The Energy Performance Certification: A tool for smarter cities?

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1. ABSTRACT

One of the existing tools that could help creating *smart cities* is the Energy Performance Certification (EPC) of residential buildings, by introducing energy efficiency as a comparative criterion for real-estate purchase choices, influencing real-estate market value, stimulating energy saving investments, moving the housing market towards greater energy efficiency and creating comprehensive databases which are fundamental for shaping smart strategies on urban, regional and national levels. The impact on potential buyers or tenants is crucial in order to reach these goals but EPC's results, in their actual form, do not help raise people awareness: often distant from reality, overestimating consumption, they usually result is a general misunderstanding and misuse of the document.

This study aims at verifying that the actual calculation method used in certification could approach real building consumption, by using additional data on occupant behaviour and household characteristics. It first presents the concepts behind smart cities, then an overview of the uncertainties that weight on the Belgian certification calculation method parameters. It also presents variations that could be applied to the EPC calculation method in order to add behavioural parameters… inspired from case studies of buildings.

Keywords: energy performance certification, behavioural patterns, smart city.

2. INTRODUCTION

A new strategic concept recently appeared on the European energy efficiency landscape: smart cities, defined as *"cities well performing in governance, economy, environment, mobility, people and living, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens"* (Giffinger, et.al, 2007).

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.

"*Against the background of economic and technological changes caused by the globalisation and the integration process, cities in Europe face the challenge of combining competitiveness and sustainable urban development simultaneously. Very evidently, this challenge is likely to have an impact on issues of Urban Quality such as housing, economy, culture, social and environmental conditions*.[1]"

European Union's strategy for a sustainable growth makes the building sector energy consumption reduction a central objective for meeting the commitments taken under the Kyoto protocol on climate change. At a worldwide scale, this sector is thus regarded as one of the most

[1] http://www.smart-cities.eu

cost-effective options for saving CO_2 emissions (IPCC, 2007). Newly built housing can obviously enter the “smart cities” frame more easily than the existing building sector, but a tool has been developed to target this 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 an assessment of the building energy performance and reference values, allowing performance comparisons between buildings. The EPC also includes recommendations for technically possible improvements. It is believed that the clear information given by the certificate should 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, which are fundamental for shaping smart strategies on a local (‘smart cities’), regional (‘smart regions’) and national levels.

The impact on potential buyers or tenants is therefore crucial in order to reach these goals. Two different families, living in two identical homes, would receive identical EPCs, but their real consumption would vary from one to three or four (CPDT, 2005), depending on occupants’ behaviour and household characteristics. The actual calculation method does not provide realistic results, and this is confirmed by energy bills; 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) allows us to draw general conclusions: the EPC is often considered unhelpful, unrealistic (and therefore mistrust), distant from reality, overestimating consumption, too long and technical, confusing…

This proves that, in order to achieve its goals, the EPC needs to be improved, by closing the gap between theoretical and real consumptions; this way, it can be understood, trusted and used by its owner.

3. UNCERTAINTY PARAMETERS OF THE EPC

The first step is to identify in the regulatory calculation method those uncertainty parameters that create a gap between calculated and measured consumptions and put the software precision into perspective. The idea here is not to question every parameter or to blame the calculation method, as it often results from a difficult balance between necessary parameters, precision possibilities and the time and cost required to make a full calculation. Any parameter could be pointed out as uncertain, as it is often the reflection of an average or a disadvantageous default value that secures best results when more precise information is available. The calculation method has been designed to compare buildings, not their users; this paper will focus on those general shortcuts that have been decided in order to withdraw human factor from equations.

First to be pointed out is the fundamental choice[2] that led to the use of a standardised consumption calculation method instead of a measured-data based method. Measured certification normalizes real consumption data in order to reach standardized energy consumption, using calculation parameters such as climate, building size and type, behavioural habits and pattern of use (EPBD, 2011[3]). Besides the need to divide the measured energy into its different uses, adjustments to standardised energy use can be a huge problem, as real consumption data are obviously greatly influenced by the behaviour of the occupants. In contrast, the calculated energy rating evaluates the performance using building characteristics

[2] The 2002/91/Ce and 2010/31/UE European Directives imposed domains of energy consumption that had to be considered, but left the choice of the calculation method and its details to the member states (or regions).

[3] This source states that, in 2010, Sweden, Finland, Germany and Luxemburg used measured data. Every other country used calculated consumption to assess a building’s performance.

(as close to reality as possible), default values (when no accepted proof of a more accurate value is available) and standardized parameters (which cannot be replaced by more accurate values, even if they are known).

The Belgian regulatory calculation method uses, for outside climate, the average monthly temperature in Uccle (Brussels) for the last 50 years, preventing "unnecessary" geographical differentiation in such a small country. But variations do exist: there is a 3°C variation gap in the annual average temperatures of the main Belgian climatic station[4]; one can easily argue that the lower the outside temperature, the higher the energy consumption in order to reach the same indoor climate.

In order to "certify the building, not its users", occupants' behaviour, comfort and building occupation have been standardized: the whole dwelling is considered used at all times, and heated at a constant temperature of 18°C; though permanent occupation increases internal loads, it also extends heating periods and, therefore, energy consumption. Reality displays a complete range of behaviours, set temperatures and heating habits that are bound to influence greatly the final energy consumption. Examples of previous studies on behaviour – related residential energy consumption are given by P. O. Fanger (1977), J.-M. Hauglustaine (1979), L. Lutzenheiser (1993), H. Wilhite et al. (1996, 1998 and 2000), A.-L. Linden et al. (2005), G. Wallenborn (2006), De Groot et al. (2008) or, more recently, O. Guerra-Santin (2010) and B. Allibe (2012). These studies pointed metabolism, activity, gender and clothing amongst important comfort factors, provided insight into behavioural patterns (describing the inside climate as a rather energy-intensive heating habit) or showed variations in household behaviours, equipment rates and energy consumption.

The building being ideally empty of any occupancy, other ways of estimating behaviour-related consumptions have been imagined, such as domestic hot water (DHW, which should be based on the number of inhabitants and personal hygiene habits), ventilation rates (normally depending on household composition and windows opening habits) or internal gains (with no consideration for the level of equipment or human presence). Those consumptions are, indeed, evaluated on the basis of the protected volume only.

We will, in this paper, focus on the behavioural variables that could be added to the calculation method in order to close the gap between real and estimated consumptions.

4. SIMULATION

The study concentrates on three dwellings, each representing a widely spread building typology in Belgium. We created for these three dwellings an EPC with precision and respect to the regulation. Then we created "alternative" certificates by entering the calculation method and establishing different values for standardized parameters, in order to compare results.

4.1 Dwellings and households description

4.1.1 Apartment

The first dwelling is a two bedrooms apartment, located in a 1920's building in Liege:

- Total heated floor surface (Ach): 95 m² (walls included);
- Total heated volume (Vp): 330 m³ (walls, floor and ceiling included);
- Its envelope is composed of brick walls, concrete floors and ceilings and recent (2011)

[4] www.meteobelgique.be

double glazed windows. The average envelope U-value (according to regulatory calculation method) is 2.2 W/m²K;

- There is no ventilation system; the owner, however, opens his windows quite often, even during winter (at nights). An extractor hood in the kitchen exhausts vapour when preparing meals;
- The system producing heat and domestic hot water is an old (1985) shared (between ten flats) oil-fired boiler (the EPC considered a 68% efficiency for heat production, 40% for hot water production); a non insulated hot water loop with a very low efficiency (30%) worsens the global efficiency. There is no thermostat in the dwelling, so that the owner heats up the place with only reference to his comfort, and shuts down the system at night (or when opening windows).
- It is occupied by a single person, who works full-time outside of his apartment (only heating in the evenings during the winter weeks), but is often present in the week-ends. He is aware of his environmental impact and tries to limit his consumption. The heating is usually completely shut down from May to October.
- He owns a relatively high number of electrical equipment, but he tries to completely shut some of them down when possible.

The results of the regulatory calculation indicate a total primary energy consumption of a 148,933 MJ per year (which represents a specific primary energy consumption of 433.4 kWh/m² - labelled F on the EPC scale - or an equivalent fuel consumption of 3,835 litres per year).

The real average consumption however (which data could only be collected for the three previous years), is approximately five times lower (around 800 litres of fuel per year).

4.1.2 Detached house

The second dwelling analysed in this study is a more recent (1985) detached house, in the suburbs, quite representative of the post-WWII extra-urban development, representing about 15% of the Walloon housing (Monfils and Hauglustaine, 2013). It has:

- A total heated floor surface (A_{ch}) of 205 m² (walls included);
- A total heated volume (V_p) of 517 m³ (walls, floor and ceiling included);
- An envelope composed of cavity walls (with unknown presence of insulation – the default value considers them to be slightly insulated, due to the building date), concrete floor (insulated with 4 cm of expanded polystyrene), well insulated roofs and ceilings (20 to 24 cm of mineral wool witnessed by the certifier) and double glazed windows (from different manufacture dates). Its calculated global average U-value is 1 W/m²K.
- An incomplete ventilation system (only natural extraction from both bathrooms).
- A rather recent (yet high temperature) oil-fired boiler producing heat and domestic hot water heating system (global efficiency: 66.4% for heat production, distribution, emission and storage, 65% for hot water); a thermostat, placed in the living room, monitors the temperature and insures a constant 21°C in winter days, 16°C in winter nights. There is also a wood-supplied fireplace, which the owners like to use in winters and mid-seasons.

In this house lives a family of four (father, mother and 2 children). The father works out of home, the children go to school (away from home from 8 AM to 4 PM in average, even on Wednesdays, when they go to sport activities) and the mother works outside of home also, but is present when her children are. They consider their house well insulated and heat for comfort.

They usually use the boiler for heating from October to May (included), and use the fireplace as extra, also in mid-season periods if needed. But they would not give specific periods of non-heating, for "it depends too much on Belgian weather".

The regulatory certification would present an annual theoretical consumption of 299.4 kWh/m² (221,727 MJ or 5,703 litres of fuel-equivalent), which classes this building at the D level of the certificate scale.

The real consumption data, relating to the last ten years, reveals a real consumption around 2,500 litres a year (around 25,000 kWh). The regular use of wood in the fireplace (around 1 ton a year) adds another 3,500 kWh[5] to the total (28,500 kWh or 140 kWh/m².yr).

4.1.3 Row house

The third dwelling, which also represents around 15% of Walloon dwellings, is a three bedrooms row house, built in the early 1970's:

- It has a total heated floor surface (A_{ch}) of 225 m², for a total heated volume (V_p) of 612 m³. These unusually high values (for this kind of typology) translate the inclusion of basement rooms, indirectly heated through the open staircase;
- This building has been slightly renovated on several occasions. As a result, (relatively thin) layers of insulation here and there improve the overall thermal efficiency (the average envelope U-value is 1.6 W/m²K).
- The only ventilation system is a mechanical extractor in the bathroom. Attention is paid to close windows when the heating is on.
- The heating (and hot water producing) system is a rather new condensation boiler (global heat system efficiency: 80%; global hot water system efficiency: 75%); a thermostat is set to keep the temperature at 16°C during cold nights and 21°C during cold days; an external probe measures outside temperature and communicates with the boiler. A wood fireplace is present in the living room, as an extra heating source.

It is occupied by a family of four people as well, with grown-up children (one of which leaves the house for the whole week, but was present for the period covered by the real consumption data). Both parents work full-time, the mother being there for her children after school. They are environment-conscious and careful about their consumption.

Its calculated annual consumption rises to 3,609 litres of fuel-equivalent (or 152,229 MJ), whereas the real consumption reaches 2,000 m³ of natural gas and around 1 ton of wood per year. The announced specific consumption, 188.5 kWh/m², would credit the building with a C label on the official scale.

4.2 Tool

This study uses the regulatory EPC calculation method (Wallonia, 2013) provided by the Walloon public administration in charge of the certification, for the simulations. The only official tool implementing it, however, does not allow any modification: we therefore used an Excel sheet. This tool was initially developed, before EPBD implementation, to help voluntary architects to undertake an early evaluation of their clients' house performances, in exchange for advice and subsidies in the "Building with Energy… Naturally" action frame, set up since 2004 by Wallonia in order to introduce the building sector with the EPB regulations). The sheet has

[5] Considering 1kg of wood supplies 3,5kWh (http://www.apere.org/index/node/41)

been modified to stick to the certification calculation method, and is used in parallel with the official certification software (for U-values or system efficiency default values, for example).

For each of the following parameter variation, the modifications proposed to the equations will be explained.

4.3 Modification of the calculation method

In this next part, we will develop the method used to introduce new parameters in the calculation method, such as the “real” inside set temperature and outside climate, the equipment rate (influencing internal gains and electricity consumption) or the occupation rate of the building, which influences heating periods and internal gains calculation.

4.3.1 Climate and location

Climate can (even in small Belgium) be dependant on the location, and it obviously influences heating habits and real annual consumptions. It seems therefore important to assess the variation gap brought by the “single climate zone” hypothesis, using more realistic climates from cities closer to the actual location of the studied dwellings: Spa for the row house, Liege (Bierset) for the others. The data, given by the official Belgian weather forecast website[6], correspond to the years for which we possess real consumption data.

In the official calculation method (Wallonie, 2013), the targeted parameter is $\theta_{e,m}$, the average monthly outside temperature. The table hereunder shows the official values (1st line) and the average (between 2003 and 2013) temperatures in Spa and Liege. In the following graphs, monthly temperature of each year have been used in calculations, in order to compare with real consumption data.

Table 1: Average monthly temperature comparison

Average monthly temperature $\theta_{e,m}$ [°C]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Uccle (official)	3.2	3.9	5.9	9.2	13.3	16.2	17.6	17.6	15.2	11.2	6.3	3.5
Spa (average 2010 to 2012)	0.2	-0.1	5.4	8.7	11.6	14.6	16.2	16.2	13.1	9.3	5.5	0.7
Liege (average 2010 to 2012)	2	1.6	6.9	10.2	13.1	16.4	18.2	17.9	14.7	10.9	6.9	2.4

4.3.2 Internal gains

It is widely acknowledged that inhabitants (their number, habits and equipment) influence the consumption (EPBD, 2011; Hauglustaine, 1979; Hauglustaine, 2002; Guerra Santin, 2010) by increasing heating and Domestic Hot Water (DHW) demand, as well as internal loads; these last are composed of metabolic loads (depending in reality on the occupation rate, clothing, activities…) and equipment loads (mainly depending on the equipment level and devices efficiencies).

In the official calculation method, internal gains vary linearly with the protected (heated) volume; the monthly internal loads (from both metabolisms and equipment) are evaluated as follows:

$$Qi,seci,m = (0,67 * VPER + 220) * tm * Vsec,i/VPER \qquad (1)$$

[6] www.meteobelgique.be

With:

- $Q_{i,seci,m}$: the monthly internal gains for the energy sector 'i' [MJ];
- V_{PER}: the protected volume of the dwelling [m³];
- $V_{sec,i}$: the protected volume of the energy sector (part of the unit heated and cooled by the same systems) [m³];
- t_m: the length of the month [Ms].

The proposition in this study consists in taking a more realistic approach on the evaluation of internal loads, considering electrical equipment, lighting and dwelling occupation. For each of the houses, a small questionnaire to the occupants allowed to set up the list of actual equipment that are used in the dwelling, as well as all other parameters that will be discussed below (number of inhabitants, heating patterns…).

Equipment

Only main appliances were considered here: fridges, freezers, electric hobs, ovens, dishwashers, microwaves ovens and extractor hoods in the kitchen; washing and drying machines, irons and vacuum cleaners in the laundry; televisions, computers and others entertainment devices in the living room. Their annual consumption has been evaluated (see table 2) according to literature (Hauglustaine, 1979; Sidler, 1998), technical product specifications from commercial websites, average power values and use patterns[7]. In order to consider the consumption due to other small appliances, occasional uses and sleep modes, a consumption of 100 kWh/year + 25 kWh/person.year is added to the total. By hypothesis, we considered that the whole installed power takes part in the internal loads. The complete list can be seen in the table below.

Some appliances are used all year round, others on very occasional times. For most of them however, the size of the chosen device or use pattern can depend on the number of inhabitants, the area of the dwelling (influencing the use of the vacuum cleaner for example) or the tendency to adopt environment-friendly behaviours (which can be obtained from the questionnaire). Theses parameters were taken into account for the consumption evaluation.

For each case study, the sum of every appliances consumptions is therefore made considering the questionnaire each household filled, then the corresponding daily internal loads are evaluated as follows:

$$Q_{E,d} = (C_A * t_d * 1000)/N_h \quad (2)$$

With:

- $Q_{E,d}$: the daily internal loads due to the equipment [J];
- C_A: Sum of every appliances consumptions [kWh/year];
- t_d: the length of the day: 86400 seconds.
- N_h: the length of the year: 8760 hours.

[7] www.energuide.be; www.curbain.be; http://documentation.bruxellesenvironnement.be; www.lesnumeriques.com; http://energie-developpement.blogspot.be;

Table 2: Calculation of the equipment-related internal loads

EQUIPMENT		Average power	Considered use pattern		Consumption			Case studies consumptions		
					Per cycle	Annual		[kWh/yr]		
		[W]	Fixed	Variable	[kWh/cycle]	[kWh/yr]	[kWh/pers.yr]	Apartment	Detached house	Row house
Fridge A+++ (with freezer)			continuous			117	9			
Fridge A++ (with freezer)			continuous			169	14			
Fridge A+ (with freezer)			continuous			212	19		288	288
Other fridges			continuous			277	25	302		
Electrical hobs		1500	15 min/day	5 min/pers.day		130	45		310	310
Separate freezer A+++			continuous			74	14			
Separate freezer A++			continuous			165	16		229	
Separate freezer A+			continuous			205	18			
Other freezers			continuous			300	20			380
Dishwasher A+++				1 cycle/pers.week	0.83		42			
Dishwasher A++				1 cycle/pers.week	0.92		46		184	
Dishwasher A+ ou A				1 cycle/pers.week	1		50			
Other dishwashers				1 cycle/pers.week	1.2		60	60		240
Microwaves ovens		900	30 min/week	10 min/pers.week		22	8	30	54	54
Oven		2500	30 min/week	10 min/pers.week		60	20	80	140	140
Extractor hood		120	15 min/day	5 min/pers.day		11	4	25	37	37
Washing machine A+++			1 cycle/week	1 cycle/pers.week	0.85	43	43		215	
Washing machine A++/A+			1 cycle/week	1 cycle/pers.week	1	50	50	100		250
other washing machine			1 cycle/week	1 cycle/pers.week	1.2		120			
Dryer A+++	32 weeks/yr			1 cycle/pers.week	1.43		45.8			
	50 weeks/yr			1 cycle/pers.week			71.5			
Dryer A++	32 weeks/yr			1 cycle/pers.week	1.75		56			
	50 weeks/yr			1 cycle/pers.week			87.5			
Dryer A+	32 weeks/yr			1 cycle/pers.week	2.25		72		288	
	50 weeks/yr			1 cycle/pers.week			112.5			
Dryer A	32 weeks/yr			1 cycle/pers.week	3.7		118.4			
	50 weeks/yr			1 cycle/pers.week			185			
Other dryers	32 weeks/yr			1 cycle/pers.week	4		128			512
	50 weeks/yr			1 cycle/pers.week			200			
Iron		2400	1 hr/week	30 min/pers.week		120	60	180	360	360
Vaccum cleaner		1820		1 min/m².week		1,52 *		115.5	250.2	272.8
Television (new, flat)		50	20 h/week			50		50	50	50
Television 2 (old, flat)		100	20 h/week			100				
Television (cathod screen)		150	20 h/week			150				
Flat screen computer		130	20 h/week			130				
Cathod screen computer		150	20 h/week			150				
Laptop		25	20 h/week			25		25	25	100
(TVD/ADSL) decoder		25	20 h/week			25		25	25	25
Wi-Fi/TV/Telephone router		20	continuous			175.2		175.2	175.2	175.2
OTHERS (small appliances, occasional uses and sleep modes)						100	25	125	200	200
* : kWh/m².yr						TOTAL	[kWh/yr]	1292.7	2830.4	3394
							[W/m²]	1.55	1.57	1.73

Occupation pattern

The occupation pattern influences heating and lighting periods (see below) as well as internal gains. 4 different patterns of use have been proposed to the users, and internal loads have been evaluated in accordance:

- Pattern 1: someone is present the whole day, which is then split between 8 hours of sleep, 1 hour of family morning presence, 10 hours of “light work” during the day and 5 hours of family evening presence.
- Pattern 2: someone is present half the day, which is split between 8 hours of sleep, 1 hour of family morning presence, 4 hours of “light work” at home, 6 hours of absence and 5 hours of family evening presence.
- Pattern 3: the household is present 8 hours a night (sleep), 1 hour in the mornings and 5

hours in the evenings; the house is empty of occupants for 10 hours a day.

- Pattern 4: the house is considered unoccupied for 14 hours a day, the household being there 1 hour in the mornings, 1 hour in the evening, and 8 hours at nights.

Users were asked, in the questionnaire, to describe an average week using these four patterns; the number of days a week corresponding to each pattern is then used to calibrate monthly loads. For each period (sleep, morning presence, day presence, absence and evening presence) of each pattern, internal loads are evaluated as follows:

$$Q_{O,i,j} = P_{O,i,j} * N_{O,i,j} * t_{O,i,j} \quad (3)$$

With

- $Q_{O,i,j}$: the internal gains due to occupation patterns, during the period 'i' of the pattern 'j' [J];
- $P_{O,i,j}$: the load due to the metabolism of the person present during the period 'i' of the pattern 'j'(ISO 7730: 2005):
  - o $P_{O,i,j}$ = 80 W/person at night;
  - o $P_{O,i,j}$ = 100 W/person during mornings and evenings;
  - o $P_{O,i,j}$ = 120 W/person during daytime;
- $N_{O,i,j}$: the number of occupants present during the period 'i' of the pattern 'j' [-];
- $t_{O,i,j}$: the length of the period 'i' of the pattern 'j' [s].

Then, adding periods of a pattern 'j':

$$Q_{O,T,j} = \Sigma_i \, Q_{O,i,j} \quad (4)$$

With $Q_{O,T,j}$: the daily total internal gains due to the pattern 'j' of occupation [J].

Finally, using the number of days a week corresponding to each pattern:

$$Q_{O,T,a} = \Sigma_j \, Q_{O,T,j} * N_{d,j}/7 \quad (5)$$

With :

- $Q_{O,T,a}$: the daily average internal gains due to occupation [J];
- $N_{d,j}$: the number of days a week corresponding to the pattern 'j' [-].

<u>Lighting</u>

Lighting is not usually evaluated in residential EPB calculation, believed to be rather insignificant with regards to other energy uses. It is, however, part of electricity bills; in order to ease comparisons between measured and calculated consumptions, it has been decided to include it in the calculated results. The default installed power, used in non residential calculations, is 20 W/m², which is considered far above real installations. A more realistic approach has been inspired by (CSTC, 2011) and (SPW, 2013), considering several installations efficiencies and average rooms areas. Some rooms are obviously better provided with natural light, some need more artificial installations; these first results rely more on statistical average: very efficient, minimal installations have an average 3 W/m² artificial lighting power, whereas less efficient installations see their power rise to 8 W/m².

The importance of natural light also influences the number of hours during which artificial lighting is needed. In Liege, the year is shared between 4474 hours and 15 minutes of daylight, and 4285 hours and 45 minutes of night[8]. Considering 3 annual weeks of absence (2 in the summer, 1 in the winter) and sleep hours (8 hours a night for the remaining 344 days), this leads to 1307 hours and 30 minutes of darkness a year that has to be artificially illuminated. Calculation to obtain an equivalent fixed power value for the whole year is as follows:

$$P_L = P_r * N_{h,l}/N_h \quad (6)$$

With:

- P_L: the equivalent fixed lighting power, considered used the whole year [W/m²];
- P_r: the realistic installed power, according to installation efficiency [W/m²];
- $N_{h,l}$: the number of hours during which artificial lighting is needed: 1,307.5 hours/year.
- N_h: the length of the year: 8,760 hours.

This gives, for the three case studies, an equivalent fixed power value of 0.6 W/m² for the apartment, 0.75 W/m² for the row house and 0.9 W/m² for the detached house. The corresponding internal gains are evaluated as follow:

$$Q_L = P_L * A_{ch} * t_d \quad (7)$$

With:

- Q_L: the daily internal gains due to artificial lighting [J];
- A_{ch}: the heated floor area, as defined in the regulatory calculation method (Wallonie, 2013) [m²];
- t_d: the length of a day: 86,400 s.

Internal gains

These three components are added as follows, to represent the average internal gains corresponding to the occupation pattern distribution, equipment and lighting:

$$Q_{I,a,d} = Q_E + Q_{O,T,a} + Q_L \quad (8)$$

With $Q_{I,a,d}$: the average total daily internal gains due to equipment, occupation and lighting [J]. The value for each month is obtained thus:

$$Q_{I,a,m} = Q_{I,a,d} * N_{d,m} * 10^{-6} \quad (9)$$

With:

- $Q_{I,a,m}$: the monthly internal gains due to occupation patterns, electric equipment and lighting habits [MJ].
- $N_{d,m}$: the number of days in the month (taking winter and summer vacations into account).

Here are the final results for $Q_{i,seci,m}$ and $Q_{I,a,m}$:

- Apartment:
  - Official loads: $Q_{i,seci,m} \in$ [1,066 MJ, 1,180 MJ]
  - Calculated loads: $Q_{I,a,m} \in$ [548 MJ, 686 MJ]
- Detached house:
  - Official loads: $Q_{i,seci,m} \in$ [1,369 MJ, 1,516 MJ]

[8] www.ephemeride.com

  - Calculated loads: $Q_{I,a,m} \in [1{,}024\ MJ, 1{,}323\ MJ]$
- Row house:
  - Official loads: $Q_{i,seci,m} \in [1{,}524\ MJ, 1{,}687\ MJ]$
  - Calculated loads: $Q_{I,a,m} \in [1{,}002\ MJ, 1{,}295\ MJ]$

The lower calculated values can be explained by a single occupant in the apartment and out-working occupation patterns.

Table 3: calculation of the internal loads for the row house

Total internal heat gains - row house								
Patterns of use	$N_{d,j}$ [-]	**Description**	$t_{O,i,j}$ [s]	$N_{O,i,j}$ [-]	$P_{O,i,j}$ [W]	P_L [W/m²]	P_E [W/m²]	$Q_{I,a,d,j}$ [J]
Pattern 1	1	8h sleep	28,800	4	320	0.75	1.73	16,033,421
		1h morning presence	3,600	4	400	0.75	1.73	2,292,178
		10h day presence	36,000	4	480	0.75	1.73	25,801,776
		5h evening presence	18,000	4	400	0.75	1.73	11,460,888
		Daily total	**86,400**					**55,588,263**
Pattern 2	1	8h sleep	28,800	4	320	0.75	1.73	16,033,421
		1h morning presence	3,600	4	400	0.75	1.73	2,292,178
		4h day presence	14,400	4	480	0.75	1.73	10,320,710
		6h absence	21,600	0	0	0.75	1.73	5,113,066
		5h evening presence	18,000	4	400	0.75	1.73	11,460,888
		Daily total	**86,400**					**45,220,263**
Pattern 3	5	8h sleep	28,800	4	320	0.75	1.73	16,033,421
		1h morning presence	3,600	4	400	0.75	1.73	2,292,178
		10h absence	36,000	0	0	0.75	1.73	8,521,776
		5h evening presence	18,000	4	400	0.75	1.73	11,460,888
		Daily total	**86,400**					**38,308,263**
Pattern 4	0	8h sleep	28,800	4	320	0.75	1.73	16,033,421
		1h morning presence	3,600	4	400	0.75	1.73	2,292,178
		14h absence	50,400	0	0	0.75	1.73	11,930,486
		1h evening presence	3,600	4	400	0.75	1.73	2,292,178
		Daily total	**86,400**					**32,548,263**
Presence/absence ratio [s]		**403200**	**201,600**				$Q_{I,a,d}$ =	**41,764,263**

In the official calculation method, these loads (added to solar gains), are tamed by a reduction factor, $\eta_{util,heat,seci,m}$, the monthly heat gains application rate. It depends on the heat losses (through thermal envelop and ventilation) and heat gains ratio, and applies the following principle: when losses diminish and gains increase (in summer), the internal loads will be less used than in cold weather conditions: occupants use windows openings to regulate their indoor thermal comfort under overheating, so that the air renewal is larger than the fixed constant value used in the calculation. It has been decided to keep that part of the calculation method, taking the new internal gains into account to calculate that factor.

4.3.3 Heating habits

<u>Heating period</u>

In order to adapt the calculation method to a more realistic, behaviour based approach, the next step is, obviously, to consider the heating patterns of the users. In the official approach, the heat is turned on when needed, in order to obtain an inside temperature of 18°C, day or night, which can even lead to a heating consumption during the summer. In reality, dwellings are obviously not heated all day, let alone all year round. In the Belgian temperate climate, heating systems are often shut out from May to September included (depending, of course, on the climate, the building characteristics and the occupants' comfort). This hypothesis will be considered here, since this particular enquiry was missing from the "beta version" questionnaire filled by the owners. Knowing the occupation patterns, it is however easy to extrapolate daily heating patterns and average number of heating hours per day. This last data is obtained using the presence/absence ratio, as visible in the table 3 above. The number of seconds in a month (t_m in the official calculation method, see above Eq. 1) can be split between three terms:

$$t_m = t_{m,h} + t_{m,lh} + t_{m,nh} \tag{10}$$

With:

- $t_{m,h}$: the number of seconds during which the heat is on [Ms];
- $t_{m,lh}$: the number of seconds during which the set temperature is lowered [Ms];
- $t_{m,nh}$: the number of seconds during which the heat is shut out [Ms].

Set temperature

Some people tend to heat less because of low income, environment-friendly behaviour or low-temperature comfort standard (Guerra-Santin, 2010); others tend to heat more (for obvious and opposite reasons). Some people heat the whole house; others only specific rooms (living room, bathroom…). Some need a strict and define comfort temperature; others tolerate a wider range of them. The definition of a comfort temperature is quite hard, as it depends on many parameters, among which the air temperature and average walls temperature, activity, clothing (Fanger, 1977), gender or even the time elapsed since the occupant last ate… When no thermostat allows precise temperature control, people are often not able to tell whether they heat to reach 18 or 22°C. They just seek sensible comfort, which could therefore fluctuate.

All those parameters of comfort are difficult to apprehend in a questionnaire. Thus, this calculation method will use simple data:

- Both houses owners announced the use of a thermostat, set to 21°C when inhabitants are present, and 16°C otherwise. Both set temperatures have to be integrated in the calculation method; they will referred below as "$T_{set,max}$" et "$T_{set,min}$".
- The apartment owner does not have a thermostat, and is therefore heating his home with deemed comfort for only parameter. The widely accepted average comfort temperature of 20°C will be adopted for this dwelling.

Equations

The set temperatures being integrated early (from the heat losses calculation) in the calculation method, the modifications have to be made in consequences.

The heat losses through envelope are evaluated as follows in the official method:

$$Q_{T,heat,seci,m} = H_{T,heat,seci} * (18 - \theta_{e,m}) * t_m \tag{11}$$

With:

- $Q_{T,heat,seci,m}$: the monthly heat losses through the envelope [MJ];
- $H_{T,heat,seci}$: the transmission heat losses coefficient [W/K];
- $\theta_{e,m}$: the monthly average exterior temperature [°C];
- t_m: the length of the month [Ms].

The modification is proposed as follows, for envelope heat losses:

$$Q_{T,heat,seci,m} = H_{T,heat,seci} * [(T_{set,max} - \theta_{e,m}) * t_{m,h} + (T_{set,min} - \theta_{e,m}) * t_{m,lh}] \tag{12}$$

The same modification have to be implemented in the ventilation heat losses evaluation:

$$Q_{V,heat,seci,m} = H_{V,heat,seci} * [(T_{set,max} - \theta_{e,m}) * t_{m,h} + (T_{set,min} - \theta_{e,m}) * t_{m,lh}] \quad (13)$$

These manipulations have two consequences: first, when $t_{m,h} = t_{m,lh} = 0$ (see Eq. 10), the heat losses will also equal zero. Second, by using other set temperatures and other climatic data, it happens that these equations result in negative figures, meaning heat gains instead of heat losses. No heating is therefore needed, and the related periods of time will not be taken into account in the heating consumptions ($Q_{T,heat,seci,m}$ =0). The same happens with the $\eta_{util,heat,seci,m}$ (monthly heat gains application rate, see above) calculation, which has to be annulled when heat gains exceed heat losses. These adaptations insure that the net heating demand is null (not negative), and so will be the consumptions.

4.3.4 Domestic Hot Water

The other consumption evaluation which depends on the number of inhabitants is the domestic hot water (DHW) production. In the official method, the demand is calculated with the building's protected volume as only parameter:

$$Q_{water,bathi,net,m} = f_{bathi} * \max [64, 64 + 0,22 * (V_{PER} - 192)] * t_m \quad (14)$$

$$Q_{water,sinki,net,m} = f_{sinki} * \max [16, 16 + 0,055 * (V_{PER} - 192)] * t_m \quad (15)$$

With:

- $Q_{water,bathi,net,m}$, $Q_{water,sinki,net,m}$: the net energy demand for a bath or a kitchen sink DHW consumption [MJ];
- f_{bathi}, f_{sinki}: the part of the bath or kitchen sink in the total DHW net energy demand [-];
- V_{PER}: the protected (heated) volume of the EPB unit, as defined in the regulatory calculation method (Wallonie, 2013) [m³];
- t_m: the length of the month [Ms].

In this study, we adopted as first approach the hypothesis of 45l of water to be heated, everyday, for each occupant, to a minimal temperature of 60°C (Hauglustaine, 1979). The water supplied everywhere in Belgium comes out of the network at an average temperature of 10°C. The net energy demand for DHW consumption becomes:

$$Q_{water,net,m} = [N_{lt} * N_{d,m} * 4,1855 * (\theta_{water,out} - \theta_{water,in})]/1000 \quad (16)$$

With:

- $Q_{water,net,m}$: the net energy demand for domestic hot water production [MJ];
- N_{lt}: the number of litres to be heated [l];
- $N_{d,m}$: the number of days in the month (see above Eq. 9) [-];
- 4,1855: the energy needed to raise of 1°C the temperature of 1 cm³ of water [J];
- $\theta_{water,out}$: the temperature of the heated water = 60°C;
- $\theta_{water,in}$: the temperature of the supplied water = 10°C.

Here are the final results variations for $Q_{water,net,m}$:

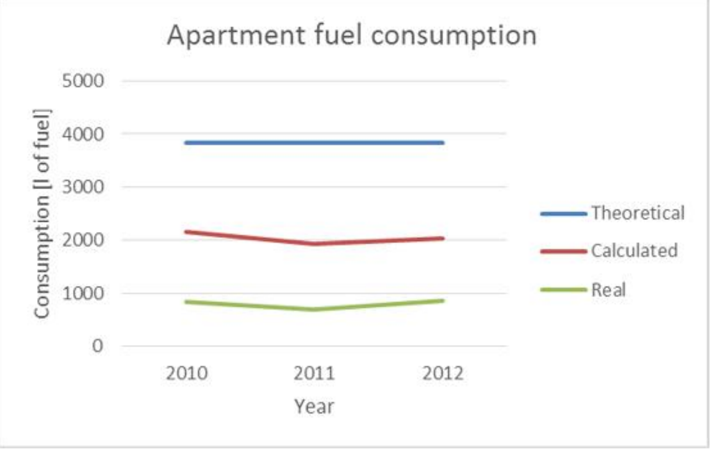
- Apartment:
  - Official demand: $Q_{water,seci,net,m} \in$ [285 MJ, 315 MJ];
  - Calculated demand: $Q_{I,a,m} \in$ [226 MJ, 292 MJ];
- Detached house:

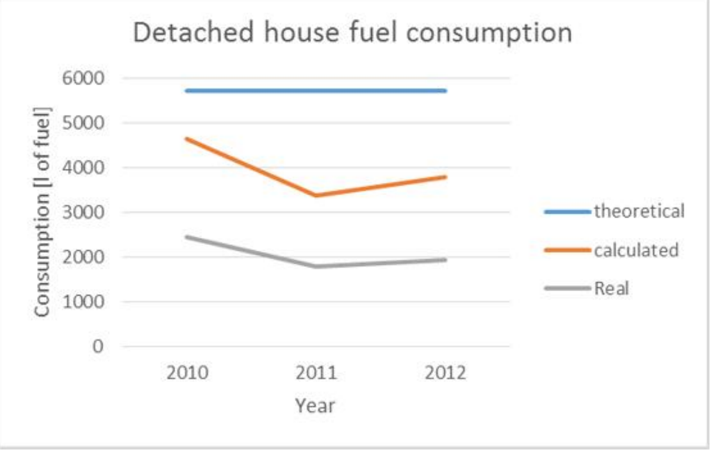
  - Official demand: $Q_{i,seci,m}$ ϵ [409 MJ, 453 MJ];
  - Calculated demand: $Q_{I,a,m}$ ϵ [904 MJ, 1168 MJ];
- Row house:
  - Official demand: $Q_{i,seci,m}$ ϵ [473 MJ, 524 MJ];
  - Calculated demand: $Q_{I,a,m}$ ϵ [904 MJ, 1,168 MJ].

5. RESULTS

Here are graphs that show three different consumptions for each dwelling:

- The theoretical consumption: the result of the official Energy Performance Certificate, calculated with strict respect to the only regulatory method and procedure.
- The calculated consumption: the result of all the modifications proposed here above: change of climate, adaptation to real occupancy, heating patterns and more realistic internal loads…
- The real consumption, as announced by the dwellings owners.





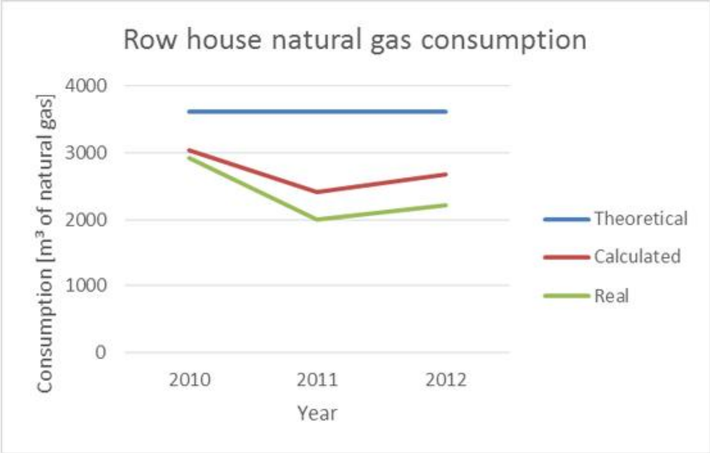


Figure 1: Comparison of the theoretical (official) consumption, calculated (proposal) consumption and real consumption in the cases of the apartment (a), detached house (b) and row house (c).

In the case of the apartment, the official standardised consumption was 4.46 to 5.49 times the real consumption on these 3 years (4.79 on average). The calculated consumption that integrates behaviour parameters is now 2.37 to 2.75 times the average real consumption (2.5 on average). The average consumption was thus decreased by 44 to 50% (47% on average).

In the case of the detached house, the official standardised consumption was 2.33 to 3.19 times the real consumption on these 3 years (2.77 on average). The calculated consumption that integrates behaviour parameters is now 1.89 to 1.95 times the average real consumption (1.91 on average). The average consumption was thus decreased by 19 to 41% (31% on average).

In the case of the row house, the official standardised consumption was 1.24 to 1.81 times the real consumption on these 3 years (1.52 on average). The calculated consumption that integrates behaviour parameters is now 1.04 to 1.21 times the average real consumption (1.15 on average). The average consumption was thus decreased by 16 to 33% (25% on average).

6. DISCUSSION AND CONCLUSION

As foreseen, the calculated results are closer to real results, without entirely closing the gap. This is normal: the uncertainties of the Energy Performance Certificate approach are not all behaviour-related, but also stand in other specificities of the protocol. One examples stands in the default values that are attributed to heating and DHW systems efficiencies, according to their type and age, and induce obvious reservations towards consumption results.

In the row house, better insulated and equipped with new systems characterised by “real” (acknowledged) efficiency rates, the gap is narrower, thanks to the increased data precision. This can also be seen in the case of the apartment, where the DHW system was given (by default) a (very) bad efficiency, due to an old boiler and a non insulated hot water loop. Having decreased the heating consumption, the part of DHW in the overall balance increases, inversely proportional to the accuracy of the data. As a general rule, the better known the heating and hot water producing systems efficiencies, the lower the influence of the number of inhabitants on the certification result. One idea could be to use another requirement of the 200/91/CE European Directive, the annual inspection of heating production systems, to get more accurate efficiency rates.

The influence of the climate data is clear however: using real climatic data is surely an important factor to compare calculated results with real consumption data.

It seems that, with a small amount of additional data (on the number of inhabitants, the set temperatures, the heating schedules), the certification calculation method is strong enough to approach real consumption data. These results are encouraging but other parameters ought to be studied as well, like the presence of a thermostat which allows to better knowing the set temperature and heating periods, the actual heated volume as opposed to the indirectly heated volume… Literature (Allibe, 2012; De Groot et al., 2008; Wallenborn et al., 2006) brings also out several factors that influence the energy consumption of a dwelling:

- Socio-demographic variables: skills and knowledge, income, occupation, type of housing, age of the head of the household, size of the family, rights on the dwelling (owner / tenant)...
- Attitudes and representations: motivation to save energy, attitudes towards energy saving, comfort representation, perceived behaviour efficiency, social standards, identification to others, image of the dwelling, costs and benefits evaluation, representation of the available technology…
- Behaviour variables: temperature in the main room, global temperature management, proportion of house not heated, number of days spent outside home, habits of ventilation, shower and bath frequency, use of available devices…

The Energy Performance Certification is a great opportunity for monitoring and trying to improve the housing stock, in every country that wishes to reduce its energy consumption, but that potential remains underexploited. In order for the scheme to reach its goals, it is essential to find a way to make it understandable by anybody. Though acknowledging the necessity of presenting a “legal” result as a comparison base, based on the approved standardized calculation method, it is believed that other results could be displayed, based on building characteristics and a minimum of behavioural inputs, creating a closer bond between future renters/owners and the results displayed in the EPC. Also, a highlight of the financial implications is now evidently necessary: the certificate could be used to foresee a rough monthly bill (taking energy and rent or loan repayment into account). The expected outcomes would be the creation of a complementary “custom-made” certification that would help raise energy consumers’ awareness of their environmental impact. Also, data collection and actuation of the existing buildings stock energy consumption would be possible, with the creation of comprehensive benchmarking databases, fundamental for shaping smart strategies on urban / regional / national levels.

Then, and only then, the EPC will be able to reach its goal and so become a tool for smarter cities.

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