Measure of Occupants' Satisfaction in High Energy Performance Residential Buildings:

Results from the action *Construire Avec l'Energie* in Belgium.

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ABSTRACT: In Europe, energy requirements are even stronger leading the construction sector to design buildings whose energy consumption is continuously reduced. Mainly, the global challenge today is to identify lacks in construction processes and misuse or misunderstanding on the side of the occupants in order to improve the design of efficient and comfortable high energy performance buildings.
This paper presents the results of a large post occupancy evaluation (POE) by means of a survey questionnaire conducted on a sample of 458 Walloon high performances houses built within the frame of the action "Construire Avec l'Energie" (CALE). The results of the POE allow to qualify and discuss: the satisfaction regarding thermal and respiratory comfort; the occupants' behaviour and satisfaction in relation to the use of the building and its systems; the actual consumptions compared with the predicted ones.
Keywords: Post Occupancy Evaluation, comfort, energy consumption, dwellings.

INTRODUCTION

Since the implementation of the European Energy Performance of Buildings Directive (EPBD), energy requirements have been even stronger, pushing the construction sector to design buildings with continuously lower energy consumption.

In Belgium, a Western Europe country characterised by a cold temperate climate, high energy performance buildings are mainly characterised by reduced heating needs, a south oriented main facade, a very high insulation level, an improved air tightness and a mechanical ventilation. Moreover, "Passive House Standard" buildings are becoming more frequent in Belgium. Indeed, if in Wallonia energy requirements for new dwellings tend to approach the passive standard (maximum U-value of 0.24 W/(m².K) for roofs and walls – maximum primary energy consumption of 130 kWh/(m².year), etc. (Gouvernement-wallon, 2014)), in Brussels, the regulation for new buildings called Bruxelles passif 2015 (Bruxelles-passif!) is directly inspired by the passive standard (Building-Research-Establishment-Ltd., 2011; Feist, Schnieders, Dorer, & Haas, 2005; Passive-House-Institute, 2015).

Furthermore, in Belgium as in all European countries, regulations impose the use of specific calculation methods to theoretically describe the energy quality of the buildings from the design phase on. However, while studies in neighbouring countries (Gupta & Kapsali, 2014; Itard, Majcen, & Visscher, 2012) show that the expected performance may not be obtained, no large-scale experience feedbacks on the effectiveness of the performance and on the satisfaction of the occupants are available in the Walloon context. Many questions remain thus largely unanswered for the construction sector: *Are high energy-efficient dwellings always comfortable in our context? ; Do actual energy consumptions correspond to calculated consumptions?*

Trying to answer these questions, this paper presents the results of a large Post Occupancy Evaluation (POE) conducted on high energy performance residential buildings built in Wallonia and occupied for several years.

METHODOLOGY

The main goal of the conducted Post Occupancy Evaluation is to verify if the current construction techniques (insulation, air tightness, mechanical ventilation, etc.) used in the construction of high energy performance residential buildings in Wallonia (Belgium) satisfy the occupants regarding indoor comfort and building energy consumptions. To achieve that, an online survey questionnaire was sent to the occupants of a sample of 458 Walloon high performances houses (Belgium) built within the frame of the action "Construire Avec l'Energie" (CALE).

Initiated by Wallonia since February 2004, the CALE action sets a voluntary approach to build more efficient dwellings than required by the regulations. Mainly, these requirements cover (with progressive steps):

- Maximum U- values [W/m²K].
- Maximum mean U-Value [W/m²K].
- Ventilation rates for each space [m³/h.m²]

- Maximum Primary Energy Consumption [kWh/(m².an)]
- Limited overheating risk [%]

(For details and description of the steady state calculation method see (Gouvernement-wallon, 2008)).

The CALE dwellings present the advantage for this study to have been occupied for several years, nullifying the enthusiastic effect of the first years of occupation (Mlecnik et al., 2012). Also, all the technical information about these buildings has been checked by experts after the construction and implemented in a specific database.

The setup of the questionnaire and a complete description of the measured notions are presented in *Measure: establishment of a questionnaire to evaluate occupants' satisfaction adapted to high energy performance residential buildings* (Dartevelle, Obyn, 2015). Mainly, in addition of information available from the database, the questionnaire was designed to qualify the occupant's behaviour and satisfaction regarding comfort, the use of the building and its systems, and the parameters influencing the satisfaction (Figure 1).

A total of 149 responses have been received, representing a response rate of nearly 33%. Table 1 presents the main characteristics of the corresponding dwellings obtained from the CALE database. The presented Energy Performance values were calculated according the CALE software based on European standards (Langendries, Lethé, 2010) and are representative of the complete sample of CALE (458 buildings): similar mean value and distributions far almost all characteristics. Mainly, we can noticed: a big part of detached houses (92.5%), an average heating surface area of 219m², an average U value of 0.32 W/(m²K), ranging from 0.12 to 0.48 W/(m².K), a mechanical ventilation with heat recovery installed in 95% of the cases, an average heating demand of 40 kWh/(m².year), ranging from 0 to 105 kWh/(m².year).

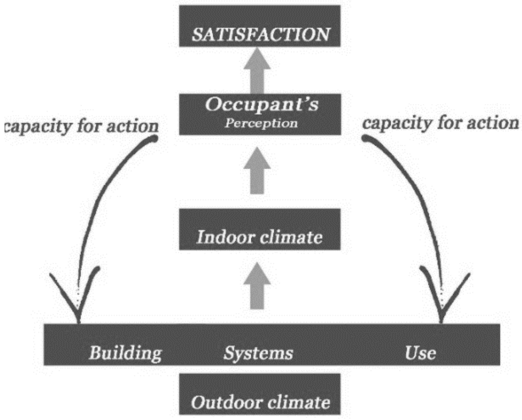

Figure 1: factor of influence of occupant's satisfaction

Table 1: main geometrical and technical characteristics of the 149 studied dwellings

		4	***3***	***2***
Number of facades	[% of cases]	*92.5*	*1.3*	*6.2*
		South (from SE to SW)	***E or W***	***North (from NE to NW)***
Main Orientation	[% of cases]	*59.9*	*26.5*	*13.6*
		Mech. Vent. with heat exchanger	***Mech. Vent. exhaust air only***	***Nat. Vent.***
Ventilation System	[% of cases]	*95.6*	*3.4*	*1.0*
		Oil or Gas boiler	***Heat pump***	***Electric heater***
Heating System	[% of cases]	*47.1*	*28.1*	*2.0*
		Elec. resistance on ventilation	***Wood or pellet-boiler***	***None***
		1.3	*6.1*	*15.4*
		Int., Ext. or Both	***None***	
Solar shading	[% of cases]	*51.5*	*48.5*	
		Very Low Low	***Medium***	***High***
Thermal Mass	[% of cases]	*0.7 25*	*52.1*	*22.3*
		Mean	***Min***	***Max***
Protected volume	[m³]	*677*	*238*	*1672*
Heating surface area	[m²]	*219*	*83*	*569*
Compactness Ratio	[m]	*1.38*	*0.98*	*2.71*
Glazed Surf. /Heated Surf ratio	[%]	*19.0*	*9.4*	*45.1*
Main orientation Glazing Surface	[m²]	*24.8*	*8.1*	*96.1*
Airtightness	[m³/(h.m²)]	*1.5*	*0.1*	*8.1*
Mean U value	[W/(m².K)]	*0.32*	*0.12*	*0.48*
Heating Demand	[kWh/m²]	*40.1*	*0*	*105*
Overheating risk	[%]	*33*	*0*	*100*
Calculated primary energy Consumption for Heating, Cooling and DHW (incl. renewables).	[kWh/m²]	*96.2*	*-19.1*	*197.6*

SURVEY RESULTS

The survey allows to first obtain more details about the profile and habits of the occupants, the building and the systems and secondly to measure the occupants' satisfaction.

Occupants Profile

The survey shows that, on average, the respondents' households are composed of 3.5 people with children/students. Also, the sample is characterised by a quite high socioeconomic level of the occupants, generally well informed about the Energy Performance of Building issues (e.g. 99% of respondents own their dwellings, most adults (99%) are employed, 92-95% of people feel they understand or are familiar with the technical aspects of their home (heating, ventilation, insulation)).

In terms of **occupancy**, the majority of homes are occupied in the evening and on weekends (61%), while 33% of homes occupied continuously. The remaining 6% have intermediate or variable occupancy (part-time work).

Intermittence is common practice: more than 50% practice intermittent heating. Of these, 62% do so at night and 53% if they are not present. 67% of respondents declare that they vary their level of air ventilation (mainly when using the kitchen or the bathroom or depending on weather conditions).

With regard to **opening windows**, while 90.6% state that they never open the living room windows during the winter, there is a reverse trend for the rest of the year with 71.2% of respondents opening the windows (during the day, night or both). The same trend can be seen in the bedroom with 72.3% never opening the windows in the wintertime and 74.8% opening them during the rest of the year. The main purpose of windows opening is to cool down the premises, followed by opening to the outside, ensuring good air quality and to expel smells. Only 15.4% of respondents never open their windows.

Also, some respondents seem to have **adapted the way they dress** (mainly in winter) since living in their high energy performance house. They state that they usually dress less (or much less) warmly during the winter (in 56% of cases) and dress more (or much more) lightly the rest of the year (in 34% of cases).

Additional systems

Figure 2 presents the system that were finally added after some times of occupation. It shows that a **supplementary heating system** (space heater) has been added in 47% of the homes. They were originally planned in 17% of the cases, and were added to improve comfort in 30% of cases.

Based on the open comments provided by respondents, there is often an electrical backup located in the bathroom. Moreover, it is likely that a number of cases planned, from the design stage, a central heating system only on the ground floor of the building.

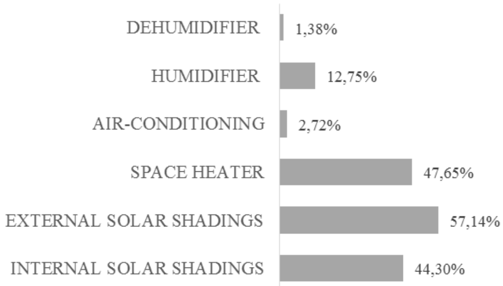

Figure 2: systems added after some times of occupation

Respondents state that **sunscreens** were directly installed for only 26% of cases. Ultimately, 77% of cases are fitted with sunscreens (external: 44%; internal 57%; both 25%). Counteracting sun heat is the main reason for adding a sunscreen (84%).

The installation of a **dehumidifier and air-conditioning** system is marginal (1 and 2% respectively). The installation of a **humidifier**, on the other hand, is more common (13% of cases).

Overall satisfaction

Figure 3 illustrates the overall satisfaction regarding the main notions measured in the survey.

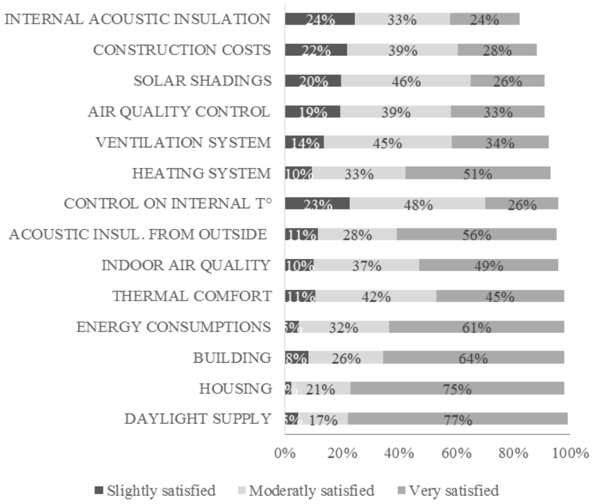

Figure 3: satisfaction rates regarding the main notions measured in the survey

Global satisfaction rates (from slightly to very satisfied) reach 98% for the global appreciation of the dwellings, 96% for indoor air quality and 98% for thermal comfort. However, respondents' satisfaction regarding systems is slightly lower (93% for heating and ventilation system, 91% for sunscreens). In terms of acoustics, the insulation between rooms (interior) has generated less satisfaction (82%) than the insulation from outside noise (95%). The daylight supply has gained 100% satisfaction. 89% are satisfied with the cost of construction/rental price, and 98% are satisfied with their energy consumption.

A large majority of respondents are also satisfied with their global control level over the indoor environments (air quality and temperatures).

Satisfaction regarding thermal and respiratory environments

Figure 4 illustrates the frequency of encountered discomfort related to thermal and respiratory environments. It shows that discomforts associated with **overheating** is very common (73% of respondent's state that they experience overheating problems). (Specific questions in the survey show that they are primarily related to the summer period in the living areas: bedroom (60%), living room (62%) and kitchen (51%).)

Excessive heat from sunlight is encountered in 65% of cases. Furthermore, 38% of cases state that **temperatures decrease too slowly** and that they **increase rapidly** in 25% of homes.

Problems of **discomfort in relation to cold floors** (19% of cases), **cold windows** (12% of cases) and **overly cold air ventilation** (23% of cases) are **present** albeit to a lesser extent. 17% of respondent's mention airflow problems in the joinery (doors/windows) and 17% in grids and vents.

Dry air is mentioned in 32% of cases. Logically, these problems are related to dry living areas (bedroom and living room) and are more significant in wintertime. Conversely, very **few problems relate to air being too damp** have been found.

In terms of **air quality**, we can see that the most common problems encountered by respondents are the presence of large amounts of dust (32%), the presence of persistent odours (11%) and bad air quality (9%), mainly in the bedrooms and living room all year round, and in the kitchen during the summer.

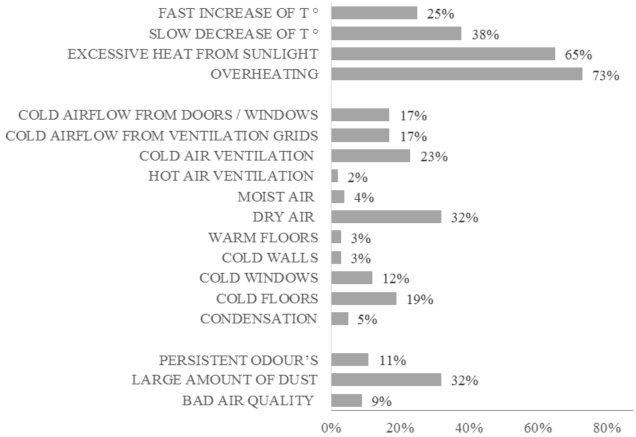

Figure 4: frequency of encountered discomforts

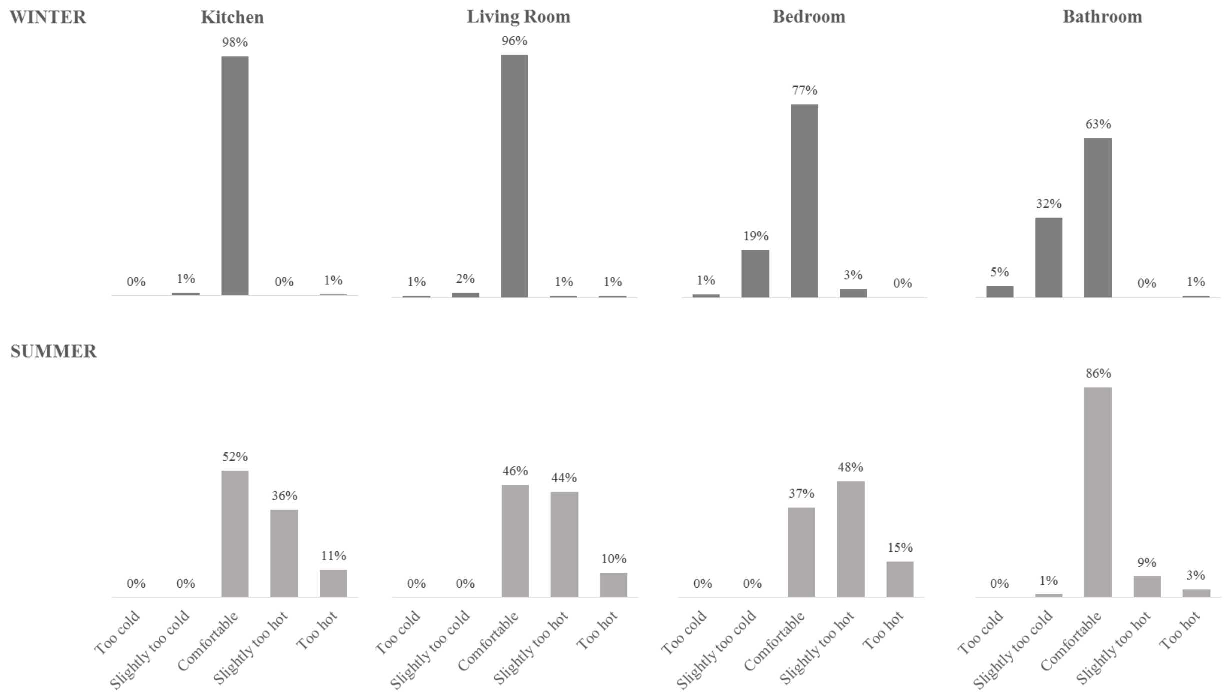

Figure 5: appreciation of the respondents regarding the seasonal usual temperature

Figure 5 presents the appreciation of the respondents regarding the usual temperature of several rooms. It shows that **in wintertime,** the problem of **(slightly) too cold temperatures** arises mainly in the **bathroom** (36%) and bedroom (20%). Winter temperatures are almost unanimously deemed to be pleasant in the living room and kitchen.

During the summer, respondents state that they feel **temperatures that are slightly high or too high** mostly in **living areas**: bedroom (63%), living room (54%) and kitchen (48%).

Satisfaction regarding the systems

Overall, the **systems tend to be satisfactory for their users in terms of efficiency** (99% are globally satisfied with the efficiency of heating systems, 96% with ventilation and 100% with the automated sunscreens (present in 18% of the cases). However, they often require a **subsequent setup** (in 1 in 4 cases for ventilation and sunscreens and more than 1 in 3 cases for heating).

Figure 6 describes more in depth the reasons for dissatisfaction regarding the use of heating, ventilation and automated solar shadings systems.

In terms of **ease of understanding**, heating is what causes the most dissatisfaction (14% as opposed to 6% for ventilation and 0% for automated sunscreens).

The **available documents** also raise a certain degree of dissatisfaction among respondents: there is a dissatisfaction rate of 22% for heating systems, 19% for ventilation and 10% for sunscreens.

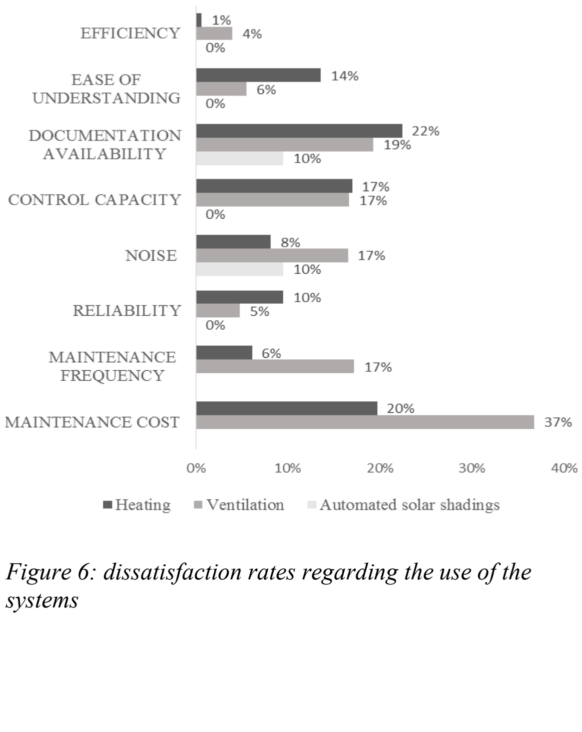

Figure 6: dissatisfaction rates regarding the use of the systems

In relation to their **ability to make adjustments,** 17% of respondents are dissatisfied with the heating and also 17% with ventilation (none with sunscreens).

The **noise generated** by the ventilation system is a source of dissatisfaction for 17% of respondents, and is of 8% for the heating system.

The **frequency and duration of maintenance** seems to be satisfactory, albeit to a slightly smaller extent for the ventilation system (83% satisfaction for the ventilation system and 94% for the heating system).

Conversely, the **cost of maintaining** the ventilation system proves less satisfactory (63%) than for heating (80%).

Actual consumption

Figure 7 presents the normalised actual energy consumption for heating reported by the respondents compared to the previsions.

Even if there is an important uncertainty regarding the reliability of these data, the calculated average consumption estimate seems correct (+3%) when compared with the actual figures provided by the occupants. However, a high degree of variance can be seen (from -73% to +185%).

On the other hand, the main value obtained regarding electricity consumption (2.580 kWh) seems to be higher than the national average (around 10% excluding heating (Consommation moyenne d'électricité en Belgique, 2015)), but the homes are also larger on average (210m² as opposed to 150m²).

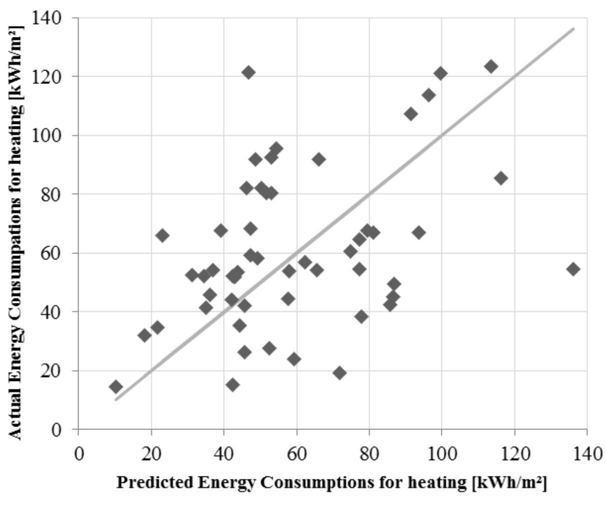

Figure 7: comparison of the normalised actual energy consumption for heating VS previsions

CONCLUSIONS

The analysed houses seem to have gained high satisfaction among the occupants, with a certain degree of variability.

However, it appears that these **homes are more thermally comfortable during the winter than the summer**. Whilst the temperature in the living room and kitchen is found, almost across the board, to be pleasant in wintertime, supplementary heating seems necessary in almost half of cases (mainly in the bathroom and upstairs rooms). This shows the necessity to take into account at the design stage the specific heating needs of each space of the dwellings even if the insulation levels are very high.

Cold floors, cold windows and draft problems are present, albeit to a small extent (less than 1 in 5). However, the discomfort associated with ventilation air being too cold (1 in 4) and air dryness (1 in 3) is more common.

Furthermore, **management of overheating and, in particular, solar gains does not seem to have been resolved**. Few sunscreens were directly installed during construction but in most cases have proven to be a necessity. While few air-conditioning systems are present (2%), windows are opened by most occupants in summertime (7 out of 10 cases), mainly to cool down the premises. More generally, this shows the importance to properly consider the overheating risk at the conception stage and to install solar shadings in order to guarantee thermal summer comfort in such houses. It also suggests that the current standard method for the evaluation of overheating risk could be improvable.

The **general indoor air quality** is almost always perceived positively. We can see, however, that the most common problems encountered by respondents are the presence of large amounts of dust (1 in 3), the presence of persistent odours and the feeling of not having clean air (1 in 10), mainly in the bedrooms and living room.

Compared to their attitude in their former home, it seems that that the occupants have **adapted their behaviour,** and focus on energy consumption (e.g. by lowering the set temperature), but not always in the appropriate way (wearing fewer clothes even in winter for example).

It is also worth noting that the **systems** are generally well-received by the occupants and that there is ultimately little difference between the heating and ventilation systems in terms of the available documentation and adjustability. In terms of ease of understanding, the heating is what causes the most dissatisfaction. Whereas, generated noise is still a relatively common problem (1 out of 6 cases) in the case of ventilation. In comparison with heating systems, the frequency, duration and cost of maintaining the ventilation systems are perceived less positively by occupants. The systems require a subsequent setup in about 1 in 4 cases (24%) for ventilation and sunscreens, and more than 1 in 3 cases for heating (35%).

The temperature level and air quality control prove widely satisfactory (more than 9 out of 10 occupants are satisfied). Intermittence is also common practice especially for ventilation (67% as opposed to 50% for heating). In this regard, the wide awareness of the majority of respondents, and their particularly sound technical knowledge should be recalled.

Moreover, average **heating** energy **consumption**, at this stage, seems to match expectations (although with a high degree of variance). Electricity consumption (excluding heating) proves higher than average (around 10%) but the homes are generally larger.

In addition to these findings, the survey results show a **high level of overall satisfaction** in terms of the housing, construction system, acoustic insulation (to a slightly lesser extent for insulation between rooms), energy consumption and natural light (100% satisfied).

FUTURE WORKS

A statistical analysis (multiple factor analysis) will be conducted on these data in order to identify the potential impact of some parameters on satisfaction levels. In parallel, this qualitative analysis will be compared with quantitative data obtained from the complete monitoring of a representative sample of 25 selected dwellings.

Finally, these analyses should contribute to identify possible lacks and necessary improvements of the current Belgian building energy regulation.

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