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An evaluation of Indoor Climate in a school building in Portugal

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Abstract

In Portugal, a major rebuilding and refurbishment program of school buildings has been carried out in the last few years. Due to the new more demanding regulations about thermal comfort (TC) and indoor air quality (IAQ), the retrofitting process, generally, contributed to increased energy demands.
Starting from a practical case, a non-intervened school in Coimbra has been subjected to an indoor climate evaluation.
The procedure was initiated with the evaluation of energy consumption bills and data collection about the buildings and respective systems. Afterwards, some IAQ physical parameters and the concentrations of chemical indicators were measured and monitored in one classroom, during a period in the heating season (HS) and another period in the "pre-cooling" season. At the same time, a questionnaire was applied to the occupants of the same classroom during the HS.
The experienced IAQ conditions revealed not to be adequate and need to be improved.

Keywords: School, Natural ventilation, Indoor air quality, Thermal comfort

1. Introduction

In Portugal, as in the UK, a major rebuilding and refurbishment program of the schools has been carried out in the last few years. Before this intervention, in a general way, the annual energy consumption per m^2 in Portuguese schools was relatively low. More than a sign of energy efficiency, this reflected the Portuguese climate - which is relatively mild - and, most of all, the lack of comfort indoors. In general, indoor temperatures in classrooms ranged between 5ºC in winter and 35ºC in summer (Martins et al (1991) cited in Mota (2003)). Most of these schools were not equipped with central heating systems - the school case next presented is not an exception.

Buildings' envelope intervention besides making part of the "energy rehabilitation" process helps to improve the levels of indoor comfort. The current EU legislative system makes these interventions, in the outer walls and openings, a mandatory condition (as a way to reduce energy consumption in HVAC systems).

In the Portuguese case in particular, the *2015 Efficiency Program* [2] provides incentives to the isolation of the existing buildings' envelope. From one case study not embraced by the refurbishment program already mentioned, the authors performed an assessment of the conditions of indoor air quality (IAQ) and thermal comfort (TC), considering also their construction characteristics. Afterwards, measurements of IAQ parameters were collected during two different occupation periods - the first during the heating season (February 2010) and the second period in a "pre-cooling" season (May 2010).

Finally, these results were compared with a subjective assessment - a questionnaire applied to the occupants, conducted within the class that had most lessons in the room were data was collected.

2. Case study characterization

The studied school is located in Coimbra, a city in the center of Portugal, 40 km away from the Atlantic coast. The main group of buildings dates approximately from 1983 and the D building dates 1986. The E building is the most recent of the classroom buildings, built in 1992 and the gymnasium dates 1996. The School has 55 classrooms, and an average of 25 students per class.

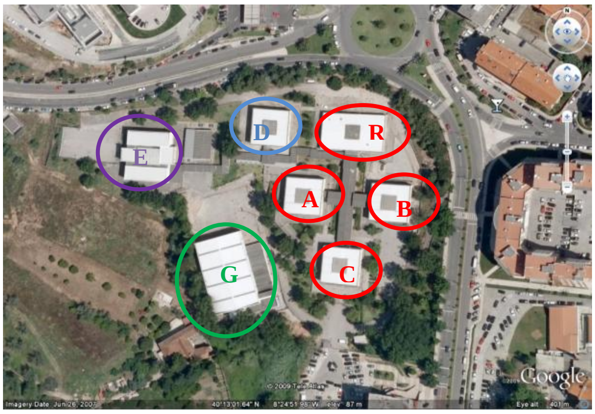

Fig. 1. School coordinates 40°13'1"N 8°24'53"W [Google Maps (2009)]

2.1. Energy Consumption Indicators

From the collection of energy consumption bills (gas and electricity) some considerations and indicators were driven:

a) The present tariff is the most advantageous; therefore no annual reduction could be achieved in terms of tariff change (the tariff simulation was provided by the company *EDP* – the main supplier in the electrical energy sector in Portugal). The major cost reduction opportunity was reducing the contracted power – it was proposed the analysis on processes of reducing consumption on *peak-load hours* (e.g. through a better distribution of timetables), and it was suggested an evaluation on implementing compensation of reactive energy.

b) This school presented low *energy use per school year/student* indicators, resulting from the absence of mechanical ventilation or heating/cooling systems. Most of the spaces are naturally ventilated (NV). Exceptionally, in the library, in the teacher's room and the ITC (information technology communication) classroom, there are individual HVAC units. The most common process of space heating is oil heaters, even in the most recent building – E (2 heaters/classroom).

c) Values on the following tables show that, contrary to the decrease of students number from year 2007/08 to 2008/09, energy consumption per user increased, and therefore also CO_2 emissions: a more populous school community promotes a "greener" school – both CO_2 values, per user and area, decrease with an increasing number of students.

Table 1. CO_2 emissions in school year 2007/08 & 2008/09 per student, per area and per user

School year	Kg (CO_2)/student.year*	Kg (CO_2)/m^2.year*	Kg (CO_2)/user.year*,**
2007/08	144,02	19,01	116,37
2008/09	163,68	19,86	128,56

*conversion factors obtained in Defra (2006)
**based on an estimation to school community - 1250 users (2007/08) or 1200 users (2008/09) - admitting the number of teachers is circa 20% the students' number and school functionaries is 10%.

2.2. Building characteristics

Assuming the relatively recent intervention on the coverage/roofs, and the school buildings' construction period, it was inferred that the school walls were absent of thermal insulation. Windows are of the sliding type, and have single glass mounted in aluminum frames without thermal cutting.

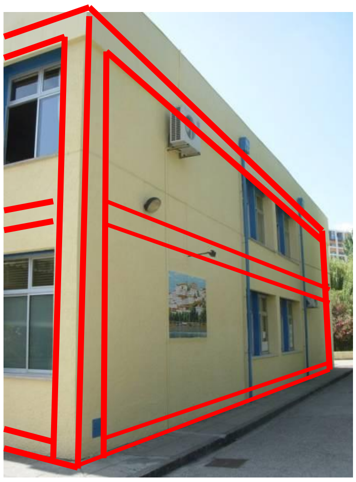

Fig. 2: Main cold bridges presentation: structural components.

Considering the absence of thermal isolation in the vertical envelope, the "easiest" way to improve walls thermal performance would be recurring to the ETICS (External Thermal Insulation Composite Systems) method. In this case, instead of a U value of 1,1W/m^{2o}C, a value around 0,45W/m^{2o}C could be achieved. This solution would allow a fast and efficient correction of cold bridges, as those identified in Fig. 2.

3. Measurements in the school

Indoor Environmental Quality (IEQ) parameters, such as relative humidity (RH), air temperature and CO_2 concentrations were monitored on February 11th and May 26th and 27th, 2010.

Measurements were carried out in the room 11 (≈46,5m^2), located on the 1st floor in the N/NE corner of building A (the room's exterior openings are oriented NE). The used monitoring equipments - Fluke 975 Air Meter and SENSOTRON PS32 data-logger - were kept inside the room during the whole measurement time, positioned in the center of the space, about 100cm above the floor, corresponding to the breathing zone of occupants, assuming a "representative" condition.

All the outdoor meteorological information was obtained in *www.meteo.pt*.

3.1. Monitoring results - I (heating season)

On February 11th, exterior temperature varied in Coimbra between 4ºC and 10,5ºC. From the monitoring indoors it was verified that all the recorded values were out of the thermal comfort interval (20-24ºC), reaching values lower than 15ºC during the occupation period. The average temperature (during class time period) was 16,2ºC.

The maximum recorded CO_2 concentration was higher than 4600ppm, circa 4.5 times the maximum recommended value in the national legislation system (1800mg/m^3≈1000ppm) (RSECE, 2006). The lowest value was recorded during the night, about 370ppm (infiltration period – unoccupied room). The decay period registered between 10:20 until 12:00 was caused by room vacancy. After 15:40 the decay was justified by room occupancy decrement, from 25 to 11 people. During class time period (8h30-18h00) the medium CO_2 value was 1927ppm, circa twice the regulated value - 72% of this time concentration levels were over 1000ppm, (fig. 3).

As regards relative humidity (RH), the recorded values during the occupation time of the room were mostly within the recommended values, only exceeding them during the first recorded hours – late evening and night of the measured period. Nevertheless, only 30% of time class RH was under 50%.

Table 2. Synthesis presentation table of the recorded values on February 11th 2010

Parameter	Lowest record	Highest record	Reference value	Percentage of compliance
Room temperature	13,2 ºC	17,6 ºC	20 ºC – 24ºC	0%
Relative Humidity	43,4 %	73,3 %	30-70%	85,9 %
Carbon dioxide (CO2)	374 ppm	4640 ppm	≤1000 ppm	28,5 %
Carbon Monoxide (CO)	0 ppm	0 ppm	0 ppm	100%

3.2. Monitoring results - II (“almost cooling season”)

On May 26th and 27th, exterior temperature varied in Coimbra between 13ºC and 20ºC. During occupancy period, temperature recorded values were between the reference values.

Concerning CO_2 levels, on the first day, the maximum CO_2 concentration recorded value was lower than 1750ppm.On the second day, the highest value was almost 2250ppm – more than twice the maximum recommended value. The lowest value was recorded during the night, about 390ppm (infiltration period – unoccupied room). In both days, it was verified that CO_2 concentrations increased during room occupation and decayed either in vacancy periods (more significantly) or when a door or window was opened. The difference between the values recorded in February and those recorded in May is explained by the cross ventilation verified during almost the entire day on May 27th – main door and two windows were opened during most of the teaching period.

3.3. Discussion – monitoring I & II

The recorded values of CO_2 concentration in room A.11 in both periods are presented on the next pictures (occupancy period is signaled in grey). These values show that IAQ in this school is a stronger problem during the HS than during the cooling season. It was verified that the maximum recorded CO_2 value on February 11th is practically the double of the values recorded in May.

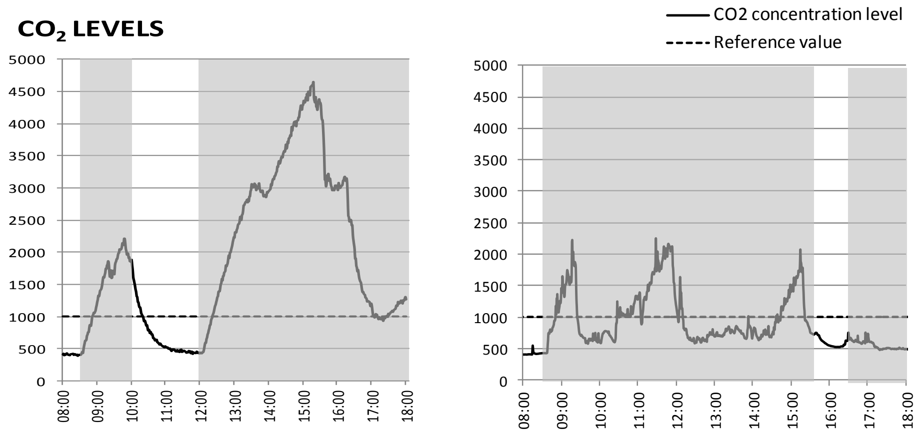

Fig. 3 & 4. CO_2 concentration values in room A.11 on February 11th and May 27th 2010

As regards indoor air temperature it was concluded: if during “almost cooling season” room A.11 had a comfortable temperature (mainly because of crossed ventilation induced by its occupants – teacher/students), during winter, temperatures inside the room were very low, even with closed windows. Differences between outdoor and indoor temperatures were also more significant during the heating season.

Relating this information with CO_2 concentrations, it can be assumed that during summer, lower levels of CO_2 can be achieved by introducing cross ventilation into NV spaces. This is also significant when evaluating thermal comfort – considering airspeeds of 0,2m/s (Brager and de Dear, 2001), higher temperatures can be tolerated indoors. The same reasoning cannot be applied for winter, especially because of occupants comfort – window opening would increase even more their thermal discomfort. Even so, values demonstrate that IAQ is a problem and that CO_2 recorded values in February must be lowered.

4. IEQ Questionnaire

All the individuals responding to the questionnaire were less than 20 years old - 6th grade students. In terms of clothing, 83% of the students were using trousers and a sweater, while the rest had a raincoat or an overcoat putted on. The students’ location in the room (near a window, internal wall, centre of the space and/or near the main door) was also considered on this analysis.

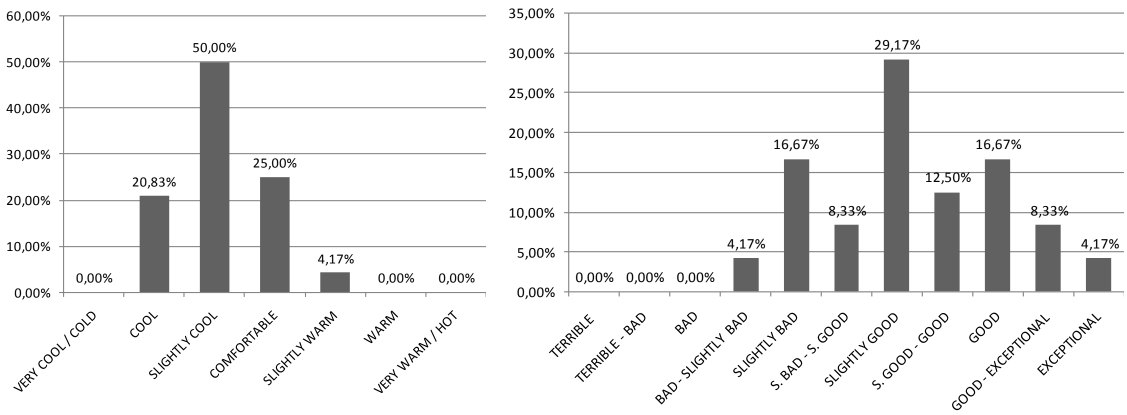

Fig. 5 & 6. Thermal Comfort & Polluted Air/ Clean Air

From the students seated near the window, 66% affirmed being *cold*, while the rest declared feeling *comfortable*. Most of the students felt *cold or slightly cold*, and only 29% felt *comfortable or slightly warm*. This reveals the asymmetry of the thermal radiation caused by a *cold window* or door opening – the more "comfortable" students were those seated in the middle of the room or near an interior wall.

In terms of IAQ (polluted air–clean air), around 30% of students did not even consider it slightly good, almost 30% considered the air *slightly good* and the rest gave a "positive vote".

Generally speaking we can affirm that the survey confirmed the impression first obtained from data collection in February - in terms of comfort, it was not expectable that individuals seated in classroom under 20ºC felt thermally neutral (comfort).

5. Conclusion

The envelope characteristics of this school condition the school's thermal comfort behavior. A refurbishment intervention in the exterior walls and openings should be considered in order to improve the internal conditions of the spaces.

Regarding IAQ measurements, CO_2 concentration values during occupation period showed that unheated rooms, without adequate ventilation systems do not provide adequate comfort temperatures and clearly exceed CO_2 concentration reference values. Analyzing the values obtained in February and May and, assuming the leading character of the openings handling, we can conclude that the IAQ in this school is a stronger problem in the heating season than during the cooling season.

This study also allows us to conclude that NV, when enhanced by users' behavior, can significantly help improving IAQ and, should therefore be explored. Nevertheless, since the values are above the national reference values, NV should be compensated when it is insufficient. This should boost further studies on the potential of NV, as a contradictory trend to the energy increased demand enhanced by HVAC systems.

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