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SMART-RENO-IEQ: Evaluation of energy retrofits impacts on indoor thermal and air quality of single-family houses

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SUMMARY

Task 3 of the French research project Smart-Réno (2019-2021) aims at analysing the impacts of energy retrofits on indoor thermal and indoor air quality (IAQ) in single-family houses. Based on an analysis of the existing building stock and retrofitting done in recent years and on a literature review of indoor environmental quality (IEQ) metrics, this project development intends to elaborate a set of simulations to evaluate the renovation actions effects on thermal comfort and IAQ. This paper presents the main results obtained from the preliminary literature review tasks. First, the envelope characteristics (thermal transfer, air infiltration), heating and ventilation systems have been identified according to the construction year. Then, the main renovation actions have been classified according to their occurrences and performance levels. To finish, the renovation actions have been linked to the IEQ indices via their effects on intermediate variables such as air/surface temperature, pollutant sources, etc.

KEYWORDS

Energy retrofits, thermal comfort, indoor air quality, single-family houses

1 INTRODUCTION

In building energy renovation, the notion of payback time is often presented as the sole objective i.e. it is important to demonstrate that energy savings can rapidly pay back the investments made to generate them. These estimates are generally based on fairly reliable technical data, based on a few hypotheses, particularly in terms of the evolution of energy costs, and thus provide an element of the argument in favour of the work proposal. However, the comparison between these estimates and real life is often disappointing. The expected gains are rarely achieved and almost never exceeded.

Some technical biases can be suspected, such as the wrong estimation of the initial situation, or even discrete faults with no visible consequences for human sensitivity, but measurable by the energy meter. These potential reasons are studied in other subtasks of the present project.

Another cause is the so-called rebound effect that characterises the impact of the occupants' behaviour on their actual energy consumption. An occupant who pays his energy bill heats more than expected when he lives in a high-performance building. He therefore tends to consume less than expected before renovation and more than expected afterwards. All this tends to effectively to lower the expected gain, which is conventionally estimated. From this point of view, the rebound effect is a very annoying element for public policies but it is also an interesting element when one seeks to better understand the perceived value of an energy retrofit operation. If, after renovation, the inhabitant heats more, it is because, more or less consciously, he is ready to give up part of his savings for more comfort. The rebound effect is therefore a tangible element showing that in the personal equation of the candidate for renovation, beyond the payback time, the notion of comfort and comfort gain has real importance and real value. The value associated with a comfort gain will undoubtedly vary from one individual to another, but it seems to us that the comfort gain can be estimated. The purpose of this part of the project is to try to objectify this notion of comfort gain by renovation through quantifiable indicators related to the indoor environment.

The issue is complex for several reasons. First of all, comfort has many components: thermal, hygrothermal, acoustic, visual, indoor air quality (IAQ), ... There are therefore at least several criteria to be considered. Moreover, the inhabitant is not consciously sensitive to all these criteria. The excessive presence of a gaseous pollutant, for example, will not be "perceived" by the human being whereas it can be very harmful to him from the point of view of health. Moreover, for each criterion, several approaches and levels of approach are possible. Finally, for the same criterion and the same approach, it is very rare that an indicator is unanimously agreed upon.

The objective of task 3 of the research project Smart-Réno (Smart-Réno, 2020), started in 2019 and focusing on single-family houses, is to employ a pragmatic approach to this question by focusing on physical, modelable and measurable indicators for which renovation will have an impact. Our aim will not be to rank or judge the relevance of these indicators, but to evaluate them. The aim is to study a wide range of indicators, which will eventually be prioritized posteriorly according to future projects’ objectives. In addition, special emphasis will be placed on thermal and hygrothermal criteria, IAQ, and the acoustical impact of renovation solutions.

This paper will first present the overall research project in the methods part. Then the main results from the three first tasks will be presented and discussed.

2 METHODS

The scope of the project is limited to the case of French single-family houses. Figure 1 presents an overview of the different tasks numbered 1 to 6. Task 1 was dedicated to the analysis of the existing building stock has been done to identify its main characteristics (envelope composition, heating system, infiltration and ventilation rates…) according to the building construction year. In a second task, house energy retrofit actions such window replacement, wall/roof insulation improvement, changing the heating/ventilation systems, done in recent years have been compiled and ranked. A literature review of indoor IEQ metrics suitable to evaluate the benefit/burden of retrofits was the goal of task 3. Based on previous developments, studied cases of building retrofits have been defined to be modelled in task 4. The modelling accounts for heat and mass (air and pollutants) transfers in multizone houses during winter and summer periods using both the TRNSYS-CONTAM coupling and an integrated Modelica-based building energy and IAQ simulation program called

BuildSysPro. In parallel, in situ measurements will be done in a house to acquire real data on thermal and indoor air quality (IAQ) before and after an energy retrofit. The IEQ metrics will be calculated from the numerical results in task 5 to evaluate the comfort/IAQ gain/loss. Finally, additional measurements will be performed in two test-houses (task 6) to consolidate the trends observed in task 5.

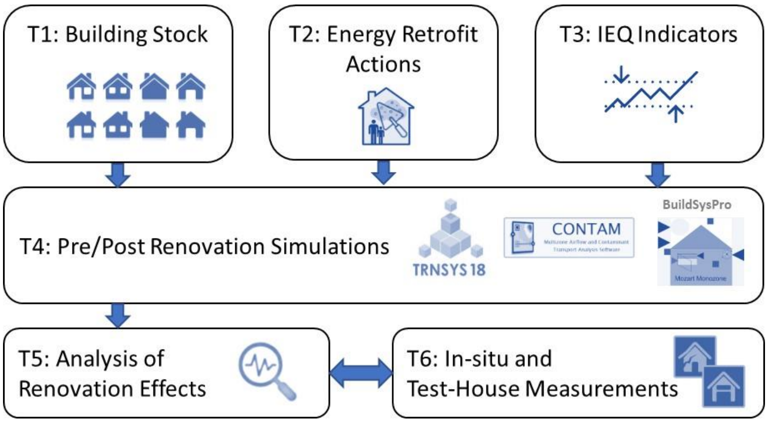


Figure 1. Overview of the Smart-Réno-IEQ project.

3 RESULTS

3.1 Task 1: Characteristics of current single-family houses

Task 1 was dedicated to the collection of data regarding the current building stock of French single-family houses. The main envelope characteristics are extracted from the European TABULA (Typology Approach for Building Stock Energy Assessment) database for the French single-family houses (Rochard et al., 2015) regarding the overall heat transfer coefficients and floor surface areas and from Bailly et al. (2015) for the infiltration rates (Figure 1). These values were compared to the one available in the French energy audit database (3.6 million households, DPE database).

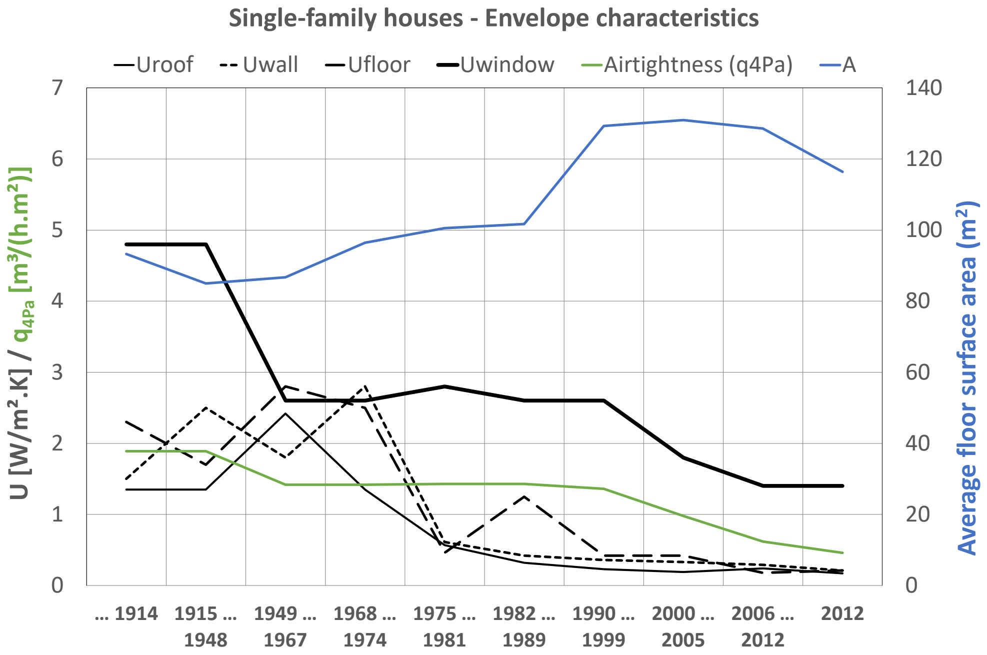


Figure 2. Historical evolution of French single-family houses envelope characteristics.

Figure 2 illustrates the effect of the successive national thermal regulations on the reduction of the overall heat transfer coefficient (U) for all parts of the building envelope. Also, one can observe the decrease of the infiltration rate (q_{4Pa}), particularly in the last three decades. The average size of the French houses (floor surface area A) was below 100 m^2 before the 1980's, strongly increased in the 1990's and is nowadays stabilized around 120 m^2.

Regarding the energy production systems, particularly noteworthy is the evolution from high-temperature heat emission systems to low-temperature systems and the shift from natural ventilation to mechanical exhaust ventilation from pressure self-regulated system in the 1990-2010 period to humidity (hygro B) self-regulated ones (and balanced ventilation) in the last decade.

In terms of IEQ, the QUALITEL barometer (2017) evaluates the quality of housing in the French housing stock according to different criteria such as acoustic insulation, ventilation or airing, humidity level, energy consumption level, thermal comfort, etc. Their 2017 study reveals that 50% of the occupants say they are sometimes or often too cold in winter and too hot in summer, 20% complain of poor ventilation/airing and 30% complain about noise problems but it reduces to only 7% for those living in single-family homes. The study shows also that the overall quality of housing varies according to the year of construction of the dwelling. However, it is important to note that IAQ, when considered alone, is not correlated to the year of construction as showed by the statistical analysis of the French database on indoor air pollution in dwellings (Langer et al., 2016).

3.2 Task 2: Current renovation actions

The objectives of Task 2 were to identify the renovation actions actually held in France in the last decade. Figure 3 compiles data from OPEN (2016), TREMI (2018) and Rochard et al (2015) in one graph. This Figure shows the main renovation actions held in the 2014-2016 period along with the identification of the renovated building construction year (pie chart) and the key elements defining standard and high-performance retrofits in France. A total of 12 million retrofit actions have been performed during this two-year period: 23% of window replacement, 20% (roof) + 18% (walls) of insulation improvement and 17% of heating system renewal. The three other actions represent only 9%, 7% and 5%, respectively.

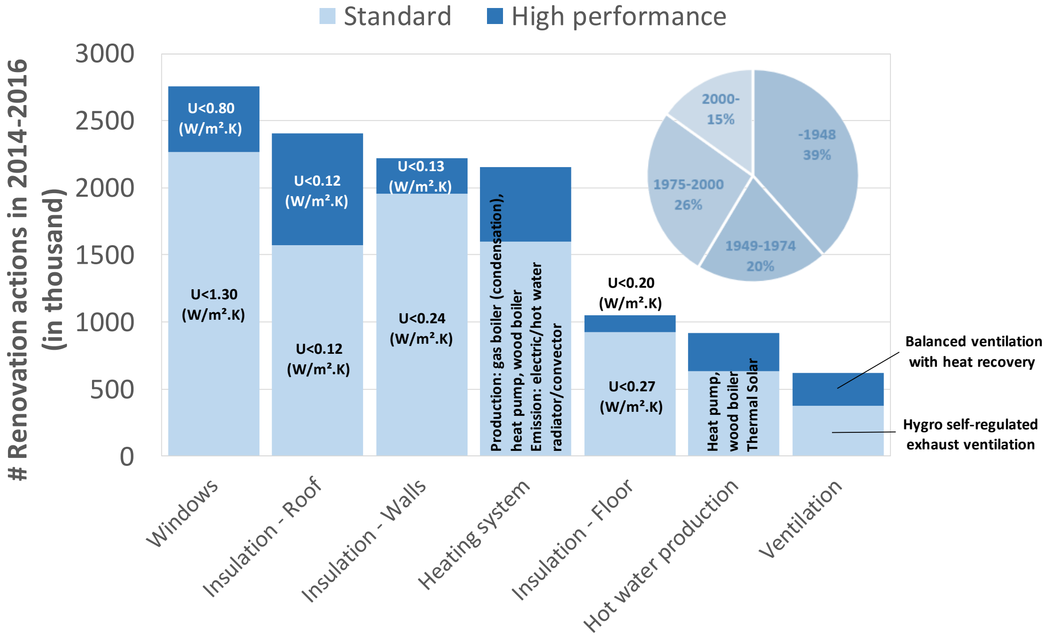


Figure 3. Renovation actions in French single-family houses in 2014-2016.

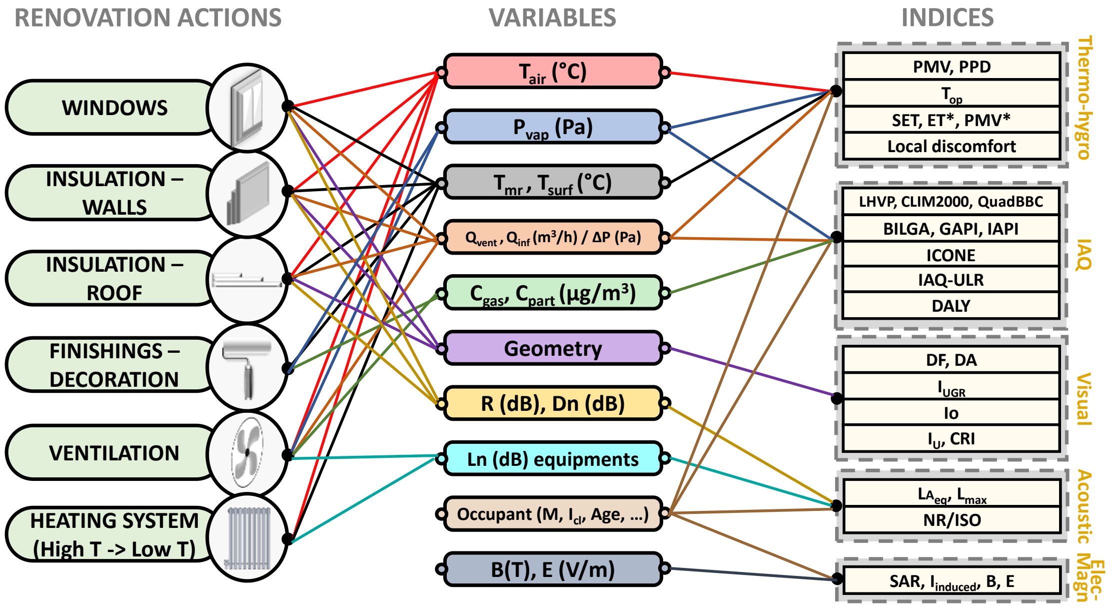
Most of the actions were of basic/standard performance according to the national building energy performance requirements for existing buildings. Two actions present slightly higher proportion of better performance: roof insulation and ventilation because it is not too expensive to upgrade to a better solution in comparison to the other actions. TREMI (2018) concluded also that ventilation does not appear in the top 10 of renovation package. Finally, the renovation actions have been held in buildings constructed before 1948 (the oldest ones) and between 1975 and 2000 as those between 1949 and 1974 have been the focus of previous renovation period because of the bad energy performance of the post-war constructions.

3.2 Task 3: IEQ parameters and indices

Task 3 aimed at defining the IEQ parameters for the present project and to review the IEQ indices available in the scientific literature. In this review, we considered the thermal, acoustic and visual comforts, IAQ and electromagnetic fields.

Figure 4 presents a schematic view showing the IEQ variables and, as a consequence, the IEQ indices directly concerned by renovation actions. For example, let's considerer the replacement of an old single-glazing window by a double-glazed one. This action will modify the air temperature (lower U-value of the envelope), the internal window pane surface (and also the mean radiant temperature), the infiltration rate (by increasing the airtightness of the junction with the wall), the geometry (if not identical with the original window) and on sound transmission (higher sound transmission class). Consequently, a change of window will have an effect on thermal comfort, IAQ, acoustic and visual comfort.

Most renovation actions may have multiple effects and should be considered altogether. Also, one can see from Figure 4 that we did not detect any link between the renovation actions and electromagnetic fields (even if, for particular cases, modification of the EM fields can take place consecutively of renovations). We also consider that renovation actions do not modify the occupant in terms of activity in order to evaluate the before/after renovation IEQ with the same reference.



HT/LT: High/Low temperature, T_{air}: air temperature (°C), P_{vap}: vapor pressure (Pa), T_{mr}: mean radiant temperature (°C), T_{surf}: surface temperature (°C), Q_{vent}: ventilation airflow rate (m^3/h), Q_{vent}: infiltration airflow rate (m^3/h), ΔP: pressure gradient (Pa), C_{gas}: gaseous pollutant concentration ($\mu g/m^3$), C_{part}: particulate matter concentration ($\mu g/m^3$), R, Dn: sound transmission loss indices (dB), Ln: sound pressure level of equipment (dB), M: metabolic heat production (W/m^2), I_{cl}: thermal insulation of the clothing ($m^2.K/W$), B: magnetic field (T), electric field (V/m), PMV: Predicted Mean Vote (-), PPD: Predicted Percentage of Dissatisfied (-), T_{op}: operative temperature (°C), SET: standard effective temperature (°C), LHVP, Clim2000, QuadBBC, BILGA, IAPI, GAPI, IAQ-ULR, DALY: IAQ indices (-), DF: daylight actor (%), DA: daylight autonomy (%), UGR: unified glare rating (-), Io: opening surfaces index (-), I_U: uniformity of light index (-), CRI: colour rendering index (-), L_{Aeq}: A-weighted equivalent sound level (dB), L_{max}: maximum sound pressure level (dB), NR/ISO: noise rating curves or ISO curves (-), SAR: specific absorption rate (W/kg), $I_{induced}$: skin induced current due to electromagnetic fields (A/m).

Figure 4. Schematic overview of renovation action influences on IEQ indices.

4 DISCUSSION

The three first tasks of the present project are now over. Their objectives were to help designing the simulation specifications in terms of definition of the current building stock and recurrent renovation actions and to define the IEQ key indicators. We have shown that these indicators participate differently from the definition of IEQ, especially in the context of the energy renovation of buildings. This is fundamental to consider for the future phases of the project in order not only to judge the relevance of the envisaged renovation actions (and to evaluate their energy efficiency); but also, to propose sustainable solutions that consider the subjectivity of the occupant's behaviour.

The next step of the project is to establish and perform simulations to quantify the variation of the various listed IEQ indices when renovations occur. Data from Task 1 will serve as initial inputs to define the pre-renovated houses. It was chosen to consider 3 different periods of construction i.e. before 1948, 1949-1974 and 1975-2000. The 7 renovation actions presented in Figure 4 and different groups of them will be then simulated. The renovation impacts will be quantified by calculating the IEQ indices.

5 CONCLUSIONS

A constant improvement is observed, in terms of thermal comfort, from uncomfortable old buildings to recent buildings limiting discomfort due to cold. A similar trend is observed for IAQ, but only for newer buildings; an improvement that can be explained by the reduction of indoor pollutant sources and better control of ventilation. Therefore, a beneficial effect of energy retrofitting of older buildings can be expected for both of these items and should be demonstrated/quantified in the following of the present project. The results of this project will assist in the implementation of energy retrofits as we believe that occupants are looking to improve the quality of their environment as well as to save money by reducing energy consumption.

6 ACKNOWLEDGEMENTS

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