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IAQ Assessment in Higher Education Classrooms with Natural Ventilation during the Cold Season

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ABSTRACT

Indoor air quality (IAQ) control in educative centres, where students spend most of their time, is essential. The presence of high levels of contaminants can impact the academic performance of the students and, ultimately, their health. A study has been carried out to assess the IAQ of higher education classrooms with natural ventilation in order to quantify the exposure of the occupants to certain contaminants during the cold season. CO_2, PM_{10}, $PM_{2.5}$, $PM_{1.0}$, and volatile organic compounds (VOC) have been measured. IAQ has been monitored throughout the normal functioning of two students' groups for their whole academic period in a week, characterizing occupancy and distribution. Ventilation was made only occasionally by manually opening the windows. Also, during break periods when students move from one classroom to another and doors remain open, producing some air change between the classroom and circulation areas, and because of air infiltration. The airtightness of the classrooms was measured by means of pressurization tests. High concentrations of CO_2 during the whole period were obtained, concluding that ventilation strategies need to be implemented to improve IAQ.

INTRODUCTION

Air quality is an important factor for people's well-being, even more, when it comes to an indoor environment where people spend a long time. Also, if the activity developed in this environment is academic, specific comfort conditions must be considered. Indoor air quality (IAQ) can influence the students at two levels: their health and well-being, and their attention span and task performance (Sarbu & Pacurar, 2015). These conditions must favour and facilitate this learning and knowledge environment. High levels of CO_2, particulate matter (PM), and volatile organic compounds (VOC) increase the incidence of respiratory diseases, and minor pathologies such as irritation of the mucosa or headaches (Shendell et al., 2004). These medical issues, at the same time, cause absenteeism, as well as a reduction in concentration during the lessons, which could have an impact on academic performance (Satish et al., 2012).

IAQ depends on the presence of users in classrooms (time and number of students), construction materials and furniture (Di Giulio et al., 2010), the air conditioning systems, as well as the level of outdoor pollution (Gomes et al., 2007). Proper ventilation of university premises is essential to keep acceptable IAQ.

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IAQ involves many parameters and types of pollutants, among which CO_2, VOC, and PM seem to have a significant influence on educational environments (Becerra et al., 2020). Although in high concentrations it can be considered a pollutant, which influences the attention and decision-making capacity of subjects (Griffiths & Eftekhari, 2008; Satish et al., 2012), CO_2 has traditionally been an indicator of air quality and the air change capacity of the rooms. However, some authors emphasize that CO_2 should not be used as a sole measure of IAQ (Asif & Zeeshan, 2020; Ramalho et al., 2015). The analysis of CO_2 has been performed by taking the values established by the Spanish standard for educational indoor environments as indicators, determined as IDA 2 (Reglamento de Instalaciones Térmicas En Los Edificios, 2013). The defined indoor CO_2 limit is 500 ppm, calculated as the difference between the indoor and the outdoor CO_2 concentration.

PM is derived from the anthropic activity, either the recirculation of existing ones within the classroom due to the activity, those that come from outdoor, or due to the use of different materials associated with academic activities. The World Health Organization (WHO) recommends that PM in sizes <2.5 µm ($PM_{2,5}$) and <10 (PM_{10}) should be kept, on average, below 25 µg/m^3 and 50 µg/m^3, respectively throughout the day (World Health Organization, 2005). VOC can come from different sources (building materials, academic material, furniture, cleaning products, traffic waste, etc.). There are several sources of recommendations regarding VOC levels, but an acceptable range from 0.6 to 1 mg/m^3, or 500 ppb can be considered (Ahmed Abdul–Wahab et al., 2015; Umweltbundesamtes et al., 2007).

The objective of this study is to evaluate the IAQ to which the students of the Technical School of Architecture in Valladolid are exposed during one-week in the cold season. Air quality has been determined based on experimental concentration values of the stated indicators, as well as temperature and relative humidity obtained in real environments.

METHODOLOGY

Sites and building

The study was carried out in a higher educational centre located in the periurban zone of Valladolid, which is a medium-sized city with low density in the continental area of Spain. The centre is close to an avenue with heavy traffic separated from it by green public space. The classrooms under study (Table 1) and are located in two close buildings: the academic building (1) and the classroom building (2). Building 1 was built in 1989 with a façade made of an exterior layer of facing brick and an interior layer of ceramic brick. Windows are made of aluminium, with double glazing and air chamber, without thermal break. There is a water-air heating system, in which the indoor air of the classrooms is recirculated, warming it without renewal.

Building 2 was built in 1978 but it was renovated in 2010, improving the envelope. It maintains its original structure with interior courtyards. It has a stone ventilated façade, with an internal layer of insulated prefabricated plasterboard. Windows were replaced and have thermal break and double glazing and air chamber. The heating system has aluminium radiators as terminal units.

The air renewal in both buildings is done naturally, by manually opening windows and doors to circulation spaces during breaks and air infiltration.

Table 1. Classrooms Characteristics

Building	Classroom	Height	Orient.	Area (m^2)	Max. Occupation	Volume (m^3)	Window area	Number of doors
1	B.1	0	S	128.24	85	474.5	13.6	2
1	B.2	0	SE	128.24	85	474.5	13.6	2
1	B.4	0	NE	94.82	63	405.1	14.2	2
2	B.9	0	NE	94.8	63	284.4	3.75	1
2	1.4	1	SE	61	40	183	7.5	1
2	1.5	1	SW	168	112	504	30	1
2	1.6	1	S	164.7	109	494.1	26.25	1
2	1.8	1	NW	90.57	60	271.71	7.5	1

During measurements, windows remained closed in most cases. Only in the case of the 5th year group, during the second hour on Thursday, two windows remained open in an oscillating position for the first 15 minutes. Doors were opened on average during the first 10 minutes to enter, 10 minutes during short breaks each hour, and 30 minutes during the break between subjects. Once the morning lessons end, the classrooms are closed until the following day.

Sample

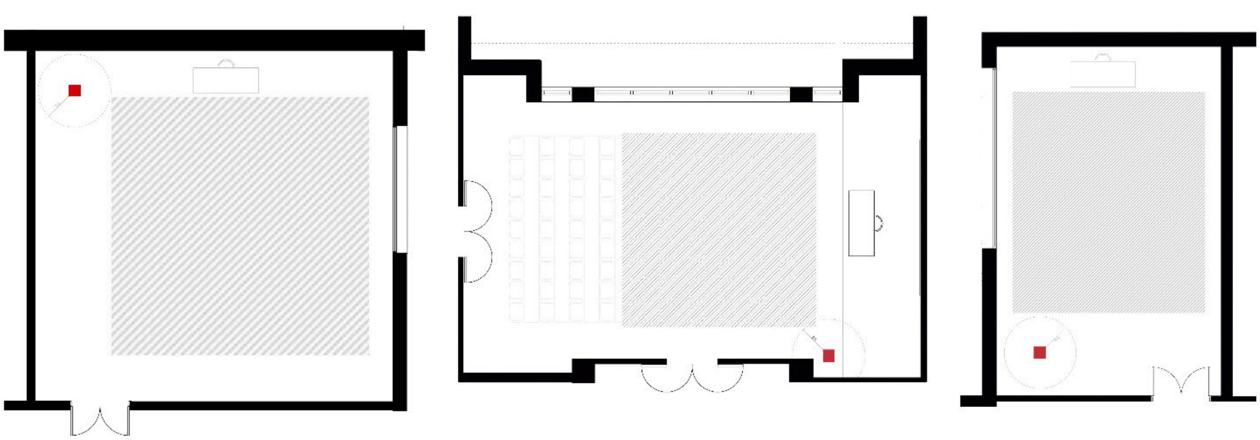
The user profile during academic life is variable among courses. For this reason, a representative sample was selected, which can be extrapolated to all the students of the centre, obtaining a sample of 318 students. To assess the IAQ to which the students are exposed, two groups of the first year and fifth year of the bachelor's degree were selected, following their schedule for one week in the cold season (November - March).

The schedule is mainly distributed from Monday to Friday from 8:30 a.m. to 2:00 p.m., with a break from 10:30 a.m. to 11:00 a.m. The monitoring of the first-year students was carried out for five days (21.5 hours), while the monitoring for the fifth-year students was carried out for four days (15.5 hours) since they do not have lessons on Fridays. On average, students spend 4.5 hours inside a classroom. The students were not provided with any information that could condition neither their behaviour, nor their position within the classroom, nor the opening and closing of windows and doors.

IAQ Monitoring

Air temperature, relative humidity (RH), CO_2, VOC, PM_{10}, $PM_{2.5}$, and $PM_{1.0}$ were measured with integrated AirQualityEgg devices. The temperature sensor had a margin of error of ±0.3ºC, and the RH ±2%. Model K30 10.000 ppm was used to measure CO_2, with a margin of error of ± 30 ppm/± 3% of the measured value. VOC were measured with an iAQ-Core Indoor Air Quality Sensor Module device, whereas PM was measured with a Digital Universal particle concentration sensor PMS5003 with a margin of error of ±10%. Measurements were taken approximately every minute during the whole academic period.

To determine the number and position of the measurement devices within the classroom, previous tests were carried out in order to guarantee the representativeness of the data obtained and to limit distortions produced by the academic material and instruments, students, teachers, doors, or windows. It was determined that one device is enough for the monitoring of classrooms with a partial occupation since the variation of data between devices was negligible. However, devices must have a specific position with respect to different elements and occupants that may affect data collection (Fig. 1). Their location was determined at a distance between 1 m and 2 m from the area where the students are, and at least 1 m away from possible disturbances and outside the direct influence of the recirculating airflow. Regarding height, negligible variations of less than 3% in CO_2 and pollutant levels were observed between the breathing plane of the students in the sitting position (1.20 m) and 1 m above (2.20 m above the floor level).



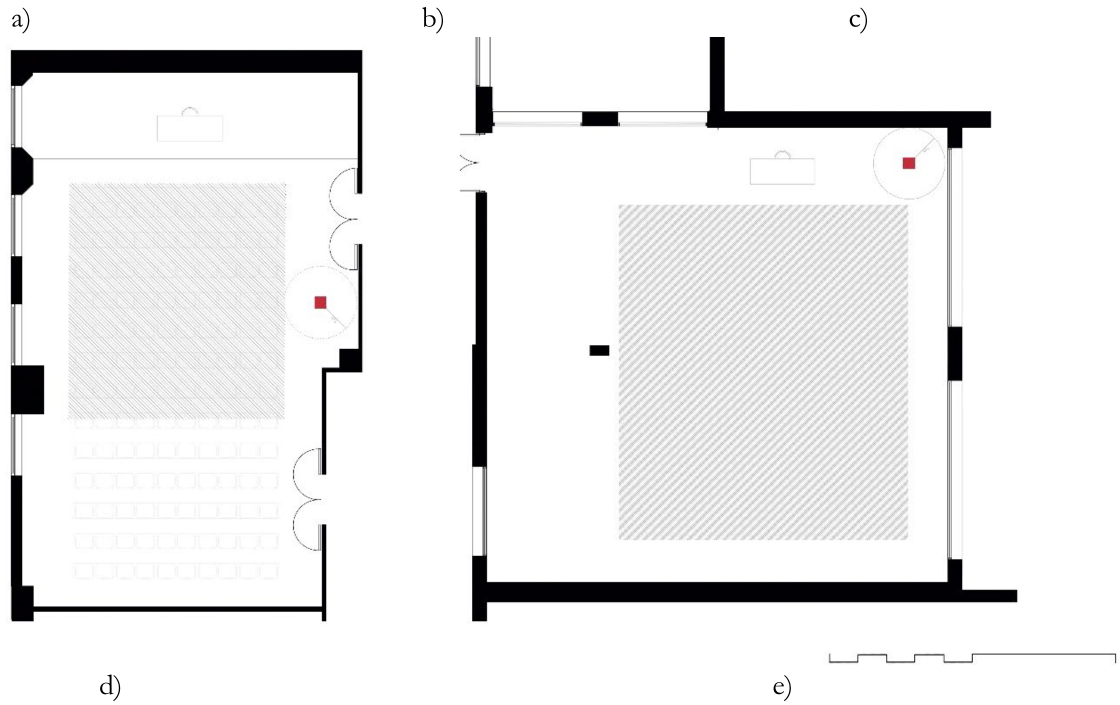


Figure 1 Location of measurement devices within the classrooms during the test. a) B.9 and 1.8 b) B.4 c) 1.4 d) B.1 and B.2 e) 1.5 and 1.6

Permeability characterization

Given that air infiltration is one of the sources of the air change in the classrooms, the airtightness of a representative classroom was assessed. Pressurization tests were performed in classroom B.2 according to ISO 9972 (ISO, 2015). All the windows and doors were closed, whereas air inlets and outlets of the heating system (with air recirculation) were sealed.

To avoid inter-zonal leakages from other classrooms, three tests were performed: individual classroom test, guard-zone pressure test (upper room), and guard-zone test (lower room). Airflow rates of the guard-zone tests have been deducted from those of the single- unit test in order to determine the airtightness of the external envelope (outdoor and circulation areas). Thus, the air change rate (n_{50}), the air permeability rate (q_{50}), and the pressure exponent n, which can be considered as an indicator of the flow regime, were obtained for the different configurations of the test. The correct calibration of the equipment was ensured to maintain accuracy specifications of 1% of sampling, or 0.15 Pa. During the depressurization stage, leakage points were identified by thermal imaging.

The calculated air leakage rate (V_{inf}), the air change rate (ACH), and the air permeability (q_{inf}) were obtained from pressurization test results using the extended simplified model (Sherman, 1987) adapted to the climate characteristics of the location under study and building parameters.

RESULTS

Mean values obtained in the classrooms where the students of the first and fifth year attended courses during the week (M-T-W-Th-F) under study are shown (Table 2 and Table 3).

Table 2. Mean values obtained during the week for students of the first year

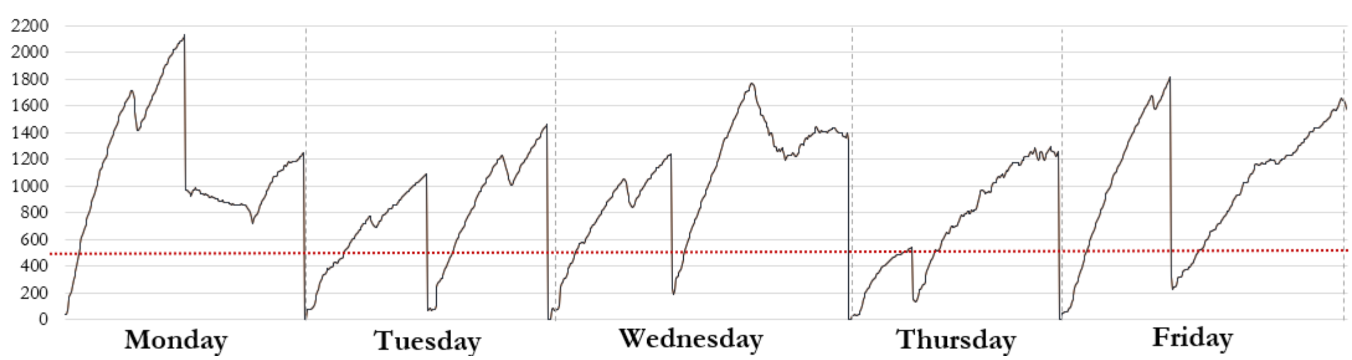
Day	Class	Occup. [%]	Time [hours]	Temp. [°C]	RH [%]	CO_2 [ppm]	$PM_{1.0}$ [µg/m³]	$PM_{2.5}$ [µg/m³]	PM_{10} [µg/m³]	VOC [ppb]
M	B.2	74	2	23.1	43	1739	0.1	0.4	0.5	259
	B.5	30	2	23.4	51	1362	0.0	0.2	0.3	156
T	B.4	38	2	22.6	35	1053	2.6	3.3	3.6	193
	B.2	43	2	22.3	39	1287	2.2	3.4	3.9	261
W	B.2	68	2	22.8	35	1176	1.6	2.5	2.7	221
	B.9	98	3	23.9	41	1821	3.0	4.5	4.9	182
Th	B.2	30	1	21.1	38	732	2.1	3.6	4.3	210
	1.6	34	2.5	22.6	42	1402	0.2	0.5	0.7	212
F	B.2	61	2	22.7	44	1423	0.0	0.0	0.0	253
	1.8	23	3	22.5	43	1657	0.8	1.2	1.5	210

Table 3. Mean values obtained during the week for students of the fifth year

Day	Class	Occup. [%]	Time [hours]	Temp. [°C]	RH [%]	CO_2 [ppm]	$PM_{1.0}$ [µg/m³]	$PM_{2.5}$ [µg/m³]	PM_{10} [µg/m³]	VOC [ppb]
M	1.4	30	3.5	23.9	44	1304	0.2	0.5	0.7	169
T	1.5	30	2	22.3	44	1340	1.2	1.4	0.7	179
	1.4	25	3	24.1	42	1484	7.9	12.3	13.5	187
W	1.5	13	3	24.1	38	895	3.9	5.7	6.4	156
Th	B.1	18	2	21.9	39	948	1.2	2.3	2.7	172
	B.2	15	2	22.7	39	1337	6.0	9.1	10.1	245

During the period under study, the average temperature in the classroom was 22.8ºC (first year), and 23.3ºC (fifth year), which is within the range established in regulations (Reglamento de Instalaciones Térmicas En Los Edificios, 2013). The average relative humidity was 40.6% and 41.1% respectively, close to the lower limit recommended in regulations. In fact, it was below these limits during almost 40% of the monitored time.

The average of the CO_2 levels, taking into account the concentration of the outdoor air (corrected CO_2) was 960 ppm and 846 ppm for the first and fifth-year groups, respectively. CO_2 concentration outdoors was between 396 and 432 ppm and an average of 502.8 ppm was obtained in circulation areas through which the classrooms are accessed. The CO_2 concentration inside the classrooms is much higher than the ones established by Spanish regulations (Reglamento de Instalaciones Térmicas En Los Edificios, 2013). The maximum concentration (2527 ppm) was reached during the first hour on Monday in the first-year group, with an occupancy of 74%. Acceptable CO_2 levels for this academic environment were exceeded during 73.2% of the week's teaching time (Fig. 2).



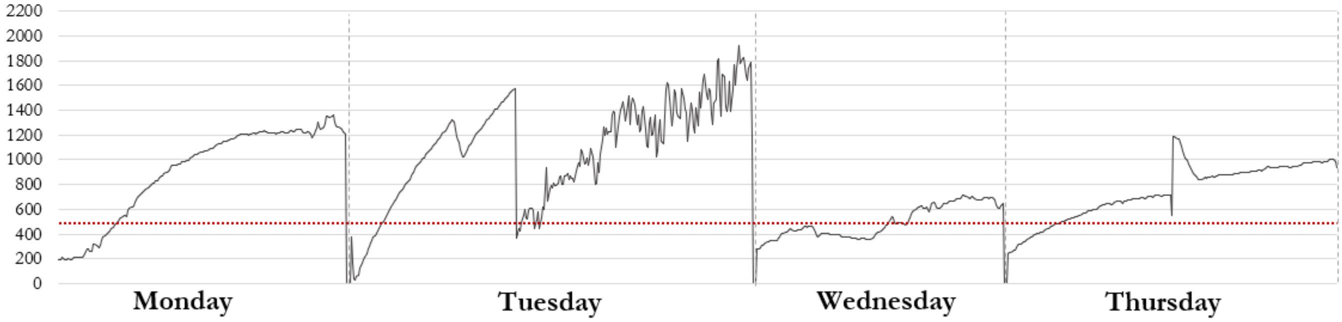


Figure 2 CO_2 measurements (corrected) during the week (a) First year (b) Fifth year.

Regarding the particulate matter of different sizes, no significant values were reached, except for peaks in $PM_{2.5}$ and PM_{10} within acceptable ranges (Fig. 3). Something similar occurs with VOC levels, obtaining average values around 200 ppb, which is non-relevant. The results obtained from the pressurization tests are shown in Table 4.

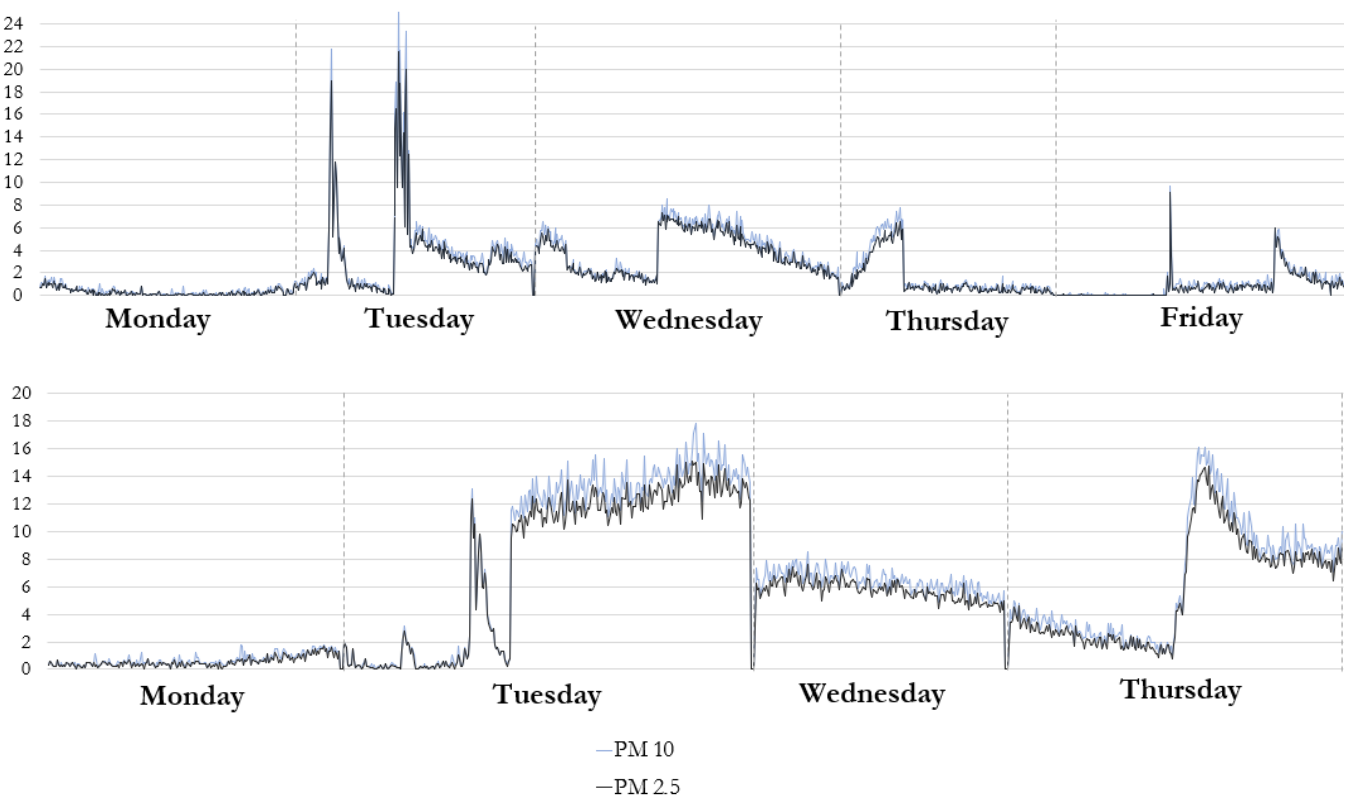


Figure 3 PM_{10} and $PM_{2.5}$ measurements during the week (a) First year (b) Fifth year.

Table 4. Airtightness results

Pressurization test	V_{50} [m³/h]	n_{50} [h⁻¹]	q_{50} [m³/m²·h]	n [-]
Single unit	8724	18.5	19.9	0.5
Guard-zone (upper room)	8468	18.0	19.4	0.5
Guard-zone (lower room)	8417	17.9	19.2	0.5
Internal leakages deducted	8161	17.3	18.7	-

The air change rate of the classroom at 50 Pa (n_{50}), excluding internal leakages, was 17.3 h^{-1} and the air permeability rate (q_{50}) was 18.7 $m^3/h·m^2$. The pressure exponent n shows that the flow regime is turbulent and leakage paths are expected to be large. Only 6.5% of the leakages can be considered to be internal, through classrooms. Air leakage paths detected with thermal imaging were mostly located around the window area and at the bottom of the door. The calculated air leakage rate (V_{inf}) was 555.2 m^3/h, the air change rate (ACH) was 1.2 and the air permeability rate (q_{inf}) was 1.3 $m^3/m^2·h$.

DISCUSSION

The data obtained show that the IAQ in the classrooms under study is undoubtedly characterized by high concentrations of CO_2, both in the case of classrooms that have only a natural ventilation system and those that have a natural ventilation system with air recirculation.

During the first minutes of the class, CO_2 concentration has an exponential increase, due to the entry of the students and the effect caused by the air recirculation system. Subsequently, a linear increase was observed since the beginning of the class and a small decrease was registered during the change of class when the doors to the circulation areas remain open. The increase in CO_2 concentration continues until the 30-minute break, where the classroom doors remain open again. The steepest decrease of CO_2 concentration occurs during the first 10 minutes, both when doors to the hall or windows are opened. From this point, the concentration stabilizes. Once the day is over, the classrooms recover low CO_2 levels, so that the following day begins with acceptable concentration. Therefore, there is no fatigue effect during the week (Fig. 2). The upward jump in the CO_2 levels in the fifth-year classroom during the second hour of Thursday was due to the fact that the classroom was occupied during the previous hour, and the break time did not allow the CO_2 concentration recovery.

There are only two cases in which CO_2 concentration is below the accepted limits for IDA 2: the first hour on Thursday in the first-year group and on Wednesday in the fifth-year group. The first scenario was due to two factors: the short duration of the class and the low occupancy. In the second case, the low occupancy and a short break can explain the steep trend of CO_2 concentration. Thus, the corrected CO_2 concentration barely exceeded 600 ppm.

On the other hand, the results obtained in the pressurization tests show that the envelope is not airtight, which generates an involuntary air leakage rate (V_{inf}) of 555.2 m^3/h, which means almost 15% of the ventilation airflow required in regulations for this kind of environment (Reglamento de Instalaciones Térmicas En Los Edificios, 2013). Real ventilation airflows considering the opening of doors and windows could not be calculated, given that its performance can be unpredictable. However, windows are expected to be closed during the cold season, and doors usually remain open only during breaks, which means that ventilation airflows are far from optimum values.

CONCLUSION

The IAQ to which a sample of university students was exposed during the cold season in two buildings with a natural ventilation system has been assessed. Although PM and VOC levels are within acceptable ranges, the CO_2 concentration during the period under study is alarming.

CO_2 levels were exceeded during more than 70% of the time that the students spent in the classroom, taking the values established by the Spanish standard for educational indoor environments as a reference. It has been discarded that the excess CO_2 was due to overcrowding since maximum occupancy levels were only reached in one of the classes. In almost all cases there has been an average occupation of 39%. Therefore, it seems clear that the high concentration of CO_2 can be due to insufficient classroom ventilation. It is expected that the CO_2 concentration would be much higher if the classrooms were fully occupied. It is undeniable that it is necessary to correct the high levels of CO_2 concentration registered and to maintain adequate relative humidity levels within the classrooms of the centre that guarantee the health and academic performance of the students. Since the air renewal by opening doors and windows and air infiltration is insufficient during the cold season, the solution to this problem should be directed towards the implementation of a ventilation system that allowed maintaining adequate IAQ and hygrothermal comfort in the classrooms. Besides, it would be advisable to improve the airtightness of the thermal envelope, which would allow the proper operation of the ventilation system and the reduction of energy loss caused by air infiltration.

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