



Economical and environmental impacts of several retrofit options for residential buildings

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Abstract

Title: Economical and environmental impacts of several retrofit options for residential buildings

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Nowadays, important efforts are deployed to reduce our actual residential building consumption which represents about 40% (25% for the residential sector and 15% for the non-residential sector) of the total energy consumption in Europe. The aim of this paper is to evaluate the environmental and economical impact of several retrofit options for residential buildings. Our study focuses on the Walloon Region of Belgium. A “bottom-up” methodology is applied: this methodology focuses first on a micro-analysis. Results from this micro-analysis are then used and extended to a macro-analysis. The presented methodology does not permit to determine with precision the global consumption of residential buildings in the Walloon Region. However, the latter methodology allows pointing out some economical and environmental trends related to the different investigated retrofit options.

The first part of this end-of-study work offers an overview of the Walloon building stock by presenting statistic data on the Walloon residential houses. From these latter statistic data, it is possible to divide the Walloon building stock by means of arborescence. Each type of building is characterized by constructive data (mean area, U_{wall} , U_{window} ...) and by heating production system efficiency.

Thanks to these data, it is possible to determine the gas and electrical annual consumption for each type of residential building by means of a computer program that simulates residential building.

The latter computer program is also used to determine the annual energy consumption of envelope retrofitted houses. Retrofit options related to heat and/or cool production are also investigated.

A macro-point of view study is carried out in order to determine the potential of energy saving of each investigated options. An environmental comparison between the several envisaged retrofit options is realized in terms of CO₂ emission, final and primary annual energy consumption for each type of building.

An economical study is carried out in order to determine the profitability of each investigated options for citizens.

The work also proposes a reflection about the actual incentive policies.

Résumé

Titre: Evaluation de l'impact environnemental et économique de plusieurs options de rénovation des bâtiments résidentiels

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Une part importante de la consommation énergétique en Europe (environ 40%) est due aux bâtiments. D'importants efforts se doivent d'être réalisés afin de réduire nos consommations dans ce secteur afin de diminuer nos émissions. Le but de ce travail de fin d'étude est d'évaluer l'impact environnemental et économique de plusieurs options de rénovation de bâtiments résidentiels, et plus particulièrement de bâtiments situés en région wallonne. Une méthodologie de type « bottom-up » sera appliquée pour cette étude. Nous partirons donc d'une « micro » analyse (investigations sur un grand nombre de cas) pour ensuite l'étendre à une « macro » analyse.

La première partie de ce travail de fin d'étude consiste à obtenir un maximum de statistiques sur le bâtiment wallon (âge, types,...) et le marché énergétique belge (prix du gaz, du pétrole, Subsidies gouvernementales,...).

La seconde partie du travail consiste à diviser le parc résidentiel wallon via la détermination d'une arborescence. Grâce aux données statistiques recueillies dans la première partie du travail, il est possible de quantifier le pourcentage de chaque type de bâtiments (i.e. un appartement dont la date de construction datant du 19^{ème} siècle, etc...). A chaque type de bâtiments (donc à chaque extrémité de l'arborescence) correspond des caractéristiques constructives et un type de production de chaleur.

Grâce à ces données, il est possible de déterminer les consommations annuelles de chaque type d'habitations grâce à l'utilisation du logiciel «CALE».

Le logiciel « CALE » nous permet également de déterminer les consommations annuelles des bâtiments dont les composants de l'enveloppe ont été rénovés.

L'étude ne se limite pas à l'impact environnemental et énergétique de la rénovation de l'enveloppe, mais également du système de production de chaleur.

Une étude est menée afin de déterminer l'impact environnemental et énergétique de la mise en place des options de rénovation envisagée. Celle-ci a pu être réalisée grâce à la réalisation de l'arborescence du parc résidentiel wallon.

Finalement, une étude économique est effectuée en termes de 'Net present value' (NPV), afin de déterminer la rentabilité des options de rénovation investiguées.

Au vu des divers résultats obtenus, une critique de la politique des primes est également abordée dans ce travail.

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1 Introduction

The first part of this end-of-study project consists in a short overview on the current (at the international and national levels) energetic context.

1.1 International energetic context

Nowadays, with the increasing of energy costs and the growing concern about human impact on climate, important efforts are deployed to reduce our actual consumption. In reality, world final energy consumption has drastically raised from 1971 to 2007, as we can observe on Figure 1 (a). More precisely, world final energy consumption has almost doubled: from 4675 Mtoe in 1973 to 8286 Mtoe in 2007.

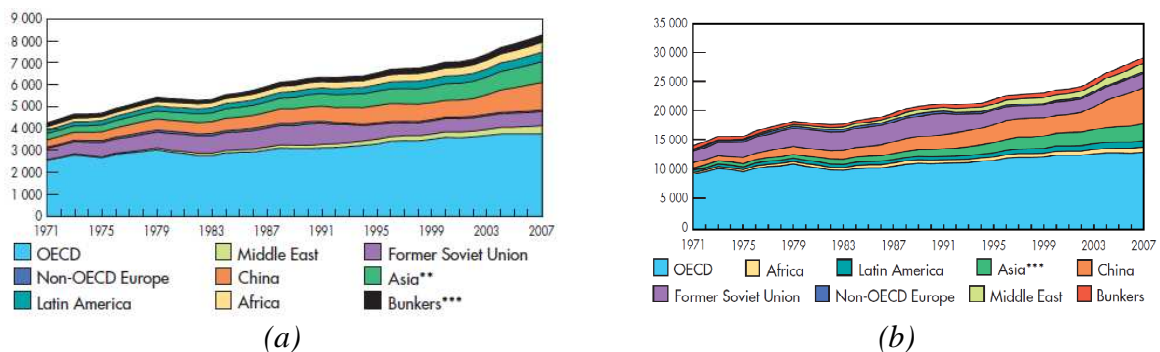


Figure 1 : Evolution from 1971 to 2007 of world total final consumption by region (Mtoe) (a) and world CO2 emissions (b) (IEA, 2009)

As a matter of fact, world CO2 emissions and world final energy consumption are deeply linked and follow the same evolution (from 15640 Mt of CO2 in 1973 to 28962 Mt of CO2 in 2007).

Mainly due to the growing scarcity of the world energetic resources (and many others such as speculation, economical crisis...), energy prices increase. As an example, evolution of the natural gas import prices for different IEA countries is given on Figure 2:

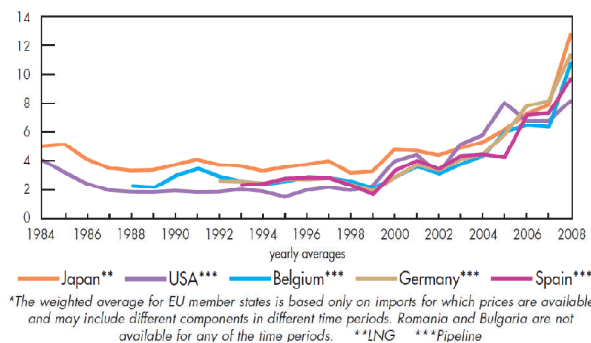


Figure 2 : Natural gas import prices in US dollars/MBtu (IEA, 2009)

The main conclusion to be drawn from this brief point on international energetic context is that techniques have to be applied to reduce energy consumptions in every sector (transport, buildings, industries...).

1.2 Europe 2020: objectives

The increasing of the CO2 emissions pushed governments to take action in order to reduce our greenhouse gas. As a result, European commission fixed objectives to reach in 2020 via a plan called 3x20%.

This plan is based on:

- a reduction of **20%** of greenhouse gases emissions in 2020 compared to 1990 (which corresponds to a reduction of 14% compared to 2005);
- an increasing of **20%** of renewable energy in the final energy consumption in 2020 compared to 1990 (which correspond to an increasing of 14.5% compared to 2005);
- an improvement of **20%** of the energy savings and energy efficiencies;
- a presence of 10% of bio-fuel on the fuel market (obviously, if the production is sustainable).

The European directive CE 2002/91/CE fixes rules to be applied by State Members in term of energy building efficiencies. Here are some of the European measures:

- Establishing a calculus method to determine the energy building efficiency;
- Fixing minimal exigencies concerning efficiencies for new buildings;
- Fixing minimal exigencies concerning retrofit of building larger than 1000 m²;
- Making the building efficiency certification obligatory for a new construction and for the renting or the selling of a building;
- Setting up a regular inspection of heating and cooling production systems.

1.3 International building sector consumption

International energy consumption can be divided according to different consuming sectors, as shown on *Figure 3*:

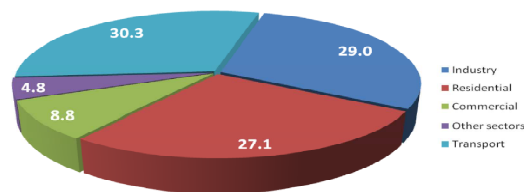


Figure 3 : Energy consumption in different sectors - Share of final end use in % (IEA (2008))

According to IEA (2008), the residential and commercial sectors count for almost 40% of the final energy used in the world. The major part of this consumption is in buildings.

From these results, it is obvious that improvement of building's efficiency represents an attractive solution to reduce a large part of energy consumption (and thus to reduce energy bills).

The major part of energy used in residential buildings is due to 'Space heating' as shown on *Figure 4 (a)*. Differences can be observed between different countries, especially in terms of total (not normalized) energy use.

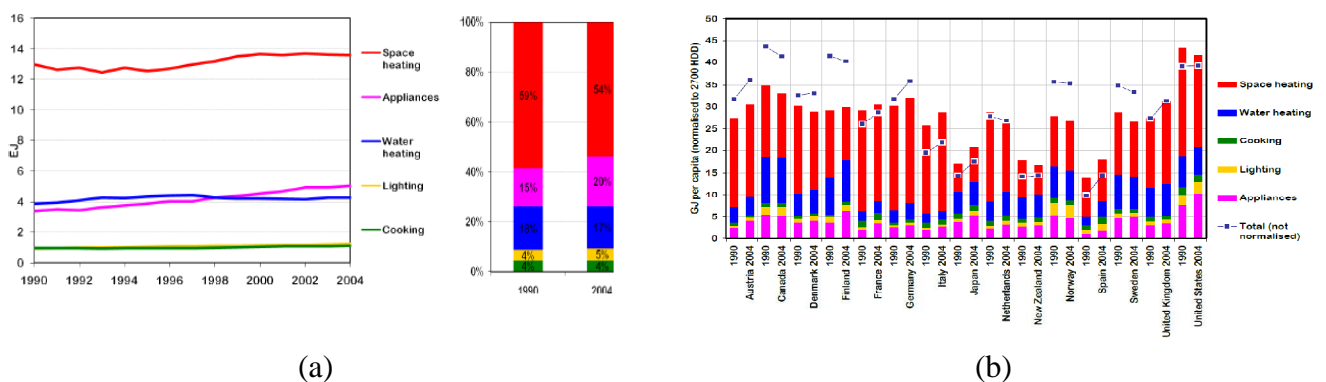


Figure 4 : Subdivision of energy consumption in residential buildings in different countries (IEA (2008))

Energy consumption due to appliances is rising since 1990. This fact can be partly explained by the growing use of electrical equipment in residential buildings (computer, cell chargers, washing machine...). In 2004, the third source of energy used concerns the domestic hot water supply. Energy dedicated to lighting and cooking stays relatively stable and represents a smaller part of energy consumption (less than 10%).

This end-of-study project only focuses on the ‘Space heating’ and ‘Water heating’ energy reduction. Energy dedicated to these two sectors represents the major part of the residential used energy (more than 70%).

Moreover, cooking, lighting and appliances energy consumption highly depends on the electrical devices efficiencies and the human behavior (switching off lights, computer...).

1.4 Studied region

The present work focuses on the residential building situated in the Walloon Region of Belgium but this study could have been extended to another country by applying the same methodology.

The choice to focus only on the Walloon Region can be justified by this main fact: there are different energetic incentive policies (principally in terms of subsidy) between the North and the South of the Kingdom of Belgium. Moreover, many differences exist between the Flemish and the Walloon building stock in terms of year of construction and type of buildings (see *Figure 9*).

1.5 Research topic in the field of building sector: a short overview

As previously mentioned, many efforts are deployed in order to reduce our consumption in the (tertiary and residential) building sector. Several (International, European and Belgian) research projects have been, and are still, carried out to reach this goal. Examples are numerous. Here are some of the research projects carried out by the ‘*Applied Thermodynamics Laboratory of the University of Liege*’ which is very active in the energy domain:

- The ‘Appendix 53’ project consists in the development of analysis and evaluation procedures for total energy used in buildings;
- The ‘Harmonac’ project consists in the development of benchmarking, inspection and audit procedure for air-conditioned buildings. An aim of this project was to propose and evaluate some Energy Conservation Opportunities (ECO’s);
- The ‘Green +’ project consists in the development of an air-to-air heat recovery system for residential buildings;
- ...

The whole description of these projects (and many others!) in the field of energy performance of building can be found on the website¹ of the ‘*Applied thermodynamics of the University the Liege*’.

¹ www.labohtap.ulg.ac.be

2 Statistic data on residential buildings situated in the Walloon Region of Belgium and Belgian energetic market

The present chapter focuses on the Walloon building census (typology, year of construction...), the Belgian energetic market (governmental Subsidies, oil and fuel price...) and the economical hypotheses used for the economical analysis.

2.1 Statistic data on residential buildings

The most recent national census related to residential buildings dates from 2001 and was performed by Vanneste et Al. (2001). Others used sources are the survey concerning the Walloon residential consumption carried out by the ICEDD (2005) and the investigation on the Walloon residential building stock performed by the MRW (2006-2007).

In the frame of the IEA-37 project (2006), a study (mainly based on the data presented in the three previously mentioned surveys) was managed by Kints (2008). The main part of the following results is extracted from this report.

2.1.1 Building Stock and Population

Wallonia's total area is 16844km² (29.5% of forest, 52.6% of cultivated area and 13.6% of urban zone). The total number of houses is equal to +/- 1 490 000 (+ secondary building). The total amount of people who live in Wallonia is 3 456 775 and the total amount of active people (15 to 64 years old) is equal to +/- 1 390 000. Density of population stands at 205.2 people per km².

2.1.2 Buildings Type

Residential buildings can be classified in four categories:

- 4 Frontages houses,
- Semi-detached houses,
- Row houses,
- Flats.

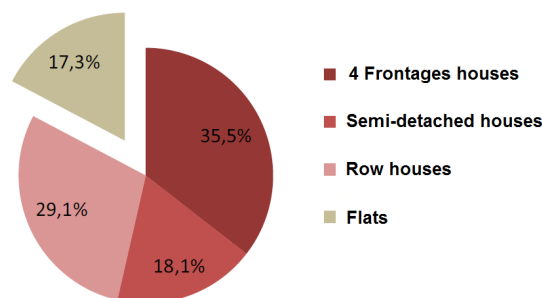


Figure 5 : Types of building in the Walloon Region (Kints (2008))

2.1.3 Buildings Size

The buildings can be classified according to size, as shown on the Figure 6. This factor is important since the consumption dedicated to heating is proportional to the size of buildings.

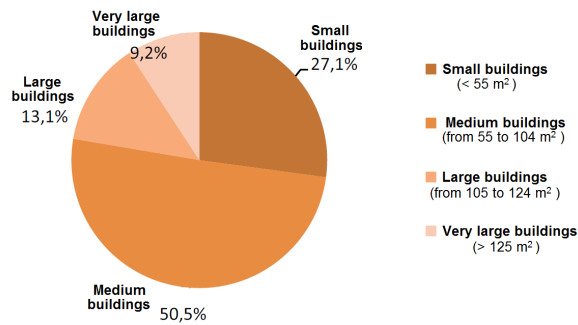


Figure 6 : Buildings size distribution in the Walloon Region (Kints(2008))

2.1.4 Correlation between sizes and types of buildings

Obviously, size and types of the building are highly correlated. On average, the number of rooms per residential building is 3.7 rooms per flat and 5.3 rooms per house. As expected, small flats (<55m²) are twice more numerous than small houses (< 55 m²).

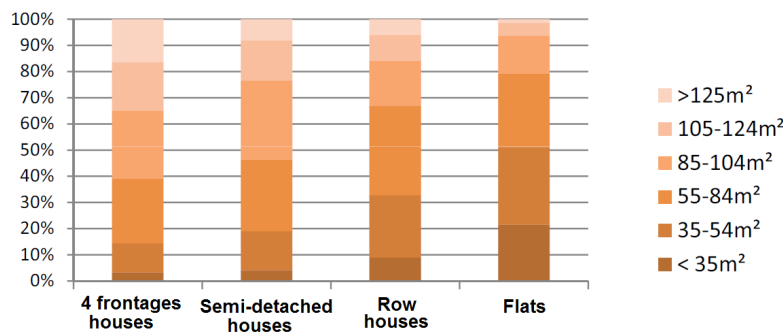


Figure 7 : Correlation between sizes and types of buildings in the Walloon Region (Kints(2008))

From these results, it is possible to determine the mean area per types of buildings. Results are given in Table 1:

(m ²)	Mean inhabitable area	Mean total area
4 frontages houses	97.7	146.6
Semi-detached houses	85.3	128.0
Row houses	77.4	116.1
Flats	60.3	90.4
Every types	83.2	124.9

Table 1 : Mean area according to types of building in the Walloon Region (Kints (2008))

2.1.5 Year of construction

Year of construction is a primordial factor in our study since it is highly correlated with the insulation and the air tightness of the buildings. The global distribution of buildings according to their year of construction in the Walloon Region is given in the Figure 8:

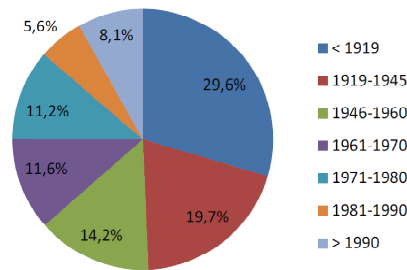


Figure 8 : Global distribution of buildings according to their year of construction in the Walloon Region (Kints (2008))

As shown in the Figure 8, the Walloon housing stock is globally old: half of the residential building stock dates before 1945 and 75% dates before 1980. By assuming the fact that the buildings constructed before 1990 need a retrofit, 91.9% of the global stock is concerned. From this point of view, difference between the Flemish and the Walloon building stock is quite important, as shown in the Figure 9 :

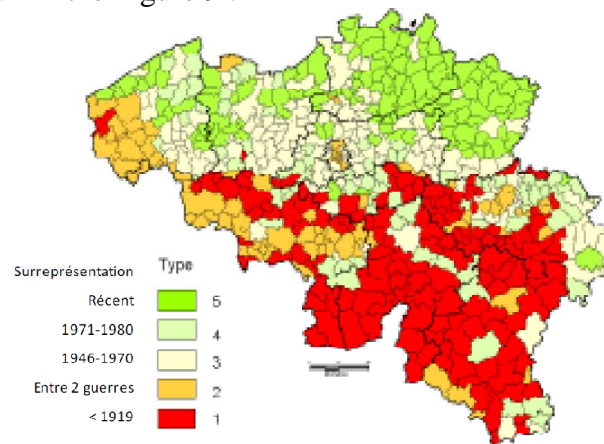


Figure 9 : Spatial variation of the construction year of the building stock in Belgium

Such differences can be explained by:

- a higher population density in Flanders;
- a higher purchasing power in Flanders;
- a different socio-economic history between these two regions (industrial area in Wallonia);
- an interest for ancient buildings in Wallonia;
- a larger destruction of the buildings stock during the two world wars in Flanders;
- ...

2.1.6 Correlation between year of construction and types of buildings

Types of building can be linked with the year of construction, as exposed on the Figure 10:

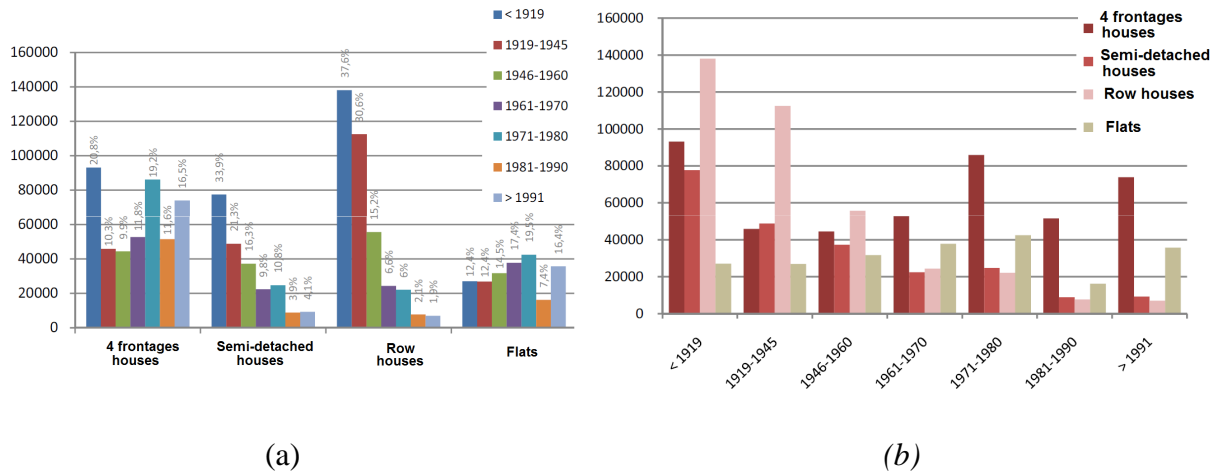


Figure 10 : Correlation between year of construction and type of buildings (Kints(2008))

2.1.7 Constructive building stock characteristics

This part of the work describes the constructive characteristics of the Walloon building stock and focuses mainly on the wall, the roof and the window insulation.

Wall insulation

As we can observe on Figure 11, the main part (71%) of the residential building in the Walloon region is not totally insulated, which represents a high potential of amelioration.

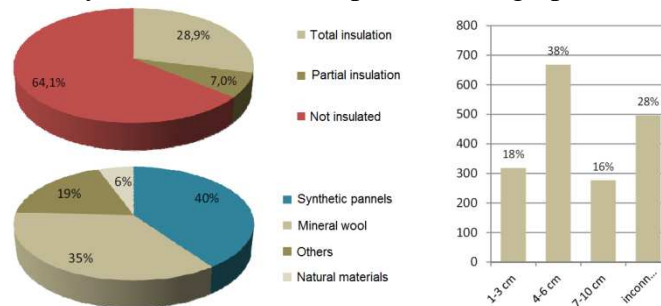


Figure 11 : Insulation of the exterior walls: percentage of houses with insulation, type of insulation and insulation thickness (Kints (2008))

Obviously, a correlation between year of construction and degree of insulation exists. This correlation is represented hereafter, in Figure 12.

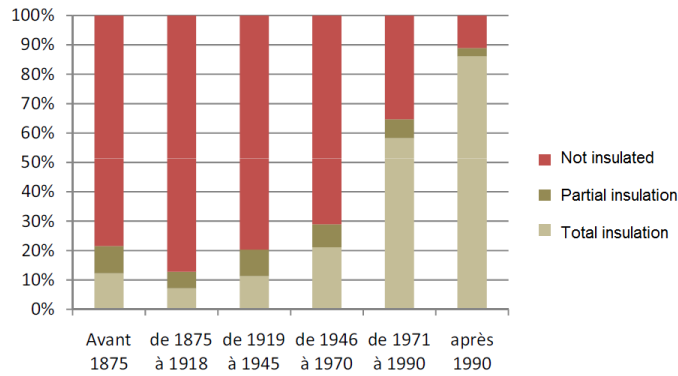


Figure 12: Correlation between year of construction and degree of insulation

Unfortunately, statistic data about the correlation between the degrees of insulation and the type of building do not exist. In our study, we assume the same proportional repartition of the degree of insulation whatever the different type of building.

Roof insulation

There is a larger part (52%) of the roof insulated building stock compared to the exterior wall insulated building stock. However, almost 50% of the total building stock is not completely insulated, which also represent a high potential of amelioration.

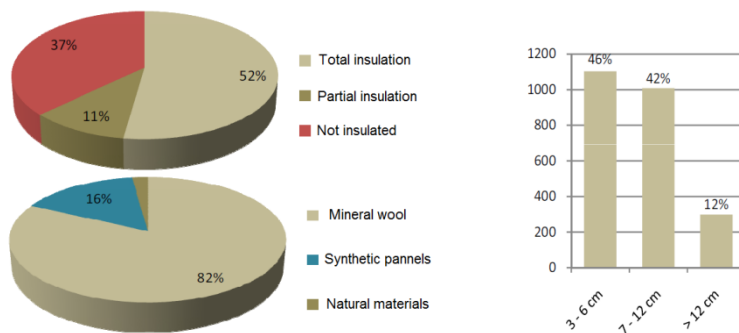


Figure 13: Insulation of the roof: percentage of houses with insulation, type of insulation and insulation thickness (Kints (2008))

Unfortunately, correlation between year of construction and roof insulation are not available.

Windows

Figure 14 represents the part of insulated windows in the residential building stock of the Walloon region.

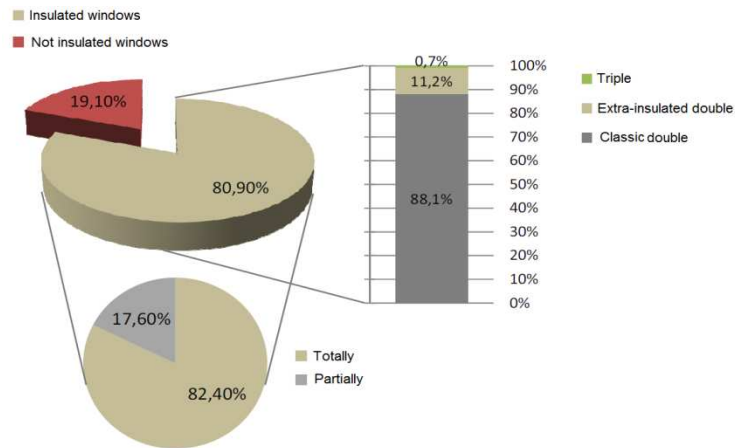


Figure 14 : Type of windows (Kints (2008))

Floor

Floor insulation also represents a high potential of amelioration due to the high number of non-insulated residential buildings, as we can observe on Figure 15:

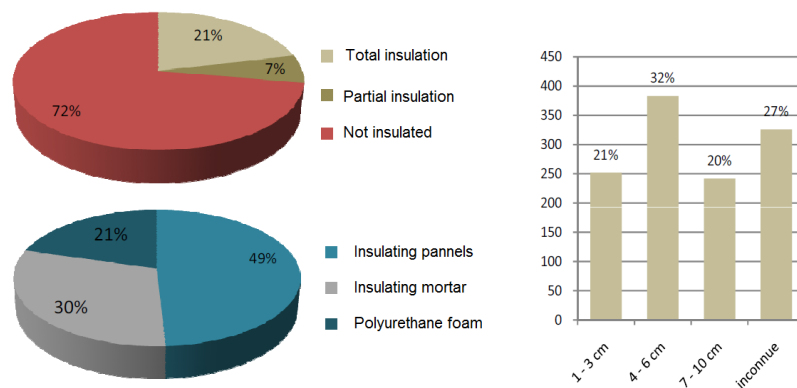


Figure 15: Floor insulation: percentage of houses with insulation, type of insulation and insulation thickness (Kints (2008))

Example of U value

Determining a mean value of the convective coefficient for all types of building is really difficult. To have an order of magnitude of U values of the existing building stock, examples of values measured on-site from real cases (in the frame of IEA 37 project), are given hereafter. One of the parts of this international project was to evaluate the energetic performance of residential houses before and after retrofitting (transforming into passive house).

	<u>Year of construction</u>	<u>Type of building</u>	<u>U wall</u> [W/m ² K]		<u>U roof</u> [W/m ² K]		<u>U window</u> [W/m ² K]		<u>U floor</u> [W/m ² K]	
			<u>BR</u>	<u>AR</u>	<u>BR</u>	<u>AR</u>	<u>BR</u>	<u>AR</u>	<u>BR</u>	<u>AR</u>
<u>Case 1</u>	19 th century	Row house	3.14	0.135	5.5	0.14	4.65	0.72	2.2	0.165
<u>Case 2</u>	Beginning of the 20 th	Farm	3.14	0.26	0.76 (attic floor)	0.18	4.5	1.1	2.2	0.35
<u>Case 3</u>	50's	Semi-detached house	1.9	0.126	5.5	0.12	5	0.74	2.7	0.086
<u>Case 4</u>	1959	Social housing tower	2.78	0.41	0.77 (attic floor)	0.28	5.1	1.19	6.66	0.26
<u>Case 5</u>	1960	Single-detached house	2.12	0.2	3	0.21	2.6	1.1	3.65	0.49

*BR: Before retrofit

*AR: After retrofit

As we can observe in the previous table, it is very complex to establish a correlation between the year of construction, the type and the U value of the construction. Correlation between U values used for our simulation and year of construction is presented in the chapter relative to the annual consumption simulation of the existing building stock.

2.1.8 Air tightness

One important factor to determine the annual energy consumption is the air tightness. Unfortunately, statistic data in relation with ages or building types about air tightness are difficult to find. A mean observed value of 12 [m³/h-m²] was chosen for non-retrofitted houses. This value is given by Renard (2008).

2.1.9 Ventilation

Residential ventilation can be divided into four categories:

- System A : natural ventilation;
- System B: mechanic pulsing ventilation;
- System C: mechanic extracting ventilation;
- System D: mechanic pulsing and extracting ventilation.

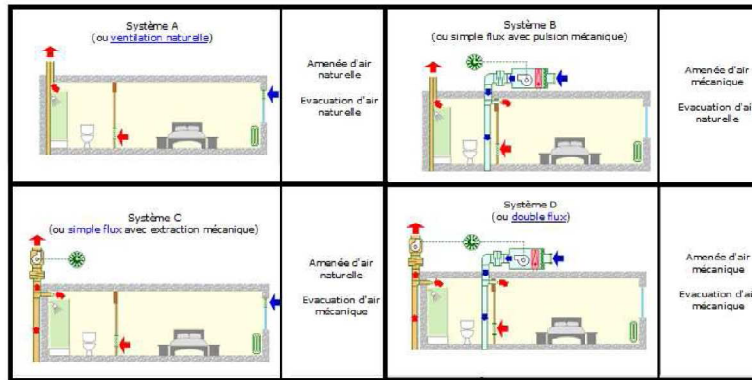


Figure 16 : Ventilation system according to NBN D50-001

In reality, detailed statistic data about ventilation system are not available in Walloon Region but it is a well known fact that the most widespread system is the **system A** (no mechanical ventilation) in non-retrofitted existing buildings. For our simulations, we consider this fact as an assumption.

2.1.10 Heating production system

This part of the work consists in presenting statistic data about the heating production system:

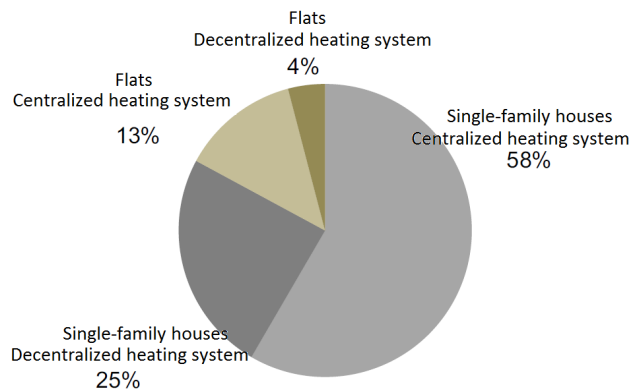


Figure 17 : Distribution of the building stock as a function of the heating production system (Kints (2008))

As we can see in Figure 17, Kints (2008) does not make difference between row houses, semi-detached houses and four frontages houses. In this end-of-study work, the distribution presented in Figure 17 is assumed to be equal for all types of houses. This remark can also be enounced for the following figure, which presents the distribution of the type of used combustible:

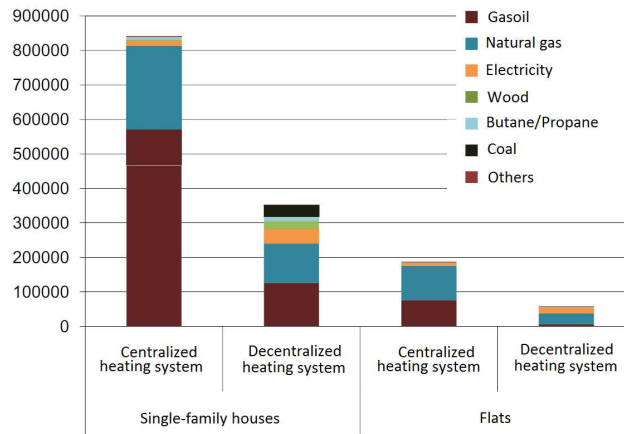


Figure 18 : Combustible used for space heating

70% of single-family houses and 76% of the flats are equipped with centralized heating production system. In both cases, gasoil and natural gas represent the main part of the energetic vector used:

- 68% of gasoil in single-family houses;
- 53% of natural gas and 41% of gasoil in flats.

Concerning decentralized heating production systems, natural gas and gasoil are less widespread than in centralized heating production systems. They represent 68% of the heating production system in the single-family houses, before electricity (12%), coal (10%) and wood (7%).

Electricity represents 30% of the combustible used in the decentralized heating production systems in flats.

There is a correlation between combustible used and year of construction, as we can observe on the following figure:

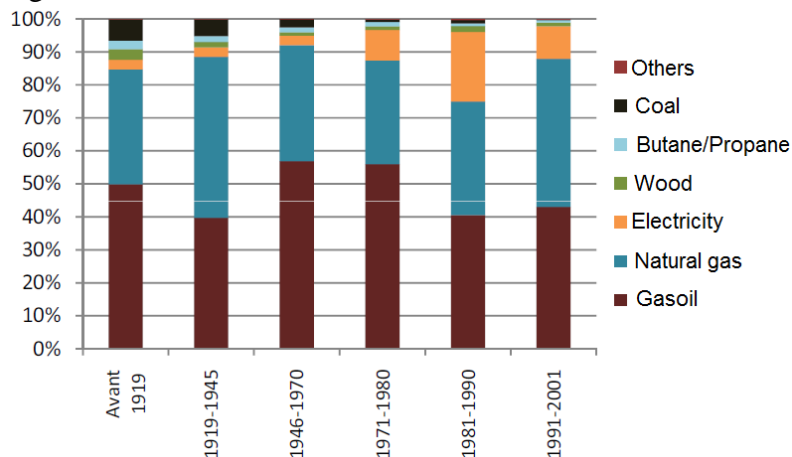


Figure 19 : Correlation between year of construction and type of combustible for space heating (Kints (2008))

2.1.11 Domestic hot water

As we can see on Figure 20, the production of domestic hot water is the second consuming use sector (11% of the total energy use), just after the space heating (74% of the total energy use):

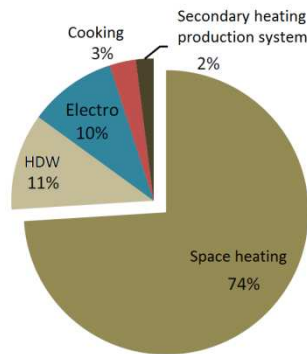


Figure 20 : Distribution of the building consumption as a function of the type of use (Kints (2008))

Lighting is included in the electro part of the building consumption and represents 14% of this part. An easy way (maybe the easiest!) to reduce our environmental impact is to replace traditional lighting by low consumption (such as led) lighting. This solution will not be investigated in this end-of-study work.

Domestic hot water is mainly provided by electricity, natural gas and gasoil (in respectively 34%, 33% and 24% of investigated cases).

2.1.12 Assumptions concerning the determination of the envelope area

One important criterion in the determination of the building consumption is the heat loss area (and thus, the compactness of the building). Unfortunately, available statistic data about building area only concern the inhabitable and the total area (see 2.1.3).

Assumptions concerning the shape of the building have to be done in order to achieve the present study. The following part describes and justifies hypotheses used for each type of investigated residential building.

Figure 21 represents a schematic residential building and shows the nomenclature used in the rest of the paragraph:

- α is the slope of the roof;
- y is the height of a storey;
- x is the length of the side frontage;
- z is the length of the “street” frontage.

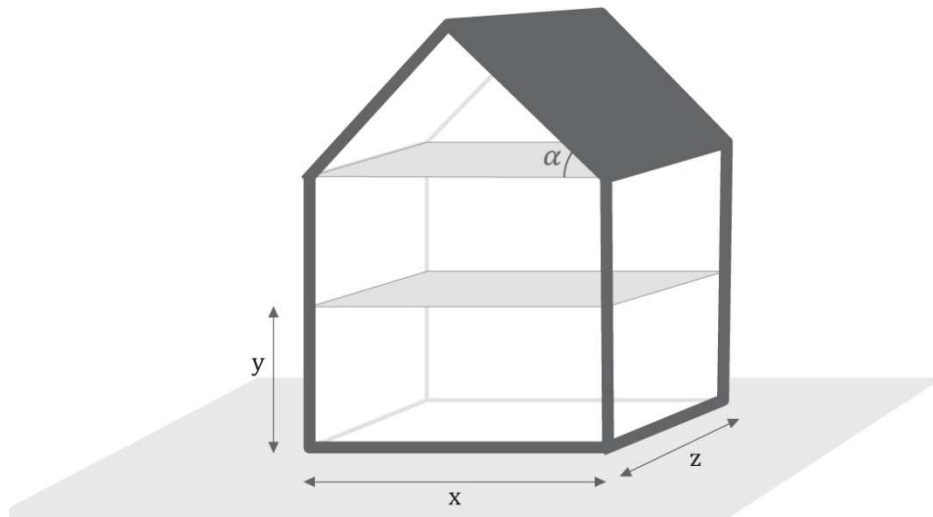


Figure 21 : Schematic representation of a residential building and used nomenclature

4 frontages houses

Concerning the 4 frontages houses, the first assumption is to consider the ground floor as a square ($x=y$). This fact can be justified by the observation of a sky view of a 4 frontages houses living district (Figure 22). The number of floor is equal to 3 (the ground floor, the first floor and the second floor also called the “under roof” floor) and the height of a storey (y) is chosen equal to 2.6 m.



Figure 22 : Sky view of a 4 frontages houses living district (Beaufays)

The rest of the assumptions are the same than the ones presented by Servais (2010):

- α , the slope of the roof, is chosen equal to 25° ;
- the last floor of the building is supposed to be inhabitable when the height is comprised between 1.5 and 3m;
- the “street” frontage is composed of 30% of glazed area;
- the “back” frontage is composed of 40% of glazed area;
- the “side” frontages are composed of 30% of glazed area;
- the building is positioned in a way that it faces the “street” frontage to the east.

Semi-detached and row houses

Concerning the semi-detached and the row houses, it is established that the “street” frontage length is equal to 6 m. Once again, this fact can be justified by the observation of a sky view of row houses living district (see *Figure 23*).



Figure 23 : Sky view of rows houses living district (Grivegnée)

The rest of the assumptions relative to these two kinds of residential buildings are the same than the ones previously mentioned. One exception concerns the “under roof” floor. This latter is not supposed to be inhabitable, according to Servais (2010).

Flats

Obviously, α is equal to 0 and just one floor is considered. This latter is considered as a square. An example of apartment building is given in *Figure 24*.



Figure 24 : Apartment building (Liege: St Gilles)

Assumptions relative to the percentage of glazed area are given hereafter:

- the “street” frontage is composed of 60% of glazed area;
- the “back” frontage is composed of 40% of glazed area;

These values have been measured in a typical apartment from Liege (Quai Churchill, 11a).

The rest of the assumptions are the same than the ones previously presented:

- the height of a storey is equal to 2.6 m;
- the apartment building is positioned in a way that it faces the “street” frontage to the east.

2.1.13 Determination of the envelope area and the volume

Thanks to the previously mentioned hypotheses (and the mean inhabitable area presented in 2.1.3), it is possible to determine the envelope area of each type of building by means of a set of simple equations (use of EES Software for calculus). Calculation details are given hereafter for each type of buildings.

4 Frontages house

In order to introduce the nomenclature used for our calculus, *Figure 25* presents a schematic representation of a 4 frontages houses:

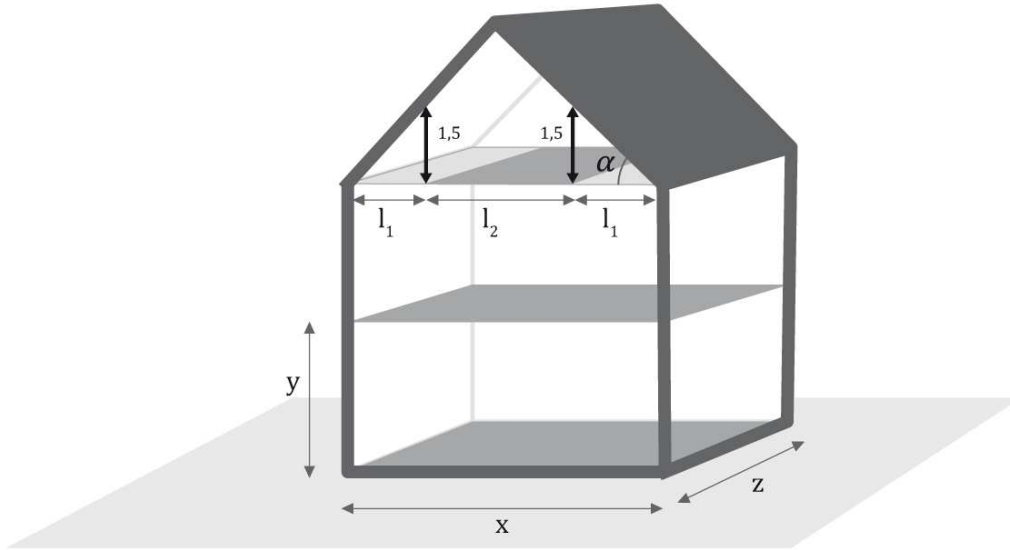


Figure 25 : Schematic representation of a 4 frontages house and its nomenclature

$$x_{4,front} = z_{4,front} \quad (1)$$

$$y_{4,front} = 2.6 \quad (2)$$

$$l_1^2 + 1.5^2 = \left[\frac{l_1}{\cos(25)} \right]^2 \quad (3)$$

$$x_{4,front} = 2 \cdot l_1 + l_2 \quad (4)$$

$$l_2 \cdot z_{4,front} + 2 \cdot x_{4,front} \cdot z_{4,front} = 146.6 \quad (5)$$

$$A_{total,roof,4,front} = 2 \cdot z_{4,front} \cdot \frac{x_{4,front}}{\cos(25)} \quad (6)$$

$$A_{wall,street,4,front} = 2 \cdot z_{4,front} \cdot y_{4,front} - A_{wind,street,4,front} \quad (7)$$

$$A_{wind,street,4,front} = 0.3 \cdot 2 \cdot z_{4,front} \cdot y_{4,front} \quad (8)$$

$$A_{wall,back,4,front} = 2 \cdot z_{4,front} \cdot y_{4,front} - A_{wind,back,4,front} \quad (9)$$

$$A_{wind,back,4,front} = 0.4 \cdot 2 \cdot z_{4,front} \cdot y_{4,front} \quad (10)$$

$$A_{wall,side,4,front} = 2 \cdot x_{4,front} \cdot y_{4,front} - A_{wind,side,4,front} \quad (11)$$

$$A_{wind,side,4,front} = 0.4 \cdot 2 \cdot x_{4,front} \cdot y_{4,front} \quad (12)$$

$$A_{tot,wall,side,4,front} = 2 \cdot A_{wall,side,4,front} \quad (13)$$

$$A_{\text{tot,wind,side,4,front}} = 2 \cdot A_{\text{wind,side,4,front}} \quad (14)$$

$$A_{\text{tot,ext,wall,4,front}} = A_{\text{tot,wall,side,4,front}} + A_{\text{wall,street,4,front}} + A_{\text{wall,back,4,front}} \quad (15)$$

$$A_{\text{tot,wind,4,front}} = A_{\text{tot,wind,side,4,front}} + A_{\text{wind,street,4,front}} + A_{\text{wind,back,4,front}} \quad (16)$$

$$h_{4,\text{front}}^2 + \left[\frac{x_{4,\text{front}}}{2} \right]^2 = \left[\frac{x_{4,\text{front}}}{2 \cdot \cos(25)} \right]^2 \quad (17)$$

$$\text{Vol}_{4,\text{front}} = x_{4,\text{front}} \cdot 2 \cdot y_{4,\text{front}} \cdot z_{4,\text{front}} + \frac{x_{4,\text{front}}}{2} \cdot z_{4,\text{front}} \cdot h_{4,\text{front}} - l_1 \cdot 1.5 \quad (18)$$

Semi-detached house

The same method that the one presented for the 4 frontage houses is applied. One of the difference concerns the determination of the total exterior area due to a common wall between the two attached buildings. Another difference is the fact that the under roof level is considered as uninhabitable.

$$y_{\text{SDH}} = 2.6 \quad (19)$$

$$z_{\text{SDH}} = 6 \quad (20)$$

$$2 \cdot x_{\text{SDH}} \cdot z_{\text{SDH}} = 128 \quad (21)$$

$$A_{\text{total,roof,SDH}} = 2 \cdot z_{\text{SDH}} \cdot \frac{x_{\text{SDH}}}{2 \cdot \cos(25)} \quad (22)$$

$$A_{\text{wall,street,SDH}} = 2 \cdot z_{\text{SDH}} \cdot y_{\text{SDH}} - A_{\text{wind,street,SDH}} \quad (23)$$

$$A_{\text{wind,street,SDH}} = 0.3 \cdot 2 \cdot z_{\text{SDH}} \cdot y_{\text{SDH}} \quad (24)$$

$$A_{\text{wall,back,SDH}} = 2 \cdot z_{\text{SDH}} \cdot y_{\text{SDH}} - A_{\text{wind,back,SDH}} \quad (25)$$

$$A_{\text{wind,back,SDH}} = 0.4 \cdot 2 \cdot z_{\text{SDH}} \cdot y_{\text{SDH}} \quad (26)$$

$$A_{\text{wall,side,SDH}} = 2 \cdot x_{\text{SDH}} \cdot y_{\text{SDH}} - A_{\text{wind,side,SDH}} \quad (27)$$

$$A_{\text{wind,side,SDH}} = 0.4 \cdot 2 \cdot x_{\text{SDH}} \cdot y_{\text{SDH}} \quad (28)$$

$$A_{\text{tot,wall,side,SDH}} = 1 \cdot A_{\text{wall,side,SDH}} \quad (29)$$

$$A_{\text{tot,wind,side,SDH}} = 1 \cdot A_{\text{wind,side,SDH}} \quad (30)$$

$$A_{\text{tot,ext,wall,SDH}} = A_{\text{tot,wall,side,SDH}} + A_{\text{wall,street,SDH}} + A_{\text{wall,back,SDH}} \quad (31)$$

$$A_{\text{tot,wind,SDH}} = A_{\text{tot,wind,side,SDH}} + A_{\text{wind,street,SDH}} + A_{\text{wind,back,SDH}} \quad (32)$$

$$h_{\text{SDH}}^2 + \left[\frac{x_{\text{SDH}}}{2} \right]^2 = \left[\frac{x_{\text{SDH}}}{2 \cdot \cos(25)} \right]^2 \quad (33)$$

$$\text{Vol}_{\text{SDH}} = x_{\text{SDH}} \cdot 2 \cdot y_{\text{SDH}} \cdot z_{\text{SDH}} + \frac{x_{\text{SDH}}}{2} \cdot z_{\text{SDH}} \cdot h_{\text{SDH}} \quad (34)$$

Row house

Same method is applied than the two previously presented:

$$y_{\text{RH}} = 2.6 \quad (35)$$

$$z_{\text{RH}} = 6 \quad (36)$$

$$2 \cdot x_{RH} \cdot z_{RH} = 116.1 \quad (37)$$

$$A_{total,roof,RH} = 2 \cdot z_{RH} \cdot \frac{x_{RH}}{2 \cdot \cos(25)} \quad (38)$$

$$A_{wall,street,RH} = 2 \cdot z_{RH} \cdot y_{RH} - A_{wind,street,RH} \quad (39)$$

$$A_{wind,street,RH} = 0.3 \cdot 2 \cdot z_{RH} \cdot y_{RH} \quad (40)$$

$$A_{wall,back,RH} = 2 \cdot z_{RH} \cdot y_{RH} - A_{wind,back,RH} \quad (41)$$

$$A_{wind,back,RH} = 0.4 \cdot 2 \cdot z_{RH} \cdot y_{RH} \quad (42)$$

$$A_{wall,side,RH} = 0 \quad (43)$$

$$A_{wind,side,RH} = 0 \quad (44)$$

$$A_{tot,wall,side,RH} = 0 \quad (45)$$

$$A_{tot,wind,side,RH} = 0 \quad (46)$$

$$A_{tot,ext,wall,RH} = A_{tot,wall,side,RH} + A_{wall,street,RH} + A_{wall,back,RH} \quad (47)$$

$$A_{tot,wind,RH} = A_{tot,wind,side,RH} + A_{wind,street,RH} + A_{wind,back,RH} \quad (48)$$

$$h_{RH}^2 + \left[\frac{x_{RH}}{2} \right]^2 = \left[\frac{x_{RH}}{2 \cdot \cos(25)} \right]^2 \quad (49)$$

$$Vol_{RH} = x_{RH} \cdot 2 \cdot y_{RH} \cdot z_{RH} + \frac{x_{RH}}{2} \cdot z_{RH} \cdot h_{RH} \quad (50)$$

Apartment

Apartments are the easiest type of building to determine the envelope area, since it is considered as a simple parallelepiped:

$$z_{flat} \cdot x_{flat} = 90.4 \quad (51)$$

$$z_{flat} = x_{flat} \quad (52)$$

$$y_{flat} = 2.6 \quad (53)$$

$$A_{total,roof,flat} = 0 \quad (54)$$

$$A_{wall,street,flat} = x_{flat} \cdot y_{flat} - A_{wind,street,flat} \quad (55)$$

$$A_{wind,street,flat} = 0.6 \cdot x_{flat} \cdot y_{flat} \quad (56)$$

$$A_{wall,back,flat} = z_{flat} \cdot y_{flat} - A_{wind,back,flat} \quad (57)$$

$$A_{wind,back,flat} = 0.4 \cdot z_{flat} \cdot y_{flat} \quad (58)$$

$$A_{wall,side,flat} = 0 \quad (59)$$

$$A_{wind,side,flat} = 0 \quad (60)$$

$$A_{tot,wall,side,flat} = 0 \quad (61)$$

$$A_{tot,wind,side,flat} = 0 \quad (62)$$

$$A_{tot,ext,wall,flat} = A_{tot,wall,side,flat} + A_{wall,street,flat} + A_{wall,back,flat} \quad (63)$$

$$A_{tot,wind,flat} = A_{tot,wind,side,flat} + A_{wind,street,flat} + A_{wind,back,flat} \quad (64)$$

$$Vol_{flat} = x_{flat} \cdot y_{flat} \cdot z_{flat} \quad (65)$$

Values resulting from the set of equations are given hereafter. These are the ones that we will use for our simulations:

$A_{\text{total,roof,4,front}} = 73.19$
 $A_{\text{total,roof,SDH}} = 70.62$
 $A_{\text{tot,ext,wall,RH}} = 40.56$
 $A_{\text{tot,wall,side,flat}} = 0$
 $A_{\text{tot>wind,4,front}} = 63.53$
 $A_{\text{tot>wind,SDH}} = 32.93$
 $A_{\text{tot>wind,side,RH}} = 0$
 $A_{\text{wall,back,flat}} = 14.83$
 $A_{\text{wall,side,4,front}} = 25.41$
 $A_{\text{wall,side,SDH}} = 44.37$
 $A_{\text{wall,street,RH}} = 21.84$
 $A_{\text{wind,back,flat}} = 9.888$
 $A_{\text{wind,side,4,front}} = 16.94$
 $A_{\text{wind,side,SDH}} = 11.09$
 $A_{\text{wind,street,RH}} = 9.36$
 $h_{\text{RH}} = 2.256$
 $l_2 = 1.711$
 $\text{Vol}_{\text{RH}} = 367.3$
 $x_{\text{flat}} = 9.508$
 $y_{4,\text{front}} = 2.6$
 $y_{\text{SDH}} = 2.6$
 $z_{\text{RH}} = 6$

$A_{\text{total,roof,flat}} = 0$
 $A_{\text{tot,ext,wall,4,front}} = 105.9$
 $A_{\text{tot,ext,wall,SDH}} = 84.93$
 $A_{\text{tot>wall,side,RH}} = 0$
 $A_{\text{tot>wind,flat}} = 24.72$
 $A_{\text{tot>wind,side,4,front}} = 33.88$
 $A_{\text{tot>wind,side,SDH}} = 11.09$
 $A_{\text{wall,back,RH}} = 18.72$
 $A_{\text{wall,side,flat}} = 0$
 $A_{\text{wall,street,4,front}} = 29.65$
 $A_{\text{wall,street,SDH}} = 21.84$
 $A_{\text{wind,back,RH}} = 12.48$
 $A_{\text{wind,side,flat}} = 0$
 $A_{\text{wind,street,4,front}} = 12.71$
 $A_{\text{wind,street,SDH}} = 9.36$
 $h_{\text{SDH}} = 2.487$
 $\text{Vol}_{4,\text{front}} = 403.1$
 $\text{Vol}_{\text{SDH}} = 412.4$
 $x_{\text{RH}} = 9.675$
 $y_{\text{flat}} = 2.6$
 $z_{4,\text{front}} = 8.144$
 $z_{\text{SDH}} = 6$

$A_{\text{total,roof,RH}} = 64.05$
 $A_{\text{tot,ext,wall,flat}} = 24.72$
 $A_{\text{tot>wall,side,4,front}} = 50.82$
 $A_{\text{tot>wall,side,SDH}} = 44.37$
 $A_{\text{tot>wind,RH}} = 21.84$
 $A_{\text{tot>wind,side,flat}} = 0$
 $A_{\text{wall,back,4,front}} = 25.41$
 $A_{\text{wall,back,SDH}} = 18.72$
 $A_{\text{wall,side,RH}} = 0$
 $A_{\text{wall,street,flat}} = 9.888$
 $A_{\text{wind,back,4,front}} = 16.94$
 $A_{\text{wind,back,SDH}} = 12.48$
 $A_{\text{wind,side,RH}} = 0$
 $A_{\text{wind,street,flat}} = 14.83$
 $h_{4,\text{front}} = 1.899$
 $l_1 = 3.217$
 $\text{Vol}_{\text{flat}} = 235$
 $x_{4,\text{front}} = 8.144$
 $x_{\text{SDH}} = 10.67$
 $y_{\text{RH}} = 2.6$
 $z_{\text{flat}} = 9.508$

3 Walloon residential building stock arborescence

This part of the work is the most delicate one. Actually, it is really difficult (and even impossible) to create an arborescence of the different kind of residential buildings situated in the Walloon Region: purists would say that there are as many cases as there are buildings! It also exists a compromise between a large numbers of investigated cases (to be as complete as possible and to analyze as many cases as possible) and a small numbers of analyzed cases (to be as efficient as possible in terms of calculating time). In order to reduce the case number, the idea is to neglect marginal cases.

Moreover, the creation of the building stock arborescence requires a large numbers of assumptions. Error sources are also abundant: statistics and data compilation, used assumptions, used weather data...

In conclusion of this chapter's introduction, it is important to keep in mind that the presented method does not permit to determine with precision the global consumption of residential buildings in the Walloon Region. On the other hand, this latter method allows pointing out some economical and environmental trends related to the different investigated retrofit options.

3.1 Determination of the existing building stock arborescence

As already mentioned, a compromise exists between a large numbers of investigated cases and a small numbers of analyzed cases. In a first time, a large arborescence with a maximum of investigated cases will be created; then simplifications will be made in order to reduce the number of cases.

3.1.1 Large arborescence

The creation of the largest building stock arborescence can be made by investigating all possible cases from the statistic data previously presented.

Large building stock arborescence	
Type of building (Separated, Semi-detached and Row houses + Apartment)	4
Area (Small, Medium, Large and Very large)	4
Year of construction (<1919, 1919-1945, 1946-1960, 1961-1970, 1971- 1980, 1981-1990, >1990)	7
Wall (Insulated, Partially insulated, Not insulated)	3
Roof (Insulated, Partially insulated, Not insulated)	3
Window (Insulated, Not insulated)	2
Floor (Insulated, Partially insulated, Not insulated)	3
Heating production system (Centralized, Not centralized)	2
Type of combustible (Gasoil, Natural gas, Electricity, Wood, Butane/Propane, Coal, Others)	7
DHW (Gasoil, Natural gas, Electricity)	3
Total number of cases	190 512

Table 2 : Large building stock arborescence

3.1.2 Simplified arborescence

First step

As we can observe in the previous paragraph, the large building stock arborescence presents 190 512 of investigated cases, which is way too high in the field of this study. Simplifications have to be done.

3.1.2.1.1 Simplification concerning the type of building and the inhabitable area

It has been decided to correlate the type of building and the inhabitable area, by using the mean value presented in *Table 1*. So, a mean inhabitable area corresponds to a type of building. This simplification divides the number of investigated cases by 3.

3.1.2.1.2 Simplification concerning the year of construction

Year of construction is divided into seven parts rewritten henceforward:

- <1919, 1919-1945, 1946-1960, 1961-1970, 1971-1980, 1981-1990, >1990.

Simplification consists in aggregating the first and second group, the third and fourth group and lastly the fifth and sixth group.

Year of construction is now classified as presented hereafter:

- <1919-1945, 1946-1970, 1971-1990, >1990.

This simplification can be justified by the observation of *Figure 10* and *Figure 12* which shows the same trends of characteristics for each aggregated groups.

3.1.2.1.3 Simplification concerning wall, roof and floor characteristics

Simplifications concerning the wall, roof and floor characteristics consist in neglecting the partially insulated case, which is quite negligible. Parts relative to the partially insulated case are proportionally split up.

3.1.2.1.4 Simplification concerning the heating production system

No simplifications can be made concerning the heating production system.

3.1.2.1.5 Simplification concerning combustible and domestic hot water (DHW)

Simplification concerning the combustible and the domestic hot water is to focus only on the main used combustible: gasoil, natural gas and electricity. Moreover, another simplification consists in assuming that production of domestic hot water can be done only by the same type of combustible than the one used for the space heating or by electricity.

3.1.2.1.6 Determination of the total number of investigated cases

Simplified building stock arborescence	
Type of building correlated with mean inhabitable area (Separated, Semi-detached and Row houses + Apartment)	4
Year of construction (<1919-1945, 1946-1970, 1971-1990, >1990)	4
Wall (Insulated, Not insulated)	2
Roof (Insulated, Not insulated)	2
Window (Insulated, Not insulated)	2
Floor (Insulated, Not insulated)	2
Heating production system (Centralized, Not centralized)	2
Type of combustible and DHW (Gasoil + Gasoil, Natural gas + Natural gas, Gasoil + Electricity, Natural gas + Electricity, Electricity + Electricity)	5
Total number of cases	2560

Table 3 : Simplified building stock arborescence (First step)

Second step

As we can observe in *Table 3*, the total number of cases from the first simplified arborescence is equal to 2560 which is too numerous in the frame of this study. Thus, it has been decided to reduce this number by making more simplifications:

- The first simplification consists in neglecting the insulation of the floor. A mean value will be used for our simulation. This can be justified by the fact that most of the basement floor is situated above a technical local or a cellar which reduce the influence of the floor insulation. Moreover, retrofit options relative to the floor insulation are not widespread (heavy building work).
- It has also been decided not to take into account the type of heating production (centralized or decentralized) but only the energetic vector. This simplification can be justified by a weak influence of the heating production system in the annual consumption. In our study, we will only consider a centralized system for two reasons. It is the most widespread system and retrofit options are mostly centralized ones.
- Obviously, roof insulation is not taken into account in the flat simulation (roof of an apartment is not an “exterior” wall).
- Since the walls are not the easiest component to insulate and if the walls are insulated, it has been decided to consider the roof and the windows as also insulated (if the owners have decided to insulate their walls, they have probably/certainly made the efforts to insulate their roof and their windows).

- Windows (even if the wall is not insulated) are considered as insulated for building constructed after 1990.

3.1.3 Repartition hypotheses

Some of the simplifications presented in the previous paragraph (and more precisely the two last ones) can be justifiably considered as repartition hypotheses.

In reality, statistic data about Walloon residential building stock presented in the Chapter 2 does not permit to generate a complete arborescence. The creation of this latter requires the use of some repartition hypotheses. For example, no correlation exists between windows insulation and year of construction of the building (or between windows insulation and type of building).

Thus, as already mentioned, it has been decided to consider windows from building constructed after 1990 as insulated. For building constructed between 1946 and 1970 or between 1970 and 1990, repartition is the same than the one presented in *Figure 14* (19.1% insulated vs 80.9% not insulated). In order to reach the same repartition as the one presented in *Figure 14* for a type of building, repartition for windows from building constructed before 1945 is adapted (an Excel file was created to generate the arborescence).

Concerning the repartition of the roof insulation, the same problem that the one met with the windows insulation can be enounced: correlation between year of construction and/or type does not exist. The same method that the one presented in the case of the windows insulation is applied. Roof of building constructed after 1990 are considered as insulated. Another hypothesis is to consider as not insulated, roofs from building with windows and walls not insulated. Percentages of insulated roofs constructed between 1970 and 1990 and between 1946 and 1970 are respectively equal to 80%. In order to reach the same repartition as the one presented in *Figure 13* for a type of building, repartition for roofs from building constructed before 1945 is adapted (in view of the previous hypotheses and repartition presented in *Figure 13*, it is obvious that most of the non insulated roofs comes from building constructed before 1945).

All of these previously presented simplifications/repartition hypotheses allow reducing the number of investigated cases to 265 which is considered as satisfactory for this study. An example of 20 cases resulting from the arborescence is given hereafter, in *Figure 26*. The whole arborescence is given in Appendix D.

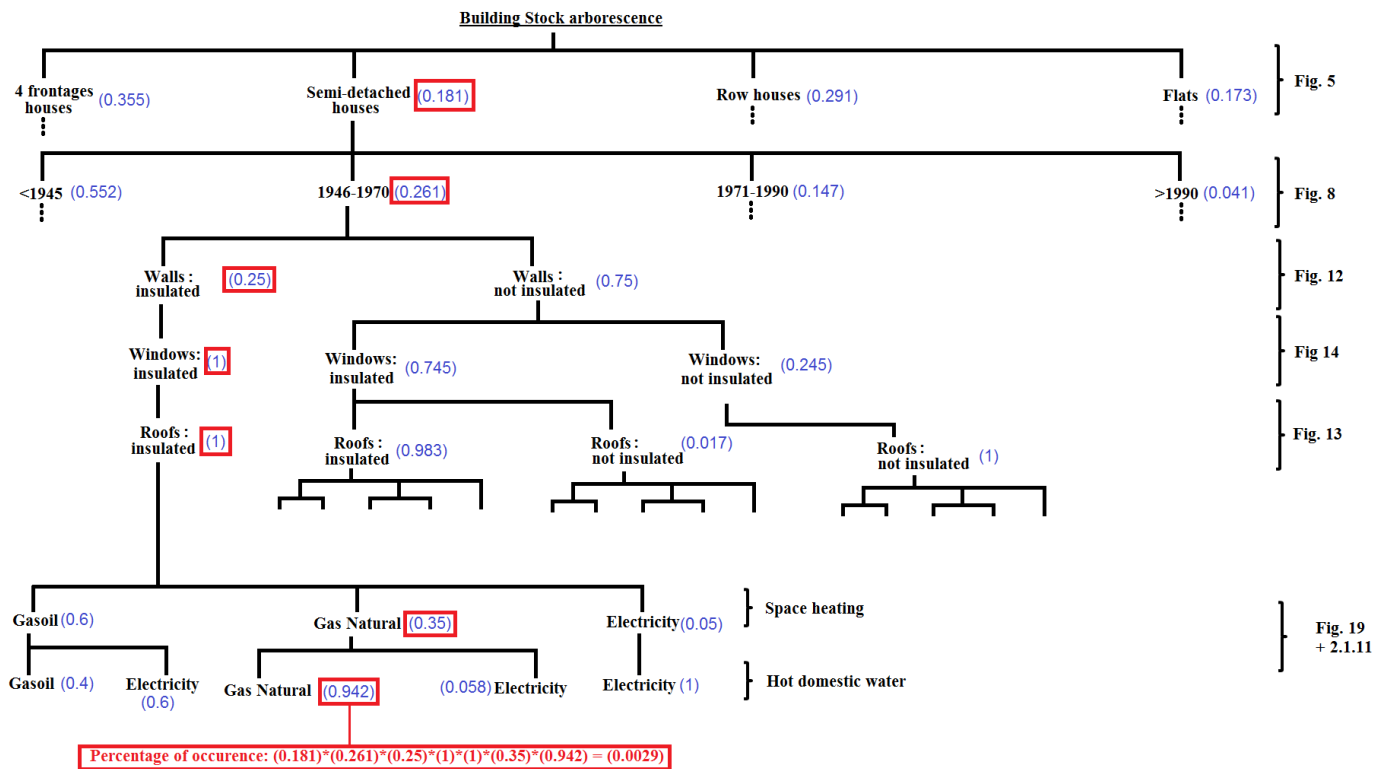


Figure 26 : Building stock arborescence

3.2 Arborescence: some interesting numbers

Some interesting numbers can be stressed by creating the Walloon building stock arborescence.

Among them and as an example, the most represented building (2.8% of the building stock) is a row house constructed with not insulated walls, insulated windows and roofs, and natural gas as an energetic vector (for both heating space and domestic hot water). The less represented one (negligible part of the building stock) is a row house constructed between 1971 and 1990 with not insulated walls and roofs, and insulated windows with natural gas for space heating and electricity for domestic hot water.

4 Envisioned Retrofit Options

In the field of residential building, a high number of retrofit options can be investigated. As already mentioned in paragraph 2.1.11, replacement of traditional light by diodes is a good way (and maybe the easiest) to reduce our consumption.

In the frame of this end-of-study project, envisioned retrofit options concern only envelope insulation and heating/electricity production system improvement.

More precisely, our study focuses on:

- walls, roof and windows insulation;
- replacement of the current heating production system by a condensing boiler or an heat pump. Investigations about solar panels will also be carried out.

We may extend this list of retrofit options, but it has been chosen to investigate the most widespread ones in the frame of this end-of-study work. As an example, we could investigate photovoltaic panel but this latter does not match to the frame our subject which concern energy consumption reduction relative to building. In this context, photovoltaic panels can be considered as a system of electricity production and investigated as such.

This section briefly presents some of the retrofit options investigated in this end-of-study work.

4.1 Insulation

There are several methods of wall insulation. We can classify them into 3 categories:

- “inside” wall insulation (a);
- “outside” wall insulation (b),
- “by cavity” wall insulation (c).

Examples of the three types of retrofit insulation are given in Figure 27:



Figure 27 : Types of wall insulation

4.2 Condensing boiler

A **condensing boiler** utilizes the latent heat of water produced from the burning of gasoil or natural gas, in addition to the standard sensible heat, to increase its efficiency.

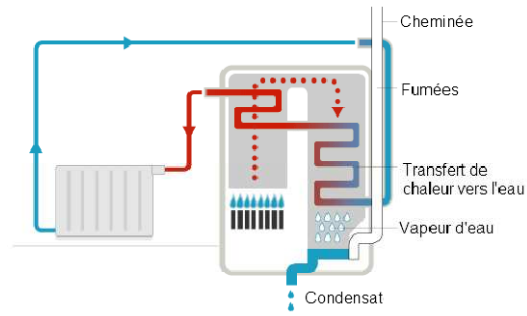


Figure 28 : Schematic representation of a condensing boiler (Makaire et al. (2010))

To take advantage of this technology, the supply water temperature has to be inferior to the dew-point temperature of the flue gas. As we can observe in Figure 29, the supply water temperature highly influences condensing boiler performance.

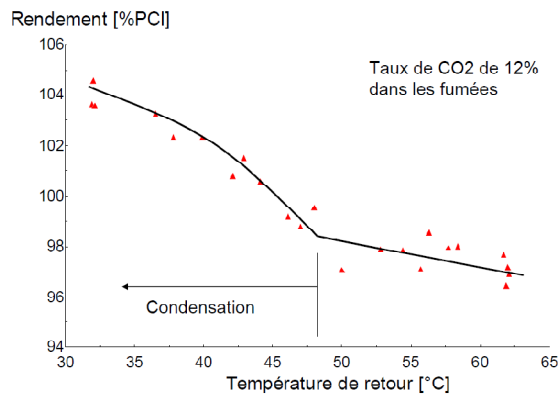


Figure 29 : Measured condensing boiler performances (Makaire et al. (2010))

From this fact, it is important to keep in mind that the emission system has to be designed to reach a supply temperature as low as possible.

4.3 Heat pump

According to Ashrae (2004), a **heat pump** is a machine or device that diverts heat from one location (the 'source') at a lower temperature to another location (the 'sink' or 'heat sink') at a higher temperature using mechanical work or a high-temperature heat source.

A heat pump is made of 4 main components:

- **A compressor:** its role is to raise the pressure of the refrigerant by means of a mechanical work. It operates thanks to an electrical motor.
- **A condenser:** is a heat exchanger. Its role is to allow the condensation (passage from the vaporous state to a liquid state) of the refrigerant. This latter release an amount of heat to a secondary fluid.
- **An expansion valve:** its role is to decrease the pressure of the refrigerant.
- **An evaporator:** is also a heat exchanger. Its role is to evaporate the refrigerant by allowing the absorption of an amount of heat from a secondary fluid.

A schematic representation of a heat pump is given in Figure 30:

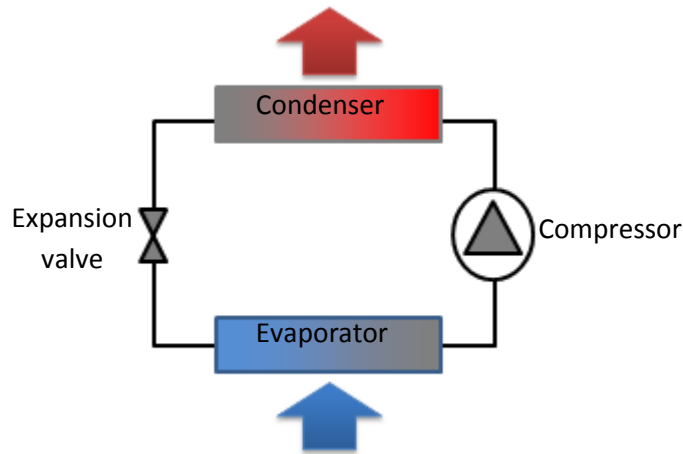


Figure 30 : Schematic representation of a heat pump

The P-h evolution of a refrigeration cycle is given hereafter:

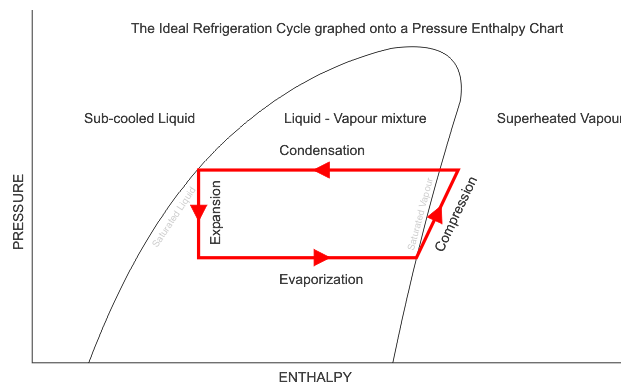


Figure 31 : P-h diagram of a heat pump cycle²

A four-ways valve can be added to the previous list of heat pump components. This component allows the reversibility of the cycle.

Heat pump performances are characterized by their Coefficient Of Performance (COP) when the device working in heat pump mode, or by their Energy Efficiency Ratio when the machine working in chiller mode.

COP and EER are defined by the two following equations:

$$COP = \frac{\dot{Q}_{cd}}{\dot{W}}$$

$$EER = \frac{\dot{Q}_{ev}}{\dot{W}}$$

4.4 Solar panels

Solar panels, also known as solar collectors, are placed on the roofs of buildings, oriented as much as possible towards the south. They receive heat from the sun and transmit it to an antifreeze fluid that circulates inside. This fluid goes through insulated pipes to a storage tank.

² Source : <http://www.refrigerationbasics.com>

This storage tank can be used to provide domestic hot water, or contribute to the central heating system. They are usually coupled to a conventional boiler in order to provide heat demand in every condition.

An example and schematic representation of the system is given in Figure 32:

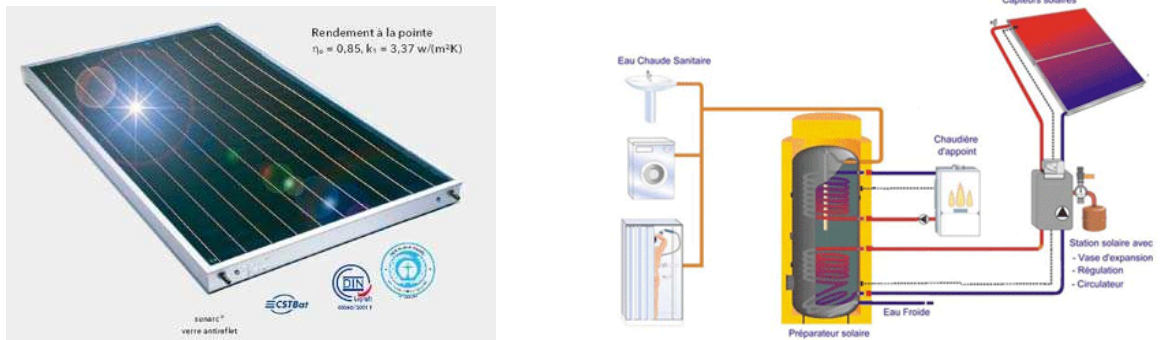


Figure 32 : Basic principle of thermal panels³

³ Source : <http://www.enersol.be>

5 Simulated annual consumption for existing building stock

5.1 CALE

Several existing software such as Opti-maison (Architecture et climat, 1998) or SISAL (which means in French “**S**imulation de **S**ystèmes **A**ccessibles en **L**igne”) are available to carry out this kind of study. It has been decided to choose the CALE (also called PEB which means in French “**P**erformance **E**nergetique des **B**âtiments”) Software for its easiness of use and also mainly for its small calculation time (less than one second) compared to SISAL Software (more or less one hour). SISAL Software is more precise (hourly-based dynamic simulation) than CALE Software (interpolation). This end-of-study work is based on many assumptions and, as already mentioned, these assumptions don't lead to precise calculus. Considering this fact, it would be ridiculous to prefer a long-time simulation precise Software.

5.1.1 Description of the 'CALE' software

'CALE' software is a tool able to estimate the annual consumption (and the cost relative to the annual energy consumption) for residential buildings. The tool is mainly intended for engineering consulting firm, architects, components manufacturers and retailers. The CALE Software was developed on 'Excel'.

The 'residential' (in opposition of 'tertiary') version obviously permits the analysis of all types of building:

- Single family houses,
- Row houses,
- Semi-detached houses,
- Flats.

5.1.2 Input data

Obviously, 'CALE' software requires a minimum number of inputs to run simulations:

- Surface of walls, windows, doors, floor, roof;
- Thermal transmittance, (in W/m^2K), is the rate of transfer of heat (in W) through one square meter of a structure divided by the difference in temperature across the structure. These values have to be specified for walls, windows, floor, roof...;
- Type of ventilation and the ventilation flow rate;
- Presence or not of a heat recovery device;
- Centralized or decentralized heating production;
- Type of heating production (heat pump, boiler, condensing boiler, ...);
- Type of emitters (radiators, heating floor,...);
- Type of heating production for domestic hot water;
- Cost of energy (electricity, gas, annuity, etc...);
- Air tightness;
- other inputs such as the number of sinks;
- ...

An example of an input data sheet from the CALE Software is given in Figure 33. This input data sheet concerns the geometric characteristic and the degree of insulation of the building.

A	Parois de déperdition	U_i (k_i) [W/m²K]	A_i [m²]
1	Fenêtres, tabatières, coupoles, et autres parois translucides		
2	Portes extérieures		
3	Murs extérieurs, façades		
4	Toitures (plates ou inclinées) ou plafonds supérieurs en dessous des espaces non protégés		
5	Planchers au-dessus de l'ambiance extérieure		
6	Planchers au-dessus d'espaces voisins non à l'abri du gel (vide sanitaire)		
7	Planchers au-dessus d'espaces voisins à l'abri du gel (caves)		
8	Planchers sur sol		
9	Murs extérieurs en contact avec le sol (murs enterrés)		
10.1	Parois intérieures en contact avec des espaces voisins non à l'abri du gel		
10.2	Portes intérieures en contact avec des espaces voisins non à l'abri du gel		
11.1	Parois intérieures en contact avec des espaces voisins à l'abri du gel		
11.2	Portes intérieures en contact avec des espaces voisins à l'abri du gel		
12	Totaux (Superficie de déperdition): $A_T = \sum A_i$ [m²]		242.62
B	Ponts thermiques	Ψ_{ij} [W/mK]	l_i [m]
13	suyant les définitions de la NBN B62-002		
14	Volume protégé du bâtiment ou du secteur 1 [m³]		
15	Surface de plancher chauffée A_{ch} [m²]		

Figure 33 : Example of an input data sheet from the "CALE" Software

5.1.3 Weather data

Walloon climate is supposed to be equivalent from one Walloon geographical zone to another since the small area considered (16844 km²). The Software does not permit the modification of the weather data (contrary to "SISAL" Software by example).

5.1.4 Output data

CALE Software is able to produce the following outputs:

- Annual total consumption due to the space heating, the space cooling (almost always equal to zero in residential building), domestic water heating and auxiliaries;
- Total cost relative to the consumption mentioned in the previous point;
- Total amount of final energy consumed;
- Total amount of primary energy consumed;
- Total amount of CO₂ produced per year.

An example of result synthesis sheet from the CALE Software is given in Figure 34:

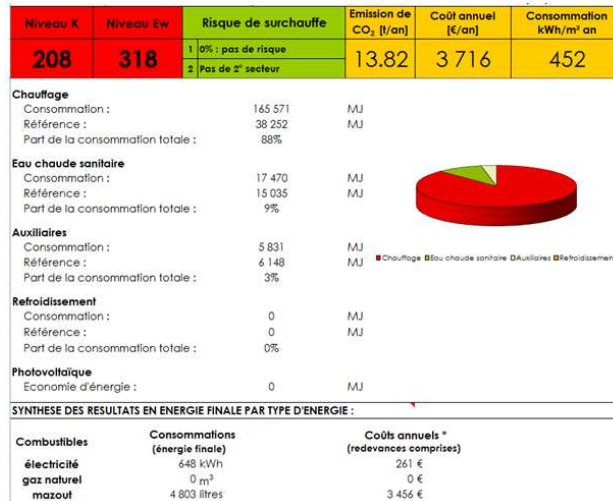


Figure 34 : Results synthesis sheet from the CALE Software

5.1.5 Assumptions concerning simulations

Such as for the creation of the building stock arborescence, statistic data and/or correlations (with year of construction and/or type of building by instance) do not exist about U value or heating production system efficiency. Assumptions concerning these values have to be done in order to realize our study.

The first type of assumptions concerns U value. We consider a U value for windows, walls and roofs of respectively 4.65, 3.14 and 3.13 for non insulated buildings constructed before 1945. We consider an improvement of buildings efficiency over the years and thus, a reduction of 20% and 40% of the previously presented U value for buildings respectively constructed between 1946 and 1970 and buildings constructed after 1970.

Concerning insulated components (walls, roofs and windows), we use mean value measured in situ on new constructions. These values are given by Legendries (2008).

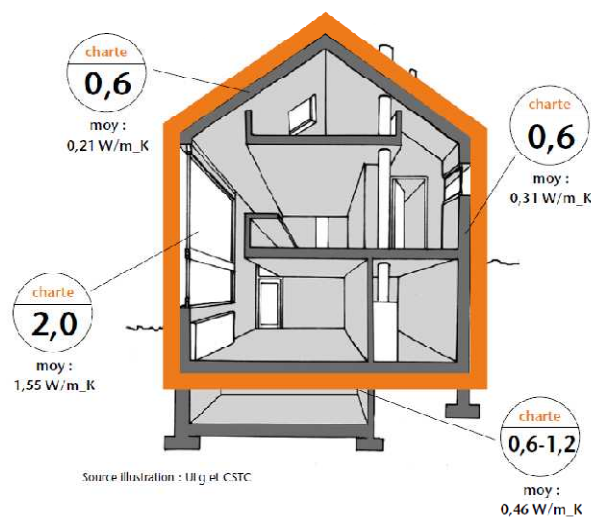


Figure 35 : Walls, windows and roofs U value for new building

The second type of assumptions concerns heating production system efficiency. Values of 77%, 85%, 87% and 89% have been chosen for buildings respectively constructed before 1945, between 1946 and 1970, between 1971 and 1990 and after 1990. A value of 85% has been chosen to characterize the emission system efficiency.

5.2 Validation of the developed method

The present part of the work consists in comparing results obtained from the exposed method and the actual building consumption.

According to Kints (2008), the mean average value for a residential house in term of total final energy is equal to 26.8 MWh. As shown in Figure 36, the part relative to the space heating is comprised between 75% and 78% of this total energy. The part relative to the domestic hot water is comprised between 10 and 12%. The mean annual consumption relative to space heating and domestic hot water in term of final energy is estimated (a top-down methodology is used: repartition of the total amount of consumed energy per sector) equal to 24120 MWh per year with 13.3% due to water heating (if we only consider these two energy vectors).

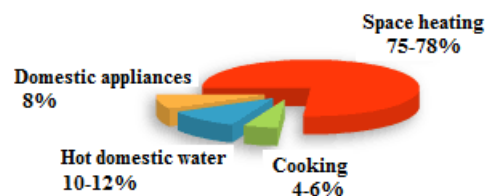


Figure 36 : Building consumption (DGSIE and ICEDD for the DGO4 (data from 2007))

Our simulations (total amount of 265) have permit to determine the annual consumption relative to domestic hot water and space heating for each type of building. These latter results have been average weighted by means of percentage of occurrence determined by the building stock arborescence. A mean annual consumption per Walloon residential building (in term of final energy) of 27558 kWh per year was found with 8.83% due to domestic hot water. It has been decided not to take into account ‘auxiliaries’ consumption (considered as domestic appliance). It has also been possible to determine the mean annual CO2 emission per house: 8.25 t/an.

Difference between official results and our results is less than 12.5% and difference between the repartition of domestic hot water is less than 5%.

Can we consider results from our simulations as satisfying and can we explain the difference between the two results?

In reality, differences between results from our calculation and official results can be explained by many reasons:

- Our method uses a high number of assumptions (geometric characteristics, evolution of U value over the year of construction, repartition assumptions, weather,...),
- “Official” method (top-down methodology) also uses a high number of assumptions,
- CALE Software overestimates annual consumption (practical comparison with measure in situ confirms this fact).

- Simulation-based consumption determination of a building is quite difficult (because of the influence of a high number of factors) and requires a calibration (adjustment of parameters of the model) to fit the reality. To have an order of magnitude, a comparison between actual consumption and simulation-based results as a function of the simulation runs (tertiary building) is given hereafter by Bertagnolio et al (2010) :

Calibration – simulation runs			
Run #	Error	Fuel	Electricity
0	MBE	-70.9%	-47.8%
(benchmark)	CV(RMSE)	22.2%	13.8%
1	MBE	-4.4%	-25.6%
(base case)	CV(RMSE)	4.2%	7.4%
2	MBE	-11.9%	-9.4%
	CV(RMSE)	4.5%	2.8%
3	MBE	-6.6%	-3.2%
(baseline)	CV(RMSE)	3.4%	1.6%

Figure 37 : Calibration vs simulation runs

Determination of the annual consumption of the building stock in term of final energy could be the object of a calibration by adjusting some of the parameters (such as U value or efficiency of heating production system) in order to fit the mean “official” consumption. As official method (top-down) also uses a high number of assumptions, it has been decided to not carry out this “calibration”.

In conclusion, we can consider results of our simulation as (very) satisfying. Moreover, as already mentioned, the aim of this study was not to determine with precision the mean consumption in the Walloon region, but to stress some trends resulting from a refurbishment.

5.3 Consumption vs type of building

Obviously, consumption is linked (among other things!) to the type of building. We can stress some trends relative to this latter fact. As an example, row houses consume less than 47% of energy compared to 4 frontages houses (average value). This can be justified by two major facts:

- Row houses are considered smaller (21.4 % in term of inhabitable area) than 4 frontages houses, in our simulations (146.6 vs 116.1 m² of mean inhabitable area: see *Table 1*);
- “Exterior” walls area (and thus windows area) is obviously smaller for row houses than for 4 frontages houses.

We can compare our results with the ones given by Renard (2008): he shows that a row house consumes 36% less than a 4 frontage houses (by considering the same inhabitable area for both types). Our results are in the same order of magnitude than the ones presented by Renard (2008).

If we transform these results in annual consumption per square meter (normalized consumption), we can observe that row houses are 26% more efficient than 4 frontages houses.

Obviously, we can extend this analysis to semi-detached houses (which consumes 24.4% less than 4 frontages houses) and apartments (which consumes 76% less than 4 frontages houses).

Apartments are the type of building the most efficient in term of energy consumption. This can be justified by the two previously mentioned facts (smaller inhabitable area and smaller “exterior” wall area) and one supplementary: in our simulations, roof area is consider equal to zero.

This first observation of our simulation results is highly important and a **major conclusion of this end-of-study work can already be enounced:**

- type of residential construction highly influences energy consumption. Obviously, the ranking is the following one: the best type of building in terms of energy efficiency is the apartment type, the second one the row house type, the third one is the semi-detached house type and the worth one is the 4 frontages house type.

As we can observe in *Figure 10*, major part of the new construction (after 1991) concerns 4 frontages houses. Better information and/or incentive policies should be given to urge builder to opt for row house type than 4 frontage house type.

6 Economic analysis

One of the aims of this end-of-study project is to evaluate the economical potential of different (combination of) retrofit options.

The present chapter is divided into several parts. First, investment costs related to each retrofit option are investigated. Secondly, energy costs are detailed. The third part of the section investigates different economic methods. One of them is chosen in order to carry out the study and compare the investigated retrofit options.

The comparison of the retrofit options in terms of economic analysis will be done in section 8.

6.1.1 Investment costs

Investment cost relative to each investigated refurbishment option corresponds obviously to one of the most important factor in an economic study. Prices given in this end-of-study come from an interview of one of the founders of “Enersol” and from different websites^{4 5} dedicated to professionals in the building sector. A list of indicative prices of windows is given in Appendix E.

The boiler chosen for this end-of-study work is the boiler ALU DOMUS (KV 120 20 SAI) from the brand Riello. This boiler is suitable for heating only or for heating and DHW. It has an average power of 12.5 kW with performances of about 102-108%. The purchase price is € 3750.

Just as the boiler, the chosen heat pump comes from the brand RIELLO. The model can operate in SINTESY reversible air conditioning in summer. Rated power is 6.6 kW for a COP of 3.9. Its purchase price is € 5535.

<u>Retrofit options</u>	<u>Price</u>
Wall insulation [€/m ²]	40-60 for int. insulation 60-75 for ext. insulation 65- by insufflations
Roof insulation [€/m ²]	50
Windows [€/m ²]	90
Condensing boiler [€]	3750
Heat pump [€]	5538
Thermal panels [€/m ²]	1000-1200

6.1.2 Energy costs

This section presents the cost of energy depending on the energetic vector (fuel, electricity and gas).

Fuel cost

The mean price of the Belgian heating fuel is given by Statbel (2011):

⁴ <http://www.livios.be/>

⁵ www.energieplus-lesite.be

	tva excl., en euro	% tva	tva incl., en euro
Gasoil de chauffage (1000ppm): minimum 2000l	0,5739/l	21	0,6944/l
Gasoil de chauffage (1000ppm): moins de 2000l	0,5946/l	21	0,7194/l
Gasoil de chauffage extra (50S) : minimum 2000l	0,5976/l	21	0,723/l
Gasoil de chauffage extra (50S): moins de 2000l	0,6182/l	21	0,748/l
50S = à faible teneur en soufre			

Figure 38 : Mean fuel cost (Statbel, (2011))

Concerning our study, just one price is considered and corresponds to the mean average value of the four previous values exposed in the tab: 0.7212 €/liter

Electricity cost

Since 2007, the Belgian electricity market is liberalized. The electricity cost depends on the supplier (their total number is fifteen according to the CREG which means in French “Commission de Régulation de l’Electricité et du Gaz”).

Actually, the electricity price is also dependant on the time schedule in the day. To be as precise as possible, it is important to notice that the total electricity price corresponds to the sum of several parts:

- Annual fixed fee and green contribution;
- Energy cost;
- Electrical network use cost (distribution cost + transport cost);
- Use tax, fee, contribution and excess load.

The repartition of the electricity price is important because the SISAL Software requires “Annual fixed fee” and “Electricity Cost for Night and Day” as inputs.

In order to have a control on the electricity price and to protect citizens against an eventual monopole, an organism called the CREG regulate the electricity market by fixing electricity price.

According to a major Belgian supplier (Luminus (2011)), the electricity cost disaggregation is given hereafter. The following prices take into account the value added taxes and consider a bi-hour electricity meter (the most widespread one). Concerning the electrical network use cost and the electricity meter renting, the presented price corresponds to the mean average of the prices of the several electrical network manager in the Walloon Region.

- Annual fixed fee = 117.53 [€/an];
- Day energy cost = 9.58 [c€/day kWh];
- Night energy cost = 5.91 [c€/night kWh];
- Green contribution = 1.06 [c€/kWh];
- Electrical network use cost = distribution cost + transport cost = 8.84 + 1.06 = 9.9 [c€/kWh];
- Electricity meter renting = 16.04 [€/an];
- Use tax, fee, contribution and excess load = 0.943[c€/kWh].

From these results, it is possible to disaggregate the electricity cost in three categories:

- Annual fixed cost = Annual fixed fee + Electricity meter renting
= 117.53 + 16.04 = 133.57 [€/an]
- Day electricity cost = Day energy cost + Green contribution + Electrical network use cost + Use tax, fee, contribution and excess load
= 9.58 + 1.06 + 9.9 + 0.943 = 21.48 [c€/day kWh]
- Night electricity cost = Night energy cost + Green contribution +

$$\begin{aligned} & \text{Electrical network use cost +} \\ & \text{Use tax, fee, contribution and excess load} \\ & = 5.91 + 1.06 + 9.9 + 0.943 = \underline{17.81 \text{ [c€/day kWh]}} \end{aligned}$$

An example of a real electricity bill disaggregation is given in Appendix B.

Obviously, each supplier offer is specific. For example, some of them give discount to their first or loyal customer. The previous presented values are the one used for our economic study.

More details about disaggregation of the electricity price are given by Lilien (2007).

Gas cost

The gas cost can be disaggregated in the same way that the electricity cost but the gas cost does not vary at different times of the day. CREG is also an actor in the gas market and regulates prices of the gas.

According to a major Belgian supplier (Luminus (2011)), the gas cost disaggregation is given hereafter. The following presented prices take into account the value added taxes. Once again, concerning the distribution cost and the gas meter renting, the presented price corresponds to the mean average of the several electrical network manager prices in the Walloon Region for a middle consumption.

- Annual fixed fee = 49.95 [€/an];
- Energy cost (transport included)= 4.29 [c€/kWh];
- Variable distribution cost = 1.45 [c€/kWh];
- Fixed distribution cost = 85.13 [€/an];
- Gas meter renting = 8.45 [€/an];
- Use tax, fee, contribution and excess load = 0.1805 [c€/kWh].

From these results, it is possible to disaggregate the gas cost in two categories:

- Annual fixed cost = Annual fixed fee + Fixed distribution cost + Gas meter renting = 143.53[€/an]
- Variable cost = Energy cost + Variable distribution cost + Use tax, fee, contribution and excess load = 5.92 [c€/kWh].

6.1.3 Incentive Policies: Subsidies

The list of subsidies can be divided into five categories:

- Insulation ;
- Equipment (Heating and/or cooling production);
- Audit ;
- Ventilation;
- Solar protection.

All Subsidies (for all types of residential building: new, passive and retrofitted houses) can be found on the website of the Wallonia government. Subsidies and Subsidies relative to our study are given in Appendix A.

6.1.4 Maintenance Costs

Maintenance costs concerning retrofit options are difficult to determine and several assumptions have been done:

- maintenance cost relative to air tightness and wall insulation are considered equal to zero ;
- maintenance costs relative to heating production system are supposed to be the same before and after refurbishment.

In conclusion, differences in term of maintenance costs, before and after refurbishment, are considered equal to zero for all investigated cases.

6.1.5 Investigation on several economic methods

In this section, several investment evaluation methods are presented and compared. Then, one of them is chosen in order to compare the several investigated retrofit options.

Pay Back Time (PBT) method

The **Pay Back Time** method is the simplest one: it evaluates “the period of time required for the return on an investment to "repay" the sum of the original investment”.

$$PBT = \frac{INV}{CF} [Year]$$

where

- **PBT** is the Pay Back Time in year;
- **INV** is the Investment Cost in €;
- **CF** is the (generated) Cash Flow in € per year. Obviously, retrofit house options do not allow generating cash flow (except for the co-generation and the photovoltaic panels by injecting current on the electrical network) but allow saving money in comparison to the initial situation. It is the latter amount of saved money compared to an initial situation that we should take into account for the analogy of the systems.

The two main drawbacks of the payback time method are, according to Bodson (2011):

- It ignores all benefits that occur after the payback period and, therefore, does not measure profitability.
- It ignores the time value of money.

Net Present Value (NPV) method or Net Present Worth (NPW)

This method was initially used in finance as an indicator of how much value an investment or project adds to the firm. Contrary to the Pay Back Time method, the **Net Present Value** method takes into account the time value of money by using the actualization principle. The method is the following one: the future value of the generated cash flow has to consider the actual value of money balanced by an actualization rate:

$$FV = AV * (1 + k)^t$$

With:

- FV: the Future Value;
- AV: the Actual Value;
- k: the Actualization Rate;
- t: the time considered (generally in years).

The Net Present Value method takes into account the initial investment and the cash flow generated during the period. The general definition is given by Bodson (2011):

$$NPV = -INV + \frac{CF_1}{(1+k)^1} + \frac{CF_2}{(1+k)^2} + \frac{CF_3}{(1+k)^3} + \dots + \frac{CF_t}{(1+k)^t} = -IC + \sum_{t=1}^n \left(\frac{CF_t}{(1+k)^t} \right)$$

With:

- IC : the Investment Cost ;
- CF_t : the Cash Flow generated at time “t” thanks to the investment;
- k: the actualization Rate;
- t: the time considered (generally in years).

Obviously, three situations can be met (Net Present Value Rule):

- **NPV>0**: investment is financially interesting and the retrofit project is worth taking on;
- **NPV<0**: investment is not financially interesting and the retrofit project should be rejected;
- **NPV=0**: investment does not create loose or gain. Other criteria (such environmental one) should be considered to decide if investment is interesting or not.

The aim of this end-of-study work is to evaluate the profit of a retrofit option versus an initial situation (non-retrofitted house). Soccia (2009) adapted the previous Net Present Value equation in order to compare several heat pumps systems to a reference one in non-residential building. Since we also compare different options to a reference one (non retrofitted house), the same equation could be used:

$$NPV = -INV_0 + \sum_{t=1}^n \left(\frac{F_1 * (1+j)^{(t-1)} + (E_1 + M_1) * (1+i)^{(t-1)}}{(1+k)^t} \right)$$

Where:

- **INV₀** : Investment Cost relative to the retrofit option considered (difference between the cost relative to the retrofit option considered and Subsidies) ;
- **F₁** : the difference of money spent the first year in fuel between the system considered and the reference system. This value can be either positive or negative ;
- **j** : the inflation rate on the fuel ;
- **E₁** : the difference of money spent the first year in electricity between the system considered and the reference system. This value can be either positive or negative ;
- **M₁** : the difference of money spent the first year in other expenses such as maintenance between the system considered and the reference system. This value can be either positive or negative ;
- **i** : general inflation rate. The same inflation rate will applied for the electricity and the other yearly costs ;
- **n** : the period considered ;
- **k** : the actualization rate.

Life Cycle Cost (LCC) method

Life Cycle Cost Analysis Handbook (1999) defines **Life Cycle Cost (LCC)** as “the total discounted dollar cost of owning, operating, maintaining, and disposing of a building or a

building system” over a period of time. “Life Cycle Cost Analysis” (LCCA) is an economic evaluation technique that determines the total cost of owning and operating a facility over a period of time.

The unit of the Life Cycle Cost is € and take into account the investment cost, the energy cost, the maintenance cost. These values are obviously balanced by economic parameters such as inflation and actualization rate. Soccal (2009) used an equation allowing the determination of the Life Cycle Cost for different heat pump systems. This latter equation is given hereafter:

$$Life\ cycle\ cost = INV_0 + \sum_{t=1}^n \left(\frac{C_{f,1} * (1 + j)^{(t-1)} + (C_{e,1} + C_{m,1}) * (1 + i)^{(t-1)}}{(1 + k)^t} \right)$$

Where:

- INV_0 : the initial investment at the start of the period of study. Obviously, the initial investment corresponds to the difference between cost relative to the retrofit option and Subsidies;
- N : the period considered;
- $C_{f,1}$: annual cost of the fuel for the first year;
- $C_{e,1}$: annual cost of the electricity for the first year;
- $C_{m,1}$: annual cost of other items for the first year (mainly maintenance);
- j : fuel inflation;
- i : general inflation.

6.1.6 Economic Parameters

Economic parameters used in our economic study are the following ones (given by Soccal (2009)):

- Period considered is chosen equal to 20 years because this is the value used in economic study related to building or building system. Renard (2008) assumed a life cycle of 25 years for his study ;
- Actualization rate is in a range comprised between 4% and 8% in energy saving activity according to Alexandros (2007). The mean value (6%) will be chosen for our economic study ;
- According to Stanley et al. (2000), fuel inflation is comprised between 3% and 6%. The latter mean value is considered in this end-of-study work (4.5%);
- According to Rushing et al. (2006), the value of the electricity inflation is taken at 1.6%.

6.1.7 Choice of the economic study

In order to compare retrofit options from an economic point of view, the net present value method has been chosen. This fact is justified by the previously presented advantages of this method. Moreover, it is the most widespread method to carry out this kind of study.

7 Environmental analysis

The present section presents the philosophy concerning the environmental analysis by presenting the two most used environmental indicators: the consumed primary energy and the CO₂ emissions.

7.1.1 Final and primary energy

In this kind of study, two types of energy have to be considered: the annual final energy and the annual primary energy. A definition of both of these energies was found on Isover website:

'Final energy is a form of energy available to the user following the conversion from primary energy. Final forms of energy include gasoline or diesel oil, purified coal, purified natural gas, electricity, mechanical energy, etc... When going from primary energy to final energy, we must take into account the efficiency of the conversion device (typically a power plant in the case of electricity), and, as the case may be, of transportation. Generally speaking, a country always has higher primary energy consumption than final energy consumption, the difference between the two representing the losses in the energy system.'

In the frame of this work, the primary energy coefficient (the ratio between final and primary energy) is chosen equal to 1 in the case of natural gas and fuel. Primary energy coefficient relative to electricity is the one stored in the CALE Software and equal to 2.5. It corresponds to the European coefficient according to Bertagnolio et al. (2010) and this is the one used in the PEB program (which means in French 'Performance énergétique des bâtiments').

7.1.2 CO₂ emissions

In building energy sector, CO₂ emissions can be produced on site (by heating or cooling production system using fuel or natural gas) or on the place of the power plant that provides electricity to the building systems.

In order to compare our retrofit option versus the initial situation in terms of CO₂ emissions, it is important to determine the quantity of CO₂ emitted:

- by kWh of consumed fuel;
- by kWh of consumed natural gas;
- and by electricity kWh.

These quantities are called the CO₂ emission coefficient. Obviously, the electricity CO₂ emissions coefficient highly depends on the power plant type (nuclear, hydraulic, combined cycle,...) used in the country.

For example, the smallest European CO₂ emission coefficient is the Swedish one (0.044 [kgCO₂/kWh]) according to Andre et al. (2008). This can be explained by the fact that electricity is mainly provided by nuclear (42.3% in 2008 according to IEA.org) and hydraulic (46.1% in 2008 according to IEA.org) power plants. France with its huge nuclear park is second in the ranking.

Greece is the country with the highest CO₂ emissions coefficient (0.814 [kgCO₂/kWh]) according to Andre et al. (2008). This high value can be explained by a large number of coal power plants (52.3% of the total production in 2008).

Belgian CO₂ emission coefficient for electricity is 0.268 kgCO₂/kWh according to Andre et al. (2008).

CO₂ emission coefficient relative to burning natural gas is equal to 0.231 kgCO₂/kWh according to Bertagnolio et al. (2010).

Concerning the CO₂ emission coefficient generated by burning fuel is equal to 0.272 kgCO₂/kWh, according to ADEME (2005).

According to the previous source, in Belgium, CO₂ emission coefficient for each type of energetic vector are quite close.

Value concerning these CO₂ emission coefficients for electricity differs from one source to another. Assumptions relative to the determination of each of the CO₂ coefficient obviously generate different value. It is also very difficult to choose the CO₂ coefficient for this kind of study: should we choose the Belgian CO₂ emission coefficient for electricity or the European one (by considering the European electrical network as interlinked)?

In the frame of this end-of-study project, we used values previously stored in the CALE Software. Concerning the CO₂ emission coefficient for the natural gas and the fuel, values are the same than the previously mentioned ones.

On the other hand, CO₂ emission coefficient for electricity (the most delicate one to determine) is chosen equal to the same as used in the PEB program (which means in French 'Performance énergétique des bâtiments'): 0.713kg/kWh.

It would be interesting to investigate and compare other type of mix for the determination of the CO₂ emission coefficient for electricity. In reality, different points of view exist. As an example, you can take a supplier mix by only focusing on the power plant of a specific producer. This approach could be interesting in the frame of the study for a precise case (as an example, for the determination of the annual consumption of an University). Another point of view consists in considering the production of every new kWh of produced electricity as renewable. It is called the renewable mix.

Comparison of the different retrofit options in term of environmental analysis will be done in section 8.

8 Energy consumption reduction resulting from retrofit options envisioned

Our investigation concerning the retrofit options can be divided in two steps:

- The first step focuses on insulation;
- The second step focuses on the heating production system.

The first section of this chapter evaluates the global impact of a (or a combination) retrofit option(s) from a macro point of view.

8.1 Global reduction of the residential sector: “macro” point of view

One of the aims of the construction of the building arborescence is to point out some global trends by evaluating energy reduction resulting from the application of a retrofit option.

This can be done by balancing simulation results by percentage of occurrences. The method/philosophy applied in this end-of-study work could be a decision tool for our politic leader.

Thus, thanks to the building arborescence, it is possible to determine global final energy reduction of the Wallonia building sector by assuming a total or partial insulation of each type of building and without changing the current heating system.

Mean value of annual consumption (dedicated to space heating and domestic hot water) and CO2 emissions per Wallonia residential building has been determined in 5.2:

- 27558 kWh (in term of final energy) per year;
- 128770 MJ (in term of primary energy) per year;
- 8.25 tCO2/an.

8.1.1 Windows insulation

This section presents the global reduction of the Walloon building sector by assuming the insulation of the total amount of “non-insulated” windows. Mean annual consumption and CO2 emission per residential building would become:

- 26010 kWh (in term of final energy) per year;
- 122368 MJ (in term of primary energy) per year;
- 7.84 tCO2/an.

Insulation of the total amount of non-insulated windows only decrease our final energy per year by 5.6%, our primary energy by 4.9% and our CO2 emissions by 5% (compared to the current situation).

8.1.2 Roofs insulation

This section presents the global reduction of the Walloon building sector by assuming the insulation of the total amount of “non-insulated” roofs compared to the current situation. Mean annual consumption and CO2 emission per residential building would become:

- 23589 kWh (in term of final energy) per year;
- 110736 MJ (in term of primary energy) per year;
- 7.14 tCO2/an.

Roof insulation represents a global reduction of 14.40% in term of final energy, 14% in term of primary energy and 13.45% in term of CO2 emissions. These results are superior to the ones presented in the previous section.

8.1.3 Walls insulation

This section presents the energy saving compared to the current situation by assuming the insulation of the “non-insulated” walls of the Walloon building stock. The mean annual consumption and CO₂ emission per residential building house would become:

- 18954 kWh (in term of final energy) per year;
- 90249MJ (in term of primary energy) per year;
- 5.837 tCO₂/an.

Insulation of the non-insulated wall of the current Walloon building stock arborescence permits savings of 31.2% in term of final energy, 29.9% in term of primary energy and 29.25% in term of CO₂ emissions.

8.1.4 Conclusion about the potential of the three types of insulation

This section presents some conclusions about results previously presented. The first conclusion to be enounced concerns the important potential of energy saving resulting from the wall insulation (compared to the two others).

Concerning windows insulation, results stress a little potential of energy saving, which could seem surprising. This fact can easily be explained by the simple observation of the statistic data about the Walloon building stock. In reality, the major part of the Walloon building has already insulated windows (see *Figure 14*). Moreover, the difference between the U value of “non-insulated” windows and the U value of insulated window are inferior than the one observed for the wall or the roof insulation. Windows considered area is also inferior to the wall area, for example. All these facts can explain the little potential of energy saving of windows insulation.

However, if we take a look to the list of subsidies, we can observe that subsidies concerning windows retrofit options constitute a larger amount of money than the ones concerning walls or windows retrofit options. From this fact, repartition about incentive policies concerning insulation has to be reconsidered.

8.1.5 Total insulation

If we consider a complete insulation of the entire building stock, mean annual consumption per residential building become:

- 13437 kWh (in term of final energy) per year;
- 65 813 MJ (in term of primary energy) per year;
- 4.317 tCO₂/an.

As we can observe, insulation of the whole Wallonia building stock could permit to save 48% of final energy and 48.8% of primary energy and to reduce CO₂ emissions of 51%.

These results stress the fact that (total) insulation have to be the first step of any refurbishment (replacement of the current heating system by a better one will never permit to save as much energy as the insulation could).

If we take a look to the list of subsidies (Appendix A), we can observe that there are no priorities to retrofit options. One of the improvements of the system of Subsidies would be to consider total insulation as a priority retrofit option. From this fact, an audit could be interesting to be carried out to determine the degree of insulation of each Subsidies seeker building.

8.1.6 Heat pump

This section concerns global reduction in term of energy saving, if the replacement of the current system by a heat pump is envisioned. A seasonal annual COP of 3 is used for our simulation. DHW is also provided by the heat pump.

Annual results are given hereafter:

- 8440 kWh (in term of final energy) per year;
- 75959 MJ (in term of primary energy) per year;
- 6.01 tCO₂/an.

The replacement of all of the current systems by heat pump would lead to reduction of 69% in term of final energy, a reduction of 41% in term of primary energy and 27% in term of CO₂ emissions.

8.1.7 Condensing boiler

Replacement of current heating system production by condensing boiler is investigated in the present chapter. Energetic vector concerning the space heating are supposed to be the same before and after the replacement of the current heating system; except for electrical heating system which is considered to be natural gas after the refurbishment. Annual performance of condensing boiler is supposed to be equal to 102%. Condensing boiler is also supposed to provide hot domestic water.

Results from simulation are given hereafter:

- 22017 kWh (in term of final energy) per year;
- 97357 MJ (in term of primary energy) per year;
- 5.57 tCO₂/an.

The replacement of all of the current system by heat pump would lead to reduction of 20.1% in term of final energy, a reduction of 24% in term of primary energy and 32.5% in term of CO₂ emissions.

8.1.8 Conclusion about potentials of the two type of heating production system investigated

In term of final energy and primary energy, replacement of the current system by heat pump seems more interesting compared to the condensing boiler option. But in term of CO₂ emission, the condensing boiler option seems to be more efficient.

Assumption concerning the total amount of CO₂ emitted per kWh elec (see 7.1.2) is very important to conclude to a better system in term of CO₂ emissions. If we had chosen the hypothesis of 0.268 kgCO₂ per kWh elec, conclusions would have been different.

A reflection about the actual incentive policy could also be enounced in view of results. Subsidies concerning condensing boiler are more than three times smaller. Once again, we

could enounce the same conclusion that the one presented for insulation: a better repartition of subsidies between the two heating system has to be re-considered.

8.1.9 Solar panels

Investigation about solar panels is different from the two other ones since it does not consider the replacement of the current heating system production. It considers the solar panels as an additional heat production source. For our simulations, we consider 5 square meters of solar panels which faces to the south with a horizontal angle of 35°C. Solar panels are only dedicated to the DHW.

Simulations give the following results:

- 26304 kWh (in term of final energy) per year;
- 118634 MJ (in term of primary energy) per year;
- 7.66 tCO₂/an.

Installation of solar panels would lead to reduction of 4.5% in term of final energy, a reduction of 7.8% in term of primary energy and 7.1% in term of CO₂ emissions.

Subsidies concerning installation of thermal panels is 1600 € for 5 m². Once again, compared to subsidies relative to condensing boiler, this amount of money is three times bigger.

8.2 Economic comparison

The present section determines the economic viability of each system by estimating the total costs over a period of simulation. Each (combination of) retrofit option is compared in term of Net Present Value to each non-refurbished building case (defined in the previous chapter: building stock arborescence). So this economic study is interesting at many levels:

- it could help owners deciding whether a house retrofit should be envisaged or not, and determine the best retrofit option to be envisaged by identifying his type of building in the arborescence,
- it could determine an order of magnitude of the initial investment cost of each investigated retrofit option,
- it could determine the best retrofit option as a function of initial available budget.

Net present value has been determined for each investigated cases thanks to formula and economical assumptions presented in section 6.1.5. NPV calculated for each investigated cases are all positives. Once again, this economical study was performed thanks to EES Software.

Obviously, the higher NPV concerns worth residential building in term of energy efficiency: the ones with bad insulation and electrical heating production system. Since electricity is the more expensive energetic vector, building owners with this kind of production have interest to quickly consider retrofit options presented in this end-of-study.

All results from this economical investigation are given in Appendix F. These latter can constitute a reference directory to permit to citizen to have an order of magnitude of the NPV of their investment (by identifying their type of building in the arborescence).

An interesting remark can be enounced in view of results presented in Appendix F. All of the investigated retrofit options concerning the envelope improvement present a NPV superior to

zero (with or without subsidies). It is not the case of heat pump and condensing boiler retrofit options.

Conclusions concerning the profitability of heat pump are different: sometimes, the NPV is inferior to zero. It happens when the natural gas heating production system is replaced. In reality, this can be easily explained by the difference between electricity and gas cost.

8.3 MCMA method

What is the best configuration to choose?

Answer is not obvious. It depends on several criteria: economical criteria, environmental criteria, social criteria and technical criteria. In this end-of-study work, we only focus on the two first mentioned ones but the others are also important. A deeper analysis of each retrofit (or combination) option could be investigated under the MCMA “Multi Criteria Methods Analysis”. An interesting introduction of this method applied in energy field and many references on the subject are given by Colen (2010).

8.4 Improvement of the developed tool

An improvement of the presented method could be the development of an algorithm able to determine the best retrofit options or combination of retrofit options for each investigated cases.

Inputs of this algorithm will be the type, the year of construction of the building, the initial investment, the degree of insulation and the energetic vector for the space heating and the domestic hot water. These parameters are very easy to determine for each user of the algorithm.

Consumption relative of the investigated building will be stored in a data base thanks to results from our building arborescence.

Algorithm will be able to determine the best solution for each investigated case according to two criteria: NPV and CO₂ emission. This method which requires simple inputs could help citizens to have an idea of the best retrofit options for their houses as a function of their initial investment. This algorithm could be considered as a “pre-audit” residential building.

The integration of the MCMA method to our algorithm could also be considered as an improvement.

9 Conclusions and perspectives

This present end-of-study work focuses on the study of the Walloon region building stock. It proposes a **bottom up method** to determine the mean annual consumption of residential building. This bottom up method is based on the creation of a **building stock arborescence**.

Each kind of building composing the arborescence is characterized according several criteria:

- Type of building (4 frontages, semi-detached house, row houses, apartments);
- Year of construction;
- Degree of insulation (walls, roofs, windows);
- Energetic vector (for both domestic hot water and space heating).

Annual consumption relative to space heating, domestic hot water and auxiliaries have been determined by means of the use of building simulation software for each type of building (total amount of **265 simulations**). Thanks to the percentage of occurrences and the annual consumption for each type of building, it has been possible to determine a **mean annual final energy consumption per residential building house** from the Walloon region. This value has been compared with (“official”) results from a top down method. Differences between these two methods are considered as **very satisfying** (see 5.2) in the building sector (12.5% of difference in the space heating prediction and a difference of 5% in the repartition of the domestic hot water).

First **major conclusion** (see 5.3) of this end-of-study results from the simple observation of the mean annual consumption of each type of building (4FH, SDH, RH and apartments): 4 frontages houses are the worth type of building in term of energy consumption (principally because of two major factors: its larger inhabitable area and its larger “exterior” wall area compared to other types of building). As an example, row houses consume 47% less than 4 frontages houses. Obviously, the best type of building in term of energy consumption is the apartment (smallest inhabitable area, smallest exterior wall area and roof area considered as zero). Unfortunately, the main part of new constructions is 4 frontages houses...

Once the method validated (see 5.2), **investigations about retrofit options** were carried out. First, we consider retrofit options concerning insulation of the building. Secondly, we focus the improvement/replacement of the heating system production.

Some **reflections concerning the actual incentive policies** have been enounced in the sections of this end-of-study project.

The first one concerns new buildings. Major part of them is **4 frontages** houses. However, this type of building is the **worth one in term of energy efficiency**. A better information or incentive policies should be given to urge builder to opt for row house (or apartment) type than 4 frontage house type (see 5.3).

The best way to economize on energy is to reduce energy demand. Thus, insulation seems to be the best way to improve building efficiency. From this fact, a second reflection about incentive policies can be enounced. This latter concerns the **non-priority** given to the subsidies. One of the improvements of the system of subsidies would be to consider **insulation (and especially wall insulation) as a priority retrofit option** (no improvement of heating production system could be as efficient as the insulation). Subsidies relative to heating production system could be **balancing by the degree of envelope performance** of the

building. Moreover, urging people to improve their envelope before their heating production system would permit to **decrease initial investment relative to heating system production** (lower nominal heating power of the device). From this fact, an **“obligatory” audit** (before replacing the current heating system) could be interesting to determine the degree of insulation of each subsidies seeker building (see 8.1.5).

A third reflection about incentive policies is also enounced. This latter reflection concerns the repartition of the **subsidies concerning insulation** (see 8.1.4). Environmental impact relative to the replacement of windows would permit to save only 5% of energy. Thus, **compared to roof and wall insulation, it represents a little potential of energy saving**. However, subsidies concerning windows retrofit options constitute a larger amount of money than the ones concerning walls or windows retrofit options. From this fact, **repartition about incentive policies concerning insulation has to be reconsidered**.

Same conclusions can be enounced in the view of simulation results concerning the **installation of heat pump, condensing boiler and solar panels**. Subsidies relative to condensing boiler are three times smaller compared to the ones concerning solar panels. However, replacement of the total current heating production system by condensing boiler could permit to reduce our CO₂ emissions of 32.5%. Installation of solar panels in every residential building could reduce our CO₂ emissions of 7.1%. Having said that, it is quite difficult to compare both systems and several points of view exists. **The long term one justifies the current incentive policy** by considering solar panels as a “passive” system and renewable. The **short term** one evaluates the direct impact of the installation of condensing boiler. From this point of view, incentive policy **has to be reconsidered**.

An economic study was also carried out in this end-of-study. In reality, each retrofit option was economically evaluated by means of the **Net Present Value** method for each case from the arborescence. Results from this investigation are given in **Appendix F**. These latter can constitute a reference directory to permit to citizen to have an order of magnitude of the NPV of their investment.

Moreover, some interesting subjects are tackled in the frame of this end-of-study project:

- The **repartition of the electricity and natural gas price** (see 6.1.2);
- A comparison of **different economical method** (see 6),
- An investigation on **retrofit initial investment** concerning;
- An introduction to the **MCMA** method (see 8.3),
- An investigation on the determination of the **kgCO₂/kWh_elec** (see 7.1.2).

As already mentioned, the method presented in this end-of-study work **could be improved** at many levels:

- Statistic data could be more precise (degree of insulation, correlation between year of construction and degree of insulation, and so on...). This improvement requires a **new national study**;
- Assumptions presented in this study could be justified by **in-situ measurements**;
- Arborescence could take into account a **higher number of cases** (see 3.1.1);
- An **algorithm** could be develop to determine the best retrofit options as a function of the initial investment (see 8.4);
- Taking into account the **ventilation issue**;
- **More retrofit** options could be investigated;
- **A life cycle analysis** of the different retrofit options could also be investigated.

To conclude, this end-of-study presents a method/philosophy of investigation which permits to stress/confirm some trends related to the application of some retrofit options in the field of the building sector.

This latter method could be used at many levels:

- by citizens by identifying their type of building and thus evaluating the economical potential of some retrofit options for their residential house;
- by politic leaders to evaluate the application of retrofit options from a macro point of view and thus adapting their incentive policies.

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Appendix A

List of Subsidies concerning refurbishment and granted by the Walloon government is given hereafter. This list can be found on the energy web portal of the Walloon region¹:

	<u><i>Affectation</i></u>	<u><i>Subsidies and Subsidies</i></u>	<u><i>Restriction</i></u>	<u><i>Extra-Subsidies</i></u>
<u>Insulation</u>				
Roof insulation realized by the citizen	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 1996	<ul style="list-style-type: none"> - 5€/m² for base case - 6€/m² for modest seeker[*] - 7€/m² for precarious seeker^{**} 	Max.: 100 m ² for single house Max.: 200m ² for other type of building	Extra-subsidy of 3€ if used material is natural
Roof insulation realized by an building contractor	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 1996	<ul style="list-style-type: none"> - 10€/m² for base case - 12€/m² for modest seeker[*] - 14€/m² for precarious seeker^{**} 	Max.: 100 m ² for single house Max.: 200m ² for other type of building	Extra-subsidy of 3€ if used material is natural
Wall insulation	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 1996	<u>Wall insulation (inside)</u> <ul style="list-style-type: none"> - 20€/m² for base case - 24€/m² for modest seeker[*] - 28€/m² for precarious seeker^{**} <u>Wall insulation (in wall cavity)</u> <ul style="list-style-type: none"> - 10€/m² for base case - 12€/m² for modest seeker[*] - 14€/m² for precarious seeker^{**} <u>Wall insulation (outside)</u> <ul style="list-style-type: none"> - 30€/m² for base case - 36€/m² for modest seeker[*] - 42€/m² for precarious seeker^{**} 	Max.: 120 m ² for single house or flat Max.: 240m ² for other type of building	Extra-subsidy of 3€ if used material is natural
Floor insulation	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 1996	<u>Floor insulation (cave)</u> <ul style="list-style-type: none"> - 10€/m² for base case - 12€/m² for modest seeker[*] - 14€/m² for precarious seeker^{**} <u>Floor insulation (on paving stone)</u> <ul style="list-style-type: none"> - 27€/m² for base case - 30€/m² for modest seeker[*] - 35€/m² for precarious seeker^{**} 	Max.: 80 m ² for single house Max.: 160m ² for other type of building	Extra-subsidy of 3€ if used material is natural

Double glazing	Houses built 15 years ago	<ul style="list-style-type: none"> - 45 €/m² for base case - 50 €/m² for modest seeker* - 60 €/m² for modest seeker* 	Max: 40 m ² per building	
Equipment				
Installation of a condensing boiler	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 2010 <u>and</u> Every building	<p>400€ only for high efficiency boilers + extra-subsidy in function of the heating power:</p> <p>>50kW : 400€ + 25€ per extra-kW</p> <p>>150kW : 2900€ + 12€ per extra-kW</p> <p>>500kW : 7100€ + 6€ per extra-kW</p>	Max.: 12500€ per installation	<p>Extra-subsidy of 200€ if an audit is previously realised</p> <p>50€ if there is a functional regulation</p>
Installation of a natural gas water heater	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 2010 <u>and</u> Every building	<p>75€ (flow rate < 1l) or 125€ (flow rate > 10l)</p> <p>25€/kW for condensing water heaters</p>	Max.: 12500€ per installation	
Installation of aerotherms, warm air generators and radiant devices	Every building	Between 12.5 and 25€/kW, depending of the type of the device	Max.: from 6250 to 12500€ depending of the type of the device	
Installation of an heat pump dedicated to domestic hot water	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 2010 <u>and</u> Every building	750€		
Installation of an heat pump dedicated to space heating	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 2010 <u>and</u> Every building	1500€	Max.: one subsidy for space heating or combination of space heating and domestic hot water per building	
Installation of an heat pump combining domestic hot water and space heating	Every building whose acknowledgement of receipt of building permit is previous than 1 st	2250€	Max.: one subsidy for space heating or combination of space	

	December of 2010 <u>and</u> Every building		heating and domestic hot water per building	
Installation of micro cogeneration	Every building	20% of the bill	Max.: 15000€	
Installation of an automatic biomass boiler	Every building	1750€ + extra-subsidy in function of the heating power: >50kW : 1750€ + 35€ per extra-kW >100kW : 3500€ + 18€ per extra-kW >500kW : 10700€ + 8€ per extra-kW	Max.:	
<u>Audit</u>				
Realization of an energetic audit	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 1996	60% of the bill	Max.: 360€ for a single family house Max.:1000€ for another type of building	
Realization of an energetic audit by thermography	For every buildings	50% of the bill	Max.: 200€ for a single family house Max.:700€ for another type of building	
<u>Ventilation</u>				
Installation of an heat recovery ventilation device	For every type of building	75% of the bill	Max.: 1500€	
<u>Solar protection</u>				
Exterior solar protection	Every building whose acknowledgement of receipt of building permit is previous than 1 st December of 1996	15€/m ² of protected glazing	Max.: 15€/m ² per	

* Precarious seeker: income inferior to 12000€/year for isolated people and 16400€/year for couple (married or not)

* Modest seeker: income comprise between 12000 and 24100 €/year for isolated people and between 16400 to 30100€/year for couple (married or not)

¹<http://energie.wallonie.be/fr/Subsidies-energie-nouveautes-a-partir-du-1er-mai-2010.html?IDC=6302&IDD=23470>

Appendix B

Consommateurs résidentiels

Luminus Actif Electricité (février 2011)

Conditions particulières (REF EA1CS1.7) Valable pour les raccordements avec relevé de compteur annuel, d'une capacité < 56 kVA et/ou avec une consommation de gaz < 1 Gwh. Dans le cas contraire, Luminus se réserve le droit d'adapter votre tarif.

Informations concernant votre tarif

Les montants mentionnés ont été arrondis. La redevance fixe et le coût de l'énergie ont été calculés sur base des index mensuels connus les plus récents (janvier 2011). Ne = 1,5734 et lem = 1,9118. Formules de tarifs pour la redevance fixe: jour = 56,38 x Ne, nuit = 18,32 x Ne. Formules de tarifs coût de l'énergie: jour (compteur de jour) = 3,00 x Ne + 2,05 x lem, jour (compteur de jour et de nuit) = 3,59 x Ne + 2,05 x lem, nuit = 1,71 x Ne + 1,89 x lem, exclusif nuit = 1,47 x Ne + 1,89 x lem. Où lem = 0,684633 + 0,03856 x DAHS11 + 0,006321 x Belgex311 + 0,002479 x CosIS11. La méthode de calcul, ainsi que les valeurs mensuelles de l'em et de ses composantes sont publiées sur le site www.luminus.be. L'index Ne est défini dans l'arrêté ministériel du 12/12/01 et est publié tous les mois sur le site www.creg.be. Nous nous réservons le droit d'utiliser de nouveaux paramètres ou composantes pour calculer la formule du prix ou de l'em si les paramètres actuels viennent à changer, sont supprimés ou s'ils devaient ne plus être disponibles. Dans ce cas de figure, Luminus s'efforcera de maintenir le prix moyen au même niveau.

Lors du décompte de votre consommation effective, la redevance fixe et le coût de l'énergie sont calculés sur base des index mensuels applicables durant la période pour laquelle vous êtes facturés. Les montants mentionnés dans votre bilan récapitulatif peuvent dès lors varier par rapport aux prix ci-dessous. Les coûts d'utilisation des réseaux en question sont ceux approuvés par la CREG, au moment de l'impression de la présente liste de prix. Les taxes, redevances, cotisations et surcharges sont mentionnées telles que connues le 1er février 2011. Les éventuelles modifications des coûts d'utilisation des réseaux, taxes, redevances, cotisations et surcharges vous seront toutes entièrement refacturées au prix coûtant. Si vous optez pour une formule de prix indexée, les tarifs mentionnés sont ceux en vigueur au moment de la formulation de l'offre. Ces tarifs peuvent modifier et facturer en fonction de l'évolution des paramètres composant la formule tarifaire indexée.

Tarifs

Votre tarif électricité se compose de 3 parties, chacune comprenant la TVA:

1. Redevance annuelle fixe, coût de l'énergie, contribution énergie verte et coûts cogénération

	Redevance fixe (€/an)	Coûts de l'énergie (c€/kWh)		
		Jour	Nuit	Excl. nuit
Compteur de jour	88,71	8,65	-	-
Compteur de jour et de nuit	117,53	9,58	5,91	-
Compteur de jour et exclusif nuit	88,71	8,65	-	5,55
Compteur de jour, de nuit et excl. nuit	117,53	9,58	5,91	5,55

	Flandre	Wallonie
Contribution énergie verte 2011 (c€/kWh) (*)	1,06	1,63
Coûts cogénération 2011 (c€/kWh)	0,28	-

2. Coûts d'utilisation des réseaux

Gestionnaire de réseau	Coûts de distribution (c€/kWh)				Coûts de transport (c€/kWh)				Location compteur (€/an)
	Jour (compteur de jour)**	Jour (compteur de jour et de nuit)**	Nuit	Exclusif nuit	Jour (compteur de jour)	Jour (compteur de jour et de nuit)	Nuit	Exclusif nuit	
FLANDRE									
AGEM	6,41	6,41	4,52	3,22	0,72	0,72	0,72	0,72	1,80
BIAC	9,18	9,18	9,18	9,18	0,88	0,88	0,88	0,88	95,24
EWGHA	10,59	10,59	10,59	10,59	0,69	0,69	0,69	0,69	4,82
GASELWEST	10,82	10,82	5,72	3,49	1,02	1,02	1,02	1,02	6,75
IMEA	7,05	7,05	4,44	2,96	1,16	1,16	1,16	1,16	6,75
IMWOW	8,67	8,67	4,86	3,12	1,13	1,13	1,13	1,13	6,75
INFRAX WEST	9,97	9,97	6,47	4,29	1,09	1,09	1,09	1,09	6,35
INTERELECTRA	9,17	9,17	5,95	3,95	1,24	1,24	1,24	1,24	6,35
INTERGEM	8,76	8,76	4,84	3,18	1,14	1,14	1,14	1,14	6,75
INTERMOSANE	10,94	11,55	7,15	6,01	1,42	1,42	1,42	1,42	16,36
MEG	8,79	8,79	5,80	3,94	1,06	1,06	1,06	1,06	6,35
MEKA	7,60	7,60	4,47	2,96	1,08	1,08	1,08	1,08	6,75
NERLEK	8,79	8,79	5,09	3,33	1,11	1,11	1,11	1,11	6,75
PBE	9,58	9,58	7,84	3,93	1,00	1,00	1,00	1,00	16,61
SIBELGAS-N	8,04	8,04	4,96	3,33	1,06	1,06	1,06	1,06	6,75
WALLONIE									
AIEG	5,92	6,35	4,42	3,66	1,38	1,38	1,38	1,38	20,50
AIESH	9,35	10,02	6,74	4,99	1,02	1,02	1,02	1,02	18,30
GASELWEST	10,10	10,10	5,55	3,52	0,96	0,96	0,96	0,96	6,75
IDEG	9,69	9,69	5,63	4,62	1,26	1,26	1,26	1,26	16,92
IEH	8,31	8,31	5,24	4,45	1,22	1,22	1,22	1,22	17,73
INTEREST	12,22	12,22	6,75	5,94	1,20	1,20	1,20	1,20	16,03
INTERLUX	11,51	11,51	6,81	5,95	1,20	1,20	1,20	1,20	17,85
INTERMOSANE	10,70	10,70	6,28	5,16	1,38	1,38	1,38	1,38	16,36
PBE	6,61	6,61	5,47	2,89	0,93	0,93	0,93	0,93	16,61
SEDILEC	8,38	8,38	4,88	4,02	1,05	1,05	1,05	1,05	17,32
SIMOGEL	7,05	7,05	4,33	3,63	0,90	0,90	0,90	0,90	16,96
TECTEO RESA	8,11	8,96	4,79	4,18	0,78	0,78	0,78	0,78	18,30
WAVRE	5,08	5,08	3,40	3,40	0,51	0,51	0,51	0,51	8,96

(*) La contribution "énergie verte" est déterminée et facturée sur base de l'arrêté administratif émis par l'État. (**) Applicable aux compteurs avec une puissance de raccordement >= 35 kVA. (***) Applicable aux compteurs avec une puissance de raccordement < 35 kVA.

3. Taxes, redevances, cotisations et surcharges

c€/kWh	Flandre	Wallonie
Cotisation fédérale (*)		
Fonctionnement CREG	0,0184	0,0184
Fonds social (CPAS)	0,0590	0,0590
Fonds Kyoto	0,1564	0,1564
Passif nucléaire	0,2810	0,2810
Clients protégés	0,1058	0,1058
Primes chauffage	0,0164	0,0164
Cotisation sur l'énergie	0,2310	0,2310
Redevance raccordement (**)	-	0,0750
Total	0,8680	0,9430

(*) Taxes dégressives : réduction (uniquement applicable pour des consommateurs professionnels) selon les tranches de consommation suivantes:
 0-20 MWh: 0%
 20 MWh-50 MWh: 15%
 50 MWh-1 GWh: 20%

(**) Non applicable sur les premiers 100 kWh. Cette redevance est majorée d'un montant forfaitaire de 0,075 €.

La cotisation fédérale appliquée sera majorée de la surcharge Elia de 0,1 %, d'un pourcentage de compensation pour la perte de réseau, d'une surcharge administrative de 1,1% et éventuellement diminuée des ristournes d'application. Vous pouvez consulter les prix détaillés sur www.CREG.be. Une remise est accordée sur les cotisations Fonds Kyoto et Passif nucléaire sur la base du mix énergétique.

Paiement

Vous choisissez votre mode de paiement (domiciliation ou virement) et la fréquence de facturation (mensuelle, bimestrielle ou trimestrielle). Si vous n'effectuez pas encore vos paiements par domiciliation mais décidez d'opter pour ce mode de paiement, vous bénéficiez d'une réduction unique de 10 euros. Par la suite, vous ne recevrez plus vos factures d'acompte par courrier. Seul le décompte annuel vous sera envoyé.

Facture digitale

Via Zoomit vous pouvez consulter, télécharger, sauvegarder et payer vos factures Luminus dans l'environnement familier de votre Internet banking.

Si vous souscrivez à ce service, vous recevez une réduction unique de 10 € sur votre prochain décompte d'électricité.

La réduction n'est pas cumulable avec la réduction pour la domiciliation de vos factures.

Durée de votre contrat

Luminus Actif Electricité est un contrat à durée déterminée de 1 an, qui sera automatiquement prolongé pour des périodes successives d'un an. Si vous êtes un nouveau client, le présent contrat entre en vigueur à la date du début de la fourniture. Si vous êtes déjà un client de Luminus pour la fourniture d'électricité au point de fourniture et que vous souhaitez conclure un contrat Luminus Actif Electricité conformément à l'article 11.3 des conditions générales, le nouveau contrat entrera en vigueur dès l'enregistrement dans nos systèmes, sauf si nous

avons convenu d'une autre date de commun accord. Si nous recevons et enregistrons votre contrat dans nos systèmes avant le quinzième jour du mois, le contrat entrera en vigueur le premier jour du mois suivant. Si nous recevons et enregistrons votre contrat dans nos systèmes après le quinzième jour du mois, celui-ci entrera en vigueur le premier jour du deuxième mois suivant.

Les articles 4.2 et 4.4 des conditions générales demeurent inchangés.

Origine de votre énergie

FLANDRE

Origine de l'énergie pour le produit que vous utilisez :

➔ 100% sources d'énergie renouvelables.

Origine de l'énergie pour le total d'énergie fournie par Luminus :

➔ 100% sources d'énergie renouvelables.

Pour des informations sur les conséquences pour l'environnement en ce qui concerne les émissions CO2 et déchets radioactifs de la production d'électricité à partir de différentes sources d'énergie, consultez les sites www.climat.be et www.ondrat.be.

WALLONIE

Origine de l'énergie pour le produit que vous utilisez :

➔ 100% sources d'énergie renouvelables.

Origine de l'énergie pour le total d'énergie fournie par Luminus :

➔ 100% sources d'énergie renouvelables.

Appendix C

Consommateurs résidentiels

Luminus Actif Gaz (février 2011)

Conditions particulières (REF GA1CS1.7) Valable pour les raccordements avec relevé de compteur annuel, d'une capacité < 98 kVa et/ou avec une consommation de gaz < 1 Gwh. Dans le cas contraire, Luminus se réserve le droit d'adapter votre tarif.

Informations concernant votre tarif

Les montants mentionnés ont été arrondis.

La redevance fixe et le coût de l'énergie ont été calculés sur base des index mensuels connus le plus récents (janvier 2011). lgm = 1,2693 et lgd = 1,7027.

Formule de tarif pour la redevance fixe: $29,54 \times lgd$. Formule de tarif pour le coût de l'énergie: $2,58 \times lgm + 0,80 \times lgd$. Ou $lgm = (0,000468 \text{ GOL603} + 0,00025 \text{ HUB} - 0,00323) / 0,02121479$.

La méthode de calcul, ainsi que les valeurs mensuelles de lgm et de ses composantes sont publiées sur le site www.luminus.be, lgd tel que défini dans l'arrêté ministériel du 12 décembre 2001 (ou dans tout arrêté modifiant ou remplaçant cet arrêté) est publiée tous les mois sur le site www.creg.be.

Nous nous réservons le droit d'utiliser de nouveaux paramètres ou de nouvelles composantes pour calculer la formule de prix ou l'lgm si les paramètres actuels viennent à changer, sont supprimés ou s'ils devaient ne plus être disponibles. Dans ce cas de figure, Luminus s'efforcera de maintenir le prix moyen au même niveau.

Lors du décompte de votre consommation effective, la redevance fixe et le coût de l'énergie sont calculés sur base des index mensuels applicables durant la période pour laquelle vous êtes facturés. Les montants mentionnés dans votre bilan récapitulatif peuvent être légèrement en rapport aux prix ci-dessous.

Les coûts d'utilisation des réseaux en question sont ceux approuvés par la CREG, le régulateur belge de l'énergie, au moment de l'impression de la présente liste de prix. Les taxes, redevances, cotisations et surcharges sont mentionnées telles que connues le 1er février 2011. Les éventuelles modifications des coûts d'utilisation des réseaux, taxes, redevances, cotisations et surcharges vous seront toutes entièrement re facturées au prix courant.

Si vous optez pour une formule de prix indexée, les tarifs mentionnés sont ceux en vigueur au moment de la formulation de l'offre. Ces tarifs peuvent modifier et fluctuer en fonction de l'évolution des paramètres composant la formule tarifaire indexée.

Tarifs

Votre tarif de gaz se compose de 3 parties, chacune comprenant la TVA:

1. Redevance annuelle fixe et coût de l'énergie

Redevance fixe (€/an)	43,95
Coût de l'énergie (coût de transport compris) (€/kWh)	4,29

2. Coûts d'utilisation des réseaux

Gestionnaire de réseau	Coûts de distribution						Location compteur
	Petite consommation < 6 000 kWh		Consommation moyenne > 6 000 et < 150 000 kWh		Grande consommation > 150 000 et < 1 000 000 kWh		
	Variable (€/kWh)	Fixe (€/an)	Variable (€/kWh)	Fixe (€/an)	Variable (€/kWh)	Fixe (€/an)	
Flandre							
GASEWEST	2,65	17,07	1,34	75,21	0,90	734,18	7,19
IMEA	2,26	14,88	0,89	93,09	0,51	372,33	7,19
IMEWO	3,01	20,06	1,16	112,58	0,86	555,91	7,19
INH-FAZ WELSI	2,77	7,20	1,22	83,65	0,68	304,56	6,23
INTELECTRA	2,43	15,19	1,21	76,57	0,61	369,63	6,23
INTFCAS	0,14	110,54	0,14	110,38	0,14	110,53	12,10
INTEPGEM	2,38	15,88	1,17	76,68	0,81	517,08	7,19
MEG	2,17	14,70	0,74	85,47	0,69	159,30	6,23
MEKA	2,35	15,81	0,97	84,55	0,67	531,01	7,19
MERLEK	2,28	15,29	1,06	76,19	0,73	571,10	7,19
SIBELGAS-N	2,81	18,05	1,17	100,15	1,09	621,60	7,19
Wallonie							
ALG	2,45	24,20	1,01	94,58	0,44	357,89	6,11
GASEWEST	2,53	17,07	1,37	75,21	0,90	734,18	7,19
IEH-G	3,17	14,71	1,34	91,22	1,25	320,86	9,17
IGH	3,17	14,90	1,62	92,54	1,22	328,51	9,17
INTEHLUX	3,03	12,62	1,73	77,87	1,49	328,70	9,17
SEOLEC	3,05	14,46	1,35	89,62	1,19	510,03	9,17
SIMUGEL	2,54	12,17	1,27	75,47	0,98	513,88	9,17

3. Taxes, redevances, cotisations et surcharges

eMWh	Fléurie	Wakuzit	
Cotisation Métrale			
Fondement CREZ	0,0029	0,0029	
Fonds social (CPAS)	0,0134	0,0134	
Prises chauffage	0,0020	0,0020	
Cotisation sur l'énergie	0,1197	0,1197	(*)
Surcharge clients protégés	0,0051	0,0051	Non applicable sur les premiers 100 kWh.
Redevance raccordement(*)	-	0,0075	Cette redevance est majorée d'un montant forfaitaire de 0,0075€.
Total	0,1339	0,1805	

Paement

Vous choisissez votre mode de paiement (domiciliation ou virement) et la fréquence de facturation (mensuelle, bimestrielle ou trimestrielle).

Facture digitale

Via Zoomit vous pouvez consulter, télécharger, sauvegarder et payer vos factures Luminus dans l'environnement sécurisé de votre Internet banking.

Durée de votre contrat

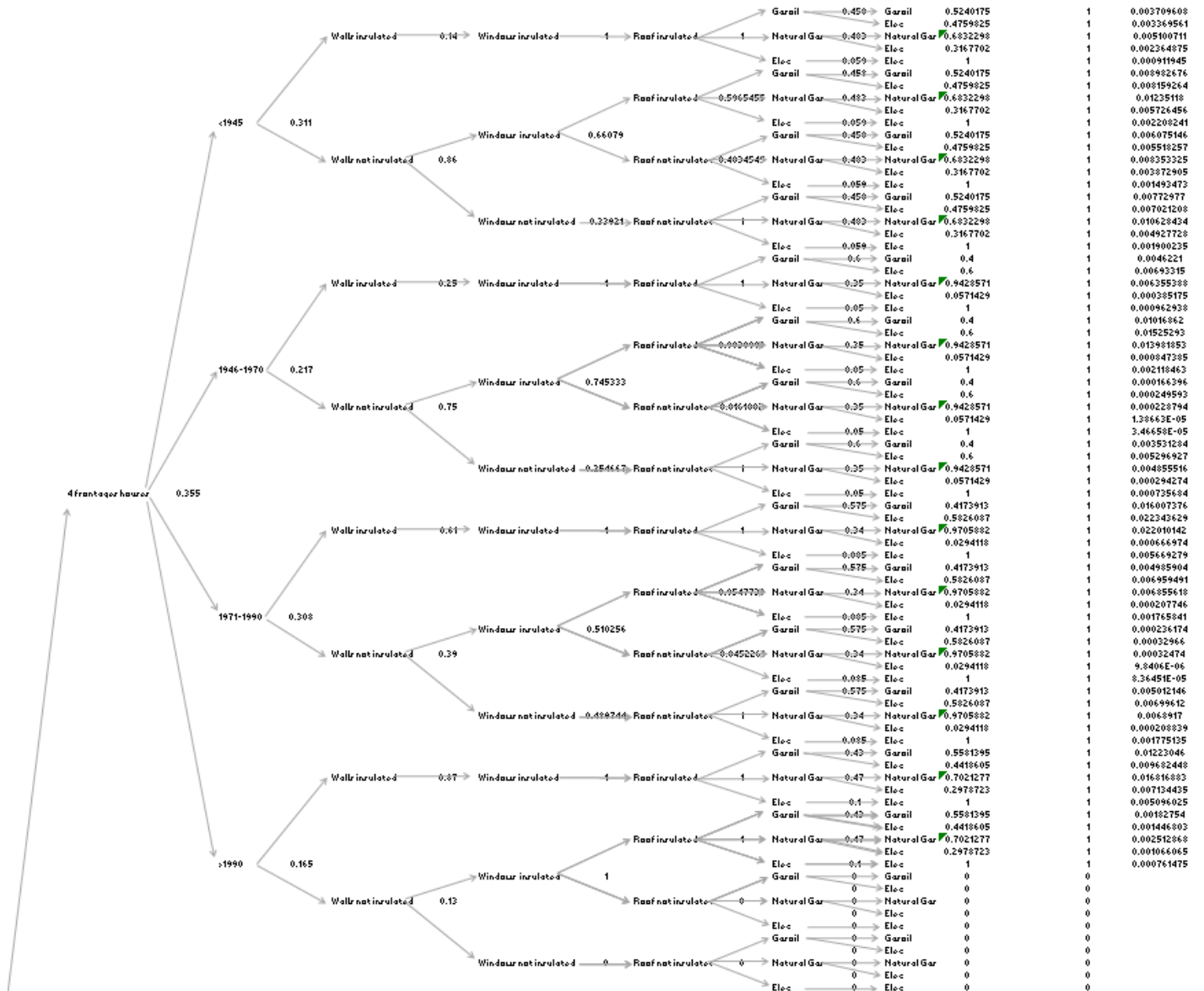
Luminus Actif Gaz est un contrat à durée déterminée de 1 an, qui sera automatiquement prolongé pour des périodes successives d'un an. Si vous êtes un nouveau client, le présent contrat entre en vigueur à la date du début de la fourniture. Si vous êtes déjà un client de Luminus pour la fourniture de gaz au point de fourniture et que vous souhaitez conclure un contrat Luminus Actif Gaz conformément à l'article 11.3 des conditions générales, le nouveau contrat entre en vigueur dès l'enregistrement dans nos systèmes, sauf si nous avons convenu

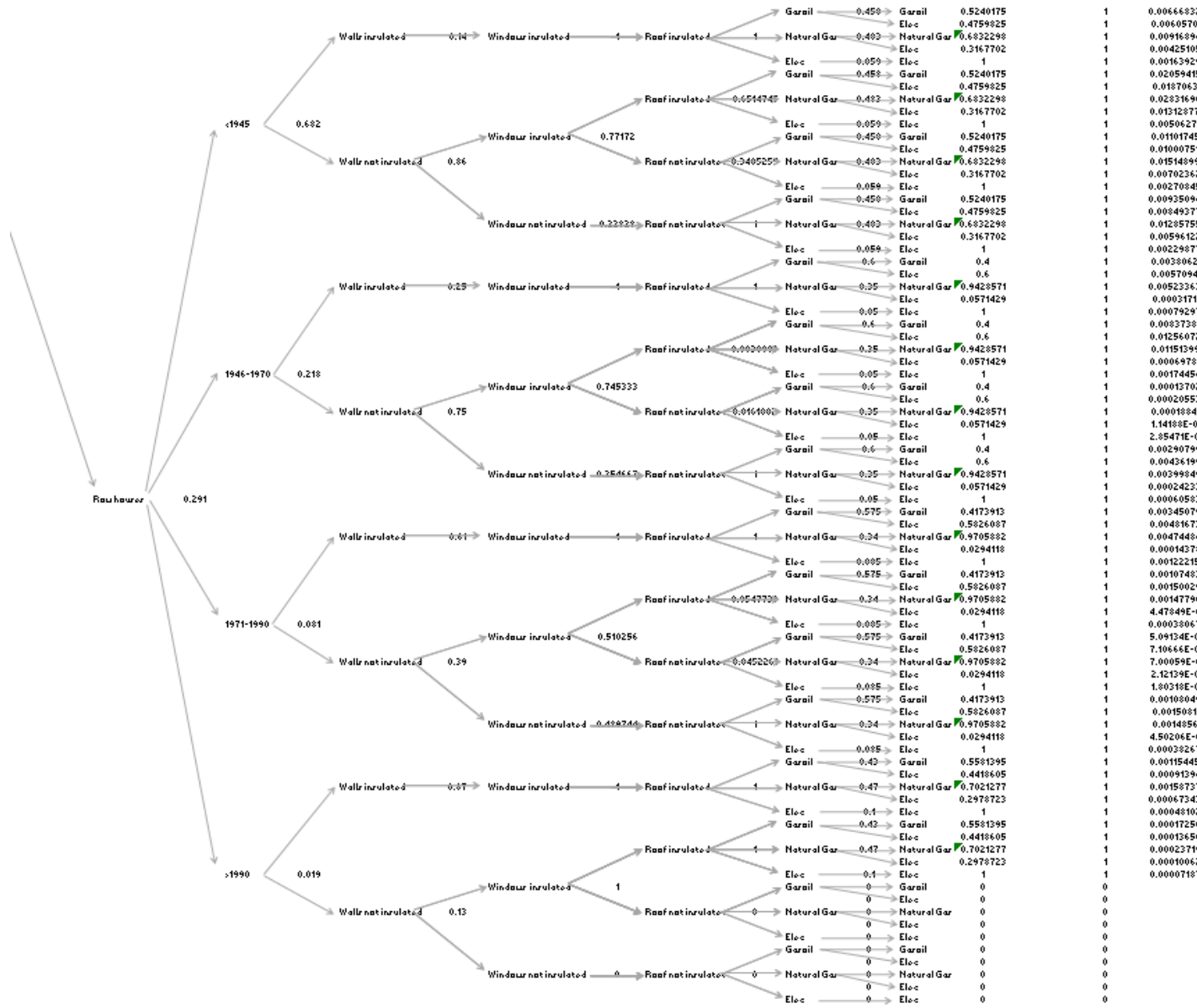
d'une autre date de commun accord. Si nous recevons et enregistrons votre contrat dans nos systèmes avant le quinzième jour du mois, le contrat entre en vigueur le premier jour du mois suivant. Si nous recevons et enregistrons votre contrat dans nos systèmes après le quinzième jour du mois, celui-ci entre en vigueur le premier jour du deuxième mois suivant.

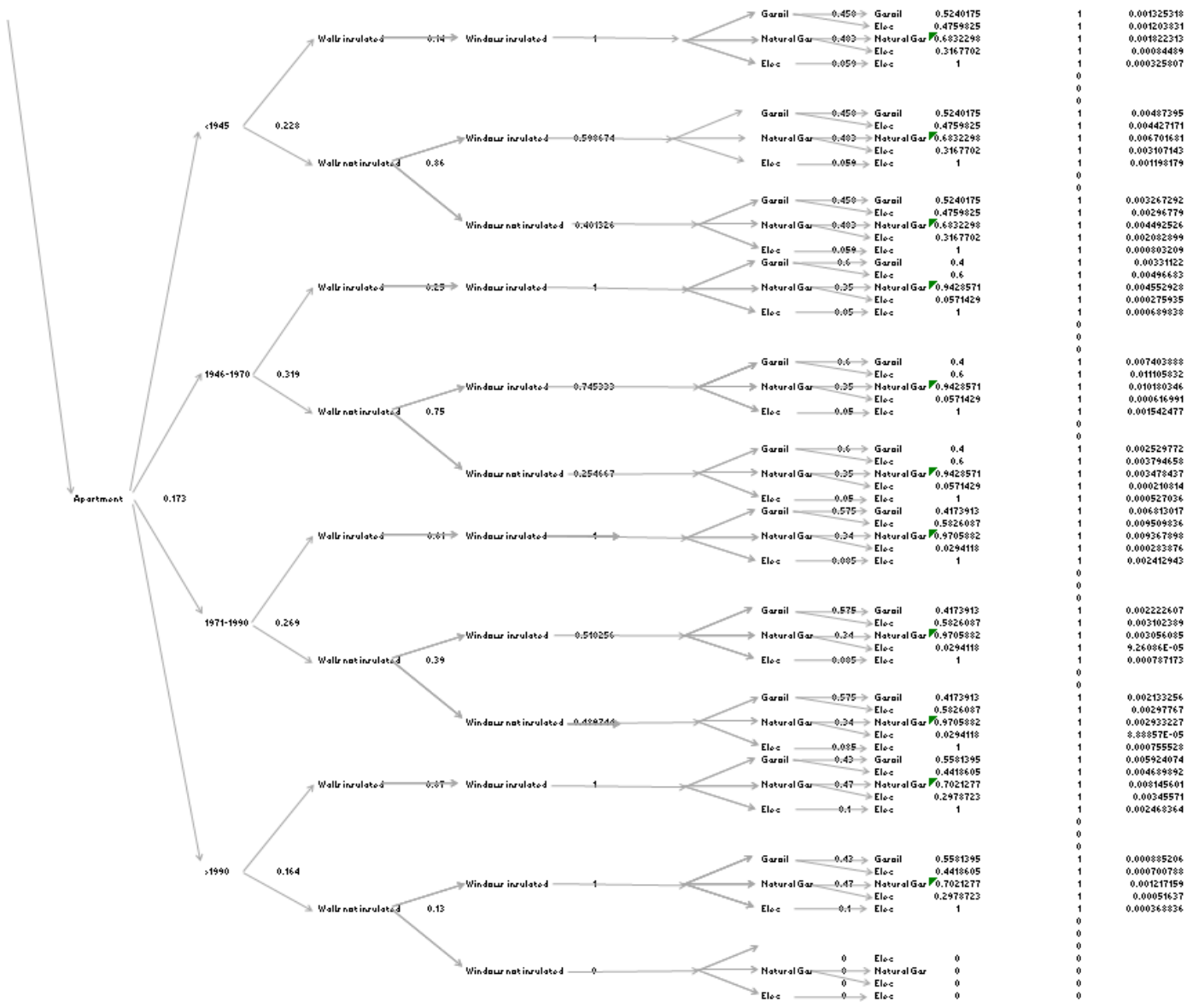
Les articles 4.2 et 4.4 des conditions générales demeurent applicables.

Appendix D

The whole building stock arborescence is given hereafter:







Appendix E

The list of indicative prices coming from the Energy Plus website⁶ is given hereafter.

Windows

Type de verre ou vitrage	Composition en mm	Estimation en €/m ²	
Vitre simple claire neutre	6 mm	45	50
Vitre simple claire neutre	12 mm	110	130
Vitre simple claire réfléchissante	6 mm	95	105
Verre armé*	6 mm	35	37
Verre feuilleté*	44,2	60	85
Vitrage Rf (résistant au feu)*	1/2 heure	310	400
Vitrage Rf (résistant au feu)*	1 heure	570	620
Double vitrage ordinaire (U=2,9 W/m ² K)	4-12-4 mm	48	50
Double vitrage ordinaire (U=2,9 W/m ² K)	6-12-6 mm	52	57
Double vitrage isolant à basse émissivité (U=1,5 W/m ² K)	6-12-6 mm	65	75
Double vitrage réfléchissant clair	6-12-6 mm	145	150
Double vitrage acoustique	8-12-4 mm (38 dB)	115	120
Double vitrage acoustique	10-20-4 mm (41 dB)	125	130
Vitrage chromogène	11 mm	2 480	2 975
Triple vitrage	28 mm	80	85

⁶ www.energieplus-lesite.be

Appendix F

The number of case is the same than number in the arborescence presented in the previous appendix.

<u>Case</u>	<u>Total insulation</u>		<u>Heat pump</u>		<u>Condensing boiler</u>	
	<u>NPV without subsidies</u>	<u>NPV with subsidies</u>	<u>NPV without subsidies</u>	<u>NPV with subsidies</u>	<u>NPV without subsidies</u>	<u>NPV with subsidies</u>
<u>1</u>	0	0	2552	4802	2325	2725
<u>2</u>	0	0	6980	9230	7194	7594
<u>3</u>	0	0	-2558	-307.9	490.7	890.7
<u>4</u>	0	0	3780	6030	6774	7174
<u>5</u>	0	0	24382	26632	29749	30149
<u>6</u>	26527	32881	14388	16638	10384	10784
<u>7</u>	26527	32881	18816	21066	15253	15653
<u>8</u>	16828	23182	-421.3	1829	6173	6573
<u>9</u>	16837	23191	5925	8175	12458	12858
<u>10</u>	56781	63135	66472	68722	75378	75778
<u>11</u>	47082	57095	23109	25359	16319	16719
<u>12</u>	47082	57096	27537	29787	21188	21588
<u>13</u>	30243	40257	1160	3410	10358	10758
<u>14</u>	30244	40257	7498	9748	16641	17041
<u>15</u>	99603	109616	97459	99709	108975	109375
<u>16</u>	63840	79572	45585	47835	21828	22228
<u>17</u>	63841	79572	50013	52263	26697	27097
<u>18</u>	40328	56060	16963	19213	14231	14631
<u>19</u>	40374	56105	23346	25596	20525	20925
<u>20</u>	93885	109616	97459	99709	97011	97411
<u>21</u>	0	0	1917	4167	85.32	485.3
<u>22</u>	0	0	6345	8595	5415	5815
<u>23</u>	0	0	-2674	-423.5	-1075	-675.3
<u>24</u>	0	0	3664	5914	5519	5919
<u>25</u>	0	0	22105	24355	26333	26733
<u>26</u>	18382	24736	11926	14176	5654	6054
<u>27</u>	16659	23013	14630	16880	9251	9651
<u>28</u>	11603	17957	555.9	2806	3364	3764
<u>29</u>	9877	16231	5168	7418	8225	8625
<u>30</u>	37828	44182	51559	53809	56990	57390
<u>31</u>	30082	40095	16344	18594	6768	7168
<u>32</u>	30094	40107	20784	23034	12100	12500
<u>33</u>	18266	28280	-62.43	2188	3638	4038
<u>34</u>	18266	28280	6275	8525	10233	10633
<u>35</u>	66992	77006	73442	75692	79773	80173
<u>36</u>	38566	54298	21463	23713	9135	9535
<u>37</u>	38567	54298	25891	28141	14465	14865
<u>38</u>	22554	38285	859.3	3109	5306	5706
<u>39</u>	22554	38285	7197	9447	11900	12300
<u>40</u>	88525	104256	91609	93859	98685	99085
<u>41</u>	0	0	1765	4015	-425.4	-25.42
<u>42</u>	0	0	6205	8455	5022	5422

<u>43</u>	0	0	-840	1410	431.1	831.1
<u>44</u>	0	0	3644	5894	5242	5642
<u>45</u>	0	0	21600	23850	25571	25971
<u>46</u>	9741	16095	7560	9810	1942	2342
<u>47</u>	9744	16098	12002	14252	7390	7790
<u>48</u>	4996	11350	-1653	597.4	237.7	637.7
<u>49</u>	4990	11344	4687	6937	6912	7312
<u>50</u>	24546	30900	42200	44450	46797	47197
<u>51</u>	17975	27988	11846	14096	3690	4090
<u>52</u>	17965	27978	16276	18526	9137	9537
<u>53</u>	2354	12368	-8242	-5992	387.4	787.4
<u>54</u>	9717	19731	5468	7718	8145	8545
<u>55</u>	43708	53722	57414	59664	62465	62865
<u>56</u>	20114	35845	14672	16922	4846	5246
<u>57</u>	20102	35834	19100	21350	10291	10691
<u>58</u>	9232	24963	1070	3320	3988	4388
<u>59</u>	9532	25263	5969	8219	8958	9358
<u>60</u>	53084	68815	67476	69726	72838	73238
<u>61</u>	0	0	1637	3887	-915.7	-515.7
<u>62</u>	0	0	6064	8314	4645	5045
<u>63</u>	0	0	-2725	-475.3	-1774	-1374
<u>64</u>	0	0	3612	5862	4976	5376
<u>65</u>	0	0	21118	23368	24855	25255
<u>66</u>	9372	15726	7294	9544	1089	1489
<u>67</u>	9387	15741	11736	13986	6652	7052
<u>68</u>	4742	11096	-1698	551.7	-360	40.01
<u>69</u>	4744	11098	4642	6892	6392	6792
<u>70</u>	23852	30206	41255	43505	45379	45779
<u>71</u>	0	0	0	0	0	0
<u>72</u>	0	0	0	0	0	0
<u>73</u>	0	0	0	0	0	0
<u>74</u>	0	0	0	0	0	0
<u>75</u>	0	0	0	0	0	0
<u>76</u>	0	0	0	0	0	0
<u>77</u>	0	0	0	0	0	0
<u>78</u>	0	0	0	0	0	0
<u>79</u>	0	0	0	0	0	0
<u>80</u>	0	0	0	0	0	0
<u>81</u>	0	0	2640	4890	2926	3326
<u>82</u>	0	0	5384	7634	6118	6518
<u>83</u>	0	0	-2847	-597.1	-311.1	88.92
<u>84</u>	0	0	3571	5821	6053	6453
<u>85</u>	0	0	18417	20667	23272	23672
<u>86</u>	17940	23036	10929	13179	8572	8972
<u>87</u>	17952	23048	13679	15929	11764	12164
<u>88</u>	12888	17984	390.1	2640	5407	5807
<u>89</u>	11154	16250	5073	7323	10036	10436
<u>90</u>	39145	44241	47911	50161	55247	55647
<u>91</u>	37885	46512	19667	21917	14326	14726
<u>92</u>	37885	46512	22406	24656	17515	17915

<u>93</u>	25905	34532	2200	4450	9463	9863
<u>94</u>	24171	32798	6883	9133	14092	14492
<u>95</u>	79827	88454	77387	79637	86968	87368
<u>96</u>	48993	60583	33455	35705	17775	18175
<u>97</u>	46624	58214	33825	36075	20383	20783
<u>98</u>	30966	42556	9941	12191	11430	11830
<u>99</u>	29458	41049	14851	17101	16114	16514
<u>100</u>	77714	89305	77954	80204	81590	81990
<u>101</u>	0	0	423.7	2674	-613.1	-213.1
<u>102</u>	0	0	4897	7147	4781	5181
<u>103</u>	0	0	-2939	-688.8	-1569	-1169
<u>104</u>	0	0	3488	5738	5113	5513
<u>105</u>	0	0	16710	18960	20709	21109
<u>106</u>	12771	17867	7966	10216	3811	4211
<u>107</u>	11037	16132	10705	12955	7470	7870
<u>108</u>	8018	13113	-149.8	2100	2063	2463
<u>109</u>	6283	11379	4542	6792	7011	7411
<u>110</u>	25877	30973	37359	39609	42201	42601
<u>111</u>	25824	34450	13935	16185	6575	6975
<u>112</u>	24089	32716	16674	18924	10234	10634
<u>113</u>	16218	24845	967	3217	4019	4419
<u>114</u>	14447	23074	5623	7873	8960	9360
<u>115</u>	54191	62818	58589	60839	64299	64699
<u>116</u>	30253	41843	16597	18847	7807	8207
<u>117</u>	28518	40109	19336	21586	11466	11866
<u>118</u>	18425	30016	1407	3657	4880	5280
<u>119</u>	16691	28281	6099	8349	9828	10228
<u>120</u>	65419	77009	68050	70300	74152	74552
<u>121</u>	0	0	315	2565	-1026	-625.9
<u>122</u>	0	0	4788	7038	4485	4885
<u>123</u>	0	0	-2959	-708.9	-1856	-1456
<u>124</u>	0	0	3468	5718	4905	5305
<u>125</u>	0	0	16333	18583	20143	20543
<u>126</u>	6214	11310	4386	6636	637.3	1037
<u>127</u>	6226	11321	8871	11121	6150	6550
<u>128</u>	2883	7979	-2219	31.02	-683	-283
<u>129</u>	2883	7979	4207	6457	6078	6478
<u>130</u>	16620	21716	30810	33060	35054	35454
<u>131</u>	15931	24557	10268	12518	4066	4466
<u>132</u>	14196	22823	13006	15256	7842	8242
<u>133</u>	9203	17830	265.9	2516	2246	2646
<u>134</u>	7468	16095	4958	7208	7273	7673
<u>135</u>	35188	43815	45542	47792	50230	50630
<u>136</u>	17062	28653	11741	13991	4668	5068
<u>137</u>	15328	26918	14479	16729	8444	8844
<u>138</u>	8965	20556	369.8	2620	2647	3047
<u>139</u>	7394	18985	5226	7476	7698	8098
<u>140</u>	40091	51681	50787	53037	55632	56032
<u>141</u>	0	0	209.7	2460	-1426	-1026
<u>142</u>	0	0	4695	6945	4204	4604

<u>143</u>	0	0	-2969	-719.4	-2133	-1733
<u>144</u>	0	0	3448	5698	4706	5106
<u>145</u>	0	0	15972	18222	19603	20003
<u>146</u>	5952	11048	4181	6431	-17.5	382.5
<u>147</u>	5952	11048	8666	10916	5612	6012
<u>148</u>	2692	7788	-2258	-7.765	-1141	-740.6
<u>149</u>	2701	7797	4169	6419	5700	6100
<u>150</u>	16133	21229	30124	32374	34029	34429
<u>151</u>	0	0	0	0	0	0
<u>152</u>	0	0	0	0	0	0
<u>153</u>	0	0	0	0	0	0
<u>154</u>	0	0	0	0	0	0
<u>155</u>	0	0	0	0	0	0
<u>156</u>	0	0	0	0	0	0
<u>157</u>	0	0	0	0	0	0
<u>158</u>	0	0	0	0	0	0
<u>159</u>	0	0	0	0	0	0
<u>160</u>	0	0	0	0	0	0
<u>161</u>	0	0	-721.8	1528	139.5	539.5
<u>162</u>	0	0	3513	5763	4785	5185
<u>163</u>	0	0	-3195	-944.8	-1048	-648.3
<u>164</u>	0	0	2824	5074	4914	5314
<u>165</u>	0	0	13097	15347	17559	17959
<u>166</u>	10007	12440	3754	6004	3189	3589
<u>167</u>	10019	12452	7746	9996	7701	8101
<u>168</u>	6345	8778	-2381	-131	1103	1503
<u>169</u>	6336	8769	3622	5872	7059	7459
<u>170</u>	21460	23894	29026	31276	34836	35236
<u>171</u>	29671	35307	12963	15213	10104	10504
<u>172</u>	27948	33584	15474	17724	13016	13416
<u>173</u>	19772	25408	590.5	2841	6490	6890
<u>174</u>	18037	23673	4874	7124	10716	11116
<u>175</u>	59233	64869	56343	58593	64558	64958
<u>176</u>	35444	43045	20838	23088	12000	12400
<u>177</u>	33720	41321	23343	25593	14910	15310
<u>178</u>	21532	29134	4454	6704	6092	6492
<u>179</u>	21523	29125	10457	12707	12048	12448
<u>180</u>	56855	64457	56068	58318	60032	60432
<u>181</u>	0	0	653.8	2904	466.8	866.8
<u>182</u>	0	0	3157	5407	3803	4203
<u>183</u>	0	0	-3258	-1008	-2028	-1628
<u>184</u>	0	0	2760	5010	4223	4623
<u>185</u>	0	0	11843	14093	15678	16078
<u>186</u>	6281	8714	2056	4306	182.5	582.5
<u>187</u>	6286	8720	6302	8552	5258	5658
<u>188</u>	3709	6143	-2690	-440.5	-1004	-604.1
<u>189</u>	3709	6143	3327	5577	5246	5646
<u>190</u>	14292	16725	22993	25243	27285	27685
<u>191</u>	17995	23631	9168	11418	4404	4804
<u>192</u>	17990	23626	11668	13918	7743	8143

<u>193</u>	12757	18393	18.64	2269	2484	2884
<u>194</u>	11012	16648	4038	6288	6833	7233
<u>195</u>	39711	45347	42074	44324	47243	47643
<u>196</u>	20910	28512	10923	13173	5218	5618
<u>197</u>	20905	28507	13423	15673	8556	8956
<u>198</u>	14235	21837	336.8	2587	3058	3458
<u>199</u>	12491	20092	4611	6861	7571	7971
<u>200</u>	47124	54725	48326	50576	53660	54060
<u>201</u>	0	0	-1158	1092	-1593	-1193
<u>202</u>	0	0	3088	5338	3590	3990
<u>203</u>	0	0	-3274	-1024	-2253	-1853
<u>204</u>	0	0	2745	4995	4069	4469
<u>205</u>	0	0	11565	13815	15263	15663
<u>206</u>	3674	6107	1041	3291	-695	-295
<u>207</u>	3674	6107	5288	7538	4488	4888
<u>208</u>	1874	4307	-2875	-624.6	-1620	-1220
<u>209</u>	1874	4307	3144	5394	4703	5103
<u>210</u>	9290	11724	19381	21631	23313	23713
<u>211</u>	12540	18176	6500	8750	2560	2960
<u>212</u>	10793	16429	8999	11249	6006	6406
<u>213</u>	7695	13331	-460.9	1789	1188	1588
<u>214</u>	5951	11587	3813	6063	5774	6174
<u>215</u>	25918	31554	32601	34851	36935	37335
<u>216</u>	13277	20879	7473	9723	2958	3358
<u>217</u>	11530	19131	9972	12222	6403	6803
<u>218</u>	7520	15121	-400.5	1850	1451	1851
<u>219</u>	5893	13495	3992	6242	6054	6454
<u>220</u>	29141	36743	36061	38311	40496	40896
<u>221</u>	0	0	-1228	1022	-1907	-1507
<u>222</u>	0	0	3019	5269	3383	3783
<u>223</u>	0	0	-3287	-1037	-2471	-2071
<u>224</u>	0	0	2732	4982	3924	4324
<u>225</u>	0	0	11300	13550	14864	15264
<u>226</u>	3531	5964	919.2	3169	-1146	-746.4
<u>227</u>	3531	5964	5161	7411	4141	4541
<u>228</u>	3510	5943	-1160	1090	-199.1	200.9
<u>229</u>	1774	4207	3118	5368	4457	4857
<u>230</u>	9017	11451	18934	21184	22646	23046
<u>231</u>	0	0	0	0	0	0
<u>232</u>	0	0	0	0	0	0
<u>233</u>	0	0	0	0	0	0
<u>234</u>	0	0	0	0	0	0
<u>235</u>	0	0	0	0	0	0
<u>236</u>	0	0	0	0	0	0
<u>237</u>	0	0	0	0	0	0
<u>238</u>	0	0	0	0	0	0
<u>239</u>	0	0	0	0	0	0
<u>240</u>	0	0	0	0	0	0
<u>241</u>	0	0	-2983	-732.5	-1238	-837.7
<u>242</u>	0	0	552.7	2803	2585	2985

<u>243</u>	0	0	-3753	-1503	-2008	-1608
<u>244</u>	0	0	1052	3302	2755	3155
<u>245</u>	0	0	6380	8630	10457	10857
<u>246</u>	0	0	0	0	0	0
<u>247</u>	0	0	0	0	0	0
<u>248</u>	0	0	0	0	0	0
<u>249</u>	7551	9034	1381	3631	2287	2687
<u>250</u>	5814	7298	3178	5428	4372	4772
<u>251</u>	5406	6889	-1535	715.2	990.9	1391
<u>252</u>	3660	5143	1523	3773	4015	4415
<u>253</u>	12528	14012	15721	17971	20586	20986
<u>254</u>	0	0	0	0	0	0
<u>255</u>	0	0	0	0	0	0
<u>256</u>	11735	15690	2667	4917	2608	3008
<u>257</u>	11723	15679	6190	8440	6427	6827
<u>258</u>	7113	11068	-2725	-475.2	704.6	1105
<u>259</u>	7104	11059	2070	4320	5465	5865
<u>260</u>	26166	30121	26461	28711	32230	32630
<u>261</u>	0	0	-1410	840.5	-329.1	70.89
<u>262</u>	0	0	302	2552	1986	2386
<u>263</u>	0	0	-3815	-1565	-2635	-2235
<u>264</u>	0	0	1067	3317	2384	2784
<u>265</u>	0	0	5667	7917	9358	9758
<u>266</u>	0	0	0	0	0	0
<u>267</u>	0	0	0	0	0	0
<u>268</u>	0	0	0	0	0	0
<u>269</u>	3612	5095	-1365	885.2	-1292	-891.7
<u>270</u>	3624	5107	2170	4420	2836	3236
<u>271</u>	2115	3599	-3455	-1205	-2036	-1636
<u>272</u>	2106	3589	1340	3590	2932	3332
<u>273</u>	8233	9716	12145	14395	-12149	-11749
<u>274</u>	0	0	0	0	0	0
<u>275</u>	0	0	0	0	0	0
<u>276</u>	6378	10333	519	2769	-418.6	-18.65
<u>277</u>	6390	10345	4054	6304	3710	4110
<u>278</u>	3333	7288	-3120	-869.6	-1421	-1021
<u>279</u>	3333	7288	1685	3935	3549	3949
<u>280</u>	15824	19779	18853	21103	23091	23491
<u>281</u>	0	0	-1456	793.8	-537.7	-137.7
<u>282</u>	0	0	308.9	2559	1883	2283
<u>283</u>	0	0	-2009	240.5	-968	-568
<u>284</u>	0	0	1051	3301	2290	2690
<u>285</u>	0	0	5499	7749	9111	9511
<u>286</u>	0	0	0	0	0	0
<u>287</u>	0	0	0	0	0	0
<u>288</u>	0	0	0	0	0	0
<u>289</u>	2088	3571	-1956	294.5	-1824	-1424
<u>290</u>	2088	3571	1568	3818	2379	2779
<u>291</u>	1034	2517	-3563	-1313	-2410	-2010
<u>292</u>	1034	2517	1233	3483	2611	3011

<u>293</u>	5294	6777	10017	12267	13768	14168
<u>294</u>	0	0	0	0	0	0
<u>295</u>	0	0	0	0	0	0
<u>296</u>	2485	6440	-928.5	1322	-1402	-1002
<u>297</u>	2497	6452	2607	4857	2803	3203
<u>298</u>	470.3	4426	-1700	549.7	-332.5	67.46
<u>299</u>	597.5	4553	1426	3676	2910	3310
<u>300</u>	8348	12303	13701	15951	17558	17958
<u>301</u>	0	0	-3293	-1043	-2553	-2153
<u>302</u>	0	0	242.6	2493	1729	2129
<u>303</u>	0	0	-3806	-1556	-2921	-2521
<u>304</u>	0	0	998.9	3249	2152	2552
<u>305</u>	0	0	5286	7536	8813	9213
<u>306</u>	0	0	0	0	0	0
<u>307</u>	0	0	0	0	0	0
<u>308</u>	0	0	0	0	0	0
<u>309</u>	2005	3488	-1808	441.8	-2108	-1708
<u>310</u>	2005	3488	1727	3977	2173	2573
<u>311</u>	979.5	2463	-3347	-1097	-2607	-2207
<u>312</u>	970.4	2454	1449	3699	2465	2865
<u>313</u>	4528	6011	9293	11543	12683	13083
<u>314</u>	0	0	0	0	0	0
<u>315</u>	0	0	0	0	0	0
<u>316</u>	0	0	0	0	0	0
<u>317</u>	0	0	0	0	0	0
<u>318</u>	0	0	0	0	0	0
<u>319</u>	0	0	0	0	0	0
<u>320</u>	0	0	0	0	0	0

Appendix G

Constant used in this end-of-study work (Kints (2008))...

PCI combustibles (Valeurs extraites de Energie ')

- mazout ou gasoil : 1 litre = 36 MJ = 10 kWh
 - gaz naturel type H (riche) : 1 m³ = 36,43 MJ = 10,12 kWh
 - gaz nat. type L (pauvre - Bt wall.) : 1 m³ = 32,97 MJ = 9,16 kWh
 - électricité : 1 kWh = 3,6 MJ
 - butane : 1 kg = 45,56 MJ = 12,7 kWh
 - propane : 1 litre = 23,72 MJ = 6,59 kWh
 - charbon : 1 kg = +/- 30 MJ = 8,33 kWh
 - bois : bûches sèches : 1 kg = 15 MJ ou 4,17 kWh
bûches humides : 1 kg = 9 MJ ou 2,5 kWh
- Note : une stère de chêne séché à l'air pèse 488 kg et équivaut à 160 litres de mazout, une stère d'épicéa pèse 315 kg («105 l mazout»)*
- pellets : 1 kg = 17,5 MJ ou 4,86 kWh

Unités

- 1 tep (tonne d'équivalent pétrole) = 11 628 kWh
- 1 kWh = 3,6 MJ ; 1 kcal = 4.187 J = 1,163 10⁻³ kWh
- 1 m³gaz = 1 l mazout = 10 kWh = 36 MJ (sauf gaz type L)

Executive summary

Title: Economical and environmental impacts of several retrofit options for residential buildings

Author: Samuel Gendebien

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Nowadays, important efforts are deployed to reduce our actual residential building consumption which represents about 40% (25% for the residential sector and 15% for the non-residential sector) of the total energy consumption in Europe. The aim of this paper is to evaluate the environmental and economical impact of several retrofit options for residential buildings. Our study focuses on the Walloon Region of Belgium. A “bottom-up” methodology is applied: this methodology focuses first on a micro-analysis. Results from this micro-analysis are then used and extended to a macro-analysis. The presented methodology does not permit to determine with precision the global consumption of residential buildings in the Walloon Region. However, the latter methodology allows pointing out some economical and environmental trends related to the different investigated retrofit options.

The first part of this end-of-study work offers an overview of the Walloon building stock by presenting statistic data on the Walloon residential houses. From these latter statistic data, it is possible to divide the Walloon building stock by means of arborescence. Each type of building is characterized by constructive data (mean area, U_{wall} , U_{window} ...) and by heating production system efficiency.

Thanks to these data, it is possible to determine the gas and electrical annual consumption for each type of residential building by means of a computer program that simulates residential building.

The latter computer program is also used to determine the annual energy consumption of envelope retrofitted houses. Retrofit options related to heat and/or cool production are also investigated.

A macro-point of view study is carried out in order to determine the potential of energy saving of each investigated options. An environmental comparison between the several envisaged retrofit options is realized in terms of CO₂ emission, final and primary annual energy consumption for each type of building.

An economical study is carried out in order to determine the profitability of each investigated options for citizens.

The work also proposes a reflection about the actual incentive policies.

