How to Transform European Housing into Healthy and Sustainable Living Spaces?
– the RenovActive principles tackle climate and renovation challenges

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ABSTRACT: This renovation concept seeks to offer healthy, affordable, easy to reproduce, scalable solutions for the existing building stock of European housing. The concept was developed and tested in a prototype phase, where 7 principles have been applied to a semidetached house built in 1920s, situated in a garden city in Brussels. The prototype was now occupied by a family and monitored for two years. The monitoring was performed both through data, sensors and extensive interviews and questionnaires with the family. In general, living in the house is positively perceived by the family, who state they are very satisfied with the indoor environment, such as temperature, air quality and daylight. Sensor data results show a general indoor CO_2-concentration below 900 ppm. Indoor temperature measurements vary between 21°C and 26°C. The occupants are very satisfied with the house, however the technical and sociological monitoring show there is further potential to optimise and improve indoor comfort levels and perception. There are discrepancies between setpoints and programming, based on predicted behaviours, and user actions and preferences in real life, as well as situational perceptions and culture. This goes to prove that technical systems operating the indoor environment must be both flexible and robust to accommodate for multiple and varying preferences of building inhabitants.
KEYWORDS: Renovation, POE, Building Monitoring, Active House, Healthy Buildings

1. THE RENOVACTIVE CONCEPT

Through 2008-2012, several Model Home 2020 demonstration buildings were designed and constructed. The objective of the Model Home 2020 project was to combine excellent indoor environment with high energy efficiency. Thereby, the houses were designed, built and constructed as state-of-the-art homes with the newest technological developments and high-quality materials, and designed to strike the best balance between the three Active House principles [1] (Figure 1):

- Comfort: the building should provide indoor living conditions that support the health and comfort of its inhabitants
- Energy: the building achieves high levels of energy efficiency and makes use of renewable energy
- Environment: the building has a minimal impact on the environment.

In the Model Home 2020 projects, all buildings were monitored in use to measure and understand both the buildings' performance and the perception of the occupants. From the monitoring part, one of the conclusions was that it is possible with available products and technology to meet the 2020 energy requirements without compromising sustainable living.

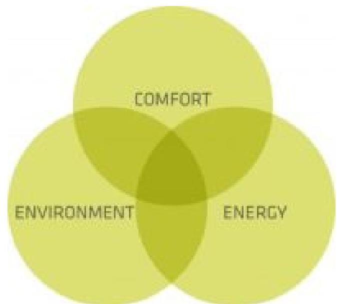


Figure 1 - The Active House principles

The need for meeting legislative requirements is especially poignant with pre-existing structures. The RenovActive project builds on these learnings, while focusing on renovation. Indeed, all the current dwellings in Europe have been built between 1945 and 1980, and the average age of our total building stock continues to grow increasingly older. Eurostat has registered a 30% decline in construction output in the EU's 28 member states since 2008. If the trend continues, 90% of our current residential properties will still be in use by the year 2050. The RenovActive project in Anderlecht seeks to offer healthy, affordable, scalable solutions [2] by testing the Active House principles in social housing and in the single-family housing segment.

2. SEVEN PRINCIPLES FOR A HEALTHY AND AFFORDABLE CLIMATE RENOVATION

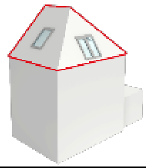
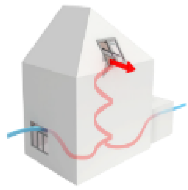
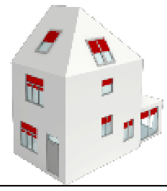
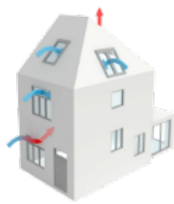
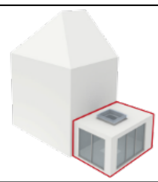
A key aspect of the RenovActive (Figure 2) project is to prove the financial viability of a renovation according to the Active House principles in social housing across Europe, where challenges are:

- Ill-maintained homes are more common in rental properties due to tenants' lack of ownership
- Energy poverty means that nearly 11% cannot afford to heat their home sufficiently
- Unsuitable behaviors, e.g. lack of regular airing and the drying of clothes indoors, lead to a bad indoor climate

Figure 2 RenovActive prototype before and after renovation

Dividing the concept into seven individual building elements makes it possible to create a better match between the financial plan of the project and the different needs of the housing company, and the very wide span of existing housing conditions. To be able to meet the different points of departure, and enable a standardized approach, the affordability concept bases on the proven quality of each principle, as well as the ability to be reproduced, allowing economies of scale to take effect; as such it is an approach of systemic enablement with a combination of elements.

Table 1: Seven principles applicable and cost-effective solutions for renovation.

1: Attic conversion: The attic is converted into living space (area 12,5m²) and connected to the home via an open stairwell.	
2: Increased glazed area: Distribution of windows (both new and existing) in every room and on every floor to improve daylight conditions	
3: Staircase shaft for daylight & ventilation: An open stairwell topped with roof windows allows ventilative cooling through open roof windows as well as downward daylight distribution.	
4: Dynamic sunscreening: External sun screening reduces overheating.	
5: Hybrid ventilation system: During summer, windows and stairwell are used to provide natural cooling in the building, During winter, mechanical ventilation maintains indoor air quality and while limiting risk of draughts.	
6: Improved thermal envelope: New facade insulation, a new roof construction and new windows all around ensure reduced energy consumption. New ground floor heating and modern radiators on the 1st and 2nd floors.	
7: Building extension: The extension (area 15m²) creates additional living space on the ground floor and space for one more family member in total.	

The RenovActive Concept is based on seven principles, seen to be the most applicable and cost-effective solutions for renovation (Table 1). Each element is created to give existing buildings the ability to perform on the same level, or close to, as newly built houses. Depending on the existing building design and renovation budget, the different elements can be implemented to increase the level of daylight, improve ventilation, strengthen the envelope or expand the living space through densification or extension. The concept's modularity adapts to each house typology.

To investigate the concept, the house has been tested by the first family to move in and monitored post occupancy to evaluate how the elements function in practice. The post occupancy evaluation is conducted by a research team of social scientists and engineers. The sociologists took a close look at the occupants' perspective, experiences and their interaction with the building. The engineers checked physical data and performances of the house. The post occupancy monitoring of the first RenovActive project wanted to explore the performance of this healthy and affordable renovation, targeting both energy savings and user comfort.

The following targets were laid down to make the RenovActive House in Belgium a success and validate the concept - all of them were met by the completion of the project:

- Indoor climate: The house offers high daylight levels, protection against overheating and a good indoor air quality
- Affordability: The renovation (incl. all technical equipment) is executed within the budget lines of social housing in Brussels
- Reproducibility: The concept should be based on existing technologies and materials
- Energy performance: The primary energy use complies with the strict Brussels EPB (Energy Performance of Buildings) legislation

2.1 From an occupant perspective

The sociological monitoring included three different instruments of data collection and several data collection points. There were face-to-face-interviews, online questionnaires and a time-diary-tool. These three instruments were linked together, and each is referring to the other. After filling in questionnaires, the adults were interviewed face-to-face by a scientist, directly after the interview, both adults were asked to fill in a time diary for a one-week period. The online questionnaire quantified the opinions, level of satisfaction and comfort behaviour of the dwellers, an input that was then extended during the face-to-face-interview.

2.2 From a monitoring perspective

The post occupancy building monitoring included measurements of indoor air quality and thermal comfort, as well as energy consumption. The monitoring aimed at establishing knowledge and documentation on the house's performance, the inhabitants' perceptions and on the contribution of the different renovation principles to both.

2.3 Methodological challenges

In this project, there proved to be several methodological challenges to be dealt with when monitoring and evaluating the results, the most prominent one being the dependency on a single case exploration, which makes generalising difficult Some findings can thus be to some extent, related to the observed family and the special conditions of their former home.

3. RESULTS

The complete monitoring program took place from July 2017 until September 2019. Data from the social monitoring [3] show that the family is very satisfied with the level of indoor comfort. In the questionnaires, the time diary as well as during the interviews, the family stated that they were very happy with the indoor temperature, the indoor air quality and daylight levels. However, the family pointed towards too high temperatures during the summer months of the first year. Based on this feedback, adjustments were made to the ventilation system to improve the stack effect of the staircase by automatic window openings. Moreover, a better solar shading device in the attic significantly improved the indoor comfort. The occupants perceived the house to be well-lit by daylight thanks to the different windows, even if they were using the ground-floor solar protection almost all the time for privacy reasons.

There is generally enough space for the family and the layout ensures that the house can be used optimally.

To further improve the level of comfort, the family had various options to adjust appliances manually, such as opening windows, lowering blinds, adjusting heating and ventilation systems, etc. Besides daily adjustment of the heating in the bedrooms during winter, and the opening of windows during cooking and cleaning in order to let the 'smelly' air out, few adjustments were made to improve the indoor climate. Nevertheless, occupants reported a sense of being able to adjust the different indoor parameters according to their needs, and when doing so, to experience an improvement of the indoor environment. Interestingly, the ventilation system as well as the home automation system were left unadjusted, along with sporadic manual window opening to cool down the house.

The mother reports a positive development on her state of health. She reported irritated airways in the former home because of high humidity during winter. This has disappeared. The quality of sleep has also been greatly improved since the family moved in. Although the general perception of the house is very positive and associated with increase of happiness, health level and overall wellbeing, there are a few elements that occupants identify as challenging: the presence of mosquitos during night, lack of outdoor storage facilities, and a technical mistake of the slope of the bathroom floor.

the lowest possible airflow (an airflow has to be maintained as the Healthbox unit contains the indoor climate sensors) and the windows are used to control

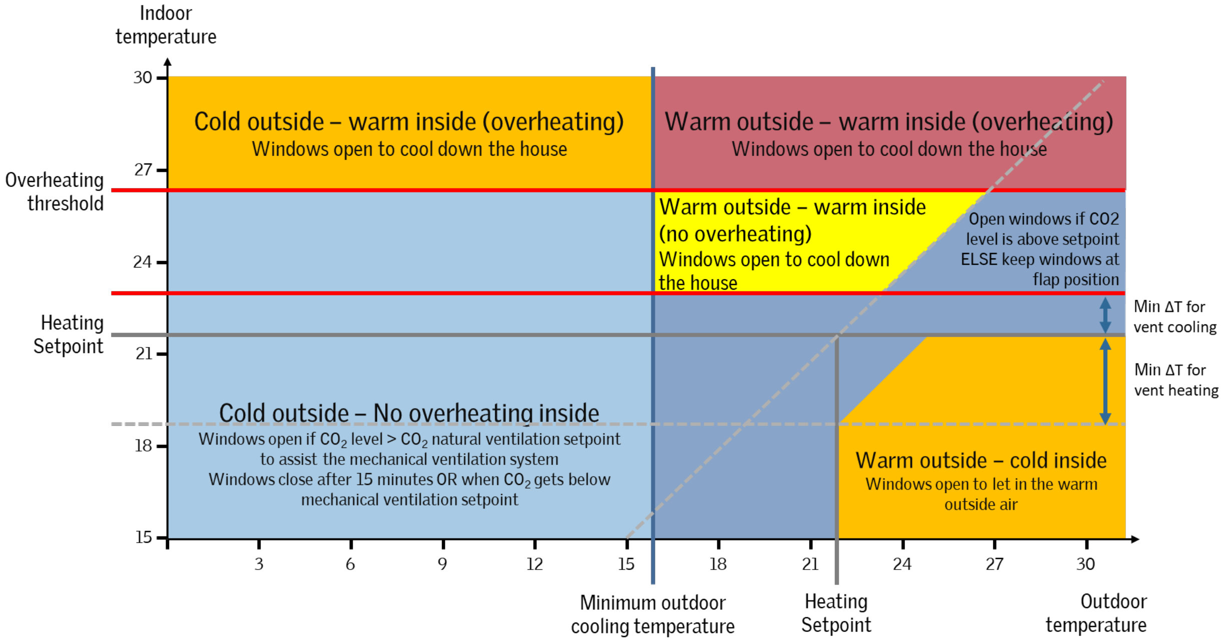


Figure 3: Schematic diagram explaining the hybrid ventilation system of the Healthbox.

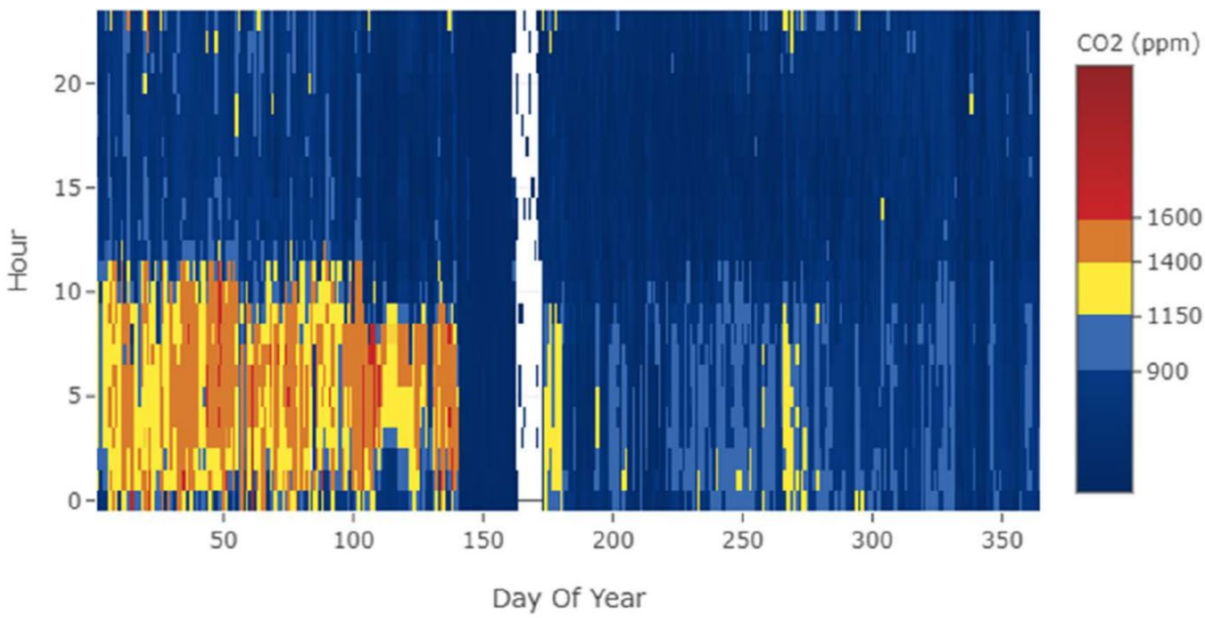


Figure 4: Temporal map of the CO_2 concentration in the parent's bedroom, 2018. Each column represents one day of the year and each of the rows the hours. The colour scale indicates the CO_2 level. The white area around May is due to a period of missing data.

From a monitoring perspective [4], the results show that the indoor air quality is very good. The hygienic ventilation system, Healthbox, in the house is a demand-controlled ventilation system with natural supply vents and mechanical extraction, designed according to Belgian standards. Figure 3 show the schematic diagram, where the control is based on the indoor and outdoor temperature. When the outdoor temperature is above "minimum outdoor cooling temperature, the mechanical ventilation is reduced to the indoor climate. Below the setpoint the mechanical ventilation runs in demand control mode with the windows as a backup system (for birthdays and other occasions where the mechanical ventilation is not sufficient to cope with the pollution load.

The mechanical extract ventilation was roughly 9 L/s for the bedrooms and 22 L/s for the kitchen. Additionally, a peak ventilation through automatically controlled window openings is available. The control of the switch between hygienic and peak ventilation is based on indoor air quality parameters (CO_2, RH) and indoor air temperature. The setpoint for the mechanical extract ventilation is 850 ppm. During warm periods, windows open at 1100 ppm and during winter at 1500 ppm (natural peak ventilation is thus used as a backup for the mechanical system providing hygienic ventilation). The design goal was to maintain at least category II of EN 16978-1 (5), Table B.12, corresponding to 1200 ppm (outdoor level 400 ppm). For more than 95% of the time, the CO2-concentration in the house, in general, is below 900 ppm. Slightly higher values were measured in the parents sleeping rooms (e.g. 1100 ppm, Figure 4). On the other hand, the mechanical ventilation system did not perform according to the intended strategy from the beginning, due to some of the supply vents unintentionally closed, as well as the fact that the fan system was set, by the family, to eco-mode instead of demand control mode due to noise, resulting in low ventilation rates. Automatic operation of the staircase windows, and attic window was turned off at night (as a mosquito protection). In this timeframe, the 95th percentile CO2 concentration where slightly above 1300 ppm. Indoor temperature measurements show that the thermal comfort is good, but in case of extremely hot temperatures, indoor temperatures increase quickly if the solar shading devices are not used as intended.

The temperatures stay for more than 95% of the time between 21°C and 26°C (e.g. similar to category II of EN 16798-1 Table B.4), while the attic has slightly higher values, but stays under 28°C, after improved staircase- and attic-window openings, especially by encouraging the family to use cross ventilation in the attic to reduce peak temperatures. During the 2018 hot spell, the indoor temperatures were too high, and the automatic system did not resolve this, but could have been improved by ensuring cross-ventilation operation.

Energy consumption for heating is higher than the predicted value, mainly due to higher indoor temperature (about 21°C) than the setpoint used in the calculation (19°C). The average yearly energy consumption for heating (gas consumption) and domestic hot water is around 70 kWh/m2/year. The electricity consumption is slightly above a moderate household use (+400 kWh). There is most likely a rebound effect as explanation on year 1, and the energy consumption was reduced during year 2.

4. CONCLUSION

In general, home satisfaction is very high. The family indicated that they are very happy with the indoor climate, such as the indoor temperature, air quality and the automatic system. The health and sleep quality of the family have improved considerably since they moved into the RenovActive house. They also report that their family life as well as social contacts outside the family have greatly improved. During their daily life, few adjustments of the automatic system are operated by the family. One reason could be that the family indicates that they feel unqualified to make adjustments; they consider that the system is smarter than they are, not daring to overrule it. Another reasoning is that as long as the system does not interfere with their primary needs (privacy, mosquito bites etc.) they tolerate it.

Finally, an important learning is that the family operates the technical systems, as well as its adjustment possibilities, slightly differently than the intended strategy. Consequently, the flexibility and robustness of the technical systems operating the indoor environment is essential to accommodate for the occupants' preferences. For example, a system detecting significant deviations from planned parameters could return to a default setting or provide feedback to occupants to allow them to make informed decisions.

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