Energy and Comfort Performance Evaluation after Renovation of an Office Building

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ABSTRACT: The construction sector has been highlighted as a key potential area for reducing global energy consumption and thus for acting on climate change. As they represent a huge part of the built environment, refurbishment of existing buildings is an important issue to consider. But efficient processes of renovation need to be well defined in order to be generalized. Although energy is an important consideration, health and comfort should not be sacrificed for low energy strategies, and the renovation must be as global as possible. For the success of the operation, occupants must be included from the very beginning of the process. This paper is about the refurbishment of an office building from the 70's, used as a real case study. The complete monitoring of the building both for energy and comfort, will allow a better understanding of mechanisms and barriers, technological but also psychosocial. Measurements will be compared with the perception of the occupants and we will try to evaluate human interactions' impacts on the building behavior.

Keywords: refurbishment, monitoring, energy efficiency, comfort

INTRODUCTION

In Europe over 40% (42.5% in France) of our energy consumption is used in buildings, more than in transport or industry, and the sector represents a high potential of evolution and innovation in term of energy savings. If numerous progresses are made for the construction of new buildings, there is still a lot to do for renovation which corresponds to the main part of buildings stock. Thus renovation is a main issue, as it is a huge cost-effective potential of energy saving. If energy is today the main focus with the current issue of climate change, efficient refurbishment program must also include improvement of indoor comfort for the well-being of occupants and the good acceptance.

The methodology developed by INES (National Institute of Solar Energy) in Chambery (France) focuses on reducing consumption of primary energy and decreasing greenhouse gas emissions in the built environment, while increasing users comfort. For this purpose, it aims to make the building renovation process more efficient by elaborating generic guidelines and tools. To achieve that objective, the work is first based on case studies.

CASE STUDY PRESENTATION

The building (Fig. 1) houses the ALLP head office (Association Lyonnaise de Logistique Post-hospitalière – Lyon post-hospital logistics association). The construction is located in Lyon, France, in a continental climate area, and was achieved in 1974. About 70 persons work currently in the three storey building. The total floor area is 2850m².

Figure 1: ALLP building before and during retrofit.

The building has a concrete structure and energetic performances were poor due to an old and low-grade internal insulation, simple glazing window and many cold bridges. Existing solar protections were unadapted.

There was no mechanical ventilation thus fresh air came only by infiltrations and windows hand-openings. Adequate air change is necessary to reach good working conditions and can not be insured in these conditions. A complete diagnostic of the building and the systems was realised by an engineering office in 2005 [1]; it showed a heating consumption of about 140kWh/m². The other problem underlined by the building owner was summer overheating and global discomfort. A temperature of 34 °C was for instance measured in June 2005 in an office of the first floor oriented toward the South. These working conditions were not acceptable for the employees and the productivity decreased by almost 20%. This situation accounts for the intent of the ALLP managers to equip the building with an air conditioning system, but the energetic audit showed the interest to set a complete refurbishment program.

Just before the retrofit operation, we organised a survey led by an independent organism [2]. Questionnaires to the occupants and local measurements confirmed the overall discomfort. This kind of study needs to be more systematic when a refurbishment operation is considered, like the one existing for household, the EPIQR methodology (Energy Performance Indoor Environmental Quality Retrofit) [3], whose goals are: optimisation of energy consumption, improved indoor environmental quality and cost-effectiveness.

During the conception phase, ALLP was modelled with the dynamic simulation software TRNSYS and the building was split in eight thermal zones. The ground floor comprises two zones (entry rooms, lobby and workshops); the first and second floors are identically zoned in three parts: two office zones and a common zone where comfort is not essential (staircase, etc). The two office zones on first and second floors are critical because they comprise most of the people working in the building, inducing a rather high population density and also high internal gains. The dynamic simulation was used to develop sensitivity studies on technical parameters. The building was considered from a macro-scale (envelop) to a micro-scale (regulation of the energetic systems) and significant energy savings were identified at each level. The analysis was coupled with an economical approach, keeping in mind that the project had to be a demonstration case and thus reproducible. The main focus for this first case study was energy saving, and the simulation results prove that a reduction by a factor 2 on primary energy consumption and by a factor 4 on CO2 emission can easily be reached.

Thanks to the preliminary studies and with the coupled work of the architect, fluid engineering office, INES and the ALLP managers, the building renovation was planned. First enhancements were passives solutions including improvement of the envelope (low-emissivity double glazing filled with Argon windows, external insulation), new effective external solar protections (Fig. 2) and night ventilation. But simulations demonstrated that during summer comfortable conditions would not be reached. The need of a cooling system guided the choice towards a heat pump. The system was chosen reversible even if a highly efficient new gas boiler of 350 kW had been set up in 2004, and so an air-water heat pump of 100kW was installed (Fig. 2). Distribution is done by fan coil unit in every room. An attempt was also done to improve the efficiency of office lighting (control of artificial lighting in response to occupancy and amount of daylight). 90 m² of photovoltaic panels were disposed on the roof. The 10 kW grid connected system should produce about 11 MWh per year.

Figure 2: Details of the renovation: heat pump and solar shading device

MONITORING

Refurbishment was achieved by mid 2007 and the building was fully equipped with sensors. The monitoring allows the gathering of the necessary feedback on energy consumption and comfort in the offices. The tele-supervision of the building is done by a Building Management System (BMS) that integrates an internet protocol. The remote access permits to automate, control and monitor the building with a lot of freedom in the data acquisition. All the results allow feedback at two levels. The first one is focused on the global behavior of building and is based on energy counters and ambient temperature probes, as well as exterior weather sensors. The second one applies to the scale of an office room in which wireless sensors described the temperature, humidity rate, luminosity, occupancy, opening of window (Fig. 3). The aim of the first level of monitoring is to detect failure, evaluate the global performance of the renovation and compare measurements of energy consumption with predicted values. A longer observation period is also necessary to evaluate the software model accuracy. The second level of monitoring illustrates the working conditions in critical office rooms, and thus the occupants' level of comfort. It also gives an idea of the evaluation of the airflow distribution on comfort.

Measurements help to identify potential problems associated with the control of heating, cooling, ventilation and air conditioning (HVAC) regulation.

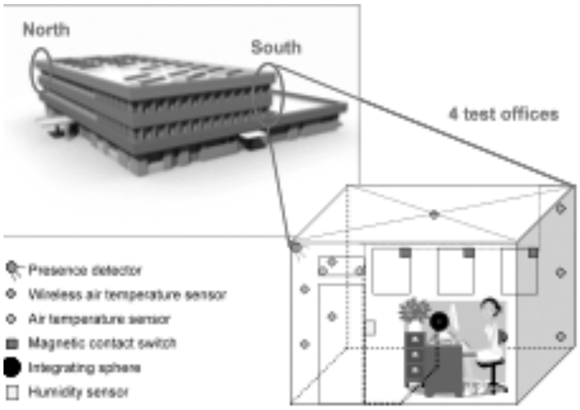

Figure 3: Local monitoring of 4 test offices

The web platform allows to access to the data from any internet-connected computer. The interface was made as user-friendly as possible and is in continuous improvement.

ENERGY BALANCE

The initial feedback confirms that energy consumption was consequently reduced. The monitoring measurements of the HVAC systems help us to identify non-optimal performances and enable us to react quickly for improvement. Some problems were found in the heating system, for the alternate functioning of the gas boiler and the heat pump. The boiler should take over when outside conditions do not permit to reach a coefficient of performance (COP) of 2.5 (2.5 is the French conversion factor for primary energy). Adjustments required maintenance service interventions.

COMFORT: FIRST RESULTS

Investigation of occupants' satisfaction with the indoor environmental quality helps to detect impacts on well-being and productivity. A first analysis of the measurements showed that renovation was beneficial for the users' comfort. In order to know their feelings, a survey was established in December 2008. The workers were inquired with rapid questionnaire dealing with their overall comfort. 30 persons answered: 26 women and 4 men. They were from 22 to 57 years old with a mean around 40. The results are surprising: 100% of the users were dissatisfied with at least one parameter. The main complaints are focused on hygrothermal comfort: too warm or too cold, difference of temperature between head and foot, air dryness. The second problem highlighted is about the system by itself ; the fact that the heating is done by an air system causes a feeling of draught, noise, a rapid change of temperature when the system is stopping and the fear of hygienically/sanitary problem. The last point is about the difficulty to act on the thermostat and the lack of possibilities to control one's work environment. Interestingly, neither the orientation of the offices nor the floor level has an influence on the results. Women were largely over-represented in the study sample, and gender based differences exist both for physiological and psychosocial factors.

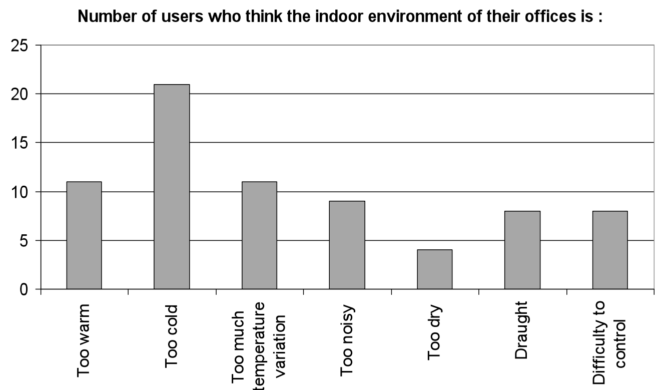

Table 1: Results of the first users' survey

Some criticisms seem excessive and reveal a lack of adaptability. Hence users contest that offices are warmer in summer than in winter, or that they do not wear appropriate clothes during winter period. Distrust and resistance towards the new system spread among the occupants. Inconsistent behaviours were also revealed during a visit of the building. For example, heating is on and windows are open. Visual comfort seems also to be a key point as despite the new efficient artificial lighting system, some occupants continue to use their individual halogen lamp. For sure users were not informed enough about the behaviour to adopt in coherence with the renovation. Furthermore some employees were uncomfortable with the HVAC and lighting automatic regulation. Means of control to adjust the indoor environment to their own requirements need to be improved. Adaptive strategies have to be implemented. Anyway the level of acceptance and adaptation varies from one person to another and it is not trivial to generalize

This case study shows that it is important to promote communication and co-operation between the various partners involved with the operation and the non-expert users of the buildings, and that, from the very beginning of the process. Research has shown that human perception of thermal comfort is a mixture of the physiological and psychological factor [4]. According to

Lahtinen and colleagues [5], those who perceived their psychosocial work environment more negatively had more complaints regarding the indoor environment.

WAYS OF INVESTIGATION

The difficulty in defining the monitoring instrumentation is that the different parties (employees, managers, buildings owners, technical experts, safety personnel) have different perceptions of the problems and different expectations. Here the choice was made to focus on energy and global improvement of the building. But finally, the role of the occupants appears to be central to achieve the goals of the refurbishment. Now that the building has been renovated and that dysfunctions of HVAC systems have been fixed, it is essential to focus on occupants perceptions. A more precise comfort survey will be carried out, consisting on measurements and simultaneously gathered questionnaire data by office occupants. For measurements, a mobile unit (Fig. 4) equipped with air temperature, air humidity, vertical air temperature difference (VATD), radiant temperature asymmetry, illuminance and air velocity sensors will be used. The survey will allow comparison of the measured data with the subjective statements given by the occupants.

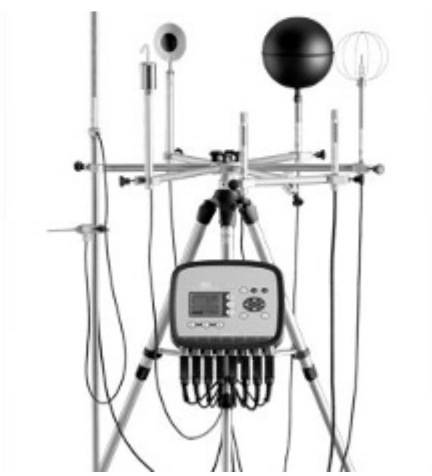

Figure 4: Mobile unit of thermal microclimate data logger.

Indoor air quality (IAQ) is also planned to be checked, including CO and CO2 quantity, radon, volatile organic compounds (VOC), and particles. A detailed study of visual comfort will be intended as well, in order to underline the overall quality of offices lighting system, possible inconveniences (glare or excessive contrast) and limits of artificial lighting regulation [6]. New software should be used in this purpose (DaySim in parallel with Energy Plus). A CFD model is also considered in order to model in detail air movement and thermal flux inside a room.

CONCLUSION

In the construction sector, refurbishment of old buildings stock has been highlighted as an area which has a significant potential for improvement.

The impact of the renovation on energy consumption of the building is positive. And globally the retrofit improves the comfort although some claims remain about thermal and visual perception. The notion of comfort is too often neglected in energy-efficiency programs. It is very difficult to value the various attendant effects of comfort because of its inherent subjectivity and also because there has been so little empirical work undertaken in the area.

In order to succeed, the renovation process has to be as transparent as possible. As this case study revealed, there is a true need to relate occupants and their behaviour to the energy performance of the building early on the conception phase. Human interactions with the systems were not fully taken in account in the simulation and we now try to evaluate real occupants' impacts on the building behaviour.

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