

*Case Study Report*

**Indoor air quality audit and evaluation on thermal comfort in a school in Portugal**

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## **Indoor air quality audit and evaluation on thermal comfort in a school in Portugal**

### **ABSTRACT**

Given the Portuguese national program for rehabilitation of school buildings and the new regulations for thermal comfort and air quality in Portugal, whose demands contribute to increase energy costs, it became relevant to study a case before any refurbishment intervention, in order to assess the potential of different methods of actions and to improve results. It was also intended with this study to evaluate the indoor thermal quality (ITQ) and the indoor air quality (IAQ) experienced by the school occupants. From a practical case, a school in Coimbra, the procedure passed through the measurement of some environmental physical parameters [dry bulb temperature and relative humidity (RH) and the concentrations of chemical indicators, such as carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>)]. Contributing to the indoor environment characterization, it was developed a survey directed to the occupants, in parallel with the measurements taken inside a classroom during a period in the heating season and another period in the "pre-cooling" season. An estimation of the predicted percentage of dissatisfied (PPD) and predicted mean vote (PMV) comfort indices was done based on the school measured data. The results were compared with those obtained from the questionnaire. In the end, an analysis was also done based on CO<sub>2</sub> concentration values.

## Introduction

Before the implementation of the recent program for the rehabilitation of school buildings in Portugal, in Portuguese schools, in a general way, the annual energy consumption per m<sup>2</sup> was relatively low: this did not necessarily mean they were efficient, but reflected both the effect of the Portuguese climate which is relatively mild and, the lack of comfort in the classrooms [1]. In general, those schools were not equipped with central heating systems; the case next presented is not an exception.

The necessity to stop the increase of energy consumption for heating and cooling, balance simultaneously with the needs of comfort in the use of spaces; has made the "energy rehabilitation" of a building envelope a great opportunity. The main interventions are usually related to the outer walls and openings - improving their thermal behaviour would necessarily lead to a reduction in energy consumption/costs needed for obtaining the reference comfort conditions. The current EU legislative system makes this a mandatory condition. In the Portuguese case in particular, the *2015 Efficiency Program* [2] provides incentives to the isolation of the existing buildings' envelope.

Similarly to others studies [3, 4], the authors performed an assessment of the conditions of indoor air quality (IAQ) and thermal comfort (TC) of a school none embraced by the rehabilitation program, similarly to a simple audit for the Portuguese energetic certification system. Data about the building construction characteristics (not presented in the present text) was collected and several parameters were measured during different occupation periods in a typical classroom (A.11) – first in the heating season (February 2010) and secondly in a "pre-cooling" season (May 2010). In addition, the obtained results were compared with a subjective assessment based upon a questionnaire applied to the students of the class that had most lessons in the room.

After this, the evolutions of the predicted mean vote (PMV) and of the predicted percentage of dissatisfied (PPD) thermal comfort indices were calculated based upon the data collected about the measured environmental indoor parameters and the values assumed for others.

The study presented next, based on a real case-study, intends to demonstrate the indoor environmental conditions in non-intervened Portuguese schools.

### **Case study presentation**

The studied school is located near the main hospital of Coimbra, a city in the centre of Portugal. The main group of buildings (buildings A, B, C and R) dates approximately from 1983, the D building dates 1986 and the E building is the most recent of the classroom buildings, constructed in 1992. Although the E building is the “youngest”, but oil heaters is still found in this building as the regular heating system). The School has 55 classrooms and an average of 25 students per class (Fig. 1.a)).

### **Characteristics of the Buildings**

Most of the buildings in this school are circa 25 years old. Given its construction period, it was inferred that like the majority of similar buildings, the school walls do not have thermal insulation. Assuming the relatively recent intervention on the coverage/roofs, the issue of lack of insulation was only considered in the vertical envelope.

After exterior walls, openings correct isolation is one of the most important things to assure – reducing the air infiltration through watertight and trims frames in windows and doors. In this school, windows have single glass and aluminium frames without thermal cutting. The installation of double-paned or low-emissivity coating glasses could be an opportunity to reduce cooling/heating costs and to maintain thermal comfort conditions.

## **Space cooling/space heating**

The most common equipments for the heating of spaces, in this school, are oil heaters, which are not recommended - besides high energy consumption they are inefficient in large spaces, since they only heat their surrounding area. Even in the most recent building – E, there are 2 heaters in each “typical” classroom.

Most spaces are naturally ventilated. In some rooms – as in the library, the teacher’s room and the ITC (information technology communication) classrooms, there are individual HVAC split units. Once there is not a global controlled system, all system performance and efficiency would depend strongly on human behaviour.

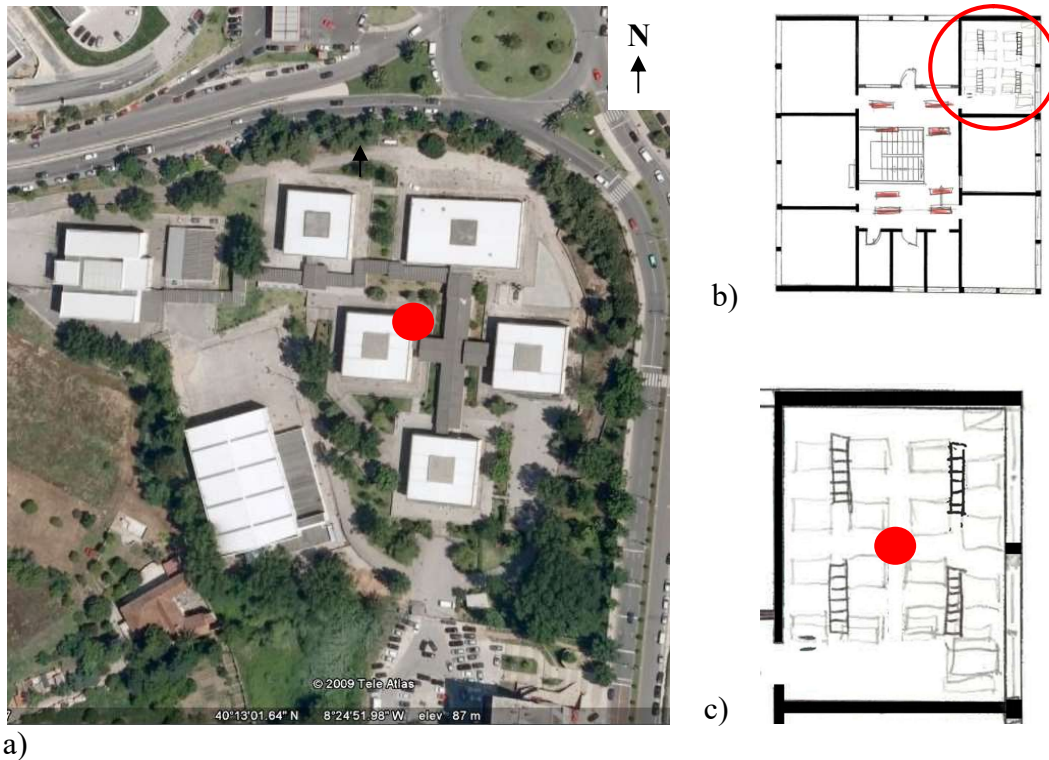
## **Measurements in the school**

Once thermal comfort influences the efficiency/performance of the study and work [5], it was important to measure some physical parameters such as relative humidity and air temperature. For this, simple equipments used in thermal environment and indoor air quality system audits of energy certification of buildings were used. The assessment of indoor air quality (IAQ) was based primarily on values of CO<sub>2</sub> concentrations. Measurements were performed on February and May, 2010.

All the meteorological information used in this study, was obtained in *www.meteo.pt* (Coimbra weather station – Aeródromo).

## **Room A.11 – spatial description and methodology**

Measurements were carried out in the room 11 whose characteristics are shown in Table 1. The room is located on the first floor in the N/NE corner of building A and the exterior openings of the room are NE oriented, as shown in the Figure 1 [a); b) and c)].



**Fig. 1.** a) & b) School coordinates 40°13'1"N 8°24'53"W [Google Maps (2009)] and Room A.11 location in the school; c) Measurement equipment location inside room A.11

The used measuring equipments - Fluke 975 Air Meter and SENSOTRON PS32 - were kept inside the room during the whole measuring interval, positioned in a "representative" location, at the centre of the space, 1,10 m above the floor, in the breathing zone of occupants [6].

Area (m <sup>2</sup> )	Ceiling (m)	Volume (m <sup>3</sup> )	Number of occupants
46,24	3,10	143,34	25 (medium)

	Height (m)	Width (m)	Area (m <sup>2</sup> )
Window	1,90	1,55	2,95
Window (opening)	1,28	0,78	0,99
Door	2,60	0,90	2,34
Door (opening)	1,94	0,90	1,75

**Table 1.** A.11 room characteristics & openings dimension

The first monitoring period started on February 10<sup>th</sup> at 17:10 and ended at 18:10 on the 11<sup>th</sup>, over a 24 hours measurement period. The second collecting data phase started on May 26<sup>th</sup> at 8:00 and ended on May 28<sup>th</sup>, at 08:20, over a 48 hours measuring period, as detailed in Table 2.

	Mon	Tue	Wed	Thu	Fri	Sat	Sun
<b>1<sup>st</sup> monitoring (February 2010)</b>			<b>10<sup>th</sup></b> Start: 17:10	<b>11<sup>th</sup></b> End: 18:10			
<b>2<sup>nd</sup> monitoring (May 2010)</b>			<b>26<sup>th</sup></b> Start: 8:00	<b>27<sup>th</sup></b>	<b>28<sup>th</sup></b> End: 8:20		

**Table 2.** Monitoring planning schedule 2010

According to the provided time schedule information, on Wednesdays there were classes on room A.11 during the morning between 8:30 and 13:30 (26/05/2010), but on Thursday there were lessons all day long – from 8:30 until 18:00. Exceptionally on February 11<sup>th</sup> room A.11 was empty between 10:20 and 11:50 and on May 27<sup>th</sup> room A.11 was unoccupied between 15:20 and 16:20.

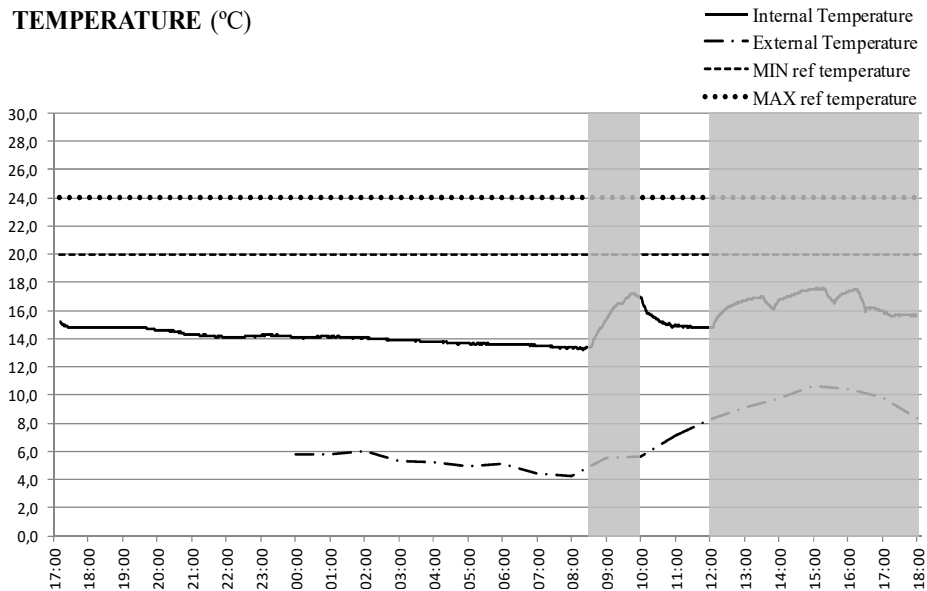
## **Audit results and discussion**

### **Heating season evaluation**

The recorded values of air temperature, relative humidity and concentration of carbon dioxide in room A.11 on February 11<sup>th</sup> 2010 are next presented. On this day, according to the available meteorological information, exterior temperature varied in Coimbra approximately between 4°C and 10.5°C. Occupancy periods are represented by the grey shadowed areas.

#### *Air Temperature*

The time evolutions of air temperatures on February 11<sup>th</sup> are depicted in Figure 2. It is possible to verify that the air temperature values were always out of the reference interval (20-24°C), [7,8], reaching values lower than 15°C during the occupation period. The average air temperature (class time period) was 16.2°C.



**Fig. 2.** Temperature values in room A.11 on February 11<sup>th</sup> 2010

The uncomfortable conditions in terms of the thermal environment are due to:

- a) the building envelope is poorly insulated (or absent);
- b) the heating power is low in each room and was off on the day of the monitoring. Since, the idea was to assess the indoor comfort without influencing the normal routine of the building; the conditions were kept as they were.

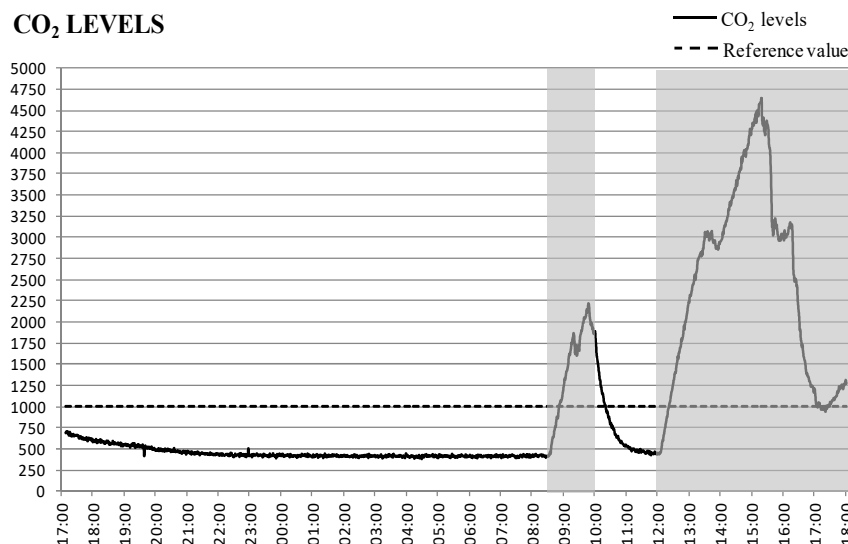
### *CO<sub>2</sub> levels*

The time history evolution of CO<sub>2</sub> concentration in room A.11 is presented in Figure 3. It was verified that the CO<sub>2</sub> concentrations were in an interval range, during the occupancy period, from 374 - 4640 ppm. The maximum value was reached at about 15:00 which is 4.5 times the maximum recommended value of 1000 ppm established in the



Portuguese regulation Regulamento dos Sistemas Energéticos de Climatização de Edifícios (RSECE) [7].

The lowest value was recorded during the night, about 370 ppm (infiltration period – unoccupied room). The decay period registered between 10:20 and 12:00 was caused by window opening during room vacancy. The fitting of this decay period with an exponential function, as suggested by [9], gives an infiltration rate of 1.9 air exchanges per hour (272 m<sup>3</sup>/h). After 15:40, the decay in CO<sub>2</sub> concentration was justified by room occupancy decrement, from 25 to 11 people. During class time period (from 8h30 until 18h00) the average CO<sub>2</sub> value was 1927 ppm, circa twice the recommended value, 72% of this time concentration levels were over 1000 ppm.

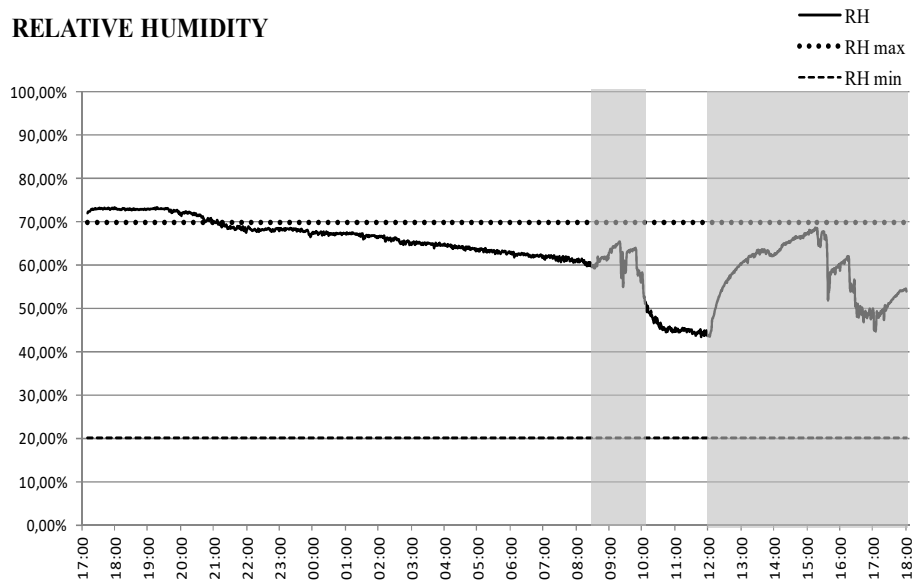


**Fig. 3.** CO<sub>2</sub> concentration values in room A.11 on February 11<sup>th</sup> 2010

### *Relative Humidity*

The recorded relative humidity values are presented in Figure 4. During the occupation period (shaded area in the figure), the values were within the recommended interval (20-70%) [10]. Only during a short period, in the beginning of the acquisition, the

values were slightly exceeding 70%. Nevertheless, only during 30% of the occupation period the RH was below 50%.



**Fig. 4.** Relative Humidity values in room A.11 on February 11<sup>th</sup> 2010

### Discussion

Parameter	Lowest record	Highest record	Reference value	Percentage of compliance
Room temperature	13.2°C	17.6°C	20°C – 24°C	0%
Relative Humidity	43.4 %	73.3 %	30-70%	85.9 %
Carbon dioxide (CO <sub>2</sub> )	374 ppm	4640 ppm	≤1000 ppm	28.5 %
Carbon Monoxide (CO)	0 ppm	0 ppm	0 ppm	100%

**Table 3.** Synthesis presentation table of the recorded values

As exposed before, HVAC systems in this school are practically absent. Room A.11, as in the majority of classrooms, is naturally ventilated and heated with electric heaters. This condition does not satisfy, in most of the time, the users' comfort requirements. From the results of the recorded measurements inside room A.11 (Table 3), it can be concluded that indoor thermal quality in the classrooms of this school has a

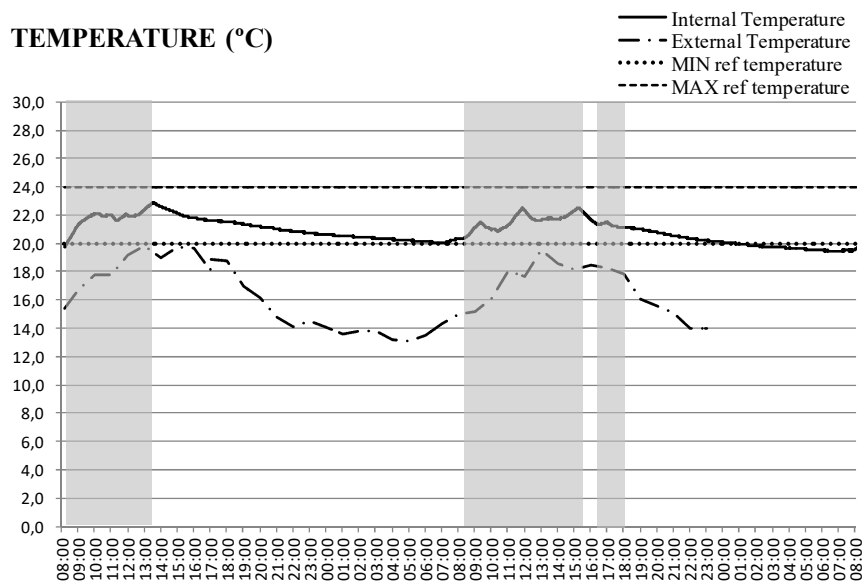
problem: air temperature values were out of the thermal comfort interval during the entire occupation period and only in 28.5% of the time CO<sub>2</sub> levels were within the limit.

### Intermediate season evaluation (“almost cooling season”)

On May 26<sup>th</sup> and 27<sup>th</sup> 2010, during the intermediate (almost cooling) season another audit was carried out. According to the meteorological information, exterior temperature varied in Coimbra, during this period, between 13°C and 20°C.

#### *Air Temperature*

The time evolutions of temperatures on May 26<sup>th</sup> and 27<sup>th</sup> are depicted in Figure 5. During occupancy period from the obtained data, relating indoor temperature, it was possible to verify that all the recorded values were within the reference interval (20-24°C, defined for indoor air temperature in [7]), and for the operative temperature in [8], for a category B building.



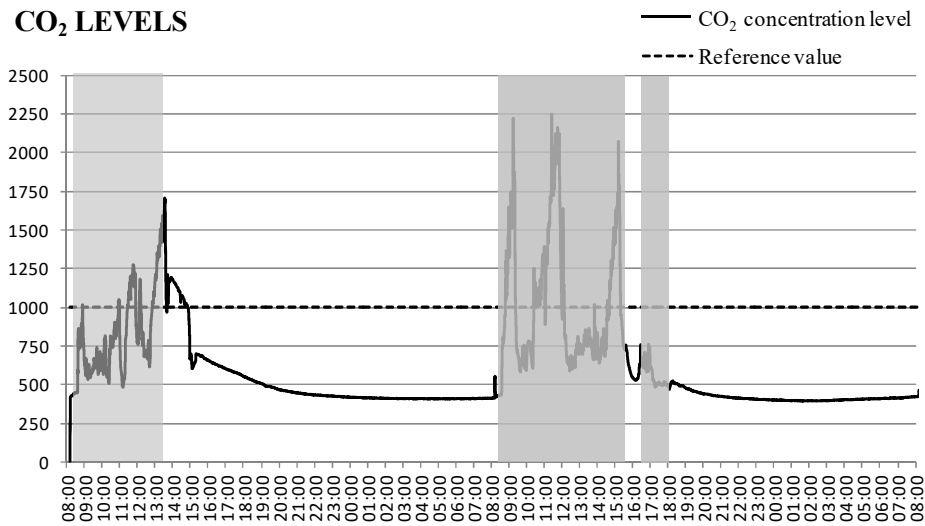
**Fig. 5.** Temperature values in room A.11 on May 26<sup>th</sup> and 27<sup>th</sup> 2010

#### *CO<sub>2</sub> levels*

The time history evolution of CO<sub>2</sub> concentration in room A.11 on May 26<sup>th</sup> and 27<sup>th</sup> is presented in Figure 6. On the first day, the maximum CO<sub>2</sub> concentration recorded value was lower than 1750 ppm (about 13:00 – during the last class in the occupancy period measured). On the second day, the maximum value was higher, almost 2250 ppm – more than two times the maximum recommended value (1800 mg/ m<sup>3</sup> ≈ 1000 ppm, according to [7]). The lowest value was recorded during the night, about 390 ppm (infiltration period – unoccupied room).

The large difference between the morning periods values on both days was justified by room occupancy, but most of all by openings manipulation. On May 26<sup>th</sup>, room occupancy decreased from 25 to 3 occupants between 10:00 and 10:20, and the room was empty from 11:00 to 11:15 and from 11:50 to 12:00. On this morning at 8:35 a window was opened. At 10:00 a second window was opened and at 12:00 a third one was opened (though blinds were down). Besides, during break periods, the door was kept open promoting cross ventilation.

On the next day, the decay period registered over 15 minutes after 9:20 was caused by cross ventilation – two windows and the door were opened. During the break from 11:50 to 12:00, the door was left opened and later at 12:15 two windows were opened, promoting again cross ventilation. During the afternoon, this was also verified over a half of an hour period, after 15:15 – though the room was unoccupied one window and the door, were opened.



**Fig. 6.** CO<sub>2</sub> concentration values in room A.11 on May 26<sup>th</sup> and 27<sup>th</sup> 2010

It has been verified that that the maximum recorded CO<sub>2</sub> concentration on this evaluation period was practically half of the maximum recorded on February 11<sup>th</sup>.

#### *Relative humidity*

The results of the recorded values on May 26<sup>th</sup> and 27<sup>th</sup>, demonstrate that during the occupation time of the room, RH values were within the recommended, though, only for short moments it was below 50%.

#### *Discussion and analysis of the results*

Since on Wednesday afternoons there were no classes in room A.11, and no measurements were performed on February 10<sup>th</sup>, therefore it is reasonable to compare the values recorded on February 11<sup>th</sup> and May 27<sup>th</sup>, during the teaching periods.

In both days, it was verified that CO<sub>2</sub> concentrations increased during room occupation and decayed either in vacancy periods (more significantly) or when a door or window was opened. Break time periods between classes can be clearly identified, corresponding to small decays in the graphics (Fig. 3 and Fig. 6), caused by door opening.

The difference between values recorded in February and those in May could be explained by cross ventilation verified during almost the entire day on May 27<sup>th</sup> – main door and two windows were opened during most of the teaching period.

About indoor air temperature, conclusions are quite objective: if during “almost cooling season” room A.11 had a comfortable temperature, mainly because of crossed ventilation induced by its occupants – teacher and students, between 20-24°C, during winter, temperatures inside the room were very low, even with closed windows.

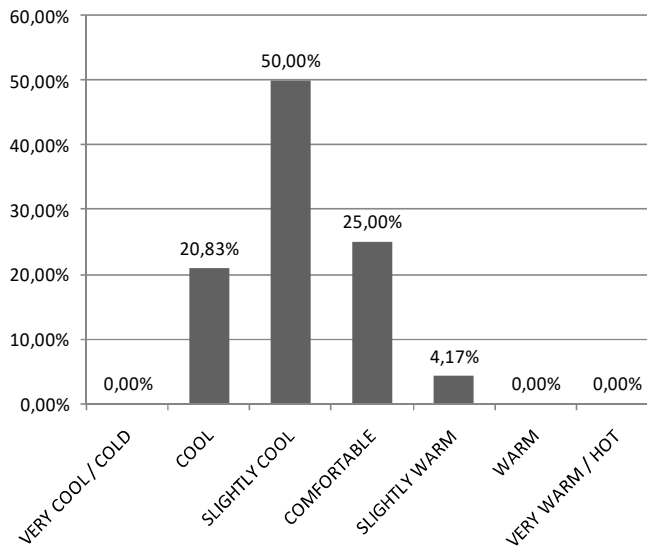
Relating this information with CO<sub>2</sub> concentrations, it can be assumed that during summer, lower levels of CO<sub>2</sub> could be achieved by the effect of cross ventilation inside the spaces. This could be significant when evaluating thermal comfort – considering air speeds of 0.2 m/s [11], higher temperatures could be tolerated indoors – this represents immediate cooling energy savings.

The same reasoning cannot be applied for winter, especially because of occupants’ comfort – window opening would increase even more their discomfort. Even so, the values recorded have demonstrated that there could be problem of IAQ and that CO<sub>2</sub> recorded values in February must be reduced.

### **IEQ Questionnaire**

For a more complete study on thermal comfort of the school, students of the same classroom were asked to fill in a questionnaire, which took place on February 25<sup>th</sup> 2010, at 9:15 a.m., two weeks after IAQ measurements. This survey was used to assess how well the school building was performing from the viewpoint of its main occupants – students. The external temperature in Coimbra varied between 9.5°C and 15°C during the questionnaire day.

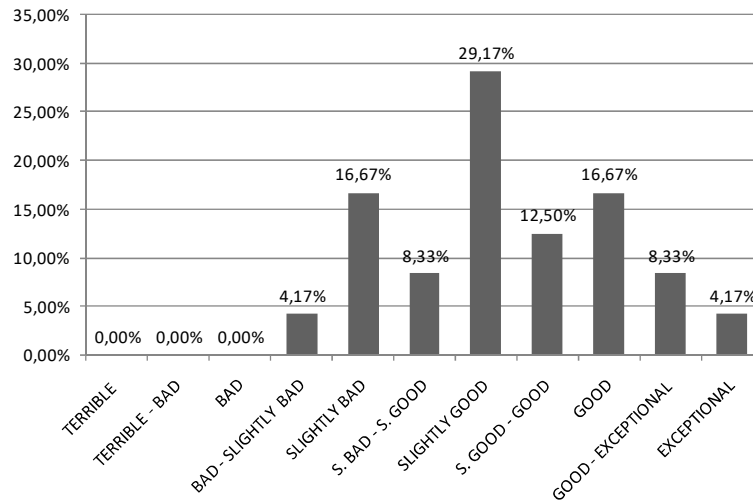
Students' answers to the questionnaire relating TC and IAQ are presented on the next three figures (Fig. 7, Fig. 8 and Fig. 9). All the individuals responding to the questionnaire were less than 20 years old - 6<sup>th</sup> grade students. In terms of clothing, 83% of students were insulated with trousers and a sweater, while the rest had a raincoat or an overcoat on.



**Fig. 7. Thermal Comfort**

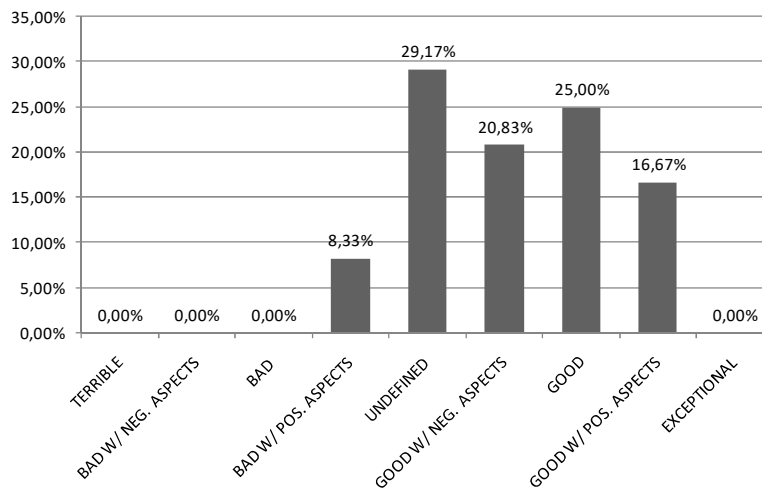
Of all the students seated near the window, 66% affirmed being *cold*, while the rest in this position declared feeling *comfortable*. Generally, most of the students felt *cold or a slightly cold* and only 29% were feeling *comfortable or slightly warm*. This particular subject reveals the asymmetry 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. Vertical air temperature difference and floor temperature were not considered in this study.

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 remaining votes were good or better.



**Fig. 8.** Polluted Air/ Clean Air

In a global IAQ observation (also regarding smells and odours), opinions varied from *bad with positives aspects* to *good with positive aspects*. Over 60% considered the air, at least, as *good with negative aspects*.



**Fig. 9.** Global Air Quality

The survey confirms the first impression obtained from the measured values on the 11<sup>th</sup> February - in terms of comfort, it was not expected that individuals seated in the classroom with temperatures below 20°C would feel thermally neutral (comfort).



## Estimation of PMV and PPD indices based on the school data collection

From Fanger's [12] method and ISO Standard 7730:2005 [8]; adaptation based on PMV index calculation, Gameiro da Silva [13, 14] developed a set of spreadsheets to calculate thermal comfort indices. For the present study, the tool used to determine PMV and PPD index, is a variation from this author's first version, which directly applies the method recommended by [8]. In the presented case-study, data input for which convergence is included within the limits defined in [8], relating to environmental conditions are air temperature, mean radiant temperature, air velocity and relative humidity - instead of partial vapour pressure. The other determinant parameters are: metabolic rate, effective mechanical power and clothing insulation.

Aiming at comparing PMV and PPD index, with the results obtained from the questionnaire on February 25<sup>th</sup>, the considered values for each of the parameters are next presented:

Parameters	Input value	Considerations
<b>M</b> (Metabolic heat production rate)	1.2 to 1.5 met	Varying from 1.2 met [15] (or 70 W/m <sup>2</sup> ) to 1.5 met (or 85 W/m <sup>2</sup> ), according to the activity but considering students age, around 11-12 years, whose metabolic rate was higher
<b>W</b> (Mechanical work rate)	0 met	« <i>W</i> is considered to be null, because this was a very low value in the context of the balance equation» [3]
<b>I<sub>cl</sub></b> (clothing insulation)	0.9 clo	Although variable among individuals answering the questionnaire (0.8 to 1.0 clo), 0.9 clo was used as a representative medium value
<b>T<sub>a</sub></b> (Air temperature)	19°C	Although not measured on February 25 <sup>th</sup> , T <sub>a</sub> was estimated from the difference between indoor and outdoor temperatures, based on the difference values on days February 11 <sup>th</sup> , May 26 <sup>th</sup> and 27 <sup>th</sup> at 9:15, questionnaire time, ≈ 5° C to 6°C. Exterior temperature on February 25 <sup>th</sup> was 13.9°C
<b>HR</b> (Relative humidity)	50%	HR admitted value considered "reasonable" for a non rainy day. Not determinant once PPD and PMV index were not very "sensible" to RH
<b>T<sub>r</sub></b> (Mean radiant temperature)	16°C to 17°C	Since it was not continuously monitored, the assumed value was an estimated approximation from T <sub>a</sub> decreasing, 2°C to 3°C, based upon measurements carried out <i>a posteriori</i>
<b>V<sub>ar</sub></b> (relative air velocity)	0.1m/s	Although doors and windows were closed, room A.11 was not absolutely tight, for which was admitted a minimum air velocity value ≠ 0m/s, admitting infiltration from the openings.

**Table. 4.** Synthesis table of data input in the simulation spreadsheet

From the variation of two of the inserted parameters,  $M$  and  $T_r$ , using the simulation computational tool referred, four results were obtained (see Appendix I):

Parameters Simulation	I	II	III	IV
<b>M</b>	<b>1.2 met</b>	<b>1.2 met</b>	<b>1.5 met</b>	<b>1.5 met</b>
<b>W</b>	0 met	0 met	0 met	0 met
<b>I<sub>cl</sub></b>	0.9 clo	0.9 clo	0.9 clo	0.9 clo
<b>T<sub>a</sub></b>	19°C	19°C	19°C	19°C
<b>HR</b>	50%	50%	50%	50%
<b>T<sub>r</sub></b>	<b>16°C</b>	<b>17°C</b>	<b>16°C</b>	<b>17°C</b>
<b>V<sub>ar</sub></b>	0.1m/s	0.1m/s	0.1m/s	0.1m/s
<b>PMV</b>	-1.03	-0.93	-0.37	-0.29
<b>PPD</b>	27.4	23.2	7.8	6.7

**Table. 5.** Summarizing table of the obtained results in the four simulations

#### *Comparison between PPD and PMV indices and results from the questionnaire*

The simulated results show that the percentage of dissatisfied people becomes lower when the mean radiant temperature is higher. The same reasoning can be applied to metabolic rate. As expressed in [13, 14], PMV value «is calculated from the heat balance of the human body (...), obtained by the difference between the heat produced (...) and the sum of the exchanges with the surrounding environment». Since in all four situations the balance result was negative (see Appendix I), «the body is in a net loss of heat, which means that the simulated person would feel cold, even though slightly», [13, 14].

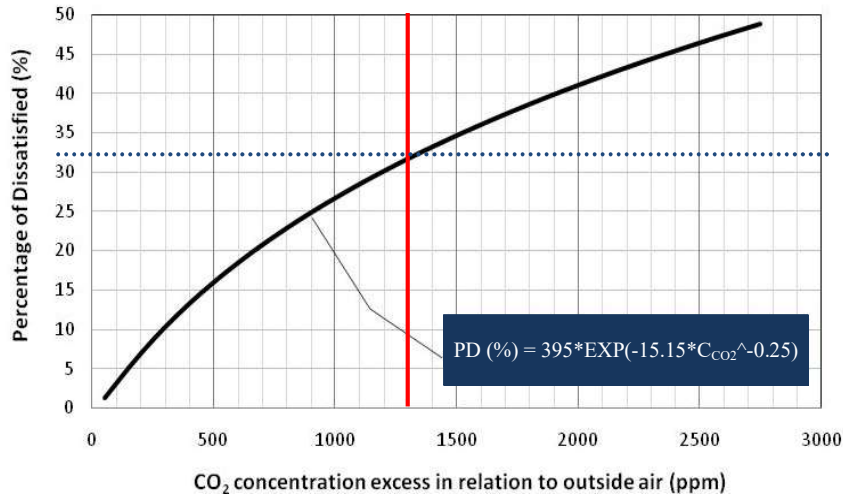
Comparing the simulation results with those obtained in the questionnaire, where a significant majority of students answered being in a state between cold or slightly cold, the most approximate estimate was simulation I.

#### **Estimation of IAQ based on the school data collection**

##### *Indoor comfort analysis based on CO<sub>2</sub> concentration values*

Another analysis of indoor comfort was conducted based on CO<sub>2</sub> concentration values inside room A.11. On February 25<sup>th</sup> 2010, the class answering the questionnaire at 9:15 was the same class present on February 11<sup>th</sup>, the first day on IAQ measurements.

Admitting the same value of CO<sub>2</sub> concentration, 1680 ppm obtained on February 25<sup>th</sup>; and from the figure (Fig. 10) below that around 32% of the individuals may be dissatisfied with the conditions.



**Fig. 10.** IAQ in function of CO<sub>2</sub> (CR 1752-1998) [16, 17]

## Conclusion

In the present work, the envelope characteristics of this school have been investigated and a relation between these and the school's thermal comfort behaviour was determined. Therefore, in order to improve indoor climate, a refurbishment intervention in the exterior walls and openings should be considered.

Human health could be affected by multi-dimensional facet of factors and therefore we should consider not only the physical factors but also the psychological and social environment that could be contributed to the holistic well-being of people in any environment. Humans have «survival needs», related to environmental health factors such as air, water and acoustic levels, and «well-being needs» that include both social and psychological health factors. As regards to ITQ the main conclusions of this study are:

- Measuring CO<sub>2</sub> concentration in classrooms during occupation period would allow the interpretation that in non warmed rooms, with the absence of adequate

ventilation systems would not assure comfortable temperatures and the desirable CO<sub>2</sub> concentration value (even if adopting a relaxation criteria admitting as reference 1500 ppm) was clearly exceeded;

- The PMV and PPD comfort indices, even if normally used for evaluating thermal comfort in HVAC buildings, were confirmed by the results obtained in the survey, illustrating the degree of dissatisfied individuals in room A.11, where TC measurements were conducted;

As regards natural ventilation (NV), research has shown that when enhanced by users, it can help improve IAQ and should for this reason be explored. To evaluate NV potential, further studies considering real needs of fresh air flow rate should be conducted, based on *in-field* monitoring or computer simulations. In case of a “genuine” intervention in the buildings, it would be interesting to compare the new indoor conditions with the present ones and contrast them with other refurbished schools in which HVAC systems were implemented: both in terms of IEQ parameters and occupants’ satisfaction.

### **Acknowledgments**

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### **References**

1. Mota F. *Uso eficiente de energia em edificios escolares*. Master Thesis, University of Coimbra, Portugal, 2003.

2. *Portugal Eficiência*. Plano Nacional de Acção para a Eficiência Energética. Resolução do Conselho de Ministros N°80/2008, 2015.
3. F. R. A. Alfano, L. Bellia, A. Boerstra, F. van Dijken, E. Ianniello, G. Lopardo, F. Minichiello, P. Romagnoni, and M. C. G. da Silva, *Indoor Environment and Energy Efficiency in Schools*. REHVA - Federation of European Heating, Ventilation and Air-conditioning Associations, 2010.
4. de Carvalho PM, Gameiro da Silva MC, Ramos JE. *Influence of weather and indoor climate on clothing of occupants in naturally ventilated school buildings*. *Build Environ* 59 2013; 38-46.
5. Shendell DG, Prill R, Fisk WJ, Apte MG, Blake D, Faulkner D. *Associations between classroom CO2 concentrations and student attendance in Washington and Idaho*. *Indoor Air* 2004; 14: 333-341.
6. ISO, EN ISO 7726:2001. Ergonomics of the Thermal Environment—Instruments for Measuring Physical Quantities. International Standardisation Organisation, Brussels, 2001.
7. RSECE. *Regulamento dos Sistemas Energéticos de Climatização de Edifícios, Decreto-Lei 79/2006*. Lisboa: Diário da República, I Série-A, 4 de Abril de 2006.
8. ISO 7730:2005. Moderate thermal environments – determination of the PMV and PPD indices and specification of the conditions for thermal comfort. Geneva: International organization for standardization, 2005.
9. Asadi E, Gameiro da Silva MC, Costa JJ. *A systematic indoor air quality approach for public buildings*. *Environ Monit Assess* 2013; 185: 865-875.
10. CEN/EN 15251:2007. Indoor environmental parameters for assessment of energy performance of buildings, addressing indoor air quality, thermal environment, lighting and acoustics, European Committee for Standardization, Brussels, 2007.

11. Brager G, de Dear R. *Climate, Comfort & Natural Ventilation: A new adaptive comfort standard for ASHRAE Standard 55*. [Online]. Available at: <http://escholarship.org/uc/item/2048t8nn> (accessed 14 May 2010).
12. Fanger PO. *Thermal comfort: analysis and applications in environmental engineering*. New York: McGraw-Hill, 1972.
13. Gameiro da Silva MC. Aplicações Computacionais para Avaliação do Conforto Térmico. *Revista Climatização*, nº 56, Ano VIII, Março/Abril 2008, pp. 56-68.
- [14] Gameiro da Silva MC. Folhas de cálculo para determinação dos índices de conforto térmico PMV e PPD. In: *Climamed 2006*, Lyon, France, 20-21 November 2006, pp.499-504.
15. ISO 8996:2004. Ergonomics of the thermal environment – Determination of metabolic rate, Geneva: International organization for standardization, 2004.
16. Gameiro da Silva, MC. *Requisitos de Ventilação em Edifícios Escolares – Parecer técnico* elaborado para Parque Escolar EPE. ADAI, Department of Mechanical Engineering University of Coimbra, Portugal, 2009.
17. CEN/CR 1752:1998. Ventilation for buildings - Design criteria for the indoor environment, European Committee for Standardization, Brussels, 1998.