Smart Energy Regions

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Influence of incentives, occupancy and energy-related behaviours on renovation strategies decision making

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Abstract. The European policy for energy consumption and greenhouse gases emission reductions has imposed, in its 2002/91/CE Directive, the certification of any existing building's energy performance that witnesses its energy consumption and efficiency, when it is sold or rented. That Energy Performance Certification (EPC) calculated with a standardized approach which purposefully (and understandably) gets human factor out of the equations, aims at influencing real-estate market by introducing energy efficiency as a comparative criterion in the search for a dwelling and stimulating energy saving investments. So far, the influence of the EPC has been negligible however: often distant from reality, overestimating the consumption, it results is a general misunderstanding, misuse or non-use of the document.

Furthermore, the EPC offers recommendations to the reader in order to reduce consumption; what appears however, is an automatic response to EPCs inputs, such as "insulate your roof" when no insulation is present or visible there, or "change the windows" when single glazing is still present. Assessors cannot tailor these recommendations to the particular house they are assessing, or to the household, its needs and desires for its dwellings. It is not even designed to offer financial or economical advice on renovation strategies, and appears, therefore, uninformative on the cost or potential impacts on the consumption.

The following questions arise naturally: how can the EPC reach this goal? How can it become a decision-helping tool that would actually be used by real-estate enthusiasts? Previous studies have shown that implementing real occupancy and energy-related behaviour parameters in the regulatory calculation method can help close the gap between theoretical and real energy consumption. This study takes one more step by integrating financial incentives and occupants strategic planning in the energy and economic performance assessment of progressive renovation scenarios, focusing on two urban single-family houses, chosen for their representation of the Belgian urban residential stock. The aim of this study is to develop decision-helping routines that take into consideration economic and energy performances of renovation strategies, occupancy scheme and energy-related behaviours, potential incentives and occupants' budgets and preferences, whether they relate to comfort, materials or strategies on the use of the dwelling.

1. Introduction

European Union's strategy for a sustainable growth makes energy consumption reduction in the building sector a central objective for meeting the commitments taken under the climate change challenge. At a worldwide scale, this sector is thus regarded as one of the most cost-effective options for saving CO_2 emissions (IPCC, 2007). To target the existing buildings potential, the European Union introduced (through the 2002/91/CE European Directive) Energy Performance Certificates (EPC), which should provide clear information about the energy performance of a building when it is sold or rented, including reference values, allowing performance comparisons between buildings. The EPC should also include "clear" recommendations for technically possible improvements, in order to increase investments in energy efficiency, move the housing market towards greater energy efficiency, influence real-estate market value and help built up comprehensive benchmarking databases, fundamental for shaping smart strategies on a local, regional and national level.

Given necessary standardization, the calculation method does not provide realistic results, and this is confirmed by energy bills; in theory, two different families living in two identical homes would receive identical EPCs, but in reality, their real consumption would vary from one to three or four (Hens, 2010), depending on occupants' behaviour and household characteristics. As a consequence, crossing several studies that have been led in Belgium (Vanparys et al., 2012), the UK (Laine, 2011; O'Sullivan, 2007) or in Germany (Amecke, 2012) enlightens a general conclusion: the EPC is often considered unhelpful, unrealistic (and therefore mistrusted), distant from reality, overestimating consumption, too long and technical, confusing…

Sociology of energy points the lack of appropriation of results as a missed opportunity. This study is therefore based on the assumption that, though acknowledging the importance of a standardized approach to allow building comparisons, other and more accurate results could be obtained from EPC inputs, by closing the gap between theoretical and real consumptions. Previous papers (Monfils, 2014, Monfils 2015) listed the uncertainty parameters of the Walloon EPC protocol and calculation method, and proposed a method for the introduction of additional data (on the number of inhabitants, occupation patterns of the dwelling, levels and quality of electr(on)ic equipment and lighting) into a recalculation of internal gains, Net Heat Demand (NHD) and Domestic Hot Water (DHW) demand.

This paper will present a study where these calculation methods are applied to the assessment of two very typical Walloon urban houses, on their initial state and in the decision-making process of deep renovation. The first part describes the method, houses, households, a selection of renovation scenarios (with reference to owners requirements), and the criteria that will be used to compare the results. The second part presents results for both projects, both evaluated with the official standardized "default" calculation method and the proposed, "users included" method. Conclusions and discussions will compose the last parts of this paper.

2. Method

This study evaluates a selection of decision-making criteria for the renovation of two houses. These criteria have been selected to cover a range of habitual concerns:

- CO_2 emissions (considering only those related to energy consumption), in tons per year;
- Energy performance criterion (the specific primary energy consumption level – Espec – evaluated in $kWh/m^2.yr$) adding primary energy consumptions for heating, domestic hot water, auxiliaries and cooling (when appropriate), and withdrawing renewable supply.
- Financial criteria (using an Excel sheet, developed by EnergySuD for previous studies), considering the total cost of interventions, available financial incentives, a loan with progressive length and fixed interest rate, VAT, inflation and discount rates. The outputs are all given for a 20 years' time span:
    - The energy bills, expressing energy consumption in a monthly cost of energy, instead of an annual sum of "kWh" of "primary energy". Profitability is, therefore, easier to understand and closer to people concerns.
    - The available incentives (important part of owners' renovation decision-making processes).
    - The cost of all interventions, without loan, alongside the corresponding available incentives. This cost does not consider necessary fitting, decoration, or any other work unrelated to energy performance.
    - The total cost on 20 years, which could be given with or without loan or incentives; we decided to consider both loan and incentives (most probable situation).
    - The Net Present Value (NPV) of each case, representative of its profitability (if > 0).

- Comfort criteria:
    - Summer comfort evaluation is based on the overheating risk evaluation that already exists in the official calculation method.
    - Winter comfort is evaluated differently: a list of 4 priority comfort improvements is given by the owner (based on a list of typology usual weaknesses); if one of the 4 related interventions is conducted, the overall “winter comfort increase global index” will rise by 20% for the first priority, 15% for the second, etc., up to 50% for all 4 actions. The remaining half of this index reflects the improvement percentage of the Net Heat Demand (NHD) between the initial value and the minimal NHD attainable for the house. The NHD has been chosen for its accurate reflection of several important parameters of the winter comfort: envelope insulation (presence of cold walls), ventilation and airtightness related losses, internal and solar gains.

When facing the renovation of a house, infinite combination of interventions could be studied; the ones presented in this study have been selected among others in order to take owners requirements into consideration, as well as for their logical progression in the overall renovation of the houses. The cost of each scenario have been evaluated (sources: EnergySuD data bases for Reno2020, COZEB and SISAL research projects, UPA 2009), as well as the effects on the different decision-making criteria.

3. Hypotheses

This study concerns two typical Walloon houses, built before WWII and generally poorly insulated. Both households gave additional information on their levels (and use) of equipment, occupation and heating patterns, comfort habits and other pertinent data (that will not be described here) that allowed us to recalculate internal gains, net heating and domestic hot water demands for “users included” results, as described in (Monfils, 2014) and (Monfils, 2015).

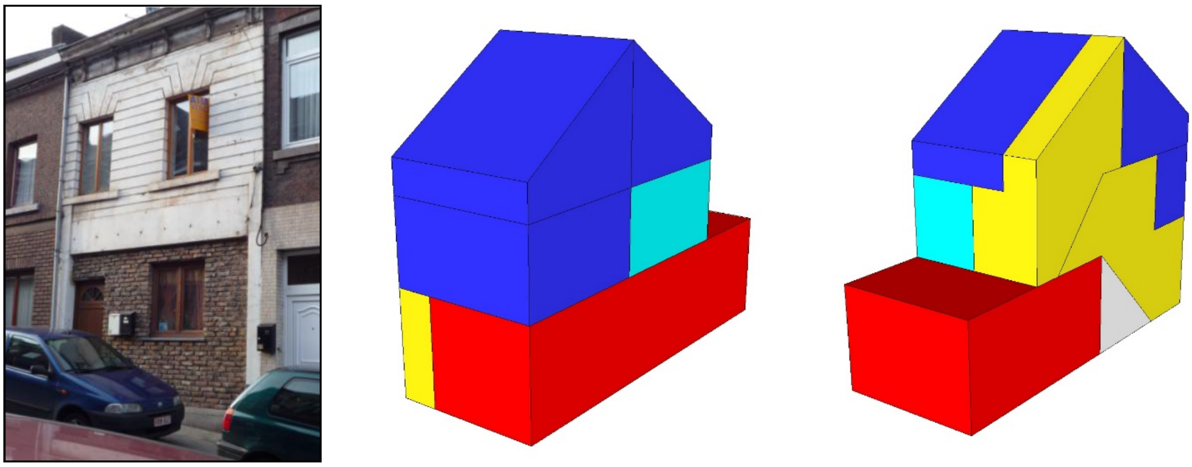


Figure 1: Blue Collar (BC) house front façade and 3D front and back views of initial occupation pattern; the blue volume is the “night zone” (with bathroom in clearer); the red one, the “day zone”; circulations are in yellow.

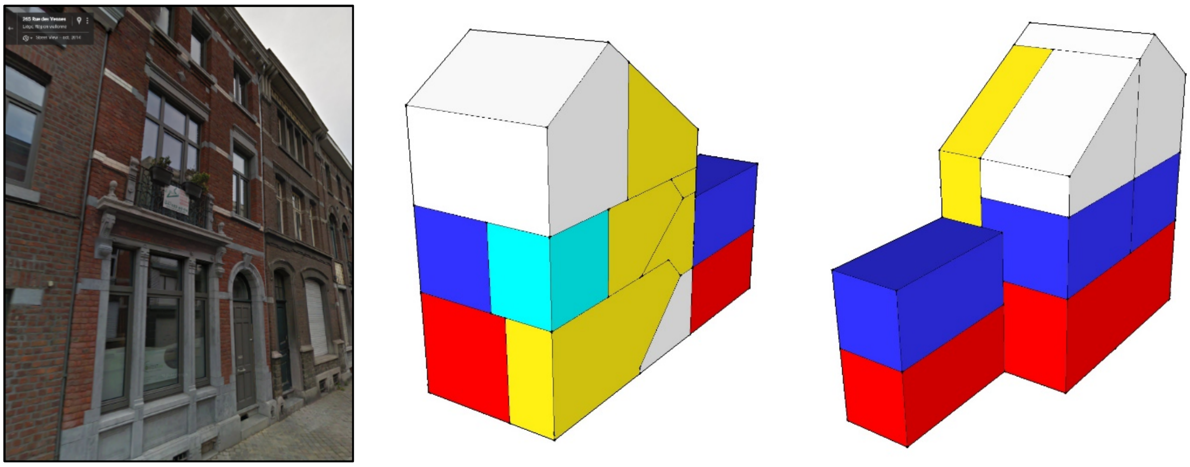


Figure 2: Master (M) house front façade and 3D front and back views of initial occupation pattern; the blue volume is the "night zone" (with bathroom in clearer); the red one, the "day zone"; circulations are in yellow. White zones are unused and unheated.

Figure 1 presents the modest "blue-collar" house (~ 18 to 20% of Walloon dwellings), characterized by simple architecture, small spaces and general bad condition – especially the annex at the rear. The dwelling contains, on the ground floor, a living room, circulation spaces, basement access, a toilet, and a kitchen in the annex; the upper floors of the main volume contain 3 (small) bedrooms and a bathroom. It is inhabited by a family of four; one of the parents works outside the house during the week, the other stays at home to care for their smallest child while the second child attends school. After renovation, the occupation pattern is likely to change, as the "stay-at-home" parent will take a half-time job back.

The four sources of winter discomfort given by the owners are the windows (simple glazing and high infiltration rate), the basement-adjacent walls (cold walls), the need for more light in the top floor (skylights), and the heating production system, old and weak. Among other important information and requirements are the low renovation budget (€50.000, with the necessary loan), the simplicity of building operation (programmable regulation) and the need to occupy (most of) the building during operations, which lowers the number of possible solutions. Difficult access to the rear façade and urban planning constraints also play a role in the present scenarios selection.

The second house (see figure 2) is similar to the first but presents superior size and architectural quality ("master house"), especially on the front façade, which makes outside intervention impossible. The annex is generally in the same (bad) condition; in this case, it leans on half the width of the rear façade, on two levels (with a bedroom above the kitchen). The dwelling initially contains 3 bedrooms, and the top floor is unused (and un-usable without important fitting); the owners, a family of 5, wish to invest this space, in order to create two bedrooms and an additional bathroom, and to enlarge the parents' bedroom on the lower floor (see figure 3). The building is usually heated following children school schedule during the week.

Sources of discomfort also find an echo in the blue collar house, as windows, basement-adjacent walls and bad heating production system are pointed out as problematic. In this case, though, the main discomfort comes from the attic, uninsulated and highly "ventilated". The maximal budget is €100.000, from which 20.000 have to be withdrawn for necessary interior fitting, the new bathroom and other non-performance related works. The same difficulties arise, as far as urban planning regulations and access to the backyard are concerned.

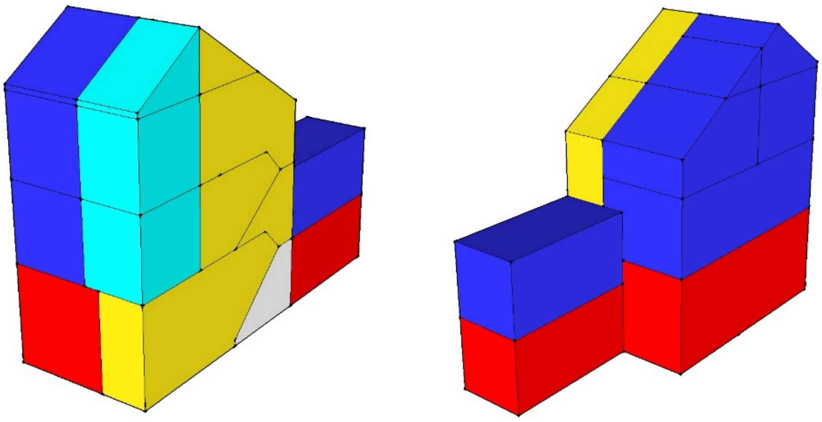


Figure 3: Master house 3D front and back views of final occupation pattern; the blue volume is the "night zone" (with bathroom in clearer); the red one, the "day zone"; circulations are in yellow. White zones are unused and unheated.

For both dwellings, a series of renovation works has been proposed: for each renovation case, the improvement (when compared to the previous case) has been highlighted in the Table1.

Table 1. Proposed renovation case options for both blue-collar and master houses

	Units	Base	Renovation cases													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Blue collar house																
Protected volume	m^3	338.3														
Heated floor area	m^2	125														
Windows	W/m^{2}K	5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1	1
Doors	W/m^{2}K	4	1	1	1	1	1	1	1	1	1	1	1	0.6	0.6	0.6
Front facade[1]	W/m^{2}K	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
Rear facade	W/m^{2}K	2.3	2.3	2.3	2.3	2.3	0.24	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Annex facade	W/m^{2}K	2.7	2.7	2.7	2.7	2.7	0.24	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Tilted roof	W/m^{2}K	0.6[2]	0.6[2]	0.6[2]	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Flat annex roof	W/m^{2}K	0.6[2]	0.6[2]	0.6[2]	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Floor on basement[3]	W/m^{2}K	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Annex floor (on ground)[3]	W/m^{2}K	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Stairs (on basement)	W/m^{2}K	1.6	1.6	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Basement-adjacent wall 1	W/m^{2}K	2.2	2.2	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Basement-adjacent wall 2	W/m^{2}K	2.6	2.6	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Average U-value	W/m^{2}K	1.57	1.3	1.19	1.08	1.08	0.79	0.79	0.79	0.79	0.79	0.77	0.77	0.71	0.71	0.71
v50 (air tightness)	m^3/h.m^2	12	9.6	8.4	6	6	3	3	3	3	3	3	3	3	3	3
Ventilation system[4]	-	-	C	C	C	C	C	C	C	D	D	D	D	D	D	D
Heating system[5]	-	1	1	1	1	2	2	2	3	2	3	2	3	2	3	4
Global efficiency (PE[6])	-	0.64	0.64	0.64	0.64	0.96	0.96	0.96	1.452	0.96	1.452	0.96	1.452	0.96	1.452	0.95
Domestic Hot Water system[5]	-	1	1	1	1	2	2	2	5	2	5	2	5	2	5	5
Global efficiency (PE[6])	-	0.26	0.26	0.26	0.26	0.39	0.39	0.39	0.21	0.39	0.21	0.39	0.21	0.39	0.21	0.21
Thermal solar installation	m^2	-	-	-	-	-	-	-	-	-	-	-	-	4	-	6
PV solar installation	kWc	-	-	-	-	-	-	-	-	-	-	-	-	-	2	2
Master house																
Protected volume	m^3	505	686													
Heated floor area	m^2	150	195													
Windows	W/m^{2}K	5/3.1[7]	1.5/3.1[7]	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	1	1
Doors	W/m^{2}K	4	4	1	1	1	1	1	1	1	1	1	1	0.6	0.6	0.6
Front facade[8]	W/m^{2}K	2.4	2.4	2.4	2.4	2.4	2.4	2.4	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Rear facade	W/m^{2}K	2.4	2.4	2.4	2.4	2.4	2.4	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Annex facade	W/m^{2}K	3	3	3	3	3	3	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Tilted roof	W/m^{2}K	2.4	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Flat annex roof	W/m^{2}K	2	2	2	2	2	0.24	0.24	0.24	0.24	0.24	0.19	0.19	0.15	0.15	0.15
Floor on basement[3]	W/m^{2}K	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
Annex floor (on ground)[3]	W/m^{2}K	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7	0.7
Stairs (on basement)	W/m^{2}K	1.7	1.7	1.7	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Basement-adjacent wall 1	W/m^{2}K	2.2	2.2	2.2	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Basement-adjacent wall 2	W/m^{2}K	2.4	2.4	2.4	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35	0.35
Average U-value	W/m^{2}K	2.07	1.73	1.53	1.47	1.47	1.37	0.82	0.55	0.55	0.55	0.52	0.52	0.43	0.43	0.43
v50 (air tightness)	m^3/h.m^2	12	9	7.2	6	6	5.4	3	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.4
Ventilation system[4]	-	-	-	C	C	C	C	C	C	D	D	D	D	D	D	D
Heating system[5]	-	1	1	1	1	2	2	2	2	2	3	2	3	2	3	4
Global efficiency (PE[6])	-	0.64	0.64	0.64	0.64	0.96	0.96	0.96	0.96	0.96	1.452	0.96	1.452	0.96	1.452	0.95
Domestic Hot Water system[5]	-	1	1	1	1	2	2	2	2	2	5	2	5	2	5	5
Global efficiency (PE[6])	-	0.26	0.26	0.26	0.26	0.39	0.39	0.39	0.39	0.39	0.21	0.39	0.21	0.39	0.21	0.21
Thermal solar installation	m^2	-	-	-	-	-	-	-	-	-	-	-	-	6	-	8
PV solar installation	kWc	-	-	-	-	-	-	-	-	-	-	-	-	-	3	4

[1] No intervention possible from the outside or the inside without important costs and urban planning constraints; considered unprofitable.

[2] The roof initially contained 6 cm of old mineral wool; only insulation for the whole envelope.

[3] No intervention possible from the basement (low ceiling); no intervention possible for both from the upper floor (costs, dwelling in use…).

[4] C = semi-mechanical ventilation system (natural supply, mechanical exhaust); D = all mechanical ventilation system with heat recovery.

[5] 1= old natural gas boiler; 2= new condensing natural gas boiler; 3= air-water heat pump (COP=4); 4= pellets boiler; 5= DHW electric boiler.

[6] PE = Primary energy; primary energy conversion factors are 1 for fossil fuels and biomass and 2.5 for electricity.

[7] Some windows already presented (old) double glazing; first case only considered replacement of single galzed windows.

[8] Intervention is possible from the inside, as works can be carried out room by room

The first few renovation works (steps 2 to 7 for the first, 2 to 8 for the second) present a progressive insulation of the protected volume, the installation of a ventilation system and of new heating and DHW production systems, with respect to the owners' priorities and requirements. Cases 8 (for the first; 9 for the second) to 10 see some variations in the previous cases (heat pump, all mechanical ventilation system with heat recovery). The third part (cases 11 and 12) shows an increase (level 2) of the insulation of cases 9 and 10, which are yet furthermore insulated (level 3 ≈ passive recommended level) in cases 13 and 14. Case 15 displays the results for a pellets boiler for heating system, combined with solar systems (also present in cases 13 and 14).

The financial hypotheses are as follows:

- Inflation rate: 1,5% (source: Federal Planning Bureau, for 2014)
- Mortgage loan rate: 2,5%
- VAT on renovation works and pellets: 6%
- VAT on fossil fuels and electricity: 21%
- Discount rate: 4% (source: Federal Public Service Finances)
- Initial energy prices per kWh: pellets: €0,056; natural gas (NG): €0,066; electricity: €0,212 (day) / €0,1272 (night) (source: Renouvelle magazine, June 2015)
- Scenario of price evolution: 1,75%/yr (moderate)
- The length of the loans are progressively increased from 5 to 20 years, so as to keep a monthly payment below €400 (for the blue collar house) or €500 (for the master house, except for the last 3 cases where the payments rise to €600 to €700 per month to keep the loan at 20 years max.).

4. Results

The results for the blue collar house are displayed in the Table 2 below; the results for the master house are listed in Table 3. The first half of each Table displays "default" results (using the official standardized calculation method for EPC results), while the second half presents "users" results (using additional behavioural data and heating patterns to introduce human factor in the equations of that steady state calculation method). For each performance criterion, renovation cases have been classified to distinguish worst results (black cells) from best results (white cells): the clearer the cell, the better the result.

In a complete and exhaustive case study, other scenarios would be displayed outside this organized guiding thread, proposing different renovation scenarios and/or different technical/technological solutions. As it is to be expected from this selection, scenarios displayed here see global gradual improvement of CO_2 emissions, energy performance and (winter) comfort index. Actually, among non-financial criteria, only the overheating risk does not gain from deep renovation works, but this is a logical result from added insulation and air tightness.

Despite a progressive increase in intervention costs and available incentives (identical in "default" and "users" methods), energy bills and total costs on 20 years, and NPVs, do not seem to follow the same simple logical progression, and therefore bring obvious complication to the renovation scenarios assessment. Most ambitious renovation scenarios (cases 13 to 15 in both houses) get top scores in all but those aspects, and should be discarded on first analysis, due to costs above the owners' limit and clear unprofitability (in both "users" and "default" methods). Still, it appears possible to target less ambitious, but profitable, renovation scenarios below the maximum budget, in the "moderate" cases (7 to 12). In a similar fashion, less ambitious projects (cases 1 to 4) do not appear profitable, due to high renovation costs and low energy gains.

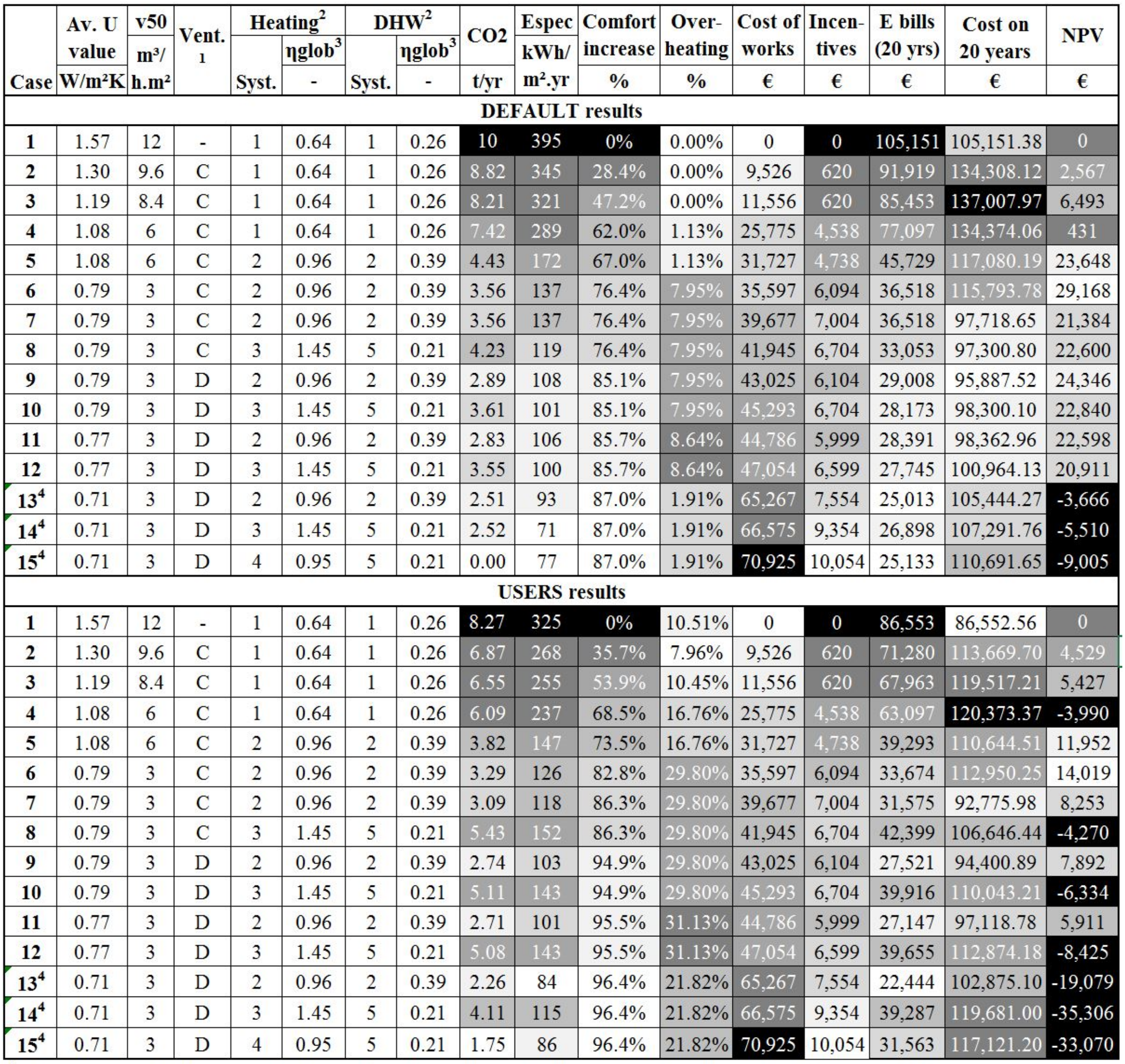
The official ("default") calculation method usually overestimates the NHD of a dwelling, but it also appears to underestimate the Domestic Hot Water (DHW) demands, with the protected volume as only evaluation parameter. "Users-included" calculations, on the other hand, present lower NHD (thanks to lower set temperatures, higher internal gains, shorter heating periods…) and higher DHW demands. Therefore, detrimental default efficiencies values exercise higher influence on the final DHW energy consumption, as can be seen in cases that propose electric heating of water for domestic purposes, with the added influences of high electricity primary energy conversion factor, high electricity prices and low incentives. This usually result in unprofitable solutions (where NPV < 0).

In "users" results, differences appear that must be noted (except for the cost of works and incentives, which remain the same in both methods):

- Projects are visibly evaluated with lower CO_2 emissions and energy consumption ("Espec" criterion); these criteria even present a less progressive evolution through the cases;

- Comfort index (winter comfort) is given higher figures here, due to lowered NHD. Summer comfort ("overheating" criteria) presents the same variation (higher figures) due to increased internal gains in "users" calculation method.
- Energy bills on 20 years appears to have increased, but only for cases that propose electric DHW production solutions (case 8 in the BCH project, cases 10 and 12 for both), resulting in negative NPVs.

Table 2. Results for the blue collar house



Case	Av. U value	v50	Vent. [1]	Heating[2]		DHW[2]		CO2	Espec	Comfort increase	Over-heating	Cost of works	Incen-tives	E bills (20 yrs)	Cost on 20 years	NPV
					ηglob[3]		ηglob[3]									
	W/m²K	m³/h.m²		Syst.	-	Syst.	-	t/yr	kWh/m².yr	%	%	€	€	€	€	€
DEFAULT results																
1	1.57	12	-	1	0.64	1	0.26	10	395	0%	0.00%	0	0	105,151	105,151.38	0
2	1.30	9.6	C	1	0.64	1	0.26	8.82	345	28.4%	0.00%	9,526	620	91,919	134,308.12	2,567
3	1.19	8.4	C	1	0.64	1	0.26	8.21	321	47.2%	0.00%	11,556	620	85,453	137,007.97	6,493
4	1.08	6	C	1	0.64	1	0.26	7.42	289	62.0%	1.13%	25,775	4,538	77,097	134,374.06	431
5	1.08	6	C	2	0.96	2	0.39	4.43	172	67.0%	1.13%	31,727	4,738	45,729	117,080.19	23,648
6	0.79	3	C	2	0.96	2	0.39	3.56	137	76.4%	7.95%	35,597	6,094	36,518	115,793.78	29,168
7	0.79	3	C	2	0.96	2	0.39	3.56	137	76.4%	7.95%	39,677	7,004	36,518	97,718.65	21,384
8	0.79	3	C	3	1.45	5	0.21	4.23	119	76.4%	7.95%	41,945	6,704	33,053	97,300.80	22,600
9	0.79	3	D	2	0.96	2	0.39	2.89	108	85.1%	7.95%	43,025	6,104	29,008	95,887.52	24,346
10	0.79	3	D	3	1.45	5	0.21	3.61	101	85.1%	7.95%	45,293	6,704	28,173	98,300.10	22,840
11	0.77	3	D	2	0.96	2	0.39	2.83	106	85.7%	8.64%	44,786	5,999	28,391	98,362.96	22,598
12	0.77	3	D	3	1.45	5	0.21	3.55	100	85.7%	8.64%	47,054	6,599	27,745	100,964.13	20,911
13[4]	0.71	3	D	2	0.96	2	0.39	2.51	93	87.0%	1.91%	65,267	7,554	25,013	105,444.27	-3,666
14[4]	0.71	3	D	3	1.45	5	0.21	2.52	71	87.0%	1.91%	66,575	9,354	26,898	107,291.76	-5,510
15[4]	0.71	3	D	4	0.95	5	0.21	0.00	77	87.0%	1.91%	70,925	10,054	25,133	110,691.65	-9,005
USERS results																
1	1.57	12	-	1	0.64	1	0.26	8.27	325	0%	10.51%	0	0	86,553	86,552.56	0
2	1.30	9.6	C	1	0.64	1	0.26	6.87	268	35.7%	7.96%	9,526	620	71,280	113,669.70	4,529
3	1.19	8.4	C	1	0.64	1	0.26	6.55	255	53.9%	10.45%	11,556	620	67,963	119,517.21	5,427
4	1.08	6	C	1	0.64	1	0.26	6.09	237	68.5%	16.76%	25,775	4,538	63,097	120,373.37	-3,990
5	1.08	6	C	2	0.96	2	0.39	3.82	147	73.5%	16.76%	31,727	4,738	39,293	110,644.51	11,952
6	0.79	3	C	2	0.96	2	0.39	3.29	126	82.8%	29.80%	35,597	6,094	33,674	112,950.25	14,019
7	0.79	3	C	2	0.96	2	0.39	3.09	118	86.3%	29.80%	39,677	7,004	31,575	92,775.98	8,253
8	0.79	3	C	3	1.45	5	0.21	5.43	152	86.3%	29.80%	41,945	6,704	42,399	106,646.44	-4,270
9	0.79	3	D	2	0.96	2	0.39	2.74	103	94.9%	29.80%	43,025	6,104	27,521	94,400.89	7,892
10	0.79	3	D	3	1.45	5	0.21	5.11	143	94.9%	29.80%	45,293	6,704	39,916	110,043.21	-6,334
11	0.77	3	D	2	0.96	2	0.39	2.71	101	95.5%	31.13%	44,786	5,999	27,147	97,118.78	5,911
12	0.77	3	D	3	1.45	5	0.21	5.08	143	95.5%	31.13%	47,054	6,599	39,655	112,874.18	-8,425
13[4]	0.71	3	D	2	0.96	2	0.39	2.26	84	96.4%	21.82%	65,267	7,554	22,444	102,875.10	-19,079
14[4]	0.71	3	D	3	1.45	5	0.21	4.11	115	96.4%	21.82%	66,575	9,354	39,287	119,681.00	-35,306
15[4]	0.71	3	D	4	0.95	5	0.21	1.75	86	96.4%	21.82%	70,925	10,054	31,563	117,121.20	-33,070

[1] C = semi-mechanical vent. system (natural supply, mechanical exhaust); D = all mechanical vent. system with heat recovery.

[2] 1= old NG boiler; 2= new condensing NG boiler; 3= air-water heat pump (COP=4); 4= pellets boiler; 5= DHW electric boiler.

[3] Global efficiency (primary energy); primary energy conversion factors are 1 for fossil fuels and biomass and 2.5 for electricity.

[4] Case 13: 4m² of solar thermal panels; Case 14: 2kWc of PV panels; Case 15: 6m² of solar thermal panels + 2kWc of PV panels.

Table 3. Results for the master house

Case	Av. U value	v50	Vent.[1]	Heating[2]		DHW[2]		CO2	Espec	Comfort increase	Over-heating	Cost of works	Incentives	E bills (20 yrs)	Cost on 20 years	NPV
	W/m²K	m³/h.m²		Syst.	ηglob[3]	Syst.	ηglob[3]	[t/yr]	[kWh/m².yr]	%	%	€	€	€	€	€
DEFAULT results																
1	2.07	12	-	1	0.64	1	0.26	20.15	661	0%	0.00%	0	0	211,584	211,584.46	0
2	1.73	9	-	1	0.64	1	0.26	17.82	450	28.1%	0.00%	19,222	1,057	186,614	264,421.40	7,452
3	1.53	7.2	C	1	0.64	1	0.26	16.42	411	48.2%	0.00%	39,907	2,402	170,833	255,708.91	-756
4	1.47	6	C	1	0.64	1	0.26	15.75	395	60.1%	0.00%	42,203	2,402	163,857	253,927.58	3,355
5	1.47	6	C	2	0.96	2	0.39	9.38	233	65.1%	0.00%	48,512	2,602	96,796	200,940.49	60,892
6	1.37	5.4	C	2	0.96	2	0.39	8.89	220	67.6%	0.00%	51,722	2,818	91,600	202,790.76	62,464
7	0.82	3.0	C	2	0.96	2	0.39	6.09	149	81.9%	7.15%	62,095	5,903	62,067	152,523.98	77,809
8	0.55	2.4	C	2	0.96	2	0.39	4.78	116	88.5%	17.82%	65,147	6,379	48,279	143,143.65	87,862
9	0.55	2.4	D	2	0.96	2	0.39	3.92	92	94.3%	17.82%	69,917	6,379	38,464	140,961.64	91,575
10	0.55	2.4	D	3	1.45	5	0.21	5.29	95	94.3%	17.82%	72,321	6,979	41,292	147,036.95	86,547
11	0.52	2.4	D	2	0.96	2	0.39	3.79	89	95.0%	19.51%	69,479	6,377	37,077	138,877.00	93,431
12	0.52	2.4	D	3	1.45	5	0.21	5.17	93	95.0%	19.51%	74,781	6,977	40,330	150,015.23	84,516
13[4]	0.43	2.4	D	2	0.96	2	0.39	3.14	72	96.5%	8.85%	118,533	8,092	30,256	169,901.02	34,282
14[4]	0.43	2.4	D	3	1.45	5	0.21	3.41	61	96.5%	8.85%	119,411	11,242	38,154	187,007.02	17,791
15[4]	0.43	2.4	D	4	0.95	5	0.21	0.22	58	96.5%	8.85%	126,566	13,292	33,438	178,098.57	26,007
USERS results																
1	2.07	12	-	1	0.64	1	0.26	12.4	406	0%	0.00%	0	0	129,967	129,966.59	0
2	1.73	9	-	1	0.64	1	0.26	11.57	291	28.1%	0.00%	19,222	1,057	120,709	198,516.29	-7,657
3	1.53	7.2	C	1	0.64	1	0.26	11.04	275	48.2%	0.00%	39,907	2,402	114,086	198,961.77	-24,670
4	1.47	6	C	1	0.64	1	0.26	10.75	267	60.1%	0.00%	42,203	2,402	111,066	201,136.28	-24,363
5	1.47	6	C	2	0.96	2	0.39	6.67	164	65.1%	0.00%	48,512	2,602	68,260	172,405.29	9,851
6	1.37	5.4	C	2	0.96	2	0.39	6.36	156	67.6%	0.00%	51,722	2,818	64,940	176,131.39	9,620
7	0.82	3.0	C	2	0.96	2	0.39	4.85	118	81.9%	7.82%	62,095	5,903	49,000	139,456.95	11,895
8	0.55	2.4	C	2	0.96	2	0.39	4.10	99	88.5%	18.93%	65,147	6,379	41,144	136,008.25	16,244
9	0.55	2.4	D	2	0.96	2	0.39	3.71	87	94.3%	18.93%	69,917	6,379	36,228	138,726.38	15,246
10	0.55	2.4	D	3	1.45	5	0.21	6.62	119	94.3%	18.93%	72,321	6,979	51,698	157,442.98	-1,937
11	0.52	2.4	D	2	0.96	2	0.39	3.63	85	95.0%	20.67%	69,479	6,377	35,439	137,239.36	16,527
12	0.52	2.4	D	3	1.45	5	0.21	6.55	118	95.0%	20.67%	74,781	6,977	51,151	160,835.52	-4,367
13[4]	0.43	2.4	D	2	0.96	2	0.39	2.95	67	96.5%	8.60%	118,533	8,092	28,261	167,906.09	-42,278
14[4]	0.43	2.4	D	3	1.45	5	0.21	4.92	89	96.5%	8.60%	119,411	11,242	50,035	198,887.70	-72,111
15[4]	0.43	2.4	D	4	0.95	5	0.21	2.12	58	96.5%	8.60%	126,566	13,292	38,084	182,744.24	-56,939

[1] C = semi-mechanical ventilation system (natural supply, mechanical exhaust); D = all mechanical ventilation system with heat recovery.

[2] 1= old NG boiler; 2= new condensing NG boiler; 3= air-water heat pump (COP=4); 4= pellets boiler; 5= DHW electric boiler.

[3] Global efficiency (primary energy); primary energy conversion factors are 1 for fossil fuels and biomass and 2,5 for electricity.

[4] Case 13: 6m² of solar thermal panels; Case 14: 3kWc of PV panels; Case 15: 8m² of solar thermal panels + 3kWc of PV panels.

NPVs presented above will obviously change if the loan or the incentives conditions are different. The graph hereunder (Figure 4) shows the evolution of NPVs for all 15 cases of the master house (the results are similar for the BCH), with the 4 upper curves (round marks) representing the “default” results, and the lower 4 (square marks), the “users” results. Each of these 4 curves represents a variation: with or without the loan, with or without the incentives. Tables 2 and 3 only present the results for the “with loan and incentives” variation.

The graph shows quite clearly the cost optimum situation: if ‘extreme” scenarios (cases 1 to 4, cases 12 to 15) seem to become unprofitable (NPV < 0) with “users” method, it could be acknowledged that there still exists profitable scenarios among more moderate choices.

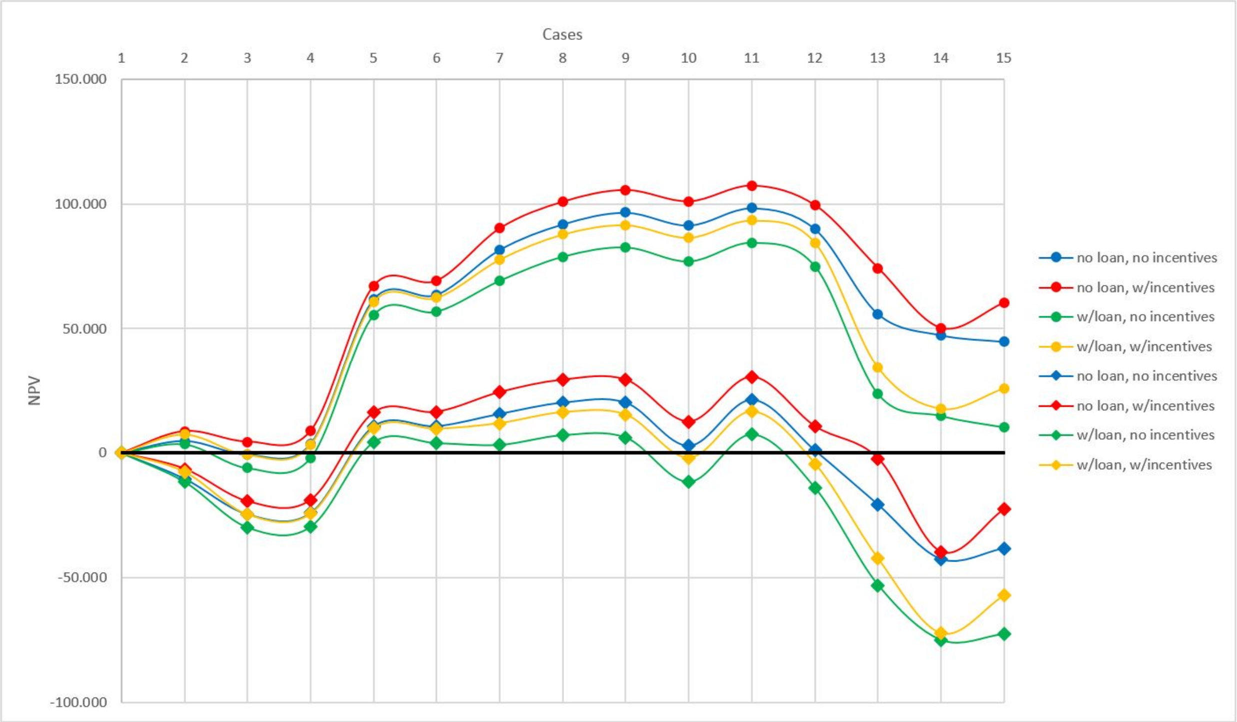


Figure 4. NPV evolution for 15 renovation cases of the Master house, showing discrepancies between the cases with or without loan or incentives, in the “default” and “users” method.

5. Discussion

Several precisions (Monfils, 2014; Monfils, 2015) must be added here, as they probably appear unclearly in the results:

- Some distortions may be found in the results due to the presence of uncertainty parameters in the EPC calculation method (other than standardization of users’ behaviour). For example, different assessors could find different results for the EPC of the same house, despite the “EPC protocol” that has been developed to avoid this problematic situation. In this particular case, all EPC assessments have been made by the same rigorous assessor to elude this difficulty.
- Results show the marks of important and disadvantageous default values (used for heating and DHW systems production efficiencies, for example). Most of these default values have been replaced, as the renovation scenarios progressed, by more accurate (yet still average, or theoretical) efficiencies, which tends to increase trust in the results as the renovation deepens.
- Climate also appears uncertain, especially in predictive simulations. In these simulations, the average climate for Liege for the years 2003 – 2013 was used. Heat Island Effect (urban increase of external temperature due to high rate of built areas, when compared to green and blue areas) has not been taken into account here, as it is yet undefined for Liege (and unsure, due to a relatively high percentage of green and blue areas).
- Results presented here derive from a “steady-state” calculation method that uses monthly average interior and exterior climates. Average set temperatures hide simplifications and, therefore, uncertainties; adaptive temperatures and fine heating regulation influences are invisible. Dynamic simulations would surely increase precision, but the purpose of this study is to find a way to use the existing EPC protocol, calculation method, inputs and outputs. Initial decisions that led to the actual EPC system have to be considered here.
- Rebound effect is the general exceeding of expected consumption that could occur after renovation, due to better comfort conditions. This remains difficult to quantify however, depending on households’ attitudes, behaviour and idea of comfort improvement (which can be shifted to increased consumption outside of the house); rebound effect therefore seemed another uncertainty parameter to add to the others. Furthermore, the Walloon calculation method already usually overestimates consumptions, even if improved by the introduction of human factors.

“Users included” calculation method lowers the profitability of all renovation cases, as stated before, by the logical reduction of energy consumptions and, therefore, absolute gains. This situation has several consequences: first, it produces more accurate NPV results, which is important to owners in their decision-making. This is, in some ways, a better “cost optimum” validation: this more severe selectivity in scenarios can help sort out “best” ones more clearly than in “default” hypotheses. Thus, it narrows the range of profitable renovation scenarios, discarding those where the energy consumption reduction is not sufficient to compensate renovation costs (first few cases) and those where the renovation additional costs are too high to be compensated by corresponding energy consumption reductions (last few cases).

Parallel assessment of incentives and NPVs can be made under that light: reality shows that incentives, in Wallonia, are not high enough to render most ambitious renovation scenarios, profitable. Figure 4 highlights the importance of loans and incentives conditions: accurate incentives system and “green” loans could help support technologies and motivate the renovation market, allowing targeted scenarios to turn profitable.

The first few cases, in both projects, display the minimal set of works asked by the owners. In the blue collar (BCH) project, this means replacing all windows and doors (due to bad frame condition or airtightness issues), and placing a semi-mechanical ventilation system, which is hardly profitable in itself, in strict financial terms, thanks to low incentives and relatively low influence on the calculation method; interest lies in the increase of winter comfort. In the master house (MH) project, first case sees the insulation of the tilted roof and the extension of the protected volume to create new spaces, which, in itself increases by 30% the global comfort, as it is the first comfort-related priority work cited by the owners. Case 3 is similar to BCH case 2 (unprofitable change of windows). BCH Case 4 appears even less profitable, as it is about increasing an already existing insulation layer in the roof (this work has been considered here as it is supposed owners would benefit from the installation of skylights to do this). The improvement in energy performance stays low, nevertheless.

Analysing the results of these cases, one could argue that the unprofitability of some works is somewhat drowned into the global scenario profitability, and almost forces to envision deeper renovation (and, therefore, added costs). It still appears possible to have deep and (almost) complete renovation of the house for less than €50,000 (in this case, thanks to small surfaces, avoidance of unprofitable interventions on the front façade and inferior floors, and the possibility of a less costly intervention on the back façade and annex). Cases 7, 9 and 11 appear as “cost optimum” solutions in this context, with the common influence of the “cost optimum” intervention that is the use of a new (and regulated) natural gas condensing boiler for heat and DHW production.

Cases 13 to 15 should be discarded on first analysis, due to costs above the owners’ limit and clear unprofitability. It is however interesting to include them in the global analysis, and to notice that, though the increase in costs (due to level 3 of insulation and solar equipment) is too high to be returned in energy gains, lower risk of overheating, CO_2 emissions, energy bills and total costs on 20 years could be positive arguments to some owners against less ambitious renovation projects. Making a general weighting system is difficult, even among the priority list; a household’s balancing and weighing of criteria is personal.

6. Conclusion

It is important to remind that the goal of this study is not to replace the actual standardized method, as it is necessary to compare buildings on a common ground; the goal is to question the uncertainty parameters, and propose a complementary calculation, based on the existing inputs and outputs of the EPC, to allow better decision-making strategies for households, as far as their real-estate ambitions are concerned. And from this point of view, the first important result is the closing of the gap between real and theoretical consumptions when users’ behaviour have been integrated in the calculation method (Monfils, 2014; Monfils, 2015).

In order to reach energy efficiency at any level, human factor is crucial: on one hand, efficient solutions (regarding transport, building energy consumptions, water and waste management…) have to be implemented by an intelligent decision-making authority who understands the complexity of the urban context and its impacts on environment. On the other hand, smart cities authorities need smart citizens, who are aware of their environmental impact, to use smart solutions to their full potential. In the field of residential use of energy, people are therefore a crucial parameter of both the problem and its solution. When facing renovation works, dwelling owners should be consulted at every step of the project and included in assessments.

“*It is becoming increasingly clear that the impact people have on the eventual performance of retrofitted dwellings is often greater than variations in the thickness of insulation or in the efficiencies of heating systems*” (Tweed, 2013).

Though renovation budgets have been fixed by owners by considering maximal real-estate value that can be expected for this house, in that kind of neighbourhood, the added real-estate value does not always appear as an important financial criterion in decision-making. This, however, is a result difficult to enlighten: choice of renovation works cannot be the only influence on real-estate value, as it also depends on location, volumes, functional spaces distribution, or architectural quality. Available incentives and loans characteristics could also exercise an influence.

It is also important to note that real DHW needs fundamentally changed the profile of renovation scenarios NPVs, thanks to high electricity prices and low incentives. Though the “users included” calculation method lowers the profitability of all renovation cases, cost optimum scenarios still exist, even amongst ambitious ones (though the “row” configuration of both houses plays an important role here). It can be noted, however, that the “users included” calculation method highlights less ambitious renovation scenarios than “default” method (considering equal weighting systems between criteria).

If value-action or attitude-behaviour gaps are to be considered when interviewing energy consumers on their energy-related behaviour, it could also be considered in the decision-making process in renovation, where comfort considerations can challenge financial interests in some decisions. For example, the change of windows would hardly appear “profitable” in the strict financial sense, but still is the most applied renovation intervention, partly because single-glazing devaluates real-estate value, partly because double glazing improves hygrothermal and acoustic conditions of the rooms.

Uncertainty on financial criteria and “value-action gap” regarding profitability, encourage to not let them lead all discussions when presenting possible scenarios to the owners, to consider them as important information but to press on interesting advantages of other criteria (which, often, are more accurate because based on less changing parameters than energy prices and loan interests).

Multi-criteria assessment could then be called to define global weighting factors between priority criteria, but it will not necessarily lead to appropriation of results, as it changes with every household (even if not the priority positions, at least the weighting factors to balance them), but it must be recognized that some criteria are important to many (like the search for comfort or the reduction of energy bills), whereas some criteria are only important to a few (like the environmental impact).

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