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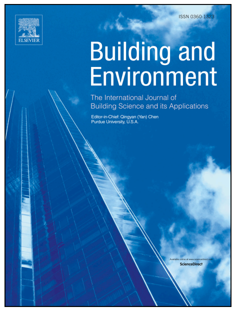

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Assessment of indoor air quality and thermal comfort in Portuguese secondary classrooms: methodology and results

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Contents

Abstract

This work shows the results of a field study about indoor thermal comfort, based on investigations in Portuguese secondary schools' classrooms. The surveys herein presented were carried out in a school in Beja, in the South-East of Portugal.

The field study was conducted by physical parameters monitoring and survey questionnaires. Both field monitoring and subjective surveys were performed at the same time during the regular class period (either at the end or at the beginning of the class). The measurement campaign consisted in measuring the environmental parameters – air temperature (T_a), air relative humidity (RH), CO_2 concentrations. Outdoor air temperature values were registered hourly at the nearest climatological station. Through these data, along with the actual people clothing and metabolic rate being know, both Fanger's comfort indices were calculated (predicted mean vote and predicted percentage of dissatisfied people).

The subjective survey investigated the thermal acceptability, the thermal sensation and the thermal preference.

The judgments about the thermal environment were compared with the results of the field measurements. Draught preference votes, air stiffness and global air quality votes were also collected.

The results show that the students found temperature range beyond the comfort zone acceptable, and revealed the occupants' accommodation to CO_2 exposure, confirming the results obtained in other studies. Moreover, it was verified that running on naturally ventilation mode, CO2 concentration limits were highly exceeded.

Key words

Indoor air quality; Thermal comfort; Metabolic carbon dioxide; School; PMV/PPD indices.

1. Introduction

Indoor Environment Comfort results on the combination of four major environmental factors, such as Thermal Comfort (TC), Indoor Air Quality (IAQ), Acoustic Comfort (AC) and Visual Comfort (VC) [1]. Thermal comfort in schools (classrooms) has lately been receiving more research attention [2], [3], [4], [5]. Either because indoor environmental quality (IEQ) has a repercussion on buildings' energy use [3] but also because this might condition students and teachers performance [6], [7], [8],[9], [10], [11], [12]. On the latest case some research has been developed but most studies are not very conclusive or show limited evidence, recalling further investigation [6], [8], [13].

Assessing occupants' satisfaction about the indoor environment has been common practice for evaluating thermal comfort (TC) and indoor air quality (IAQ) perception [14], [15], [16]. In this context, an empirical study has been driven in a Portuguese school focusing on these two factors: TC and IAQ. Monitoring parameters were faced up with perceived TC and IAQ responses.

Field research, or «the analysis of "real-world"» [3] is important to test the validity of the PMV (Predicted Mean Vote), that provides the basis of the main thermal comfort standards [17], [18]. Several field studies have been investigating the thermal sensation votes (TSV) regarding the indoor thermal environment (ITE). In various cases it has been found that people in naturally ventilated indoor environments are comfortable within a larger range of values than in fully conditioned environments. In warm climate it has even been shown that people can achieve comfort at higher temperatures, compared to the recommendations based on PMV calculation [19].

The work herein presented aims at evaluating TC and IAQ in a recently refurbished school running in free running conditions / natural ventilation mode during the mid-season. In this study, the comparison between the subjective votes (TSV) and predicted votes, deriving from the objective monitoring of some environmental parameters (T_a, RH and CO_2 concentrations), allows the test in field both in the "traditional" approach and in the adaptive one. Although adaptive opportunities in classrooms are relatively strait, in the Portuguese public schools, there is no obligatory uniform, for which students may add or remove layers of clothing. Adaptive actions to control microclimate conditions also include windows opening or closure, shading device manipulation, etc. In many situations these depend on teacher's actions, more than students'[20]. Lesson breaks are good opportunity moments for air renewal.

The field campaign was performed during spring time, for two weeks during lesson periods and weekends. Although provided of HVAC systems, namely air handling units (AHU), during the monitoring period classrooms were in "free running" conditions.

2. Methods

2.1 Object of the study

The study was conducted in the continental Portuguese territory, in a secondary school in the southern part of the country. This study is part of a wider research project [21], covering a total of eight-school selection distributed over the Portuguese mainland territory.

The school currently under study is located 85km from the oceanic line coast, 255m above the sea level, in the climatic zone W1S3 (Winter 1, Summer 3) – the number of heating degree days (HHD) are 1290 (according to the climatic zones for the heating and cooling seasons, [21]), as indicated in **Fig. 1**.

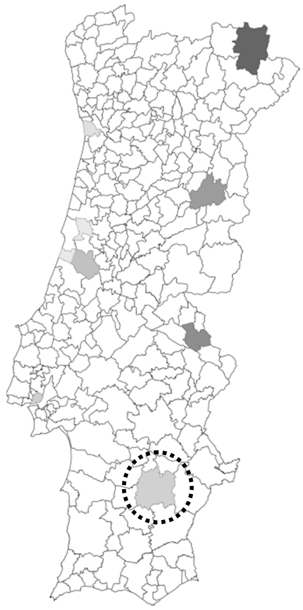


Fig. 1. Map of Portugal highlighting the 8 schools' selection (CCD[1] location). The dotted circle signs the municipality of the school presented in this work.

Field measurements and questionnaires were carried out during the mid season, for a two-week period from the end of April until mid May 2013. All data were collected inside two classrooms inside the main teaching building. The methodology is based both on objective and subjective survey – questionnaires were administrated to the students occupying the classrooms under study while the microclimate parameters were recorded.

2.2 The weather of Beja

The city of Beja is placed in a region characterized by its Mediterranean climate. This is illustrated by dry summers and moderate winters. Average monthly temperatures are sometimes quite high, over 35ºC in the summer, and in winter, average mean temperatures normally do not go under 10ºC. The annual thermal amplitude is moderate. In terms of rainfall, the total annual value is low and it occurs mostly in winter.

[1] *CCD - Census County Divison*

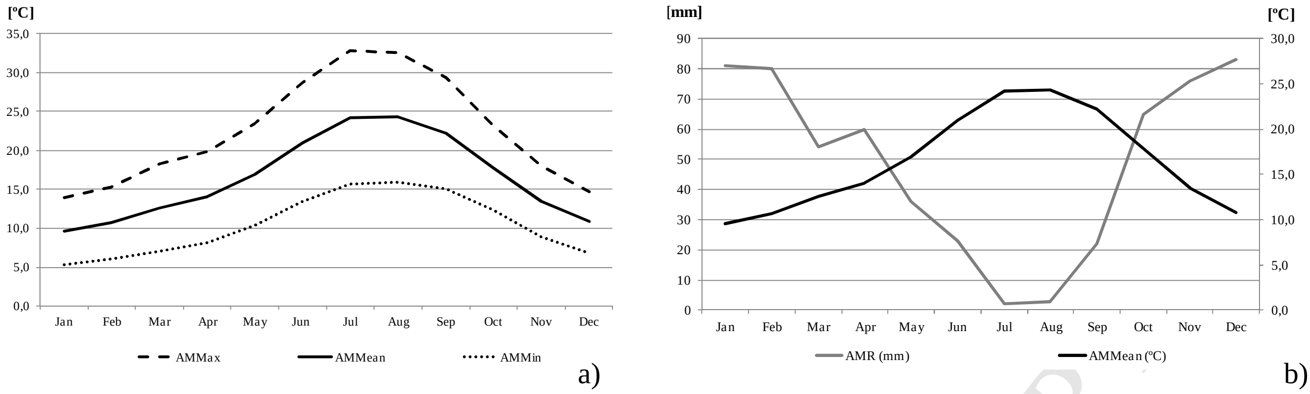


Fig. 2 Beja's Average Monthly Maximum (AMMax), Mean (AMMean), and Minimum (AMMin) Temperatures (ºC), a); Beja's AMMean temperature plotted against Average Monthly Rainfall (AMR), b).

Given the regular school year period, September - June/July, and through the observation of the climatological normal data (for the interval 1971-2000) presented in **Fig. 2**, the school in Beja is expected to have greater cooling than heating needs.

2.3 Case-study description

Inaugurated in 1960, this secondary school in Beja was recently refurbished - from October 1st 2008 until September the 30th 2009. The intervention included the refurbishment of existing facilities (buildings A,B,C) - as well as the connecting galleries between these, the construction of a new building for laboratories (G) and a new sheltered sports area (F). **Fig. 3 a)** shows a simplified layout plan of the building blocks and respective organization according to the current deployment.

Fig. 3 – Escola Secundária de D.Manuel I – Site map (post-intervention), a);
Classrooms A1 and A2 location in the school – Level 1 plan, b) [Source: *Parque Escolar,* EPE (2012)]

The studied population was constituted by high school students, with uniform gender distribution. Some studies on IEQ found no statistical significance differences between genders ([20] *cit in* [22], or in ASHRAE 2009 [23] *cit in* [24], where it is expressed that «the thermal condition preferred by the elderly and females do not differ from those preferred by younger adults and males»), while others advocate the contrary (that female tend to prefer higher temperatures under non-uniform conditions[24], e.g. «for females, the extremities (…) had a significant influence on whole-body thermal sensation»). In 2002, Parsons stated few gender differences for neutral and warm conditions, still indicating that «females tend to be cooler than males in cool conditions» [25], «at a

PMV value of -2.0 (cool)». According to [26], in laboratory experiments, gender differences are not universally consistent and TC different sexes responses have been attributed to different clothing insulation ([27] and [28] *cit in* [26]) . Although the clothing insulation value of men and women garments' does vary [29] (especially in an office environment), in the present study male and female teenagers in school environment tend to merge their outfits – no substantial differences were found (section **2.5.2** and **2.5.3**). This observation is in agreement with previous studies [3], [30], [31], where the mean clothing insulation between male and female children is small.

The two classrooms under study are located in the main classroom building (A). Each one of the classrooms is provided of an AHU. Although, school was working on "free-running" conditions and only natural ventilation strategies were used to control the T_a and IAQ. The characteristics of the analyzed classrooms are presented in **Fig.3 b)** and **Table 1**.

Table 1
Classrooms **A1** & **A2** characteristics and windows dimension (north and south oriented, respectively).

Room	Area (m^2)	Ceiling (m)	Volume (m^3)	Number of occupants (during class period)	Occupancy density (pupil / m^2)	Window to floor Ratio
A1	46,38	3,36	155,85	26 (median)	0,57 (median)	0,19
A2	46,21	3,36	155,25	26 (median)	0,57 (median)	0,19
		Height (m)	Width (m)	Area (m^2)		Total Area (m^2) | (Nº units)
A1 & A2	Window	1,8	1,2	2,16		8,64 (4)
	Window (opening)	1,24	0,60	0,74		2,98 (4)

Note: Only the sliding windows were considered on window opening because it was verified that the hopper window was always obstructed by the blinding system

2.4 IEQ analysis – monitored data

The IAQ and TC factors were analyzed by means of field measurements of the following parameters: air temperature (T_a), air relative humidity (RH) and concentration of carbon dioxide (CO_2). The recorded values of these parameters are presented next (section **2.4.1** and **2.4.2**).

Before the monitoring campaign took place, mean radiant temperature and air temperature were analyzed for a period of 24hours. It was verified that the thermal amplitude was lower than 1ºC (this was due to either the buildings' strong inertia – originally built in the 1960's, either to the period of the year the campaign was driven, mid-season). Owing to this condition and to the fact that a continuous monitoring campaign was to be driven for a longer period (including weekends), it was decided to use a datalogger of smaller dimension for practical reasons, e.g. security of the equipment itself and classes normal operation. The SD800 Datalogger by *Extech* was used to monitor all the parameters. The monitoring was performed for two weeks long, from Monday April 29th until Monday May 13th 2013.

Data were registered every 60 sec for the total monitoring period. Because of regular class action, and considering students behaviour (recommendation from the school responsible), the measurements could not be registered totally in accordance with ISO 7726 [32] - the equipment had to be "disguised" and integrated in the room furniture, at a height of circa 0.6 m above the floor (near the breathing height for seated people) and could not be placed in the middle of the room. In **Table 2** is presented a synthesis of the record values during the entire monitoring period.

The occupation periods in both classrooms were further investigated. For each of the monitored class days, an occupation period was defined according to the classroom occupation schedule, which varied daily. Along a regular day class, each of these classrooms was occupied by different classes, with a varying number of students, of different ages and different school years.

Table 2
Synthesis table of all the recorded values.

Parameter	Lowest record		Highest record		Average		St. deviation		Reference value
	A1	A2	A1	A2	A1	A2	A1	A2	
Room temperature (ºC)	16,1*	17,3***	23,1	25,9	19,5	20,7	1,64	1,85	20 – 24 [33], [18]
Relative Humidity (%)	36,6	26,9	68,8	65,9	49,9	47,2	4,71	5,21	30-70
Carbon dioxide (ppm)	325**	391****	6223	7645	684	780	635	712	≤1000 [34]

Note: value registered at 06:07am 30/04/2013 – unoccupied period*
*Note**: value registered at 00:04am 10/05/2013 – unoccupied period*
*Note***: value registered at 06:23am 02/05/2013 – unoccupied period*
*Note****: value registered at 10:44pm 01/05/2013 – unoccupied period*

The results of the percentage of compliance of each of the parameters evaluated, according with the reference values ([18] – Cat. B, [34] , [33] – Cat. II), are presented in **Table 3**, for classrooms A1 and A2, respectively. It is noteworthy that the temperature reference values presented in **Table 2** refer to operative temperature. The monitored temperature in the classrooms was air temperature (T_a). The comparison herein presented was possible because the monitoring campaign was driven during the mid-season, when temperature differences between air and mean radiant temperatures are not so significant.

Table 3
The percentage of compliance for the occupation periods in **Classrooms A1 & A2**

Occupation Period		Percentage of compliance A1				Percentage of compliance A2			
		Room A1	Temp	RH	CO_2	Room A2	Temp	RH	CO_2
I	30/04/2013	[08:15 – 17:45]	33,5%	100%	4,2%	[10:00 – 16:15]	89,0%	100%	0%
II	01/05/2013	[08:15 – 13:30]	0,0%	100%	100%	[08:15 – 16:15]	0,0%	100%	100%
III	02/05/2013	[08:15 – 17:45]	16,1%	100%	27,2%	[08:15 – 16:15]	63,5%	100%	4,8%
IV	03/05/2013	[08:15 – 16:15]	67,7%	100%	24,8%	[08:15 – 13:30]	76,8%	100%	30,2%
V	06/05/2013	[08:15 – 16:15]	96,3%	100%	7,1%	[08:15 – 17:35]	100%	98,6%	48,6%
VI	07/05/2013	[08:15 – 17:45]	100%	100%	57,5%	[10:00 – 16:15]	100%	100%	4,5%
VII	08/05/2013	[08:15 – 13:30]	100%	100%	42,2%	[08:15 – 16:15]	100%	100%	74,4%
VIII	09/05/2013	[08:15 – 17:45]	100%	100%	100%	[08:15 – 16:15]	100%	100%	100%
IX	10/05/2013	[08:15 – 16:15]	100%	100%	36,3%	[08:15 – 13:30]	100%	100%	37,1%
X	13/05/2013	[08:15 – 16:15]	100%	100%	44,4%	[08:15 – 17:35]	76,3%	100%	73,7%

Outdoor temperature can significantly impact indoor temperature. For this reason, on **Table 4**, temperature values of each of the classrooms A1 and A2, facing north and south, respectively, were plotted in parallel with outdoor temperature. On this case again, the average values presented recall the occupation periods presented in **Table 3**. Mean external temperatures were calculated during the *daily occupational period* 8:15 – 17:45. All the meteorological information used in this study, were obtained from www.ipma.pt (Beja weather station).

Table 4

Average and maximum values over the occupation periods of the indoor air temperature and CO_2 concentration in Rooms A1 & A2

Occupation Period	Room A1				Room A2				Ext
	Temp (ºC)		CO_2 (ppm)		Temp (ºC)		CO_2 (ppm)		Temp (ºC)
	average	max	average	max	average	max	average	max	mean
I	**18,5**	19,6	**2222**	3719	**20,4**	22,1	**3103**	7645	14,4
II	**17,0**	17,2	**396**	443	**17,9**	18,1	**463**	502	15,9
III	**18,0**	19,5	**1742**	3301	**19,2**	20,2	**2000**	3008	20,2
IV	**19,4**	21,0	**2016**	5043	**20,1**	21,3	**2119**	4347	22,4
V	**21,2**	22,6	**2235**	6223	**22,6**	23,9	**1376**	5251	23,3
VI	**22,9**	23,0	**917**	2237	**23,5**	24,5	**2222**	4312	25,6
VII	**22,1**	23,0	**1331**	3298	**23,1**	24,5	**1102**	7465	21,5
VIII	**20,8**	20,9	**387**	446	**22,3**	23,0	**458**	488	24,0
IX	**21,5**	23,0	**1248**	2427	**22,8**	24,0	**1346**	2529	22,6
X	**21,9**	23,0	**1116**	2200	**24,0**	25,9	**1136**	5298	25,3

The recorded values of air temperature and concentration of carbon dioxide in rooms **A1** and **A2** are presented next on **Fig. 4 - 7.** Occupancy periods are represented by the grey shadowed areas. RH values are not graphically presented because practically all the recorded values fitted the norms (see RH percentage of compliance in **Table 3**).

2.4.1 Classroom A1 | Graphical representation of the recorded values

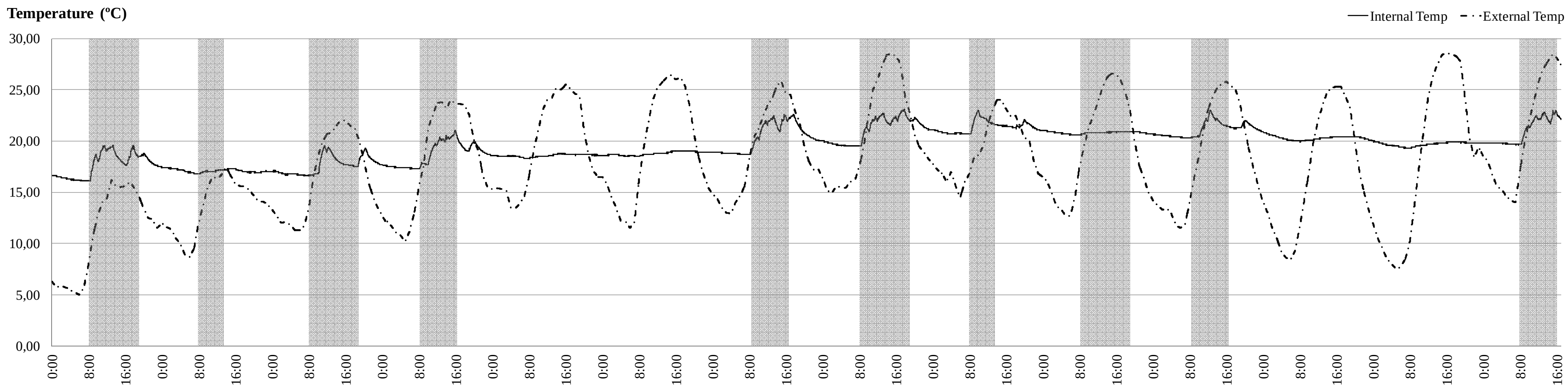


Fig. 4. Temperature values in room A1 between 30th April - 13thMay (the shadowed areas correspond to the ten occupation periods, as defined in **Table 3**).

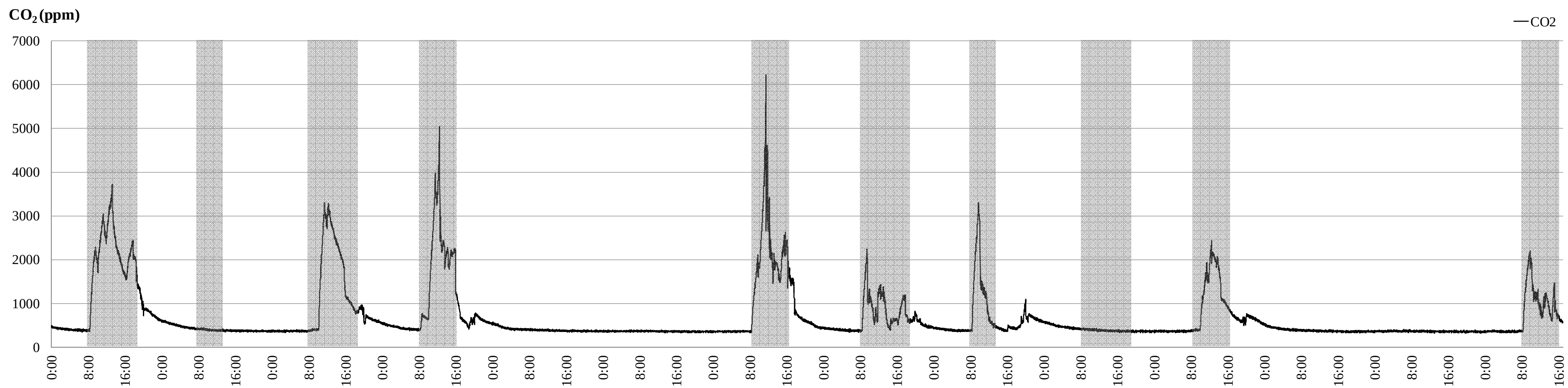


Fig. 5. CO_2 concentration values in room A1 between 30th April - 13thMay (the shadowed areas correspond to the ten occupation periods, as defined in **Table 3**).

2.4.2 Classroom A2 | Graphical representation of the recorded values

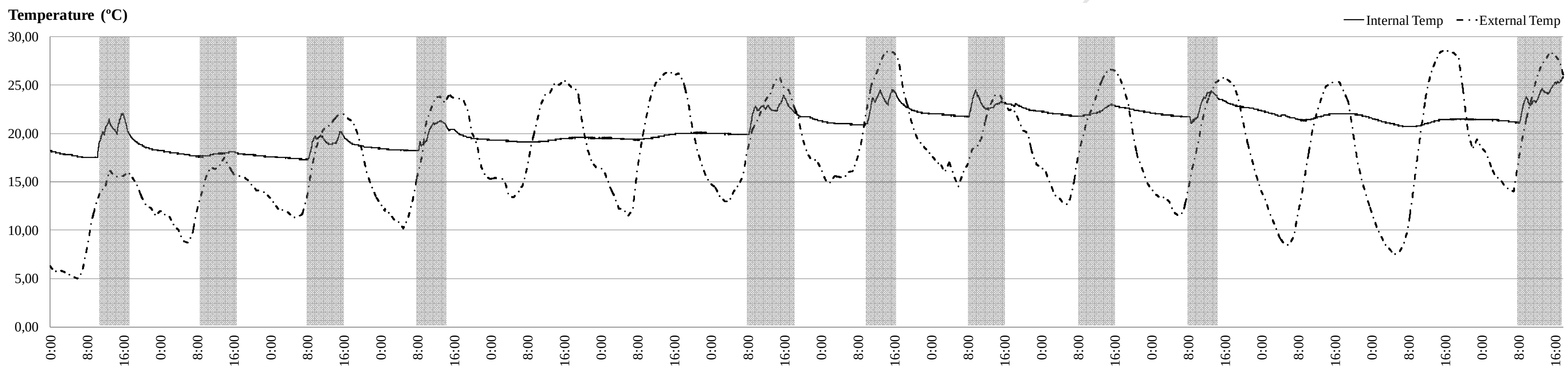


Fig. 6. Temperature values in room A2 between 30th April - 13thMay (the shadowed areas correspond to the ten occupation periods, as defined in **Table 3**).

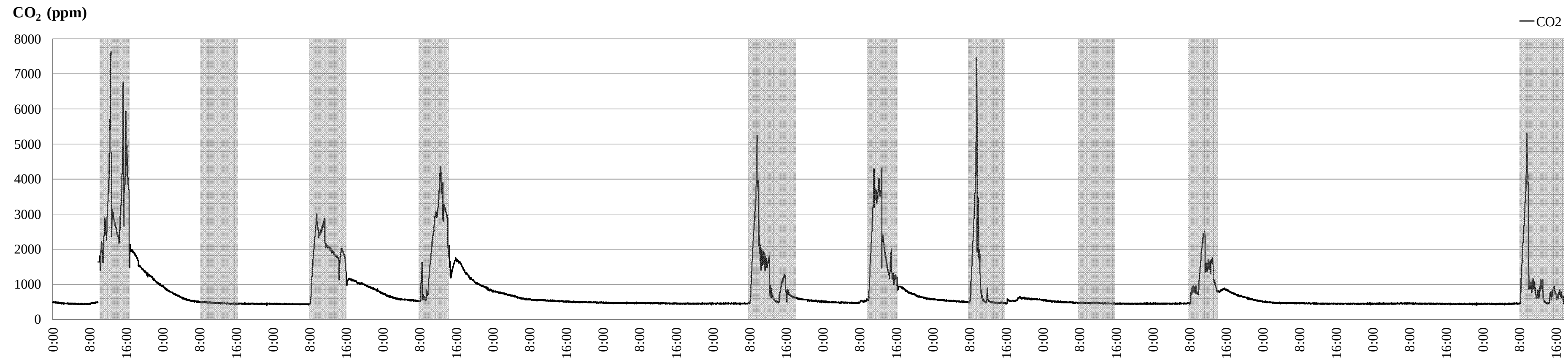


Fig. 7. CO_2 concentration values in room A2 between 30th April - 13thMay (the shadowed areas correspond to the ten occupation periods, as defined in **Table 3**).

2.4.3 Time evolutions of CO_2 and temperature values inside the classrooms

The time evolution of air temperatures in classroom A1 and A2 during the ten occupation periods (previously shown) are depicted in **Fig. 4** and **Fig.6**. Attending to the fact that the monitoring campaign proceeded in parallel in both rooms, an immediate deduction comes to sight: indoor air temperatures (T_a) are lower in A1, the classroom facing north, than in classroom A2, facing south. Moreover, in classroom A1, during the occupation periods I – IV, all the mean indoor T_a values were out of the reference interval (20 – 24ºC). Relating these same periods, in classroom A2, only during periods II and III, the mean indoor T_a values were out of the reference interval. The percentage of compliance of this parameter (**Table 3**) also reveals this “disability”. During all the other occupation periods, indoor T_a values in both classrooms generally comply with the reference interval values. The time evolution of indoor T_a values goes along with outdoor temperature evolution. This can be verified both in **Fig. 4** and **Fig.6**.

The time evolution of carbon dioxide (CO_2) in classroom A1 and A2 during the ten occupation periods (previously defined) are depicted in **Fig. 5** and **Fig.7**. Based on these figures and **Table 3**, looking at the lower compliance of CO_2 concentration values, it is deductable that IAQ parameters are not being full field. In most cases, peak CO_2 concentration values overcome 3000 ppm and some situation even 5000 ppm. Nevertheless, looking deeper into data, it was verified that during the occupation periods, mean CO_2 values are not so high: varying between 384-2173ppm and 459-2773ppm in classroom A1 and A2, respectively. Still, the maximum mean values are in both cases more than the double of the recommend value – 1000 ppm [34]. As expected, the lowest values in both classrooms were recorded during night time, in unoccupied periods.

2.5 IEQ questionnaire - subjective assessment

Auditing indoor climate quality (ICQ) in buildings, during the occupation period, is an important action [35]. Foreseeing a more complete TC study, a subjective assessment was driven within the two monitored classrooms (A1 and A2) in this school. The questionnaire was specially set-up for the assessment of environmental quality in schools and guarantees the respondents' anonymity. A previous version of the final outline of the questionnaire was formerly applied in an academic campus [22] and presented in [5].

Among the general information (age, gender, height, weight), it was asked the students to mark what they were wearing by means of a clothing check–list, so that the actual clothing level could be calculated [18]. This information was used to calculate the PPD and PMV indices presented in **section 3.1**. Students were also asked on personal habits such as smoking or respiratory history illness, such as asthma or chronicle bronchitis. Moreover, their position inside the classroom was also questioned (relative position to windows/door/interior walls). The other questions concerned Thermal Comfort (TC), Indoor Air Quality (IAQ), Acoustic Comfort (AC) and Visual Comfort (VC). The questionnaire was previously explained by the research team members, before being applied to 45 students with an age between 16-19 years and school levels varied between 10-11th grade, no special doubts in the terminology came out (e.g. the "thermal sensation"). A total of 45 individuals answered the survey. Nevertheless, the research team members answered promptly when any information was questioned.

For the present, only TC and IAQ questions are studied. The questionnaire ended with a question on global evaluation of the room environment conditions'.

Students gave a judgment on thermal acceptability, thermal sensation and thermal preference, answering questions such as:

a) Do you consider the thermal environment condition acceptable?

b) How do you feel in this moment?

c) How would you like to feel?

Question a) was asked on a discrete two-point scale (acceptable/not acceptable; yes/no); b) and c) were asked using a continuous scale with qualitative indications, latter converted to quantitative votes, as previously explained by de Carvalho *et al.* 2013, [5].

They were also questioned about draughts and air dryness, as well as on their preference on indoor air temperature: «If you could control indoor air temperature, would you prefer: a) It varied in accordance with the external climate conditions; b) It was almost the same all year despite the external climate». For the indoor air quality vote, the adopted parameters were the *Air stiffness* and the *Air smell* votes followed by *Air quality* (Global assessment).

2.5.1 Classroom A1 conditions

The questionnaire in room A1 was driven during the last occupation period (X) defined in **Table 3**, on Monday, 15th May 2013. According to the responsible teacher recommendations', the questionnaire was distributed and explained to the students at 12:00, a few minutes after the beginning of the class at 11:45 (after a small interval between classes). At that time, students had been inside the room for circa 15min. During the questionnaire (that lasted for circa 10 minutes), the classroom conditions were: T_a = 22,1ºC, RH = 55,2 % and CO_2 = 924 ppm. Outdoor temperature was 25,8ºC.

2.5.2 Classrooms A1 - answers from the questionnaires

The class answering the questionnaire in room A1 was from the 11th grade. Because three of the students were missing, only 26 answers were obtained. From these, 46% were girls and 54% were boys. The average age and height of the class was 16,7y and 1,71m, respectively (the average BMI was 21,1 kg/m^2). The average clothing insulation value (calculated according to Table C.2 in [18]**)** was 0,46 ± 0,07 (Clo_{male} = 0,46 ± 0,09; Clo_{female} = 0,46 ± 0,05) . The wooden chair insulation (0,01 clo according to Table C.3 in [18]**)** was not considered.

The answers to the first TC question - *Do you consider the thermal environment condition acceptable?* - were overwhelming: 96,2% of the students answered *YES*. Only 3,8 % disagreed (these votes corresponding to a TSV of *slightly cool*). Students' answers to the questionnaire relating TC and IAQ are presented in **Fig. 8** and **Fig.9**, respectively.

In terms of TC, 69% of the students stated feeling *neutral* (all these TSV considered the thermal environment condition acceptable), 8% voted *Slightly warm* (also considered the thermal environment condition acceptable) and 23% stated feeling *Slightly cool* (of which 83% considered the thermal environment condition acceptable).

In **Fig. 8** the thermal preference is plotted along TSV. More than 80% of students voted *No change*, although 8% of these stated feeling *Slightly warm*. No preference votes were counted on *Much cooler* or *A bit cooler*. In fact, despite T_a = 21,1 ºC, 12% of the students voted *A bit warmer* – these students have expressed their TSV as *slightly cool* and *neutral.*

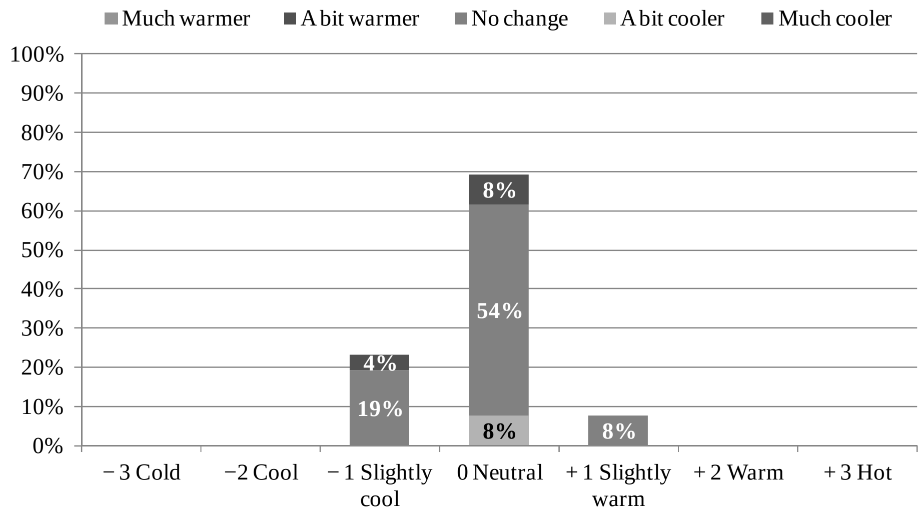


Fig. 8. TSV plotted with thermal preference votes (answer to the question: *How would you like to feel?*)

Concerning draughts and preference, almost 70% stated feeling draughts, but only 17% of these stated feeling discomfort with this. **Fig. 9 a)** and **Fig.9 b)** show the subjective answers to *Air Stiffness* (Clean Air /Polluted Air) and *Air quality* (Global assessment). Relating *Air Stiffness* , circa 60% of the students voted between *Slightly good* and *Exceptional*, 12% voted neutrally (*Slightly* *good – Slightly bad*) and 27% gave voted negatively (*Slightly bad*), no one voted *Bad* or worse. The *Air smell* votes were just a bit different – 28% of negative votes (varying between *Bad* and *Slightly bad*), 15% of neutral votes and around 55% of positive votes (between *Slightly good* and *Exceptional*). Regarding the global air quality assessment, almost 40% of the students did not express a defined vote (*Undefined*), 50% voted positively - votes varied between *Good with negative aspects* and *Good with positive aspects* (a vote closer to Exceptional), and 10% voted negatively (votes between *Bad* and *Bad with positive aspects)*.

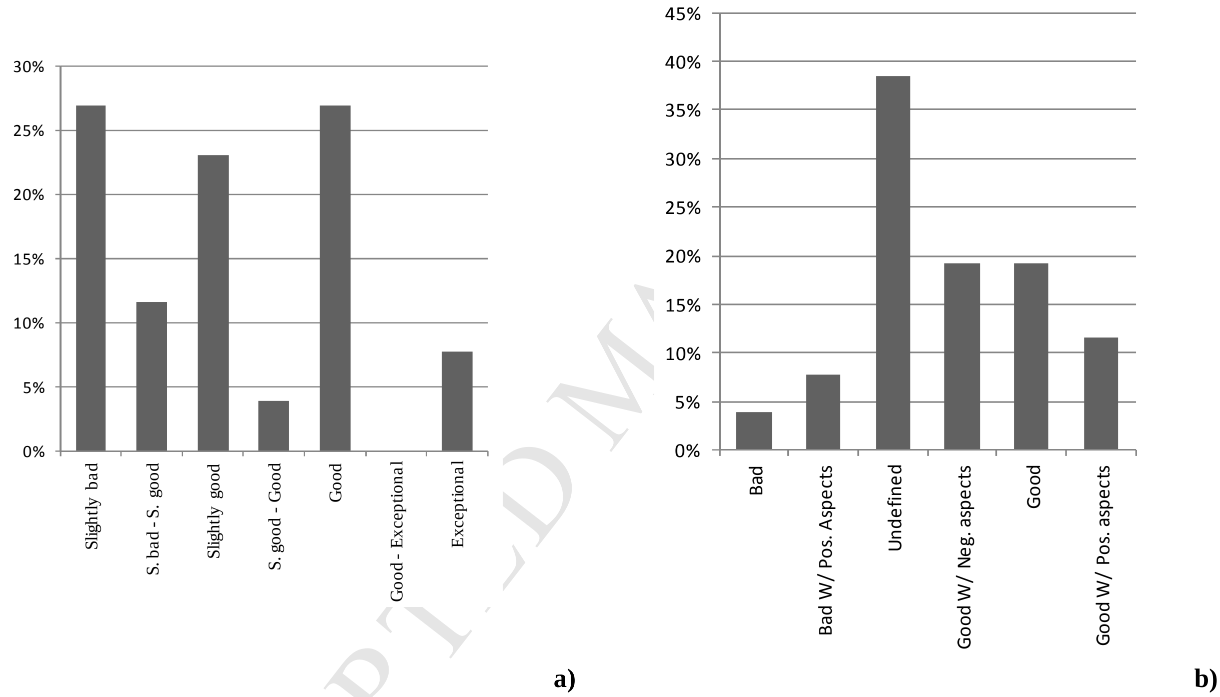


Fig. 9. Classroom A1. Air stiffness votes (*Clean Air/Polluted Air*), a); General air quality votes, b).

Relating indoor air temperature fluctuation, 92% of the students expressed preference for an environment in which temperature varied in accordance with the external climate conditions, rather than a “fixed temperature” independently of the external climate (questions were previously presented in **section 2.5**).

2.5.3 Classroom A2 conditions

The questionnaire in room A2 was driven during the last occupation period (X) defined in **Table 3**, on Monday, 15th May 2013. According to the responsible teacher recommendations', the questionnaire was distributed and explained to the students at 15:50, a few minutes before the end of the class initiated at 15:15. At that time, students had been inside the room for more than 30min. According to the room's schedule, on Mondays, «the room's lunch break» occurred between 13:30 and 14:30.

During the questionnaire (that lasted for circa 10 minutes), the classroom conditions were:

T_a = 25,2ºC, RH = 41,4 % and CO_2 = 753 ppm. Outdoor temperature was 28,1ºC.

2.5.4 Classroom A2 - answers from the questionnaires

The class answering the questionnaire in room A2 was from the 10th grade. Because two of the students were missing, only 19 answers were obtained. From these, 68% were girls and 32% were boys. The average age and height of the class was 15,6y and 1,64m, respectively (the average BMI was 21,7 kg/m^2). The average clothing insulation value was not much different from the one calculated for the class occupying room A1. Herein Clo value = 0,45 ± 0,04 (Clo_{male} = 0,44; Clo_{female} = 0,45 ± 0,05) .

The answers to the first TC question - *Do you consider the thermal environment condition acceptable?* - were overwhelming: 94,7% of the students answered *YES*. Only 5,3 % disagreed. Students' answers to the questionnaire relating TC and IAQ are presented in **Fig. 10** and **Fig.11**, respectively.

Despite indoor T_a = 25,2 ºC, 58% of the students stated feeling *Neutral* (of which 5% curiously stated not accepting the condition) and more than 35% of the students who stated feeling *Slightly warm* said they accepted their condition. The same goes for the 5% that stated feeling *Warm*. In **Fig. 10** the thermal preference is plotted along TSV. Despite T_a = 25,2 ºC, no student stated preferring a *Much cooler* environment. A big majority of the students, 84% voted for *No change*, although 32%

of these stated feeling *Slightly warm*. Only 10% stated preferring *A bit cooler*, half of these stated feeling *Neutral* and other half stated feeling *Slightly warm*. The votes for *A bit warmer*, surprise because correspond to *Warm* TSV. Even if eliminating these votes, due to its ambiguity, the global picture of the TC questionnaire in this classroom would not significantly change.

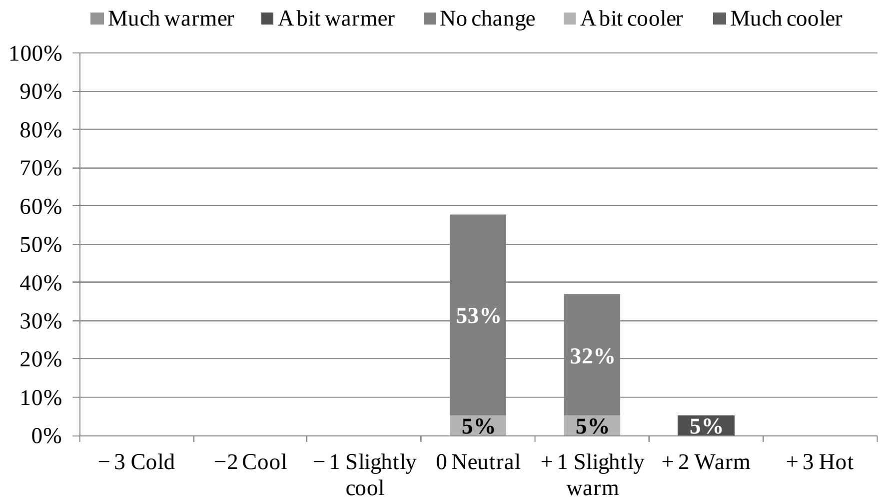
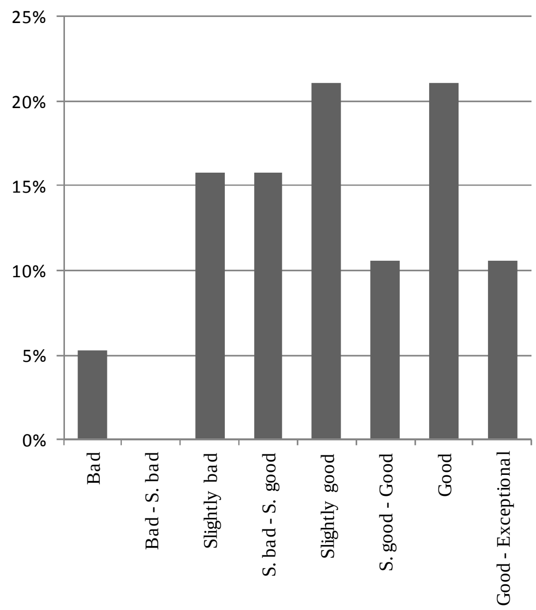
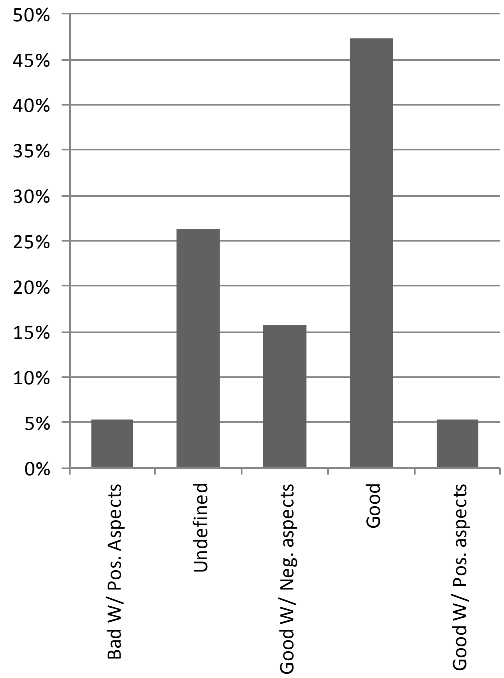


Fig. 10. TSV plotted with thermal preference votes (answer to the question: *How would you like to feel?*)

Concerning draughts and preference, a bit more than 40% stated feeling draughts, but only 13% of these stated feeling discomfort with this. **Fig. 11 a)** and **Fig.11 b)** show the subjective answers to *Air Stiffness* (Clean Air /Polluted Air) and *Air quality* (Global assessment). Relating *Air Stiffness*, more than 60% of the students voted between *Slightly good* and *Good – Exceptional*, circa 15% voted neutrally (*Slightly good – Slightly bad*) and around 20% gave voted negatively (*Bad* and *Slightly bad*). The *Air smell* votes did not differ much from the *Air Stiffness*. Regarding the global quality air assessment, although almost a quarter of the students did not express a defined vote, the results are rather positive - almost 70% of the votes varied between *Good with negative aspects* and *Good with positive aspects* (a vote closer to Exceptional), and only 5% of them are clearly negative – *Bad with positive aspects*.



a)



b)

Fig. 11. Classroom A2. Air stiffness votes (*Clean Air/Polluted Air*), a); General air quality votes, b)

Relating indoor air temperature fluctuation, 79% of the students expressed preference for an environment in which temperature varied in accordance with the external climate conditions, rather than a “fixed temperature” independently of the external climate. Relating answers obtained in classroom A1, this class revealed a higher preference for air-conditioned spaces.

3. Results and discussion

3.1 PPD & PMV indices. Simulation results: Estimation on comfort indices

The recorded data were elaborated in order to evaluate Fanger’s thermal comfort indices, PMV and PPD, according to ISO 7730 [18]. The procedure has been previously exposed [4]. Based on a simulation tool developed by Gameiro da Silva [36], [37], TC indices were calculated. In the presented case-study, data input relating to environmental conditions were: air temperature (monitored value), mean radiant temperature (estimated: based on Ta ± 1ºC), air velocity (estimated in accordance to [18]) and RH (monitored value) – instead of partial vapour pressure. The other parameters are clothing insulation (which were obtained from the questionnaires and calculated based on [18]), the metabolic rate (that was considered 1,2 met - sedentary activity**)** and mechanical power.

Aiming at comparing PMV and PPD indices, with the results obtained from the questionnaire on May 15th, the considered values for each of the varied parameters are presented in **Table 5**, from which were obtained six results (three simulations were performed for each classroom)[2].

Table 5

Summarizing table of the obtained results in the six simulations

Parameters	Simulation classroom A1			Simulation classroom A2		
	I	II	III	IV	V	VI
M (met)	1,2	1,2	1,2	1,2	1,2	1,2
W (met)	0	0	0	0	0	0
I_{cl} (clo)	0,44	0,44	0,44	0,44	0,44	0,44
T_a (ºC)	22,1	22,1	22,1	25,2	25,2	25,2
HR (%)	55,2	55,2	55,2	41,4	41,4	41,4
T_r (ºC)	**22,1**	**21,1**	**23,1**	**25,2**	**24,2**	**26,2**
V_{ar} (m/s)	0,1	0,1	0,1	0,1	0,1	0,1
PMV	-0,36	-0,53	-0,20	0,63	0,46	0,80
PPD	7,8	10,9	5,8	13,4	9,4	18,6

3.2 Indoor air quality analysis based on CO2 concentration values

In classroom A1, during the questionnaire, metered average indoor CO_2 concentration value was 924 ppm. Plotting this same value in the expression PD(%) = 395*EXP (-15,15*C_{CO2}^-0,25) [38], where the PD is expressed in terms of CO_2 concentration values in excess to outside air (ppm), circa 17% of the individuals would be dissatisfied within those conditions, what represents PMV≈ 0,7 [18]. Outdoor CO_2concentration values were not measured, an estimated value of 380ppm was considered for this estimation.

During the questionnaire in classroom A2, metered average indoor CO_2 concentration value was 753 ppm. Plotting this same value in the expression PD(%) = 395*EXP (-15,15*C_{CO2}^-0,25) [38],

[2] Graphical interface of the simulation tool is presented in the Appendix (Graphical interface of the computational tool after simulation I).

where the PD is expressed in terms of CO_2 concentration values in excess to outside air (ppm), circa 13% of the individuals would be dissatisfied within those conditions.

In **Fig. 12**, the percentage of dissatisfied (PD) with IAQ in both classrooms during the questionnaires and the preceding moments it is plotted together with PD derived from the questionnaires. It is worth noticing that PD votes, driven from the global Assessment question on *Air Quality*, just like TC votes (previously presented in section 2.5), were given in a continuous scale with qualitative indications, latter converted to quantitative votes (-500 to 500), [5]. The PD values corresponded to negatives votes with an absolute value higher than 100.

In other words, considering this pollutant concentration levels (especially during the questionnaire period in A1), it would be expected a higher value of PD. This study confirms other studies where the subjective assessment is made by "outsiders" and not by the actual occupants, whose vote was more "sensitive", i.e. not accommodated [39].

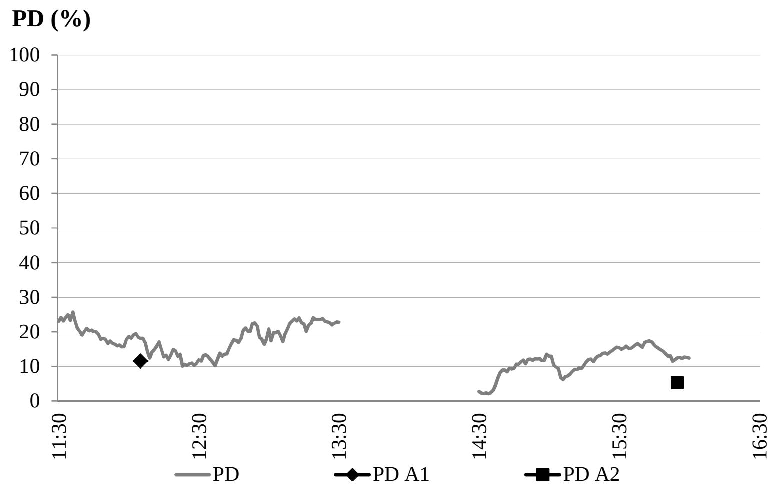


Fig. 12. Percentage of dissatisfied estimated on CO_2 concentration excess in relation to outside air (CR 1752-1998) plotted together with PD values from the questionnaire

3.3 Discussion

According to *EN 15251:2007* [33] (Table 1: Description of the applicability of the categories used)**,** when analyzing this case-study in Beja, we should be looking at *Category II* (Normal level of expectation and should be used for new buildings and renovations). Based on this same *EN*

15251:2007, for *Category II* the recommended values for PPD should be <10 and PMV should vary between ± 0.5 (table A.1, Annex A). The reference values presented for this thermal environment category are the same in ISO 7730 [18]**.**

The values herein presented in section **3.2** for classroom A2 do not respect the conditions recommended by the norms. This PPD estimation in section **3.2** is higher than the PPD estimation resulting from the simulations (section **3.1** - major differences were found for simulations in room A1).

TSV in both rooms "accompany" indoor T_a. In classroom A1 (T_a = 22,1 ºC), questionnaires answers were expressed in the interval [-1; +1], while in classroom A2 (T_a = 25,2 ºC), the TSV varied between [0; 2]. In **Fig. 13** is presented a summary of the thermal conditions of the classrooms A1 and A2 during the questionnaires' period. Indoor T_a (ºC) is plotted with TSV - mean and standard deviation votes.

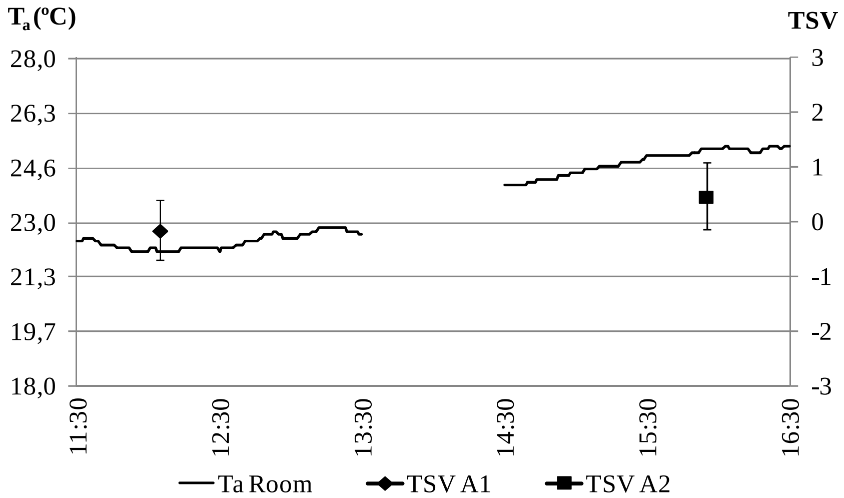


Fig. 13. Air temperature values plotted against TSV (mean and standard deviation)

From the observation of **Fig.12** and **Fig.13** it can be observed that although subjective and objective variables have different scales, their variations are consistent.

Nevertheless, in both cases thermal acceptability was close to 95%. TSV in classroom A1 have a distribution, close to the expected, while TSV in classroom A2 do surprise. Although T_a was higher than 25ºC, more than 80% of the students voted *No change*, even if a significant part of those stated feeling warm. The results confirm that people feel comfortable under a wider range of temperature than those recommended by the norms and also reinforce that «people living in warm climates can more easily accept and work longer in hot environment than people from colder climates» [35]. Other studies in classrooms have confirmed that people in naturally ventilated indoor environments are comfortable within a range of microclimate values that is larger than in a fully conditioned environments [40], «occupants seem capable of adapting to a broader range of conditions (…) than predicted by ISO7730» [41] *cit in* [42].

IAQ subjective assessment did not differ much in both classrooms. *Air stiffness* votes were rather distributed in both classrooms. *General air quality* votes varied less in classroom A2. Moreover students in this classroom were able to better define their votes (circa 25% of the votes *Undefined*).

In **Fig. 14**, the subjective evaluation of the thermal environment is plotted along with the PMV values calculated for each of the classroom (as previously presented in **Table 5**). Both votes, perceived and estimated, varied between *Slightly cool* and *Slightly warm*. Attempting separately the mean values for each of the classrooms, it can be seen that in classroom A1, students perceived the thermal environment more comfortably than it would be expected from the calculated PMV - they did not perceive the environment so *cool*. The same reasoning can be drawn in classroom A2, but from the opposite perspective – in this case, students (TSV mean vote) did not perceive the environment so *Warm*.

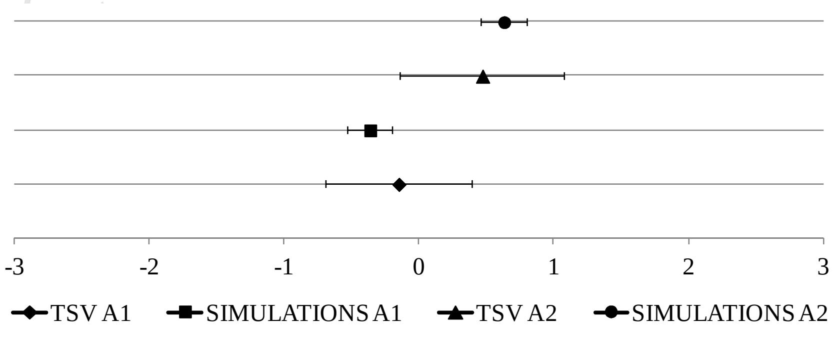


Fig. 14. Subjective responses (TSV) and PMV calculated votes (mean and standard deviation votes)

Moreover it was verified that the distribution of the votes tended to narrow with a decrease in the temperature (TSV $_{A1}$ = -0,15 ± 0,54 and TSV $_{A2}$ = 0,47 ± 0,61). This finding is divergent from to the one of H. Yun *et al*. (2014), [31] – by the time of the questionnaire Ta $_{A2}$> Ta $_{A1}$ – which may be explained by the smaller T_a difference in our case studies (~ 3ºC) in comparison to a bigger Operative Temperature difference in [31] (~ 8ºC) or by the differences of the sample size. Furthermore, in their study, H. Yun *et al*. (2014) found that *«the distribution of votes was wider for boys than for girls»*. In our study this is an half-truth: this condition was found in room A2, where TSV girls = 0,46 ± 0,52 and TSV boys = 0,50 ± 0,84, but the contrary was verified in room A1, where TSV girls = -0,25 ± 0,62 and TSV boys = -0,07 ± 0,47. From these values we can additionally state that girls' TSV was in both situations relatively lower than boys, but a consciously analysis should be withdrawn of such sample (a total of 45 individuals answered the survey). Further investigation on this subject in suggested confirming this hint.

4. Conclusions

In this work, the results of a field study investigations on TC and IAQ in Portuguese secondary classrooms located in Beja (south-east of Portugal) are shown. The investigation was carried out during the mid season in free running conditions (no HVAC systems were active during the study). The environmental parameters influencing TC and IAQ were measured, while parallel subjective assessments of the occupants were collected.

The study allowed a comparison between TC indices predictions (calculated with the monitored data) and a subjective perspective observed from the questionnaires. Furthermore, it reinforced findings from previous researches conducted in classrooms – students in secondary schools in Mediterranean climate under free running conditions in mid-season:

- stated accepting indoor T_a up to 25,2 ºC;
- expressed TSV for *no change*;
- confirmed that *thermal neutrality* is not the preferred state.

On the basis of these results, a trend was found for the thermal preference from *Slightly warm* environments in the mid season: higher temperature ranges are accepted than those presented in the norms.

Concerning indoor air quality, focusing on CO_2 concentration levels, the perceived votes reveal students' adaptation to the environment exposure. Moreover, it was found that IAQ regulations are not being full field. The concentration of this pollutant frequently exceeds the national and international reference limits.

Acknowledgments

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Appendix

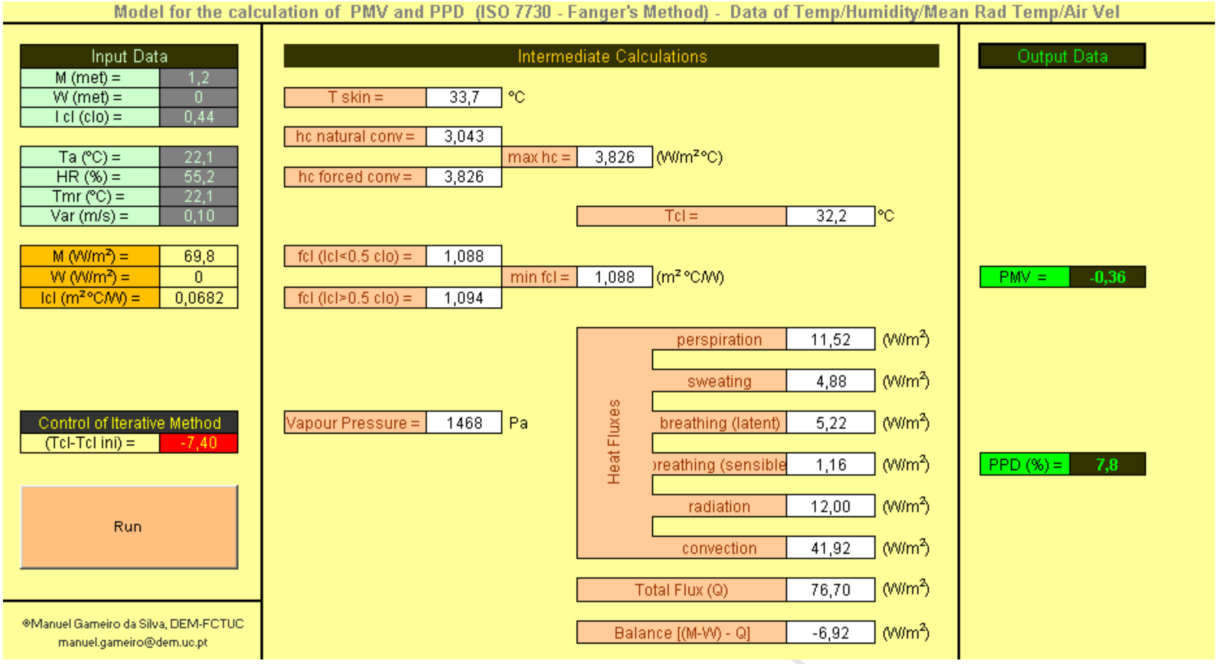

Fig.A.1. Graphical interface of the computational tool after simulation I

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Highlights

- We conducted a field study on TC and IAQ in Portuguese secondary classrooms.
- The investigation was carried out during the mid season in free running conditions.
- The study compares TC indices and subjective votes from questionnaires.
- Students in Mediterranean climate accepted indoor T_a up to 25,2 ºC.
- Higher temperature ranges are accepted than those presented in the norms.

Assessment of indoor air quality and thermal comfort in Portuguese secondary classrooms: methodology and results

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