MEASURE: ESTABLISHMENT OF A QUESTIONNAIRE TO EVALUATE OCCUPANTS' SATISFACTION ADAPTED TO HIGH ENERGY PERFORMANCE RESIDENTIAL BUILDINGS

Dartevelle Olivier	UCL, LOCI, Architecture et Climat	olivier.dartevelle@uclouvain.be
Obyn Sophie	UCL, LOCI, Architecture et Climat	sophie.obyn@uclouvain.be

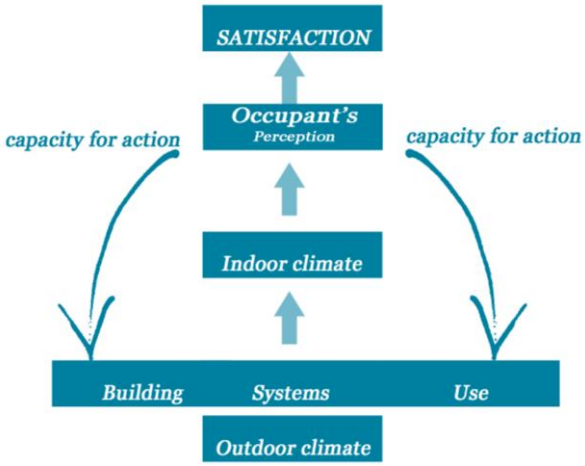

Fig 1 **:** factor of influence of occupant's satisfaction

WHICH ARE YOUR ARCHITECTURAL (R)SOLUTIONS TO THE SOCIAL, ENVIRONMENTAL AND ECONOMIC CHALLENGES OF TODAY?

Research summary

In Europe, since the application of the European Energy Performance of Buildings Directive (EPBD), energy requirements have been ever stronger, leading the construction industry to design buildings whose energy consumption is continuously reduced. Nevertheless, no large-scale experience feedbacks on the occupants' satisfaction of high efficient residential buildings are available in Wallonia.

Therefore, the first MEASURE project objective is the evaluation of occupants' satisfaction in high energy performance dwellings by the use of a questionnaire. This questionnaire, divided in several parts, covers a technical description of the building and its systems, a global appreciation of the building in terms of respiratory, thermal, acoustic and luminous comfort and a detailed evaluation of the occupants' satisfaction. The responses should permit to identify attention points and improvements required to achieve a comfortable environment for occupants and increase the effectiveness of energy performance.

This paper focuses on the methodological approach used to establish a questionnaire adapted to the evaluation of the occupants' satisfaction in high energy performance dwellings. It describes the different stages of the questionnaire realisation: the identification of dependent and independent notions to study as well as indicators defining each notion, the focus-group step and the test of the questionnaire. Studied notions and related indicators are presented in link with the Walloon context.

Keywords: Comfort, Post Occupancy Evaluation, high energy performance residential buildings.

1. Context

Since the implementation of the European Energy Performance of Buildings Directive (EPBD), energy requirements have been even stronger, leading the construction industry to design buildings whose energy consumption is continuously reduced.

On one hand, 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. On the other hand, while studies in neighbouring countries (Gupta & Kapsali, 2014; Itard, Majcen, & Visscher, 2012; Rohdin, Molin, & Moshfegh, 2014) show that the expected performance may not be reached, no large-scale experience feedbacks 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? Are occupants of these dwellings satisfied?*

This paper presents a methodological approach to establish a survey questionnaire adapted to the evaluation of the occupant satisfaction in high energy performance dwellings in order to answer these questions.

2. Survey objectives

The main aim of the survey presented in this paper 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, the questionnaire has first to qualify:

- the satisfaction of the occupants regarding thermal, visual, acoustical and respiratory comforts;
- the occupant's behaviour and satisfaction regarding the use of the building and its systems
- the satisfaction of occupants regarding the energy consumptions of the building.

Potentially, this survey questionnaire should also permit to establish correlations between, on one hand, the profile of the occupant and the characteristics of the buildings (constructive characteristics, energy performance level, etc.) and, on the other hand, the assessment of thermal, visual, acoustic and respiratory comforts in order to identify strengths, weaknesses and potential impacts on lifestyles of high energy performance design as perceived by the occupants.

The questionnaire has thus to evaluate both the satisfaction of the occupants and the parameters which can influence it as presented in *Figure 1* and in *sections 2.1* and *2.2*.

2.1 Measuring the satisfaction

Satisfaction is an abstract notion that can't be evaluated without using precise and tangible indicators (E. Mlecnik et al., 2012; Wallenborn, Gaye, & D'Audigier, 2013, 2014). Therefore, the evaluation of each notion (i.e. satisfaction with thermal indoor comfort) has to be achieved through the evaluation of tangible indicators (i.e. air temperature, air velocity, relative humidity, etc.) as specified on *Fig 2*.

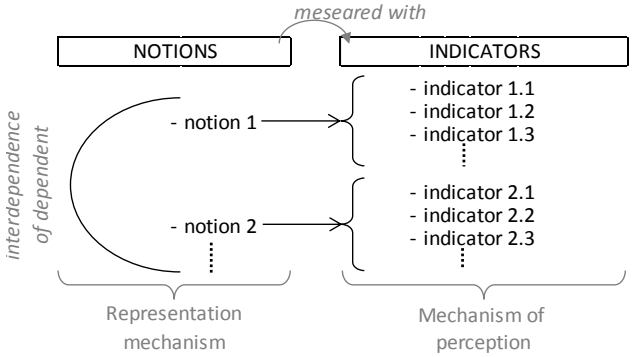

Fig 2: evaluation of abstract notions through tangible indicators (Image created by Romnée A. on the basis of De Singly, 2008; Martin & de Singly, 2009).

2.2 Measuring the factors of influence

The other aim of the questionnaire is to measure the factors which can influence the perception of the indoor climate. This is done in order to identify statistical correlation between the factors of influence (called independent parameters) and the specified notions (called dependent parameters) as presented in Table 1.

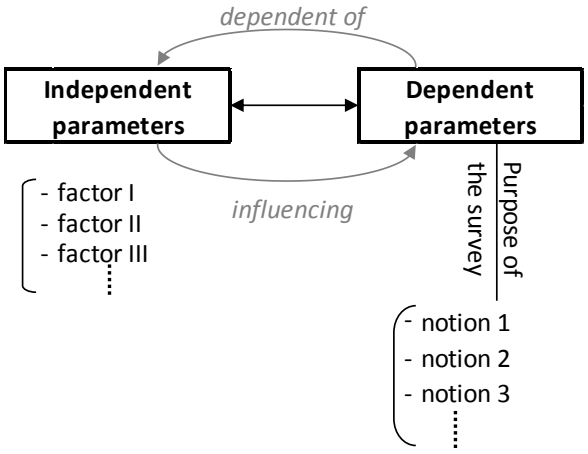

Fig 3: correlation between dependent (studied notions) and independent variables (factors of influence) (Image created by Romnée A. on the basis of (De Singly, 2008; Martin & de Singly, 2009))

3. Notions and indicators

High energy performance residential buildings are generally conceived to improve both indoor comfort and energy consumption of the building.

The evaluation of the satisfaction of occupants of such buildings should thus be achieved through the evaluation of the following notions:

- satisfaction with the thermal, visual, acoustic and respiratory indoor climates;
- satisfaction with the control over the indoor environment;
- satisfaction with the systems and their use;
- satisfaction with the costs (construction, energy consumption, etc.).

The proposed indicators related to these notions are presented in *Table 1*. They have been selected mainly according to the theory (i.e. thermal comfort parameters (Fanger, Bloss, & Pfisterer, 1988; Fanger, Melikov, Hanzawa, & Ring, 1988)) and literature (Agha-Hossein, El-Jouzi, Elmualim, Ellis, & Williams, 2013; Choi, Loftness, & Aziz, 2012; Gupta & Kapsali, 2014; HEFCE, 2006; Jaunzens, Cohen, Watson, Maunsell, & Picton, 2002; E. Mlecnik et al., 2012; Rohdin et al., 2014; Zalejska-onsson, 2014; Zalejska-Jonsson & Wilhelmsson, 2013).

For example, researches conducted in Sweden by Rohdin (Rohdin et al., 2014) show that high performance dwellings can lead to overheating (mainly in summer), to inadequate ventilation of rooms, quick variation of temperature, bad

Notions	Indicators	Detailed indicators
Thermal environment	Indoor temperature	*Perceived temperature in wintertime: kitchen, living room, bedroom, bathroom, other rooms*
		Perceived temperature in summertime: kitchen, living room, bedroom, bathroom, other rooms
		Overheating: kitchen, living room, bedroom, bathroom, other rooms
	Surfaces temperature	*Cold surfaces (walls/ceilings, windows, floors)*
		Hot floors
	Temperature fluctuation in time	
	Variation of temperature between rooms	
	Supply air temperature	
	Air speed	*Air speed in ventilation vents*
		Draughts at doors/windows
	Relative humidity of the air	*Too moist air: kitchen, living room, bedroom, bathroom, other rooms*
		Too dry air: kitchen, living room, bedroom, bathroom, other rooms
	Excessive levels of warmth due to sun radiation	
Respiratory environment	Quality of air	*Bad air quality problems: kitchen, living room, bedroom, bathroom, other rooms*
	Persistent smells	
	Dust	
Visual environment	Illuminance levels	
	Colour rendering	
	Light colour	
	Light distribution in space	
	Luminance ratios	
	Glare	
	Reflections	
	Shadows	
	Enhancement of the relief	
	Views to the outside	
	Natural light entering a room	
Acoustical environment	Reverberations	
	Vibrations	
	Transmission of airborne noise	
	Transmission of airborne noise from	
	Impact sound transmission	
	Noice from systems	
Systems and their use (heating, ventilation, solar protections)	Operational efficiency	
	Comprehensibility	
	Available documentation	
	Capacity of adjustments	
	System noise	
	System reliability	
	Frequency and duration of maintenance (heating and ventilation)	
	Costs of maintenance (heating and ventilation)	
Capacity of action on the indoor environment	Level of control over thermal environment	
	Level of control over ventilation	
Economic satisfaction	Construction cost	
	Energy consumptions	

Checking global parameters	Global satisfaction over each notion	Housing
		Building characteristics
		Heating system
		Ventilation system
		Solar protections
		Thermal comfort
		Air quality
		Recommendation of this type of building to friends and family

Table 1: proposal of indicators to evaluate the occupants' satisfaction regarding each studied notion

air quality problems and cold floors. Gupta and Kapsali (Gupta & Kapsali, 2014) conducted a study in South-East of England and observed that occupants may not completely understand the heating and ventilation systems and meet difficulties to use it, leading to inadequate use and overconsumptions. In 2012 Mlecnik and his partners (E. Mlecnik et al., 2012) published a study over nearly zero energy houses in Germany, Austria, Switzerland and the Netherlands. They specify that the comfort level varies with the energy performance level of the dwelling and with the season. Some occupants of nearly zero-energy houses also complain about bad ventilation of rooms, persistent smells and misunderstanding of systems.
For the selection of the indicators, a particular emphasis is thus given on the problems and discomfort encountered in previous studies (Gupta & Kapsali, 2014; Erwin Mlecnik, 2012; E. Mlecnik et al., 2012; Rohdin et al., 2014).

4. Factors of influence

Understanding the reasons/basis of the occupant's appreciation requires to evaluate all the factors which can influence the perception of the occupant (occupant's profile) and the indoor climate which results from the interaction between the outdoor climate, the building, the systems and the occupant's behaviour (use of and action on his indoor climate) (see Fig 1).
The proposed factors of influence, presented in Table 2, are related to buildings' and systems' characteristics, occupants' profile and behaviour. They also have been selected according to the theory (i.e. thermal comfort parameters (Fanger, Bloss, et al., 1988; Fanger, Melikov, et al., 1988)) and literature as the parameters influencing the occupants' satisfaction presented by Zalejska-Jonsson (Zalejska-Jonsson, 2014), i.e. the air quality and the level of control on heating and ventilation systems inter alia.
Some factors of influence presented in *Table 2* are difficult to evaluate with a questionnaire survey. They may be obtained through other complementary investigation methods such as a database of building characteristics (such as EPBD certification), a monitoring and specific measurements of real indoor climate.

5. Structure of the questionnaire

Since the notions and corresponding indicators have been defined, the following step is the redaction of questions to measure each indicator, notions and factors of influence. To correctly evaluate the occupants' satisfaction, it is then important to use understandable expressions and words precisely describing the corresponding feeling to the studied indicators. Therefore, it is necessary to use early validated questions (formulation) or to organize focus groups (see *section 6*).
Furthermore, different types of questions can be used according to the purpose of each question, as presented below.
Finally, the structure of the questionnaire and the order of the questions have to be defined.
In this case, the proposed questionnaire is divided into six categories and contains a total of 55 questions:
1/ *Introduction*: It consists in 6 multiple choice or list questions about the household composition, their housing preferences, their knowledge about energy efficient dwellings and the move-in date. These questions are simple so that the respondents become familiar with the interface of the questionnaire. The possible answers are based

on the literature and on focus groups (see *section 6*).

2/ *Use and habits*: This section examines the occupation of the dwelling (time and activity), the habits (heating set point for example), the use and the maintenance of the systems and the opening of windows, inter alia, with 15 questions including 3 conditional questions.

3/ *Equipment and consumptions*: The 8 questions of this category (mainly yes-no or list questions), including 4 conditional questions, verify and complete the available technical data about the energy consumptions and the presence and the reason of supplementary systems such as photovoltaic panels, thermal panels, additional heating or solar protection.

4/ *Overall satisfaction*: This category is composed of 4 Likert scaled questions (Kulas & Stachowski, 2009) (see *Figure 4*) aiming firstly to assess the overall occupant's satisfaction in relation to the different notions and secondly to check the ability of the indicators (evaluated in details in the following category) to describe the analysed notions (see *Figure 2*).

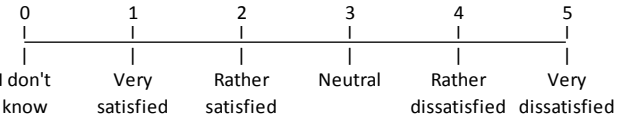

Fig 4 : Likert scale

5/ *Detailed satisfaction*: The 13 questions, including 6 conditional questions, of this category evaluate, through the indicators presented in *Table 1,* the occupant's satisfaction regarding thermal, acoustical, visual and respiratory climates, the building systems and their use.

6/ *Final questions*: This section is composed of 9 socio-demographic questions about the respondent and the household, completing the *Introduction* category. This type of questions is placed at the end of the questionnaire because it requires less attention to the respondent.

6. Test of the questionnaire

Once the identification of the studied notions and indicators has been made on the basis of literature review and previous studies (see above), the selection of indicators and the formulation of the corresponding questions have to be tested before launching the survey (Van Pachterbeke, 2014).

Therefore, a *Focus Groups* was first realised. It consists in discussions with small groups (4-10 persons) of the studied population to extract phenomena and factors of influence to focus on. This is also the opportunity to identify the vocabulary used by the occupants to describe their comfort perception and the technical characteristics of their dwelling in order to guarantee a good interpretation of these questions by the respondents.

The second step has been the *Test of the survey* on other small groups of the studied population (with the planned format and sending method of the questionnaire). This allows to check the questionnaire and the planned statistical results analysis. When working with an online questionnaire, the test permits also to check the occurrence of the conditional questions and the record of the survey responses.

Note also that the representativeness of the respondents according to the studied population and the validity of each respondent and question have to be checked at the end of the survey before statistically analysing the survey results.

Categories	Sub-category	Factor of influence
Building and systems	Geometrical characteristics	Protected volume
		Conditioned floor area
		Number of façades
		Compactness
		Total area of glazing
		Main orientation of glazed surfaces
		Area of glazing in the main orientation
	Characteristics of the envelope	Inertia
		Air tightness
		Mean U-value
		K level
		Presence of solar protection (indoor or outdoor, automated)
	System's characteristics	Type of ventilation
		Heating system
		Hot water system
		Presence of photovoltaic solar panels
		Presence of solar thermal panels
	Expected energy performance level	Heating demand
		Risk of overheating
		Primary energy consumption
		E level
	Real consumptions	Overall fuel use
		Electricity consumption
	Technical failures and defects	Presence of condensation and/or mould
Occupant	Household characteristics and composition	Move-in date
		Age distribution of the household (<2, 3-12, 13- 24 , 25 -64 , over 65 years old)
		Educational level of the household
		Work situation
	Home ownership	Owner/leaser
	Technical knowledge and interests of the occupants	Interest for high energy performance dwellings
		Source of knowledge
		Personal quality criteria for houses
		Technical knowledge (heating, ventilation, insulation)
	Health and sensitization	Sensitivity (cold, hot, respiratory)
		Smoker
	Respondent's profile	Gender and age of the respondent
		Participation in technical aspects of the house
Behaviour and occupation	Presence and activities in the housing	Occupation schedule of the house
		Work at home
	Actions on the indoor environment and behavioural adjustments	Temperature set point
		Intermittent heating according to absence, time of the day, …
		Variation of the air volume ventilation (night, absence, presence in the bathroom, etc.)
		Windows' opening habits
		Clothing adjustment
		Temperature setpoint adjustment
		Attention given to consumptions
		Reasons for windows' opening
		Reasons for installation of additional equipment and devices (cooling, heating, solar protections, etc.)
	Maintenance of systems	Maintenance periodicity (heating and ventilation systems)

Table 2: potential factors influencing the satisfaction

7. Conclusions

Based on the measurement of specific satisfaction indicators and factors of influence, the proposed methodology should permit to efficiently evaluate the occupant's satisfaction with high energy performance dwellings and the main factors which influence this

satisfaction. An online questionnaire was applied to a large sample of 458 Walloon high performances houses (Belgium) as part of the MEASURE project. The questionnaire is available (in French) on the web: https://tools.uclouvain.be/limesurvey200/index.php/129147/lang-fr.
The results obtained by its application will be also available soon.

8. Acknowledgments

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