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IEQ assessment of classrooms with an optimized demand controlled ventilation system

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Abstract

Ensuring a proper indoor environment in classrooms is crucial for the students' performance and well-being. Modern societies must, therefore, invest in the improvement of school buildings environment. However, in situ measurements in service conditions revealed a quite different scenario from the one expected at the design stage. In Portugal, the main reason is related to financial incapacity of the school board to maintain and operate the HVAC systems. This paper presents an alternative approach using different ventilation systems. This system was applied in a part of a school building and the indoor environment was monitored during two months.

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Keywords: Indoor environmental quality; classrooms; demand controlled ventilation; temperature; relative humidity; CO_2 concentration

1. Introduction

Excellence in education is a clear aim of any modern society. Several international studies have been conducted to evaluate student's performance and factors that most influence it, namely classrooms indoor environmental quality [1, 2] and it is well established that there are classroom environments where indoor environmental quality is poor [3-5].

The refurbishment of school buildings is assumed as an appropriate strategy to improve their indoor environment and is also an exceptional opportunity to guarantee a significant improvement in their energy efficiency.

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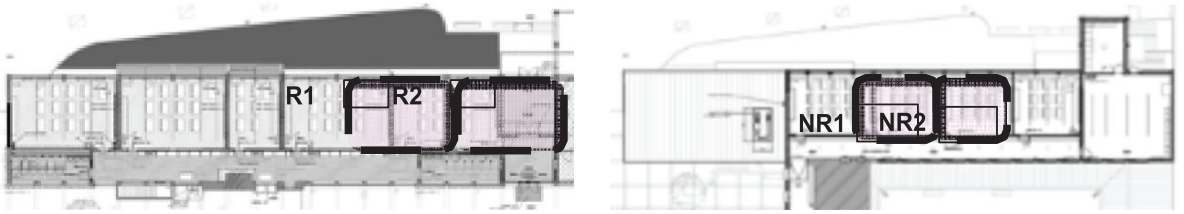
Consequently, some countries have sponsored nationwide programs for school buildings refurbishment, whose result has been, in some cases, other than the expected. Various studies have shown that the performance of buildings after refurbishment is substantially different from that assumed in the design stage [6, 7]. Indoor temperature higher than the one predicted has been a recurring leading to overheating problems. Moreover, the maintenance and operation costs of the recently refurbished buildings revealed unaffordable for the limited school budgets [5, 8]. In Portugal, in the last years, large investments for school buildings rehabilitation were made. These interventions have been planned according to the most recent energy efficiency criteria, which resulted on the implementation of HVAC systems to control both the temperature and the indoor air quality.

Therefore, an experimental demand controlled ventilation system was applied in a school building and the indoor environmental quality was monitored during two months. Students' perception was collected through a survey. This paper presents and discusses the results.

2. Case study and methodology

2.1. School building

This study has been carried out in a school building in Porto, North of Portugal. It was built in the 1960's and is currently being refurbished. The experimental campaign was developed both in refurbished and non-refurbished classrooms: 2 of each nature were selected. The refurbished classrooms (R1 and R2) are located on the ground-floor and the non-refurbished ones are on the second floor (top floor) (Figure 1). All classrooms have an approximate floor are of 50 m^2 and an internal height of 3 m.



(a) (b)

Fig. 1. School building layout. (a) ground floor; (b) top floor.

2.2. Ventilation and heating systems

No specific ventilation devices (inlet or outlet) are present in the non-refurbished classrooms. Therefore, these classrooms ventilation depends to a great extent on the window opening. Windows have wood frame and are single glazed. Apart from the large side hung external windows, also bottom-hung windows with opening above the occupied zone and small openings to the interior corridor are available, allowing for the implementation of a cross ventilation strategy when weather conditions allow it. Hot water radiators are used as heating system.

In refurbished classrooms as original hot water radiators were still in good conditions no modifications were introduced in the heating equipment. Concerning ventilation, an experimental demand controlled system was implemented: fresh air is introduced through self-regulating inlet devices in the roller shutter boxes (due to architectural reasons these devices couldn't be located behind the heating radiator, although it would be a more efficient solution) and a variable speed mechanical fan located above the entrance door is responsible for the extraction; air is then then directed outside (Figure 2).

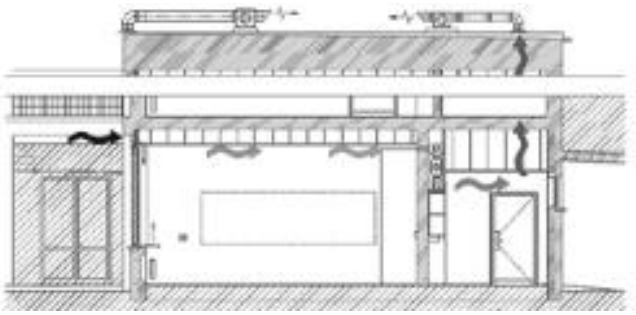


Fig. 2. Ventilation strategy.

Mechanical fan is activated by a Central Technical Management (CTM) system that receives information from two sensors located inside each classroom, one carbon dioxide (CO_2) sensor and one air temperature sensor (T_{int}), and one air temperature sensor located in the exterior (T_{ext}). This real-time data is analysed by the CTM system and the fan speed is defined according to the pre-established criteria depicted in Tables 1 and 2.

Table 1. Demand controlled ventilation starting criteria.

	$T_{ext} > 8$ºC	$T_{ext} \leq 8$ºC	Air flow [m^3/h]
CO_2 concentration [ppm]	1000	1500	240
	1400	1800	400

Table 2. Demand controlled ventilation stopping criteria.

	$T_{ext} > 8$ºC	$T_{ext} \leq 8$ºC	Air flow [m^3/h]
CO_2 concentration [ppm]	900	1400	0
	1300	1700	240

In addition to these criteria, when mechanical ventilation is activated and exterior temperature is below 8 ºC, CTM also commands the heating system to start operating (at least 5 minutes before ventilation). If by any reason CO_2 concentration level reach 2000 ppm, mechanical extraction immediately starts operating at maximum fan speed (air flow higher than the one indicated previously). Moreover, mechanical fan only operates on the period between 1 hour before classes (morning) and 30 minutes after the end of classes (evening).

2.3. Equipment and method

Monitoring consisted in recording air temperature, relative humidity and CO_2 concentration. The following equipment was used: HOBO U-12 data loggers for temperature and relative humidity (temperature accuracy ± 0.35 ºC; relative humidity accuracy ± 2.5%); and infrared dispersive measurement devices Telaire for CO_2 concentration (accuracy of ± 50 ppm or ± 5% of the reading, whichever is greater). The data loggers were positioned horizontally over the teacher's desk (0.75 m above the floor) from March 15 to May 15, accomplishing the international recommendations, avoiding windows and heaters proximity.

3. Results and discussion

3.1. Temperature, relative humidity and CO_2 concentration

The air temperature, relative humidity and CO_2 concentration level on a typical week are shown in Figure 2, as are the outdoor values obtained by the Laboratory of Building Physics of the University of Porto weather station.

Relative humidity varies within limits usually considered as adequate indoor conditions and no differences between refurbished and non-refurbished classrooms can be pointed. Air temperature revealed a performance within the comfort zone (considering only the occupied period) in both sets of classrooms. Yet, a trend for higher temperatures can be identified in the non-refurbished classrooms. Regarding CO_2 concentration a clear difference between the classrooms was found. While in the refurbished classrooms CO_2 concentration level generally does not exceed 1500 ppm, in the non-refurbished ones this level increases up to 2500 ppm.

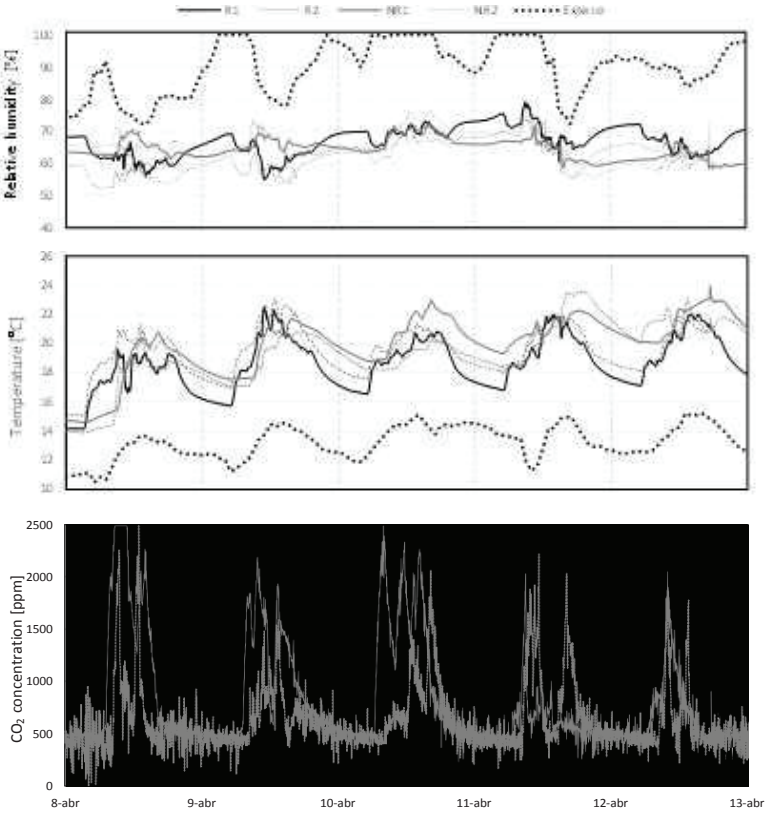


Fig. 3. Air temperature, relative humidity and CO_2 concentration on a typical week.

3.2. Statistical analysis

The results of the entire monitoring period were statically analysed considering only the classrooms period of occupation. Table 3 synthesizes the results, including the average (μ), the standard deviation (σ) and the coefficient of variation (cv) of the three parameters.

As previous mentioned, relative humidity average values and variability are quite homogeneous and within adequate limits. Air temperature also presents average values within the comfort zone and little variability occurs in both data-sets. In the non-refurbished classrooms average air temperature was marginally higher than in the refurbished ones. A distinction between the two data-sets can be found in the CO_2 concentration level. Although in both average values were relatively low when compared to other previously published studies [5, 9], non-refurbished classrooms present higher concentrations. Moreover, in the latter, standard deviation, and consequently the coefficient of variation, are quite higher, indicating several periods with CO_2 concentration levels clearly above the reference values. This situation is confirmed through the cumulative distribution depicted in Figure 4. Roughly, in

the non-refurbished classrooms, the CO_2 concentration level exceeded 1500 ppm in 20% of the period of occupancy, while in the refurbished ones, the graph shows that this value has a very weak probability of being exceeded.

Table 3. Statistical analysis of the air temperature, relative humidity (RH) and CO_2 concentration.

	T_{int} [ºC]			RH [%]			CO_2 [ppm]		
	μ	σ	cv [%]	μ	σ	cv [%]	μ	σ	cv [%]
R1	20.54	1.63	7.94	55.74	8.30	14.89	612	269	43.95
R2	21.37	2.05	9.59	49.57	8.47	17.09	735	312	42.45
NR1	21.49	1.38	6.42	52.77	8.17	15.48	898	588	65.48
NR2	21.38	1.99	9.31	54.32	9.16	16.86	1082	663	61.28

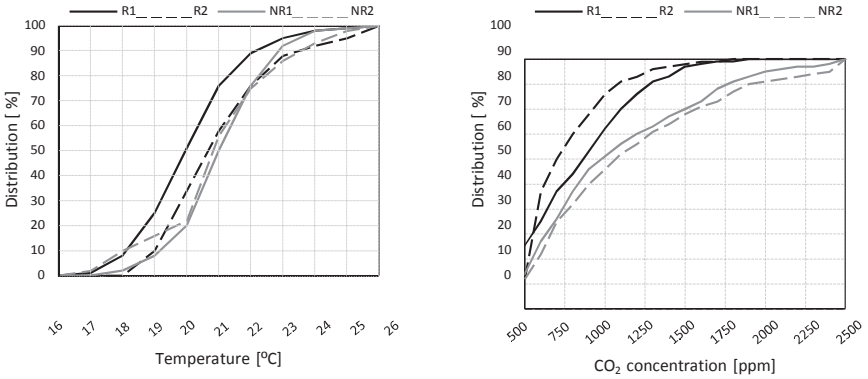


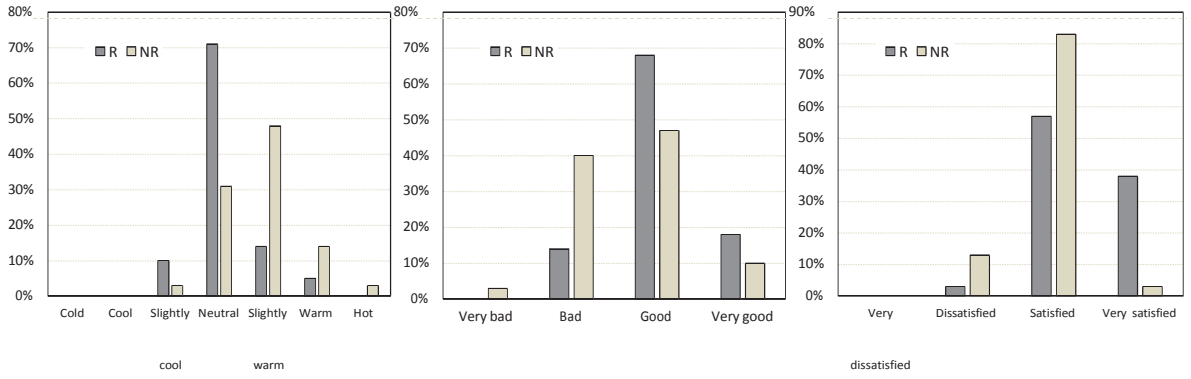
Fig. 4. Cumulative distribution of air temperature and CO_2 concentration for the entire period of analysis.

3.3. Survey

Occupants' perception of the indoor environment was collected through a survey. The questionnaire was previously explained by the research team members, stressing that questions concern the global perception of the indoor environment and should therefore not be affected by the conditions at the time of the response. The 4 classrooms were included and, in each, answers were collected in 2 periods (different students). A total of 104 individuals answered the survey. The following questions were included:

- a) How satisfied are you with the temperature in your classroom?
- b) How satisfied are you with the indoor air quality in your classroom?
- c) Overall, how satisfied are you with your classroom?

Figure 5 plots the results of the survey separately for each sample (R: refurbished; NR: non-refurbished). Relating temperature, circa 70% of the students voted as neutral in the refurbished classrooms while in the non-refurbished this value decreased down to 50%. No one considered classrooms as cool nor cold. Regarding the indoor air quality, around 70% of the students considered it as good in refurbished classroom and 45% gave the same answer in the non-refurbished ones. Concerning the overall evaluation of the classrooms, in the refurbished ones 38% answered very satisfied and 57% satisfied, while in the non-refurbished these values were 3% and 83%, respectively.



a) b) c)

Fig. 5. Results of the survey.

4. Conclusions

The impact of refurbishment which included an experimental demand controlled ventilation system was assessed through the monitoring of the indoor environment and the students' perception and opinions were collected through a survey. The following conclusions can be stated:

- Air temperature and relative humidity are quite homogeneous and within adequate limits in both data-sets. Yet, in the non-refurbished classrooms average air temperature was marginally higher than in the refurbished ones;
- Non-refurbished classrooms present higher CO_2 concentration levels. The impact of the demand controlled ventilation system was obvious. In the refurbished classrooms CO_2 concentration level almost never exceeded 1500 ppm, while in the non-refurbished ones that situation occurred in 20% of the period of occupancy;
- The positive impact of the refurbishment was confirmed by the survey. Answers confirmed that students prefer the indoor air quality of the refurbished classrooms.

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