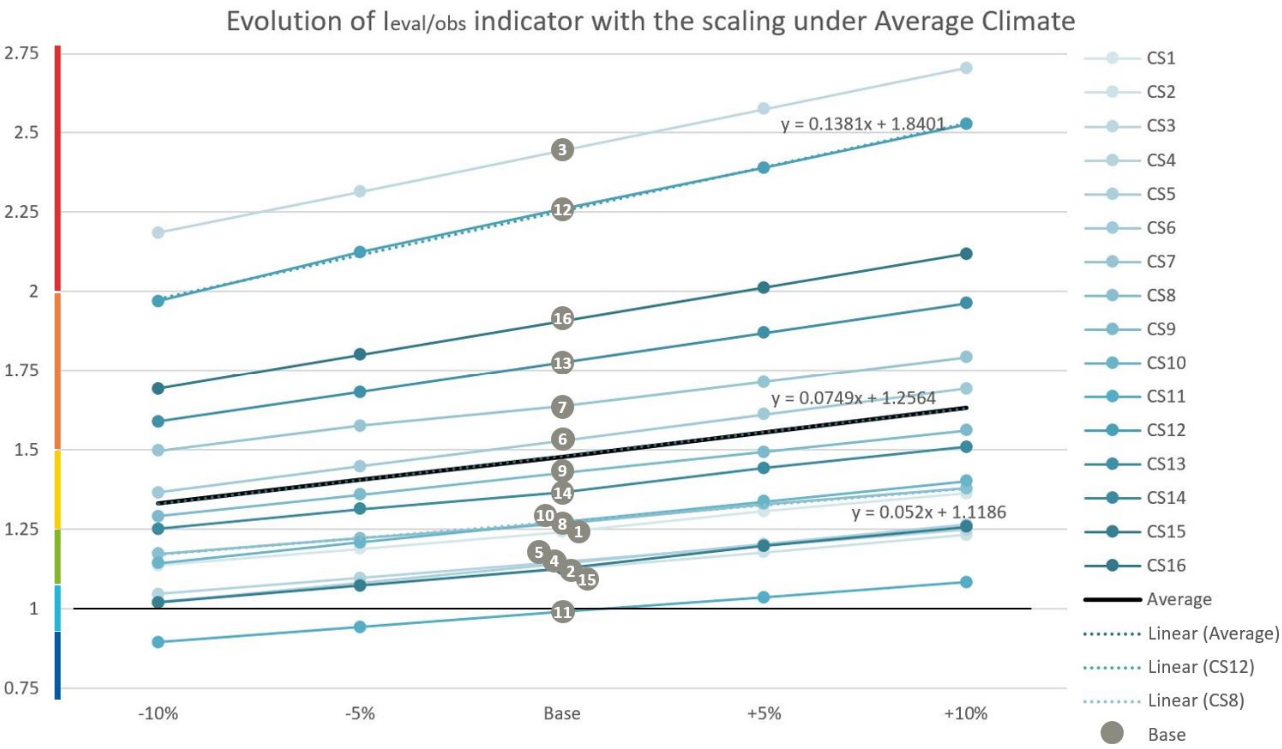

Fig. 6.5.3. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "scaling" analysis under the average climate hypotheses.

The use of real climactic data (see Figure 6.5.4) results in the same slopes for the regression lines. Consumption reductions brought by a scaling-down of 5% are therefore similar: -7% for the CS12, -4.4% for the CS8, and -5.5% on average. If, alone, the value of the protected volume is not very influential, the global scale of the building however is not to be underestimated in the calculation results. Simplifications to the measurements through a typology approach, for example, would have to be developed in order to guarantee minimal inaccuracy in the heat loss area, or the corresponding results would have to be presented with a correspondingly large range of acceptable inaccuracy.

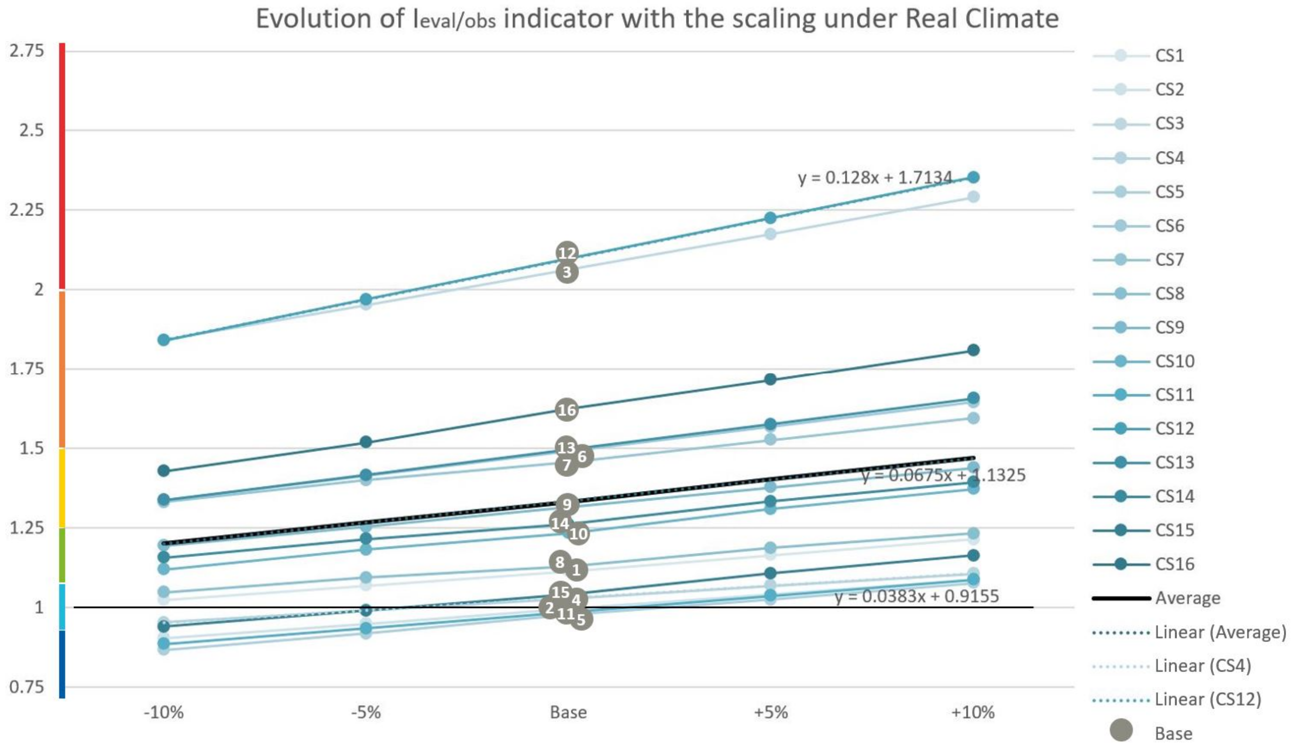

Fig. 6.5.4. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "scaling" analysis under the real climate hypotheses.

The levelling up of accuracy in the description of those case studies which are still dominated by default values will improve their theoretical efficiency, which will in turn imply that the higher "curves" in Figures 6.5.3 and 4 would tend to approach the curves of the efficient and highly accurately described case studies 8 or 15. There is however a non-reducible range of variations: the CS15, for example, is as well-known as the CS8; the influence of the scaling factor is however slightly more important (closer to the average, really) because of the higher set temperature in the dwelling. A reduction in size implies therefore a larger reduction in consumption in CS15 (-5.8% of energy consumption per decrement in scale of 5%), than in CS8 (-4.4%).

6.5.2 $H_{T,heat}$ coefficient

It is important to focus this analysis on the $H_{T,heat}$ coefficient alone, which has been used throughout this research as an important envelope performance indicator. This coefficient has been already affected by the "scaling" variations, along with the protected volume and all surfaces of the buildings. The next simulations see this coefficient alone vary under [-25%; +10%] imposed limits. Given that the $H_{T,heat}$ coefficient [W/K] can be considered as the product of the average U-value for the dwelling [W/m²K], by the total heat loss area [m²], the observations made hereunder are valid to assess a [-25%; +10%] variation on each parameters separately. However, the intent behind this analysis clearly targets the U-value: the scaling analysis highlights much more logically the doubts anyone could have on the measurements of the buildings.

The [-25%; +10%] limits have been chosen to consider the possibility that the regulatory method overestimates rather than underestimates the average U-value. It is suspected therefore that the description of the envelope partly explains why the $I_{eval/obs}$ ratio of case studies such as the CS3 or 12, could not have been reduced easily so far. There is, furthermore, a limit to the variation on this parameter; reducing it to 0 would be quite wrong and illogical, for example. In chapter 5 (section

5.2.12), the hypothesis of a hidden layer of insulation in the CS12 flat roof had been tested, and the $H_{T,heat}$ coefficient had been reduced by 20% under a believable hypothesis; -25% seemed therefore like an acceptable limit for this analysis.

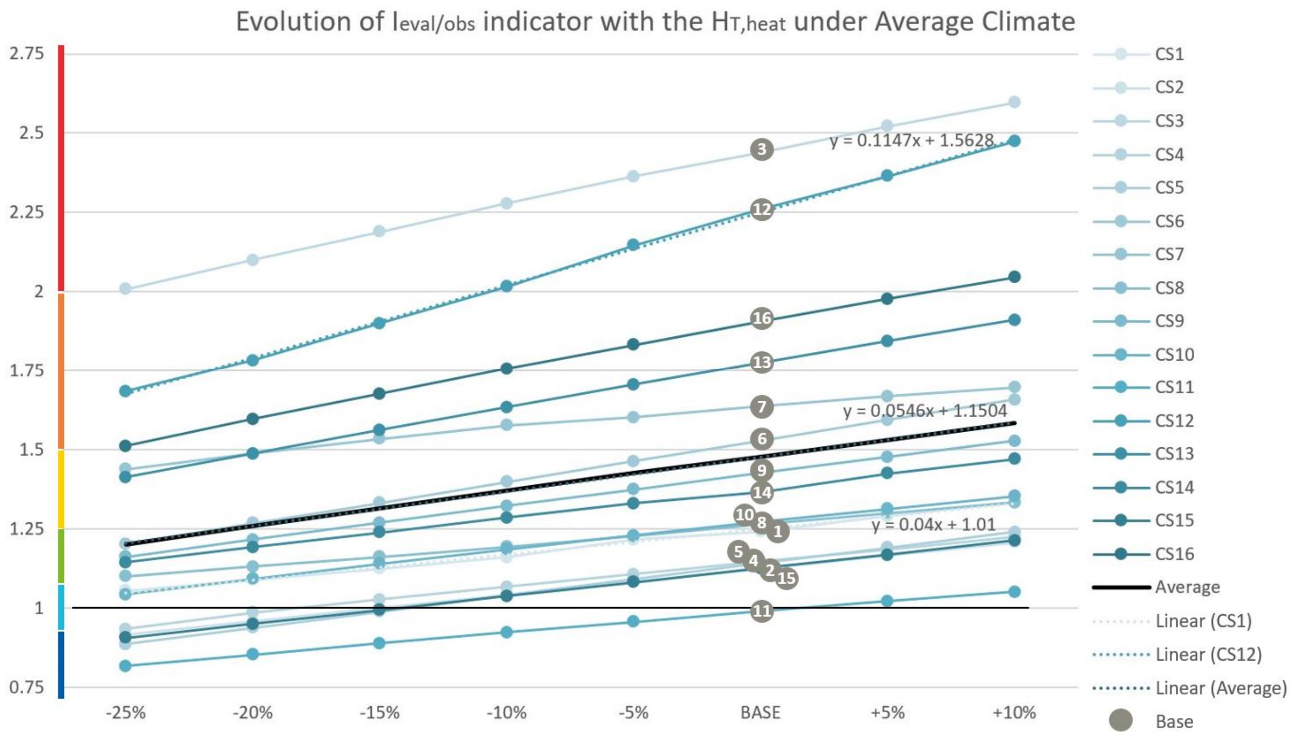

Fig. 6.5.5. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$H_{T,heat}$" analysis under the average climate hypotheses.

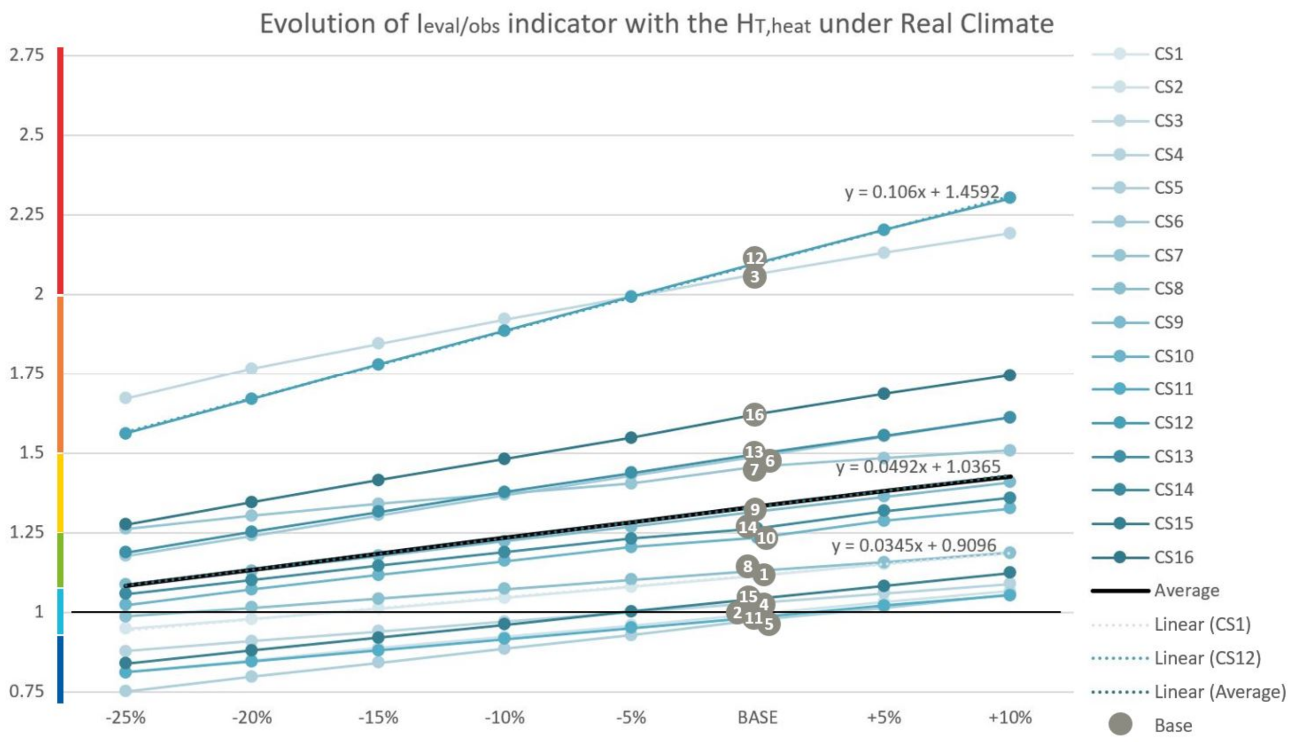

Fig. 6.5.6. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$H_{T,heat}$" analysis under the real climate hypotheses.

The main influence on the "scaling" analysis seems to be found: as expected, the results in energy consumption are still highly influenced by the $H_{T,heat}$ coefficient, evaluation base for the transmission heat losses. The CS12 sees its consumption results particularly impacted by the "$H_{T,heat}$" variation, with a 11.7% (11.8% in real climate) decrease in consumption associated to a 5% decrease in $H_{T,heat}$.

The definition of variants in chapter 5 was, also, often accompanied by an important reduction in $H_{T,heat}$ coefficients. These results, therefore, must be observed keeping in mind that the CS1, 3, 5, 10, 13 and 14 (and CS8 and 15, to a certain extent) could have entered this analysis with much higher $H_{T,heat}$ coefficients, and therefore would have seen their results vary much more, like the CS12, 5, or 6… The variation on the $H_{T,heat}$ also translates the same variation on the average U-value, at constant heat loss area. Under that light, it seems normal that the most impacted case studies should be those which still displayed important coefficients to begin with, and/or important heating shares in total consumption. It is easy, therefore, to blame the wrongfully described envelopes for the remaining $I_{eval/obs}$ ratios of CS3, CS12… Suspicions grow but (acceptable) proof is still needed.

Interestingly, the least impacted case studies are not the CS8 and 15. Such efficient dwellings are characterized by low average U-values, but their size brings their $H_{T,heat}$ coefficients at the same level of smaller but less insulated houses, such as the CS1 or the CS14. For those cases, a 5% decrease in $H_{T,heat}$ does not represent much [W/K] of losses per se, which explains the smaller impact of the variation (4 to 6% decrease in consumption associated with a 5% decrease in $H_{T,heat}$). Furthermore, those case studies are equipped with more efficient heating systems; and other case studies in the same situation, such as the CS11, also find themselves less influenced by the $H_{T,heat}$ variation (around -7% in energy consumption per 5% decrement in $H_{T,heat}$, which is the approximate sample average).

It must be acknowledged that the variation of the $H_{T,heat}$ coefficient also influences the definition of the f_{pct} factor used in the evaluation of the resulting temperature in unheated spaces. This means that, when the $H_{T,heat}$ coefficient is lowered, so is the ΔT between heated and unheated spaces, which would tend to increase consumptions. A global decrease in consumption marks the dominance of the direct influence of that coefficient on the definition of the heat losses by transmission ($Q_{T,heat}$). Other determiners exist in their evaluation, especially in this modified method; the next sections will target those.

6.5.3 Time repartition

This section places the periodic repartition of the heating pattern, used in the revaluation of the heat losses, into perspective. The Equation (6), describing the definition of the transmission heat losses coefficient in the official, standardised, regulatory method (visible below) indicated the use of a "t_m" factor that is, by the discretizing process, developed for this modified method in Equation (8):

$$Q_{T,heat,m} = H_{T,heat} \times (18 - \theta_{e,m}) \times t_m \quad (6)$$

$$t_m = t_{m,heat} + t_{m,noheat} = t_{m,noheat} + \sum_{i=1}^{i=\infty} t_{m,heat,i} \quad (8)$$

This means that for each $t_{m,i}$ period, the set temperature could be redefined to better fit the reality of the households' comfort conditions, approached on the basis of their answers to the questionnaire about the set temperatures of the different main heated spaces, and the volumetric proportions that were deduced from that. This way, a big uncertainty on an standardised annual average (T_{set} = 18°C in the regulatory calculation method) is replaced by smaller uncertainties on personalised average temperatures for the different periods of heating time "i" ($T_{set,i}$). The Figure 4.3.1, which explained the process visually, is recalled below:

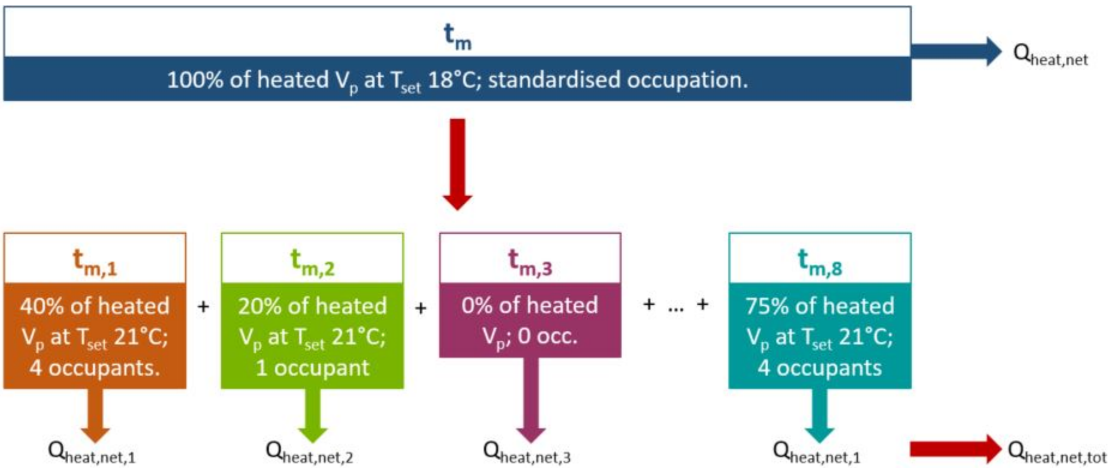

Fig. 6.5.7. Discretising pattern proposed in the modified method

6.5.3.1 Bathroom time and Night time

The repartition in eight periods cannot really be questioned here, as it is precisely the common base deduced from the answers to the questionnaire. The repartition of the 24 hours of the day between these periods, however, is mainly dependent on the number of inhabitants in the dwelling, which determines the length of the "bathroom" time periods (marked, in general, by a higher average set temperature). Thus:

- "BTR+0.5" is a set of simulations where the length of ablutions periods, initially estimated at 30min/occupant, is increased to 30min. + 30min/occupant for each case studies. This half hour is deduced from the morning and evening periods, equally.
- "TMN-1" is a set of simulations considering that the night time periods, initially imposed at eight hours, are reduced to seven hours. This increases the morning and evening periods of a half-hour, and does not affect the bathroom times.
- "BOTH" is a simulation that considers both changes above simultaneously.

The Figures 6.5.8, 9 and 10 hereunder display results, for these three sets of simulations, in the form of the $I_{eval/obs}$ indicator, with the same colour code developed in chapter 5. All results are presented following the same sequence: first, the results of the base point (defined above in chapter 5) modelled under the average climatic conditions, then the revaluated results considering the variable defined in the sensitivity analysis, under the same climatic conditions. The results, in the same order, for the revaluations made under the real climatic data conditions, follow.

The variations brought by the "BTR+0.5" set of simulations are of small range. As expected, only the households that declared heating their bathroom at higher temperature when in use (CS2, CS4, CS7 or CS10) present a small increase in consumption (and $I_{eval/obs}$ indicator, in consequence). Other case studies present small increases due to the slight reduction of unheated periods, as a consequence of the extension of heated bathroom periods. The greatest change merely brought a 2.22% difference in the revaluated total final consumption result, and therefore on the $I_{eval/obs}$ ratio. On average, the "BTR+0.5" option represents a 0.34% increase of consumption. This tends to mean that the actual length of the bathroom use period is not so important to the global result, and the hypothesis of a half hour per occupant cannot bring an important under- or overestimation.

The results of the "TMN-1" set of simulations are of the same order, with small range of energy consumptions concerned by these variations. In the CS10, the only case study where no heat is demanded at night (not even by a temperature setback), this meant the extension of the heating periods (mornings or evenings), and an increase in consumption.

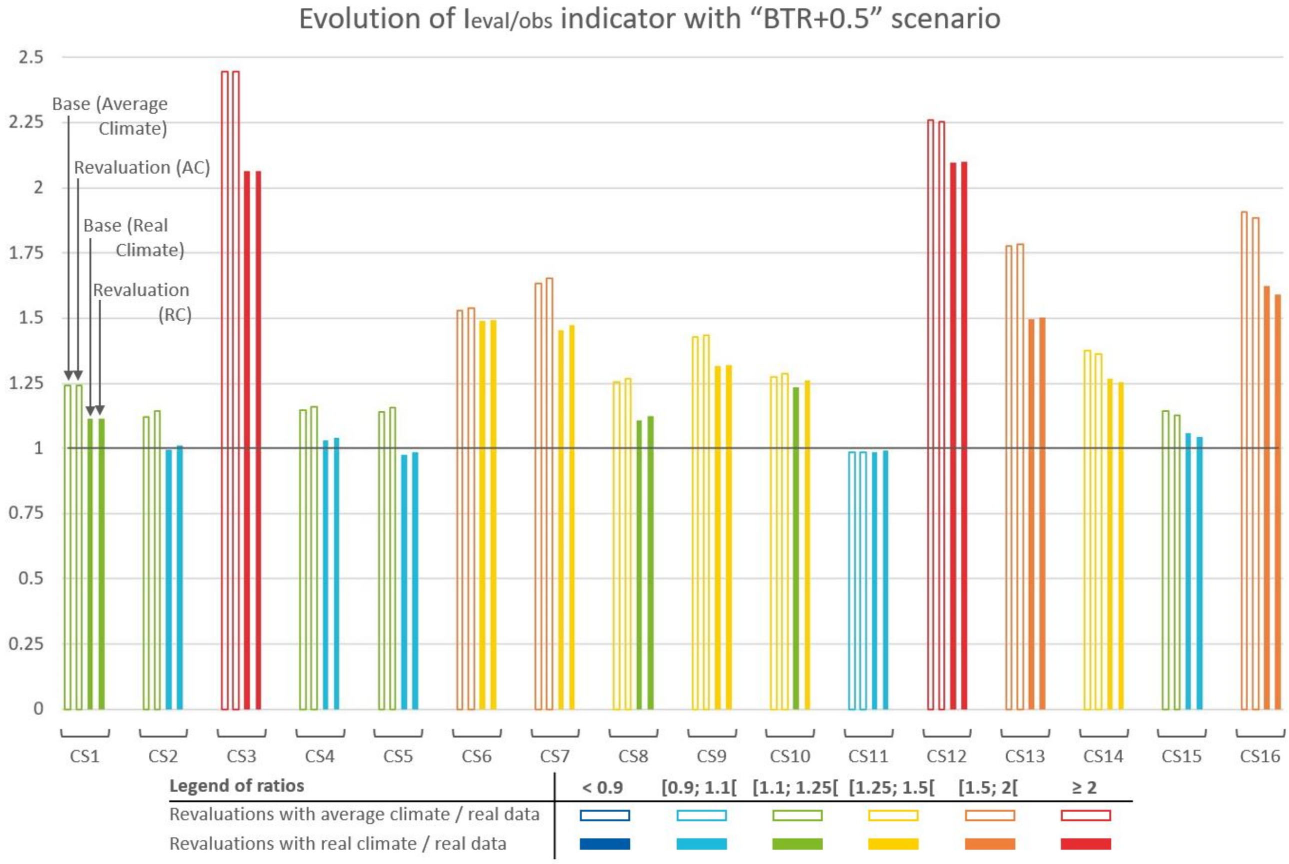

Fig. 6.5.8. Overview, for each case study, of the $I_{eval/obs}$ ratio for the "BTR+0.5" analysis.

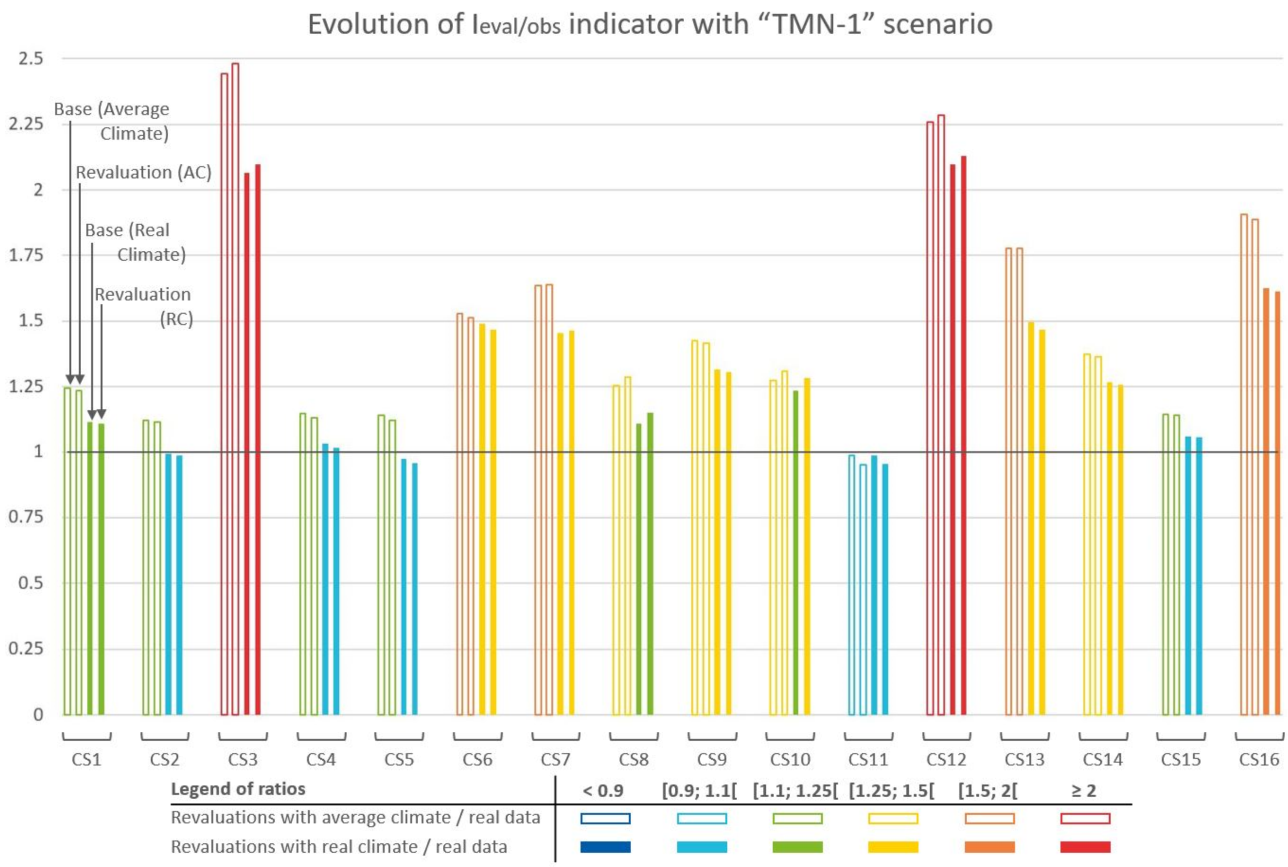

Fig. 6.5.9. Overview, for each case study, of the $I_{eval/obs}$ ratio for the "TMN-1" analysis.

The CS3, the CS8 and the CS12 display the same kind of increase, because the hour of setback heating at night is replaced by an hour of daytime heating at higher temperature, for a greater volume. The CS11 shows a decrease in consumption, because of the lighter heating pattern: diminishing the night time period of one hour mainly means the reduction of the demand, not the replacement by a period of higher heating. The range of variation of the results is a little bit wider (between -3.4% in the CS11 and +3.9% in the CS10), and the sample average is a reduction of the final energy consumption by 0.2%, indicating that the actual length of the night setback period might not be an important input, when considered alone. A 3% gap of consumption is acceptable and could be considered for those cases where the heating pattern is "light", or the night periods are unheated.

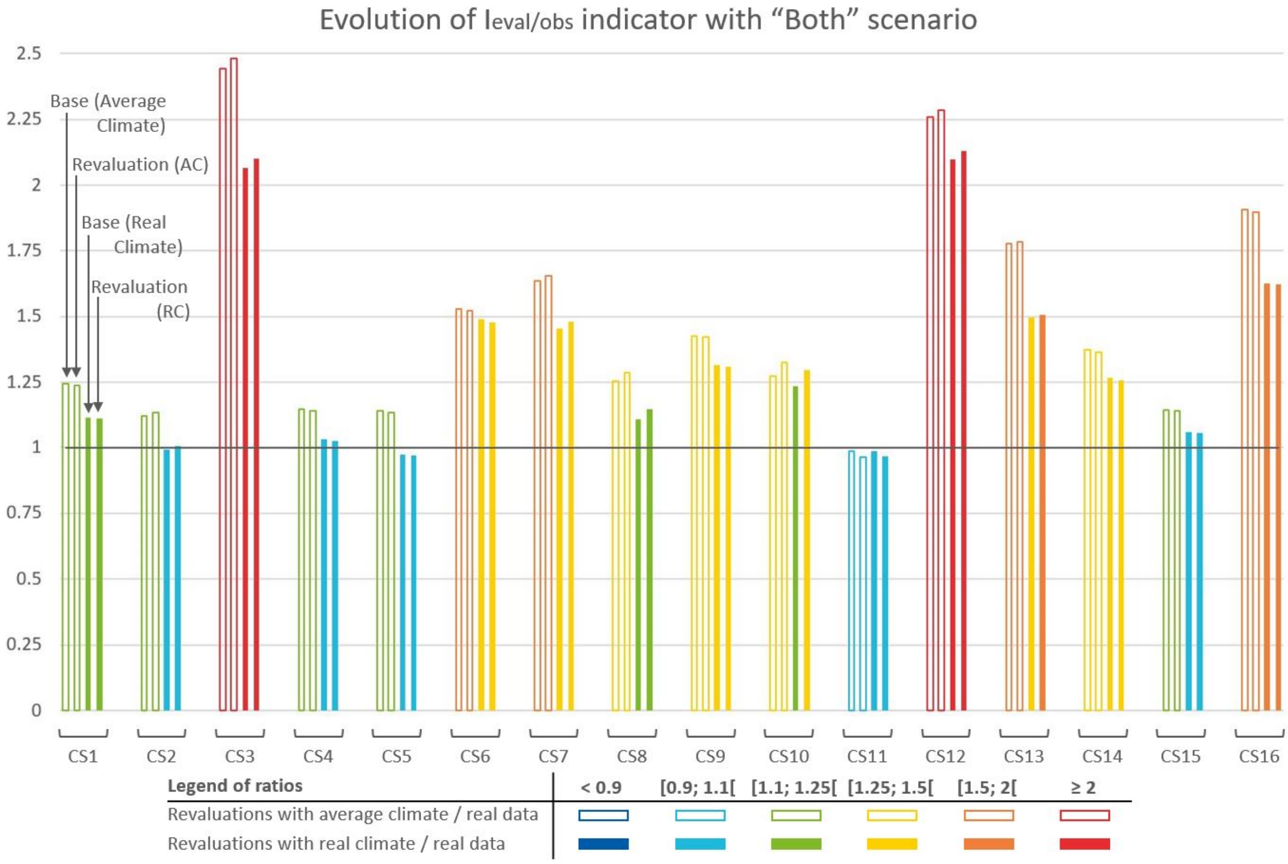

Fig. 6.5.10. Overview, for each case study, of the $I_{eval/obs}$ ratio for the "Both" analysis.

The combination of these changes translates into the simple addition of the results of both changes made separately. Most cases, such as the CS11, balance an increase due to the extension of the time spent in the bathroom, with a decrease due to the reduction of the night setback period. The range of variation is therefore kept lower (less than 3%, usually less than 2%). The CS10, which saw its expected energy consumption raised by both sets of hypotheses (due to previously unheated night time periods and overheated bathroom during ablutions), witnesses a global increase of 5.1%, the highest range of variation. The average variation is a slight increase in total energy consumption by 0.5%, which seems negligible.

6.5.3.2 Vacancy

This next section enquires about the influence of complete vacancy periods on the heating and DHW consumptions results. The first approach was to reduce the length of the months proportionally, but the heat losses and heat gains were therefore concentrated on smaller period, and not necessarily reduced. The solution was rather to keep the complete calculation of annual demands in heating and DHW, and proceed to apply a reduction factor to simulate the vacancy period. Four situations were defined; their impacts on the results can be added if they appear simultaneously in the description of a household's occupancy pattern:

- "2dpm" simulations consider the building unoccupied two days (and nights) per month. The results are visible in Figure 6.5.11 below, indicating reduction of the consumptions between 2 and 7%, depending on the case study. The smallest reduction is attributed to the CS8 (high efficiency and low set temperature), whereas the CS5, 15, 16, 11 or 12 benefit from the highest reductions, between 6 and 7%. The average reduction for this "2 days of vacancy per month" scenario is 5.65%, similar for both climates. These results indicate the need to enquire more closely on, for example, the average number of days per month when the whole house is left completely unheated, as the impact on the results are non-negligible.

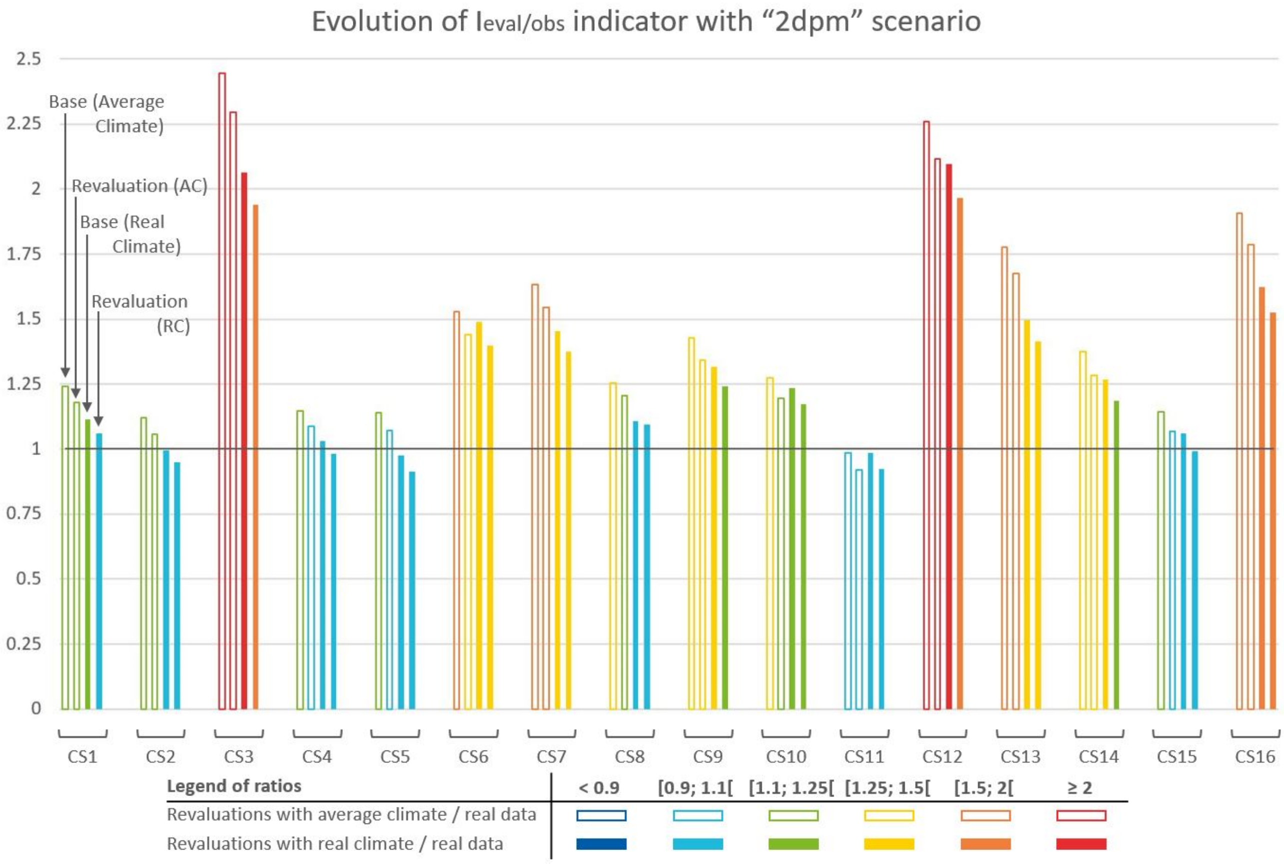

Fig. 6.5.11. Overview, for each case study, of the $I_{eval/obs}$ ratio for the "2dpm" analysis.

- "Sumhol" simulations consider the building unoccupied for two weeks in the summer (one in July, one in August), which mainly affects the DHW consumption by a factor of (351/365=) 0.96. Although all case studies see their fuel consumption reduced after the "sumhol" vacancy simulation, none of them presented important variations. Even the CS8 and 15, which have a greater share of their consumption dedicated to DHW due to their global high heating efficiency, only reduced their consumptions by 2%. A case study equipped with a cooling system might bring higher variations in the results, but the average on the sample is a 0.7% reduction (0.76% under the average climate, 0.62% under the real climate). Summer holidays do not seem to be an important input.

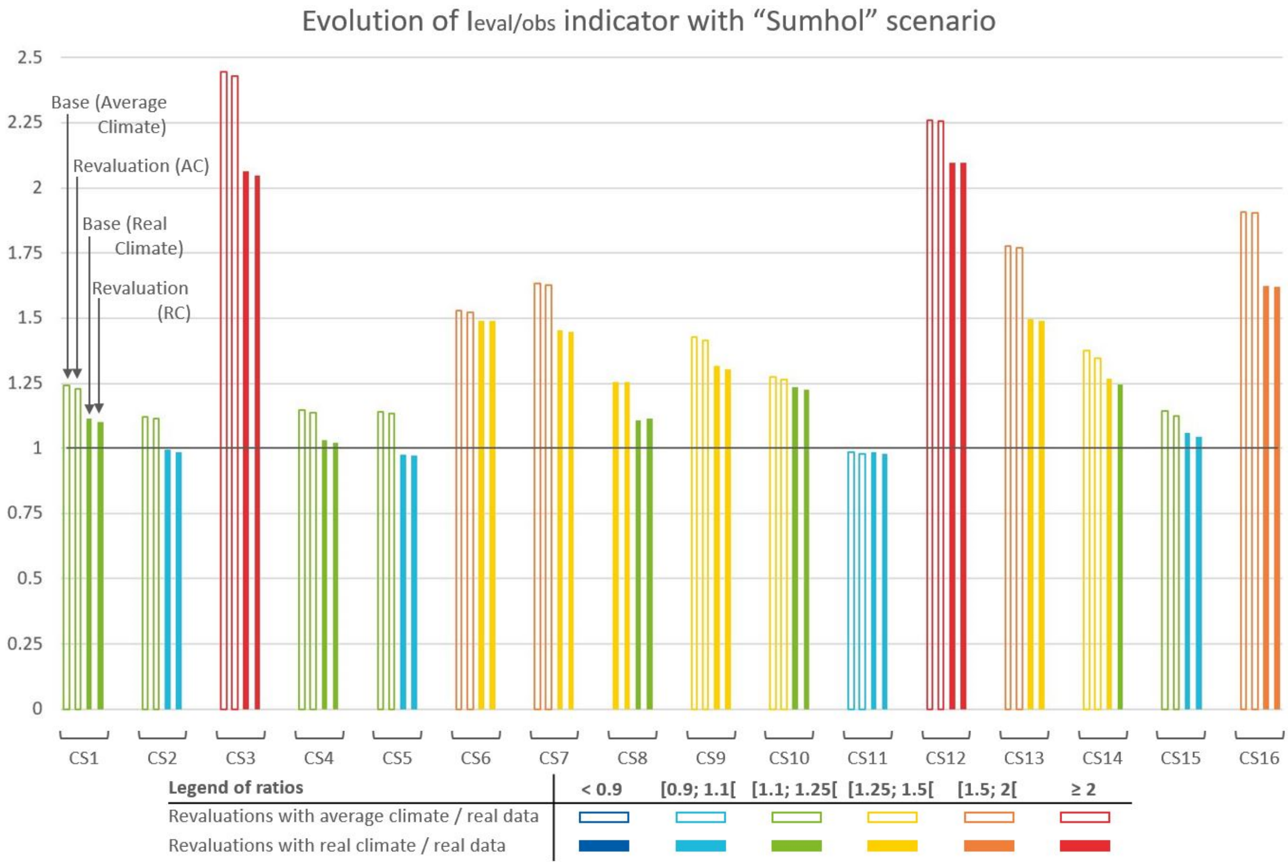

Fig. 6.5.12. Overview, for each case study, of the $I_{eval/obs}$ ratio for the “Sumhol” analysis.

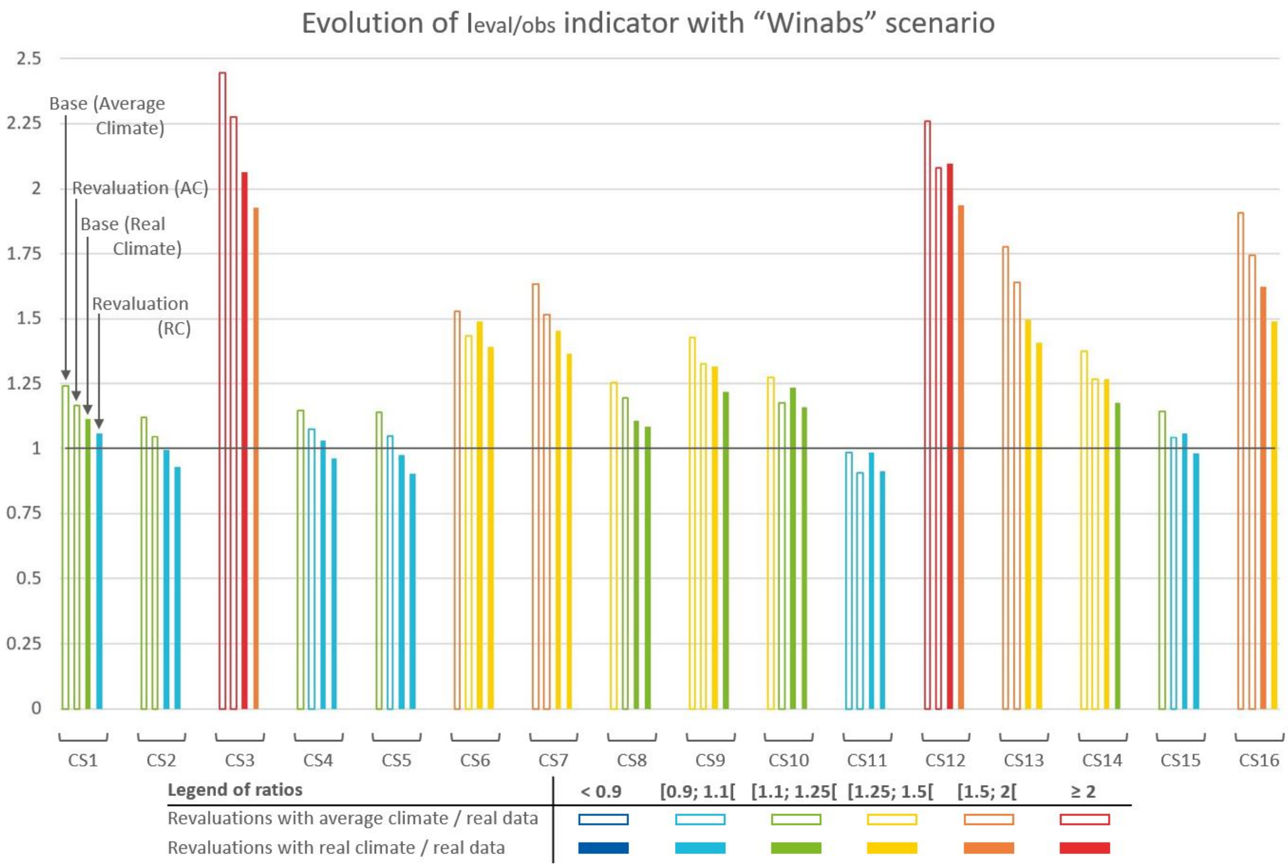

Fig. 6.5.13. Overview, for each case study, of the $I_{eval/obs}$ ratio for the “Winabs” analysis.

- "Winabs" simulations consider the building unoccupied for two weeks in the winter (one in December, one in February). To the same reduction in DHW consumption, these results add a reduction in heating consumption. The effect is more visible on those results displayed in Figure 6.5.13 above, where winter absence is translated on average by a 6.8% reduction in this sample (7.3% under AC, 6.5% under RC). Those results are quite similar in all the case studies. The maximal reduction (8%) appeared in the CS5, CS15, CS16, CS11 or CS12, and the minimal in the CS8 (around 3%), without necessarily marking a clear tendency among the sample. The variation range of results is more important here than it was for the summer holiday, so that it seems important to add a question in the questionnaire for the owner to quantify those periods properly.
- The last set of simulations enquires about an assumption often heard during the owners' interviews, declaring that their heating system did not work at night despite the temperature setback. Mrs P., owner of the CS16: "*Well, at night, the thermostat is on 14°C. This winter, it never turned on at night. It's very rare, it has to be really cold. No, it never turned back on at night.*" Mr. K., owner of the CS11: "*We never go down in temperature to 16°C. Sometimes, when I wake up at night and go downstairs… I've never seen the thermometer go that low, maybe because of air tightness, thermal mass, it takes time to lower the temperature [of the house].*" This might be perfectly true in reality, but does it mean that the night time heating should be equalled to zero in the theoretical model? Those two very different case studies have not been chosen randomly, as visible in the Figure 6.5.14 below:

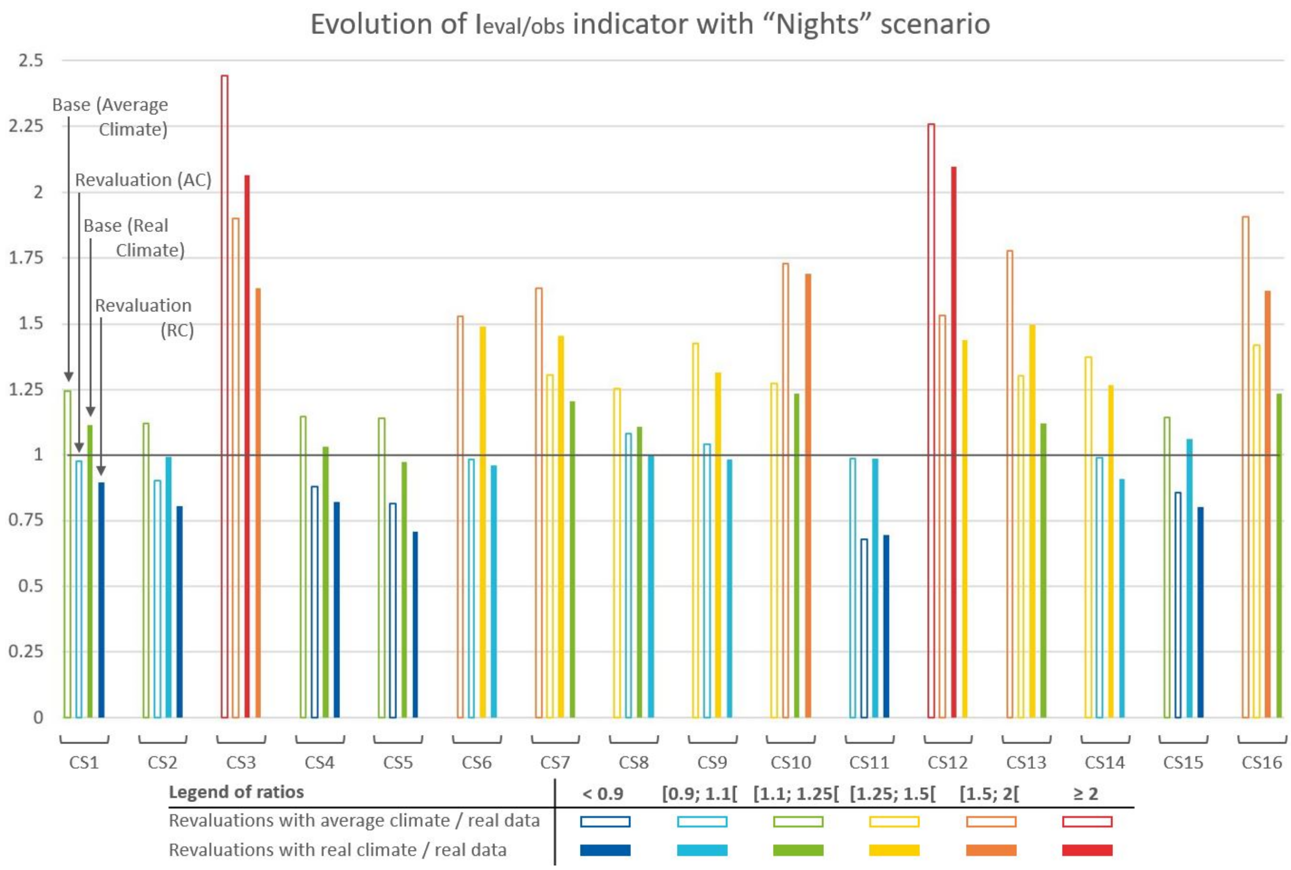

Fig. 6.5.14. Overview, for each case study, of the $I_{eval/obs}$ ratio for the "Nights" analysis.

The CS11, which already had very encouraging results with $I_{eval/obs}$ ratios close to 1, sees its consumption drop by 30% on average, landing way below the real consumption. Other case studies which presented low $I_{eval/obs}$ ratios (such as the CS1, CS2, CS4, CS5, CS14 and CS15), now display too low results when nights are considered unheated. The CS16 (along with the CS3, CS6, CS7, CS9, CS12, CS13), which presented an important remaining $I_{eval/obs}$ ratio (>1.5), benefits from the average consumption drop of 24.6% to get closer to the real data. The effect can be differentiated between case studies, however, as that reduction spans between 35% in the CS6 (where the living spaces were heated at 22°C in the base simulation), and 10 to 15% in the CS8 (which presents a low proportion of heated volume at night, a low temperature setback of 16°C and a high efficiency level) and the CS15 (where temperature settings are a little bit higher). The efficiency of the building might be an important parameter, but the weight of the nightly heating pattern is another one: households that tend to heat more rooms, at higher temperature at night, will see their energy bills more affected.

The averages and results discussed above do not take the CS10 into consideration: as the only case study which owner declared no night time heating at all, it marks an exception. In order to assess the related potential increase in consumption, a setback temperature of 16°C (average in this sample) has been imposed in the living room, dining room and kitchen (all adjacent and open spaces, common base on this sample of usual night time heated spaces), which increased the consumption by 35%. This is high, compared to the reduction brought by the opposite hypothesis in the other case studies, because this CS10's household presented the lowest number of daytime heating hours of the sample.

Considering the nights unheated in the model would be convenient in half concerned cases, but inaccurate in the other half. The repartition of consumptions between the different periods of the day is not possible in the real data, nor is it in the model, so that precise comparisons are not possible. It must be reminded that the modifications brought to this method mainly targeted the Net Heat Demand revaluations through added inputs: the single-zone stationary model that ensues still leans on averages and globalized monthly parameters (such as the monthly average exterior temperature). Unheated nights should translate in the results, without having to conveniently impose it in the model. The high share of consumption that is at stake here requires to enquire more precisely on those habits. The questionnaire asked the owners to describe a (cold) winter week, but information on warmer months nights might modify the global heating pattern, for example.

6.5.3.3 Heating hours

In the regulatory calculation method, the house is heated 100% of the time. Lengths of the months, represented by the t_m parameter, are simply added to form the length of the heating period. Chapter 4 modified the Equation (9) into Equation (13) for the calculation of the heat losses by transmission, notably by discretizing the length of each month and reducing the heating period to a total length $t_{m,heat,m} < t_m$. It must be noted that this $t_{m,heat}$ represents the periods of demand in comfort: a $t_{m,heat}$ of 80%, for example, indicates that there is a set temperature somewhere in the house (even if for only one room) during 80% of the week, regardless of the exterior climate and the necessity – or not – to effectively turn the heat on. This last set of simulations dedicated to the time repartition takes an interest in the proportion of heated vs unheated hours, in order to assess its influence on the results and the possible necessity to define this $t_{m,heat}$ more precisely. The Figure 6.5.15 hereunder shows the evolution of the $I_{eval/obs}$ ratio, under the average climate hypotheses, for all case studies, if the $t_{m,heat}$ parameter is imposed at different values comprised between 75% and 100% of t_m, for each month.

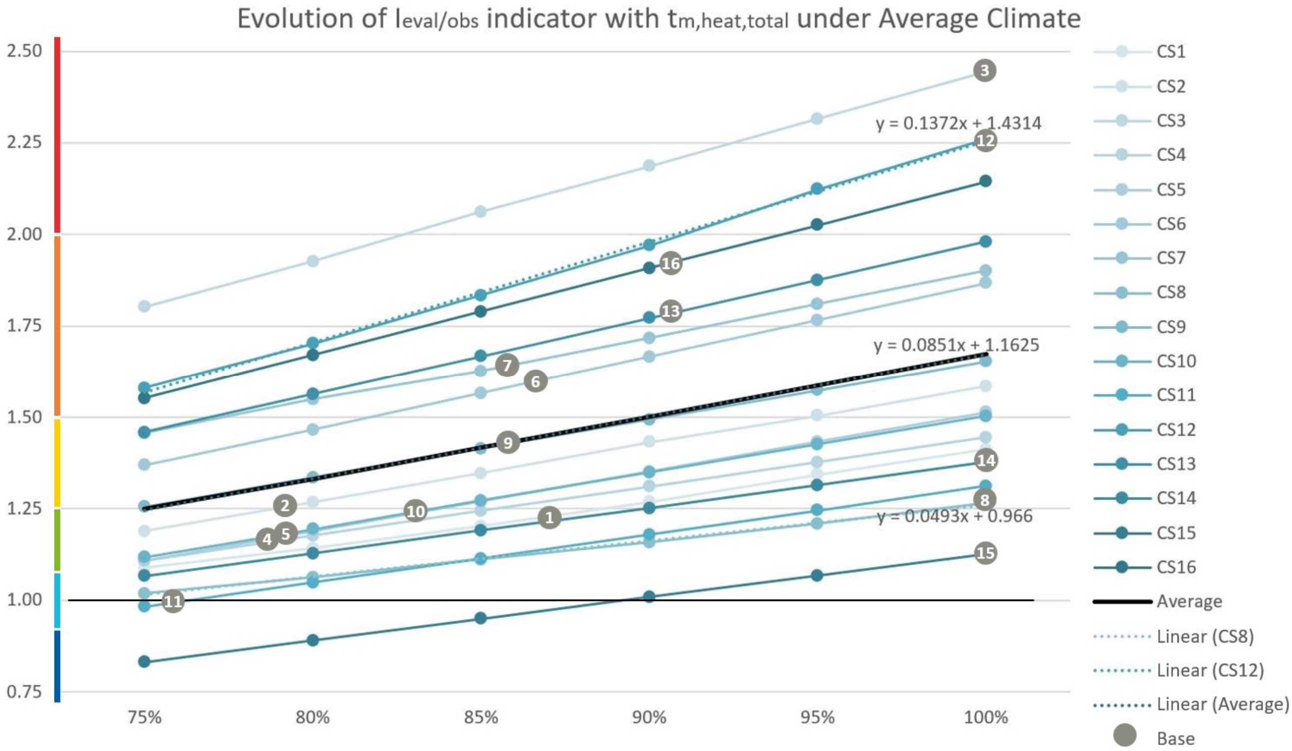

Fig. 6.5.15. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$t_{m,heat,total}$" analysis under the average climate hypotheses.

These limits on the variation range are applied on the daytime heating pattern described by the owners; the results of the "no night time heating" scenario has been evaluated above. All case studies presented total heating periods comprised between 75 and 100% of the time periods, as visible in Figure 6.5.15 and in the Table 6.5.2 below, which therefore defined the boundaries of this part of the sensitivity analysis.

Table 6.5.2 Heated periods (in % of the total time periods) for all case studies

Case study	Daytime heating [%]	Night time heating [%]	Total [%]
CS1	80.4%	100%	86.9%
CS2 (ES1)	69%	100%	79.3%
CS3	100%	100%	100%
CS4	67.9%	100%	78.6%
CS5	69%	100%	79.3%
CSS6 (ES1)	79.7%	100%	86.5%
CS7	78.6%	100%	85.7%
CS8	100%	100%	100%
CS9	78.6%	100%	85.7%
CS10	83%	0%	55.4%
CS11	63.7%	100%	75.8%
CS12	100%	100%	100%
CS13	85.7%	100%	90.5%
CS14	100%	100%	100%
CS15	100%	100%	100%
CS16	85.7%	100%	90.5%

The heating patterns of the main (daytime) energy sectors have been used to define the heating periods of the CS2 and CS6. Heating patterns of the other energy sectors, in both case studies, are covered by those main sectors' patterns. The CS8 and the CS15 have been considered heated full time, because of a constant regulation by the thermostat and external probe. Evidently, the heating system is not on at all times, but the same could be said about any other case study: it is, here again, up to the method to translate this into low demand and consumption results. This hypothesis proved to be true in the case of the CS15, as it presents too low $I_{eval/obs}$ ratios (<0.9) when the heating periods are reduced (see Figure 6.5.15 and 16). The CS14 is also considered heated full time because of the use of electric accumulators as heating system.

There is a consistency that ought to be noticed, as all case studies present similar results, or at least similar evolution of their results. Trend curves, best defined as straight lines (linear regression), have been indicated for two case studies. The CS12 is the upper curve which displays the greater linear regression slope (8.6% increase for each increment of the $t_{m,heat}$ by 5%), explained by this case study's high set temperature and heated space proportion. The lower curve is related to the CS8, which shows the smaller linear regression slope (4.9% increase for each increment of the $t_{m,heat}$ by 5%). This is not negligible, although there is a noticeable difference between the CS8 and the CS15 (7.1% increase per 5% increment in $t_{m,heat}$), both high-efficiency dwellings, attributed to the difference in set temperatures (19.3°C for the CS8, 21°C for the CS15). The curves of the CS5 and the CS10 are almost identical: the difference in heated volume proportion (around 60% for the CS5, nearly double of the CS10) is compensated by the difference in set temperature (19°C for the CS5, compared to 20.3°C for the CS10). The black sloped line represents the linear regression of the case studies average, which results present a 6.8% increase for each increment of the $t_{m,heat}$ by 5%. This seems important enough to wonder whether, when household declare full-time heating, the questionnaire should enquire specifically about the unheated periods of time.

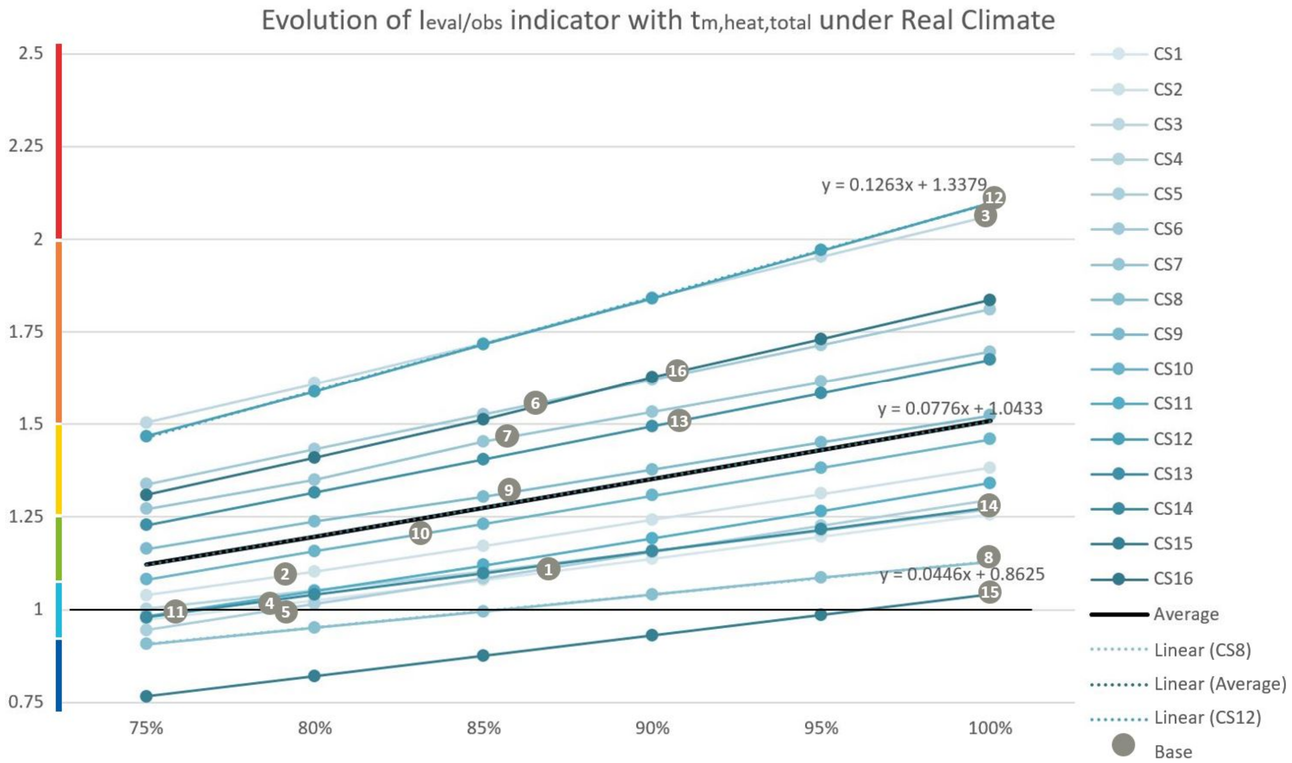

Fig. 6.5.16. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$t_{m,heat}$" analysis under the real climate hypotheses.

The Figure 6.5.16 presents the results under real climate hypotheses, which are very similar to those obtained under average climate hypothesis. These curves are globally lower and closer together (indicating that the real climate data bring revaluated consumption results closer to real data), but their slopes have not changed much (increase in consumption between 4.9 and 8.6%, 6.8% on average, for each increment of the $t_{m,heat}$ by 5%). The order of the curves have slightly changed, but this is only due to the different effects of the "real" climatic data on the different case studies.

6.5.4 Set temperatures

This section of the sensitivity analysis takes an interest in the factors that influence the temperature replacing the standardised 18°C of the regulatory calculation method in order to evaluate the heat losses by transmission and ventilation. Equations (9), (11) and (12) which define it are resumed here:

$$T_{uhs,m} = \left(T_{set,hs} + \Delta T_{tset}\right) - \left[\left(\frac{\left((T_{set,hs,m} + \Delta T_{tset}) - \theta_{e,m}\right)}{2}\right) \times \left(1 - f_{Vp,hs}\right) \times f_{\Delta T,uhs} \times f_{pct}\right] \qquad (9)$$

$$T_{set,i} = \left(T_{set,hs} + \Delta T_{tset}\right) \times f_{Vp,hs} + T_{uhs} \times \left(1 - f_{Vp,hs}\right) \qquad (11)$$

$$T_{set,m} = \sum_{i=1}^{i=8} \frac{\left(T_{set,i} * t_{m,heat,i}\right)}{t_{m,heat}} \qquad (12)$$

where:

- $T_{uhs,m}$ = monthly average temperature in unheated spaces during heating periods [°C];
- $T_{set,hs,m}$ = monthly set temperature in heated spaces when the temperature in unheated spaces is evaluated [°C];
- ΔT_{tset} = positive or negative increment in set temperature according to sensitivity to cold [°C];
- $\theta_{e,m}$ = monthly average exterior temperature [°C];
- $f_{Vp,hs}$ = ratio of the heated spaces' volumes on the total protected volume, during the heating period considered;
- $f_{\Delta T,uhs}$ = empirical factor affecting the temperature difference between heated and unheated spaces, which value depends on the tendency to close doors between them (0.8 to 1.2);
- f_{pct} = multiplicative factor considering the quality of the envelope as influence on temperature homogenization, described above.

The observation of the equations indicates two kinds of influences to watch for. On one hand, the set temperature in heated spaces, and the variation that is represented by the ΔT_{set} factor, intervene in several ways, both direct and indirect (influencing the resulting temperature in unheated spaces). Table 6.5.3 below presents, for each case study, the daytime set temperature for the living room ($T_{set,LR,day}$), the average set temperature in heated spaces during daytime, considering other rooms, heated at other temperatures during definite periods (Average $T_{set,hs}$), the nocturnal setback for the living room ($T_{set,LR,night}$) and the temperature increment during part of the heating period (ΔT_{set}). The detailed $T_{set,hs}$ for each case study and periods of the day are presented in the heating patterns, visible in chapter 5 and in the descriptive cards in the annexes. On the other hand, the $f_{Vp,hs}$, $f_{\Delta T,uhs}$ and f_{pct} factors play an influential role in the definition of that particular resulting temperature in unheated spaces, presented in the temperature curve graphs of the chapter 5 for each case study. The accuracy of that influence needs to be analysed, with the added difficulty that stands in the double (or, more accurately, squared) influence played by the $f_{Vp,hs}$ factor. On top of impacting the T_{uhs}, it also balances the Equation (11) which evaluates the $T_{set,i}$, the resulting temperature of the global V_P during the period "i". Table 6.5.4 below informs on the "base" values of those different parameters which have been fixed, as explained on chapter 4, according to the owners' answers to the questionnaire.

Table 6.5.3 Set temperatures for all case studies

Case study	$T_{set,LR,day}$ [°C]	Average $T_{set,hs}$ [°C]	$T_{set,LR,night}$ [°C]	ΔT_{set} [°C]
EPB	18	18	18	0
CS1	21	21	18	-0.5 (WHM)
CS2	21	21	16	-0.5 (WHM)
CS3	22	21.48	18	-0.5 (WHM)
CS4	21	21	16	-1 (WHM)
CS5	19	19	15	-0.5 (WHM)
CS6	22	22	22	+1 (CHM)
CS7	22	22.03	16	-0.5 (WHM)
CS8	20	19.3		-0.5 (WHM)
CS9	19	19.01	16	0
CS10	20	20.31		-1 (WHM)
CS11	21	21	16	+0.5 (CHM)
CS12	22.6	21.42	18	-0.5 (WHM)
CS13	19	19	16	-1 (WHM)
CS14	20	20.02	20	-1 (WHM)
CS15	21	21	17	-1 (WHM)
CS16	19	19	14	-1 (WHM)

Table 6.5.4 Parameters of the definition of $T_{uhs,m}$ (base point) for all case studies

Case study	$f_{Vp,hs}$ [%]	$f_{\Delta T,uhs}$ [-]	f_{pct} [-]	$(1-f_{VP,hs}) * f_{\Delta T,uhs} * f_{pct}$
EPB	100	1	1	1
CS1	38.3	1	0.378	0.233
CS2	53.4 / 53.8	1.2	0.841 / 1.256	0.47 / 0.696
CS3	34.3	1.2	0.996	0.785
CS4	50.3	1.2	0.675	0.403
CS5	59.7	1.1	0.863	0.383
CS6	49.5 / 100	1.2	0.668 / 1.022	0.405 / 0
CS7	25.8	1	1.301	0.965
CS8	57.5	1.2	0.218	0.111
CS9	33.6	1.1	0.435	0.318
CS10	31.4	1.2	0.800	0.659
CS11	25.3	1.1	0.684	0.562
CS12	64.9	1.2	1.457	0.614
CS13	51.9	1.2	1.121	0.647
CS14	28.9	1.2	0.425	0.363
CS15	52.5	0.9	0.214	0.091
CS16	38.9	1.2	1.010	0.741

6.5.4.1 Set temperature in heated spaces

The first parameter that ought to be analysed is the base from which all heat losses calculations are evaluated and which therefore represent a major influence on the results. This first set of simulations will therefore begin by considering the variation of the $T_{set,hs}$ in the Equations (9), (11) and (12), i.e. the set temperature in heated spaces. These equations indicate that imposing a variation on the $T_{set,hs}$ would also have indirect impact on the resulting temperature in the unheated spaces and on the resulting average temperature in the V_P, which replaces the standardised 18°C in the calculations. It should therefore not be a surprise that Figure 6.5.17 presents curves of the second degree, whereas the precedent figures of this sensitivity analysis showed nearly straight lines (first degree curves).

The range of possible set temperatures mentioned in the questionnaire spanned between 16°C and 24°C. In 13 case studies out of 16, a thermostat was present to attest of the answer from the owner and help fill the questionnaire. In the three other cases, the usual position of the thermostatic valves conditioned the set temperature in the different rooms (position 1 = 16°C; 2 = 18°C; 3 = 20°C; 4 = 22°C; 5 = 24°C). This set of simulations considers the variation of all set temperatures, for each period of time, with limits defined by a [-4°C; +5°C] range of variation around the base point, a minimal [-2°C; +2°C] variation for each case study, a minimal threshold of 18°C and a maximal cap of 24°C, if these temperature are outside of the [-2°C; +2°C] range.

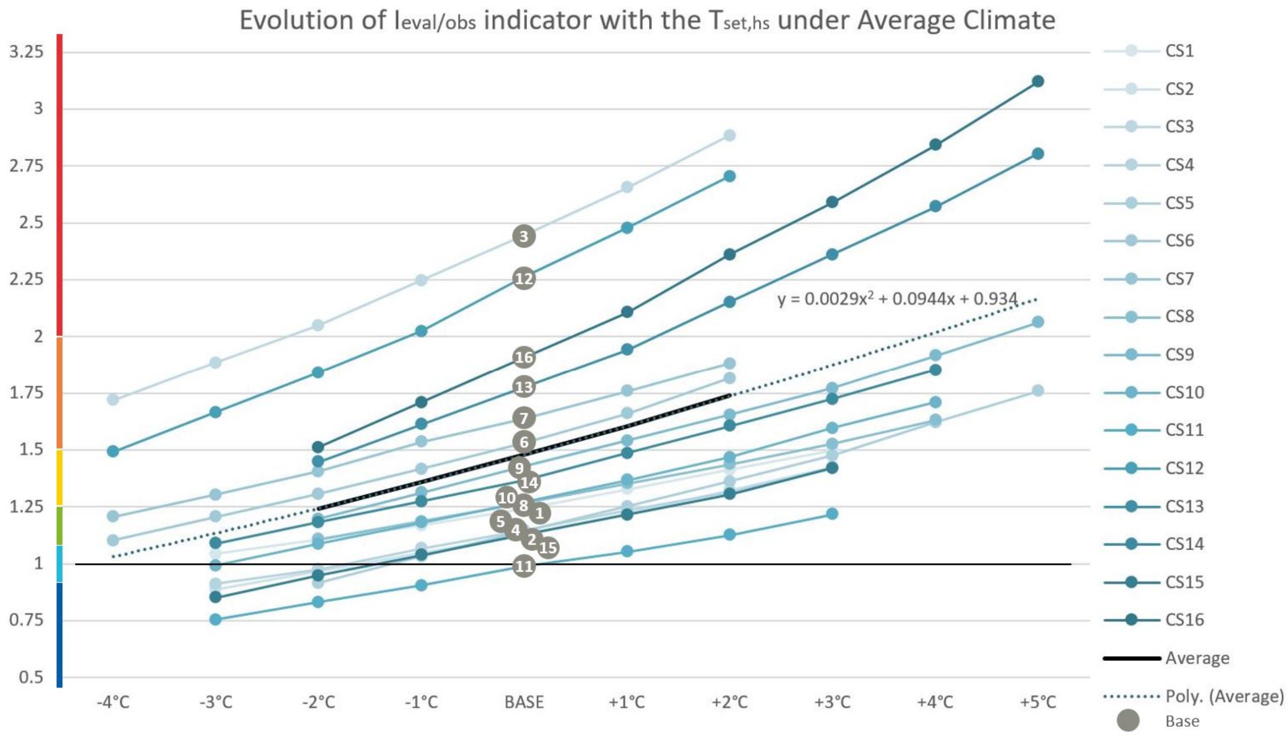

Fig. 6.5.17. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$T_{set,hs}$" analysis under the average climate hypotheses.

The most impacted case study is the CS16: in the [-2°C; +2°C] variation range, it registers the most important increase (14%) in consumption each time the $T_{set,hs}$ is increased by 1°C. This increase is then progressively reduced in CS13 and CS5 (12.1%), CS12 (11.7%), CS3 (10.2%)… Apart from the C5, they are all case studies that still showed important and unexplained $I_{eval/obs}$ ratios (>1). They all are among the least efficient buildings, expected therefore to see their consumption vary more when the average temperature inside varies. The CS5 displays a very low $[(1-f_{Vp,hs}) * f_{\Delta T,uhs} * f_{pct}]$ factor in Equation (9) (see Table 6.5.4), and the second-degree influence of its high $f_{Vp,hs}$ factor alone is visible in the relatively important results variations with the $T_{set,hs}$ parameter. The CS7 does not show the same kind of variations despite its low efficiency because of its high [(1-$f_{Vp,hs}$) * $f_{\Delta T,uhs}$ * f_{pct}] factor, the highest of the sample which maintains its influence on this set of simulations. At the other extreme end of the graph are the CS1 and 8, which register the slowest increases in consumption, around 7%, somewhat attesting the message often heard in energy saving campaigns in Wallonia, according to which "lowering your set temperature by 1°C decreases your [heating] consumptions by 7%".

The Figure 6.5.18 below displays the results for the real climate hypothesis, with a different layout: in this graph, the curves are presented according to the set temperature in the living room, instead of increments from the base set points. The order of influence has changed, by using the real climate data, marking an increased impact on colder climates (which explains the reduced variations for the CS4) and least efficient dwellings. It can be observed that, in those inefficient case studies, the living rooms were initially heated at either 19°C (CS16, CS13, CS5, all profiles showing care for the environment), or 22°C (CS3, CS12, both stay-at-home profiles). Apart from the CS5, they all still had high $I_{eval/obs}$ ratios for their base point. Should the revaluated consumption get closer to the real data, the upper curves on Figure 6.5.18 should progressively get closer to the CS8, or CS1 curves. These case studies present an 8% increase of their consumption for each °C increment in $T_{set,hs}$.

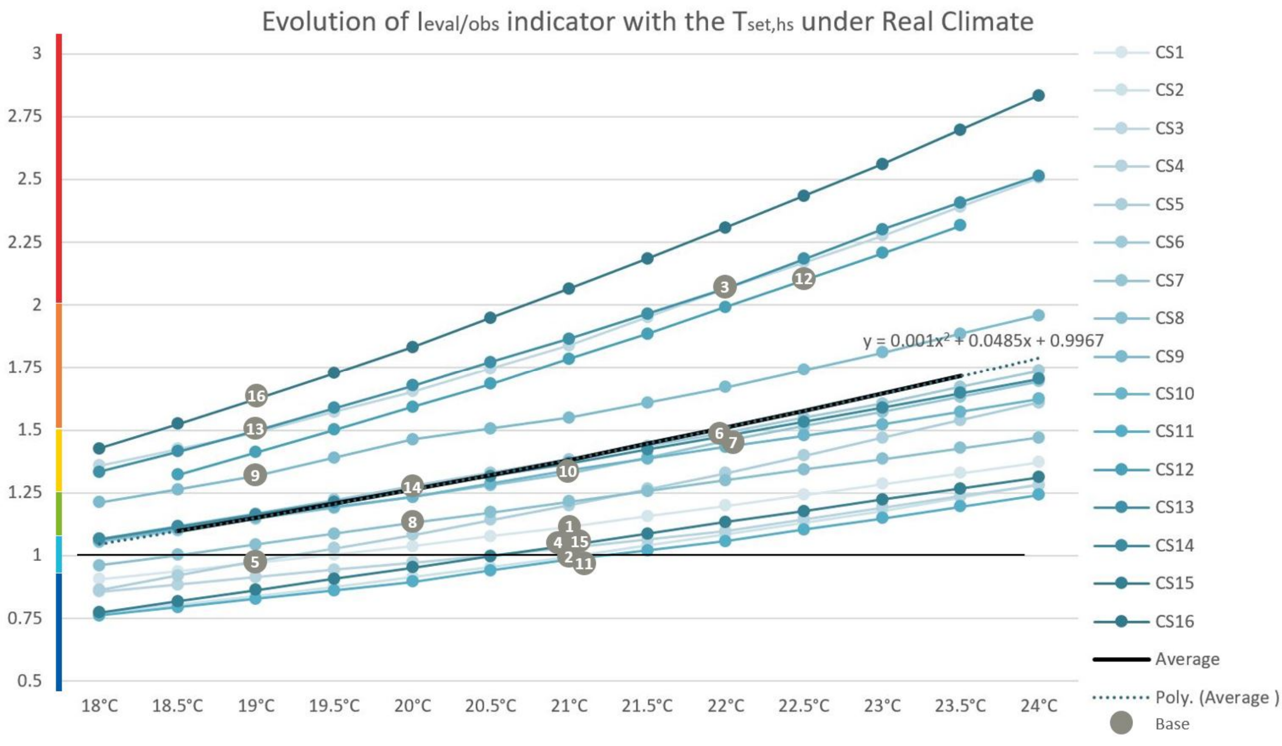

Fig. 6.5.18. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$T_{set,hs}$" analysis under the real climate hypotheses.

The second parameter of influence on the set temperature is the ΔT_{set} factor. The reaction of the owner to the following statement from the questionnaire defines its value: "Do members of your household tend to put a sweater when they are cold, instead of turning up the heat?" Agreement with the statement lowers the set temperature by 0.5 or 1°C during the warmer months of the heating period. Disagreement increases the set temperature by 0.5 or 1°C during the coldest months of the heating period, with the threshold between coldest and warmer months defined by the average monthly exterior temperature. All case studies have been submitted to the different values of that ΔT_{set} factor in order to assess the influence of this increment that translates the influence of the answer given to a single question.

The Figure 6.5.19 below displays the results for the average climate conditions. The case studies that are most influenced by this variation on the ΔT_{set} factor are the same that were most affected by the T_{set} analysis above: those that still presented high $I_{eval/obs}$ ratios, among the least efficient case studies.

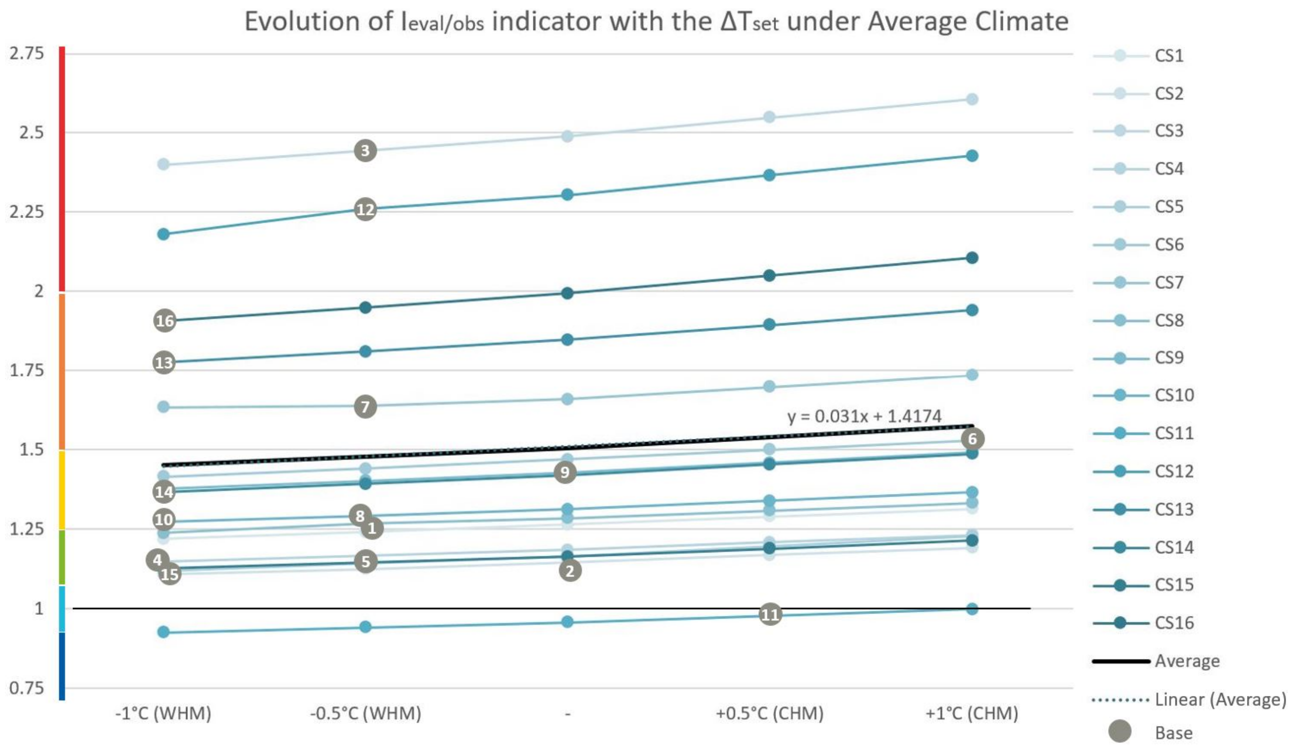

Fig. 6.5.19. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "ΔT_{set}" analysis under the average climate hypotheses.

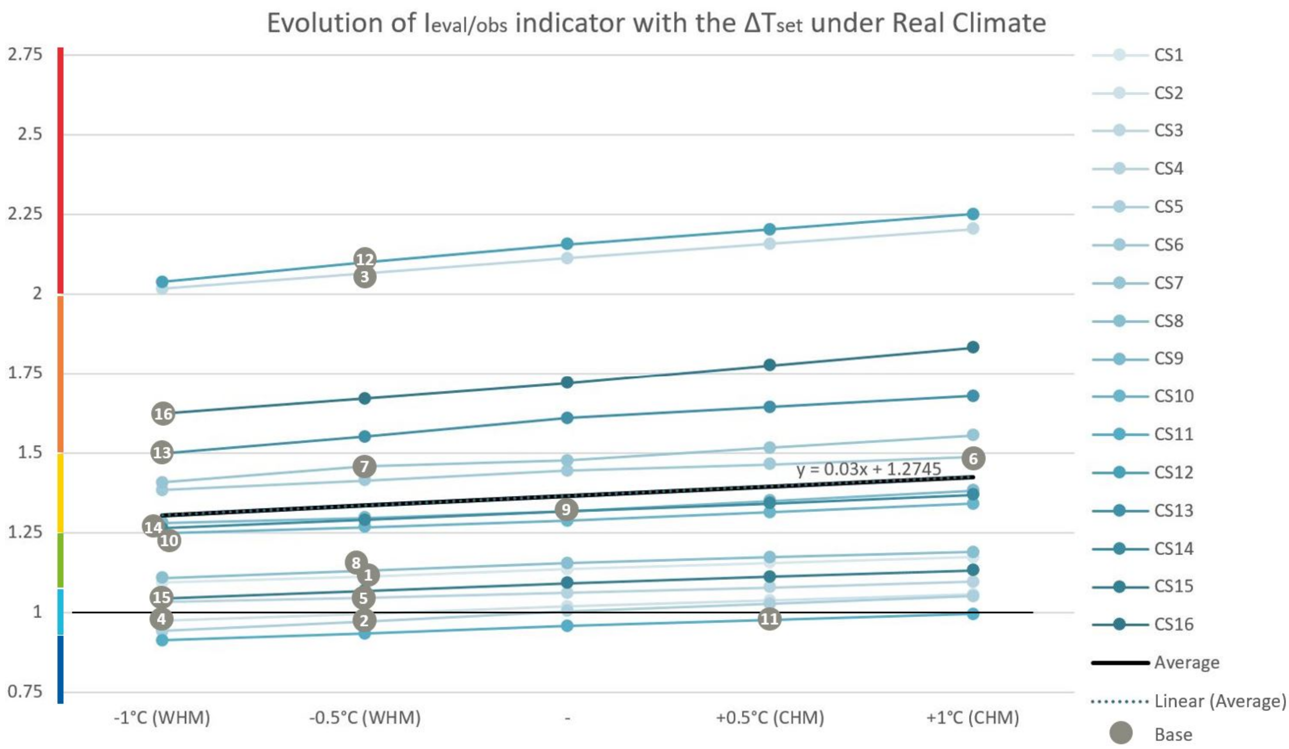

Fig. 6.5.20. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "ΔT_{set}" analysis under the real climate hypotheses.

The CS16, for example, sees its consumption decreased by 4.3% in the "WHM" scenario (-1°C of set temperature during Warmer Heating Months), and increased by 5.6% in the "CHM" scenario (+1°C during Coldest Heating Months). The same slight imbalance in the scenarios can be witnessed in all case studies: they all show smaller energy consumption reductions due to WHM scenarios (3.5% on average) than increases due to CHM scenarios (+4.5% on average). Here again, it is believed that bringing the $I_{eval/obs}$ ratio to 1 for all case studies, would translate into the convergence of the least efficient case studies' curves, towards those of the case studies that already have low $I_{eval/obs}$ ratios. In those cases, the WHM scenario brings around 3% of energy consumption reduction, whereas the CHM scenario brings around 4% of energy consumption increase. Globally the differences are few between the case studies, however.

The use of real climatic data, illustrated by the Figure 6.5.20, brings the same conclusions as the previous analyses, by generally lowering $I_{eval/obs}$ ratios and closing the gaps between case studies' curves, therefore translating the interest of those hypothesis in the search for accurate results. It also brings an interesting re-organisation of the ranking of influences: the CS7, for example, which was among the least influenced by the WHM scenario despite the dwelling's low global efficiency, is more impacted under the real climate conditions. There is also a better balance between the scenarios, as the WHM one brings an average 4.5% energy consumption reduction, and the CHM an average 4.2% increase.

6.5.4.2 Resulting temperature in unheated spaces

The resulting temperature in unheated spaces is needed in order to define the average temperature in the protected volume, which will in turn replace the standardised 18°C of the regulatory EPB calculation method. The Equation (9) of section 4.3.3.3, recalled at the beginning of this section 6.5.4, has been set in that perspective. The influence of the set temperature (and ΔT_{set} factor) in directly heated spaces, have been analysed above. This section will, therefore, focus on the other parameters of the T_{uhs}: the $f_{Vp,hs}$, $f_{\Delta T,uhs}$ and f_{pct} factors.

Similarly to the ΔT_{set} factor, the $f_{\Delta T,uhs}$ factor is conditioned by the reaction of the owner to a statement in the questionnaire: "*Do members of your household tend to close doors between heated and unheated spaces, in order to "isolate" them?*" The intent behind this question is, as mentioned in chapter 4, to consider that open doors would favour air transfers and temperature homogenisation between those spaces. As a result, full agreement with the statement, meaning a recurrent habit to close doors, is translated in a 1.2 value for the $f_{\Delta T,uhs}$ factor, increasing the temperature differential between heated and unheated spaces in Equation (9). Full disagreement (meaning that doors remain open) is given a 0.8 value for the same factor, thus reducing the temperature differential in Equation (9). This set of simulations seeks to determine the impact of that factor in the defined variation range that is [0.8; 1.2]. The Figures 6.5.21 and 22 hereunder show the results of those simulations on the sample, under both climatic sets of conditions.

The influence of this factor is globally low, with an average 2% decrease in energy consumption for each increment of the $f_{\Delta T,uhs}$ by 0.1, similar for both climates conditions sets. At the low end of the ranking can be found the most efficient dwellings, less influenced than the average (<1% decrease in consumption per 0.1 increment in $f_{\Delta T,uhs}$). At the other end of the ranking of impacts are cases that display higher values for the product of the other two factors influencing the resulting temperature in unheated spaces: $[(1-f_{Vp,hs}) * f_{pct}]$. The CS7, for example, displays the highest value for that product (0.965), and the steeper regression line slope in the Figures 6.5.21 and 22 below. The second highest value is given to the CS3, with 0.654. Under the average climate, it presents a 5.1% decrease in consumption per 0.1 increment in $f_{\Delta T,uhs}$. Under real climatic conditions, the effect is still more visible, with a 6.3% decrease in consumption per 0.1 increment in $f_{\Delta T,uhs}$. The influence of the $f_{\Delta T,uhs}$ factor can be considered negligible on the results of efficient (or accurately described) dwellings that already present $I_{eval/obs}$ ratios close to 1, but the $[(1-f_{Vp,hs}) * f_{\Delta T,uhs} * f_{pct}]$ product is much more influential on less efficient (or less accurately described) dwellings' results.

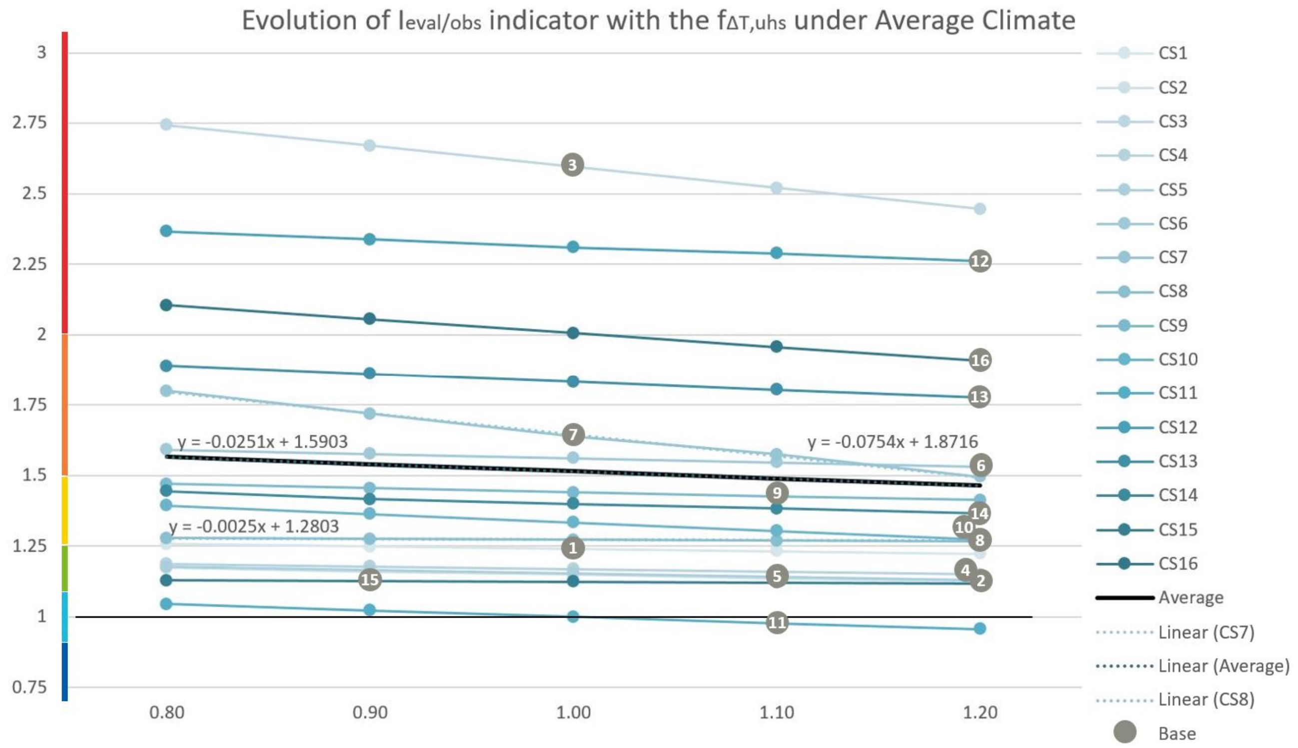

Fig. 6.5.21. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$f_{\Delta T,uhs}$" analysis under the average climate hypotheses.

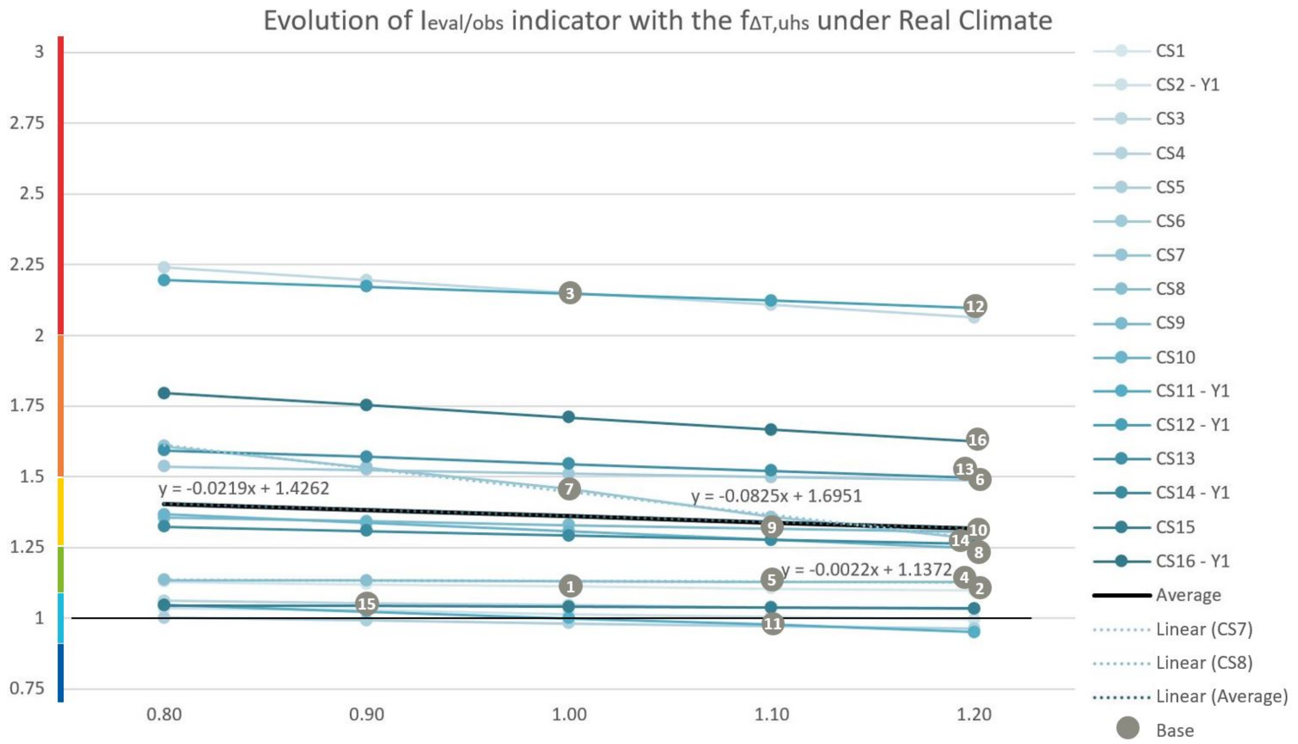

Fig. 6.5.22. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$f_{\Delta T,uhs}$" analysis under the real climate hypotheses.

Most owners (12 out of 16) declared agreeing with the questionnaire's statement, and used to close doors between heated and unheated spaces. In the CS8, it mainly meant the separation between daytime and night time spaces, heated at different temperatures during the day. The CS15, as efficient as the CS8, declared leaving the doors open, as all rooms are heated at the same temperature during the day. In inefficient dwellings (CS12, 13, 6, 10, 2…), closing the doors helps isolate heated spaces, and therefore save energy. Owners also mentioned that it serves the purpose of keeping the bedrooms colder, which is more comfortable at night. This brings a reflexion on the empirical values given to this factor, and on the position of its neutral value. In this method, its range of variation is equally spread out on each part of the "neutral" influence (value of 1) that is positioned on the "neither agree nor disagree" reaction to the statement. This "neutral" influence could have been given to the "fully disagree" reaction, thus changing the variation range of the $f_{\Delta T,uhs}$ factor to [1; 1.4], should the same 0.1 increment be kept. Most case studies would have seen their $I_{eval/obs}$ ratios drop, which is not necessarily an objective for all (CS2, 4 and 8 for example). Given the variation ranges on the other two factors ($f_{Vp,hs}$ and f_{pct}, see Table 6.5.4 above), it is expected that their influence would be more important on the results.

The $f_{Vp,hs}$ ratio is next to be evaluated here; it influences the resulting temperature in unheated spaces according to Equation (9), then the balance in the Equation (11) that defines the average temperature in the whole protected volume. In all case studies, the volumetric repartition of the different rooms in each dwelling have been modelled based on plans and/or measurements in situ, so that the ratio of heated spaces on the global volume ($f_{Vp,hs}$) can be given the highest level of accuracy. These models are visible in the presentation of each case study in chapter 5, as well as on the descriptive cards in the annexes, indicating by a colour code the position of the different spaces in the building. The Figure 6.5.23 displays the results of the first set of simulations, considering other ways to define the $f_{Vp,hs}$ ratio by averages:

- The "ALL" scenario considers volumetric repartitions of spaces based on averages evaluated on the global sample. All dwellings' spaces, and their respective shares in the global volume, have been used in the definition of these averages, in other words.
- The "TYPO" scenario considers typological volumetric repartition of spaces. The case studies have been distributed between 5 typologies: the blue collar house (CS6 and 16), the "modest" house (CS3, 7, 9 and 13), the "master" house (CS5, 10 and 15), the "urban extension" houses (CS2 and 4) and the more recent ones, built in concrete (CS1, 8, 11, 12 and 14). averages have been defined on each sets of spaces and volume shares.
- The "NbR" scenario sorts the case studies according to the number of rooms in the building, with the living room and dining room counting as 2, including the "other" spaces (heated or not) such as cellars, offices or workshops. The averages in volumetric repartitions have been made on sets that grouped the CS2, 10 and 15 (11 rooms); the CS5, 8, 9 and 11 (10 rooms, including the "cellar" and "office" basement rooms for the CS11); the CS1, 3 and 7 (9 rooms); the CS4, 12 and 13 (8 rooms) and the CS6, 14 and 16 (7 rooms).
- The "NbBDR" scenario is relatively similar to the previous one, with the exception that case studies are sorted according to the number of bedrooms: two in the CS6, 14 and 16; three in the CS1, 3, 4, 8, 11, 12 and 13; four in the CS2, 5, 7 and 9; and five in the CS10 and 15.

The Figure 6.5.23 shows that there is little variations to be expected from these different volumetric repartitions. Results of the simulations are similar under both sets of climate conditions: the range of variation spans between -5% and +6% around the base point, and there does not seem to be a way to proceed more accurate than another. No scenario approaches the "base points" results for every case study better than one other. All present the same [-5%; +6%] variation range on results, and a similar low average increase in consumption on the whole sample (between 0.3 and 1.1%).

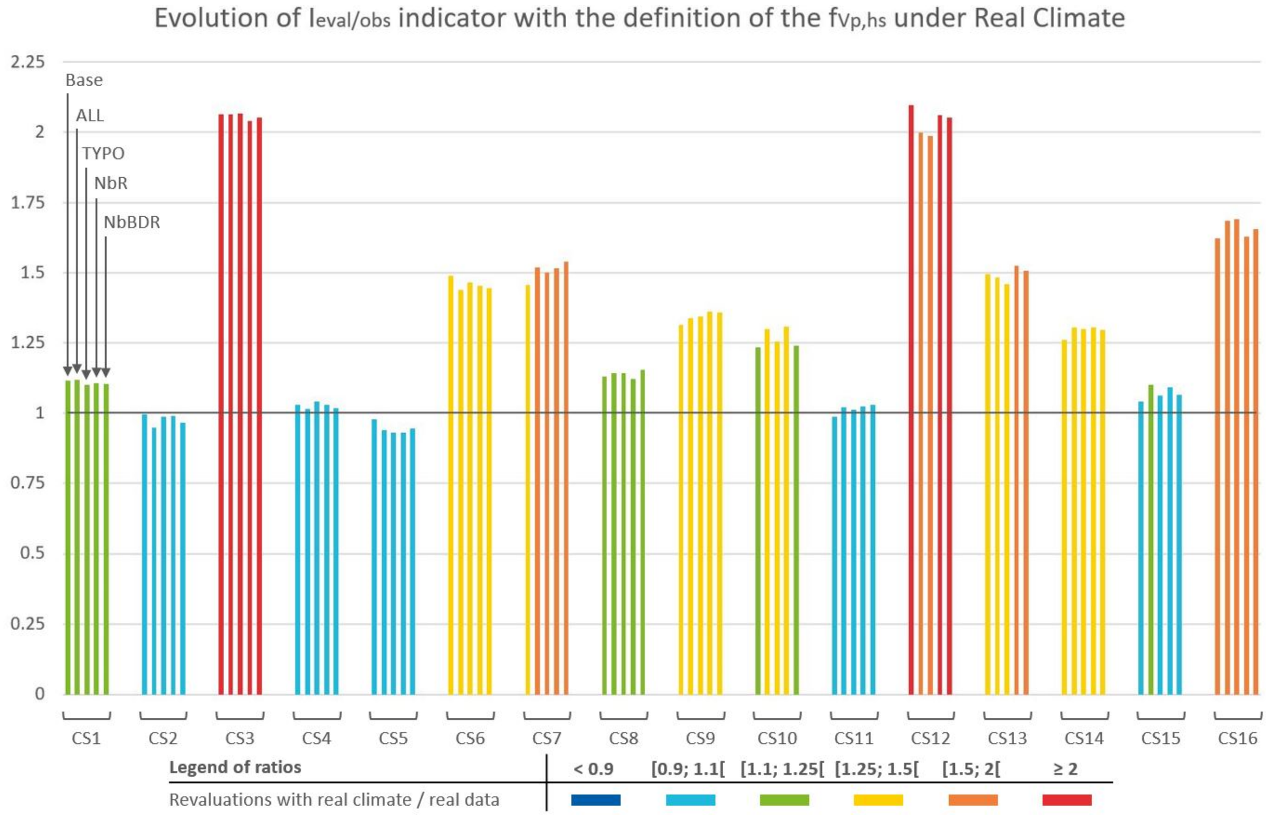

Fig. 6.5.23. Evolution, for each case study, of the $I_{eval/obs}$ ratio according to the definition of the "$f_{Vp,hs}$" ratio under the real climate hypotheses.

Case studies that benefit most from this variation on the $f_{Vp,hs}$ ratio are, in order, the CS5 (-4.2% on average), CS12 (-3.5%), CS6 (-2.6%) and CS2 (-2.3%), which presented volumetric repartitions above the averages, and/or low efficiencies. On the opposite, those who suffered the highest increase are the CS7 (+4.2% on average), CS11 and 15 (+3.8%) and CS10 (+3.4%). The order changes under average conditions, indicating the higher influence of those inputs than that of the $f_{Vp,hs}$ definition scenario.

It must be kept in mind that such a small sample cannot certify the accuracy of those averages. It would require a much bigger study on typologies to reach high accuracy levels.

The second set of simulations considers the variation of the $f_{Vp,hs}$ ratio between 0 and 100%, in order to define linear regressions, and to assess the results at the extremes that are:

- $f_{Vp,hs}$ = 0%, indicating the absence of heating by the reduction of the heated spaces to nothing. In the Equation (9) above, this translates in the suppression of the $f_{Vp,hs}$ ratio's influence on the resulting temperature in unheated spaces (see the new writing below). The Equation (11) is simplified thus:

$$T_{uhs,m} = \left(T_{set,hs} + \Delta T_{tset}\right) - \left[\left(\frac{\left(\left(T_{set,hs} + \Delta T_{tset}\right) - \theta_{e,m}\right)}{2}\right) \times f_{\Delta T,uhs} \times f_{pct}\right] \tag{33}$$

$$T_{set,i} = T_{uhs} \tag{34}$$

- $f_{Vp,hs}$ = 100%, indicating the heating of the full protected volume, whatever it includes, at said $T_{set,hs}$. This hypothesis is much closer to the standardised EPB hypotheses of the regulatory calculation method, and the Equations (9) and (11) can therefore be equalized thus:

$$T_{uhs,m} = T_{set,hs} + \Delta T_{tset} = T_{set,i} \tag{35}$$

General influence of the $f_{Vp,hs}$ ratio is not easy to decipher, as it exerts a squared influence on the results that is visible in the second-degree curves displayed in the Figures 6.5.24 and 25 below. The CS12 stands out with a curve that sees its $I_{eval/obs}$ ratio vary between 0.22 at 0% and 2.63 at 100%, and reaches the value of 1 for a little bit more than 20% of $f_{Vp,hs}$ ratio. It is the only case study to see its $I_{eval/obs}$ ratio drop so much below the value of 1 for low values of the $f_{Vp,hs}$.

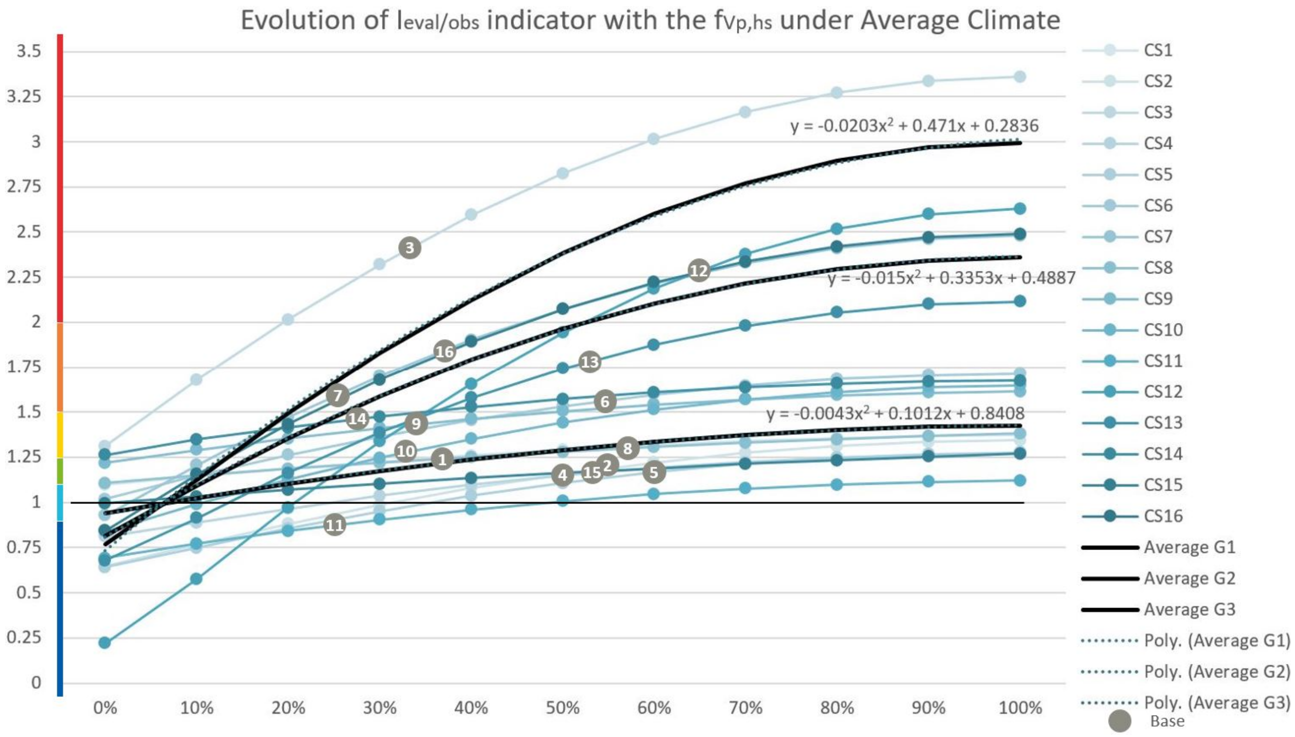

Fig. 6.5.24. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$f_{Vp,hs}$" analysis under the average climate hypotheses.

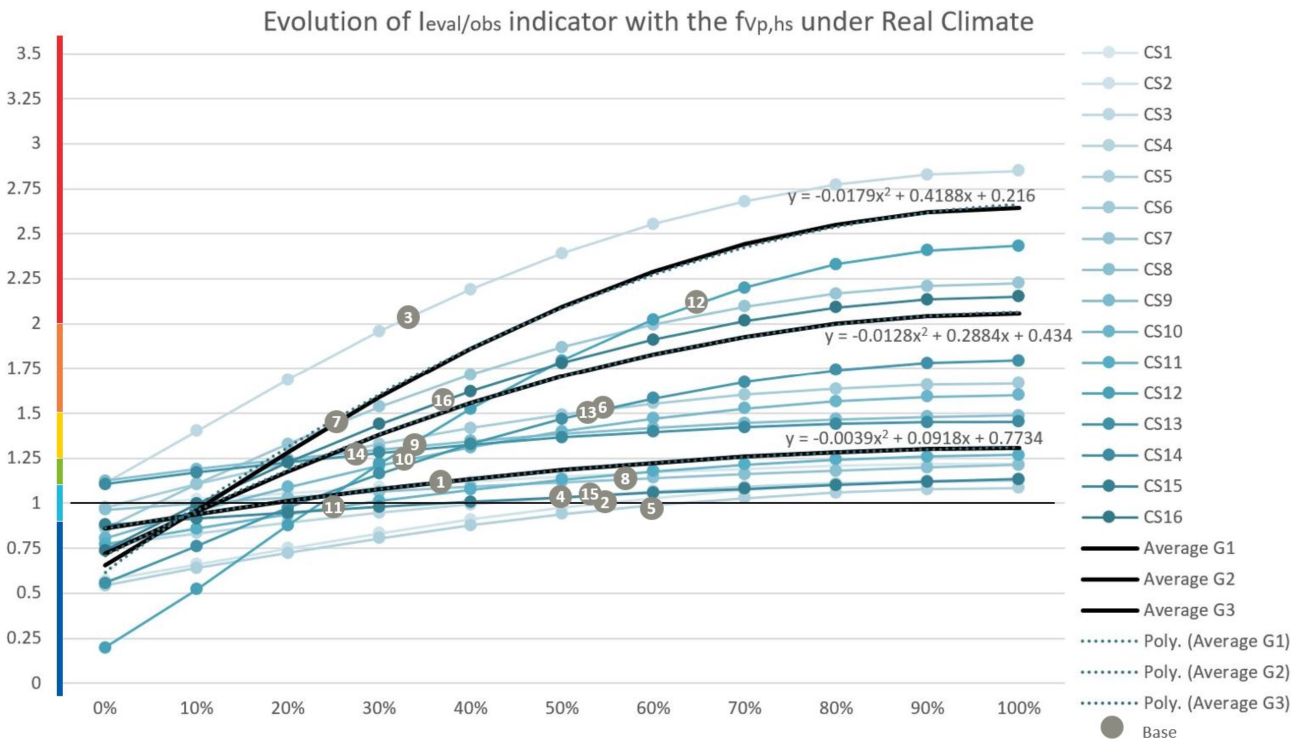

Fig. 6.5.25. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$f_{Vp,hs}$" analysis under the real climate hypotheses.

The CS3 displays a global curve similar to the CS12, although its $I_{eval/obs}$ ratio never drops below the value of 1. Even for very low values of the $f_{Vp,hs}$ ratio, the evaluated energy consumption stays well above that particular target. This is due, mainly, to the fact that even when the $f_{Vp,hs}$ ratio is imposed at 0, the $T_{set,hs}$ and ΔT_{set} parameters keep their initial values. The resulting temperature in unheated spaces is therefore estimated between $T_{set,hs}$ and $\theta_{e,m}$ (the exterior temperature) in the Equation (9), which means a demand in heating translated in consumptions. This set of hypothesis has been kept for the sake of this part of the sensitivity analysis; in the heating pattern, a period with no heating translates in the annulment of the corresponding $t_{m,heat}$ time parameter, deducing that period from the total heating time.

At very low values of the ratio, the slope of the curve depends mostly on the [$f_{\Delta T,uhs}$ * f_{pct}] product of factors, and on the set temperature in heated spaces, $T_{set,hs}$. The CS12 exemplifies this, with its value of 1.75 for the [$f_{\Delta T,uhs}$ * f_{pct}] product (the highest of the sample) and high set temperatures, which gains 160% in consumption for the first 10% increase in $f_{Vp,hs}$. Another group of case studies gather the CS3, CS7, CS13 and CS16, which show similar slopes (28 to 37% increase in consumption under the average climate conditions for the first 10% increase of the range, 26 to 37% range under real climate conditions). All these case studies are characterized by high values of the [$f_{\Delta T,uhs}$ * f_{pct}] product and low efficiencies, and came into this set of simulations with $I_{eval/obs}$ ratios superior to 1.5. Should their energy consumptions be better evaluated, their f_{pct} factors would be lowered, which in turn would make their lowered curves better match those of the other case studies. The latter display, in Figure 6.5.24, lowered curves' slopes at low $f_{Vp,hs}$ values (4 to 19% increase in consumption under both sets of climate conditions for the first 10% increase of the range), and similar global shapes and trends.

All case studies presented actual $f_{Vp,hs}$ ratios between 0.2 and 0.7. In this range, the slopes are reduced:

- For the CS12, the average increase in consumption in the [20%; 70%] range of $f_{Vp,hs}$ variation is 30% per 10% increment.
- The CS3, 7, 13 and 16 still come second, with increase in consumption between 11.4 and 14.3% per 10% increment of the $f_{Vp,hs}$ ratio, for both sets of climatic conditions.
- Other case studies see their results increase between 2.5 and 8.9% per 10% increment of the $f_{Vp,hs}$ ratio.

Higher values of $f_{Vp,hs}$ (80% to 100%) tend to see the influence of the $f_{\Delta T,uhs}$ and f_{pct} factors decrease, and the influence of the $T_{set,hs}$ and ΔT_{set} parameters, which are not varying in this set of simulations, increase. This last variation range shows therefore nearly equal slopes for all curves (1% increase in consumption per 10% increase of the $f_{Vp,hs}$ ratio, on average under the average climatic conditions; 1.2% under real climate). Inefficient case studies with high [$f_{\Delta T,uhs}$ * f_{pct}] products still have slightly steeper curves, with 1.4 to 2.2% increases.

The Figures 6.5.24 and 25 above display three averages for differentiated groups of case studies that are, first, the CS3 and the CS12 (G1); then the CS6, CS13 and CS16 (G2); and lastly the other case studies, regrouped under the G3 average. These averages help visualising a phenomenon that has been reinforced by each analysis of this sensitivity testing so far: globally, least efficient dwellings, which suffer from high remaining $I_{eval/obs}$ ratios coming into this part of the research, share the particularity of being more impacted by the variations brought in this sensitivity analysis. Generally speaking, buildings with $I_{eval/obs}$ ratios already close to one behave like the efficient ones and are less influenced by the variations on the analysis parameters.

The last factor to be analysed in this section is the f_{pct} factor that translates the influence of the envelope's efficiency on the resulting temperature in unheated spaces. It is believed, as described in chapters 3 and 4 as the "physical component of rebound effect", that better insulated dwellings see the temperature in their unheated spaces rise higher than in uninsulated buildings. The higher the insulation level, the smaller the ΔT [°C] between heated and unheated spaces.

This first set of simulation builds on the wide range of values (between 0.214 for the CS15 and 1.437 for the CS12) displayed by the case studies for the f_{pct} factor defined by the Equation (10), visible in Table 6.5.4 above and in Table 6.5.5 hereafter. This first set of simulations therefore expands this range of values in order to bring out trend curves. The limits of this analysis are set to [0; 2], and the simulations were run with a 0.2 increment in the f_{pct} value, *ceteris paribus*. The variation on the the f_{pct} factor does not impact, in any way, the $H_{T,heat}$, $H_{V,heat}$ coefficients, which remain unchanged.

The first observation of Figures 6.5.26 and 27 below is that the progressive increase in f_{pct} leads to a progressive and linear decreases in consumptions. The factor represents the quality of the envelope but the $H_{T,heat}$ and $H_{V,heat}$ coefficients being fixed, its increase will translate solely into the decrease of the T_{uhs} in Equation (9), resulting into lowered consumptions. It must be noted that previous steps in this sensitivity analysis, such as the section 6.3 on heat gains, 6.4 on air change heat losses and 6.5 on transmission heat losses, already impacted the f_{pct} factor, though less.

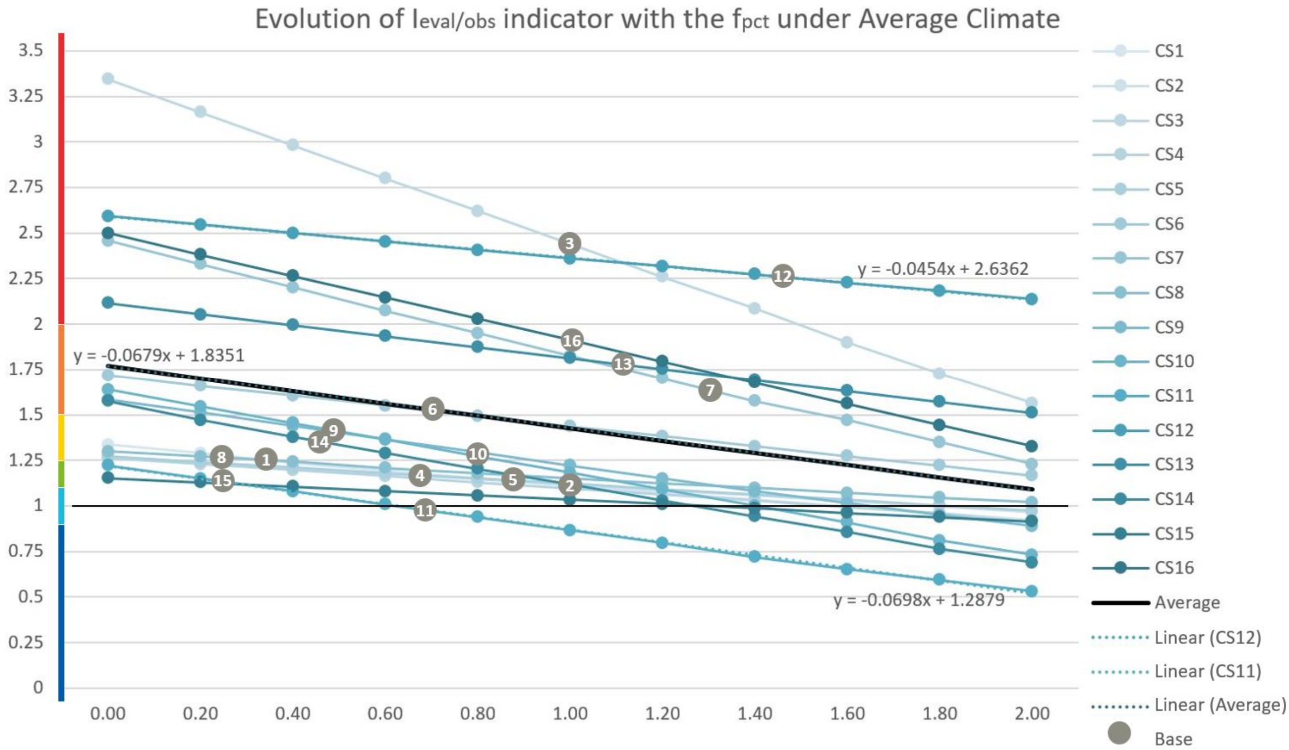

Fig. 6.5.26. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "f_{pct}" analysis under the average climate hypotheses.

It is interesting to notice that, for the first time, the CS12 is not among the most impacted case studies by this set of simulations (and this is valid also under real climate conditions, see Figure 6.5.27). It is, in fact, the case study which is the least influenced by the variations on the f_{pct}, showing a 1.8% decrease in consumption per 0.2 increment in f_{pct}. Other case studies displaying such low influences of the factor are the CS15, the CS8 (both highly efficient), followed by the CS5, 4, 2 and 13. The efficiency of the building does not seem to influence the results as much as the product of the other two factors, $(1-f_{Vp,hs})$ and $f_{\Delta T,uhs}$. C12, 15, 5, 8, 2 and 13 have the lowest values for this product. On the other side of the scale, are the CS14, 10, 11, 3 or 7, all displaying steeper slopes in their curves in figures 6.5.26 and 27. The CS11 and 14 are showing the same 5.6% reduction in consumption per increment of 0.2 in f_{pct}, with the CS11 taking the lead (5.8%) in the simulations run with the real data. Under both sets of climatic conditions, the average stands at 3.7% reduction of energy consumption per f_{pct} increase.

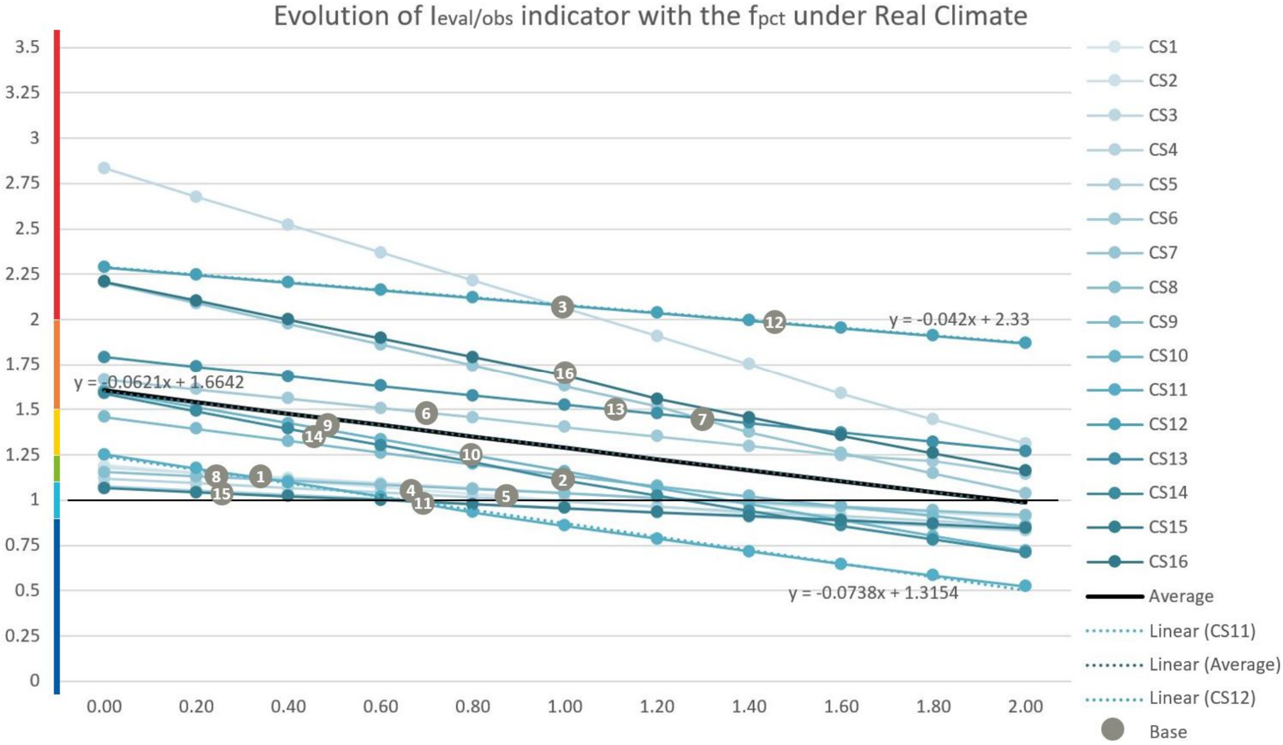

Fig. 6.5.27. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "f_{pct}" analysis under the real climate hypotheses.

The second set of simulations follows the example of the $f_{Vp,hs}$ ratio described above, considering different ways to define this f_{pct} factor. The resulting factors are stripped of all units for their purpose in the modified method:

- The "BASE" scenario, used up until now and defined in chapter 4, considers all heat losses coefficients ($H_{T,heat}$ for transmission losses, $H_{V,heat}$ for ventilation and air infiltration losses), per unit of protected volume (V_P):

$$f_{pct} = \left(\frac{H_{T,heat} + H_{V,heat}}{V_p}\right) \qquad [-] \qquad (10)$$

- The "f_{pct} = 1" scenario considers the absence of this parameter in the Equation (9), thus assessing its necessity at all;
- The "$f_{pct} = U_m$" scenario considers a f_{pct} factor equal to the average U-value of the dwelling, defined according to the Annex U of the regulatory calculation method[4];
- The "$f_{pct} = f_s$" scenario builds on the "BASE" scenario to propose a variant where the total heat losses coefficients are reported to the unit of thermal loss area (A_T) instead of the V_P:

$$f_{pct} = f_s = \left(\frac{H_{T,heat} + H_{V,heat}}{A_T}\right) \qquad [-] \qquad (36)$$

[4] SPW, Service public de Wallonie, 2014. *Annexe D: Méthode de Détermination de la Consommation Spécifique des Bâtiments Résidentiels dans le Cadre de la Certification PEB*; Belgian Monitor: Namur, Belgium ; pp. 61636–61767.

- Also building on the "BASE" scenario, the "$f_{pct} = f_{Vi}$" scenario pushes the reflexion a step further: if heat losses are believed to influence the resulting temperature in unheated spaces, the internal gains should perhaps be considered too. Having no equivalent to the heat losses coefficients for the heat gains, the "BASE" f_{pct} factor is therefore modified by a ratio of the total internal gains ($Q_{g,heat}$, [MJ]) on the total heat losses ($Q_{L,heat}$, [MJ])

$$f_{pct} = f_{Vi} = \left(\frac{H_{T,heat} + H_{V,heat}}{A_T}\right) \times \frac{Q_{g,heat}}{Q_{L,heat}} \qquad [-] \tag{37}$$

The values of those factors, for the different case studies, are displayed in the Table 6.5.5 hereunder:

Table 6.5.5 Values for the different scenarios in the definition of f_{pct}, for all case studies

Case study	BASE	1	U_m	f_s	f_{Vi}
CS1	0.378	1	0.645	0.807	0.338
CS2	0.993	1	1.269	1.389	0.456
CS3	0.996	1	1.746	1.862	0.317
CS4	0.675	1	1.177	1.329	0.439
CS5	0.863	1	1.349	1.488	0.526
CS6	0.698	1	1.09	1.23	0.22
CS7	1.301	1	1.691	1.849	0.306
CS8	0.218	1	0.208	0.304	0.168
CS9	0.435	1	0.922	0.318	0.292
CS10	0.800	1	1.575	1.055	0.405
CS11	0.684	1	1.12	1.245	0.402
CS12	1.457	1	1.862	1.982	0.472
CS13	1.121	1	1.481	1.636	0.52
CS14	0.425	1	0.63	0.747	0.184
CS15	0.214	1	0.337	0.432	0.137
CS16	1.010	1	1.8	1.896	0.367

The Figure 6.5.28 hereunder displays the results of those simulations, under real climatic conditions, on the different case studies. The first and most evident (and expected) observation is that the fifth and last scenario has to be abandoned, as it raises all case studies $I_{eval/obs}$ ratios, even more so for those who already had high ratios in the base case.

The "$f_{pct} = 1$" scenario has different effects on the case studies, depending on their initial f_{pct} value. The CS2, 3 or 16, for example, which base factors are already close to 1, are notably less impacted than the CS7, 11 or 14. It is interesting to notice, however, that the CS8 and 15, with their lowest initial f_{pct} values, are less impacted than this argument would suggest, because their very low heat loss coefficients guarantee more stable and homogeneous temperatures in the protected volume and less variations in consumption. This tends to confirm that all those parameters lose influence on the results when the house gains in efficiency, or in accuracy in their description which always brings a decrease of the heat loss coefficients.

The "U_m" scenario seems to bring, along with the "f_s" scenario, the best results in terms of lowering the $I_{eval/obs}$ ratios. Two case studies display, however, worrying results: the CS10 and the CS11. This is not the first time that the CS11 shows underestimated energy consumption revaluations, which could be related to an inaccuracy in the description of the heating pattern, as will be discussed when analysing the temperature monitoring campaign that took place in the building (see section 6.6). It is important to acknowledge that all these simulations and conclusions are mainly valid under the paradigm of their hypotheses, which in this case includes the owners' answers to the questionnaire. This model, like most engineering models, relies on a set of fixed hypotheses that are supposed to represent the average heating behaviour of the householders, whether accurately described or standardised. Models that rely on user's inputs at least have the possibility to report part of the responsibility on the accuracy of results on the user's answers. No temperature monitoring could be realised on the CS10 in order to check whether the heating pattern was accurate however. It must be reminded also that the CS10 and 11 show higher sensitivity to the f_{pct} factor given their high value of the $[(1-f_{Vp,hs}) * f_{\Delta T,uhs}]$ product that are mainly due to low portion of heated spaces ($f_{Vp,hs}$), and relatively low global efficiency (average U-values > 1W/m²K).

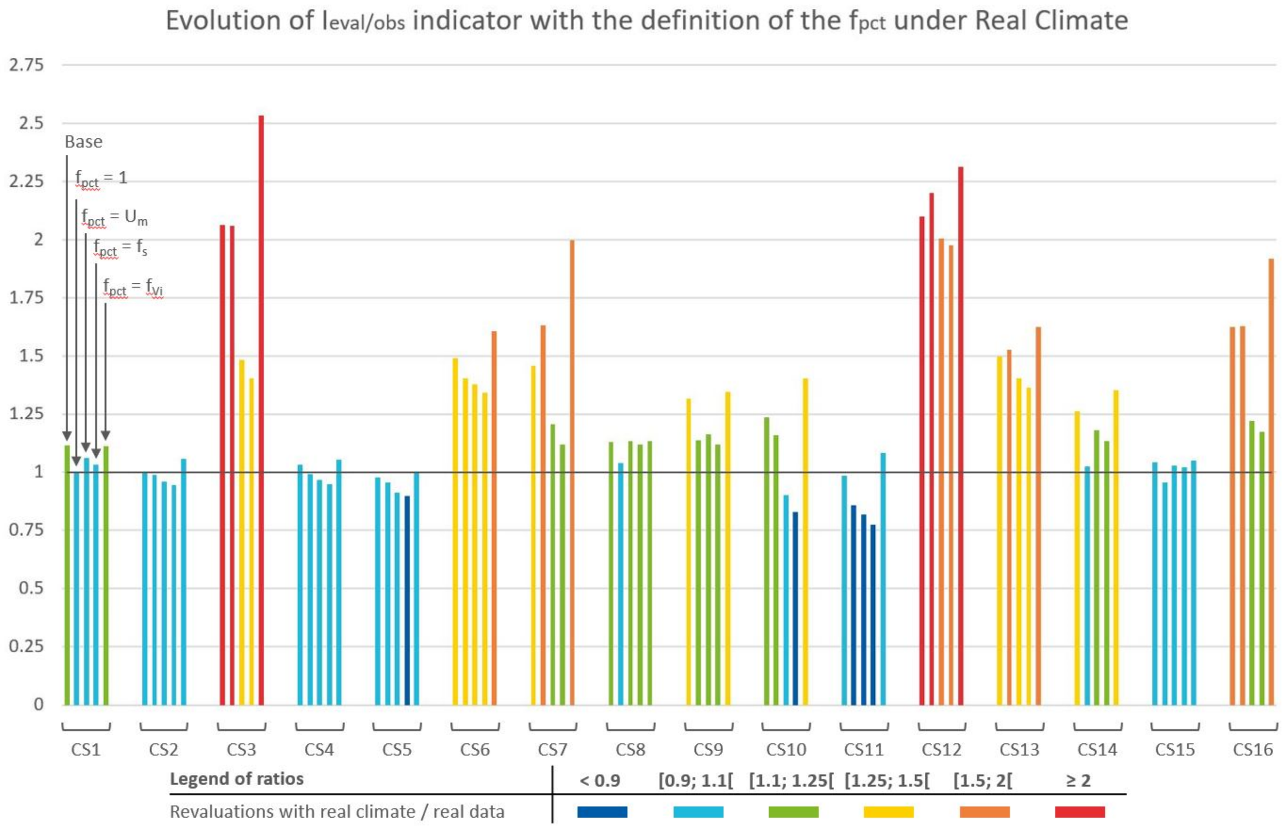

Fig. 6.5.28. Evolution, for each case study, of the $I_{eval/obs}$ ratio according to the definition of the "f_{pct}" ratio under the real climate hypotheses.

Overall, the initial calibration of the parametrisation could be faulty for those buildings, and their values for the factors studied here should be more adapted to their low-efficiency definition. But some case studies, such as the CS2 or CS5, are in many ways as inefficient as those CS3, 12, 7, 13 or 16 without displaying the same results variation. If the parametrisation was faulty, all case studies would be impacted. This tends, therefore, to blame the description of the energy system in the EPC: should the $H_{T,heat}$ coefficient and efficiencies be more accurately lower, their $I_{eval/obs}$ ratios would tend closer to one. Their f_{pct} factors would also be lowered, along with their influence on the results.

6.6 Temperature monitoring campaigns

In order to assess the accuracy of the evaluation of the resulting global temperature in the dwelling that replaces the standardised 18°C in this method, two temperature monitoring campaigns were led on two case studies. Although most of them would have been interesting to monitor, the CS11 and CS12 were not picked randomly.

Fig. 6.6.1. Street facades of the CS11 and CS12, chosen for the temperature monitoring campaigns

Both houses share some obvious architectural similarities, as shown in Figure 6.6.1. They both were built during the urban extensions that followed World War II, although on different locations. The CS12 was built on a hill South of Liege, 10 to 15 years before the CS11, located further East. Those houses appeared particularly interesting to monitor because they presented, all along this research, very different results to the revaluations of their energy consumptions:

- The CS12 has a protected volume constituted of two levels, situated on a basement level. Two unheated spaces have been included in its description for reasons explained in chapter 5: the garage at the front, and the veranda at the back. This rather badly insulated house (average U-value of 1.86W/m²K) is inhabited by two retirees who heat the space constantly, rather homogeneously and at a high set temperature (22.6°C for day-time spaces and 20°C for night time spaces during the day, 18°C everywhere at night). With a declared real consumption, witnessed on energy bills, of around 70,000kWh between September 2013 and September 2016, this case study has shown an $I_{eval/obs}$ ratio that was difficult to decrease, and remained above 2 in most simulations.
- The CS11, on the contrary, has presented very encouraging results in simulations that even tended, at times, to underestimate the final energy consumption (54,000kWh declared between January 2013 and January 2016). The protected volume includes the basement floor (unheated level, completely) and is slightly better insulated (average U-value of 1.12W/m²K). It is inhabited by a family of four (with a son in boarding school), present mostly from late afternoons to mornings, and during the weekends. They mostly heat their daytime spaces, sometimes the bathroom and the daughter's room.

The monitoring campaigns have been realised with 8 sensors of temperature and relative humidity, dispatched in a selection of each case studies' heated and unheated spaces (plus one exterior probe), to analyse the correspondence between revaluated internal temperatures, and those evaluated by the modified method. Temperatures have been read each 15 minutes during the monitoring period.

6.6.1 CS12

The first house to be monitored was the CS12, between February 21st, 2018 (at 1PM) and March 4th, 2018 (3AM, at which time the exterior sensor stopped emitting). The sensors have been placed:

- In exterior (EXT), protected from the wind and sun;
- In heated spaces that are the living room (LR, where the thermostat is present), the adjacent kitchen (K), the bathroom (BTR), the main bedroom (MBDR) and another bedroom (OBDR, used as office), on the street side.
- In unheated spaces inside the V_P (those which temperature is in question): the garage (UHS1) and the veranda (UHS2).

The Figure 6.6.2 displays the monitored temperature curves for the period mentioned above. It was a cold period in Wallonia, with exterior temperature regularly dropping below 0°C.

The observation and analysis of the temperature curves in heated spaces indicate that the heating pattern was no so far off the reality. The heating of the bathroom, especially in the mornings, brings the temperature above 27°C daily, which is more than the model hypothesis of 24°C. The running of hot water, for two people, in such a small room that is their bathroom, could explain the raise in temperature during ablution times.

During the nights, the temperature curves in the different rooms lower progressively, even, in the bedrooms, under the 18°C indicated as night time set temperature, until the morning restart around 6:30AM. There does not seem to be any indication of a night time heating, in other words, despite the declared setting. It seems like the thermal inertia of the house, and the high temperature to which it is constantly heated daily, allow a slow enough reduction of the internal temperature during the cold nights of the campaigns (average exterior temperature of -4.3°C during the monitored [12PM – 6AM] periods) without resorting to active heating. Figure 6.5.14, in section 6.5.3.2, shows what the revaluated consumption results would be without considering the night time heating periods, which would be highly beneficial for this case study's $I_{eval/obs}$ ratio. The choice, however, was made to keep the night time settings in the method, hoping that it would come to the same conclusions by itself.

The heating system apparently starts around 6:30AM (when the temperatures begin to rise on the curves), and end around 10:30PM (when temperature begin to fall). The system, also, apparently needs more than two hours in order to raise the living room temperature, which never fell under 18°C, above 22°C. This sheds another light on the calculation method, which considers the heated share of the volume to reach the set temperature within seconds. Old, uninsulated, thermally inert and globally inefficient homes need time for the installation to heat the dwelling up, efficient buildings reach comfortable temperature quicker, which might partly explain their more accurate results so far.

During [10AM – 10PM] "daytime" periods, the monitored average temperature in daytime spaces (LR – K) is 22.08°C, which is lower than the 22.6°C used as input in the model. In the night-time spaces, however, the average monitored temperature during daytime was 20.82°C, higher than the 20°C used as hypothesis. This is an example of compensation in the results, where overestimated consumptions for one end-use offset another end-use's consumption underestimation.

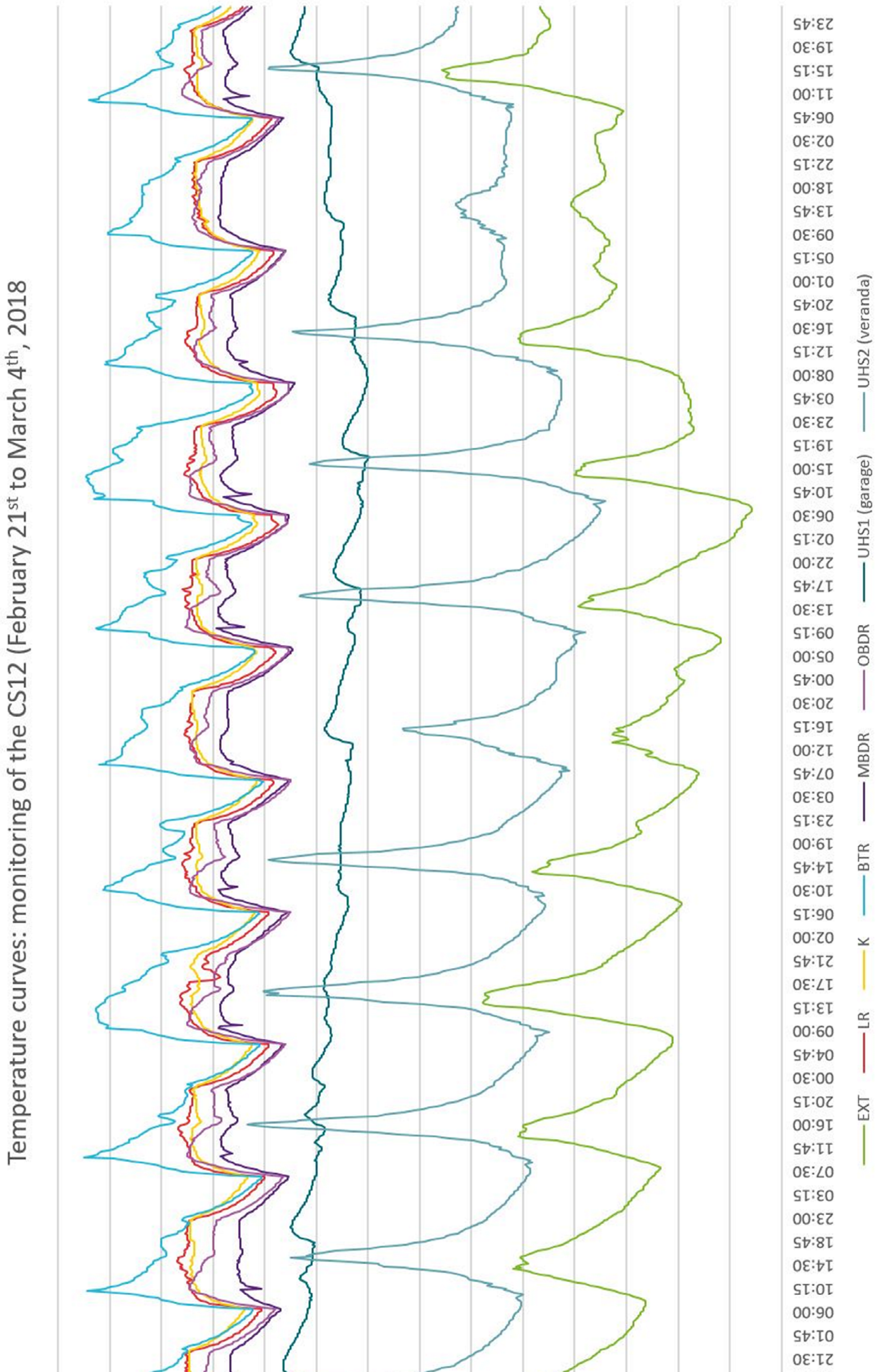

Fig. 6.6.2. Monitored temperature [°C] curves in the CS12 (February 21st to March 4th, 2018)

The observation of unheated spaces' temperature curves indicates that the temperature in the garage appears to be quite constant, varying between 11.9 and 16.9°C during the whole period. This room's temperature varies less than the exterior temperature, and less than heated spaces' temperatures. This is understandable, given the absence of solar (or internal) gains in this room, but tends to disprove the influence of the external temperature, translated in the evaluation of the resulting temperature in unheated spaces. The position of this room, surrounded by heated spaces on nearly every side, might explain this as well: the neighbours' room adjacent to the CS12's garage seems to be a living space. On the contrary, the temperature in the veranda follows the exterior temperature, and its variations, more closely. The temperature difference between the veranda and the exterior is on average 7.8°C, a difference that is more important during the day, due to the important glazed area of the veranda; at night, that temperature difference is, on average, around 5°C. The difference between the temperature curves of the garage and veranda leads to believe that the veranda, which is clearly excluded from the heating volume in the winter, could probably be considered out of the V_P in this model, in which case the only unheated space remaining in the protected volume would be the garage.

The next graph, on Figure 6.6.3, displays, in addition to the same exterior temperature curve, the average monitored temperatures of heated (upper curve, dark blue) and unheated spaces (light blue). The graph also displays the recalculated resulting temperatures in unheated spaces according to the modified method developed in chapter 4. At each time step, this theoretical temperature is revaluated considering the external temperature ($\theta_{e,m}$) and average set temperature in heated spaces ($T_{set,hs}$) as input in Equation (9):

$$T_{uhs,m} = \left(T_{set,hs} + \Delta T_{tset}\right) - \left[\left(\frac{\left((T_{set,hs} + \Delta T_{tset}) - \theta_{e,m}\right)}{2}\right) \times \left(1 - f_{Vp,hs}\right) \times f_{\Delta T,uhs} \times f_{pct}\right] \qquad (9)$$

In this equation, the ΔT_{set}, $f_{Vp,hs}$ and $f_{\Delta T,uhs}$ factors are kept identical to the "base" calculations: -0.5°C as set temperature decrement during warmer heating months, 65% of directly heated protected volume and a 1.2 value for the third factor. The revaluations in the Figure 6.6.3 are based on different values for the f_{pct} factor:

- "f_{Vp}" marks the simulations where the f_{pct} factor is considered equal to the "base point", described in Equation (10) as the sum of transmission and air change heat loss coefficients, divided by the protected volume, considered in all simulations except those in section 6.5.4.2.
- "U_m" considers the f_{pct} factor equal to the average U-value (1.86W/m²K in this case).
- "f_s" considers, as in section 6.5.4.2, the f_{pct} factor equal to the sum of transmission and air change heat losses coefficients, divided by the total heat loss area instead of the V_P.
- "2.3" is a revaluation that considers the f_{pct} factor to be equal to 2.3.

This last value can seem random but is not. In order to define the more accurate revaluation, the objective is to keep as small as possible the difference between the recalculated temperature and the monitored average temperature in unheated spaces ("Average T_{uhs}" in the graph below). As such, the "f_{Vp}" recalculations presented, averaged on the total period, a ΔT of 4.11°C; this ΔT is lowered to 2.13°C in the "U_m" calculations, and 1.53°C in the "f_s" revaluations. The f_{pct} value for which the average difference between the revaluated and monitored resulting temperature in unheated spaces could be lowered to near zero (-0.04°C), is 2.3.

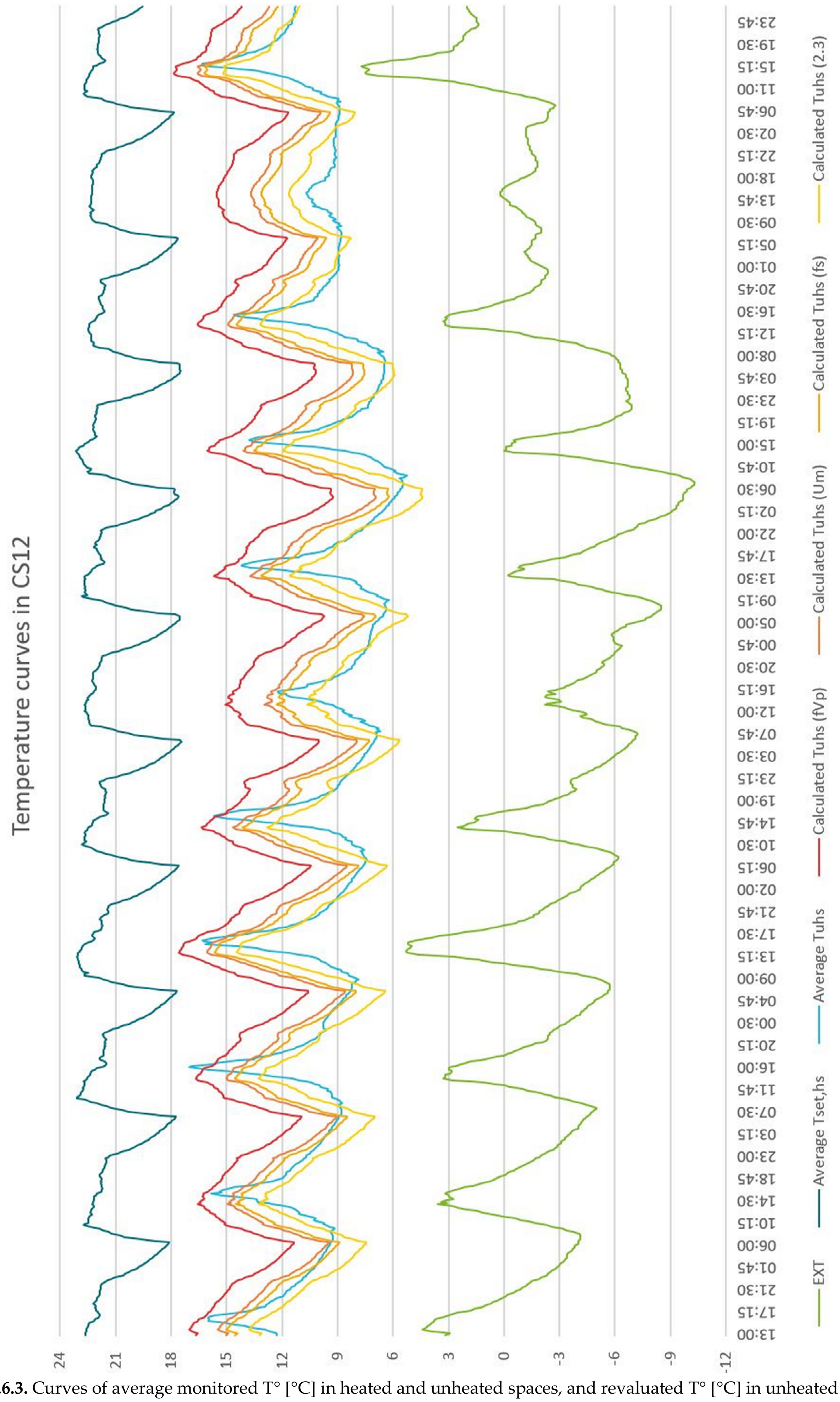

Fig. 6.6.3. Curves of average monitored T° [°C] in heated and unheated spaces, and revaluated T° [°C] in unheated spaces

It is important to note that, for $f_{pct} = 2.3$, the product $[(1-f_{Vp,hs}) * f_{\Delta T,uhs} * f_{pct}]$ is nearly equal to 1 (0.966), which would tend to withdraw the influence of the three parameters combined (for this case study). In that case, the revaluation according to Equation (38) results in an averaged ΔT between this revaluation and the monitored average temperature in unheated spaces, of -0.44°C.

$$T_{uhs,m} = (T_{set,hs} + \Delta T_{tset}) - \left(\frac{((T_{set,hs} + \Delta T_{tset}) - \theta_{e,m})}{2}\right) \quad (38)$$

The T_{uhs} values obtained by considering the three different f_{pct} factors ("f_{Vp}", "U_m" and "f_s") indicate average overestimations of those temperatures in unheated spaces by more than, respectively, 4°C, 2°C, and 1.5°C. The influence of the highly variable temperature in the veranda might explain this. The comparison of the recalculated T_{uhs} ("f_{Vp}", "U_m" and "f_s") on the garage alone (considering the veranda excluded from the V_p) leads to an averaged ΔT of -0.29°C if $f_{pct} = f_{Vp}$, -2.28°C if $f_{pct} = U_m$; -2.88°C if $f_{pct} = f_s$. In those conditions, the 2.3 value is useless, as the best revaluation comes from the hypothesis that was defended in the chapter 4.

The control simulations that were run, besides integrating the measured value of the air tightness of the house (9.11m³/h.m² under 50Pa pressure difference, replacing the default value of 12m³/h.m²), progressively incorporate the monitoring's observations in two steps:

- The first step is the adjustment of the heating pattern in itself. The first period of the day will consist of two hours of progressive heating, where the set temperature is considered equal to the daytime set temperature, but the heated share of the V_p ($f_{Vp,hs}$) is reduced by half (from 0.65 to 0.325). Then follows the "ablutions" period, where the different spaces are considered having reached their set temperature. The bathroom is still considered heated at 24°C by the system, the excess being considered brought by the hot water "losses", which are wasted according to the calculation method. For the rest of the day, daytime spaces are considered heated at the average monitored temperature of 22.08°C in the living room and the kitchen during [10AM – 10PM] periods; the night time spaces are set to be heated at the average temperature that was monitored in the two bedrooms (20.82°C). As this mainly concerns the observation of a cold winter period, the ΔT_{set} factor (-0.5°C during warmer months) is kept in these revaluations. Keeping the night time setback in the settings, the daytime heating pattern has therefore been changed as follows:

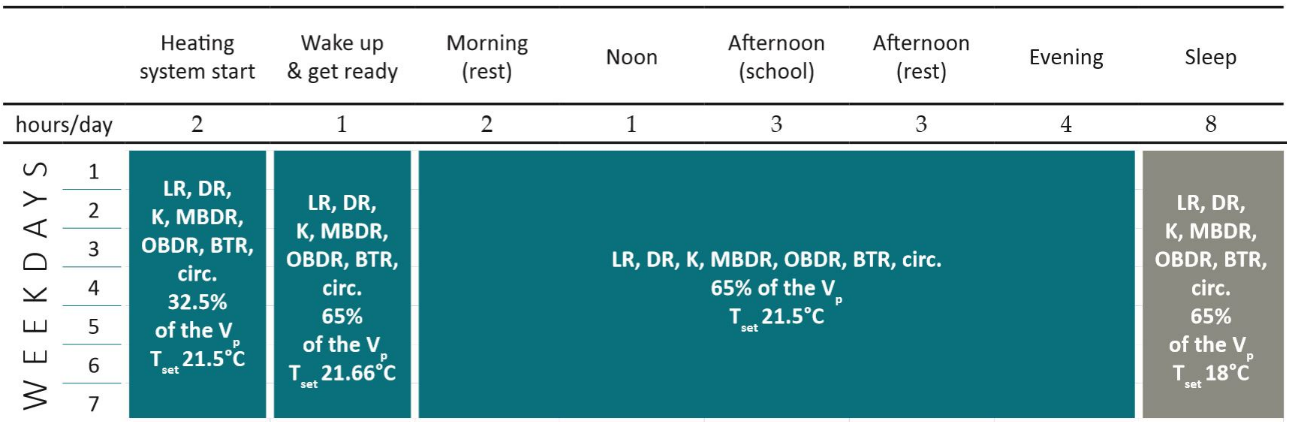

Fig. 6.6.4. Heating pattern of the CS12, modified after the temperature monitoring campaign.

- The second step is the exclusion of the veranda from the protected volume, considering it an adjacent "out-of-V_p" unheated space. The heat loss area now includes the wall and windows separating the living room and the veranda (see Figure 6.6.5). As a consequence, the heated share of the protected volume ($f_{Vp,hs}$) rose from 65% to 70%. Table 6.6.1 below resumes the main energy parameters for the case study, before (base point so far) and after these last modifications. Only the parameters that have changed are indicated.

It must be acknowledged that the $\dot{v}_{50,heat}$ value of 9.11m³/h.m² was obtained by including the veranda in the V_P; the air change rate is expected to be reduced by the exclusion of the veranda, but no such test was made at the time: the only decrease in infiltration heat losses comes from the reduction of the heat loss area (A_T). This main change on the $H_{V,heat}$ coefficient, added to the changes in $H_{T,heat}$ coefficient and protected volume that ensued the exclusion of the veranda from the V_P, induced a reduction of the f_{pct} factor from 1.457 [-] to 1.316 [-].

The reduction in solar gains is non-negligible: evaluated to 14,798 annual kWh in the initial EPC, those solar gains were reduced to 4,640kWh/year after the exclusion of the veranda's windows from the V_P envelope (the main part of those "lost heat gains" came from the single-glazed roof; to the exclusion of the doors, the total area of windows decreased from 47.5m² to 22m²). The heat gains were probably overestimated before this change, as Mrs L. keeps the access to the veranda shut during winter times and does not use the solar gains that are captured by the veranda's glazed areas but for the small share that reaches the living room. Now that the veranda is out, the calculation method cancels any solar gains that could be considered coming through the 3.6m² of window that separate the living room from the veranda, as it now has to be described as adjacent to an "out-of-V_P" unheated space.

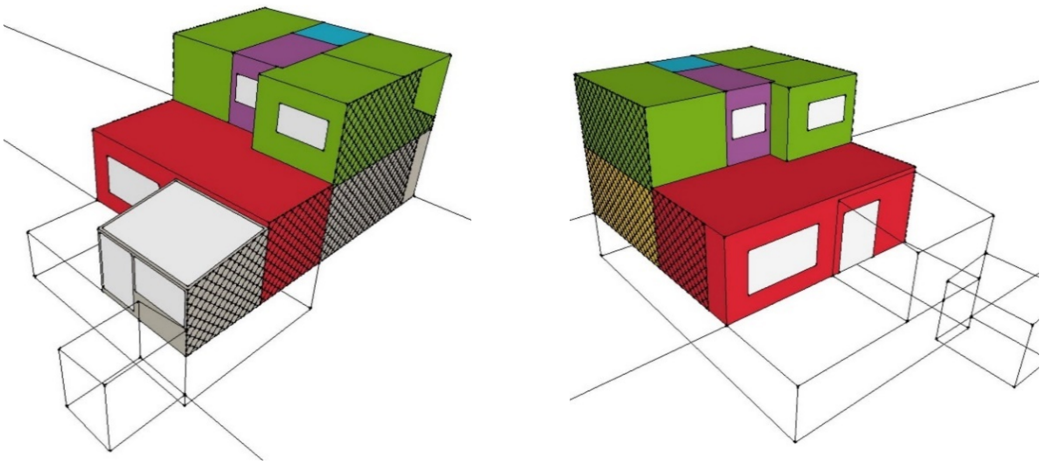

Fig. 6.6.5. 3D view of the back façade of the CS12, with (left) and without (right) the veranda.

Table 6.6.1 Energy parameters of the CS12, before and after last modifications

Parameter	Before (base)	After
Protected volume (V_P) [m³]	476	437
Heated floor area (A_{ch}) [m²]	153	139
Heat loss area (A_T) [m²]	350	314
Average U-value (U_m) [W/m².K]	1.86	1.7
$H_{T,heat}$ coefficient [W/K]	659	535
In/exfiltration rate at 50Pa ($\dot{v}_{50,heat}$) [m³/h.m²]	12 (default)	9.11
$H_{V,heat}$ coefficient [W/K]	42	40
Heated share of V_P ($f_{Vp,hs}$) [-]	0.65	0.78
f_{pct} factor [-]	1.457	1.316
Glazed area [m²]	47.51	22.05

The change in heated share of volume implied a change in the parameters of the heating schedule, as the set temperatures are averaged according to the corresponding shares in V_P. The heating pattern for this last step in simulation is the following:

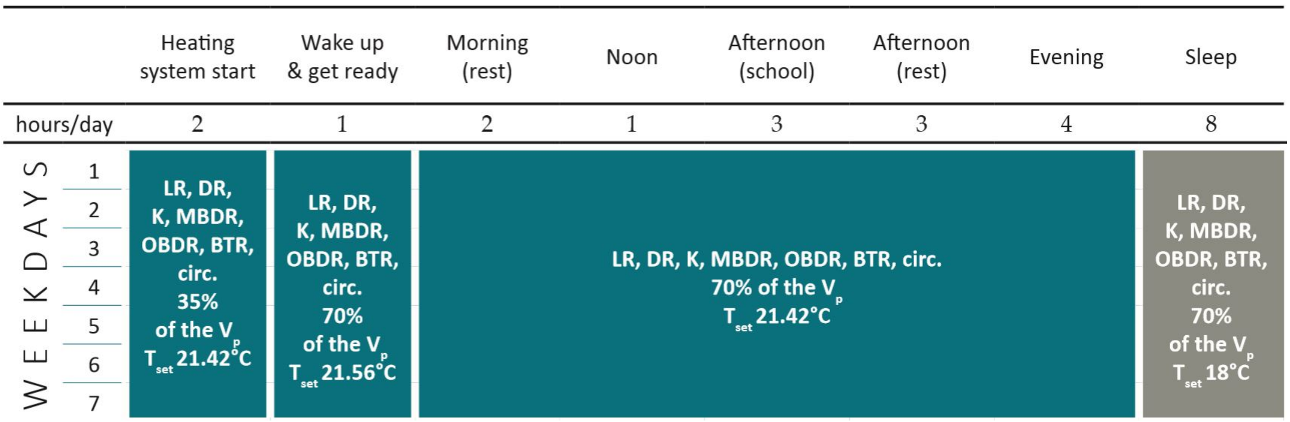

Fig. 6.6.6. Heating patterns of the CS12, modified after the change in V_P definition.

The Figure 6.6.7 below displays a comparison among the results in total final energy consumptions, highlighting the difference "before" and "after" the last modifications brought by the analysis of the monitoring campaigns:

- In grey, the official EPC results, with the differentiated descriptions of the protected volume.
- In red and yellow, the revaluated theoretical consumptions, under both sets of climatic data, for the "base point" (initial definition of the V_P with the veranda, initial heating pattern), the "CHP" scenario (for Corrected Heating Pattern), then the "CHP-NoV" scenario which includes both modifications on the heating pattern and the V_P definition.
- In green, the real data of consumption. In this case, the data and comparisons are annual, whereas they were treated globally in the first part of this chapter.

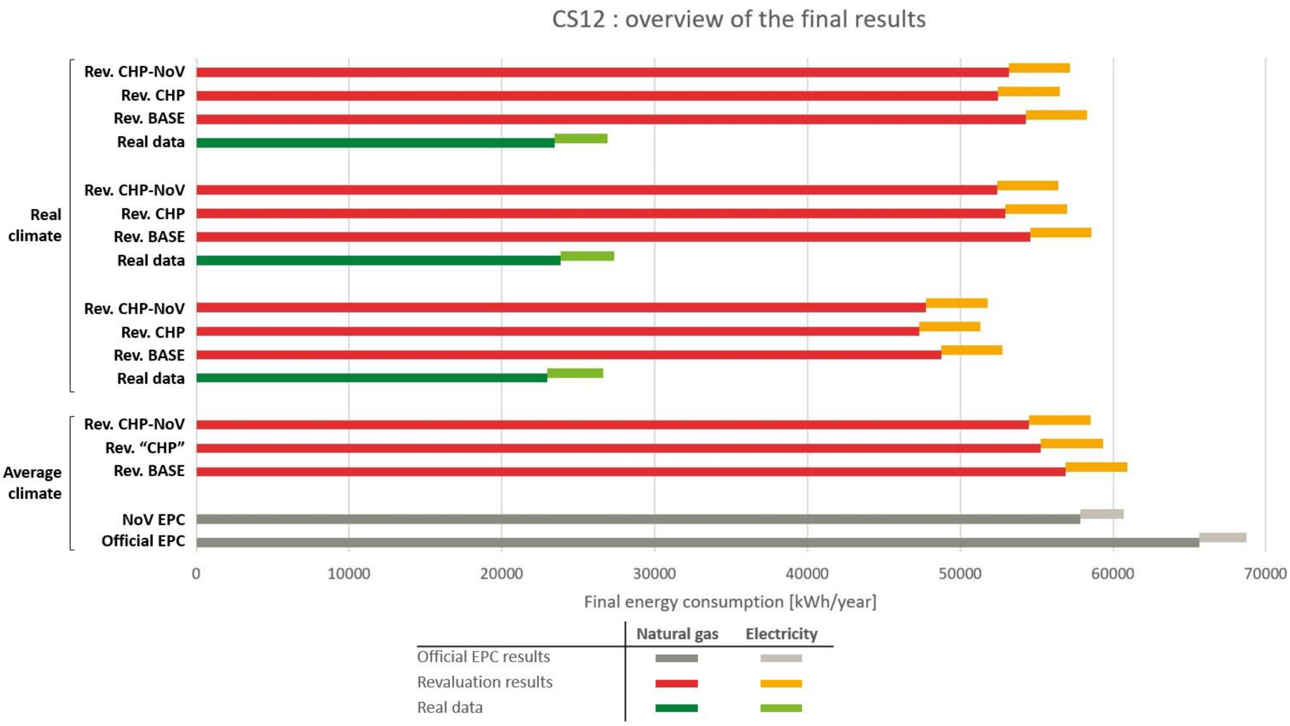

Fig. 6.6.7. Overview of the final results for the CS12: comparison of total final energy consumptions, between the official EPC, the real consumption data and the last revaluations.

The “CHP” scenario that saw the adjustment of the heating pattern to the monitored data results in a reduction of the total final energy consumption of around 2 to 3%, and his mainly (if not entirely) attributed to the first “start of the heating system” period. Results could actually be more significant, but other periods are marked by a slight increase in set temperature that raises their corresponding consumptions, offsetting therefore part of the first period’s consumption reduction.

The “CHP-NoV” scenario delivers more surprising results, thanks to the diverse consequences on the results that this scenario brings. The total heat losses (by transmission and air change) have been reduced by the combined action of the air tightness results and the removal of the heat loss areas that enveloped the veranda, which also reduced the average U-value. But the removal of a veranda’s heat losses areas would be expected to bring along an important reduction in solar gains. The results show that there is a compensation between both effects, as the revaluated results of final energy consumption do not change much on average. There is even some increase in consumption for the years 1 and 3, but year 2 presented a decrease in consumption such as the revaluations made under average climate. Part of the explanation could be found here, precisely: years covered by real climate data proved to be warmer than the average climatic conditions, and consequently reduced the heating consumptions. Although the external temperature has been adjusted, however, the solar radiation and their annual variations data have not.

As said before, the “no veranda” scenario results in a different heated share in the volume (the $f_{Vp,hs}$ ratio rose from 0.65 to 0.7) and in a different f_{pct} factor following the changes in the description of the envelope. The revaluation of the resulting temperature in unheated spaces therefore changes, and can be assessed under the light of the monitoring campaign as well. The following Figure 6.6.8 displays the curves of those revaluated temperatures, with the curve of the temperature monitored in the garage (only unheated space monitored in the “no veranda” scenario) for comparison. The “fVp” coefficient (initial definition of the f_{pct} factor, see Equation (10)) is, in this case, equal to 1.316; the “Um” value of the f_{pct} factor is 1.7 in this case, and the “fs” value, 1.83.

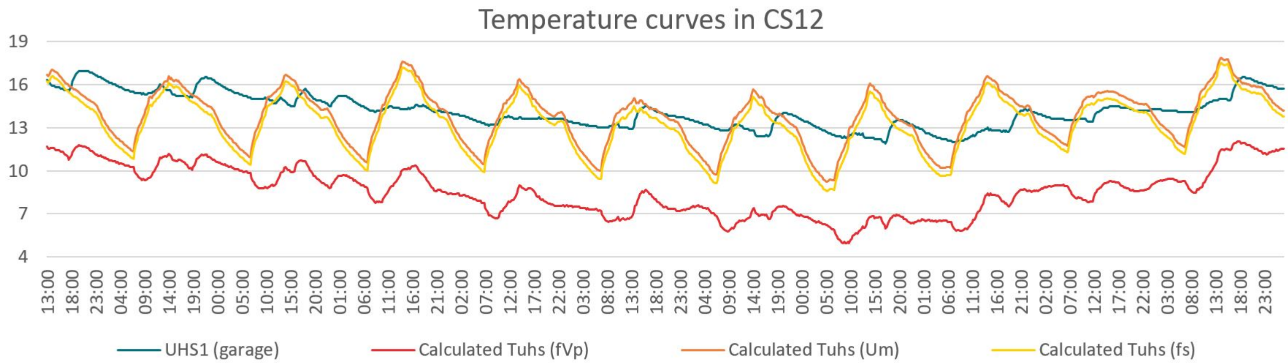

Fig. 6.6.8. Curves of average monitored T° [°C] in the unheated garage, and revaluated T_{uhs} [°C] in the “no veranda” scenario

The f_{pct} value which performs best, for which the average ΔT between the revaluated and monitored temperatures in the garage is nearly equal to 0, is the “Um” value of 1.7. The product of the three factors, [(1-$f_{Vp,hs}$) * $f_{\Delta T,uhs}$ * f_{pct}], is in this case around 0.6, which confirms their necessity. The fVp value is the least accurate value of the three tested (red curve in Figure 6.6.8): its reduction to 1.316, combined with the increase heated share in volume, brings the [(1-$f_{Vp,hs}$) * $f_{\Delta T,uhs}$ * f_{pct}] product to 0.47, and underestimates the T_{uhs}.

In any case, the $I_{eval/obs}$ ratios for this case study remain superior to 2. The fact remains that this case study presents theoretical final energy consumptions results that are twice the real consumption data. The next case study should provide an interesting comparison, as it presented the opposite tendency to underestimated revaluations in energy consumption.

6.6.2 CS11

The second house to be monitored was the CS11, between March 21st, 2018 (at 12AM) and April 17th, 2018 (9:15AM). The sensors have been placed:

- In exterior (EXT), protected from the wind and sun;
- In the heated spaces that are the living room (LR, where the thermostat is present), the adjacent kitchen (K), and the bathroom (BTR).
- In unheated spaces inside the V_P: the entrance hall, on the first floor (UHS1), the basement (UHS2: the cellar, the room down the stairs), the main bedroom (MBDR), never heated, and another bedroom on the garden side (OBDR). This last one has been considered punctually heated in the heating pattern (see Figure 5.2.68 in section 5.2.11), but has not been heated during the monitoring campaign, as visible in Figure 6.6.9 below.

The first step was to select a period inside the monitored period where heating was clearly necessary. Outdoor temperatures were quite low on March 21st, when the monitoring started. After April 4th, they frequently exceeded 12°C, then 15°C, and the necessity to resort to heating grew thinner.

The data used for this research has to be defined a little bit more than for the previous case, where nearly all the house was heated constantly during a very cold period. The first observation of Figure 6.6.9 reveals that the bathroom (BTR) is a more constant part of the heated volume than the reading of the questionnaire would have suggested. In the heating pattern, it had been considered heated only during ablutions periods; the temperature curve below indicates that this room might be heated on a similar pattern as the living room and kitchen, although lower in temperature. There might be an overestimation, also, on the number of heating hours of the daughter's bedroom.

The owner, Mr K., declared a nocturnal setback of the temperature at 16°C. He also declared that, to his knowledge, the temperature would hardly go that low, and that the heating would not need to restart at night. The temperature curves show that he is right: as in CS12, the inertia of the house does not allow the temperature to drop that low (in the living room at least, where the thermostat is; in the bathroom, the temperature can drop lower). During the covered period, the average [12PM – 6AM] periods' external temperature was 6°C (minimum 1°C).

The heating pattern in this case is more flexible, including complete "no heating of the house" daytime periods. The periods of actual heating were defined upon observation of the living room temperature curve, where the thermostat is present. It appeared quite rapidly that there was a 6:30AM starting hour on weekdays, probably one hour later on weekends. The end of heating periods were defined upon observation of the Figure 6.6.9: the temperature curves reveal that the heating system is on when the internal living room temperature is not allowed to drop below 20.6°C at the lowest (sometimes the system restarts sooner). When the temperature keeps dropping below 20.6°C, the heating system is off. As it was necessary to establish periods of time when the rooms could clearly be sorted between heated and unheated, those periods defined as heated by the living room temperature curve were yet again shortened of a few hours, when the bathroom could not be

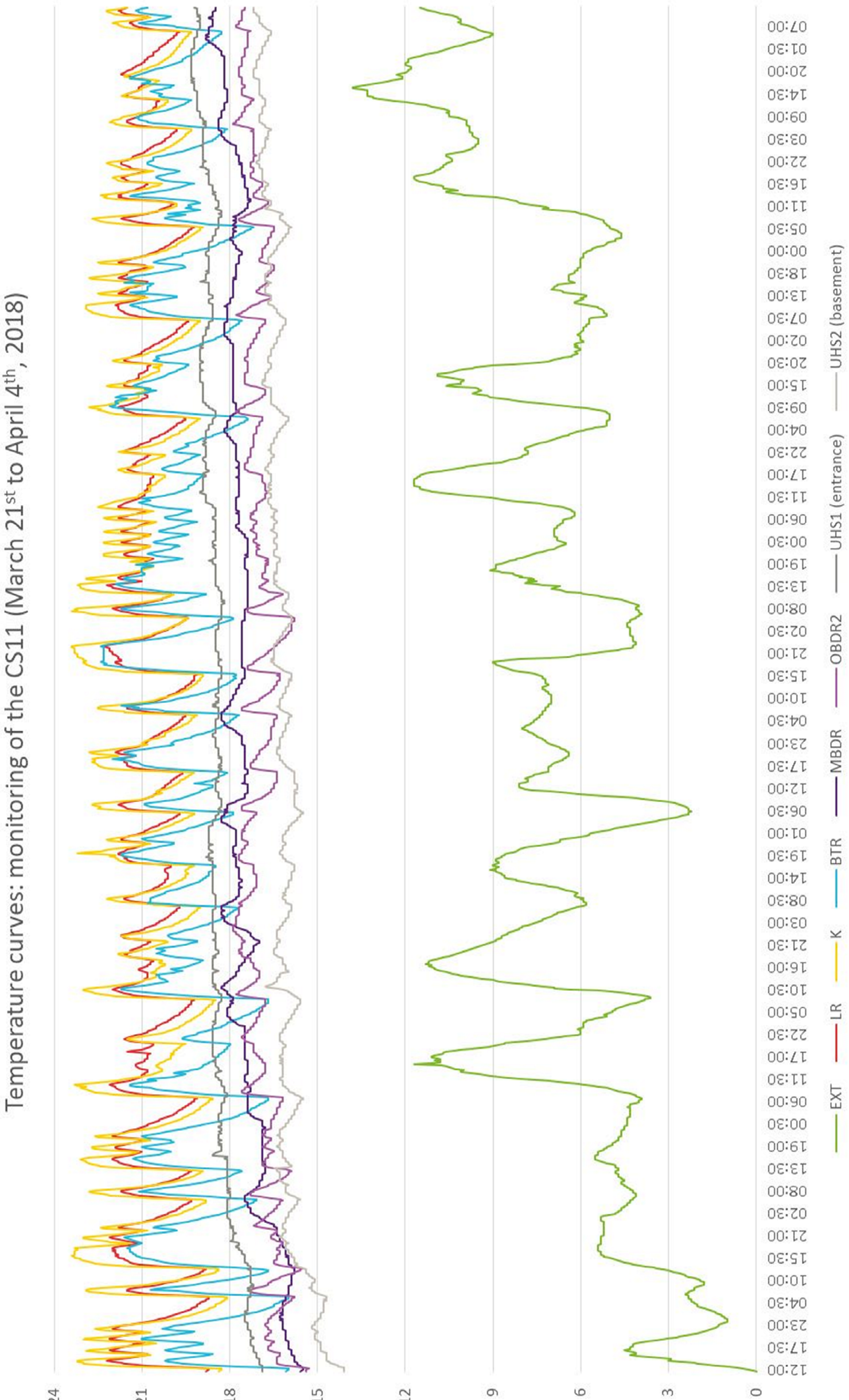

Fig. 6.6.9. Monitored temperature [°C] curves in the CS11 (March 21st to April 4th, 2018)

clearly considered heated (its monitored temperature sometimes drops below 20°C, but not enough to guarantee the absence of heating). During those periods, the average temperature is 21.12°C in directly heated rooms; 21.31°C for the living room alone; 21.66°C for the kitchen alone; 20.37°C for the bathroom alone. The average set temperature of 21°C in the directly heated spaces, used as hypothesis in revaluations, does not seem to deviate much from reality.

The temperature in the four selected unheated spaces of the house are quite constant, as was the case of the garage in the CS12. There is a difference between the halls (USH1 and USH2 in the graph below) and the bedrooms (MBDR and OBDR), marked by their solar gains, which are almost non-existent in the halls. The temperature curves allow to validate the hypothesis that those rooms were unheated during the covered monitoring period. The average temperature is at 17.32°C in those rooms, 17.37°C if only the "heating periods" defined above are considered.

The Figure 6.6.11 displays the curves reduced to those "heating periods". As in CS12, it also shows the revaluated resulting temperatures in unheated spaces with the calculation proposed in Equation (9), chapter 4. In this case, ΔT_{set} is fixed to +0.5°C during colder heating months; $f_{Vp,hs}$ = 25.3%, on average, for the global heating period; and $f_{\Delta T,uhs}$ = 1.1. The f_{pct} values used in those revaluations are the same as in CS12: the initial f_{Vp}, the average U-value U_m, and the variation on f_{Vp}, f_s. There was no need to define another value, in this case: as the Figure 6.6.11 suggests, the revaluations under the f_{Vp} value for f_{pct} are the most accurate. The average difference in temperature, between the revaluated T_{uhs} and the average monitored temperature in unheated spaces during the "heating periods", is at its lowest at -0.11°C. Comparatively, the "U_m" revaluation presents an average ΔT of 2.56°C, 3.27°C for the "f_s" revaluation. This suggests that the hypothesis of the modified calculation method is accurate for this case study, and that the reason for its very low $I_{eval/obs}$ ratios is not in the under-estimation of the T_{uhs} parameter. This confirmation of the accuracy of the f_{cp} value tends to reinforce the hypothesis that, in the CS12, the veranda should not have been included in the V_p.

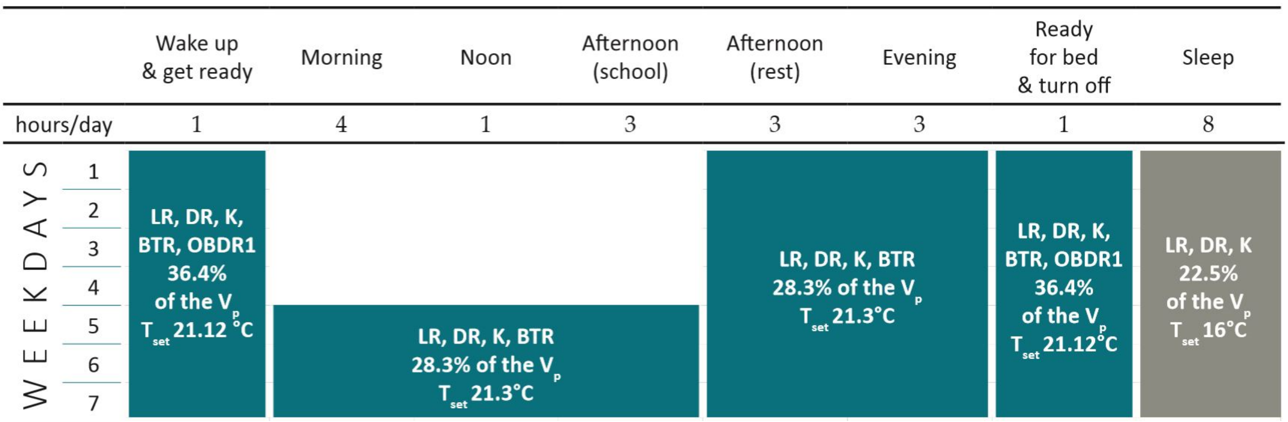

Fig. 6.6.10. Heating pattern of the CS11, modified after the temperature monitoring campaign.

In order to integrate the conclusions from the chapters 5 and 6 into the last evaluation of the CS11 final energy consumption, the following modifications to the "base" point, visible in Figure 6.6.10, are implemented:

- The heating pattern of the bathroom is based on the pattern of the living room and kitchen, except for night time periods, when the bathroom is considered unheated.
- The set temperatures considered are 21.5°C in the daytime in the living room and kitchen, 20.5°C in the bathroom (based on the average monitored temperatures), with a ΔT_{set} of +0.5°C during colder months.

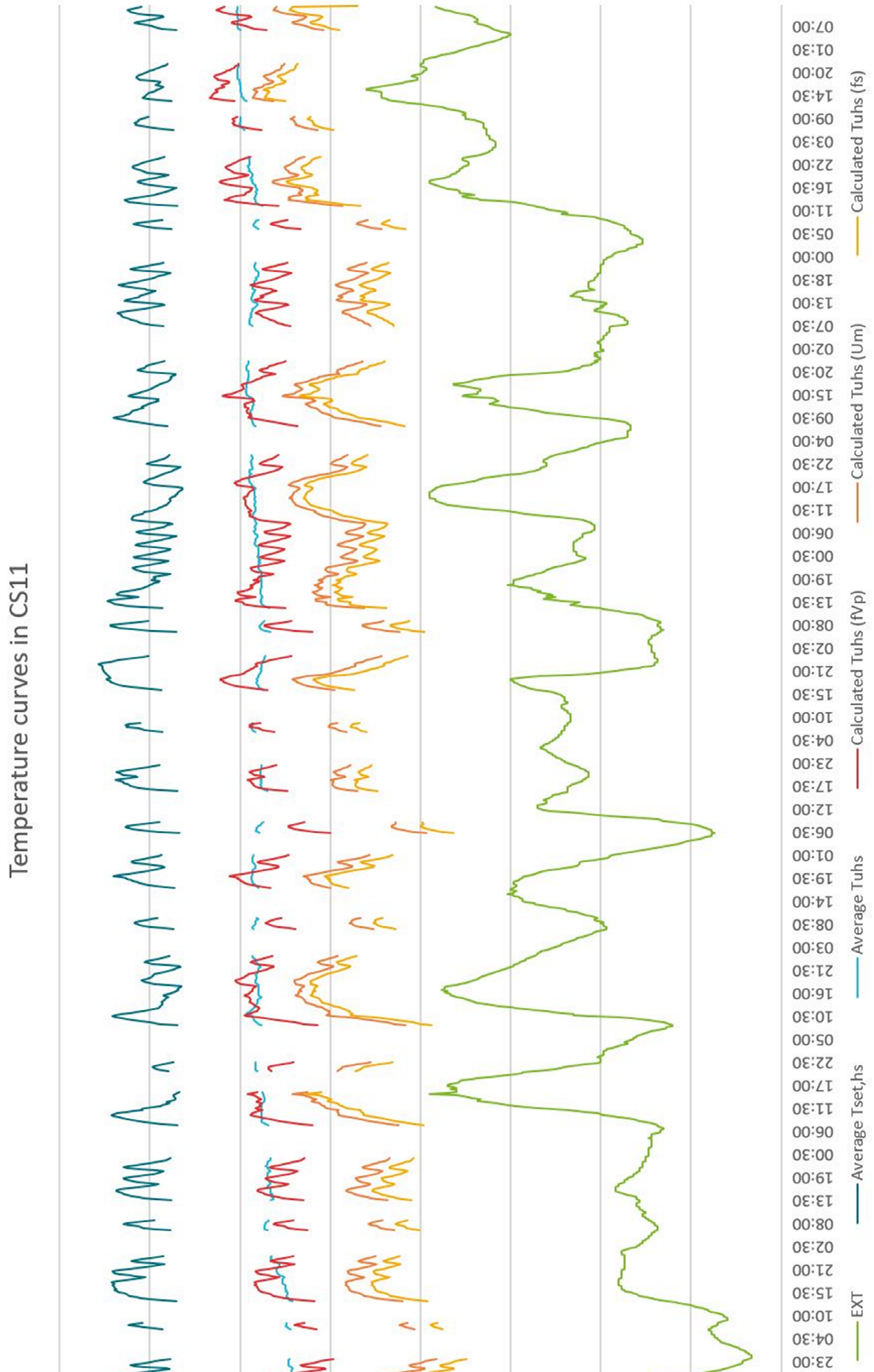

Fig. 6.6.11. Curves of average monitored T° [°C] in heated and unheated spaces, and revaluated T° [°C] in unheated spaces

- The daughter's bedroom is considered less heated than previously described. As it remains necessary to define a daily number of heated hours, these will be limited to the morning and evening "bathroom times".
- The measured value of the air tightness of the house ($\dot{v}_{50,heat}$ = 5.81m³/h.m²) is integrated, replacing the default value (12m³/h.m²).
- The night time setback is kept in the settings.
- The monitoring campaign revealed that one of the weekdays is considered heated all day, like weekends.

As a consequence, the average proportion of heated spaces in the V_P has raised from 25.4 to 27.7%; the heated periods, which represented 75.8% of the total year duration, have increased to 80.7%. The slight change in the infiltration heat losses reduced slightly the value of the f_{pct} factor from 0.684 to 0.653. Without changes to the heat gains (internal or solar), their application rate (=1), or to the systems' efficiencies and DHW evaluation, the consumption results of natural gas are displayed on Figure 6.6.12 below, where "before" and "after" refer to the last modifications brought to the heating pattern after the analysis of the monitoring campaigns. Results for electricity consumption are unchanged. The total consumptions are, on average, 6% higher, with the only heating consumption to be changed noticeably. The average $I_{eval/obs}$ ratio rises therefore from 0.98, with annual variations between 0.89 and 1.05, to 1.04 (variable between 0.93 and 1.11), under average climatic conditions. Real climate data do not change those ratios, but reduce the range in which they vary annually. Before last modifications, the annual ratios range between 0.95 and 1.02, with a 0.99 average; after modifications, they range between 1 and 1.08, with a 1.04 average. The difference is not ground-breaking, but places the CS11 more securely in the suitable range of $I_{eval/obs}$ ratios.

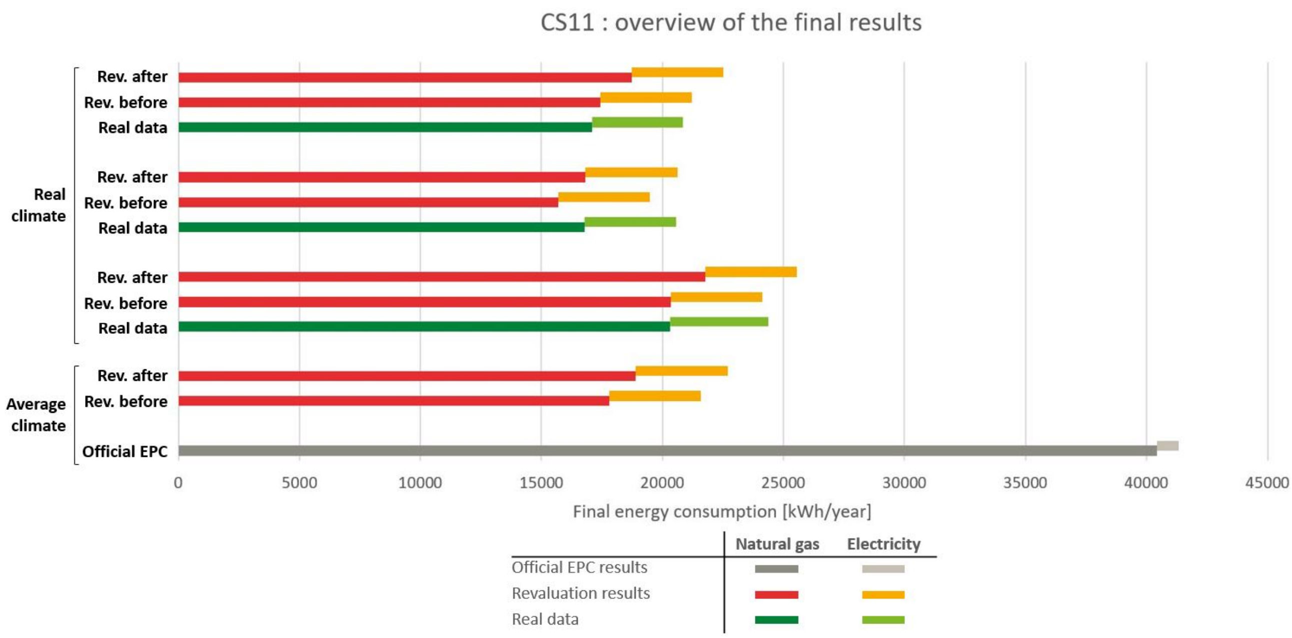

Fig. 6.6.12. Overview of the final results for the CS11: comparison of total final energy consumptions, between the official EPC, the real consumption data and the last revaluations.

Because of the slight changes in the heated share of the protected volume ($f_{Vp,hs}$), and in the f_{pct} factor, the revaluation of the resulting temperature in unheated spaces had to be updated in the monitoring campaign. The average ΔT between the calculated T_{uhs} and the monitored average temperature in the four unheated spaces changed from its value of -0.11°C, to +0.19°C after these last modifications. The Figure 6.6.13 shows the results, and the low difference with the average monitored T_{uhs}.

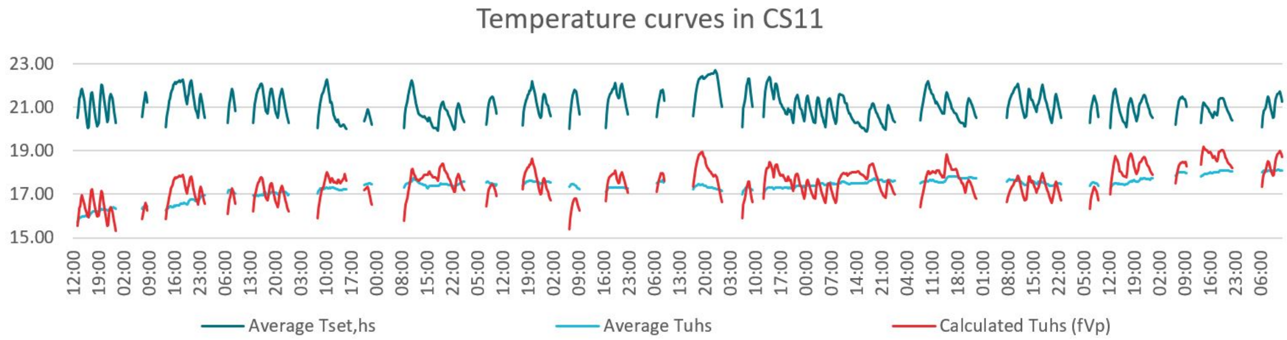

Fig. 6.6.13. Curves of average monitored T° [°C] in heated and unheated spaces, and revaluated T° [°C] in unheated spaces with the f_{pct} factor defined by Equation (10).

This does not change the conclusion that, for this case at least, the estimation is accurate, considering the f_{pct} factor as defined by Equation (10) in chapter 4:

$$f_{pct} = \left(\frac{H_{T,heat} + H_{V,heat}}{V_p}\right) \qquad [-] \tag{10}$$

Chapter 7: Conclusions and perspectives

In the words of statistician G. E. P. BOX, “All models are wrong, but some are useful”[1].

This research has been devoted to explain past energy consumptions by increasing the accuracy of their determiners in the calculation method. Results from chapters 5 and 6 undeniably show that the inclusion of behavioural parametrization into the calculation method, following a survey collecting a selected array of energy-consumption determiners on the house, the household and their habits and practices, allows to close the gap between theoretical and real energy consumptions. The Figure 7.1.1 below summarizes the final energy consumption results for all case studies after the sensitivity analysis and compare them to the official EPC results and real data of consumption, while Figure 7.1.2 displays the $I_{eval/obs}$ ratios obtained. Most official EPCs presented estimated energy consumption results that were 2, 3 or 4 times above the real consumption data given by the owners. The modified method allowed those $I_{eval/obs}$ ratios to drop below 2 in all cases, and reach 1 in some cases (CS1, 2, 4, 5, 8, 11, 15). It seems therefore possible to predict, with a 25% accuracy margin, the final energy consumptions of a household which profile is known, in a house which is accurately described.

As the refinement of calculation parameters progresses, the influence of the remaining pool of unknown (or default) parameters increases, so that it is difficult to assess the accuracy of the proposed method without an indicator that would highlight the level of (un)certainty surrounding the input data. This indicator could, for example, be based on an accuracy level on the envelope description regarding its air-tightness, (non-)insulation and systems’ efficiencies. An indication on the level of accuracy of input data would require more thorough monitoring and investigations on the building, which would completely change the certification protocol, and the financial profitability of the “job”. Well-known major obstacles to accuracy in existing buildings’ energy performance assessment are the lack of accurate data, the difficulty finding the right balance between necessary parameters, precision possibilities and the time and cost required to make a full assessment. In that perspective, the case studies that seem the most accurately described are the CS8 and CS15, the highly efficient dwellings that were presented with a complete BATEX file. The CS1 and 14 could also enter that category, if their variant using “unacceptable proofs” could be used. The four case studies display remarkably similar $I_{eval/obs}$ ratios in this research, which can only be connected to their description. This shows the limitations of a rigid assessment method (with a short and exhaustive list of acceptable proofs): even recent houses show inaccuracy of input data and gaps in results that can be comparable to old houses. On the other hand, case studies 12, 16, or 3 are examples of houses described using a (very) high share of default values, as no acceptable proofs were available, nor were there any indication that a variant could be defined based on hypothetical insulation layers. Those case studies display $I_{eval/obs}$ ratios that were difficult, if not impossible, to

[1] G. E.P. BOX, 1979. *Robustness in the strategy of scientific model building*, p.202 of Robustness in Statistics, R.L. LAUNER and G.N. WILKINSON, Editors.

reduce and bring closer to 1. In-between those groups are a number of case studies that mainly owe their encouraging results to the definition of variants that allowed to consider the envelope as better insulated than the EPC protocol would suggest. The EAP's input data collection protocol and its more open list of acceptable proofs seem more suitable for this kind of exercise.

Those $I_{eval/obs}$ ratios results include, in the total final energy consumptions, all energy vectors and end-uses. They may hide some compensations, some underestimations on end-uses that offset the over-estimations on others. Such could be the case with domestic hot water, as results clearly show that revaluated DHW demands are slightly higher than the demands from the EPC results, which is quite surprising considering the opposite tendency in the estimation of heating demands. It must be acknowledged that major obstacles to a more refined evaluation in DHW demand lie in:

- The real data from inhabitants, indivisible between cold and hot water consumptions;
- The determination of efficiency values closer to reality by the assessor;
- The difficulty to estimate real DHW demands, based on inconstant DHW use behaviour. It must be admitted that inconstant behaviour would normally also be witnessed in heating habits or use of appliances; these different reactions to DHW use might hide some privacy issues on the respondents' side (for example, the hygiene interpretation of data).

The "remaining pool of uncertainties" also includes the detrimental systems' efficiencies default values, which exercise a higher influence on the final energy consumption on the DHW demands, as it has been revaluated higher. Although they probably are under-estimated, it does not seem likely that more accurate values could solve the problem faced with the $I_{eval/obs}$ ratios evaluation of the CS3, or 12, or 16. The regulatory method appears to compensate underestimated DHW demands by underestimated system efficiencies.

In any case, DHW remains a small part of the energy consumption in those unexplained case studies, especially compared to heating-related consumptions. In their evaluation, the heat losses by ventilation or infiltration, solar and internal gains can hardly be questioned, as the results inform that they would have to be increased unreasonably to start influencing the results by more than 10% in those problematic cases. This sensitivity analysis permitted to highlight the inaccuracy of the envelope description as most likely source of that remaining gap. The CS12 is a good example of this, as the monitoring campaign has confirmed the constant heating pattern, with the exception of the night time periods, and the global temperatures within. Other parts of the sensitivity testing could reduce the $I_{eval/obs}$ ratio of the CS12, but only progressively, and superficially. The main uncertainty at this point resides in the $H_{T,heat}$ coefficient or rather, in the average U-value, as the total heat loss area cannot really be questioned in great proportions. There is no insulation layer described in the official EPC of the CS12, the thermal resistance of the envelope is evaluated mostly on default values. Materials thermal resistances are targeted by this statement, as well as the b_j coefficients taming the heat losses of some walls by considering basements or ground environments. For example, in the "no veranda" scenario of the CS12 that followed the temperature monitoring campaign, the walls separating the living room from the then-out-of-the-V_P veranda were attributed a b_j coefficient of 1, the same as exterior facades. Yet, the monitoring campaign proved its internal temperature to be 7.8°C higher than the exterior.

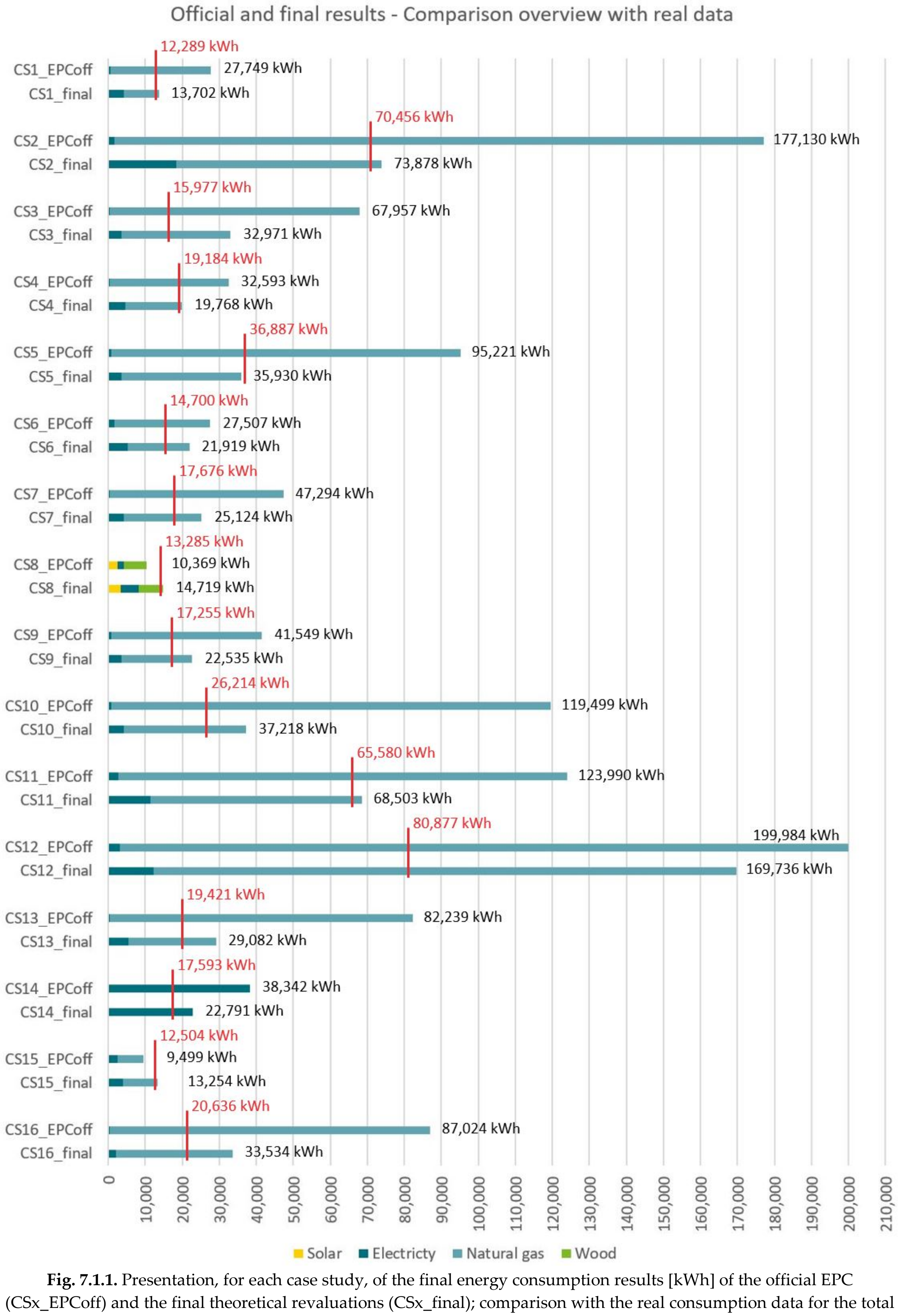

Fig. 7.1.1. Presentation, for each case study, of the final energy consumption results [kWh] of the official EPC (CSx_EPCoff) and the final theoretical revaluations (CSx_final); comparison with the real consumption data for the total covered period (in red).

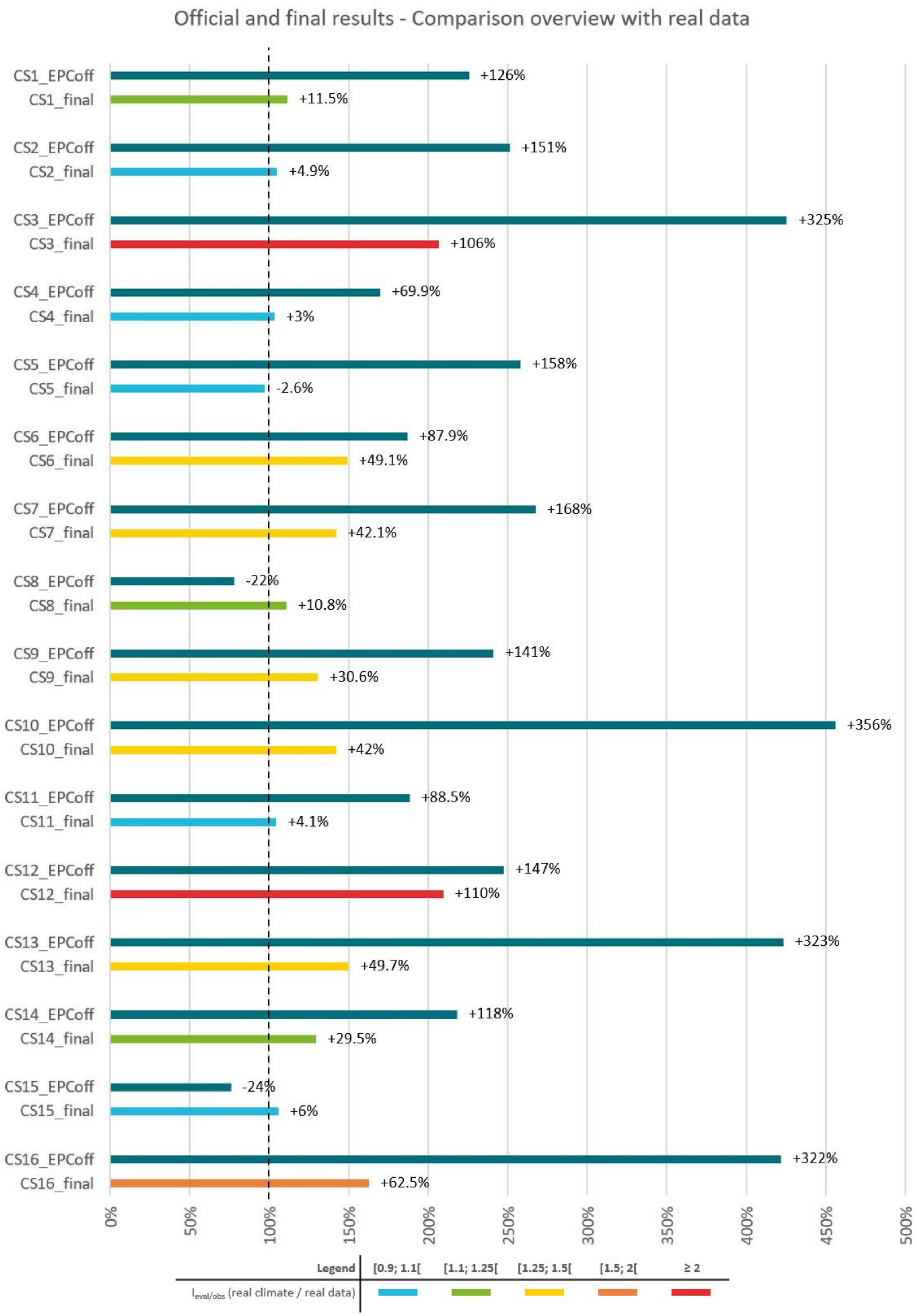

Fig. 7.1.2. Presentation, for each case study, of the Ieval/obs ratios [%] of the official EPC (CSx_EPCoff) and the final theoretical revaluations, when compared with the real consumption data (CSx_final) for the total covered period (=100%).

One of the remaining challenges concerns the **default values** and the possibilities to refine them without increasing the cost of data collection, bearing in mind that building documentation is not available for the majority of the building stock in need of renovation. The EPBD Concerted Action encourages[2] member states to "focus […] on further developing default values to allow for the comparison of buildings and on coming closer to realistic energy savings calculations at the same time", citing the publication of detailed building typologies at the regional level providing default values that are closer to reality as a good example of improvements brought in Germany and Luxemburg. A more thorough analysis of the existing Walloon dwelling stock could lead to a matrix of more accurate default values based on typologies, to replace the actual list of values that characterize the whole building stock. For example, it can be observed that this research sample of 16 case studies' results could be partitioned between "ancient houses" (built before WWII, such as the CS3, 5, 6, 7, 9, 10, 13, 15 and 16), and more recent ones (such as the CS1, 2, 4, 8, 11, 12 and 14). In this last group, only the CS12 results remain unexplained. Besides the CS15, which could be considered belonging in the second group after its recent complete renovation, nearly all dwellings of the first group present revaluated consumptions that are difficult to bring inside the acceptable range of discrepancy. S. SALAT, in 2009[3], analysed the heating needs in Parisian dwellings (in kWh/m².year) according to their construction period. The housing development of Paris cannot be easily compared with Wallonia, of course. Among factors that should differentiate both stocks, one could cite as examples the age distribution, the share of flats and isolated vernacular homes or the average available floor area. He nevertheless defined a tendency visible in Figure 7.1.1 below, in which the most ancient houses are not the more energy-hungry. This graph alone could explain part of the difference between the revaluated results of the CS11, built in the 1970's and presenting the best revaluation results of the sample; and the CS12, built in the 1950's and presenting the worst revaluation results of the sample.

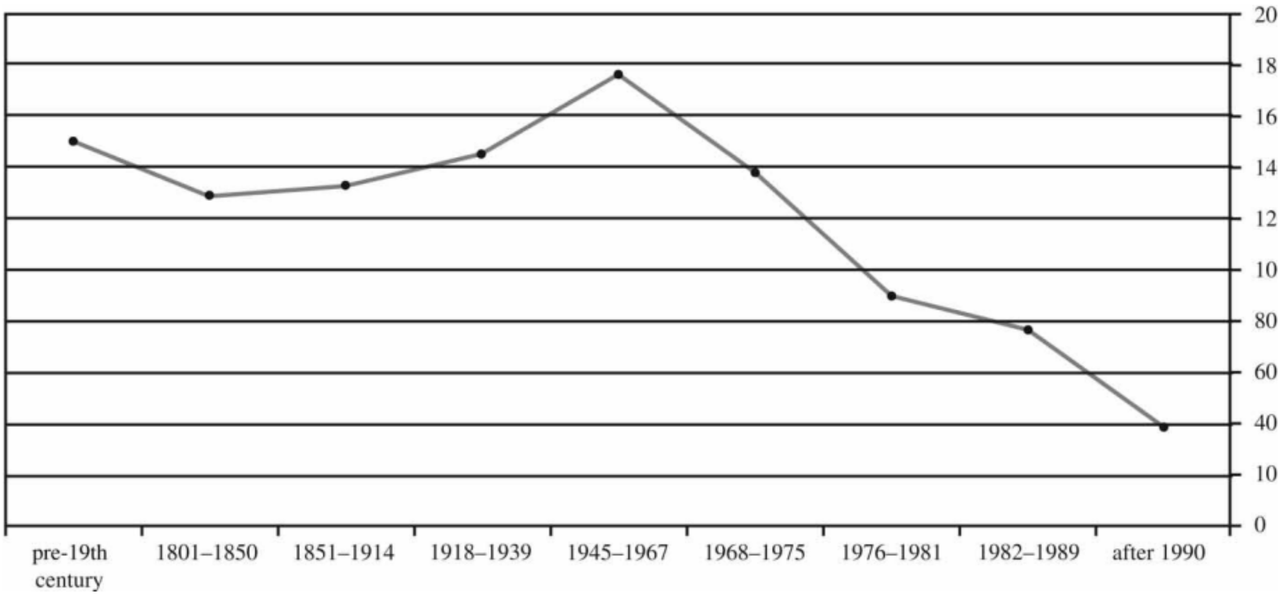

Fig. 7.1.3. Heating needs of Parisian dwellings, according to their period of construction [kWh/m².year].
(Source: S. SALAT, 2009)

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[2] EPBD Concerted Action, 2015. *Implementing the Energy Performance of Buildings Directive (EPBD), Featuring Country reports (2016)*, EU Publications Office.

[3] S. SALAT, 2009. *Energy loads, CO_2 emissions and building stocks: morphologies, typologies, energy systems and behaviour*, Building Research & Information, 37:5-6, 598-609

If the default values are defined (with understandable intent, again) to be disadvantageous, it must have been done by considering the houses presenting the least efficient parameters, which according to this graph is mainly represented by the post-war housing stock. Chapter 2 presented the reasons why those buildings are objectively less efficient. Old brick houses, which are very much represented in the Walloon stock, cannot benefit from their factual better envelope thermal resistance because they must be described using default values that simply consider all uninsulated brick walls to be equally inefficient. Inefficiency, especially when it is so much represented in the stock, could be nuanced, if the public is to take an interest in it. Any insulation layer inside those walls would still offset the little variations between the thermal resistances of the structure materials. If the default value was to remain unchanged, it could still be possible, based on a survey on a wider sample, to define uncertainty gaps that could be used in "realistic energy predictions".

The study of **typologies** could also help in presenting other scales of labels. The scale in force in the EPC procedure is supposed to compare on the same basis an ancient stone farm, an old brick house, an apartment in a 60's concrete building or a 90's suburban house; it seems like the comparison of a house among typologically similar buildings would be of more interest to potential buyers. This must be considered with caution, however, as there might be confusion in presenting several ratings with different results for the same house.

The modified method keeps the initial **steady-state** calculation method as basis for the revaluation. Multi-zone dynamic calculations could perhaps render more precise (and closer) results than the adaptation of a steady-state single-zone calculation method, but this study, in order to evaluate the potential of the existing protocol and assessment method, is purposefully based on the existing steady-state regulatory calculation method. Dynamic simulations are also expected to ask for a more precise input data collection, in order to deliver a precision in results that is not really sought in the EPC procedure. Furthermore, this exercise demands a significant adaptation of inputs, as there are multiple zones to describe and hypotheses to form on thermal exchanges among them. There are, however, two major parameters of the dynamic method that could perhaps be wisely integrated into the EPC calculation method:

- The available power of the systems. In old and inefficient houses such as the CS3, lower-than-expected consumptions during cold winter times could be explained by a potential under-sizing of the heating system. This could also be an important parameter in the detection of possible fuel poverty, defined in chapter 3 and suspected in this CS3.
- The thermal inertia. In the regulatory calculation method for energy consumption related to heating, this parameter is only present through the Heat Gain Application Rate (HGAR – $\eta_{util,heat,m}$ in Equation (5), chapter 4). This factor reduces the internal gains in all cases, more in "light" dwellings" than in "heavy" ones. The hypothesis, explained in chapter 4, to impose this factor equal to 1 in all heating consumption revaluations, therefore results in the equal maximisation of the thermal inertia as determiner of heating consumptions in each cases. Dynamic models, on the other hand, would bring a differentiation (and de-standardisation) between case studies that might explain some overestimated results.

This research allowed to deliver this document as a proof of concept, which means that the main result lies in the identification of the uncertainties rather than in their quantification, and in that perspective, **most questions used in the survey and in this research have proven to be useful or, at least, influential**. The sensitivity analysis has highlighted that some of the parametrization behind the questionnaire was crucial, and would absolutely need to be kept, or improved. The heated share of the volume, the set temperatures and the resulting temperatures in unheated spaces, or the reduction of the "time" parameter, are the behavioural components that are important to "get right". Other parameters' influence could be seen as superficial, on the contrary, and are mainly useful in order to tune the results to the household's attitudes, more than their behaviour. The $f_{\Delta T,uhs}$, the factor in Equation (9) that represents the habit of householders to close or leave open the doors between heated and unheated spaces, is an example of a parameter which exerts a weak influence on the results and could be removed from the modified calculation method. Although it is important to integrate a behavioural parameter in the revaluation of the temperature in unheated spaces, it seems that the product of the three parameters $[(1-f_{Vp,hs}) * f_{\Delta T,uhs} * f_{pct}]$ is too volatile, in a way. The T_{uhs} is such an important parameter to get right, that the effect of those three separate influences needs to be tamed. The influence of the heated share of the volume ($f_{Vp,hs}$) is undeniably important. The f_{pct} factor, which represents the crucial physical influence of the total heat losses on the homogenisation of the temperature in the dwelling, could integrate a behavioural component in its definition, decreasing for example the ventilation heat losses ($H_{v,heat}$) when the inhabitants are used to close the doors between their directly heated cocoon and the rest of the unheated (but protected) volume.

Behaviours and recurrent heating patterns are another possible output of an additional large-scale survey of the Walloon population. Opportunities for progress exist, both in the array of behaviours captured, and in improving how these behaviours are represented, across the range of domestic end uses. The dynamics of those consumptions, and the related stability of behaviours might be, for example, interesting to investigate. This research permitted to highlight a number of particular behaviours which would need to be confirmed by a quantitative survey on the Walloon population:

- As some authors[4] have stressed when observing other populations, **the energy characteristics of the building can have an important influence on the way occupants use the building and its systems**. Part of the heating behaviour is linked with the possibilities that exist in the technical energy system, and the adaptability of inhabitants who move, modify and operate their homes to achieve the thermal conditions they want. Inhabitants adjust their habits to the efficiency of the building in which they are living; for example, lower temperatures in inefficient houses and higher temperatures in efficient ones[5]. This tends to be confirmed by this research, despite its small sample. **Highly efficient houses** tend to see their average global temperatures (replacing the standardised and regulatory 18°C) rise higher than those of the poorly insulated buildings. Better insulated buildings are often equipped with **low-temperature heating installations**, which require a specific regulation and pattern of use, different from high temperature installations. The presence of **mechanical ventilation systems** in the CS8 and 15 have also consequences on the homogenisation of the temperatures in the volume, directly heated or not. Set temperatures therefore manifest a greater influence because of the high heated share of the volume submitted to it, and because of the homogenisation of the temperatures in the remaining spaces. Inefficient dwellings also see their rooms heated with more intermittence in time and space, and with more variety in the set temperatures. Set temperatures are sometimes higher in directly heated spaces, and

[4] C. Tweed, et al., 2015. *Ibid*.

[5] K. Gram-Hanssen, 2014. *Retrofitting owner-occupied housing: remember the people*, Building Research & Information, 42:4, 393-397

so is the proportion of unheated spaces in the volume. Their internal T_{uhs} being necessarily below the set temperature (see Equation (9)), the global temperature averaged on the whole volume will generally drop lower, especially during winter time.

- Other types of technical systems, which are not necessarily related to a dwelling's efficiency, can influence the behaviours of the occupants. In this sample, this was the case of the CS14, equipped with local **electric accumulators** as heating systems. The owner herself indicated that this system requires her to foresee her needs, and to often use an added heat boost in the bathroom (electric heater), in order to reach sought comfort. Another example is the presence of a natural ventilation system. It is generally related to more recent (and, therefore, efficient) dwellings, but can also be found in older buildings, installed *a posteriori*. In the CS1, the owners declared closing the supply vents in the winter in order to reduce air draughts.
- The CS1 and CS14, despite their relatively good efficiency, are still heated like the old and inefficient houses: **partially**. The "always" heated share of the volume contains mainly the kitchen, dining room and living room. The $f_{Vp,hs}$ ratio is relatively low, in other words. Only the CS8 and CS15 have a high share of heated volume, and are heated continuously. This is due, in part, to the presence of low-temperature heating installations, and centralised mechanical ventilation systems with heat recovery, which "impose" the **homogenisation** of temperature on a greater volume. Those highly efficient case studies are the only ones to find themselves, in short, in line with the EPB standardised hypotheses.
- Some behaviours would also require a subdivision of the volume into "**energy sectors**", such as the CS2. This requires to investigate into the practices of the occupants rather than describe the energy system based on the protocol, which is an added difficulty to the descriptive part. The chapter 5 concluded that the methodology used in the EPB method was more accurate in approaching the real consumption results. The EPC protocol simplified the EPB process in order to gain time in the description process, mainly. The resulting added uncertainty should be kept in mind, should the procedure remain unchanged.
- The presence of a "stay-at-home" mother in CS3 and retirees in the CS12, implies **constant heating**; in CS2 and CS4, both parents are working full time, and the heating pattern follows the children school schedule; in CS1, CS5, CS7, CS9, CS10, and CS13, the heating pattern is influenced by both the children school schedule, and the part-time presence of a parent at home. In CS6, CS11 and CS16, the households are mainly composed of adults, and their heating patterns follow their working schedule. Some case studies (CS8, CS14, CS15) are heated all day-long, even in case of absence of the occupants, but as said above, this is related to the energy system (efficiency of the envelope and the heating system).
- There is a clear distinction between some households, based on their **attitudes** towards those energy-consuming practices that are analysed here. The CS5, CS9, CS13 and CS16, for example, are inhabited by families who show clear environmental concern, and present it as the reason for heating their living rooms at 19°C. They also generally declare being careful with water consumption, and present higher "Rational Use of Energy" scores. The CS8 and CS15 could be integrated in the same group, as environment was part of the impulse motivations to the impressive renovations that gave them equal performance to newly-built dwellings. The CS6, CS12 and CS14, on the other hand, are occupied by owners who place comfort before environment, and favour higher temperatures in the directly heated spaces.

This study has the ultimate motive to try and predict the energy consumption of a household in a house that they do not (yet) live in. In terms of prediction, the uncertainty on the future **climatic component** could obviously influence the accuracy of the results. The standardised average climatic data are, once again, absolutely necessary in order to compare buildings on the same basis. There is a gap, however, between revaluation results obtained using the EPB average climate on one hand or the "real" climate data on the other; this gap is part of a permanent uncertainty margin that has to be considered in the analysis of the results, if the average EPB Belgian climate remains the same. Analysis of the local variations, however, could help tuning the revaluations in the modified method, for example based on the zip code of the building.

The prediction of energy bills is, by essence, uncertain, and in that regard, behaviour can sometimes be the main determiner of annual variations. Every parameter of the calculation method could be questioned, every aspect of a household's practices, behaviours, attitudes, and representations could be studied. Exact correspondence of real consumption data and theoretical revaluations is limited by the high number of uncertainty parameters in the method to control, particularities and special occasions in energy consumption. These revaluations, of course, only consider the "habitual consumption resulting from routine conscious and unconscious management", one of the three dimensions of consumption patterning identified by BERNARD et al.[6] The other two are the "structural consumption that occurs when the building is unoccupied", and the "daily variation consumption resulting from unusual events such as holidays, vacations, parties, sick children, broken windows, or visitors". The latter being impossible to predict, it could not be considered in those revaluations, which perhaps partly explains the difficulty in assessing correctly the CS3's consumptions, as said in chapters 5 and 6. Any description of an energy-related behaviour, therefore, is a simplification of the actual usual practices, resumed in an average. In any case, those descriptions are believed to be more accurate than any standardised occupation commonly used in home energy audit modelling. As T. CHATTERTON indicated[7]: "when considering human behaviours, it is important to remember that people do not follow simple physical laws and so we cannot model them in the way we do physical processes. In fact, we need to remember that even when we model physical processes, our models are always simplifications of reality, and that they are either only as good as we can make them, or as good as they need to be."

According to A. INGLE et al[8]., "soliciting behavioural data with a short web-based survey that could be completed by households in tandem with an audit seems well spent, given the much higher effort devoted to collecting house technical data and the size of the prospective efficiency investments." This statement could perhaps be refined by adding that in those surveys, **simplification is key**, not only in the description of the energy system, but also when considering the occupants' behaviours. Reliability in the answers is dependent on the length of the questionnaire; the number of questions has to be limited to ensure sufficient understanding and attention of respondents. The questionnaire media in itself becomes a limitation, as the number of added parameters will be restrained. It is important to keep in mind, also, that people might not accurately report their average or typical

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[6] M. J. III BERNARD, J. R. MCBRIDE, D. J. DESMOND, N. E. COLLINS, 1988. *Events-The third variable in daily household energy consumption*. Proc. Am. Cour/c. Energy Effie. Eeon., pp. 11.11-14. Washington, DC: ACEEE Press

[7] T. CHATTERTON, 2011, *An Introduction to Thinking about 'Energy Behaviour': a multi-model approach*. Edited by Oliver ANDERSON, Customer Insight Manager, Department of Energy and Climate Change.

[8] A. INGLE, M. MOEZZI, L. LUTZENHISER, R. DIAMOND, 2014. *Better home energy audit modelling: incorporating inhabitant behaviours*, Building Research & Information, 42:4, 409-421

behaviour[9], could change settings continuously or simply seek a subjective comfort unconsciously. Respondents to a survey cannot or will not always give the needed information, as some are subconscious, others can be considered private by those who have a more emotional link to energy or a more secretive approach to their life at home. The context in which the information is collected might play a role in the accuracy of the answers; in this research, respondents were informed of the purpose of the questionnaire, and their personal relationships with the author/interviewer enticed them to be as truthful as possible, trusting the use that would be made of the data. Although it must be acknowledged that this is also a crucial way to understand consumption behaviour or attitude/behaviour gaps[10], there was **no psychological side to this study**. It is necessary for the respondent to understand that the results offered by this method can only be as accurate as the information he shares.

The additional data gathered here is already quite extensive and requires about 30 minutes of interview, allowing to obtain answers to the questions, detect unmentioned behaviours and improve the progressing questionnaire. Another half hour was needed during these interviews because the initial questionnaire also included a conversation with the respondents on their understandings and views on the certification scheme, their real-estate investments decisions, and the obstacles and incentives they encounter in their renovation decisions. There is a list of questions, in the first part of the questionnaire, that did not get used either in these revaluations: those related to the level of household income, and those that complete the building description by enquiring about typology, number of levels or the presence of an annex at the back of the building. Even the age of the building has only been used in the EPC software for the default values. The reason is that those questions have been added in the questionnaire for their statistical interest. It is important to keep them in the survey in order to assess wider results in their light, before removing them if they do not explain consumptions variations.

Perspectives

It would be ill-advised to base any definite change in policy on these findings alone. As C. TWEED et al.[11] say: “As with many qualitative research projects conducted using small samples, the findings are not intended to be representative of the wider population but can highlight possible issues about thermal experience across a diverse range of environments, systems and people. […] The conclusions, therefore, are intended to inform the development of a future quantitative study rather than stand on their own.” This qualitative research was purposefully focused on a small sample of urban brick houses and their owners, which constitutes a first bias that has to be acknowledged. One could also argue that the interviewees were, in general, relatively young and educated (9 University (post-)graduates out of 16 owners). Most importantly perhaps, 6 of them were architects, who

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[9] J. LUTZ, & B. A. WILCOX, 1990. *Comparison of self reported and measured thermostat behavior in new California houses*. In Proceedings of the 1990 ACEEE Summer Study on Energy Efficiency in Buildings, 2–91. American Council for an Energy Efficient Economy.
E. VINE, & B. K. BARNES, 1989. *Monitored indoor temperatures and reported thermostat settings: How different are they?* Energy,14(5),299–308
[10] S.R. BILLETT, *Situation, social systems and learning*. Journal of Educational Work 1998, 11, 255–274.
G. BRISEPIERRE, 2013. *Analyse Sociologique de la Consommation D'énergie dans les Bâtiments Résidentiels et Tertiaires: Bilan et Perspectives*; ADEME: Paris, France, 2013; p. 51.
[11] C. TWEED, N. HUMES, G. ZAPATA-LANCASTER, 2015. *The changing landscape of thermal experience and warmth in older people's dwellings*, in Elsevier Energy Policy 84 (2015), pp. 223-232

probably knew their buildings better than the average, which was a decisive criterion of choice in this research but cannot constitute the majority. They were colleagues, family or friends of the author and interviewer, which could constitute another bias, as some respondents might have been influenced by that particular relationship during the interviews. Answering those questions might have been tinted with a wish to refrain from divulging behaviours that could be interpreted to judge their lifestyle, hygiene habits or environmental concerns. A wider quantitative study among the lay public should remove this potential bias in its bid to ascertain the description of households' profiles and the attitudes, practices and behaviours.

A. INGLE et al.[12] consider that "one alternative approach to considering occupants in home energy analysis is to calibrate modelling results to utility bills. **Calibration** approaches leverage energy use information to improve model estimates and reduce uncertainty without directly considering occupant behaviours." The EPBD Concerted Action encourages the member states to discuss "the identification of the best ways to use EPC data to monitor the energy performance of the building stock and estimate improvements, aiming at harmonising monitoring and evaluation methods."[13] It appears indeed that a calibration of the calculation method based on an increased knowledge of the stock and its households' behaviours could potentially further reduce uncertainty. The use of real energy bills to calibrate a regulatory standardised method cannot durably be realised without first a strong global study of the stock, and the ways to standardise this data back into the method. Until then, the real data can still be used to assess the accuracy of the results displayed by the method.

If theoretical revaluations of energy consumptions are more accurately lower than the regulatory results, profitability of renovation works as evaluated by the same "physico-technico-economic models" is bound to decrease, which might not work as an incentive[14]. Authors seem to disagree on the necessity to always **refer to costs, savings and profitability**. Some, such as L. LAINE, insist that "the financial value of costs and savings is much more likely to grab their attention, particularly if it is not crowded by other data. [...] Information on kWh should be limited, and is most likely to be useful if given as a basis for the calculation of energy costs."[15] Others, such as F. BARTIAUX, argue that the incessant link, in assessments, between the energy (consumed or saved) and the money, needs to be cut or at least weakened, arguing that only one on seven people link energy savings with money savings, and that renovation works on existing buildings are not necessarily sought based on economic profitability.[16] What should not be forgotten is that "money is an enabler, not a motivator per se, and that people are not investing in their house, but in their living environment, in comfort, in health, in status, and thus potentially also in other benefits than purely financial ones".[17] **Motivations to renovate** can be found in other benefits of the works, such as well-being and

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[12] A. INGLE et al., 2014. Ibid.

[13] EPBD Concerted Action, 2011. *Implementing the Energy Performance of Buildings Directive (EPBD), Featuring Country reports (2010)*, EU Publications Office.

[14] S. MONFILS, J.-M. HAUGLUSTAINE, 2016. *Influence of incentives, occupancy and energy-related behaviours on renovation strategies decision making*. In: Proceedings of the TU1104 COST Action closing conference, Cardiff, Wales, UK, Feb. 2016.

[15] L. LAINE, 2011. *As easy as EPC? Consumer views on the content and format of the energy performance certificate*, in Consumer Focus, London, UK

[16] BARTIAUX, F., et al., 2006., *La consommation d'énergie dans le secteur résidentiel : facteurs socio-techniques (SEREC)*, Scientific Support Plan for a Sustainable Development Policy (SPSDII)

[17] R. MOURIK, S. ROTMANN, 2013, *Most of the time, what we do is what we do most of the time. And sometimes we do something new*. Analysis of case studies IEA DSM Task 24 Closing the Loop - Behaviour Change in DSM: From Theory to Practice. Deliverable 2 for IEA Implementing Agreement DSM Task 24

comfort improvement, or the increased valuation of real estate. In their home, owners can often point out important (or felt like it) sources of discomfort (‘*there's a draft*’, ‘*I feel cold coming from the basement*’ (or the attic), ‘*there's condensation here and there*’). The audit points out important renovation works that would improve comfort, but it often remains linked to major heat losses or weak technical efficiencies. Real comfort added value (and satisfaction) will also come from the resolution of those discomfort feeling from the inhabitant. They would probably move forward in their apprehension of energy consumption, get more interested in further steps by discovering progressive comfort improvement: that could be a great incentive in sensitive knowledge and awareness.

Further survey might also concern the EAP Procedure and unveil the Walloon population's **desires in terms of assessments, real-estate market choices, and information on renovation solutions**. Surveys conducted by the public administration of Wallonia indicated for example that 40% of auditees would have wished for more service from the officer; 26% a simplification of results, and 18% would have wished for a simplification of the explanatory booklet. There is a niche, it seems, for a well-trained and certified referent, a well-informed, independent, objective third party able to complete a global assessment, who is there at the impulse to advice, to orientate choices on energy performance at the very least; who is there on request, when the project develops; on site, if needed, to follow up on works; and who is there at the end to help people get the better of their improved home. "Additional services" mainly, where respondents wish for an audit tailored to their needs, for which they would be ready to pay a little bit more. This includes, for example:

- **Advice** on DIY energy retrofitting works would be welcomed by those interested in making costs savings there; in general, advice on materials and contractors are also often welcome.
- **Fabric testing**: infrared thermography, co-heating test, air-pressure testing, photographic survey… Infrared thermography and airtightness tests would both be most interesting in before/after comparisons, although it must be emphasized that infrared thermography is a tool that helps visualise but not quantify heat losses. It could raise the attractiveness of the audit report. In-use measurement and monitoring of the physical environment could also be implemented, such as the temperature monitoring campaigns as realised in this research for CS11 and 12. Those are added services that could seriously raise the cost of the audits, which would tend to favour rich owners rather than the lay public.
- **Ulterior** (to the audit) **visits**, after 6 months, 1 year or two, in order to have a discussion with the beneficiaries, and assess the outputs.
- In some cases, the desired additional services are less related to energy than to **structure**, **asbestos** or **humidity** problems. The assessor could be asked to detect and solve key problems such as areas of damp and mould, boiler insulation levels, blocked radiators etc.

This opens the reflexion on the core of the problem: the **price**. An audit is a "one shot" procedure that costs 600-700€ and bears no visible fruit, with no immediate perception of interest. Its added value must be highlighted, for example with demonstrated profitability and success stories. The addition of services to a standard procedure would probably not reduce the cost, as most assessors would still have to recoup the initial investment. Regional incentives seem central in the price problem, with a clear role in encouraging the EAP. Assessors and potential clients would root for a full subsidisation of the audit (it would not make any sense in the EPC scheme, as it is obligatory), arguing notably that the use of financial incentives to (partly) pay for the audit officer's job would entice him to go and get incentives. Another proposition would be to link the EPC results to the incentives granting system. The EPBD Concerted Action informs that "the EPC is already being used in many countries as a document necessary to obtain financial support and subsidies for increased energy efficiency. In 2015, EPCs are required in 10 countries as eligibility for such schemes, most often both before and after the renovation […].”[18] The added value of the auditor’s work becomes central in the debate about incentive repartition (between auditor and owner). From incentives, it would be possible to link the EPC results to VAT on renovation works, cadastral income or land registry. The introduction of the EPC in financial or legal structures cannot be done without some intense and thorough thinking. According to L. LAINE, the lack of value attributed to the EPC in the property market, which has the up side of reducing their costs, has the down side to translate into less accurate assessments. Should the market be able to place a value on the energy efficiency, influenced in this by the EPC, there is a good chance that the accuracy level of the assessments would increase. Granting more incentives to less efficient dwellings, or forbidding that dwellings certified “G” (the lowest level on the certification scale) could be put on the selling market could, on the contrary, alter the accuracy of the documents. As for the cadastral income, which could favour energy efficiency, it remains difficult to imagine the amount of update this kind of decision would induce, for the worst or the better…

Other improvements to the current EPC could be found in the **diversification** of the tool. Its “unique” and standardised image does not help in creating a bond with the user. Appropriation of the EPC, its results and, most important, its message, is at the core of the problem. Further interest could be aroused in owners if they were able to use the information, develop their knowledge and explore the benefits of the procedure. The goal behind this research is also the possibility to create an interactive tool that might help prospective buyers of a dwelling, to simulate their energy consumption (and bills) and foresee much needed improvements, in the future. It is believed that this could have some interesting follow-up for the administration, especially in the current effort to revive the EAP and develop a complete and useful energy-related decision-making tool. Both procedures have already been partly brought together, at least in the same software (PACE), but their market distinction makes them difficult to merge. The EPC is an obligation, which means open and full market penetration. EAPs are, for now at least, a voluntary move in a niche market developed in that purpose: tools, incentives, certification system, list of certified assessors… EAPs were (and still are) mainly requested by people who are already aware of the energy problem, already sensitized to renovation works. The EAP seems to arrive too late in the renovation process, when the insulation material is already chosen and, before reform, when owners wanted financial incentives. It needs to be brought out of its present private circle of clients, back to the lay public, at the beginning, when people need advice, information and contacts. One possible way would be to clearly define the roles of the EPC and the EAP. The EPC should probably remain the energy-ID it was meant to be, and the EAP alone should concern itself about recommendations and renovation solutions. The EPC recommendations are, in any case, often considered “too general to be useful”, and audit officers often agree to reduce the EAP price for a building they have already certified. It seems possible, however, to keep the obligatory / voluntary distinction between EPC and EAP procedures, but to reinforce the link between both programs. EPCs, when they are done right, are, after all, quite close to ‘quick scans’, which can be seen as the first step into the EAP program.

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[18] EPBD Concerted Action, 2015. Ibid.

'Detailed diagnoses' and 'periodic inspections' of systems could be joined to the procedure. The EPBD Concerted Action, in 2015, recommended this alignment of the schemes to its member states[19]: "Energy auditing is a requirement of the Energy Efficiency Directive (EED). […] As both inspection and audit involve visits to site by an independent qualified expert, there is an interest in the extent to which the two Directives overlap. There is also the building certification requirement of the EPBD, making a third activity in which a qualified expert has to visit a building. […] Following the procedures and producing the reports for energy auditing and regular inspection are separate specialised activities, but some of the necessary skills and some of the data may be the same. Sharing of organisational arrangements [such as the protocol] is likely to be feasible. […] Inspections[20] include a boiler efficiency assessment and a boiler sizing assessment." This is a 'win-win' situation: systems would be analysed by certified installers, who could therefore 'sell an objective service'. Their objectivity would be better perceived if installers got into the certified agreement frame. And the audit officer, still in a global overseeing role, would be able to globalize the accurate results given by the systems' expert in the EPC or the EAP, and dialogue with him in search of adequate solutions.

EPC and EAP could, for example, play a crucial role in the development of an accompaniment structure for the owners, towards the most energy-efficient quality of their house. Incidentally, the Walloon public administration in charge of land planning, housing, built heritage and energy (also referred to as the Operational Directorate-General 4) revealed in October 2017[21], the creation of a new tool aiming to stimulate the energy-efficient renovation of dwellings. The "**building passport**" will be an evolving, interactive digital file that collects all administrative, technical or energy-related information available on a building, to be passed along, from owners to owners: permits, requested and granted financial incentives, energy audits and certificates, 'detailed diagnoses' of heating installations, renovation road maps, architecture or stability plans… This passport would be the first step towards a comprehensive database on the Walloon stock. The administration could therefore enrich its knowledge, and offer wide samples to further research. If fed by feedback data, it could also be used by owners in order to follow their consumptions, compare them to averages and deepen their knowledge about their determiners. R. RETTIE and M. STUDLEY suggest[22] that "feedback on an individual's level of performance (e.g. electricity consumption) can change their behaviour, and moreover, that this effect is enhanced if supplemented by feedback on the performance of a relevant social group". There seems to be a powerful motivation for homeowners and energy consumers to act on the reduction of their energy consumption when they can compete at a "local" level, among fellow consumers, in a healthy emulation: "defining behaviours as 'normal', through 'social norm' marketing, can make a real difference in effecting behavioural change."[23] Databases could also be helpful for the homeowners, EAP holders who would wish to start a renovation project for example.

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[19] EPBD Concerted Action, 2015. Ibid.

[20] Inspections are mandatory at least every year for oil and solid fuel boilers, every two years for gas boilers with a rated power higher than 100 kW, and every three years for gas boilers with a rated power less than or equal to 100 kW. The assessment of the boiler sizing is not repeated, as long as no changes were made to the heating system, or as regards the heating requirements of the building.

[21] SPW-DGO4, 2017. *Énergie 4: La rénovation, un enjeu majeure en Wallonie*. Official publication of the Public Service of Wallonia, Operational Directorate-General 4, n°43 of October 2017, Namur, Belgium.

[22] R. RETTIE & M. STUDLEY, 2009. *CHARM: Social Norm Marketing for Energy Efficiency*. In: Conference Proceedings "First European Conference Energy Efficiency and Behaviour", 18.10.2009, Maastricht.

[23] HUBER, A., KORTMAN, J., BENITO, A. M., SCHARP, M., 2010. *BewareE: Développer et mettre en œuvre des services efficaces de sensibilisation à l'utilisation de l'énergie domestique*. Intelligent Energy Europe Program

Such an interactive tool could give easy access to databases of qualified and trustworthy professionals (a recurrent concern for citizens), inform the homeowners with different technicity levels (simple and general, or detailed and personalised information on one's house's energy performance), search for available incentives and financing options…

Most of all, it is believed that this research can also bring its piece to this project. The questionnaire developed in chapter 4 could lead to the creation of a "household's ID", a file which would be controlled by a household, in which the necessary household-related determiners of their heating consumption could be introduced. Crossed with the information contained in the building passport, this ID could allow, for example, for potential buyers to evaluate realistic energy bills they would face, would they buy or rent the dwelling. They could also, through that questionnaire, increase their own awareness of the determiners of the energy consumption, rendering them visible. They could, progressively, relate to the bills and the influence they themselves can have on them, through their behaviour or the improvements they could bring to their homes. In the end, the EPC and EAP procedures could be the corner stones on which the education of the lay public on its energy consumption, its determiners and consequences, could be developed. There is a real possibility for the implementation of an educational framework for the owners and candidates to renovation, which is more than needed in addition to the technical and regulatory sides of these schemes.

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University of Liege

Faculty of Sciences

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Spheres Research Unit

Energy and Sustainable Development Research Team

The human factor in the energy performance assessments for renovation strategies of existing urban houses in Wallonia

ANNEXES

Dissertation submitted by Stéphane MONFILS, Ir. arch.

in completion of the requirements to obtain the degree of Doctor in Sciences

Academic year 2017-2018

Annex 1: Questionnaire

Questions	x	Possible answers

Household and respondent

	1.1	1.2	1.3	1.4
1 Please precise your ...	Gender (M or F)	Age (in years)	Highest diploma	Occupation principale
		Less than 15	No diploma	Executive
		[15 ; 24]	Primary/elementary school	Employee
		[25 ; 34]	Secondary, inferior	Public servant
		[35 ; 44]	secondary, superior	Liberal profession
		[45 ; 54]	Superior non university	Retailer
		[55 ; 64]	University diploma	Craft-/ workmanship
		65 or more	PhD	Independant
				Stay at home parent
				Student, Unemployed or Retiree

1.5 How many members does your household count ?		
1.6 How many toddlers (< 3 years old) does your household include ?		
1.7 How many schooled childre, following typical school schedule, does your household include ?		
1.8 How many retirees (> 65 years old) does your household include ?		

We are aware that the questions here can seem indiscreet and personal.

Information about your income, for example, can help build a relationship between your income category and the monthly energy costs of your household.

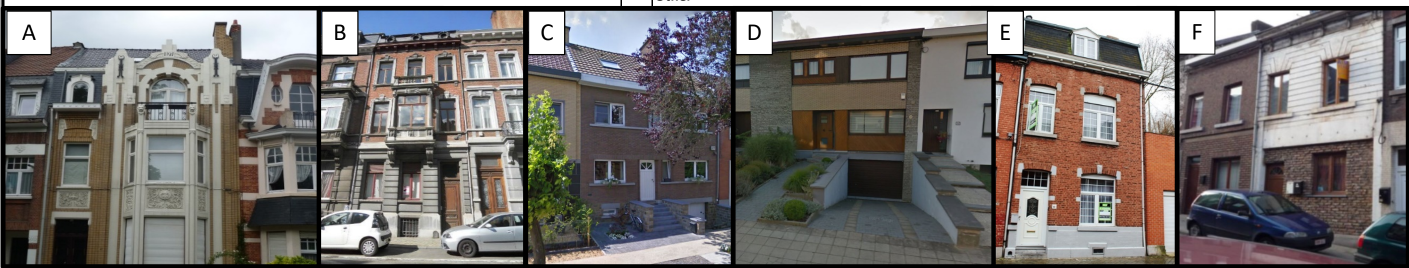
This questionnaire's data will only be exploited in the framework of scientific research. We offer the insurance of data confidentiality and anonimity.

Thank your for your understanding...

1.9 What is the range of your total household's average monthly net income?		< 1000€
		[1000€ ; 1999€]
		[2000€ ; 2999€]
		[3000€ ; 3999€]
		[4000€ ; 4999€]
		> 5000€

Dwelling

2.1 Please select, among these examples, the architectural style closest to your dwelling:		A (architectural front and back facades - large volumes)
(only one answer)		B (Master house - architectural front facade - big volumes)
		C (suburbs - larger "modest" house)
		D (1960's house on ground floor basements - flat roof)
		E (modest house - traditional facade - average volumes)
		F (blue-collar house - small volumes - simple construction)
		Other



2.2 Please select the proposition most accurately describing your dwelling's main volume position:		A - One exterior facade, in a row or a block
(only one answer)		B - Two exterior facades, in a row
		C - Two exterior facades, at a block's corner
		D - Two street facades, at a block's corner, one exterior facade at the back
		E - Three exterior facades
		F - Four exterior facades

2.3 Is an annex, built after the main volume, attached at the back of your house?		A. Yes and it is used / heated
		B. Yes, but it is not used / heated
		C. No

If A or B

2.3.1 What room(s) are in that annex?		Kitchen
		Bathroom
		Bedroom
		Living room
		Other :

2.4 When was the main part built ?		< 1919
(only one answer)		[1919 ; 1945]
		[1946 ; 1960]
		[1961 ; 1984]
		[1985 ; 1995]
		[1996 ; 2010]
		> 2010
		I do not know

2.5 **What contains the upper liveable floor** (which could be used often, with high enough ceilings) of your dwelling**?**

- Inhabited, used and heated spaces (bedrooms, for example
- An attic / a storage space INSIDE the protected volume (insulated / indirectly heated)
- An attic / a storage space OUTSIDE the protected volume

2.6 **How many levels are there in the protected volume ?**

2.7 **Are the main stairs...**

- ... located in an inside space (hall), separated or separable from used and heated spaces?
- ... open (without separations, opaque or translucent) on used and heated spaces?

Behaviours and practices in heating

3.1 **Do you possess and use any of the following devices to regulate the internal temperature in your home ?**

A - Thermostatic valves on radiators

They usually regulate by 5 positions (+ 1 "frost-free" position)

B - Manual thermostat in a living space.
No digital screen; the shift from day to night settings is manual, just like the temperature regulation settings.

C - Programmable thermostat in a living space.
Programming the thermostat allow an automatic shift from day to night settings, according to pre-determined schedule or pattern.

D - Thermostat on a boiler.
Not the aquastat, which regulates the water temperature out of the boiler. The thermostat allows for example to decide time slots when the boiler is on.

E - External temperature probe.
A box, placed on an wall, protected from sun and wind, monitoring exterior temperatures, commuinicating with the heating system to adjust water temperature.

F - No / I do not know

3.2 **Please indicate, for a normal winter week (school or work week, weekend included), the number of days when your dwelling is not heated at all during the day:**

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

For a normal winter week, (Monday to Friday):

3.3 **For the 5 days hereunder, please indicate the number of occupants of your household who are present during each time slots:**

		Mornings (8:00 → 12:30)	Noon lunch 12:30 → 13:30	Afternoons 13:30 → 16:30	Late afternoons 16:30 → 18:30	Evenings 18:30 → 23:00	Average
3.3.1	Monday						0.00
3.3.2	Tuesday						0.00
3.3.3	Wednesday						0.00
3.3.4	Thursday						0.00
3.3.5	Friday						0.00

3.4 **Please indicate the number of those week days when you heat your living room ALL DAY (from the moment you wake up until you go to bed):**

- 0
- 1
- 2
- 3
- 4
- 5

3.5 **When you do not heat it all day, how many hours per day (from the moment you wake up until you go to bed) do you heat the living room, in average?**

- A - 2 to 3 hours per day: mornings and evenings, for example.
- B - 4 to 5 hours per day : from the moment you come back from work, for example.
- C - 6 to 7 hours per day : on mornings, and after 6PM, for example.
- D - 8 to 9 hours per day : on mornings and after school, for example.
- E - 10 to 11 hours per day: the heating is turned off on mornings or afternoons.
- F - This part is not heated (0 hours) - N.A.

3.6 **What temperature do you seek in the daytime spaces of your dwellings, in winter, during daytime?**

Please consider the following order of priority:
1 - thermostat setting, if applicable
2 - thermostatic vavles positions, if applicable
3 - your feeling if you do not have any tangible proof.

- A - 16°C - Thermostatic valves on 1
- B - 17°C
- C - 18°C - Thermostatic valves on 2
- D - 19°C
- E - 20°C - Thermostatic valves on 3
- F - 21°C
- G - 22°C - Thermostatic valves on 4
- H - 23°C
- I - 24°C - Thermostatic valves on 5
- I do not know

3.7 **Is the dining room open on the living room (without separations, opaque or translucent) and/or is it heated along the same pattern (time and temperatures) than the living room?**

- A - Yes
- B - No

If No

3.7.1 **Please indicate, for a normal winter week (school or work week, weekend included) the number of days when your dining room is heated ALL DAY (from the moment you wake up until you go to bed):**

- 0
- 1
- 2
- 3
- 4
- 5
- 6
- 7

3.7.2	When you do not heat it all day, how many hours per day (from the moment you wake up until you go to bed) do you heat the dining room, in average?	Like the living room (same periods) A - 2 to 3 hours per day: for breakfast and dinner, for example. B - 4 to 5 hours per day : from the moment you come back from work, for example. C - 6 to 7 hours per day : on mornings, and after 6PM, for example. D - 8 to 9 hours per day : on mornings and after school, for example. E - 10 to 11 hours per day: the heating is turned off on mornings or afternoons. F - 14 hours per day: from the moment you wake up until you go to bed. G - This part is not heated (0 hours) - N.A.
3.7.3	What temperature do you seek in the dining room, in winter, during daytime? Please consider the following order of priority: 1 - thermostat setting, if applicable 2 - thermostatic vavles positions, if applicable 3 - your feeling if you do not have any tangible proof.	A - 16°C - Thermostatic valves on 1 B - 17°C C - 18°C - Thermostatic valves on 2 D - 19°C E - 20°C - Thermostatic valves on 3 F - 21°C G - 22°C - Thermostatic valves on 4 H - 23°C I - 24°C - Thermostatic valves on 5 I do not know
3.8	Is the kitchen open on the living room (without separations, opaque or translucent) and/or is it heated along the same pattern (time and temperatures) than the living room?	A - Yes, completely B - No, but the door between them remains open C - No, the kitchen is in a closed room, separate from the living room
	If C	
3.8.1	Please indicate, for a normal winter week (school or work week, weekend included) the number of days when your kitchen is heated ALL DAY (from the moment you wake up until you go to bed):	0 1 2 3 4 5 6 7
3.8.2	When you do not heat it all day, how many hours per day (from the moment you wake up until you go to bed) do you heat the kitchen, in average?	A - 2 to 3 hours per day: for breakfast and dinner, for example. B - 4 to 5 hours per day : from the moment you come back from work, for example. C - 6 to 7 hours per day : on mornings, and after 6PM, for example. D - 8 to 9 hours per day : on mornings and after school, for example. E - 10 to 11 hours per day: the heating is turned off on mornings or afternoons. F - 14 hours per day: from the moment you wake up until you go to bed. G - This part is not heated (0 hours) - N.A.
3.8.3	What temperature do you seek in the kitchen, in winter, during daytime? Please consider the following order of priority: 1 - thermostat setting, if applicable 2 - thermostatic vavles positions, if applicable 3 - your feeling if you do not have any tangible proof.	A - 16°C - Thermostatic valves on 1 B - 17°C C - 18°C - Thermostatic valves on 2 D - 19°C E - 20°C - Thermostatic valves on 3 F - 21°C G - 22°C - Thermostatic valves on 4 H - 23°C I - 24°C - Thermostatic valves on 5 I do not know

Bedrooms

3.9	Do you heat YOUR bedroom, during winter daytime periods (from the moment you wake up until you go to bed)?	A - Yes B - No
	If Yes	
3.9.1	Please indicate, for a normal winter week (school or work week, weekend included) the number of days when your bedroom is heated ALL DAY (from the moment you wake up until you go to bed):	1 2 3 4 5 6 7
3.9.2	When you do not heat it all day, how many hours per day (from the moment you wake up until you go to bed) do you heat your bedroom, in average?	A - 2 to 3 hours per day: for breakfast and dinner, for example. B - 4 to 5 hours per day : from the moment you come back from work, for example. C - 6 to 7 hours per day : on mornings, and after 6PM, for example. D - 8 to 9 hours per day : on mornings and after school, for example. E - 10 to 11 hours per day: the heating is turned off on mornings or afternoons. F - 14 hours per day: from the moment you wake up until you go to bed.
3.9.3	What temperature do you seek in your bedroom, in winter, during daytime? Please consider the following order of priority: 1 - thermostat setting, if applicable 2 - thermostatic vavles positions, if applicable 3 - your feeling if you do not have any tangible proof.	A - 16°C - Thermostatic valves on 1 B - 17°C C - 18°C - Thermostatic valves on 2 D - 19°C E - 20°C - Thermostatic valves on 3 F - 21°C G - 22°C - Thermostatic valves on 4 H - 23°C I - 24°C - Thermostatic valves on 5 I do not know
3.9.4	What heating system do you use in your bedroom?	Central heating Extra electric heater Other
3.10	Do you heat any other bedroom, during winter daytime periods (from the moment you wake up until you go to bed)?	A - No, none, (almost) never B - Yes, one (other than mine) C - Yes, all but one (other than mine) D - Yes, all (other than mine)

	If Yes		
3.10.1	**Please indicate, for a normal winter week (school or work week, weekend included) the number of days when that(those) bedroom(s) is(are) heated ALL DAY (from the moment you wake up until you go to bed):**		**0**
			1
			2
			3
			4
			5
			6
			7
3.10.2	**When you do not heat it(them) all day, how many hours per day (from the moment you wake up until you go to bed) do you heat that(those) bedroom(s), in average?**		**A - 2 to 3 hours per day: for breakfast and dinner, for example.**
			B - 4 to 5 hours per day : from the moment you come back from work, for example.
			C - 6 to 7 hours per day : on mornings, and after 6PM, for example.
			D - 8 to 9 hours per day : on mornings and after school, for example.
			E - 10 to 11 hours per day: the heating is turned off on mornings or afternoons.
			F - 14 hours per day: from the moment you wake up until you go to bed.
3.10.3	**What temperature do you seek in that(those) bedroom(s), in winter, during daytime?** Please consider the following order of priority: 1 - thermostat setting, if applicable 2 - thermostatic vavles positions, if applicable 3 - your feeling if you do not have any tangible proof.		**A - 16°C - Thermostatic valves on 1**
			B - 17°C
			C - 18°C - Thermostatic valves on 2
			D - 19°C
			E - 20°C - Thermostatic valves on 3
			F - 21°C
			G - 22°C - Thermostatic valves on 4
			H - 23°C
			I - 24°C - Thermostatic valves on 5
			I do not know
3.10.4	**What heating system do you use in that(those) bedroom(s)?**		**Central heating**
			Extra electric heater
			Other

3.11	**Do you heat your bathroom, during winter daytime periods (from the moment you wake up until you go to bed)?**		**A - Yes**
			B - No
	If Yes		
3.11.1	**Please indicate, for a normal winter week (school or work week, weekend included) the number of days when the bathroom is heated ALL DAY (from the moment you wake up until you go to bed):**		**1**
			2
			3
			4
			5
			6
			7
3.11.2	**When you do not heat it all day, how many hours per day (from the moment you wake up until you go to bed) do you heat your bathroom, in average?**		**A - 2 to 3 hours per day: for breakfast and dinner, for example.**
			B - 4 to 5 hours per day : from the moment you come back from work, for example.
			C - 6 to 7 hours per day : on mornings, and after 6PM, for example.
			D - 8 to 9 hours per day : on mornings and after school, for example.
			E - 10 to 11 hours per day: the heating is turned off on mornings or afternoons.
			F - 14 hours per day: from the moment you wake up until you go to bed.
3.11.3	**What temperature do you seek in the bathroom, in winter, during daytime?** Please consider the following order of priority: 1 - thermostat setting, if applicable 2 - thermostatic vavles positions, if applicable 3 - your feeling if you do not have any tangible proof.		**A - 16°C - Thermostatic valves on 1**
			B - 17°C
			C - 18°C - Thermostatic valves on 2
			D - 19°C
			E - 20°C - Thermostatic valves on 3
			F - 21°C
			G - 22°C - Thermostatic valves on 4
			H - 23°C
			I - 24°C - Thermostatic valves on 5
			I do not know
3.11.4	**What heating system do you use in the bathroom?**		**Central heating**
			Extra electric heater
			Other

3.12	**In winter, do you heat, regularly and directly, the circulation volume of your dwelling?**		**A - Yes**
			B - No

3.13	**In winter, do you heat any other room of you dwelling, regularly and directly?**		**A - Yes**
			B - No
	If Yes		
3.13.1	**Please indicate, for a normal winter week (school or work week, weekend included) the number of days when that room is heated ALL DAY (from the moment you wake up until you go to bed):**		**0**
			1
			2
			3
			4
			5
			6
			7
3.13.2	**When you do not heat it all day, how many hours per day (from the moment you wake up until you go to bed) do you heat that room, in average?**		**A - 2 to 3 hours per day: for breakfast and dinner, for example.**
			B - 4 to 5 hours per day : from the moment you come back from work, for example.
			C - 6 to 7 hours per day : on mornings, and after 6PM, for example.
			D - 8 to 9 hours per day : on mornings and after school, for example.
			E - 10 to 11 hours per day: the heating is turned off on mornings or afternoons.
			F - 14 hours per day: from the moment you wake up until you go to bed.

3.13.3	**What temperature do you seek in that room, in winter, during daytime?** Please consider the following order of priority: 1 - thermostat setting, if applicable 2 - thermostatic vavles positions, if applicable 3 - your feeling if you do not have any tangible proof.	**A - 16°C - Thermostatic valves on 1** **B - 17°C** **C - 18°C - Thermostatic valves on 2** **D - 19°C** **E - 20°C - Thermostatic valves on 3** **F - 21°C** **G - 22°C - Thermostatic valves on 4** **H - 23°C** **I - 24°C - Thermostatic valves on 5** **I do not know**
3.13.4	**What heating system do you use in that room?**	**Central heating** **Extra electric heater** **Other**
3.14	**What room(s) of your dwelling do you heat at night, in winter?**	**None** **The living room** **The kitchen** **The bathroom** **My bedroom** **One bedroom, other than mine** **All bedrooms, other than mine** **All bedrooms** **Other**
3.14.1	**What temperature do you seek in that(those) room(s), in winter, during night time?** Please consider the following order of priority: 1 - thermostat setting, if applicable 2 - thermostatic vavles positions, if applicable 3 - your feeling if you do not have any tangible proof.	**A - 16°C - Thermostatic valves on 1** **B - 17°C** **C - 18°C - Thermostatic valves on 2** **D - 19°C** **E - 20°C - Thermostatic valves on 3** **F - 21°C** **G - 22°C - Thermostatic valves on 4** **H - 23°C** **I - 24°C - Thermostatic valves on 5** **I do not know**

4	**How do you ventilate the following rooms of your dwelling, in winter ?**	
4.1	**The dining room / the living room:** Several answers possible	**We do not (or rarely) ventilate this room in winter** **This room is ventilated by blatant air leakages** **Punctually (not every day), by opening windows (when there are smells, or too many people…)** **By opening windows (almost) daily** **There are supply vents in window frames, but we shut them in winter** **There are supply vents in window frames, and they remain open in winter** **There are air vents at the ceiling or in walls, but we shut them in winter** **There are air vents at the ceiling or in walls, connected to a fan** **There is a complete mechanical ventilation system, and this room is connected**
4.2	**The kitchen:** Several answers possible	**We do not (or rarely) ventilate this room in winter** **This room is ventilated by blatant air leakages** **Punctually (not every day), by opening windows (when there are smells, or too many people…)** **By opening windows (almost) daily** **By the extractor hood when cooking (<u>/!\ extraction, not recycling hood</u>).** **There is a small fan which turns on when needed (linked to presence, humidity rate or light switch, for example)** **There are air vents at the ceiling or in walls, connected to a fan** **There is a complete mechanical ventilation system, and this room is connected**
4.3	**The bathroom:** Several answers possible	**We do not (or rarely) ventilate this room in winter** **This room is ventilated by blatant air leakages** **Punctually (not every day), by opening windows (when there are smells, or humidity…)** **By opening windows (almost) daily** **There is a small fan which turns on when needed (linked to presence, humidity rate or light switch, for example)** **There are air vents at the ceiling or in walls, connected to a fan** **There is a complete mechanical ventilation system, and this room is connected**
4.4	**The bedrooms:** Several answers possible	**We do not (or rarely) ventilate this room in winter** **This room is ventilated by blatant air leakages** **Punctually (not every day), by opening windows (when there are smells, or humidity…)** **By opening windows (almost) daily** **There are supply vents in window frames, but we shut them in winter** **There are supply vents in window frames, and they remain open in winter** **There are air vents at the ceiling or in walls, but we shut them in winter** **There are air vents at the ceiling or in walls, connected to a fan** **There is a complete mechanical ventilation system, and this room is connected**

5	**Could you specify the extent of your agreement with the following affirmations related to your lifestyle habits? We have a tendency to...**	**A. Not at all!**	**B. Rather not**	**C. It depends…**	**D. Rather, yes.**	**E. Yes, of course!**
5.1	**… weather-strip the protected volume in winter (to avoid leakages, e.g. around windows and doors).**					
5.2	**… close doors between heated and unheated spaces.**					
5.3	**… put on a sweater before raising the temperature in the dwelling.**					
5.4	**… avoid active air conditioning in the summer.**					
5.5	**… turn off the heat when opening a window.**					
5.6	**… switch off appliances instead of leaving them on sleep mode.**					
5.7	**… switch off the lights in unoccupied spaces.**					
5.8	**… use low-energy lightbulbs.**					
5.9	**… make use of good natural light quality to avoid artificial lighting.**					
5.10	**… save water, by favouring showers to baths, notably.**					

6.1	**Please indicate the (electric, electronic, household) equipment category of your dwelling:**	**Light** (basic equipment of fridge with freezer, washing machine, microwave or regular oven, extractor hood, television) **Moderate** ("light" + dishwasher + computer and router, etc.) **Average** ("moderate" + comfortable kitchen equipment + electric dryer, etc.) **Important** ("average" + independent freezer + second TV + second computer, etc.) **Heavy** ("important" + second fridge + high-tech media equipment, etc.)

6.2	Please indicate the average number of weekly uses of the following devices for the whole household:	How many ?
6.2.1	Dishwasher	
6.2.2	Washing machine	
6.2.3	Dryer (electric)	

6.3	Please indicate the average number of daily use of the following devices for the whole household:	N.A.	A - Light (< 2h/day)	B - Moderate 3 to 4 h/day	C - Average 5 to 6 h/day	D - Important 7 to 8 h/day	E - Heavy 9 to 10 h/day
6.3.1	Television(s)						
6.3.2	Computer(s)						

Real consumption data

7	Please indicate the energy vectors you use for...	...main heating	...extra heating	... prepare DHW	...cook
7.1	Coal				
7.2	Oil fuel				
7.3	Natural gas				
7.4	Butane, propane, LPG				
7.5	Wood (logs)				
7.6	Wood (pellets)				
7.7	Electricity				

If "coal"

7.1.1	What is your real annual coal consumption?	kg	per year	
		€		

If "fuel oil"

7.2.1	What is your real fuel oil consumption?	litres	over the period	
		€	from	to

If "natural gas"

7.3.1	What is your real annual natural gas consumption?	m³	over the period
		kWh	from
		€	to

If "butane, propane or LPG":

7.4.1	What is your real gas consumption?	gas canisters	per year
		€	

If "wood (logs)":

7.5.1	What is your real wood consumption?	steres	per year
		€	

If "wood (pellets)":

7.6.1	What is your real wood consumption?	kg	over the period	
		€	from	to

7.7.1	What is your annual electricity consumption?	kWh	over the period	
		€	from	to

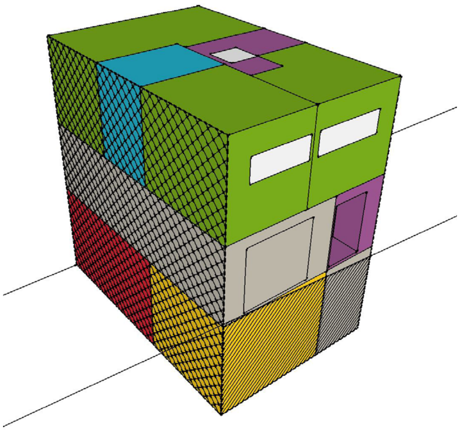
Annex 2: Case studies: descriptive cards

CS 01

PHOTO FRONT FACADE (S)

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[25; 34]
Highest diploma (R)	University
Principal occupation (R)	Independant
Nb of inhabitants (H)	4
Nb of toddlers (< 3 years old) (H)	2
Nb of schooled children (> 3 and < 15 years old) (H)	0
Nb of seniors (> 64 years old) (H)	0



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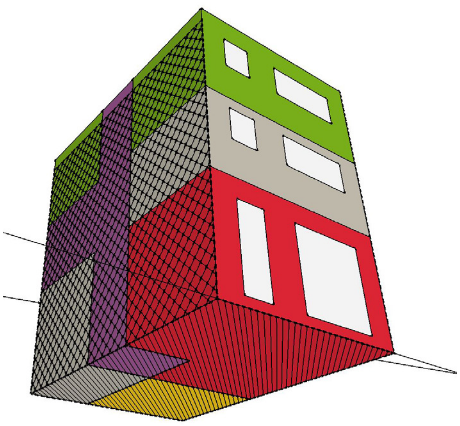


BACK FACADE (N)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_P (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_P
- Spaces outside the V_P

Building - general data and thermal characteristics

Building period	[1996; 2007]
Typology	Modern
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	3
Stairway open on heated spaces?	Yes
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	3
Temperature regulation device(s)	Thermostat
Heated Floor Area A_{ch} [m²]	161
Protected volume V_P [m³]	487
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	228
Compactness $C = V_P/A_T$ [m]	2.13
Global envelope thermal transmittance U_m [W/m²K]	0.64
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	71
Global DHW installation efficiency η_{dhw} [%]	51
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	181
Level on the official EPC certification scale	C
Annual natural gas consumption according to the official EPC [kWh/an]	27,563
Real natural gas consumption [kWh/an]	8,300
Period(s) covered	2015
Real wood consumption [kWh/an]	0
Period(s) covered	-
Real electricity consumption [kWh/an]	3,989
Period(s) covered	2015

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather high (4/5)
Dishwasher (/week)	3
Washing machine (/week)	3
Electric dryer (/week)	2
Television(s) (/day)	3 - 4h
Computer(s) (/day)	5 - 6h
Ventilation of...	
... the living room (LR)?	Occasionally + closed vents
... the kitchen (K)?	Hood
... the bathroom(s) (BTR)?	Timed (extractor)
... the bedroom(s) (BDR)?	Daily + closed vents
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	21
Temperature setting for daytime spaces - nightime	18
Temperature setting for nightime spaces - daytime	Not heated
Temperature setting for nightime spaces - nightime	18
Temperature setting for bathroom when used	21
With an added electrical heater?	Yes
Nb of heated bedrooms	2
Which bedrooms?	All but main BDR
Are circulations heated?	Indirectly
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Rather, yes.
... switch off light in unoccupied spaces?	It depends...
... use low-energy lightbulbs?	It depends...
... weather-strip windows in winter?	Yes, of course!
... close doors between heated and unheated spaces?	It depends...
... put on sweater before raising temperature?	Rather, yes.
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Rather not.
... save water?	It depends...
... make use of good natural light quality?	Yes, of course!

Not at all!
Rather not.
It depends...
Rather, yes.
Yes, of course!

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3	1	8
WEEKDAYS 1–3	LR, DR, K, BTR 37.2% of the V_p T_{set} 21°C	LR, DR, K 33.1% of the V_p T_{set} 21°C	LR, DR, K 33.1% of the V_p T_{set} 21°C	LR, DR, K 33.1% of the V_p T_{set} 21°C	LR, DR, K 33.1% of the V_p T_{set} 21°C	LR, DR, K, (OBDR) 39.2% of the V_p T_{set} 21°C	LR, DR, K, BTR 37.2% of the V_p T_{set} 21°C	LR, DR, K, OBDR 45.4% of the V_p T_{set} 18°C
4–5	LR, DR, K, BTR 37.2% of the V_p T_{set} 21°C					LR, DR, K, (OBDR) 39.2% of the V_p T_{set} 21°C	LR, DR, K, BTR 37.2% of the V_p T_{set} 21°C	LR, DR, K, OBDR 45.4% of the V_p T_{set} 18°C
6–7	LR, DR, K, BTR 37.2% of the V_p T_{set} 21°C	LR, DR, K - 33.1% of the V_p T_{set} 21°C	LR, DR, K - 33.1% of the V_p T_{set} 21°C	LR, DR, K - 33.1% of the V_p T_{set} 21°C	LR, DR, K - 33.1% of the V_p T_{set} 21°C	LR, DR, K, (OBDR) 39.2% of the V_p T_{set} 21°C	LR, DR, K, BTR 37.2% of the V_p T_{set} 21°C	LR, DR, K, OBDR 45.4% of the V_p T_{set} 18°C

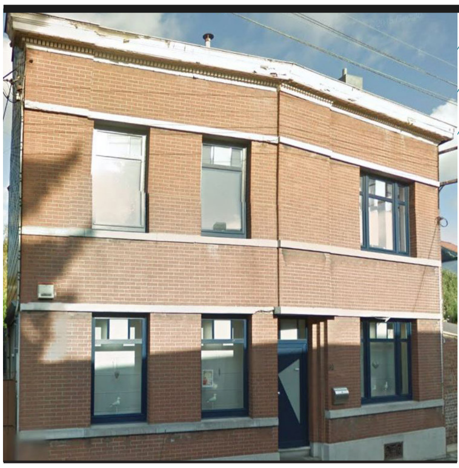
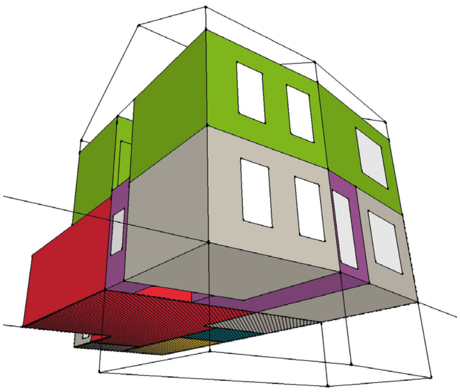


PHOTO FRONT FACADE (SE)

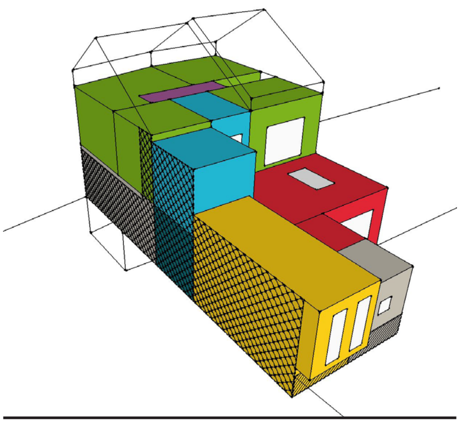
CS 02

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[35; 44]
Highest diploma (R)	University
Principal occupation (R)	Employed
Nb of inhabitants (H)	5
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	3
Nb of seniors (> 64 years old) (H)	0



FRONT FACADE (SE)



BACK FACADE (NW)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_p (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_p
- Spaces outside the V_p

Building - general data and thermal characteristics

Building period	[1946; 1960]	
Typology	Urb. extension	
Nb of exterior facades	3	
Nb of levels in the protected volume (V_p)	2	
Stairway open on heated spaces?	Yes	
Kitchen open on living room?	Yes	-
Dining room open on living room?	No	-
Nb of bedrooms	4	
Temperature regulation device(s)	Therm. + TV	-
Heated Floor Area A_{ch} [m²]	159	96
Protected volume V_p [m³]	533	309
Nb of energy sector(s)	2	
Energy sector repartition of V_p [%]	63.3	36.7
Transmission loss area A_T [m²]	372	230
Compactness $C = V_p/A_T$ [m]	1.43	1.34
Global envelope thermal transmittance U_m [W/m²K]	1.11	1.53
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)	12 (def)
Global heating installation efficiency η_{heat} [%]	69	96
Global DHW installation efficiency η_{dhw} [%]	18	54
Thermal/PV solar panels area [m²]	0/62	
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	293	
Level on the official EPC certification scale	D	
Annual natural gas consumption according to the official EPC [kWh/an]	87,724	
Real natural gas consumption [kWh/an]	72,657	
Period(s) covered	04/13 to 03/16	
Real wood consumption [kWh/an]	1970	
Period(s) covered	annual	
Real electricity consumption [kWh/an]	29,662	
Period(s) covered	01/13 to 12/15	

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Average (3/5)	
Dishwasher (/week)	4	
Washing machine (/week)	6	
Electric dryer (/week)	5	
Television(s) (/day)	3 - 4h	
Computer(s) (/day)	3 - 4h	
Ventilation of...		
... the living room (LR)?	Occasionally	
... the kitchen (K)?	Occas.+ hood	
... the bathroom(s) (BTR)?	Occasionally	
... the bedroom(s) (BDR)?	Daily	
Heating-related behaviour		
Temperature setting for daytime spaces - daytime	21	N.A.
Temperature setting for daytime spaces - nightime	16	N.A.
Temperature setting for nightime spaces - daytime	N.A.	21
Temperature setting for nightime spaces - nightime	N.A.	No heat
Temperature setting for bathroom when used	N.A.	21
With an added electrical heater?	-	Yes
Nb of heated bedrooms	3	
Which bedrooms?	All but main BDR	
Are circulations heated?	Indirectly	
Are "other" spaces directly heated during the day?	Yes (cellar)	No
With an added electrical heater?	No	-

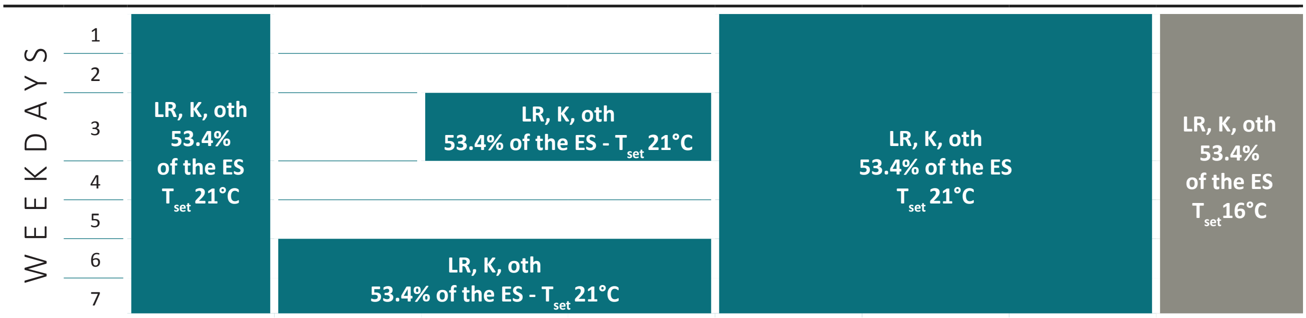
Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Rather, yes.
... switch off light in unoccupied spaces?	Rather, yes.
... use low-energy lightbulbs?	Rather, yes.
... weather-strip windows in winter?	Rather, yes.
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Rather, yes.
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Rather, yes.
... save water?	Rather not.
... make use of good natural light quality?	Rather, yes.

Not at all! (red)
Rather not. (orange)
It depends... (yellow)
Rather, yes. (green)
Yes, of course! (blue)

V_p heating schedule

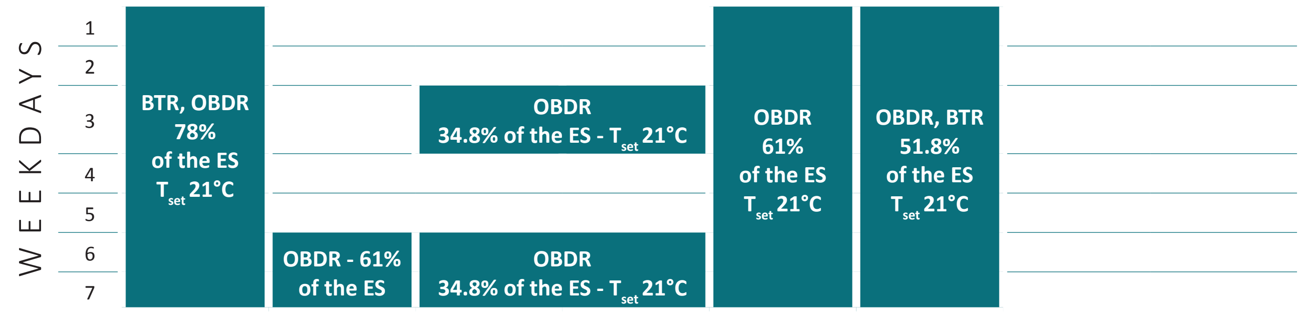
Energy Sector 1 (63.5% of V_p with daytime spaces)

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1.25	3.75	1	3	3	2.75	1.25	8



Energy Sector 2 (36.5% of V_p with nightime spaces)

hours/day	1.25	3.75	1	3	3	2.75	1.25	8



CS 03

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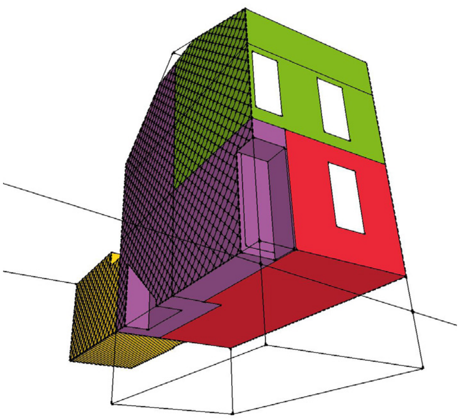

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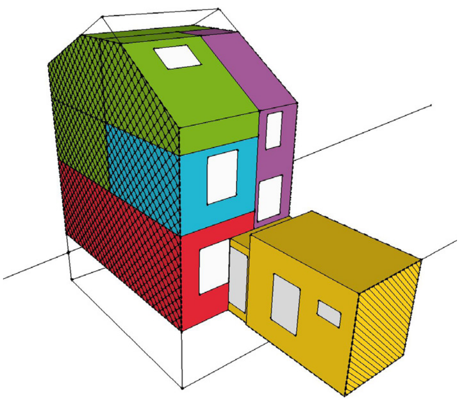


BACK FACADE (N)

- **Living room (LR)**
- **Kitchen (K)**
- **Bedrooms (BDR)**
- **Bathroom (BTR)**
- **Other heated spaces in V_p (oth)**
- **Circulations (circ)**
- **Shared with neighbours**
- **Walls against ground**
- **Non heated spaces inside the V_p**
- **Spaces outside the V_p**

Respondent (R) and Household (H) - general data

Gender (R)	M&F
Age category (R)	[25; 34]
Highest diploma (R)	Sup non univ.
Principal occupation (R)	Employed
Nb of inhabitants (H)	4
Nb of toddlers (< 3 years old) (H)	1
Nb of schooled children (> 3 and < 15 years old) (H)	1
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[1919; 1945]
Typology	Modest
Nb of exterior facades	2
Nb of levels in the protected volume (V_p)	3
Stairway open on heated spaces?	No
Kitchen open on living room?	No
Dining room open on living room?	Yes
Nb of bedrooms	3
Temperature regulation device(s)	Therm. + TV
Heated Floor Area A_{ch} [m²]	134
Protected volume V_p [m³]	421
Nb of energy sector(s)	1
Energy sector repartition of V_p [%]	100
Transmission loss area A_T [m²]	225
Compactness $C = V_p/A_T$ [m]	1.87
Global envelope thermal transmittance U_m [W/m²K]	1.75
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	60
Global DHW installation efficiency η_{dhw} [%]	33
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	511
Level on the official EPC certification scale	G
Annual natural gas consumption according to the official EPC [kWh/an]	67,598
Real natural gas consumption [kWh/an]	12,743
Period(s) covered	06/13 to 05/14
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	3,774
Period(s) covered	06/14 to 07/15

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather low (2/5)
Dishwasher (/week)	7
Washing machine (/week)	3
Electric dryer (/week)	3
Television(s) (/day)	7 - 8h
Computer(s) (/day)	1 - 2h
Ventilation of...	
... the living room (LR)?	Occasionally
... the kitchen (K)?	Daily
... the bathroom(s) (BTR)?	Occasionally
... the bedroom(s) (BDR)?	No
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	20 to 22
Temperature setting for daytime spaces - nightime	18
Temperature setting for nightime spaces - daytime	20
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	20
With an added electrical heater?	No
Nb of heated bedrooms	2
Which bedrooms?	All but main BDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

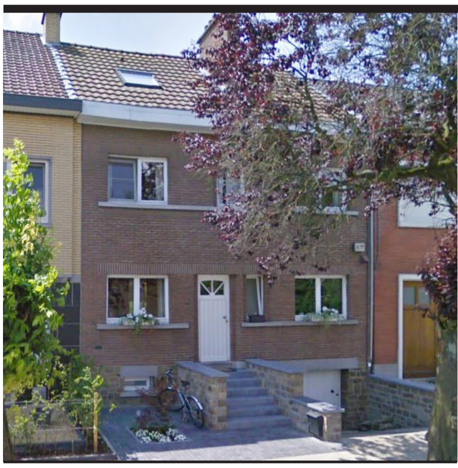
Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	It depends...
... switch off light in unoccupied spaces?	Yes, of course!
... use low-energy lightbulbs?	Rather, yes.
... weather-strip windows in winter?	Rather, yes.
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Rather, yes.
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	It depends...
... save water?	Rather, yes.
... make use of good natural light quality?	Rather not.

Not at all!
Rather not.
It depends...
Rather, yes.
Yes, of course!

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3	1	8
WEEKDAYS 1 2 3 4 5 6 7	**LR, DR, K 39% of the V_p T_{set} 21.38°C**	**LR, DR, (K) 30.4% of the V_p T_{set} 21.77°C**	**LR, DR, K 39% of the V_p T_{set} 21.38°C**	**LR, DR, (K) 30.4% of the V_p T_{set} 21.77°C**	**LR, DR, K 39% of the V_p T_{set} 21.38°C**	**LR, DR, K, (OBDR) 51.1% of the V_p T_{set} 21.09°C**	**LR, DR, K, BTR 47.8% of the V_p T_{set} 21.13°C**	**LR, DR 26.9% of the V_p T_{set} 18°C**

CS 04



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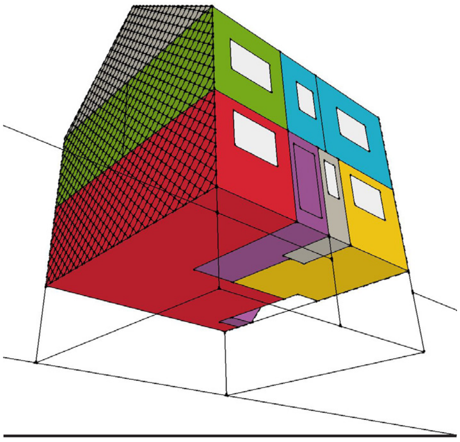

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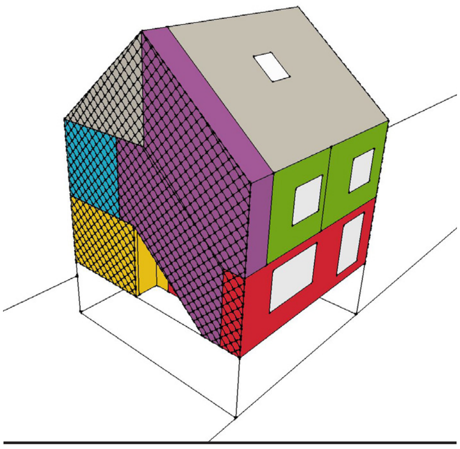


BACK FACADE (SSW)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_P (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_P
- Spaces outside the V_P

Respondent (R) and Household (H) - general data

Gender (R)	M&F
Age category (R)	[25; 34]
Highest diploma (R)	University
Principal occupation (R)	Executive
Nb of inhabitants (H)	4
Nb of toddlers (< 3 years old) (H)	1
Nb of schooled children (> 3 and < 15 years old) (H)	1
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[1946; 1960]
Typology	Urb. extension
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	3
Stairway open on heated spaces?	Yes
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	3
Temperature regulation device(s)	Therm. + TV
Heated Floor Area A_{ch} [m²]	163
Protected volume V_P [m³]	506
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	257
Compactness $C = V_P/A_T$ [m]	1.97
Global envelope thermal transmittance U_m [W/m²K]	1.18
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	78
Global DHW installation efficiency η_{dhw} [%]	49
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	204
Level on the official EPC certification scale	C
Annual natural gas consumption according to the official EPC [kWh/an]	32,163
Real natural gas consumption [kWh/an]	14,493
Period(s) covered	04/14 to 03/15
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	4,691
Period(s) covered	04/14 to 03/15

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather high (4/5)
Dishwasher (/week)	4
Washing machine (/week)	5
Electric dryer (/week)	5
Television(s) (/day)	3 - 4h
Computer(s) (/day)	3 - 4h
Ventilation of...	
... the living room (LR)?	No
... the kitchen (K)?	Daily + hood
... the bathroom(s) (BTR)?	Daily
... the bedroom(s) (BDR)?	Occasionally
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	21
Temperature setting for daytime spaces - nightime	Not heated
Temperature setting for nightime spaces - daytime	21
Temperature setting for nightime spaces - nightime	16
Temperature setting for bathroom when used	21
With an added electrical heater?	Yes
Nb of heated bedrooms	2
Which bedrooms?	All but main BDR
Are circulations heated?	Indirectly
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	● (yellow)
... switch off light in unoccupied spaces?	● (green)
... use low-energy lightbulbs?	● (blue)
... weather-strip windows in winter?	● (yellow)
... close doors between heated and unheated spaces?	● (blue)
... put on sweater before raising temperature?	● (blue)
... avoid active air conditioning in summer?	● (blue)
... switch off heating when opening windows?	● (red)
... save water?	● (orange)
... make use of good natural light quality?	● (green)

Not at all! ● (red)
Rather not. ● (orange)
It depends... ● (yellow)
Rather, yes. ● (green)
Yes, of course! ● (blue)

V_p heating schedule

<table>
<tr><th></th><th></th><th>Wake up & get ready</th><th>Morning</th><th>Noon</th><th>Afternoon (school)</th><th>Afternoon (rest)</th><th>Evening</th><th>Ready for bed & turn off</th><th>Sleep</th></tr>
<tr><td colspan="2">hours/day</td><td>1</td><td>4</td><td>1</td><td>3</td><td>3</td><td>3</td><td>1</td><td>8</td></tr>
<tr><td rowspan="7">WEEKDAYS</td><td>1</td><td rowspan="7">LR, DR, K, BTR, OBDR 53.1% of the V_p T_{set} 21°C</td><td></td><td></td><td></td><td rowspan="7">LR, DR, K, BTR, OBDR 53.1% of the V_p T_{set} 21°C</td><td rowspan="7">LR, DR, K, BTR, (OBDR) 46.9% of the V_p T_{set} 20.23°C</td><td rowspan="7">LR, DR, K, BTR, OBDR 53.1% of the V_p T_{set} 21°C</td><td rowspan="7">LR, DR, K, BTR, (OBDR) 46.9% of the V_p T_{set} 16°C</td></tr>
<tr><td>2</td><td></td><td></td><td></td></tr>
<tr><td>3</td><td></td><td colspan="2">LR, DR, K, BTR, OBDR 53.1% of the V_p - T_{set} 21°C</td></tr>
<tr><td>4</td><td></td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td><td></td></tr>
<tr><td>6</td><td colspan="3" rowspan="2">LR, DR, K, BTR, OBDR 53.1% of the V_p - T_{set} 21°C</td></tr>
<tr><td>7</td></tr>
</table>

CS **05**

PHOTO FRONT FACADE (ENE)

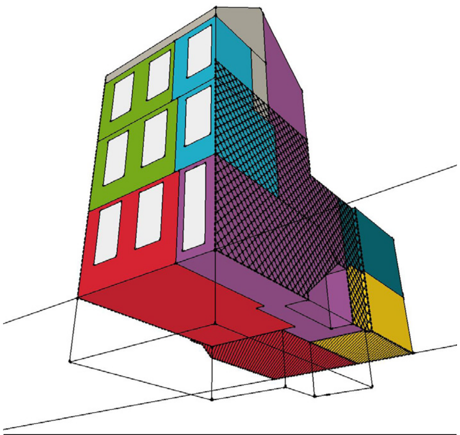
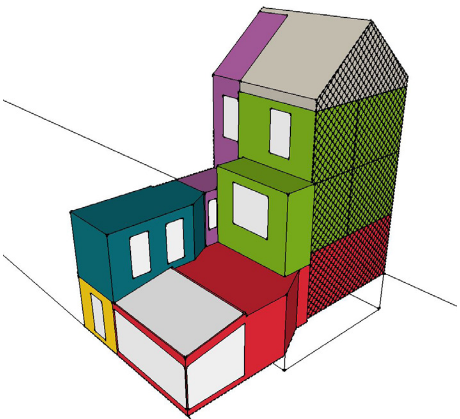


PHOTO FRONT FACADE (ENE)



BACK FACADE (WSW)

- **Living room (LR)**
- **Kitchen (K)**
- **Bedrooms (BDR)**
- **Bathroom (BTR)**
- **Other heated spaces in V_p (oth)**
- **Circulations (circ)**
- **Shared with neighbours**
- **Walls against ground**
- **Non heated spaces inside the V_p**
- **Spaces outside the V_p**

Respondent (R) and Household (H) - general data

Gender (R)	M
Age category (R)	[35; 44]
Highest diploma (R)	University
Principal occupation (R)	Independant
Nb of inhabitants (H)	5
Nb of toddlers (< 3 years old) (H)	1
Nb of schooled children (> 3 and < 15 years old) (H)	2
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[<1919]
Typology	Master
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	4
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	4
Temperature regulation device(s)	Therm. + TV
Heated Floor Area A_{ch} [m²]	271
Protected volume V_P [m³]	953
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	553
Compactness $C = V_P/A_T$ [m]	1.72
Global envelope thermal transmittance U_m [W/m²K]	1.36
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	70
Global DHW installation efficiency η_{dhw} [%]	39
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	387
Level on the official EPC certification scale	E
Annual natural gas consumption according to the official EPC [kWh/an]	94,483
Real natural gas consumption [kWh/an]	33,992
Period(s) covered	2015
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	2,895
Period(s) covered	2014

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Low (1/5)
Dishwasher (/week)	5
Washing machine (/week)	3
Electric dryer (/week)	2
Television(s) (/day)	3 - 4h
Computer(s) (/day)	1 - 2h
Ventilation of...	
... the living room (LR)?	Daily
... the kitchen (K)?	Daily
... the bathroom(s) (BTR)?	Daily
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	19
Temperature setting for daytime spaces - nightime	15
Temperature setting for nightime spaces - daytime	19
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	19
With an added electrical heater?	Yes
Nb of heated bedrooms	4
Which bedrooms?	All occupied BDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	Yes (office)
With an added electrical heater?	No

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	● (Not at all!)
... switch off light in unoccupied spaces?	● (Rather, yes.)
... use low-energy lightbulbs?	● (Yes, of course!)
... weather-strip windows in winter?	● (Yes, of course!)
... close doors between heated and unheated spaces?	● (Rather, yes.)
... put on sweater before raising temperature?	● (Rather, yes.)
... avoid active air conditioning in summer?	● (Yes, of course!)
... switch off heating when opening windows?	● (It depends...)
... save water?	● (Rather, yes.)
... make use of good natural light quality?	● (Yes, of course!)

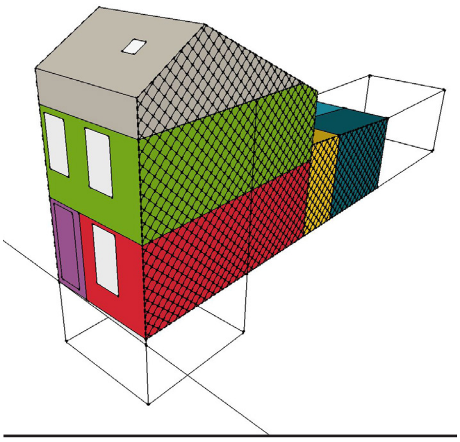
Not at all! ● (red)
Rather not. ● (orange)
It depends... ● (yellow)
Rather, yes. ● (green)
Yes, of course! ● (blue)

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1.25	3.75	1	3	3	2.75	1.25	8
WEEKDAYS 1	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C				LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, (BDR) 59.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K 34.6% of the V_p T_{set} 15°C
2	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C				LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, (BDR) 59.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K 34.6% of the V_p T_{set} 15°C
3	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C		LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, (BDR) 59.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K 34.6% of the V_p T_{set} 15°C
4	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C				LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, (BDR) 59.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K 34.6% of the V_p T_{set} 15°C
5	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C				LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, (BDR) 59.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K 34.6% of the V_p T_{set} 15°C
6	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, (BDR) 59.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K 34.6% of the V_p T_{set} 15°C
7	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p - T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, (BDR) 59.9% of the V_p T_{set} 19°C	LR, DR, K, BTR, BDR, oth 74.9% of the V_p T_{set} 19°C	LR, DR, K 34.6% of the V_p T_{set} 15°C

CS 06

PHOTO FRONT FACADE (E)



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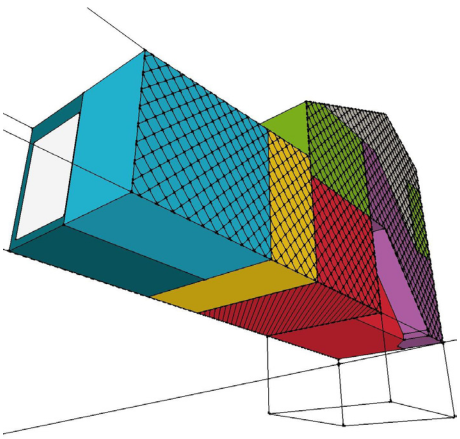


BACK FACADE (W)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_p (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_p
- Spaces outside the V_p

Respondent (R) and Household (H) - general data

Gender (R)	M&F
Age category (R)	[35; 44] & [25; 34]
Highest diploma (R)	Sup non univ.
Principal occupation (R)	Employed
Nb of inhabitants (H)	2.5
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	0.5
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[1919; 1945]	
Typology	Blue-collar	
Nb of exterior facades	2	
Nb of levels in the protected volume (V_p)	3	
Stairway open on heated spaces?	No	
Kitchen open on living room?	Yes	-
Dining room open on living room?	Yes	-
Nb of bedrooms	2	
Temperature regulation device(s)	No	No
Heated Floor Area A_{ch} [m²]	90	8
Protected volume V_p [m³]	291	27
Nb of energy sector(s)	2	
Energy sector repartition of V_p [%]	91.5	8.5
Transmission loss area A_T [m²]	158	23
Compactness $C = V_p/A_T$ [m]	1.84	1.2
Global envelope thermal transmittance U_m [W/m²K]	1.1	1.01
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)	12 (def)
Global heating installation efficiency η_{heat} [%]	63	90
Global DHW installation efficiency η_{dhw} [%]	53	78
Thermal/PV solar panels area [m²]	0/0	
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	304	
Level on the official EPC certification scale	D	
Annual natural gas consumption according to the official EPC [kWh/an]	25,928	
Real natural gas consumption [kWh/an]	10,091	
Period(s) covered	11/14 to 10/15	
Real wood consumption [kWh/an]	N.A.	
Period(s) covered	N.A.	
Real electricity consumption [kWh/an]	4,609	
Period(s) covered	11/14 to 10/15	

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather low (2/5)	
Dishwasher (/week)	3	
Washing machine (/week)	3	
Electric dryer (/week)	3	
Television(s) (/day)	7 - 8h	
Computer(s) (/day)	7 - 8h	
Ventilation of...		
... the living room (LR)?	Daily	
... the kitchen (K)?	No	
... the bathroom(s) (BTR)?	Timed (extractor)	
... the bedroom(s) (BDR)?	Daily	
Heating-related behaviour		
Temperature setting for daytime spaces - daytime	22	N.A.
Temperature setting for daytime spaces - nightime	22	N.A.
Temperature setting for nightime spaces - daytime	No heat	N.A.
Temperature setting for nightime spaces - nightime	No heat	N.A.
Temperature setting for bathroom when used	N.A.	24
With an added electrical heater?	-	Yes
Nb of heated bedrooms	0	
Which bedrooms?	No BDR heated	
Are circulations heated?	No	
Are "other" spaces directly heated during the day?	No	No
With an added electrical heater?	-	-

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	It depends...
... switch off light in unoccupied spaces?	It depends...
... use low-energy lightbulbs?	Yes, of course!
... weather-strip windows in winter?	Rather, yes.
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Not at all!
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Rather not.
... save water?	Rather not.
... make use of good natural light quality?	Not at all!

Not at all! (red)
Rather not. (orange)
It depends... (yellow)
Rather, yes. (green)
Yes, of course! (blue)

V_p heating schedule

Energy Sector 1 (91.5% of V_p with all but BTR)

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	0.625	4.375	1	3	3	3.375	0.625	8
WEEKDAYS 1–3	LR, DR, K 49.5% of the ES T_{set} 22°C	LR, DR, K 49.5% of the ES T_{set} 22°C (spans Morning to Afternoon (rest))				LR, DR, K 49.5% of the ES T_{set} 22°C (spans Evening to Sleep)		
WEEKDAYS 4–5	(spans days 1–7)	(unheated)				(spans days 1–7)		
WEEKDAYS 6–7		LR, DR, K 49.5% of the ES - T_{set} 22°C (spans Morning to Afternoon (rest))						

Energy Sector 2 (8.5% of V_p with BTR)

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	0.625	4.375	1	3	3	3.375	0.625	8
WEEKDAYS 1–7	BTR 100% of the ES T_{set} 24°C						BTR 100% of the ES T_{set} 24°C	

CS 07

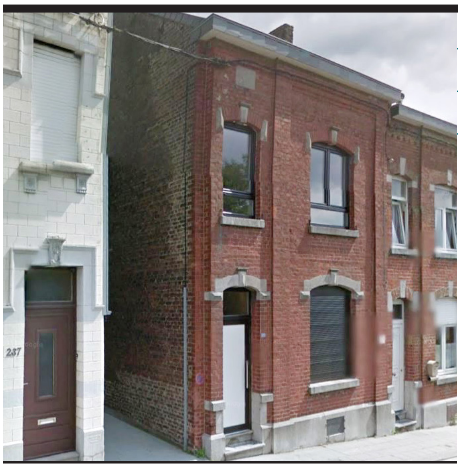
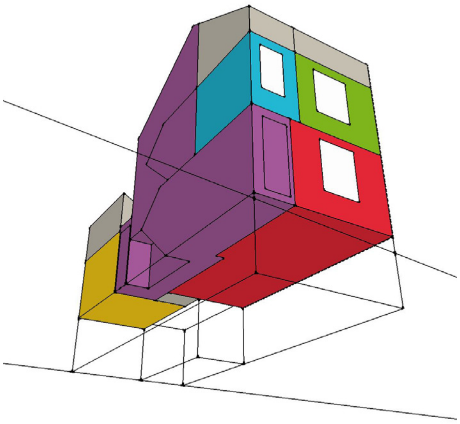


PHOTO FRONT FACADE (W)



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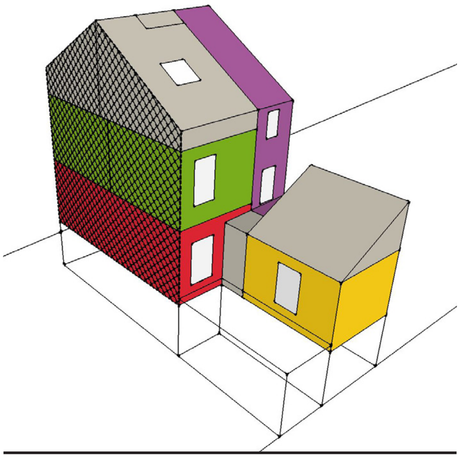


BACK FACADE (E)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_p (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_p
- Spaces outside the V_p

Respondent (R) and Household (H)-general data

Gender (R)	M&F
Age category (R)	[25; 34]
Highest diploma (R)	Sup. non univ.
Principal occupation (R)	Employed
Nb of inhabitants (H)	4
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	2
Nb of seniors (> 64 years old) (H)	0

Building-general data and thermal characteristics

Building period	[<1919]
Typology	Modest
Nb of exterior facades	3
Nb of levels in the protected volume (V_P)	3
Stairway open on heated spaces?	No
Kitchen open on living room?	No
Dining room open on living room?	Yes
Nb of bedrooms	4
Temperature regulation device(s)	Therm. + TV
Heated Floor Area A_{ch} [m²]	153
Protected volume V_P [m³]	506
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	356
Compactness $C = V_P/A_T$ [m]	1.42
Global envelope thermal transmittance U_m [W/m²K]	1.69
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	72
Global DHW installation efficiency η_{dhw} [%]	40
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	438
Level on the official EPC certification scale	F
Annual natural gas consumption according to the official EPC [kWh/an]	66,008
Real natural gas consumption [kWh/an]	14,279
Period(s) covered	12/15 to 08/16
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	3,407
Period(s) covered	09/15 to 09/16

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather low (2/5)
Dishwasher (/week)	4
Washing machine (/week)	8
Electric dryer (/week)	8
Television(s) (/day)	5 - 6h
Computer(s) (/day)	5 - 6h
Ventilation of...	
... the living room (LR)?	Occasionally
... the kitchen (K)?	Daily
... the bathroom(s) (BTR)?	Occasionally
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	22
Temperature setting for daytime spaces - nightime	Not heated
Temperature setting for nightime spaces - daytime	16
Temperature setting for nightime spaces - nightime	16
Temperature setting for bathroom when used	24
With an added electrical heater?	Yes
Nb of heated bedrooms	1
Which bedrooms?	All but main BDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	● (red) Not at all!
... switch off light in unoccupied spaces?	● (yellow) It depends...
... use low-energy lightbulbs?	● (blue) Yes, of course!
... weather-strip windows in winter?	● (red) Not at all!
... close doors between heated and unheated spaces?	● (yellow) It depends...
... put on sweater before raising temperature?	● (green) Rather, yes.
... avoid active air conditioning in summer?	● (blue) Yes, of course!
... switch off heating when opening windows?	● (green) Rather, yes.
... save water?	● (green) Rather, yes.
... make use of good natural light quality?	● (yellow) It depends...

Not at all! ● (red)
Rather not. ● (orange)
It depends... ● (yellow)
Rather, yes. ● (green)
Yes, of course! ● (blue)

V_p heating schedule

<table>
<tr><th></th><th></th><th>Wake up & get ready</th><th>Morning</th><th>Noon</th><th>Afternoon (school)</th><th>Afternoon (rest)</th><th>Evening</th><th>Ready for bed & turn off</th><th>Sleep</th></tr>
<tr><td>hours/day</td><td></td><td>1</td><td>4</td><td>1</td><td>3</td><td>3</td><td>3</td><td>1</td><td>8</td></tr>
<tr><td rowspan="7">WEEKDAYS</td><td>1</td><td rowspan="7">LR, DR, K, BTR 38.1% of the V_p T_{set} 22.23°C</td><td colspan="3"></td><td rowspan="7">LR, DR, K 33.8% of the V_p T_{set} 22°C</td><td rowspan="7">LR, DR, K 33.8% of the V_p T_{set} 22°C</td><td rowspan="7">LR, DR, K, BTR 38.1% of the V_p T_{set} 22,23°C</td><td rowspan="7">(LR, DR, OBDR1) 19.5% of the V_p T_{set} 16°C</td></tr>
<tr><td>2</td><td colspan="3" rowspan="2">LR, DR - 23% of the V_p T_{set} 22°C</td></tr>
<tr><td>3</td></tr>
<tr><td>4</td><td colspan="3"></td></tr>
<tr><td>5</td><td colspan="3"></td></tr>
<tr><td>6</td><td colspan="3" rowspan="2">LR, DR - 23% of the V_p T_{set} 22°C</td></tr>
<tr><td>7</td></tr>
</table>

CS 08

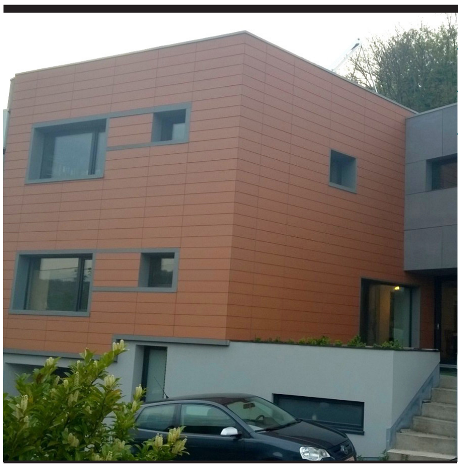


PHOTO FRONT FACADE (NW)

Respondent (R) and Household (H) - general data

Gender (R)	M&F
Age category (R)	[25; 34]
Highest diploma (R)	University
Principal occupation (R)	Employed and Indep.
Nb of inhabitants (H)	3
Nb of toddlers (< 3 years old) (H)	1
Nb of schooled children (> 3 and < 15 years old) (H)	0
Nb of seniors (> 64 years old) (H)	0

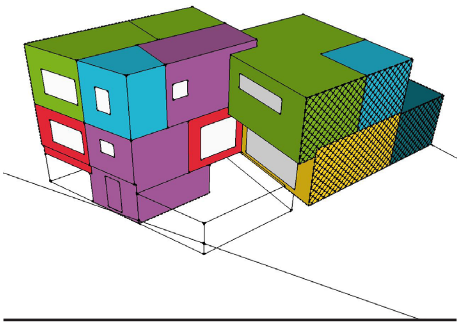
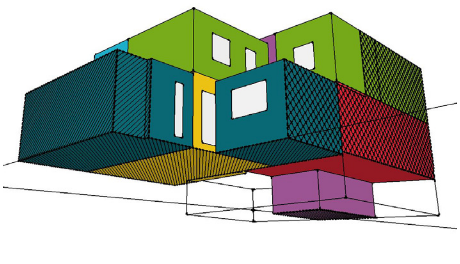


PHOTO FRONT FACADE (NW)

Building - general data and thermal characteristics

Building period	[1946; 1960]
Typology	First-floor
Nb of exterior facades	3
Nb of levels in the protected volume (V_p)	3
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	3
Temperature regulation device(s)	Ext. Probe + Therm. + TV
Heated Floor Area A_{ch} [m²]	261
Protected volume V_p [m³]	812
Nb of energy sector(s)	1
Energy sector repartition of V_p [%]	100
Transmission loss area A_T [m²]	584
Compactness $C = V_p/A_T$ [m]	1.39
Global envelope thermal transmittance U_m [W/m²K]	0.21
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	1.6
Global heating installation efficiency η_{heat} [%]	77
Global DHW installation efficiency η_{dhw} [%]	29
Thermal/PV solar panels area [m²]	10/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	41
Level on the official EPC certification scale	A+
Annual natural gas consumption according to the official EPC [kWh/an]	6,186
Real natural gas consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real wood consumption [kWh/an]	5,785
Period(s) covered	11/15 to 10/16
Real electricity consumption [kWh/an]	4,400
Period(s) covered	11/15 to 10/16



BACK FACADE (SE)

- **Living room (LR)**
- **Kitchen (K)**
- **Bedrooms (BDR)**
- **Bathroom (BTR)**
- **Other heated spaces in V_p (oth)**
- **Circulations (circ)**
- **Shared with neighbours**
- **Walls against ground**
- **Non heated spaces inside the V_p**
- **Spaces outside the V_p**

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Average (3/5)
Dishwasher (/week)	3
Washing machine (/week)	7
Electric dryer (/week)	7
Television(s) (/day)	3 - 4h
Computer(s) (/day)	1 - 2h
Ventilation of...	
... the living room (LR)?	NBN D50-001
... the kitchen (K)?	NBN D50-001
... the bathroom(s) (BTR)?	NBN D50-001
... the bedroom(s) (BDR)?	NBN D50-001
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	20
Temperature setting for daytime spaces - nightime	Not heated
Temperature setting for nightime spaces - daytime	18
Temperature setting for nightime spaces - nightime	16
Temperature setting for bathroom when used	Not heated
With an added electrical heater?	No
Nb of heated bedrooms	3
Which bedrooms?	All occupied BDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	Yes (office, cellar)
With an added electrical heater?	No

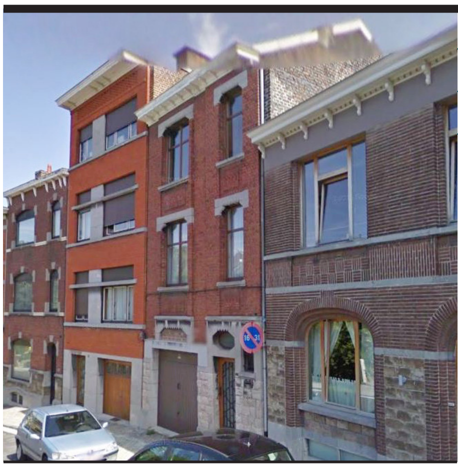
Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	● (Yes, of course!)
... switch off light in unoccupied spaces?	● (Rather, yes.)
... use low-energy lightbulbs?	● (Rather not.)
... weather-strip windows in winter?	● (Rather not.)
... close doors between heated and unheated spaces?	● (Yes, of course!)
... put on sweater before raising temperature?	● (Rather, yes.)
... avoid active air conditioning in summer?	● (Yes, of course!)
... switch off heating when opening windows?	● (Rather, yes.)
... save water?	● (It depends...)
... make use of good natural light quality?	● (Rather, yes.)

Not at all! ● (red)
Rather not. ● (orange)
It depends... ● (yellow)
Rather, yes. ● (green)
Yes, of course! ● (blue)

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	0.75	4.25	1	3	3	3.25	0.75	8
WEEKDAYS 1–7	**LR, DR, K, MBDR, OBDR, oth 78.8% of the V_p T_{set} 19.3°C**							**MBDR 14.8% of the V_p T_{set} 16°C**

CS 09



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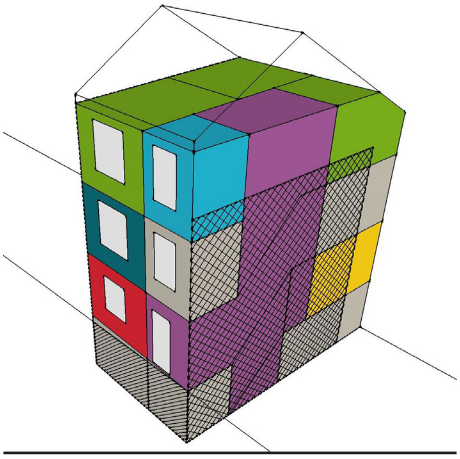
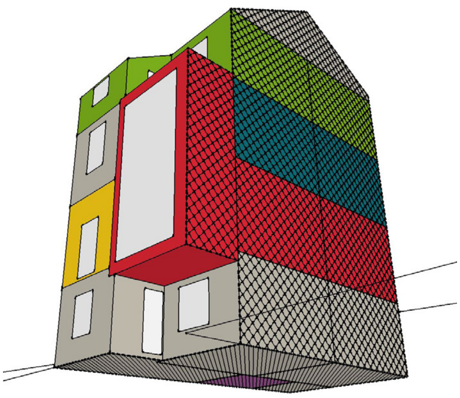


PHOTO FRONT FACADE (W)



BACK FACADE (E)

- **Living room (LR)**
- **Kitchen (K)**
- **Bedrooms (BDR)**
- **Bathroom (BTR)**
- **Other heated spaces in V_p (oth)**
- **Circulations (circ)**
- **Shared with neighbours**
- **Walls against ground**
- **Non heated spaces inside the V_p**
- **Spaces outside the V_p**

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[25; 34]
Highest diploma (R)	Sup. non univ.
Principal occupation (R)	Employed
Nb of inhabitants (H)	4
Nb of toddlers (< 3 years old) (H)	1
Nb of schooled children (> 3 and < 15 years old) (H)	1
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[1919; 1945]
Typology	Modest
Nb of exterior facades	2
Nb of levels in the protected volume (V_p)	4
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	4
Temperature regulation device(s)	Ext. Probe + TV
Heated Floor Area A_{ch} [m²]	287
Protected volume V_p [m³]	901
Nb of energy sector(s)	1
Energy sector repartition of V_p [%]	100
Transmission loss area A_T [m²]	371
Compactness $C = V_p/A_T$ [m]	2.43
Global envelope thermal transmittance U_m [W/m²K]	0.92
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	78
Global DHW installation efficiency η_{dhw} [%]	40
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	150
Level on the official EPC certification scale	B
Annual natural gas consumption according to the official EPC [kWh/an]	40,977
Real natural gas consumption [kWh/an]	13,747
Period(s) covered	09/14 to 09/15
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	3,268
Period(s) covered	12/14 to 11/15

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather low (2/5)
Dishwasher (/week)	3
Washing machine (/week)	5
Electric dryer (/week)	4
Television(s) (/day)	0h
Computer(s) (/day)	1 - 2h
Ventilation of...	
... the living room (LR)?	No
... the kitchen (K)?	Occasionally
... the bathroom(s) (BTR)?	Daily
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	19
Temperature setting for daytime spaces - nightime	16
Temperature setting for nightime spaces - daytime	Not heated
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	21
With an added electrical heater?	Yes
Nb of heated bedrooms	0
Which bedrooms?	No BDR heated
Are circulations heated?	No
Are "other" spaces directly heated during the day?	Yes (office)
With an added electrical heater?	No

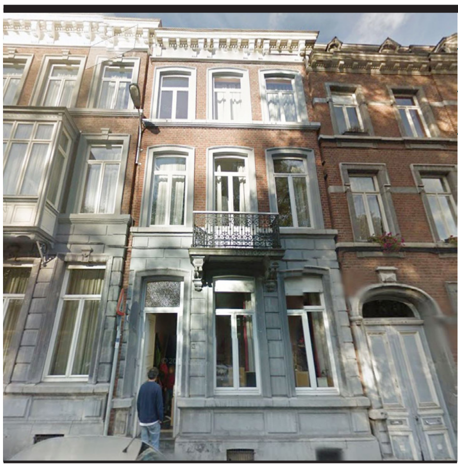
Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Yes, of course!
... switch off light in unoccupied spaces?	Yes, of course!
... use low-energy lightbulbs?	Yes, of course!
... weather-strip windows in winter?	Not at all!
... close doors between heated and unheated spaces?	Rather, yes.
... put on sweater before raising temperature?	It depends...
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Yes, of course!
... save water?	It depends...
... make use of good natural light quality?	Rather, yes.

Not at all! / Rather not. / It depends... / Rather, yes. / Yes, of course!

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3	1	8
WEEKDAYS 1–7	LR, DR, K, BTR, oth 35.3% of the V_p T_{set} 19.11°C	LR, DR, K, oth - 33.4% of the V_p - T_{set} 19°C (days 2–3); LR, DR, K, oth - 33.4% of the V_p - T_{set} 19°C (days 6–7)			LR, DR, K, oth 33.4% of the V_p T_{set} 19°C	LR, DR, K, oth 33.4% of the V_p T_{set} 19°C	LR, DR,K, BTR, oth 35.3% of the V_p T_{set} 19.11°C	LR, DR, K, oth 33.4% of the V_p T_{set} 16°C

CS 10



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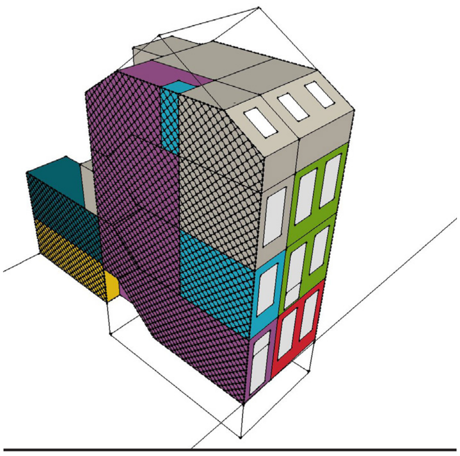
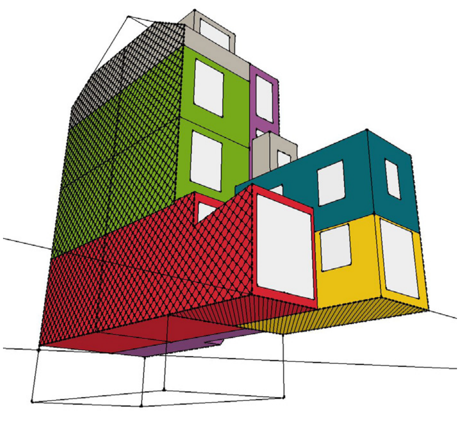


PHOTO FRONT FACADE (SE)



BACK FACADE (NW)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_P (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_P
- Spaces outside the V_P

Respondent (R) and Household (H) - general data

Gender (R)	M
Age category (R)	[45; 54]
Highest diploma (R)	PhD
Principal occupation (R)	Employed
Nb of inhabitants (H)	5
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	3
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[<1919]
Typology	Master
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	4
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	6
Temperature regulation device(s)	Ext. Probe + TV
Heated Floor Area A_{ch} [m²]	267
Protected volume V_P [m³]	949
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	436
Compactness $C = V_P/A_T$ [m]	2.17
Global envelope thermal transmittance U_m [W/m²K]	1.57
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	59
Global DHW installation efficiency η_{dhw} [%]	43
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	452
Level on the official EPC certification scale	F
Annual natural gas consumption according to the official EPC [kWh/an]	118,646
Real natural gas consumption [kWh/an]	22,625
Period(s) covered	2016
Real wood consumption [kWh/an]	3,940
Period(s) covered	annual
Real electricity consumption [kWh/an]	3,589
Period(s) covered	2015

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather low (2/5)
Dishwasher (/week)	3
Washing machine (/week)	5
Electric dryer (/week)	3
Television(s) (/day)	3 - 4h
Computer(s) (/day)	5 - 6h
Ventilation of...	
... the living room (LR)?	No
... the kitchen (K)?	Hood
... the bathroom(s) (BTR)?	Daily
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	20
Temperature setting for daytime spaces - nightime	Not heated
Temperature setting for nightime spaces - daytime	24
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	22
With an added electrical heater?	No
Nb of heated bedrooms	1
Which bedrooms?	1 OBDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	Yes (office)
With an added electrical heater?	Yes

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Yes, of course!
... switch off light in unoccupied spaces?	Yes, of course!
... use low-energy lightbulbs?	It depends...
... weather-strip windows in winter?	Not at all!
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Yes, of course!
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Yes, of course!
... save water?	It depends...
... make use of good natural light quality?	Rather, yes.

Not at all!
Rather not.
It depends...
Rather, yes.
Yes, of course!

V_p heating schedule

<table>
<tr><th></th><th></th><th>Wake up & get ready</th><th>Morning</th><th>Noon</th><th>Afternoon (school)</th><th>Afternoon (rest)</th><th>Evening</th><th>Ready for bed & turn off</th><th>Sleep</th></tr>
<tr><td colspan="2">hours/day</td><td>1.25</td><td>3.75</td><td>1</td><td>3</td><td>3</td><td>2.75</td><td>1.25</td><td>8</td></tr>
<tr><td rowspan="7">WEEKDAYS</td><td>1</td><td rowspan="7">LR, DR,K, BTR, OBDR 37.2% of the V_p T_{set} 20.58°C</td><td></td><td rowspan="7"></td><td rowspan="7">LR, DR, K, (oth) 29.9% of the V_p T_{set} 20°C</td><td rowspan="7" colspan="2">LR, DR, K, OBDR 33.6% of the V_p T_{set} 20.42°C</td><td rowspan="7">LR, DR, K, BTR, OBDR 37.2% of the V_p T_{set} 20.58°C</td><td></td></tr>
<tr><td>2</td><td rowspan="2">LR, DR, K - 26.5% of the V_p T_{set} 20°C</td><td></td></tr>
<tr><td>3</td><td></td></tr>
<tr><td>4</td><td></td><td></td></tr>
<tr><td>5</td><td></td><td></td></tr>
<tr><td>6</td><td rowspan="2">LR, DR, K - 26.5% of the V_p T_{set} 20°C</td><td></td></tr>
<tr><td>7</td><td></td></tr>
</table>

CS 11

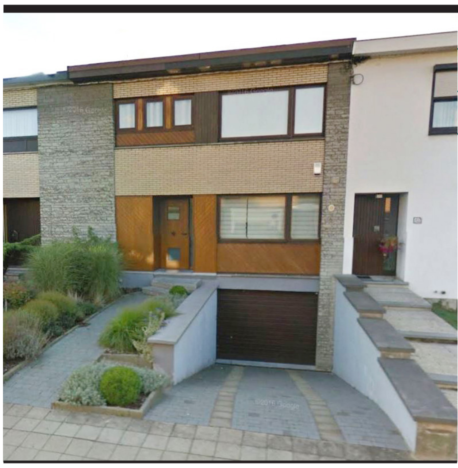
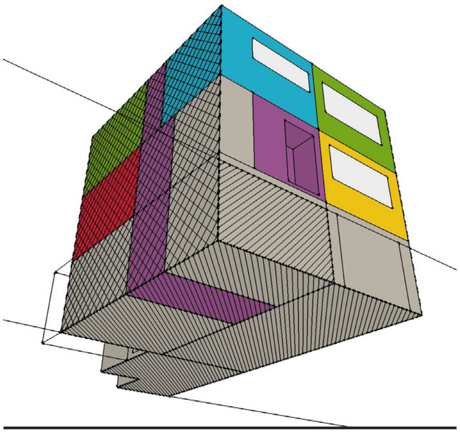


PHOTO FRONT FACADE (ENE)



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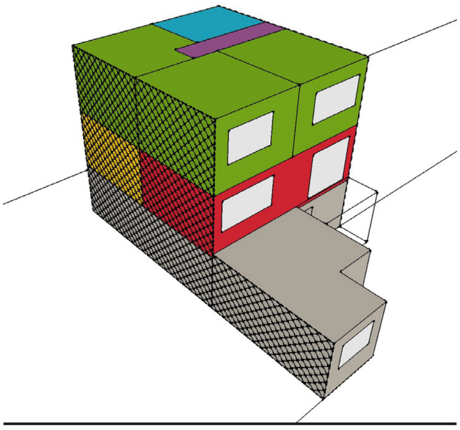


BACK FACADE (WSW)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_p (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_p
- Spaces outside the V_p

Respondent (R) and Household (H) - general data

Gender (R)	M
Age category (R)	[55; 64]
Highest diploma (R)	PhD
Principal occupation (R)	Civil servant
Nb of inhabitants (H)	3.5
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	0
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[1961; 1984]
Typology	First-floor
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	3
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	3
Temperature regulation device(s)	Ext. Probe + Therm. + TV
Heated Floor Area A_{ch} [m²]	224
Protected volume V_P [m³]	612
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	336
Compactness $C = V_p/A_T$ [m]	1.82
Global envelope thermal transmittance U_m [W/m²K]	1.12
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	80
Global DHW installation efficiency η_{dhw} [%]	47
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	190
Level on the official EPC certification scale	C
Annual natural gas consumption according to the official EPC [kWh/an]	40,428
Real natural gas consumption [kWh/an]	54,203
Period(s) covered	01/13 to 01/16
Real wood consumption [kWh/an]	1970
Period(s) covered	annual
Real electricity consumption [kWh/an]	11,451.8
Period(s) covered	05/13 to 04/16

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather high (4/5)
Dishwasher (/week)	3
Washing machine (/week)	2
Electric dryer (/week)	2
Television(s) (/day)	5 - 6h
Computer(s) (/day)	5 - 6h
Ventilation of...	
... the living room (LR)?	No
... the kitchen (K)?	Hood
... the bathroom(s) (BTR)?	Timed (extractor)
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	21
Temperature setting for daytime spaces - nightime	16
Temperature setting for nightime spaces - daytime	21
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	21
With an added electrical heater?	No
Nb of heated bedrooms	1
Which bedrooms?	1 OBDR
Are circulations heated?	Indirectly
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Not at all! (red)
... switch off light in unoccupied spaces?	Yes, of course! (blue)
... use low-energy lightbulbs?	Yes, of course! (blue)
... weather-strip windows in winter?	Rather not. (orange)
... close doors between heated and unheated spaces?	Rather, yes. (green)
... put on sweater before raising temperature?	Rather not. (orange)
... avoid active air conditioning in summer?	Yes, of course! (blue)
... switch off heating when opening windows?	Rather, yes. (green)
... save water?	Rather, yes. (green)
... make use of good natural light quality?	Rather not. (orange)

Not at all! (red)
Rather not. (orange)
It depends... (yellow)
Rather, yes. (green)
Yes, of course! (blue)

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3	1	8
WEEKDAYS 1–5	LR, DR, K, BTR, OBDR1 36.4% of the V_p T_{set} 21°C				LR, DR, K 22.5% of the V_p T_{set} 21°C	LR, DR, K, BTR, OBDR1 36.4% of the V_p T_{set} 21°C		LR, DR, K 22.5% of the V_p T_{set} 16°C
WEEKDAYS 6–7	LR, DR, K, BTR, OBDR1 36.4% of the V_p T_{set} 21°C	LR, DR, K - 22.5% of the V_p T_{set} 21°C			LR, DR, K 22.5% of the V_p T_{set} 21°C	LR, DR, K, BTR, OBDR1 36.4% of the V_p T_{set} 21°C		LR, DR, K 22.5% of the V_p T_{set} 16°C

PHOTO FRONT FACADE (ENE)

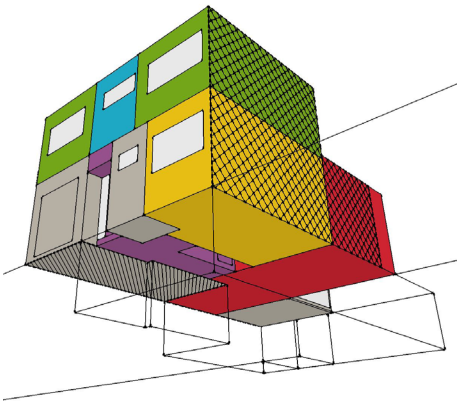
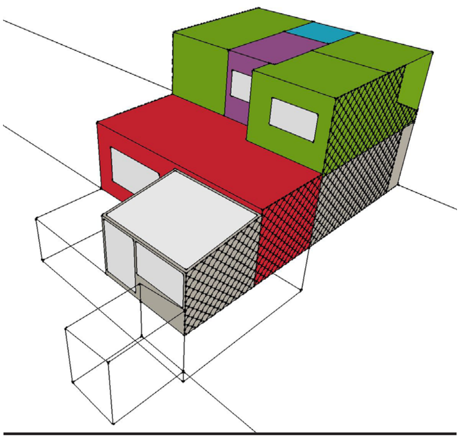


PHOTO FRONT FACADE (ENE)



BACK FACADE (WSW)

- **Living room (LR)**
- **Kitchen (K)**
- **Bedrooms (BDR)**
- **Bathroom (BTR)**
- **Other heated spaces in V_P (oth)**
- **Circulations (circ)**
- **Shared with neighbours**
- **Walls against ground**
- **Non heated spaces inside the V_P**
- **Spaces outside the V_P**

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[65 or +]
Highest diploma (R)	Sec. Sup.
Principal occupation (R)	Retired
Nb of inhabitants (H)	2
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	0
Nb of seniors (> 64 years old) (H)	2

Building - general data and thermal characteristics

Building period	[1946; 1960]
Typology	First-floor
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	2
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	3
Temperature regulation device(s)	Thermostat
Heated Floor Area A_{ch} [m²]	153
Protected volume V_P [m³]	476
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	350
Compactness $C = V_P/A_T$ [m]	1.36
Global envelope thermal transmittance U_m [W/m²K]	1.86
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	67
Global DHW installation efficiency η_{dhw} [%]	50
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	478
Level on the official EPC certification scale	F
Annual natural gas consumption according to the official EPC [kWh/an]	68,449
Real natural gas consumption [kWh/an]	70,280
Period(s) covered	09/13 to 08/16
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	10,387
Period(s) covered	11/13 to 10/16

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather low (2/5)
Dishwasher (/week)	2
Washing machine (/week)	3
Electric dryer (/week)	0
Television(s) (/day)	7 - 8h
Computer(s) (/day)	3 - 4h
Ventilation of...	
... the living room (LR)?	No
... the kitchen (K)?	No
... the bathroom(s) (BTR)?	No
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	22.6
Temperature setting for daytime spaces - nightime	18
Temperature setting for nightime spaces - daytime	20
Temperature setting for nightime spaces - nightime	18
Temperature setting for bathroom when used	24
With an added electrical heater?	No
Nb of heated bedrooms	2
Which bedrooms?	All occupied BDR
Are circulations heated?	Yes
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Rather not.
... switch off light in unoccupied spaces?	Yes, of course!
... use low-energy lightbulbs?	Rather, yes.
... weather-strip windows in winter?	Rather, yes.
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Rather, yes.
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Rather not.
... save water?	Yes, of course!
... make use of good natural light quality?	Rather not.

Not at all!
Rather not.
It depends...
Rather, yes.
Yes, of course!

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	0.5	4.5	1	3	3	3.5	0.5	8
WEEKDAYS 1–7	LR, DR, K, MBDR, OBDR, BTR, circ. 64.9% of the V_p T_{set} 21.6°C	LR, DR, K, MBDR, OBDR, BTR, circ. 64.9% of the V_p T_{set} 21.41°C					LR, DR, K, MBDR, OBDR, BTR, circ. 64.9% of the V_p T_{set} 21.6°C	LR, DR, K, MBDR, OBDR, BTR, circ. 64.9% of the V_p T_{set} 18°C

CS 13

PHOTO FRONT FACADE (NE)

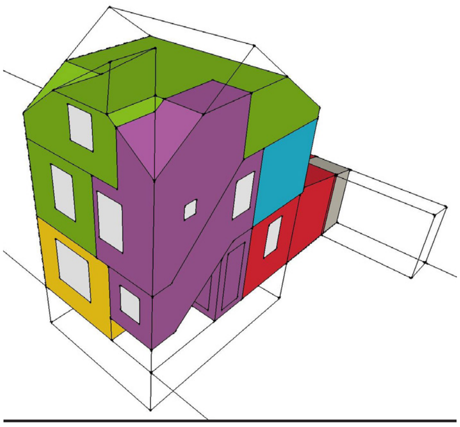
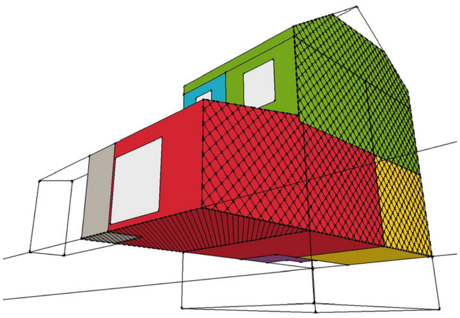


PHOTO FRONT FACADE (NE)



BACK FACADE (SW)

- **Living room (LR)**
- **Kitchen (K)**
- **Bedrooms (BDR)**
- **Bathroom (BTR)**
- **Other heated spaces in V_P (oth)**
- **Circulations (circ)**
- **Shared with neighbours**
- **Walls against ground**
- **Non heated spaces inside the V_P**
- **Spaces outside the V_P**

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[35; 44]
Highest diploma (R)	Sec. Inf.
Principal occupation (R)	Unemployed
Nb of inhabitants (H)	4
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	1
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[1919; 1945]	
Typology	Modest	
Nb of exterior facades	3	
Nb of levels in the protected volume (V_P)	3	
Stairway open on heated spaces?	No	
Kitchen open on living room?	Yes	
Dining room open on living room?	Yes	
Nb of bedrooms	3	
Temperature regulation device(s)	Therm. + TV	
Heated Floor Area A_{ch} [m²]	145	
Protected volume V_P [m³]	452	
Nb of energy sector(s)	1	
Energy sector repartition of V_P [%]	100	
Transmission loss area A_T [m²]	310	
Compactness $C = V_P/A_T$ [m]	1.46	
Global envelope thermal transmittance U_m [W/m²K]	1.48	
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)	
Global heating installation efficiency η_{heat} [%]	62	
Global DHW installation efficiency η_{dhw} [%]	66	90
Thermal/PV solar panels area [m²]	0/0	
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	573	
Level on the official EPC certification scale	G	
Annual natural gas consumption according to the official EPC [kWh/an]	81,787	
Real natural gas consumption [kWh/an]	8,458	
Period(s) covered	08/15 to 07/16	
Real wood consumption [kWh/an]	5,910	
Period(s) covered	annual	
Real electricity consumption [kWh/an]	3,641	
Period(s) covered	03/16 to 11/16	

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	High (5/5)
Dishwasher (/week)	5
Washing machine (/week)	7
Electric dryer (/week)	3
Television(s) (/day)	5 - 6h
Computer(s) (/day)	9 - 10h
Ventilation of...	
... the living room (LR)?	Daily
... the kitchen (K)?	Daily
... the bathroom(s) (BTR)?	No
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	19
Temperature setting for daytime spaces - nightime	16
Temperature setting for nightime spaces - daytime	19
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	19
With an added electrical heater?	No
Nb of heated bedrooms	1
Which bedrooms?	1 OBDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Not at all!
... switch off light in unoccupied spaces?	Yes, of course!
... use low-energy lightbulbs?	Yes, of course!
... weather-strip windows in winter?	Not at all!
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Yes, of course!
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Not at all!
... save water?	Rather, yes.
... make use of good natural light quality?	It depends...

Not at all!
Rather not.
It depends...
Rather, yes.
Yes, of course!

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3	1	8
WEEKDAYS 1	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C				LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, BTR 47.9% of the V_p T_{set} 16°C
2	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, BTR 47.9% of the V_p T_{set} 16°C
3	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, BTR 47.9% of the V_p T_{set} 16°C
4	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C				LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, BTR 47.9% of the V_p T_{set} 16°C
5	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C				LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, BTR 47.9% of the V_p T_{set} 16°C
6	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, BTR 47.9% of the V_p T_{set} 16°C
7	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 51.2% of the V_p - T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, OBDR2, BTR 56.1% of the V_p T_{set} 19°C	LR, DR, K, BTR 47.9% of the V_p T_{set} 16°C

CS 14

PHOTO FRONT FACADE (NW)

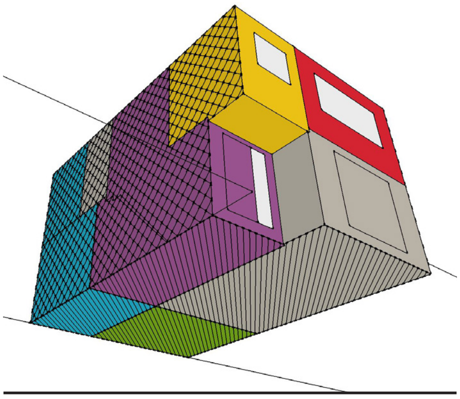
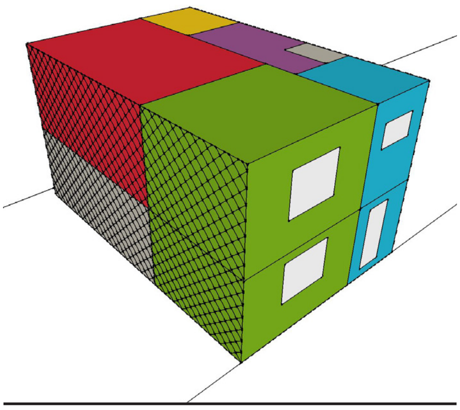


PHOTO FRONT FACADE (NW)



BACK FACADE (SE)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_p (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_p
- Spaces outside the V_p

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[45; 54]
Highest diploma (R)	Sup non univ.
Principal occupation (R)	Civil servant
Nb of inhabitants (H)	1.5
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	0
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[1985; 1995]
Typology	Modern
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	2
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	2
Temperature regulation device(s)	Thermostat
Heated Floor Area A_{ch} [m²]	127
Protected volume V_P [m³]	365
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	207
Compactness $C = V_P/A_T$ [m]	1.76
Global envelope thermal transmittance U_m [W/m²K]	0.63
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	85
Global DHW installation efficiency η_{dhw} [%]	52
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	376
Level on the official EPC certification scale	E
Annual natural gas consumption according to the official EPC [kWh/an]	19,171
Real natural gas consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	17,616
Period(s) covered	10/14 to 10/16

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather low (2/5)
Dishwasher (/week)	0
Washing machine (/week)	4
Electric dryer (/week)	2
Television(s) (/day)	3 - 4h
Computer(s) (/day)	0h
Ventilation of...	
... the living room (LR)?	Occasionally
... the kitchen (K)?	Hood
... the bathroom(s) (BTR)?	No
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	20
Temperature setting for daytime spaces - nightime	20
Temperature setting for nightime spaces - daytime	20
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	24
With an added electrical heater?	Yes
Nb of heated bedrooms	1
Which bedrooms?	All but main BDR
Are circulations heated?	Indirectly
Are "other" spaces directly heated during the day?	No
With an added electrical heater?	-

Rational use of energy : tendancy to...	Response
... switch off appliances instead of sleep mode?	Rather, yes.
... switch off light in unoccupied spaces?	Yes, of course!
... use low-energy lightbulbs?	Rather, yes.
... weather-strip windows in winter?	It depends...
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Yes, of course!
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Not at all!
... save water?	Not at all!
... make use of good natural light quality?	Rather, yes.

Not at all!
Rather not.
It depends...
Rather, yes.
Yes, of course!

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3.25	0.75	8
WEEKDAYS 1–7	**LR, DR, K 26.8% of the V_p T_{set} 20°C**					**LR, DR, K, OBDR 38.5% of the V_p T_{set} 20°C**	**LR, DR, K, OBDR, BTR 43.4% of the V_p T_{set} 20.45°C**	**LR, DR, K 26.8% of the V_p T_{set} 20°C**

CS 15

PHOTO FRONT FACADE (ENE)

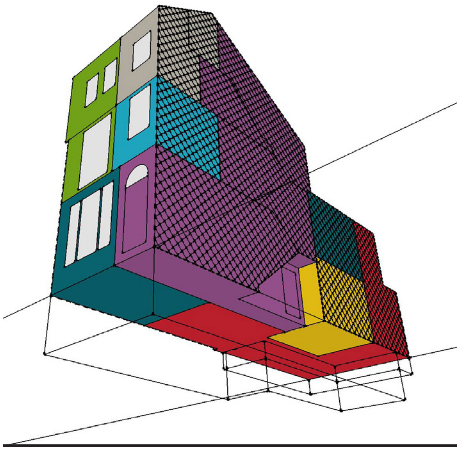
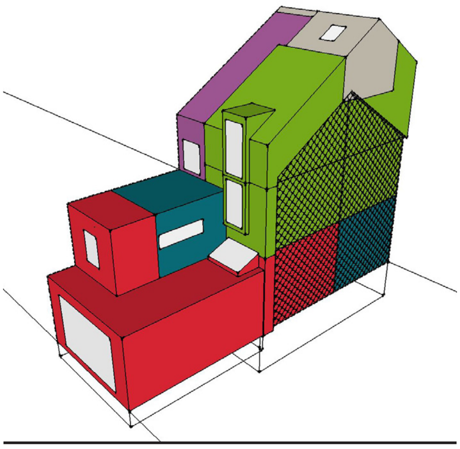


PHOTO FRONT FACADE (ENE)



BACK FACADE (WSW)

- **Living room (LR)**
- **Kitchen (K)**
- **Bedrooms (BDR)**
- **Bathroom (BTR)**
- **Other heated spaces in V_p (oth)**
- **Circulations (circ)**
- **Shared with neighbours**
- **Walls against ground**
- **Non heated spaces inside the V_p**
- **Spaces outside the V_p**

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[25; 34]
Highest diploma (R)	University
Principal occupation (R)	Employed
Nb of inhabitants (H)	2
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	0
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[<1919]	
Typology	Master	
Nb of exterior facades	2	
Nb of levels in the protected volume (V_P)	4	
Stairway open on heated spaces?	No	
Kitchen open on living room?	Yes	
Dining room open on living room?	Yes	
Nb of bedrooms	5	
Temperature regulation device(s)	Ext. Probe + TV	
Heated Floor Area A_{ch} [m²]	246	
Protected volume V_P [m³]	860	
Nb of energy sector(s)	1	
Energy sector repartition of V_P [%]	100	
Transmission loss area A_T [m²]	425	
Compactness $C = V_P/A_T$ [m]	2.02	
Global envelope thermal transmittance U_m [W/m²K]	0.34	
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	3.7	
Global heating installation efficiency η_{heat} [%]	84	
Global DHW installation efficiency η_{dhw} [%]	37	67
Thermal/PV solar panels area [m²]	7/0	
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	54	
Level on the official EPC certification scale	A	
Annual natural gas consumption according to the official EPC [kWh/an]	7,030	
Real natural gas consumption [kWh/an]	8,081	
Period(s) covered	12/15 to 12/16	
Real wood consumption [kWh/an]	N.A.	
Period(s) covered	N.A.	
Real electricity consumption [kWh/an]	2471,9	
Period(s) covered	12/14 to 06/15	

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Rather high (4/5)
Dishwasher (/week)	5
Washing machine (/week)	3
Electric dryer (/week)	1
Television(s) (/day)	5 - 6h
Computer(s) (/day)	9 - 10h
Ventilation of...	
... the living room (LR)?	NBN D50-001
... the kitchen (K)?	NBN D50-001
... the bathroom(s) (BTR)?	NBN D50-001
... the bedroom(s) (BDR)?	NBN D50-001
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	21
Temperature setting for daytime spaces - nightime	17
Temperature setting for nightime spaces - daytime	21
Temperature setting for nightime spaces - nightime	17
Temperature setting for bathroom when used	21
With an added electrical heater?	No
Nb of heated bedrooms	2
Which bedrooms?	All occupied BDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	Yes (office, mezzanine)
With an added electrical heater?	No

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	● (Rather, yes.)
... switch off light in unoccupied spaces?	● (Yes, of course!)
... use low-energy lightbulbs?	● (Rather, yes.)
... weather-strip windows in winter?	● (Not at all!)
... close doors between heated and unheated spaces?	● (Rather not.)
... put on sweater before raising temperature?	● (Yes, of course!)
... avoid active air conditioning in summer?	● (Yes, of course!)
... switch off heating when opening windows?	● (Not at all!)
... save water?	● (Rather, yes.)
... make use of good natural light quality?	● (Yes, of course!)

Not at all! ●
Rather not. ●
It depends... ●
Rather, yes. ●
Yes, of course! ●

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	0.5	4.5	1	3	3	3.5	0.5	8
WEEKDAYS 1–7	LR, DR, K, MBDR, OBDR1, BTR, oth 52.5% of the V_p T_{set} 21°C							LR, DR, K, MBDR, OBDR1, BTR, oth 52.5% of the V_p T_{set} 17°C

CS 16

PHOTO FRONT FACADE (NW)

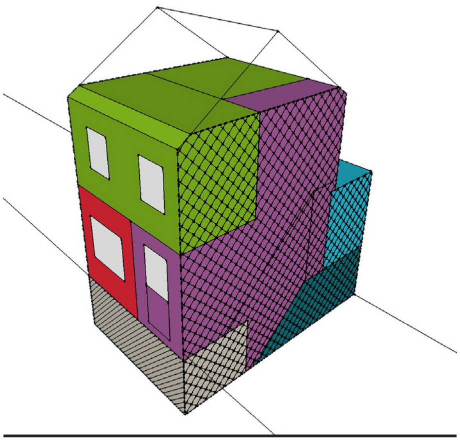
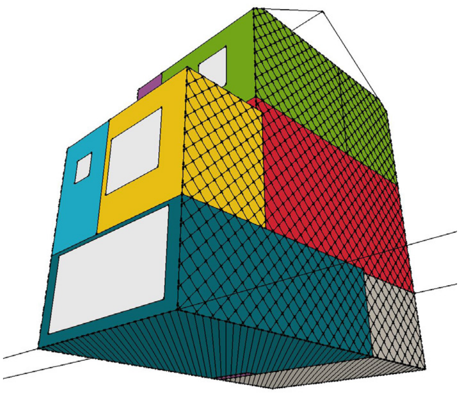


PHOTO FRONT FACADE (NW)



BACK FACADE (SE)

- Living room (LR)
- Kitchen (K)
- Bedrooms (BDR)
- Bathroom (BTR)
- Other heated spaces in V_p (oth)
- Circulations (circ)
- Shared with neighbours
- Walls against ground
- Non heated spaces inside the V_p
- Spaces outside the V_p

Respondent (R) and Household (H) - general data

Gender (R)	F
Age category (R)	[45; 54]
Highest diploma (R)	University
Principal occupation (R)	Unemployed
Nb of inhabitants (H)	1
Nb of toddlers (< 3 years old) (H)	0
Nb of schooled children (> 3 and < 15 years old) (H)	0
Nb of seniors (> 64 years old) (H)	0

Building - general data and thermal characteristics

Building period	[<1919]
Typology	Blue-collar
Nb of exterior facades	2
Nb of levels in the protected volume (V_P)	3
Stairway open on heated spaces?	No
Kitchen open on living room?	Yes
Dining room open on living room?	Yes
Nb of bedrooms	2
Temperature regulation device(s)	Therm. + TV
Heated Floor Area A_{ch} [m²]	127
Protected volume V_P [m³]	361
Nb of energy sector(s)	1
Energy sector repartition of V_P [%]	100
Transmission loss area A_T [m²]	192
Compactness $C = V_P/A_T$ [m]	1.88
Global envelope thermal transmittance U_m [W/m²K]	1.87
In/exfiltration rate at 50 Pa v_{50} [m³/h, per m² of A_T]	12 (def)
Global heating installation efficiency η_{heat} [%]	64
Global DHW installation efficiency η_{dhw} [%]	47
Thermal/PV solar panels area [m²]	0/0
Specific primary energy annual consumption E_{spec} (official EPC) [kWh/m².an]	388
Level on the official EPC certification scale	E
Annual natural gas consumption according to the official EPC [kWh/an]	43,298
Real natural gas consumption [kWh/an]	18,313
Period(s) covered	04/14 to 04/16
Real wood consumption [kWh/an]	N.A.
Period(s) covered	N.A.
Real electricity consumption [kWh/an]	2,065
Period(s) covered	07/14 to 04/16

Household-behavioural data

Average use of electr(on)ic equipment and appliances category	Low (1/5)
Dishwasher (/week)	0
Washing machine (/week)	1
Electric dryer (/week)	0
Television(s) (/day)	0h
Computer(s) (/day)	5 - 6h
Ventilation of...	
... the living room (LR)?	No
... the kitchen (K)?	Occasionally
... the bathroom(s) (BTR)?	Occasionally
... the bedroom(s) (BDR)?	Daily
Heating-related behaviour	
Temperature setting for daytime spaces - daytime	19
Temperature setting for daytime spaces - nightime	14
Temperature setting for nightime spaces - daytime	19
Temperature setting for nightime spaces - nightime	Not heated
Temperature setting for bathroom when used	19
With an added electrical heater?	No
Nb of heated bedrooms	1
Which bedrooms?	All occupied BDR
Are circulations heated?	No
Are "other" spaces directly heated during the day?	Yes (workshop)
With an added electrical heater?	No

Rational use of energy : tendancy to...	
... switch off appliances instead of sleep mode?	Yes, of course!
... switch off light in unoccupied spaces?	Yes, of course!
... use low-energy lightbulbs?	Yes, of course!
... weather-strip windows in winter?	Yes, of course!
... close doors between heated and unheated spaces?	Yes, of course!
... put on sweater before raising temperature?	Yes, of course!
... avoid active air conditioning in summer?	Yes, of course!
... switch off heating when opening windows?	Rather, yes.
... save water?	Yes, of course!
... make use of good natural light quality?	Rather, yes.

Not at all! / Rather not. / It depends... / Rather, yes. / Yes, of course!

V_p heating schedule

	Wake up & get ready	Morning	Noon	Afternoon (school)	Afternoon (rest)	Evening	Ready for bed & turn off	Sleep
hours/day	1	4	1	3	3	3	1	8
WEEKDAYS 1	LR, DR, K, MBDR, BTR 45.6% of the V_p T_{set} 19°C	LR, DR, K, BTR 33.7% of the V_p T_{set} 19°C			LR, DR, K, BTR, oth 55.7% of the V_p T_{set} 19°C	LR, DR, K, MBDR, BTR 45.6% of the V_p T_{set} 19°C	LR, DR, K, MBDR, BTR 45.6% of the V_p T_{set} 19°C	LR, DR, K, BTR 33.7% of the V_p T_{set} 14°C
2								
3								
4								
5								
6		LR, DR, K, BTR - 33.7% of the V_p T_{set} 19°C						
7								

Annex 3: Sensitivity Analysis – complement

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A3.1 Domestic Hot Water

As a result of the base hypotheses, the case studies present shares in energy consumption related to domestic hot water that range between 3% of the total final energy consumption for the least efficient case studies (CS12, which still presents very important part of consumption dedicated to heating and a high efficiency for the DHW production), and 30 to 35% for better ones (CS1, in this case), depending on the climate. Those shares are visible in details in the graphs presenting the repartition of consumptions each case study in chapter 5. The Figure A3.1.1 hereunder resumes the repartition between heating and DHW consumptions in all case studies (EPC results in grey, revaluations under different climates in red-orange).

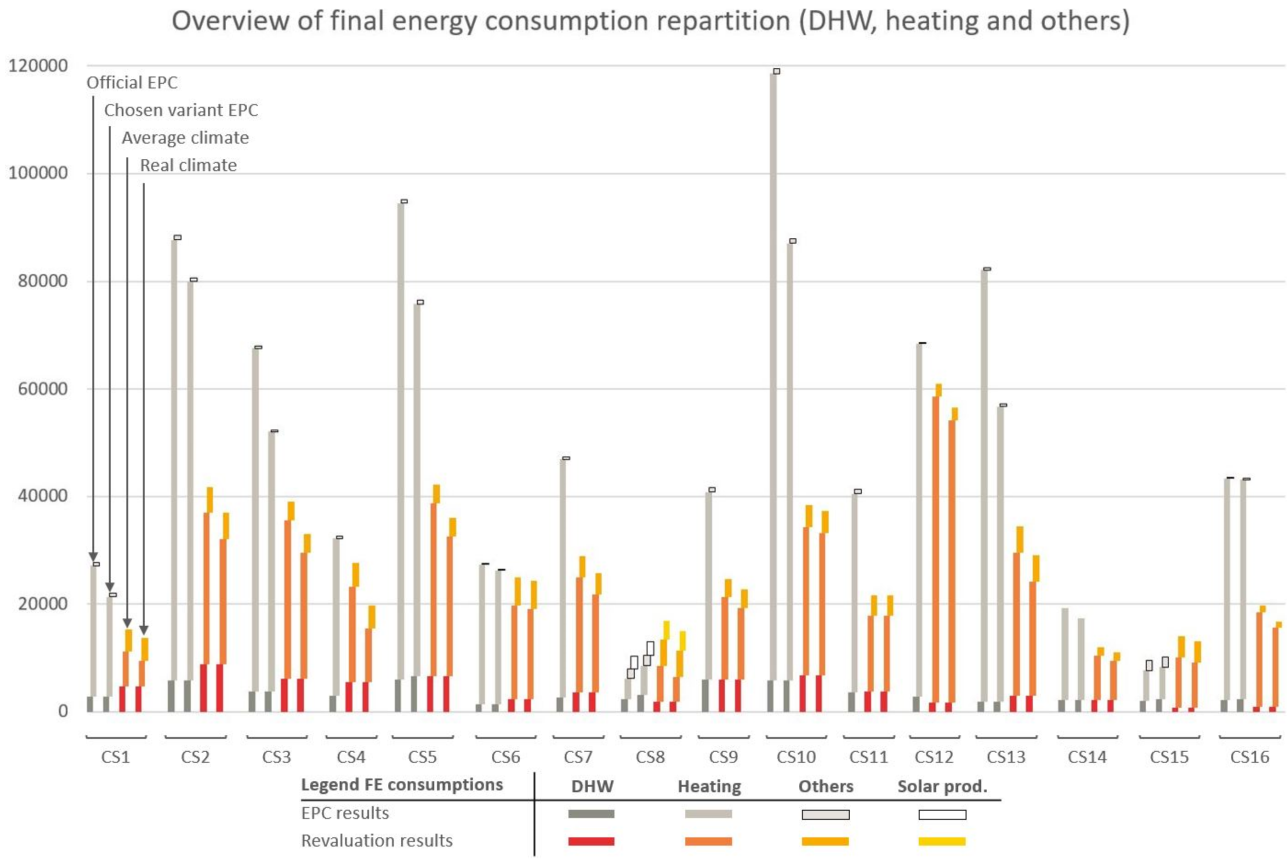

Fig. A3.1.1. Overview of the total final energy consumption evaluation results [kWh/year] for the 16 case studies, emphasizing the repartition between DHW, heating and "others" consumptions, and the solar production for CS8.

A more detailed comparison of DHW demand, evaluated under the standardised method and the modified method, can be seen in Figure 4.3.12 in section 4.3.4, considering that the DHW systems' efficiencies have been kept in the revaluated method for lack of more accurate information.

The CS8 and 15, both highly efficient dwellings equipped with solar panels that feed the DHW system, ask for a different analysis. In the CS15, the solar panels only feed the boiler that produces hot water for the bathrooms, whereas the kitchen is supplied independently by an electric boiler. Those 7m² of solar panels produce, according to the EPB calculation method, around 1,000kWh of energy, deduced from the natural gas consumptions. Unfortunately, the owners of the CS15 were unable to detail the solar production for the period covered, so that all solar contributions, actual or theoretical, have been deduced from the results presented for the CS15. The rest of the DHW consumption (around 800kWh) is shared between the natural gas boiler and the electric water heater in the kitchen, which is attributed a very high energy efficiency in the method. Because the solar production was not considered in the results, the "DHW consumption" represents around 40% of the real consumption, fictively lower than it should be. The CS15 appears therefore less influenced by the variations brought by this sensitivity analysis on DHW consumption determiners.

In the CS8, the 10m² of solar panels produce around 2,500kWh of final energy to be used by both the heating system (25 to 30% of the solar production is deduced from the final energy consumption for heating) and the DHW system (using the remaining 70 to 75% of solar production). Revaluations for the CS8 resulted in a superior global demand, thus increasing the solar production as said in chapter 5. The share of DHW in the total final energy consumption (therefore including solar production), is around 26% under average climate, and 29% under real climate. If the solar panels were absent, the share of DHW in the global energy consumption would be the same (26 to 29%). The CS8 is also the only case study which owners were capable of separating their real consumptions between DHW (2,560kWh between November 1st, 2015 and October 31st, 2016) and heating (3,225kWh between November 1st, 2015 and April 30th, 2016), as well as give their solar production during the same period covered by the DHW consumptions (3,100kWh). This sole example could hardly be used to calibrate the method, but provides an interesting comparison point. The Figure A3.1.II hereunder summarizes the Figure 5.2.51 in section 5.2.8, displaying the repartition of consumptions (and evaluated solar production) between the different theoretical evaluations (official EPC, variant EPC, and revaluations under both climatic data sets), and gives the repartition of real data for comparison:

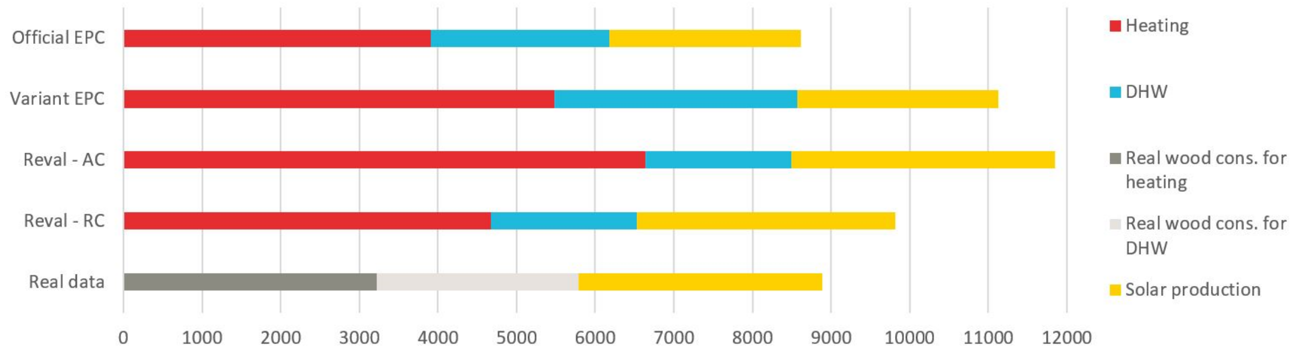

Fig. A3.1.2. Repartition, for the CS8, of the heating and DHW consumptions and solar production [kWh/year], evaluated by the EPCs or the modified method, and the real data for comparison.

The revaluations are closer to the real solar production during the covered period, especially those with the set of real climate conditions, witnessing a solar production of 3,294kWh. The consumption of wood for DHW seems underestimated, although this might be explained by, first, the slight over-estimation in solar production and, second, to the presence of a new-born, which is usually linked to a higher water consumption.

A3.1.1 DHW demand

There are very few parameters that influence the energy demand related to this particular end-use, at least in the method. The protected volume is the only one, in the standardised calculation method, as evidenced by the Equations (26) and (27) in section 4.3.4. Demand is evaluated separately for bath and showers on one hand, kitchen sinks on the other, and differentiated distribution efficiencies are attributed to each need. Equation (28), on the other hand, describes the proposition of modification for the global DHW needs, referring to the number of occupants, and an average number (25 to 45) of litres of hot water needed at 50°C, each day, by each occupant of the house. This last parameter was defined by the answer of the owners to the question "*Do members of your household tend to favour showers over baths / to save hot water as much as possible?*", although it must be admitted that discussions with the owners have often helped select the answer. Rare were the interviewees who were able to define their domestic hot water consumption, first and foremost because it cannot be singled out from other consumptions. Either prepared by using natural gas or electricity, its particular energy-related consumption is drowned in annual or monthly energy bills. The water consumption, in itself, can only be approached by bills of water supply companies, which unfortunately cannot inform on the uses that are made of it, hot or cold, related to habits in personal hygiene (clothes, body…) or dwelling upkeep (house or garden maintenance).

The first set of simulations, therefore, sees the number of litres per occupant vary between the limits imposed to the method: 25 to 45 litres at 50°C, by 5 litres increments. The Figures A3.1.3 and 4 show the evolution of the $I_{eval/obs}$ ratios for each case studies when this particular parameter varies, under both sets of climatic conditions. Grey dots mark the "base" points for each case study, representing therefore the value given until now to the parameter according to the owner's answer.

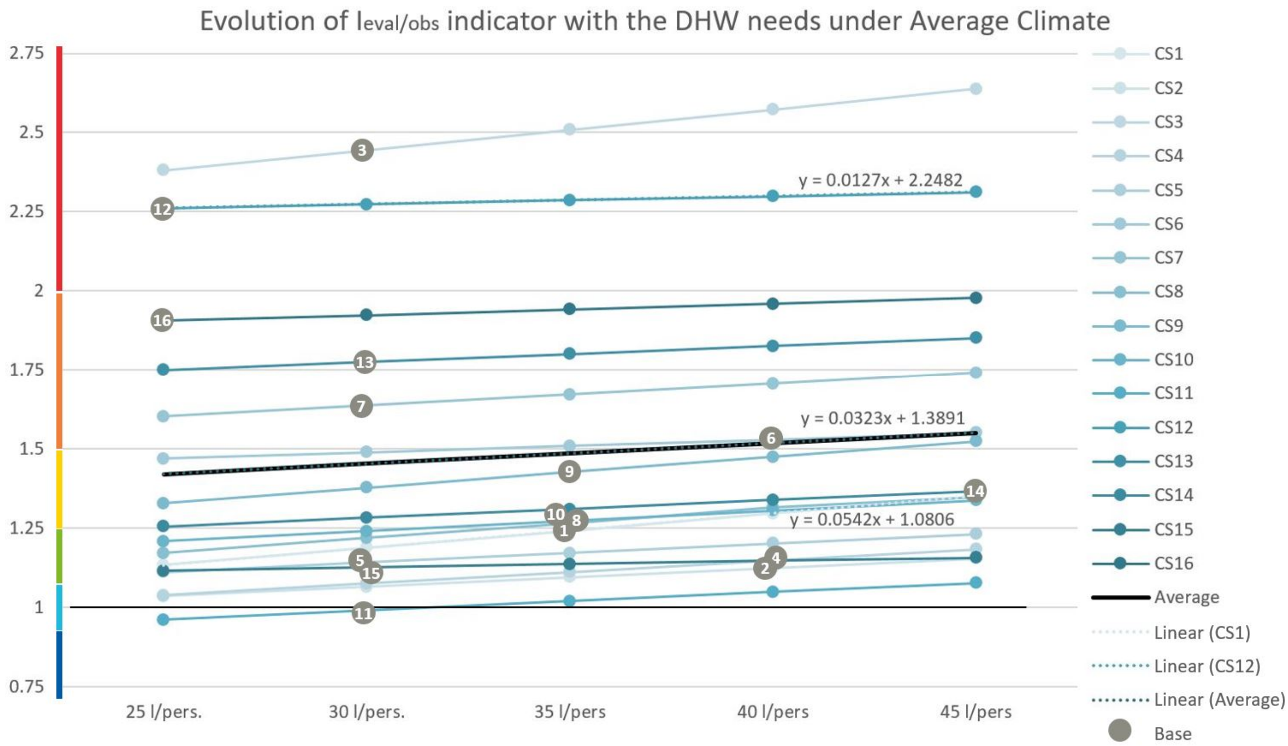

Fig. A3.1.3. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "DHW needs (litres)" analysis under the average climate hypotheses.

The first impression is that there does not seem to have a strong effect of this parameter on the results but a second and more thorough analysis highlights that cases that are the most impacted are those where the DHW consumption holds a greater place in the global final energy consumption results. The CS1, for example, sees its global consumption increase by 4.8% each time the DHW needs are raised by 5 litres/occupant. It is closely followed by the CS8 (+4.6% per increment of 5 litres/occ.), CS4 (+4.0%), CS9 (+3.9%) and CS2, all presenting DHW shares above 20% of the total revaluated consumption. The case study that is undeniably the least impacted by this analysis is the CS12 (+0.6% of energy consumption per increment of 5 litres in DHW needs), because its heating consumption still maintains a dominance on global results. The influence of the systems' efficiencies is hard to find in the ranking of most impacted case studies, as well as the influence of the number of inhabitants. This might be explained by the fact that the concerned case studies (CS6 and 16 for their low number of inhabitants; CS2 and 5 for their high number of inhabitants; CS6 or 13 for their high DHW systems' efficiencies) nearly all present low DHW shares in consumption. In other words, the higher the efficiency of the dwelling, the more precise the description of the DHW needs to be. All revaluations that have been made until now have resulted in the reduction of the theoretical global consumption, mainly in its heating end-use. Results show that the DHW evaluation of the EPB is, if not accurate in every case, at least accurate on average. Therefore, the processes up until now have all had for effect to increase the DHW share in consumption; thus increasing the need for precision in the description of the DHW demand for those cases as well. CS2, 4, 5 or 11, which cannot really be categorised as "energy-efficient", all show $I_{eval/obs}$ ratios close to 1 (which means that their global consumption is accurately evaluated, even if the repartition might not be), and relatively high DHW share in consumption. They all present steeper regression lines than the average, indicating their higher sensitivity to DHW demand.

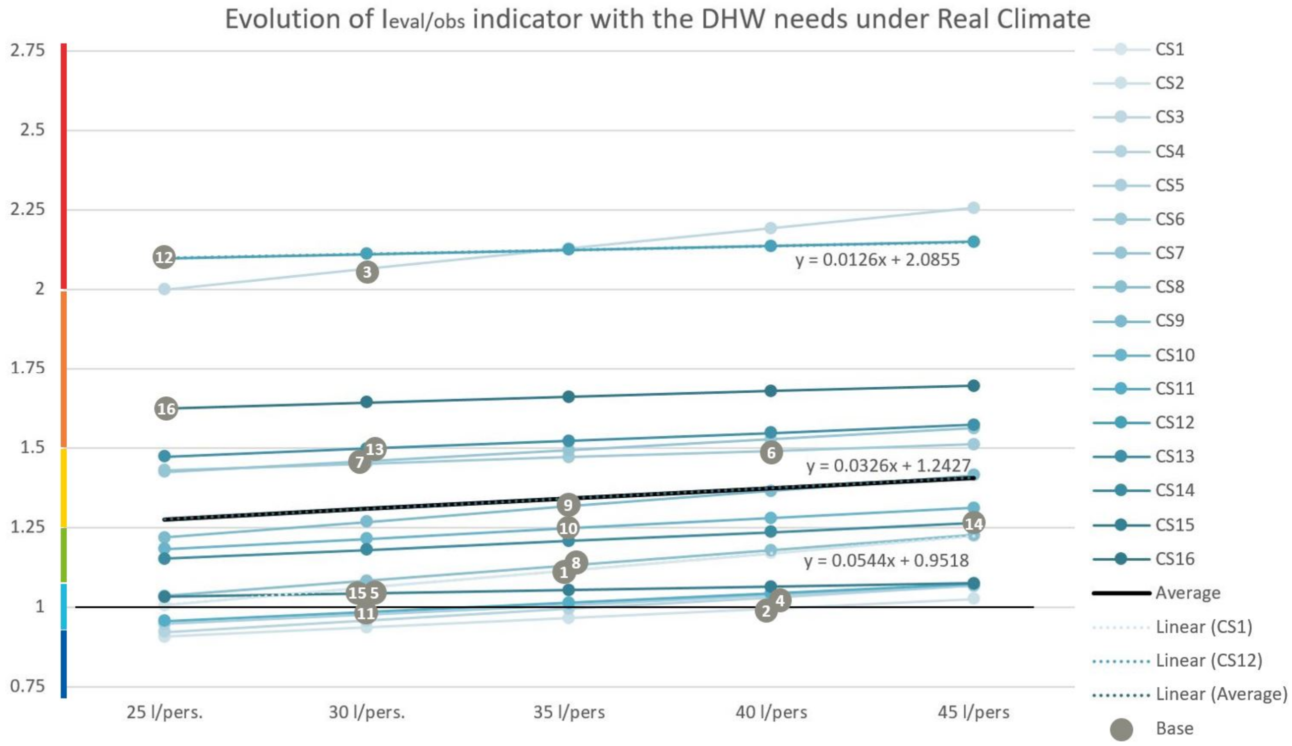

Fig. A3.1.4. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "DHW needs (litres)" analysis under the real climate hypotheses.

In both graphs (Figures A3.1.3 and 4), an average is added in black to visualise the average evolution of the $I_{eval/obs}$ ratio. Its regression line equation is given, along with those of the case studies that showed "extreme" results variations among the sample: in this case, the CS12 (low impact), and the CS1 (high impact). The results are quite logically similar under the real climate hypotheses. The ranking changes a bit; for example, the case studies located in or around Liege benefited from higher exterior temperatures and saw their consumption share in DHW rise slightly; the change in DHW demand is therefore slightly more influential but stays below 1% in absolute difference. On average, the 5 litres increment in DHW needs brings a 2.4% increase in consumption under average climate, 2.7% under real climate.

The second set of simulations is showing the same kind of results and influences. Figure A3.1.5 displays the evolution of the $I_{eval/obs}$ ratio for all case studies when the $\theta_{water,out}$ factor of Equation (28) (section 4.3.8) varies. It represents the temperature target of the heated water, and has been set to 50°C in the calculation method. The limits of variations are normally quite narrow, given hygienic needs; in this set of variation, it has been defined to [40°C; 60°C], in order to encase all scenarios.

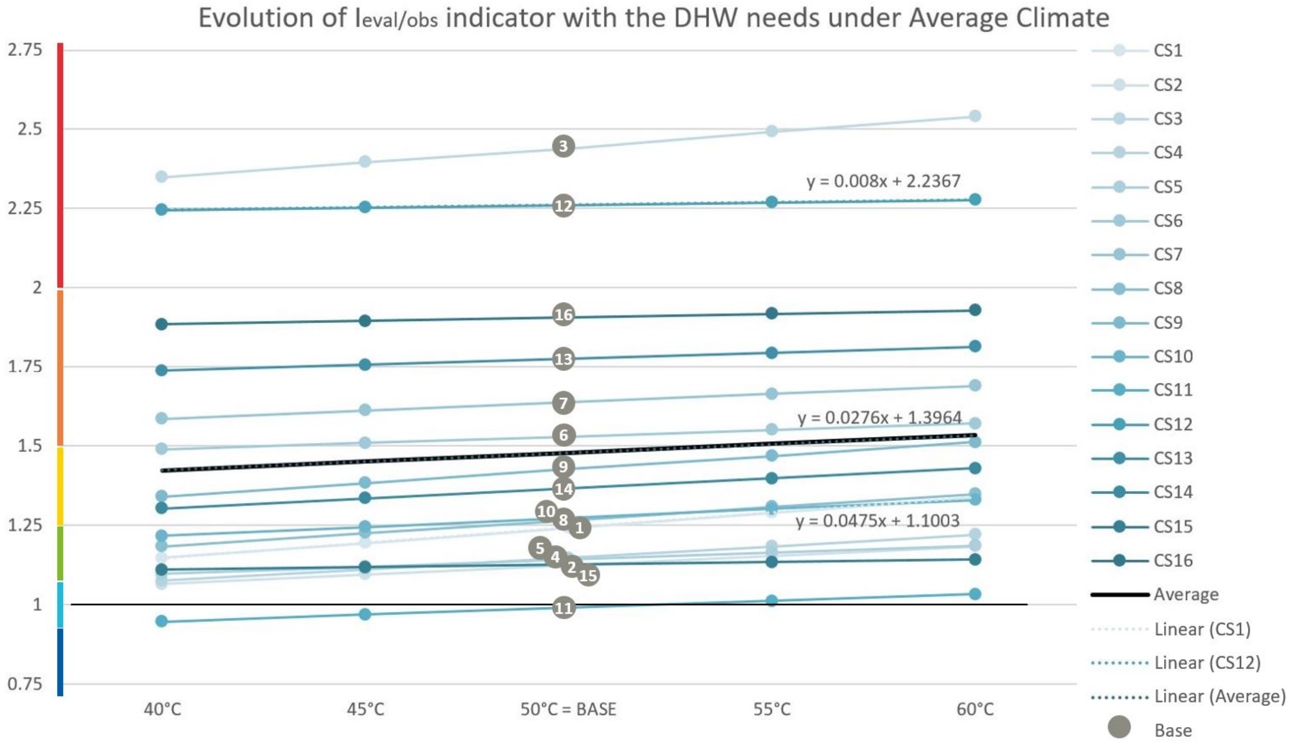

Fig. A3.1.5. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "DHW needs (temp)" analysis under the real climate hypotheses.

The ranking of case studies is globally the same: the CS12 is still the least impacted (0.4% of global consumption increase per increment of 5°C in $\theta_{water,out}$), and the CS1 the most affected (+4.7%). The DHW share in consumption in the $I_{eval/obs}$ ratio is the fundamental influence, which excludes case studies where the heating consumption is still excessively influential. The average is around +2.1% under average climate, +2.3% under real climate.

A3.1.2 DHW efficiencies

Systems efficiencies are not in the scope of this research in the sense that a monitoring would be needed in order to challenge the default values implemented by the regulation in that regard. They are, however, under the scope of this sensitivity analysis, considering that the protocol allows the assessors to precise those efficiencies, when possible, by adding regulation, storage, emission, and distribution description. There is, therefore, an element of uncertainty that surrounds some of those efficiencies. It can be wondered whether those description are accurate. This seems important when considering the DHW systems' efficiencies resumed in Table A3.1.1 below, where:

- $\eta_{tubing,bath}$ is the distribution efficiency for DHW pipes towards baths or showers;
- $\eta_{tubing,sink}$ is the distribution efficiency for DHW pipes towards kitchen sinks;
- $\eta_{tubing,global}$ is the global distribution efficiency for DHW pipes;
- $\eta_{gen,water,bath}$ is the efficiency for the preparation of DHW towards baths or showers;

- $\eta_{gen,water,sink}$ is the efficiency for the preparation of DHW towards kitchen sinks; identical $\eta_{gen,water,bath}$ and $\eta_{gen,water,bath}$ indicate a single production system.
- $\eta_{sys,water}$ is the global DHW efficiency, for the complete system. When two separate systems exist, a unique efficiency has been evaluated for their combine production.

Table A3.1.1 Domestic hot water efficiencies, for all case studies

Case study	$\eta_{tubing,bath}$	$\eta_{tubing,sink}$	$\eta_{tubing,global}$	$\eta_{gen,water,bath}$	$\eta_{gen,water,sink}$	$\eta_{sys,water}$
CS1	0.83	0.39	0.68	0.75	0.75	0.51
CS2	0.72	0.24	0.51	0.75	0.75	0.39
CS3	0.72	0.24	0.51	0.65	0.65	0.33
CS4	0.98	0.39	0.75	0.65	0.65	0.49
CS5	0.72	0.24	0.51	0.75	0.75	0.39
CS6	0.98	0.66	0.89	0.8	0.8	0.71
CS7	0.72	0.39	0.62	0.65	0.65	0.4
CS8	0.72	0.39	0.62	0.45*	0.45*	0.29***
CS9	0.72	0.39	0.62	0.65	0.65	0.4
CS10	0.72	0.39	0.62	0.7	0.7	0.43
CS11	0.76	0.39	0.63	0.75	0.75	0.47
CS12	0.72	0.39	0.62	0.8	0.8	0.5
CS13	0.83	0.95	0.85	0.8	0.95	0.7
CS14	0.8	0.39	0.65	0.8	0.8	0.52
CS15	0.83	0.95	0.85	0.45*	0.7**	0.41****
CS16	0.72	0.39	0.62	0.75	0.75	0.47

*: efficiency from the EPB method (chosen variant); in the EPC, it would be 65% for the same system
**: efficiency from the EPB method (chosen variant); in the EPC, it would be 80% for the same system
***: 43% according to the EPC; deducing the solar production from the final consumption, the global efficiency of the system (ratio of the final consumption on the net demand) rises to 71%.
****: 54% according to the EPC; deducing the solar production from the final consumption, the global efficiency of the system (ratio of the final consumption on the net demand) rises to 99%.

The Figure A3.1.6 below shows the net DHW demands (in blue) and related consumptions (in grey), according to the number of occupants, the number of litres of required DHW at 50°C per occupant and per day, and the global efficiency of the DHW system ($\eta_{sys,water}$). The light green dots represent the position of each case study in the graph, thus informing on the parameters of their consumption and the estimated results. For example, the CS1 shelters 4 inhabitants, who declared being average water consumers (=35 l/occ.day), and the global efficiency of their DHW system has been evaluated at 51% according to Table A3.1.1. Their DHW needs are evaluated a little bit under 2,400kWh, and their DHW consumption rises therefore around 4,800kWh. Yellow dots indicate, for the CS8 and 15, the actual position of their consumption when considering the solar production, as explained in the Table A3.1.1 end-notes .Dots in darker green represent the particular position of the CS6, 11 and 14, which do not correspond to the number of occupants, nor the number of litres per day that were described by the questionnaire. The CS6, for example, has been considered sheltering 2.5 occupants, because the daughter of Mr F. lives half her time at her mother's house. The CS6 consumption in Figure A.3.1.6 is therefore the average of the consumptions obtained for 2 and 3 occupants. The same has been done for the CS11 (3.5 occupants, considering a son in boarding school during the week), and the CS14 (1.5 occupants, considering a daughter in students' residence during the week).

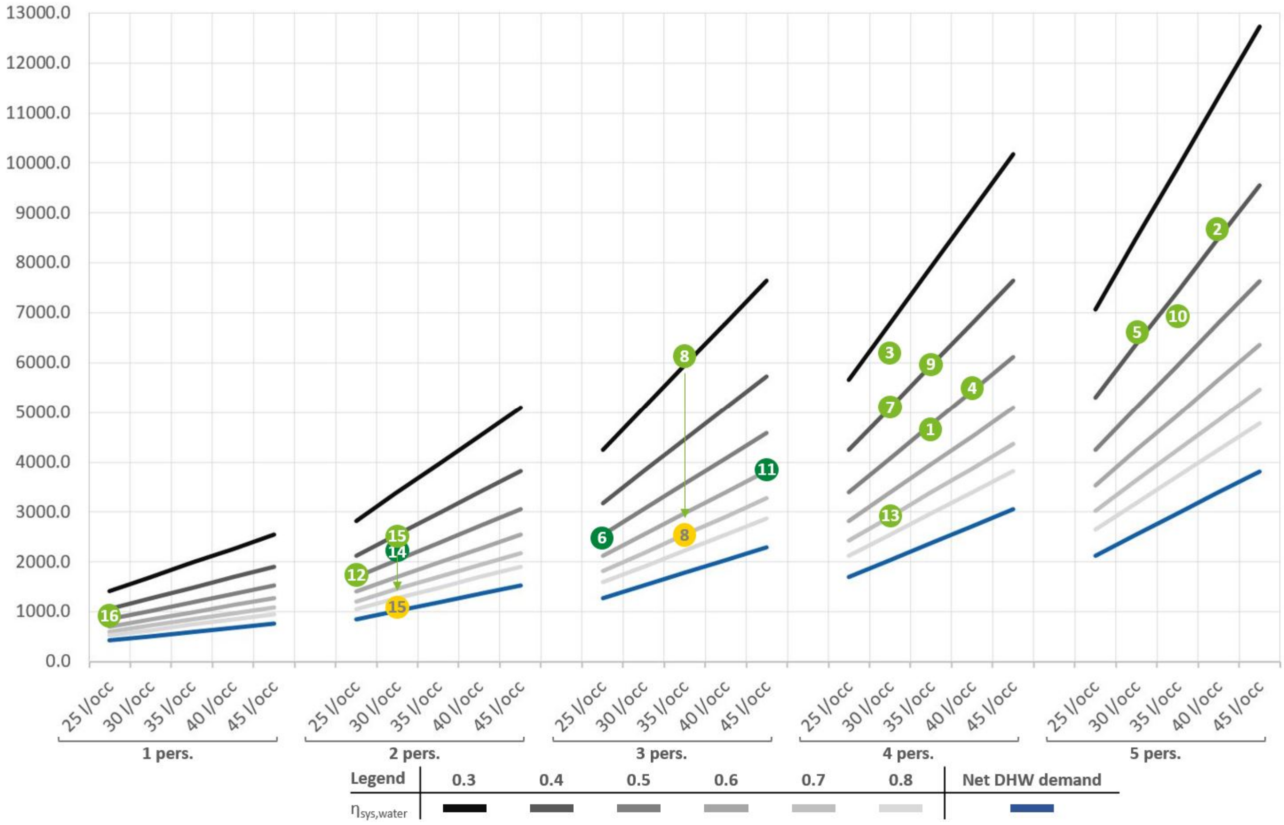

Fig. A3.1.6. Evolution, of the DHW demand (in blue), and related consumptions [kWh/year], according to the number of occupants, the drawing pattern and the system efficiency.

According to this graph, very high levels of consumption can be attained, when vary the different parameters; the most important seems to be the efficiency of the system, especially when it reaches very low levels. Table A3.1.1 displayed the efficiency output by the EPC protocol; the default values that are attributed to some systems, or part of them, can sometimes explain those very low levels, reached for example by the CS2 or 3. Distribution efficiency, especially, is given very low values by considering the length of the pipes between the preparation unit and the drawing points. The value of 0.24, for example, characterizes a segment of pipe superior to 15m between the boiler and the kitchen sink. Its needs are, therefore, multiplied by four to obtain the consumption, three quarters of which are considered lost for good.

The first set of simulations, therefore, will focus on those distribution efficiencies and propose the results for all case studies, should their efficiencies take the different values proposed by the protocol. The limits are therefore imposed by the default values of the EPC method:

- 4 values for the kitchen sink pipes: 0.24 is the length of pipes is superior to 15m; 0.39 between 5 and 15m; 0.66 between 1 and 5 m; and 0.95 when it is inferior to 1m.
- 3 values for the bath and shower pipes: 0.72 if the pipes lengths are superior to 5m; 0.83 between 1 and 5m; 0.98 if they are inferior to 1m.

The Figure A3.1.7 hereunder shows the evolution of the $I_{eval/obs}$ ratio according to the DHW global distribution efficiency for the whole dwelling ($\eta_{tubing,global}$), and the position of the "base" points (grey dots). The ranking of case studies according to the influence of this parameter is globally the same as it was in the previous simulations on DHW. The least impacted is still the CS12 because of the very low share of DHW in its consumption (or, rather, because of the very high share of heating in its consumptions), with a reduction in consumption inferior to 0.5% each time the distribution efficiency is increased by 10%. The most impacted case study is still the CS1, with its highest DHW share in consumption, showing a 5% reduction in consumption per increment of 10% in distribution efficiency. The average case study sees its consumption reduced by 2.5% for the same increments. The CS2, house of the 5 members of the B. family which declared a rather high DHW consumption (40 l/occ.day), shows a 1,500kWh difference in annual energy consumption for each variation of 5% in its global efficiency level, which can hardly be considered negligible.

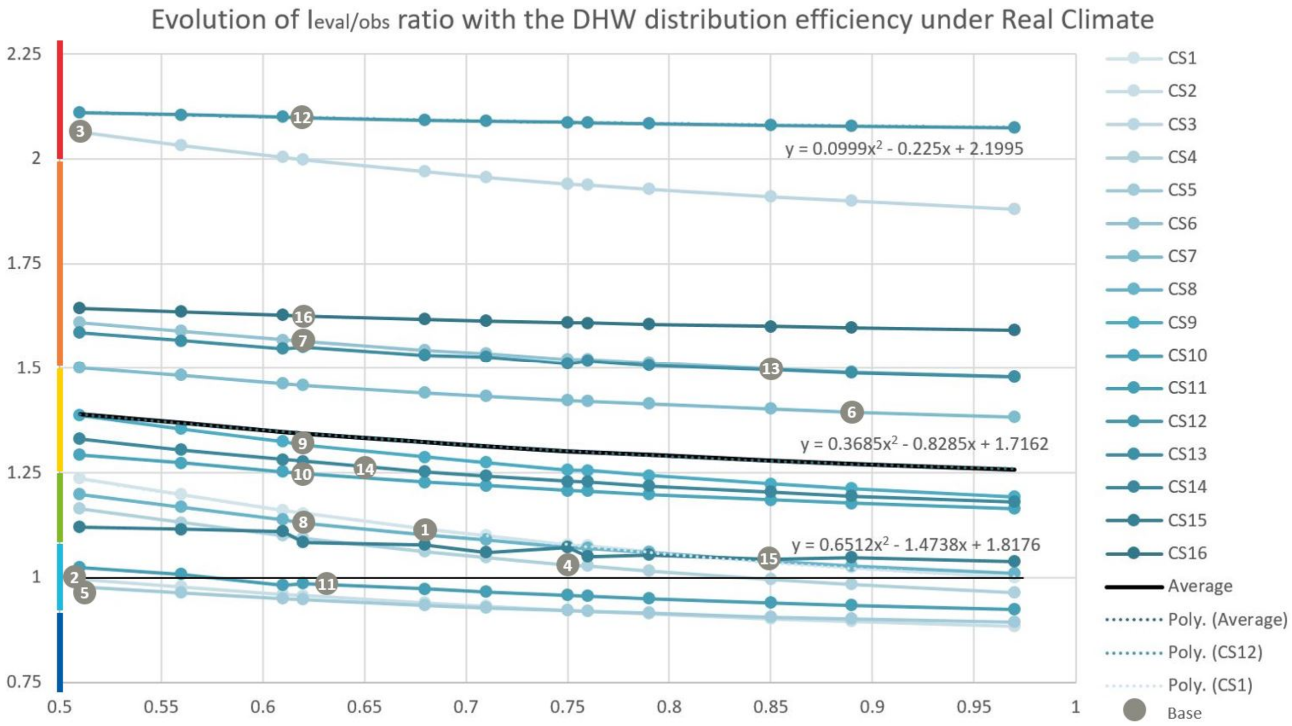

Fig. A3.1.7. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "DHW distribution" analysis under the real climate hypotheses.

The shape of the CS15 curve is particular in the sense that the solar system is only used to provide DHW to the baths and showers; the evolution of those distribution efficiencies in the global system, and their ranking in global distribution efficiency, is therefore different in this case than in others.

Most dwellings concerned by this research present low distribution efficiencies. This is, in part, due to the choice of typologies in this sample. Most old brick houses are equipped with a central and combined heating and DHW system, which production unit is often located in the basements. The distance to the drawing points (bathrooms and kitchens) is therefore often quite important. In Fig. A3.1.7, the case studies which base points are on the right of the graph are those which DHW is produced by local systems (such as the CS13 and CS15, in which electric boilers have been installed in the kitchen to avoid distribution losses), or nearby-located central systems (such as the CS6, equipped with an electric boiler less than one meter away from the bathroom).

In any case, those distribution losses are always considered… lost. This model does not consider the possibility to recover part of those losses as internal gains, despite their importance. Losses outside of the V_P are more debatable. The calculation method already reduces by a third the heat losses between the protected volume and basement spaces via a "b_j" reduction coefficient (see Equation (7), section 4.3.3.3) of 2/3. This factor, however, makes no distinction on the presence of heating systems or uninsulated pipes, even though important losses in a basement would tend to increase its internal temperature, thus diminishing the heat losses from the protected volume above.

Lastly, the Figure A3.1.8 hereunder displays the evolution of the $I_{eval/obs}$ ratios when the production efficiency for DHW is changed. This research does not seek to validate the default values that are attributed by the EPC protocol to those systems, but to evaluate the possible uncertainties in the results, such as those that could be brought by the assessor in the description of the system.

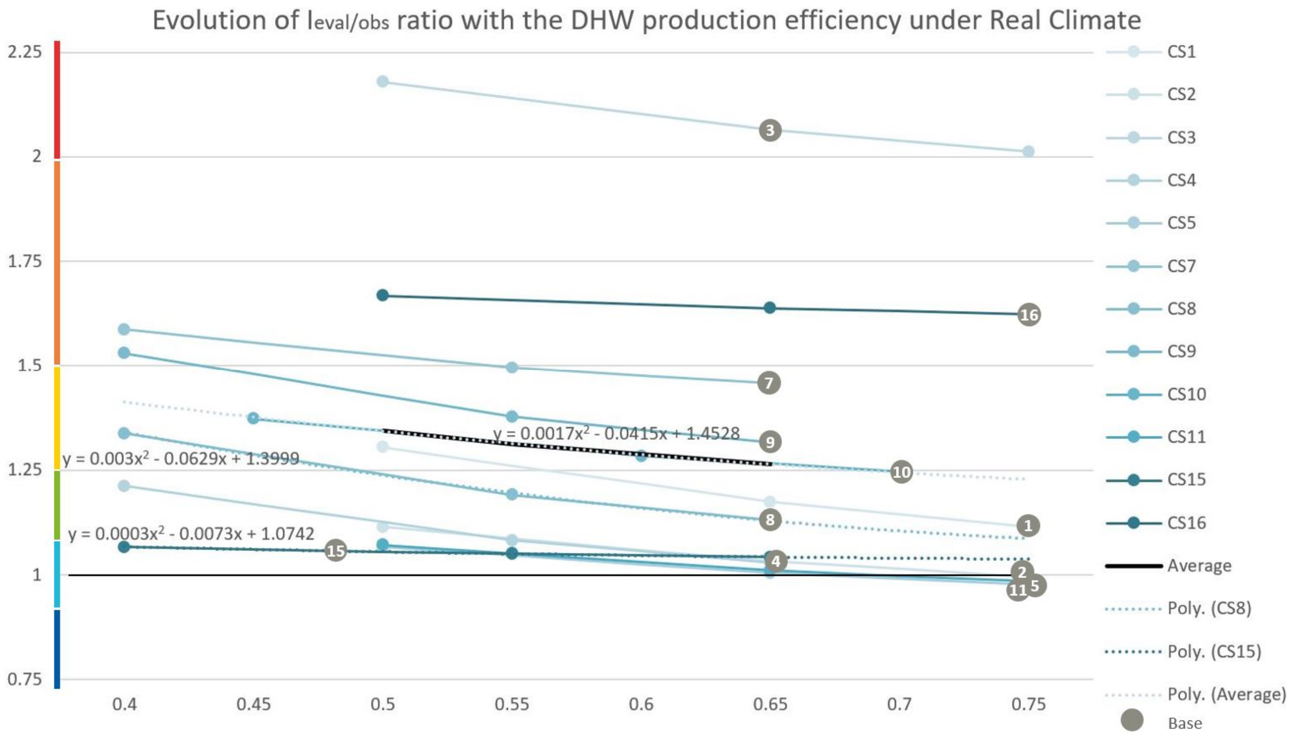

Fig. A3.1.8. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "DHW production" analysis under the real climate hypotheses.

Most of the DHW preparation systems could be given 3 different production efficiencies, depending mainly on the date of installation and regulation system. The CS1, 2, 3, 5, 11 and 16 are equipped with a boiler without storage (instantaneous DHW preparation) using natural gas, which production efficiency can be evaluated at 50% (constant temperature or unknown regulation, installed before 1990), 65% (constant temperature or unknown regulation, installed after 1990) or 75% (regulation in variable temperature). The case study CS10 is equipped with a boiler with internal storage, which efficiencies are 5% lower by default (45%, 60% or 70%); they are yet lowered by another 5% (40%, 55% or 65%) when the DHW storage is separate from the production unit, as is the case for the case studies CS4, 7, 8, 9 and 15 (for the part that provides baths and showers in DHW). Cases studies 6, 12, 13, 14 and 15 (kitchen unit) are equipped with DHW systems which production efficiencies only depend on the presence of a storage unit, such as electric boilers. The CS6, 12, 13 and 14 therefore do not appear in the graph below.

The ranking of influences is slightly changed but remains largely inspired by the ranking in DHW shares in consumptions. Interestingly, highly efficient dwellings can be found at both ends of this ranking. The CS15 is the least influenced of all case studies (-0.45% of energy consumption per increment of 10% in production efficiency) because the solar production is not taken into account, despite the fact that it covers most of the losses attributed to the "traditional" preparation systems installed. It is closely followed by the CS16 (-0.53%) which, after the CS12 and just before the CS15, has the lowest DHW share in consumption. This implies that the CS12 would probably also see its $I_{eval/obs}$ ratio remain quasi constant under the variation of its DHW production efficiency. At the other end of the ranking is the CS8, slightly more sensitive to this variation than the CS1 as it sees its production efficiency drop lower, to 40%. Its consumption is reduced by 3.1% when the DHW production efficiency increases by 10%. The average variation is -2% in global final energy consumption per 10% increment in DHW production efficiency.

A3.2 Heating efficiencies

This next section shifts the focus to the heating shares in consumption. In a similar manner to the definition of the DHW efficiencies, this section will analyse the impact of the uncertainty brought by the default values that dominate the description of the heating system's efficiencies in emission, distribution and production. The objectives are diverse, among which the will to assess the influence of the range within which they are allowed to vary, and the necessity to define the influence of the assessor on the process uncertainties. It is not unthinkable to consider that some assessors do not test the systems' regulations, if only for fear of altering the settings and disrupting the habitants' comfort. Systems engineers, installers and technical maintenance teams are sometimes much more competent and confident when it comes to assess the performance of a boiler, or a heat pump.

Table A3.2.1 below displays, for all case studies, the emission ($\eta_{em,heat}$), distribution ($\eta_{distr,heat}$), storage ($\eta_{stor,heat}$), production ($\eta_{gen,heat}$) and global ($\eta_{sys,heat}$) base point efficiencies; cases CS2 and 6 show two sets of efficiencies, one for each energy sector (ES).

Table A3.2.1 Heating installation efficiencies, for all case studies

Case study	$\eta_{em,heat}$	$\eta_{distr,heat}$	$\eta_{stor,heat}$	$\eta_{gen,heat}$	$\eta_{sys,heat}$
CS1	0.87	1	1	0.82	0.71
CS2 – ES1	0.81	0.95	1	0.9	0.69
CS2 – ES2	0.96	1	1	1	0.96
CS3	0.82	0.95	1	0.77	0.6
CS4	0.89	0.98	1	0.89	0.78
CS5	0.86	0.95	1	0.9	0.74
CS6 – ES1	0.87	1	1	0.72	0.63
CS6 – ES2	0.9	1	1	1	0.9
CS7	0.84	0.95	1	0.9	0.72
CS8	0.89*	1*	1*	0.87*	0.77*
CS9	0.89	0.95	1	0.92	0.78
CS10	0.81	0.98	0.97	0.77	0.59
CS11	0.88	1	1	0.91	0.8
CS12	0.84	0.98	1	0.81	0.67
CS13	0.82	0.98	1	0.77	0.62
CS14	0.85	1	1	1	0.85
CS15	0.94**	0.99**	1	0.9**	0.84**
CS16	0.84	1	1	0.81	0.68

*: efficiencies from the EPB method (chosen variant); identical in the EPC method for the same system

**: efficiencies from the EPB method (chosen variant); in the EPC method; $\eta_{em,heat}$ = 0.89, $\eta_{distr,heat}$ = 0.98; $\eta_{gen,heat}$ = 0.92, and $\eta_{sys,heat}$ = 0.8 for the same system

Storage efficiencies have all been set to 1, either because the installation included no storage tank or because it was inside the protected volume. The only case study presenting a tank outside of the V_P is the CS10 ($\eta_{stor,heat}$ = 0.97 by default, whether the tank is insulated or not). No sensitivity analysis was performed on this parameter alone. This 3% decrease is believed to have the same influence on the results as similar variations on $\eta_{em,heat}$ or $\eta_{distr,heat}$.

A3.2.1 Emission

The emission efficiency is defined by a single default value in the case of local heating, such as in CS2 (second energy sector), CS6, or CS14. The case study CS2, being partly heated by a central heating installation, will be kept in this simulation set, while the CS6 and 14 will be excluded. When a central heating installation[1] is certified, the emission efficiency depends on the regulation of the set temperature (presence of thermostatic valves and/or thermostat) and on the regulation of water (or air) temperature when it leaves the heating production unit. The presence of a thermostat, or valves, is relatively difficult to doubt, but the presence of a modulating-temperature control needs to be proven by manipulating the settings. It must be acknowledged that this particular input in the description of the energy system only changes the emission efficiency by 2% inside a [83%; 89%] range. The placement of heat emitters against windows or walls, adjacent to the exterior, the ground or an unheated out-of-V_P space, with a U-value superior or equal to 2.2W/m²K, decreases the “base” emission efficiency by 1% per emitter, with an 8% maximal decrease.

The assessor’s influence on this parameter is therefore only limited to the 2% variation on the presence (or not) of modulating-temperature control. The global influence such a small difference, in the absolute, could have on the results, can still be analysed. Figure A3.2.1 hereunder displays the variation range of the $I_{eval/obs}$ ratios for all case studies (except 6 and 14), for simulations done under the real exterior temperatures conditions (the difference with the average climatic conditions is quite negligible in such small variation ranges).

The effect is both minimal and important. Minimal because the variation range on the emission efficiency remains small, which could not have wildly impacted the consumption results. It is important however, because such a small variation on $\eta_{em,heat}$, brings about a [0.7%; 2.2%] variation range on the total final consumption results. The bigger the share of heating in those consumptions, the more important the effect: cases CS12, 16, 13, 10 or 3 are in the lead. Case studies with $I_{eval/obs}$ ratios already closer to 1 are less influenced, but are still impacted according to their heating share in total consumptions. The CS8 is the least impacted case study because of its high efficiency, but also its low set temperature. The CS15, which is as efficient as the CS8, is heated 1 to 2°C higher, and is therefore more sensitive to a variation in $\eta_{em,heat}$. This sheds a particular light on the observation that the EPB method characterises the emitters by a 94% efficiency, whereas the EPC method, to the same installation, gives an 89% efficiency. The first one assesses the performance of new buildings, and the second assesses the performance of existing buildings. It probably should not be surprising that default values are slightly different, but the highly efficient “existing” buildings, such as the CS8 and 15, even if renovated to the point of a new building, still have to be certified by the EPC

[1] For individual use (single-family dwelling); the certification of collective installations refers to a different part of the EPC protocol. The initial choice to focus the sample of this research on existing single-family houses occupied by their owners led to the exclusion of shared heating installations.

method. The continuity (or coherence) between methods should be guaranteed, so that those highly efficient buildings are given the same performances by both methods.

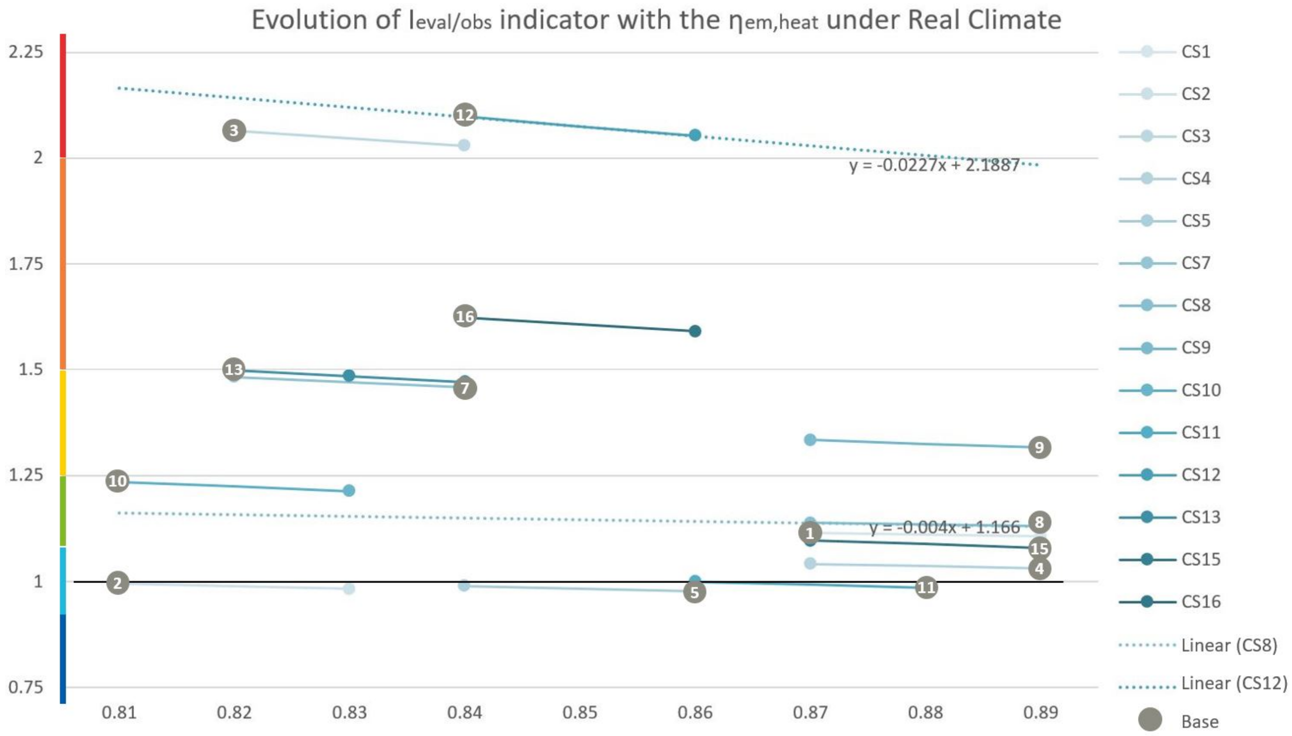

Fig. A3.2.1. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$\eta_{em,heat}$" analysis under the real climate hypotheses.

A3.2.2 Distribution

Table A3.2.1 above indicated that the distribution efficiencies vary in this sample between 0.95 and 1. Values of 1 indicate either that the dwellings is equipped with local heating systems (CS2-ES2, CS6 or CS14), or that the production unit is inside the protected volume (no distribution pipes out of the V_P). Other values[2] are defined based on two drop-down menus asking the assessor to estimate the length of heating pipes (insulated or not) that are present outside (exterior) or in unheated out-of-V_P spaces. Default values are attributed to the different possible answers; for example, $\eta_{distr,heat}$ = 0.95 when exterior pipes measure less that 2m, drops to 0.75 when they measure more than 30m (or if their length is "unknown", which is a possible acceptable answer). In this sample, there were no pipes outside the building. When they are in unheated out-of-V_P spaces, $\eta_{distr,heat}$ = 0.98 when those pipes measure less that 2m, 0.95 between 2 and 20m, drops to 0.9 when they measure more than 20m or their length is "unknown". When both cases arise (pipes in the exterior and in unheated out-of-V_P spaces), the smaller value dominates.

As in this sample, no exterior pipes were observed or described, this set of simulation will mainly focus on the [90%; 100%] limits displayed on Figure A3.2.2 and 3 below for average climate and real climate simulations. The cases CS6 and 14 have, here also, been kept out of this part of the sensitivity study, and results for the CS2 only concern its first energy sector (63.3% of the V_P with day-time spaces).

[2] For individual use (single-family dwelling); certification of collective installations answers to a different protocol.

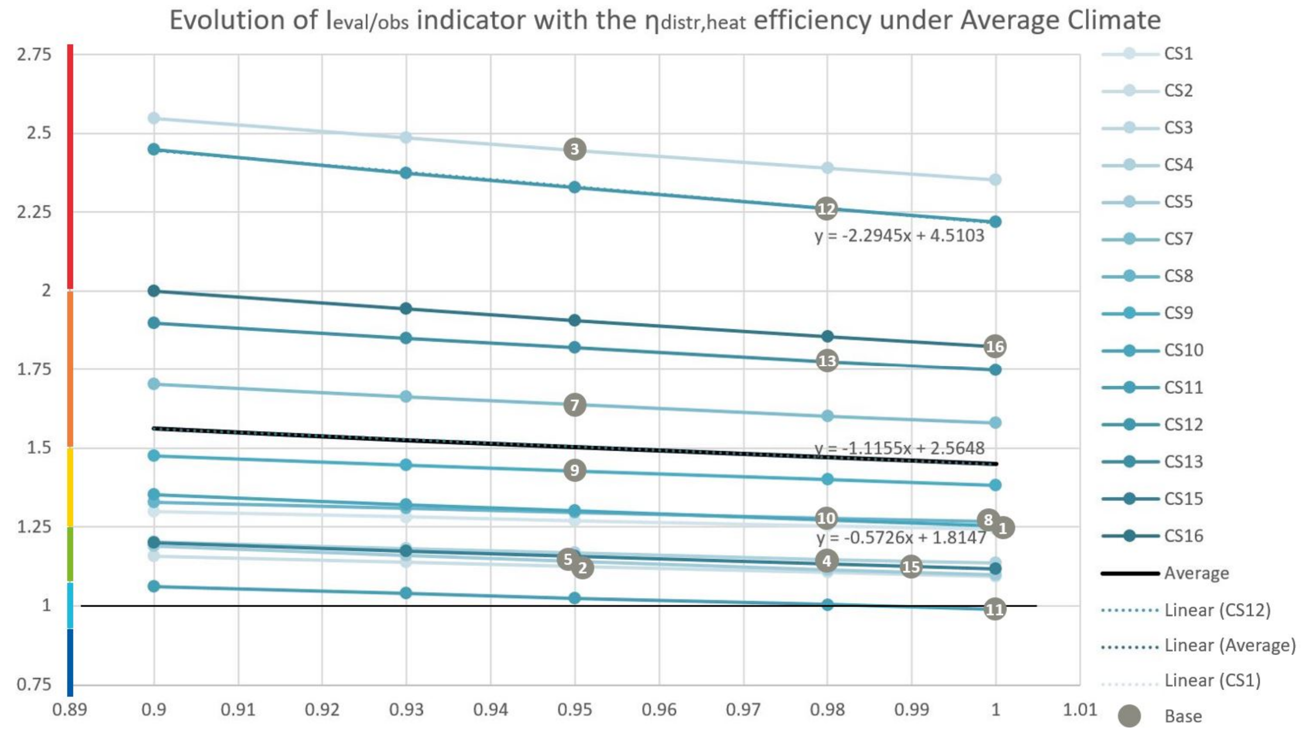

Fig. A3.2.2. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$\eta_{distr,heat}$" analysis under the average climate hypotheses.

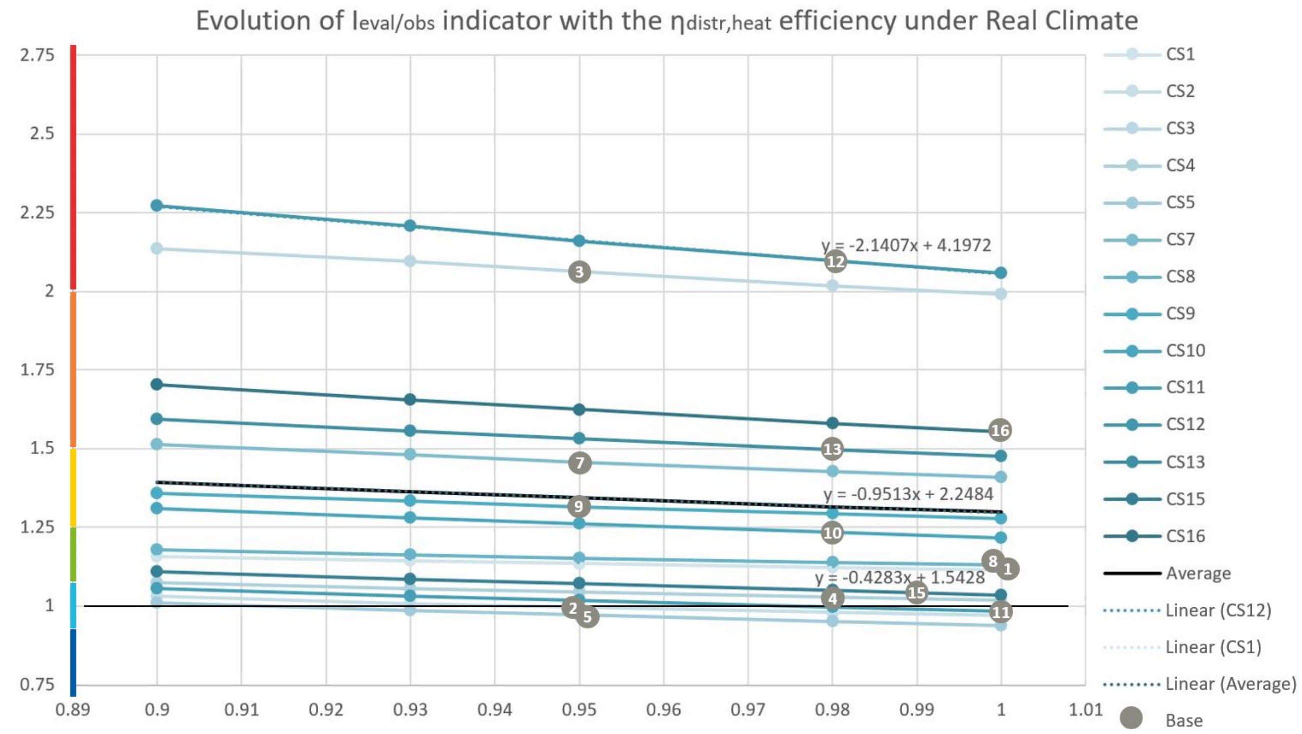

Fig. A3.2.3. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$\eta_{distr,heat}$" analysis under the real climate hypotheses.

The use of real climatic data does not change the results much, apart from the already observed reduction in heating consumptions that globally lowers the $I_{eval/obs}$ ratios. The main influence in this analysis, is a change in the ranking of case studies. The CS3, 7, 10, 11 and 15 all present an average 1.4% (1.3 to 1.5) reduction of consumption, associated with a 2% increase in distribution efficiency. The least impacted case studies are the CS1 and 8, which present average reductions in consumption inferior to 1% for the same increment. Here again, the CS15 is more affected than the CS8 because of its higher set temperature. Comparatively to the analysis of the emission efficiency, the most affected case studies are the CS12, 16, 13… all with important remaining unexplained heating consumptions, which are reduced at greater speed. In this case, the CS12 witnesses a 1.9% decrease in consumption, associated with a 2% increase in $\eta_{distr,heat}$.

It would seem that the variation on distribution efficiency is slightly less influential that the variation on emission efficiency; this is only because the distribution efficiency is higher to begin with, and closer to 1. The effects are sufficiently similar, however, to ask for similar precision in the description of their determiners, especially if the possible variation range of the distribution efficiency is wider than 2%.

A3.2.3 Production

The last efficiency that will be tested here concerns the heating production. As the other efficiencies in the EPC method, its definition is largely dominated by default values attributed to answers from drop-down menus. Local heating devices are attributed efficiencies depending on the kind of heater, but also on the date of installation (before 1985, after 2005 or in-between). Central heating production units answer to a more complex efficiency definition that depends on:

- The type of production unit: boilers (condensing, atmospheric or "other"), heat pumps (with different heat sources and heat sinks), central electric heating, cogeneration (combined heat and power – CHP), external supply or others.
- The type of energy vector used: an $f_{l/h}$ factor, attributed to each fuel, equal to the ratio of the fuels' lower heating value on its higher heating value. Theoretical production efficiencies are always given for the lower heating value.
- The (proved) knowledge about real determiners such as the theoretical production efficiency ($\eta_{30\%}$) and the inlet temperature at which it was determined ($\theta_{30\%}$), in compliance with the standards in force.
- The type of heat emitters (not always).
- The location of the production unit (in or out of the V_P).
- The presence of a label (on atmospheric or "others" boilers).
- The age of the device (its installation date), with different threshold years.
- The type of regulation controlling the boilers: constant, variable or modulating temperature (or "unknown", which forces the "constant temperature" answer).

This next set of simulations does not consider all possible values for a production efficiency, as it would seem pointless to deny the type or location of the production unit, the type of energy vector or the type of emitters, for example. In order to define trend curves, only the "regulation" determiner will be tested here, inducing a 4% to 7% variation on the "base" $\eta_{gen,heat}$ efficiency, depending on the types of systems. The Figure A3.2.4 and 5 below display the evolution of $I_{eval/obs}$ ratios under both sets of climatic conditions for those variation ranges, for all case studies. In the CS6, the local heating system's efficiency varies according to the possible date of fabrication. Electric local heaters (direct in CS2 or with storage in CS14), are always attributed a $\eta_{gen,heat}$ of 1 in the EPC method.

It is conceivable that inaccuracy in the description of the system might induce higher discrepancies between theory and reality. For example, old boilers without labels, fabrication date or known regulation, see their attributed production efficiencies drop to 60% at their lowest, it is conceivable that real efficiencies could be more than 5% apart. The same could be said for electric heat pumps, which default $\eta_{gen,heat}$ values (seasonal performance factors) span between 2 and 3.5, depending on heat sources and sinks.

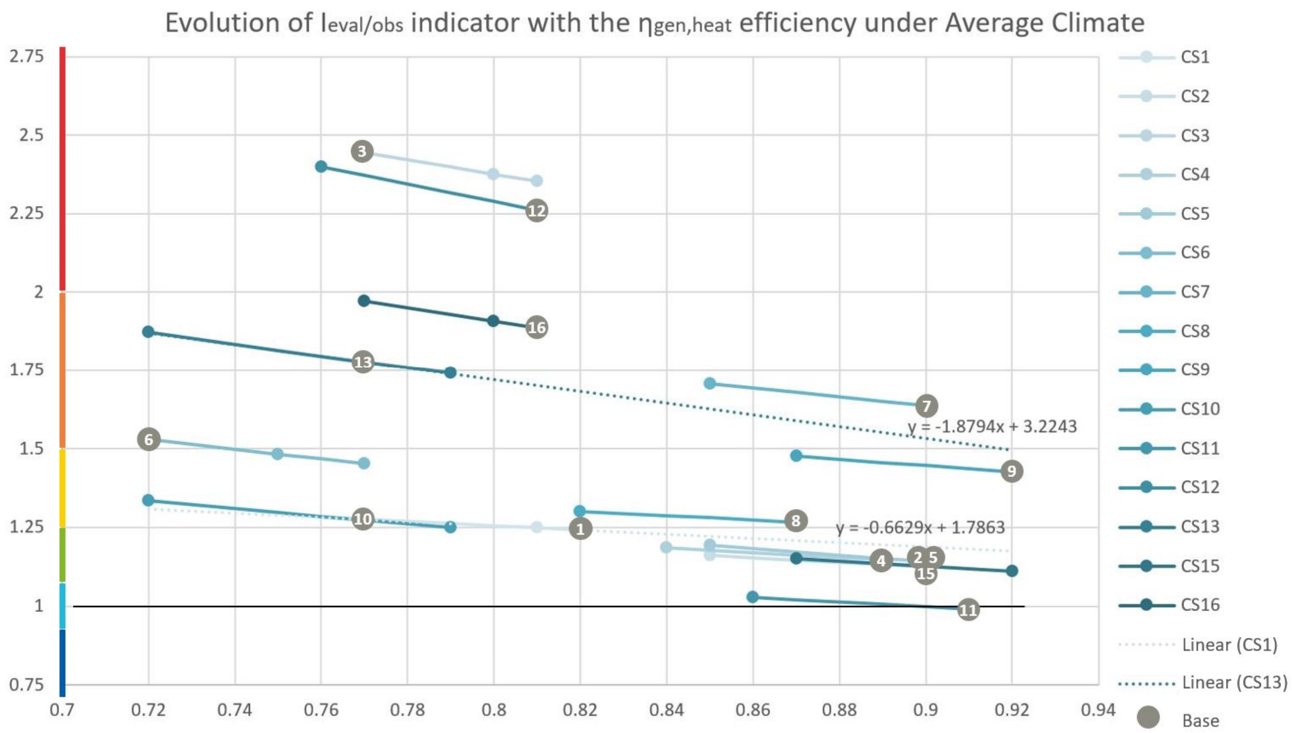

Fig. A3.2.4. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$\eta_{gen,heat}$" analysis under the average climate hypotheses.

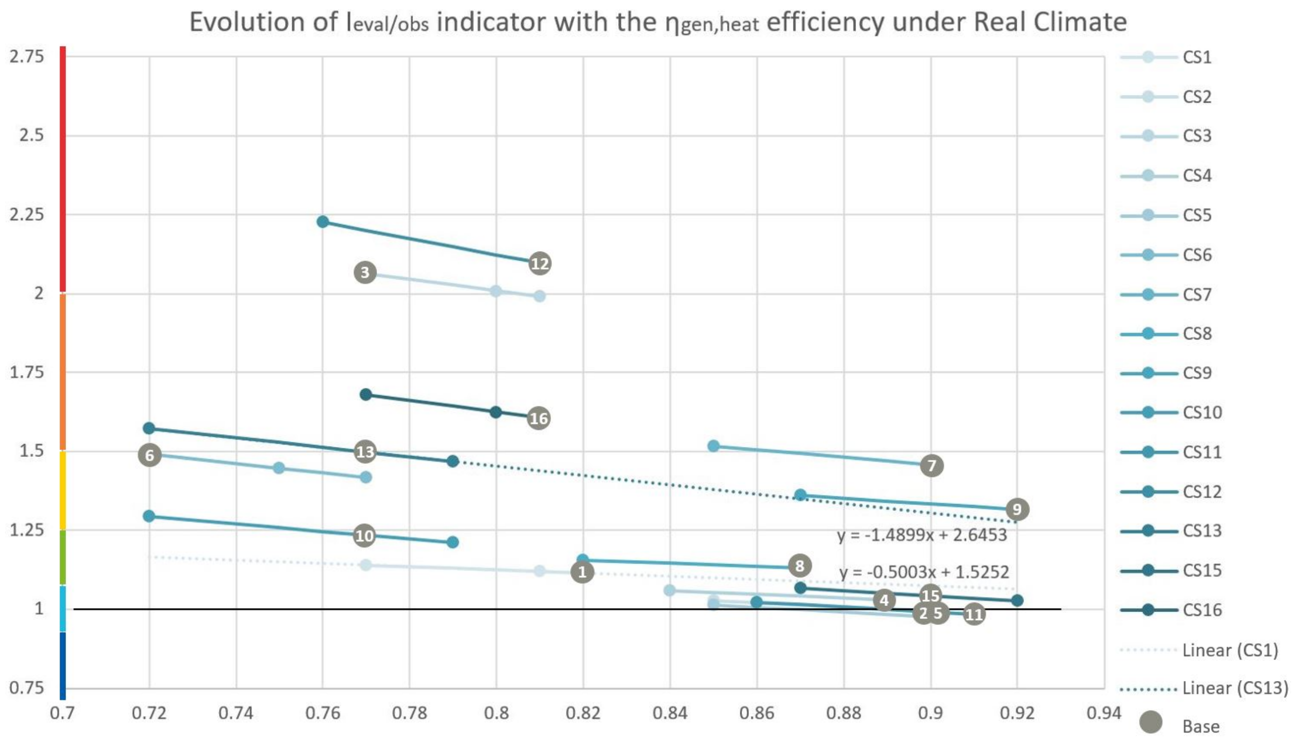

Fig. A3.2.5. Evolution, for each case study, of the $I_{eval/obs}$ ratio for the "$\eta_{gen,heat}$" analysis under the real climate hypotheses.

Although the correlation might appear linear, in Figure A3.2.4 and 5, for such a short and defined variation gap of the $\eta_{gen,heat}$, it must not be forgotten that those consumptions curves should tend to one horizontal ($\eta_{gen,heat} = \infty$) and one vertical asymptote ($\eta_{gen,heat} = 0$). Within the possible variation range of the systems analysed here, this precision should not be necessary, so that the linear trend could be extended to lower $\eta_{gen,heat}$ values.

The average change in total energy consumption brought by a 2% increase in heating production efficiency is a reduction of 1.6% (real climate) to 1.7% (average climate). Least affected case studies are the same as in the analysis of the emission and distribution efficiencies, which was to be expected: the CS1, CS8, CS4, CS2, CS9 (between 0.9 and 1.3% reduction associated to a 2% increase in $\eta_{gen,heat}$). CS13, 10, 12 and 6 all show reductions of their total energy consumption greater than 2%, each time their heating production efficiency is increased by 2%. Globally, the maximal variation is to be found in CS13, which displays a total 7% difference in total consumptions for its total 7% $\eta_{gen,heat}$ variation range. The CS1 "only" witnesses a 2.5% difference for its total 5% $\eta_{gen,heat}$ variation range.

The importance of the heating share in consumption explains the high influence of heating systems' efficiencies. It must therefore be reminded that, should those simulations have been run on the calculation method before modification, the influence of those efficiencies would have been much more important yet, as the heating share in consumption was globally higher for most case studies' official EPCs. Overall, it seems nevertheless that the importance played by all systems efficiencies in the revaluation of a dwelling's final energy consumption requires precision in their definition, if the objective is to approach real consumptions. Many case studies analysed here present $I_{eval/obs}$ ratios that are already close to 1, without more precision on their efficiencies definition, however. It would appear that either those values are accurate in most cases, or the inaccuracies in some inputs are compensated by other inaccuracies on other inputs. In any case, only a more precise certification of the heating system could lift that uncertainty. Best placed and competent people to assess technical systems might be found in the heating installation/maintenance sector: during required annual technical control, for example.

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