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INFLUENCE OF ENERGY EFFICIENCY RENOVATION ON INDOOR CLIMATE

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The buildings of the 1960s are not designed for today's conditions and sustainable building standards. One of the solution strategies is renovation, which is not only for energy conservation but also for quality-of-life improvement. However, achieving both factors at once is a challenge, mostly from a financial standpoint. For public establishments, their priority is on energy efficiency retrofits which in return could push the indoor environmental quality (IEQ) to the edge of the comfort zone. IEQ is correlated to the health, comfort, and performance of users according to previous studies. This paper presents a case study of university buildings that underwent an energy-efficient renovation, including the replacement of windows and the installation of walls and roof insulation and mechanical extract ventilation systems. The objective is to analyze if the target energy consumption is achieved while maintaining a good IEQ during the heating period. Using t-test statistics on in-situ measurements of the before and after renovations, the results have shown three important findings. One, the total energy consumption has been reduced by 67%. Two, the t-test shows a significant difference between before and after states, with temperature decreased, and CO₂ level increased. Three, a higher CO₂ concentration is due to a faulty ventilation control that provides half less of the initial design airflow rate to meet a healthy standard. Overall, both temperature and CO₂ rates remain in acceptable ranges despite the variation, but it is crucial to evaluate the HVAC controls after the renovation for safety reasons.

Keywords: University buildings, Mediterranean weather, Indoor temperature, CO₂ level.

1 INTRODUCTION

By 2030, current European policy seeks to achieve a 27% increase in energy efficiency. By using new or more energy-efficient building stock, this should be realized (Artola et al. 2016, Trotta et al. 2018). Nearly 75% of the building stock in the EU is currently energy inefficient, and about 35% of structures are older than 50 years. Therefore, the key to energy saving in Europe is the refurbishment of existing structures Jens Laustsen et al. (2011).

The health, attitude, and performance of students in educational facilities are impacted by indoor air quality (IAQ) and hygrothermal comfort Becker et al. (2007). It is difficult to simultaneously provide productive and comfortable indoor climatic conditions while improving energy performance and reducing the environmental effect of buildings toward low-energy, low-carbon, and nearly zero-energy buildings. Usually, better indoor temperature conditions lead to higher energy usage in buildings (Fasi and Budaiwi 2015, Ornetzeder et al. 2016, Ucci and Yu 2014).

This paper's primary goal is to examine the impact of energy retrofitting measures intended to reduce heating use on the quality of the indoor environment. Prior to and following the renovation, the study is carried out on university buildings in the south of France during the heating season.

2 METHODOLOGY

The evaluation of retrofitting strategies was based on the results of long-term monitoring of indoor temperature and carbon dioxide concentration (CO₂) in two renovated buildings.

2.1 Case study

The investigated buildings essentially reflect all French university buildings constructed between 1960 and 1979, when exterior structures, heating systems, and other technical systems did not meet current building sustainability criteria. The buildings of *IUT* campus were built in 1969 and is situated in southern France (Latitude 43.83, Longitude 4.36). It consists of 6 buildings with a combined net surface of 27,666 m². Two of the buildings, GEII (Electrical engineering building) and GC (Civil engineering building), had renovations later in 2021 and 2022, respectively.

These identically designed buildings have a two-story teaching section that is 5.6 meters tall and a one-story technical section that is 3.5 meters tall. They are naturally ventilated and have a district heating system. Among the improvements made to the building envelope are replacing windows, adding insulation to external wall and roof, installing mechanical extract ventilation, and adding thermostats to existing radiators. Information about the pre-state and post-state of the building envelope is provided in Table 1.

Table 1: Thermal properties of the building envelope.

Segment	Original construction	U-value (W/m ² .K)	Renovated construction	U-value (W/m ² .K)
Floor	Concrete	3.13	Unchanged	3.13
Wall	Hollowed bricks 20 cm + concrete each side 4 cm	3.13	Existing + rock wool insulation 12cm	0.3
Windows	Single/double-glazed	3.6 / 5	Double-glazed 16mm argon	1.5
Roof Teaching section	Concrete slabs 15 cm + Euro-thane 0.4 cm	0.625	Existing + polyurethane insulation 12cm	0.11
Roof Technical section	Concrete slabs 15 cm + polystyrene 1.2 cm	0.18	Unchanged	0.18

2.2 In-situ measurements

Elsys and Class'Air sensors were used to detect interior temperature and indoor CO₂ in two phases: before and after the refurbishment. Class'Air (± 0.1 °C and 1% precision) is set to a 60-minute period, whereas Elsys (± 0.2 °C and 2% precision) is programmed to a 15-minute interval. The renovation lasted five months in each building, one year apart, from May to October. The data was gathered in winter from January to March of 2021, 2022, and 2023.

3 RESULTS AND DISCUSSION

3.1 Energy

The regulatory thermal calculation of energy efficiency of existing and retrofitting buildings is done using Pleiades Comfie – IZUBA tool. The renovation objective is to decrease the heating consumption to or lower than 15 kWhEP/m².year. According to Table 2, total energy saving was 67.3% in the case of GEII building. Based on French building rating regulations, the energy rating has moved from class C to class A.

Table 2: Distribution of heat losses by fabric type of GEII building.

Segment	Before	After	Changes
Wall (W/K)	5 974.95	504.95	91.5%
Window (W/K)	1 371.69	558.59	59.2%
Skylight (W/K)	900.07	900.07	0%
Roof (W/K)	1 026.86	395.9	61.4%
Thermal bridge(W/K)	763.16	257.06	66.3%
Floor (W/K)	1 516.04	1 488.24	1.8%
Total heat losses (W/K)	11 552.77	4 104.81	64.5%
Total energy consumption (kWh _{ep} /m ² .year)	101	33	67.3%

3.2 Indoor climate

The reduction in total energy consumption comes from the combination of less heat losses through the building envelope, absence of heat losses through openings for natural ventilation and the heating control strategy. In both pre and post states, the heating controls have the same program; “Comfort” and “Eco”. The Comfort mode functions in the daytime from 7h00 to 18h00 during weekdays and maintains a room temperature at 19°C minimum. The Eco mode reduces the temperature by 10°C at nighttime and weekends to economize energy. However, in the post building, thermostatics were implemented to maintain the indoor temperature at 19°C maximum in Comfort mode. Figure 1 depicts the average evolution of weekdays temperatures in both buildings before and after renovation. Buildings tend to have larger amplitudes and warmer temperatures during occupied hours before renovation. The new building envelope conserves more heat, hence, potentially reduces the temperature fluctuation between daytime and nighttime. In addition, internal heat gains were disregarded in the absence of thermostatic controls, which increased the total temperature, particularly in southern rooms that receive a lot of solar radiation. From t-test statistics of temperature using ‘anova_test’ and ‘effect’ functions in the R studio, the results obtained prove that there is a significant difference between before and after states with P-values equal 1.38e-36 and 2.60e-14 for GC and GEII, respectively.

Contrary to natural ventilation, which heavily relies on manually opening and closing windows and doors, mechanical extract ventilation installation ensures a consistent exchange air rates without supplying new air. For this case study, the refurbishment design calls for a 90 m³/h air exchange rate at each extractor outlet. The ventilation test conducted following renovations on the GC building, however, showed that the flow rate was less than half of the intended value. Regarding GEII, during renovations, one of the analyzed rooms was transformed from an office to a classroom, causing a measurable rise in CO₂ concentration and affecting the average value of

the studied time. Figure 2 illustrates the variation of CO₂ levels before and after refurbishment over the weekdays on average.

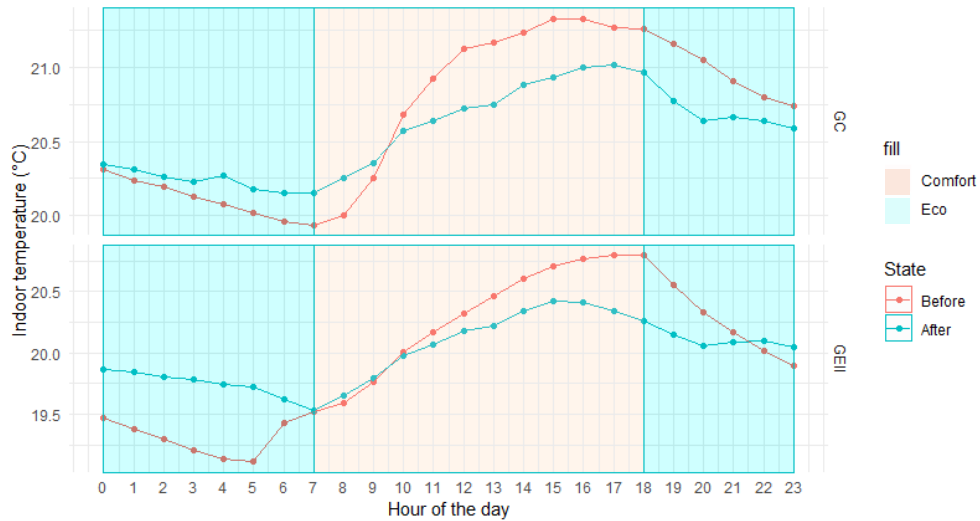


Figure 1: Hourly indoor air temperature profile for GC and GEII before and after retrofitting during weekdays over the studied period. The “Comfort” mode maintains room temperature at 19°C while “Eco” mode reduces temperature by 10°C.

The mechanical ventilation prevents the CO₂ level from exceeding the healthy range, which is more than 1000 ppm, even though it does not improve the air quality. Additionally, the post-renovation CO₂ concentration drops more quickly than it did before, often between 12h30 and 13h00, demonstrating the effectiveness of CO₂ evacuation during a brief break with mechanical ventilation.

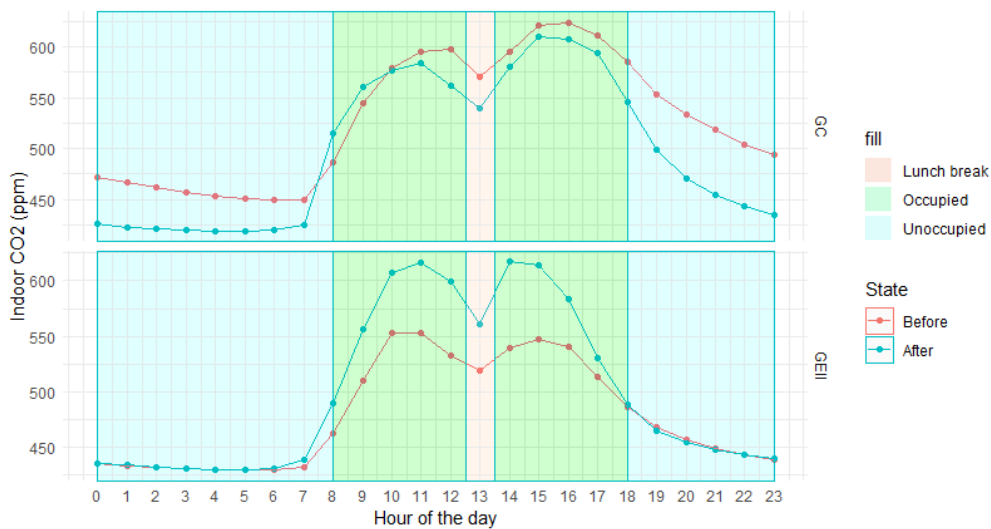


Figure 2: Hourly indoor CO₂ level profile for GC and GEII before and after retrofitting.

These results agree with those of Ghita and Catalina (2015), Veronika et al. (2015), and Vornanen-Winqvist et al. (2017) regarding the comparison of CO₂ levels. Their research revealed that in retrofitted buildings, the CO₂ levels remained the same or worsened. However, their analysis showed a rise in temperature following the renovation from 1°C to 3°C rather than a drop as in this paper. The heating set point, which is 19°C rather than 20°C or 21°C to comply with French heating regulation for school buildings, may be the cause.

4 CONCLUSION

This study validates earlier results in the literature that existing buildings must be retrofitted to fulfill current energy efficiency requirements for sustainable buildings. The energy demand for heating and overall energy consumption are reduced because of the retrofitting technique in this case study. A minor rise in CO₂ concentration and a drop in temperature are both within permissible limits, even though they don't improve users' thermal comfort. The report also highlights the fact that, while renovation is important, energy savings can also be attained through efficient energy controls. Additionally, testing and reevaluation are required following retrofitting in order to determine whether the designs have been fulfilled, for instance, whether the air flowrate through each outlet satisfies the standards for healthy indoor air quality.

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