

Characterization of indoor air quality in Mediterranean schools for natural ventilation designs.

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ABSTRACT

Indoor air quality in schools has a direct impact in the performance and wellbeing of students. Aiming to identify sustainable and affordable design solutions for new school buildings and retrofitting processes, this paper analyses a representative sample of primary and secondary schools in Mediterranean climate. They were selected to have a representative variety of ages, daily scholar schedules and building designs. The monitoring campaign was developed in the spring season, with moderate external temperatures, in order to identify air renovation requirements related to the analysed elements. The study focuses on the analysis of indoor CO₂, PM₁₀, PM_{2.5} concentration profiles and their relationship with indoor temperature, relative humidity, occupation rates and ventilation measures. The results show a wide dispersion in CO₂ concentrations, ranging between 400 and 5000 ppm, and particulate matter fractions, ranging between 1.3 and 11.8 µg/m³ for PM_{2.5} and 2.2 and 27.1 µg/m³ for PM₁₀. These variations are related to the occupation rates, metabolism of occupants, with peaks before break periods, and ventilation actions. Concentrations are also compared to external conditions, in all cases with higher indoor levels than outdoor. The analysis shows that, for the representative sample under analysis, with adequate natural ventilation designs, indoor air quality can be maintained within comfort conditions.

KEYWORDS

Indoor Air Quality; School buildings; natural ventilation; CO₂ concentration; Particulate matter;

LIST OF ABBREVIATIONS

IAQ	Indoor Air Quality
HVAC	Heating Ventilation Air-Conditioning
MVS	Mechanical Ventilation System
NVS	Natural Ventilation System

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NV	Natural Ventilation
CO ₂	Carbon dioxide
IEQ	Indoor Environmental Quality
SBS	Sick Building Syndrome
WHO	world health organization
NZEB	Nearly Zero Energy Buildings
PM _{2.5}	Particulate matter particulate matter 2.5 micrometers or less in diameter
PM ₁₀	Particulate matter 10 micrometers or less in diameter
ppm	parts per million
UK	United Kingdom
ZEB	Zero Energy Buildings

1. INTRODUCTION

Building ventilation is mandatory for living indoor quality [1]. In schools, students and teachers spent most of the scholar schedule day in closed classrooms. An adequate Indoor Air Quality (IAQ) is required to ensure their best performance and wellbeing as classrooms are spaces with high density of occupation [2]. Barrett et al [3], in United Kingdom (UK), identified seven key design parameters which explain the academic progress of students. Three of them, light, temperature and ventilation, are directly related to IAQ and building design.

Several research works suggest that poor indoor air quality (IAQ) produces respiratory and other health-related effects. The results presented within the SEARCH project [4] show the relationship between poor ventilation and respiratory symptoms in children, emphasising the importance of ventilation in classrooms by renovation the indoor air.

The World Health Organization (WHO) identifies ventilation as the last resort for exposure control indoors [5]. Source control is recognized as the priority strategy to control exposure in addition to aspects related to building: i) location; ii) design and materials; iii) and the management, use and maintenance.

The study of the IAQ pollutants in school buildings has been studied in the Sinphonie project [6], that shows a complex framework of pollutants with different origins, nature and sources (combustion processes, building materials or components and consumer products). Other publications identify the CO₂ level as the main indicator of the IAQ, as Clements-Croome et al [7] and Almeida et al [8]. WHO identified CO₂ average concentrations levels along the occupation period acceptable in the range from 1000 to 1500 ppm, when all the pollution sources are controlled [5]. Few studies address epidemiological associations between exposure to PM₁₀ in school and the health impacts of PM_{2.5} and PM₁₀ [9].

The effects of low ventilation rates in schools have been studied in different countries. Kalimeri et al [10] described low ventilation rates in classrooms of schools in Greece. Jovanovic et al determined the relationship between indoor and outdoor air pollution [11] in five classrooms in Serbia. In [12] were shown low ventilation rates in classrooms in USA. Clements-Croome et al studied the relationship between ventilation rates and learning [7] in classrooms with high occupancy density in (1.8–2.4m²/person). They analysed the effect of IAQ and ventilation rates on the performance and health of students using tests with the aim to recommend suitable ventilation rates for classrooms. They analysed 20 primary schools in the Reading area (UK) suggesting existing levels of CO₂ above 4000 ppm in classrooms with poor IAQ. Toftum et al [13] studied in Danish schools the relationship between the ventilation mode and academic outcomes. Better academic results were obtained in schools with balanced mechanical ventilation than in schools with natural ventilation where air renovation took place mostly by manual window opening. Rufo et al identified low ventilation rates in Portugal [14] mainly due to inadequate airing habits and procedures.

IAQ is directly linked with ventilation strategies and they are key design criteria for the buildings and its future energy consumption. The Building Bulletin 101 (2016) [15] of the Department for Education of United Kingdom Government, shows how different ventilation strategies can be used to provide an adequate IAQ in school buildings.

While WHO report [5] exposes that designing sustainable schools buildings is the main requisite for a sustainable school environment and that this can be achieved combining advances in architecture and engineering with traditional climate-specific approaches and regional/local cultural values, SINPHONIE report [6] exposes that the influence of architectural models and practices imported from other regions, are not always appropriately integrated in such a way as to make them coherent with local values and practice.

Although there are studies identifying mechanical ventilation systems (MVS) as more adequate to guarantee IAQ levels in schools, and even there are technical regulations promoting them [16], other documented experiences, show that these mechanical systems carry operating problems. Wargocki and Wyon studied in northern climate a mechanical ventilation system [17] which showed an inadequate IAQ due to its operation for energy conservation. Besides, other studies in milder climate as developed by Almeida et al [8] showed that in retrofitted buildings with mechanical ventilation systems they were not used because operational issues.

Novel natural ventilation opportunities are identified as promising solutions to improve the ventilation rates as a way to reduce the energy consumption in buildings, taking advantage of Mediterranean climate's conditions and according with Carvalho et al (27) study in Portugal. The specific conditions of the school buildings design in Mediterranean climate are described by Gil- Báez et al [18] (wide practicable windows, cross ventilation to corridors opportunities, etc). In mild climate, using these characteristics for ventilation supposes is an interesting option [19], but this must be present in the first design stages of the buildings, with an adequate evaluation of wind main directions, facades orientation, etc. In the other hand, other works show that it is possible to obtain similar ventilation levels to those provided by mechanical ventilation systems (MVS) with natural ventilation systems (NVS) and an adequate design of the building. Gao et al exposed in [20] the possibility of improving ventilation rates using automatic windows instead of manually operated. This solution is also proposed in SEARCH project [21]. Stazi et al studied the same solution in Italy [22]. This solution is in accordance with the current European regulations on energy efficiency in buildings which propose the reduction in energy demand considering local climatic conditions (European Directive 2010/31/EU [23].)

This paper shows the results of air quality monitoring campaign carried out in 9 schools located in the south of the Iberian Peninsula area. This campaign was done within the Interreg SUDOE ClimACT project (Transition to a low carbon economy in schools) [24], which is developed as a decision support tool that will assess and identify sustainable solutions for school buildings design. From one side studies identify Heating Ventilation and Air Conditioning (HVAC) systems as the main energy consumers in buildings, accounting for 60–70% of total energy use in non-industrial buildings [25], and from the another side, ventilation is necessary for an adequate IAQ in schools. Considering this issue, searching low carbon footprint solutions demands an adequate identification of IAQ situation in the schools under this climate and conditions. This has been the departure point in order to analyse Mediterranean school buildings situation and the carbon footprint reduction opportunities regarding with the ventilation strategy, due to the lack of data in Mediterranean zone.

A set of primary and secondary schools was taken as a representative sample of the schools at the South of Spain, with a selected variety of ages, daily scholar schedules and building designs. The monitoring campaign was developed in the spring season, with moderate external temperatures, which allow comfort conditions with air renovation most part of the day. The selected schools were ventilated with windows operated manually for airing the classrooms. There was mechanical ventilation only in one building which never was used due to high electric power consumption and because besides that the staff considered its operation not necessary. Main data analysed is CO₂ level as main IAQ indicator in classrooms naturally ventilated. In addition, PM 2.5 and PM 10 have been studied. The objective is to identify the existing IAQ levels and their relationship with building location and design.

The results show a wide dispersion in CO₂ concentrations, with peak variations between 400 and 5000 ppm, and particulate matter fractions, with peaks variations between 1.3 and 11.8 µg/m³ for PM 2.5 and 2.2 and 27.1 µg/m³ for PM10. These variations are identified with the occupation rates, metabolism of occupants, with peaks before break periods, and ventilation

actions. They are also related to particles, in all cases with higher indoor levels than outdoor levels. These data show that, for the representative sample under analysis, with adequate natural ventilation designs, Indoor Air Quality can be maintained under comfort conditions for the mild temperatures of this Mediterranean climate. They contribute to the definition of the framework for development of Natural Ventilation Systems under the specific climate, constructive and use characteristics of Mediterranean Schools.

This paper is structured as follows. First, the study framework, the geographical context, climate conditions and locations are presented. Then, the methodology applied for the definition of the campaign measure is described. In the fourth section the main results of the measurement campaign are presented and discussed. Finally, main conclusions are presented.

2. MATERIALS AND METHODS

This section shows the material and methods used in the air quality monitoring campaign carried out in 9 schools located at the South of Spain. They were chosen as representative of the building stock in terms of typology, techniques and year of construction.

Within these schools, to maximize the extracted information from the IAQ measurement campaign, classrooms with different characteristics were selected in function of their location in the building, orientation, age of students and daily schedule. On this purpose, measurements were developed simultaneously in two classrooms in each building, along two days per school. Continuous monitoring of temperature, humidity, CO₂, and particles was performed. Before and after the daily lessons, outdoor measures were taken to set the reference points.

2.1 Equipment

The main characteristics of the measurement equipment are shown in Table 1:

Table 1. Measurement Equipment Characteristics

Equipment	Used logging interval	Duration	Variables	Limit measurement range	Accuracy
Delta OHM HD 21ABE17	2 minutes	2 days (continuous monitoring)	CO ₂ Carbon Dioxide (ppm)	0...5000 ppm	±50ppm
			CO Carbon Monoxide (ppm)	0...500 ppm	±3ppm
			Atmospheric Pressure (Pa)	750...1100 hPa	±1.5 hPa at 25°C
			Relative humidity (%)	0...100 % RH	±2% RH
Optical Particle Sizer OPS 3330	2 minutes	2 days (continuous monitoring)	Temperature (°C)	-20...+60 °C	±0.2 °C
			Number and size of particles (in 10 slot ranges)	0.3 – 10 µm	5%, 0.5 µm (ISO 21501-1)

2.1.1 Outdoor measures

At the beginning and at the end of the daily lessons, outdoor measures were carried out to set references for magnitudes. Monitoring devices were located in a representative position at the door of the school building (Figure 2, left).

2.1.2 Indoor measures

Monitoring equipment was placed inside the classrooms near occupants' breathing zone (approximately 1 m above the floor). Also, they were located no closer than 2 m to any wall, window, door or active heating system (Figure 2, right). The monitoring process was supervised by a researcher who recorded information regarding classroom occupancy, ventilation and occupant behaviour and activities. Along the lessons, students in the classroom were assigned to compile any change along the lessons regarding activities, occupation, windows and door openings or any other issue that could affect to the concentrations.



Fig. 2. a) Outdoor measures equipment location (left), b) Indoor measures equipment (right)

2.2 Geographical context

The schools under study are located in Andalusia, within the Mediterranean zone, at the South of Spain, Figure 3a. The distribution of the annual average maximum temperatures in Spain and Portugal is given in Figure 3b

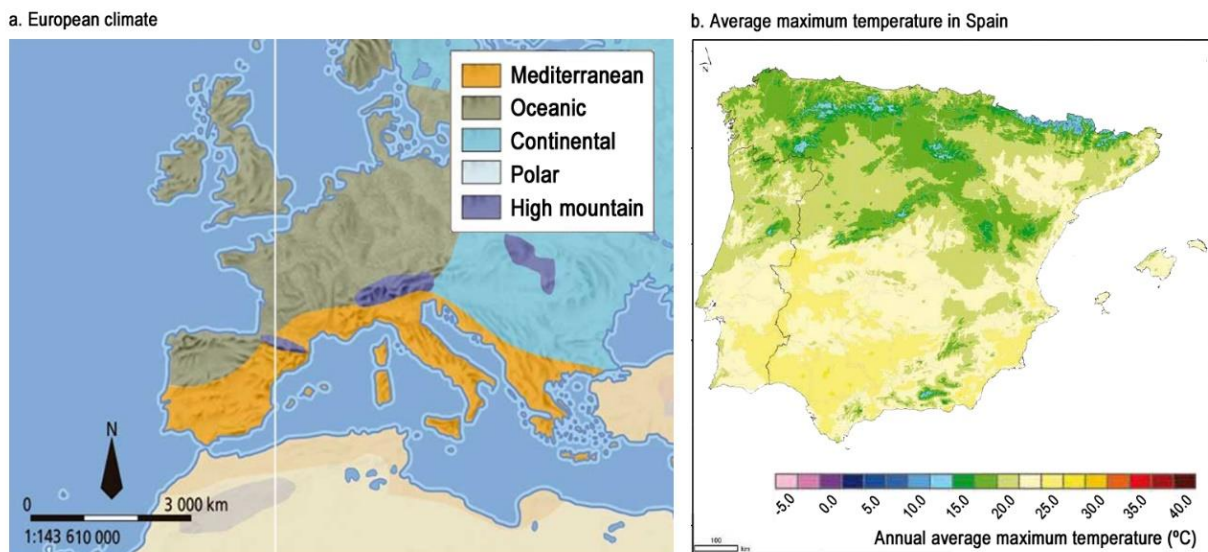


Fig. 3. a) left: European climate; b) right: Annual average maximum temperature (Iberian Climate Atlas)

The Mediterranean climate, characteristic of most of the Mediterranean region, it's characterized by dry and hot summers and winters with mild temperatures and erratic rainfalls. The feature that best identifies the Andalusian climate is a high number of sun hours per year (> 2800 h/year). Figure 12b, highlights the differences between different locations in Spain, and the different climate conditions as function of the different zones. In this study, all the selected schools are placed within Mediterranean climate areas.

2.3 Buildings use. Schools schedule

The academic year has between 175 and 178 days depending on the academic level and it is developed from mid-September to mid-June, with summer holidays from mid-June to mid-September. In Primary Schools, lessons are developed in the period from 9:00 to 14:00 hours and in Secondary Schools, the lessons are given from 8:00 to 15:00. Some extracurricular activities (mainly sports but also music, arts, languages) are developed depending on the school from 16:00 to 18:00 in the period from October to May. Each group of students usually spend most of their time in one classroom, with a short break each hour to change the activity. Besides, depending on the school, students sometimes go to another specific classroom to learn music, arts, or sports. Additionally, there is half an hour break in the middle of the day. The maximum number of students in primary and secondary classrooms is 25, meanwhile for bachelor is 30 and in other educational itineraries, as professional training, up to 35 students can be found.

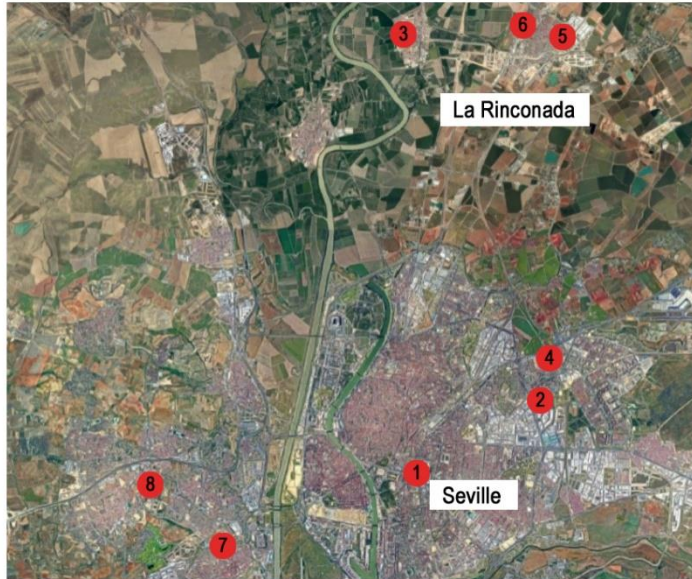
2.4 Schools location

The school buildings under study are located at the South of Spain. They are selected as representative of Mediterranean mild climate schools. The first two criteria for the selection were the location and accessibility. There are two main locations, the first one in the metropolitan area of Seville (Figure 4a) and the second one in a mountainous area in Málaga (Figure 4b). In the first location, typical urban, suburban and rural landscapes are represented (Figure 4a). In the second location, a mountain urban situation is represented (Figure 4b). In Table 2, the six different urban sites are classified.

Table 2. Locations characteristics

School	Urban City centre	Urban Outskirts	Suburban metropolitan area	Rural urban centre	Rural countryside	Mountain area
1	X					
2		X				
3				X		
4		X				
5				X		
6					X	
7			X			
8			X			
9						X

a. Location 1. Seville metropolitan area



b. Location 2. Ronda



Fig.4. Location of schools

2.5 Buildings characteristics

In Andalusia there are more than 4,500 schools with more than 5,000 buildings. The selected buildings for this campaign were considered as a representative sample the diversity of the Andalusian school buildings, regarding educational stages, activities performed, built area, as well as in materials and construction techniques used. A short summary of differences between materials and constructive elements in this set of buildings is presented in Table 3.

Table 3. Buildings characteristics and location

School	1	2	3	4	5	6	7	8	9
Sunblind	SS	SS	SS	SS	RS	RS	SS	RS	RS
Floor	TT	TT	PVC	TT	TT/PP	TT	TT	TT	TT
Walls paint	PP	PP	PP	PP	PP	PP	PP	PP	PP
Ceiling	NSC	SC	SC	NSC	NSC	NSC	NSC	NSC	NSC

SS Slats sunblind; RS Roller sunblind; TT “Terrazo” (artificial stone) tiles; PVC Polyvinyl chloride plastic tiles; PP Plastic Paint; NSC Non-suspended ceiling; SC Suspended ceiling

The materials used in these buildings are mainly non emissive. Only in one of them the floor was polyvinyl. The buildings are provided with sun blinds: orientable slats sunblinds or roller sunblinds and manually openable windows to guarantee classrooms airing. Ventilation strategy is single side in all the cases, and cross ventilation to the internal corridor is available in some of them. In Figures 5 and 6 are shown pictures of the buildings and in Table 4 their main characteristics are summarized:

Table 4
Buildings characteristics and location

Location	Building data	Pupils data
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	Gross surface (m ²)	N° floors	Construction year	Level ¹	N° pupils
School 1	1985	3	1986	Secondary	759
School 2	5189	3	2013	Secondary	950
School 3	750	1	2013	Preschool & Primary	160
School 4	1150	3	1979	Preschool & Primary	672
School 5	2680	2	2003	Preschool & Primary	372
School 6	2540	2	1973	Preschool & Primary	706
School 7	1292	2	2008	Secondary	486
School 8	3800	2	1999	Secondary & High School	801
School 9	13104	3	1979/1982	Secondary & High School& Prof. training	1050

¹ Spanish degrees of education: Preschool (3-6 years old); Primary (6-12 years old); Secondary (12-16 years old); High school (17-18); Professional training (>18)

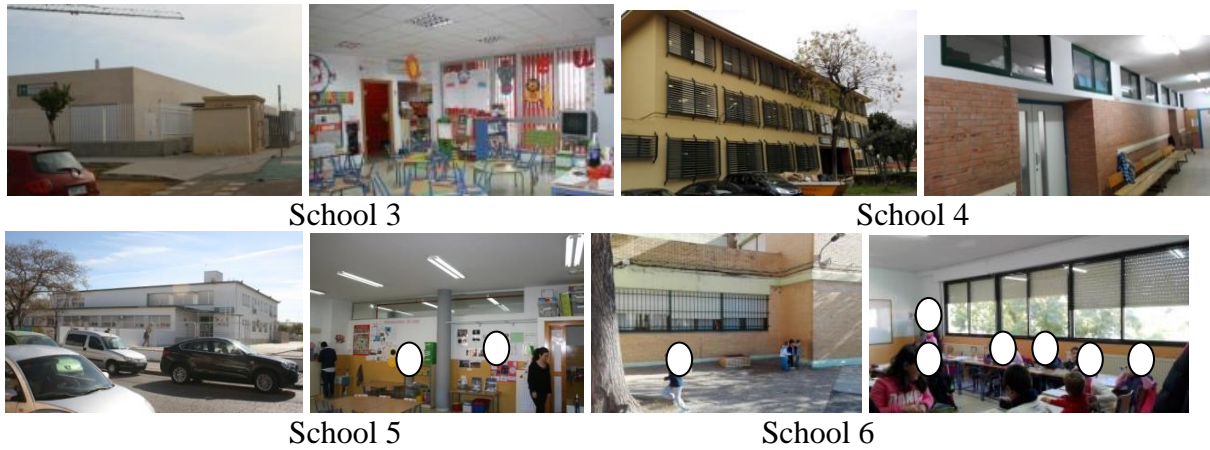


Fig. 5. Preschool and primary school buildings



Fig.6. Secondary school buildings

3. RESULTS

In this section are presented the main results obtained in the test campaign in nine representative school buildings in Andalusia

3.1 Outdoor measures

In Table 8 are presented the outdoor CO₂ and temperature mean values measured in an interval at the beginning and at the final of the two days measurement campaign in the surroundings of the preschool and primary schools:

Table 8

Outdoor measures in preschool and primary schools

Data	Initial (8:00 h)				Final (15:30 h)			
	School 3	School 4	School 5	School 6	School 3	School 4	School 5	School 6
CO ₂ (ppm)	512	503	456	488	414	462	432	447
Temperature (°C)	10.4	14.	9.9	8.1	23.8	22.7	18.4	16.7
RH (%)	84.1	62.8	72.8	67.3	30.8	43.8	38.4	33.4

In Table 8 data can be appreciated that:

- Temperatures are around 10°C at 8:00 (beginning of the lessons) and 20°C at 15:30 (finish of the lessons)
- CO₂ concentrations in the surroundings of the set of schools are around 450-500 ppm
- Humidity evolution along the day, is higher in the morning than in the afternoon (70% average vs 40%)

In Table 9 are presented the mean outdoor data obtained at the surroundings of the secondary school buildings, with different daily schedule and timing.

Table 9

Outdoor measures results in secondary schools

Data	Initial (8:00 h)					Final (15:30 h)				
	School 1	School 2	School 7	School 8	School 9	School 1	School 2	School 7	School 8	School 9
CO ₂ (ppm)	443	456	459	471	476	407	437	461	415	423
Temperature (°C)	13.6	10	11.1	11.7	9.1	28.4	13.8	21.3	25	22
RH (%)	68.4	53.6	94	82.6	59.2	25.8	81.5	53.1	42	20.7

Outdoor results obtained in secondary schools locations are similar to those obtained for preschool and primary schools.

3.2 Indoor CO₂, temperature and humidity levels

In Figures 17, 18 and 19 the results obtained from the indoor campaign are represented. They show the evolution of CO₂, temperature and humidity along the two days. Occupied and unoccupied periods are included in the figures to analyse the concentration evolution with the use and building operation.

The evolutions of indoor CO₂, temperature and relative humidity levels in the two classrooms of secondary School 1 are shown in Figure 17.

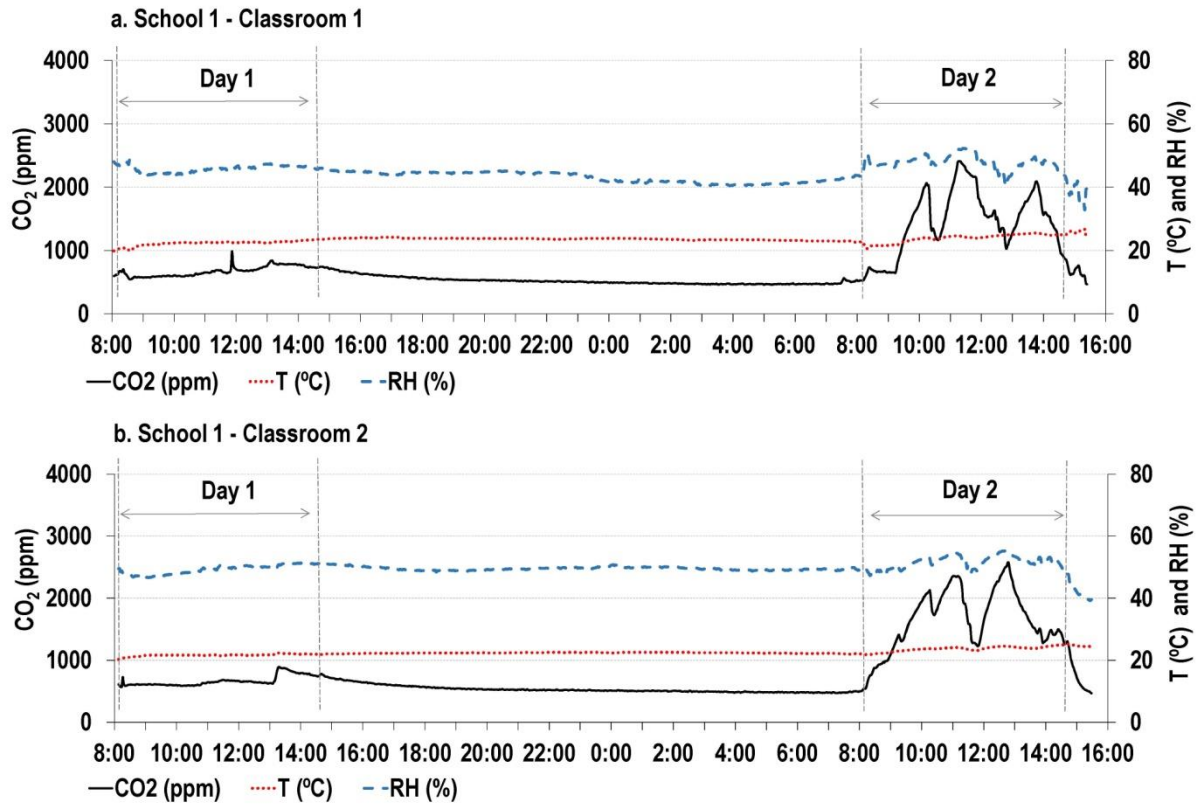


Fig. 17. Secondary level School 1. CO₂, temperature and humidity indoor levels evolution

In School 1 the lessons started at 8:15 and they finished at 14:45. The first day of the measurement campaign there weren't any lessons and the results allow to identify the maintenance of the levels and the effect of occupancy when cleaning tasks or discontinuous occupation appears. As it is clearly shown in figure 17, CO₂ levels and humidity increase with the occupation. Nevertheless, the indoor air temperature doesn't vary substantially.

In Figure 18 the evolutions of CO₂, temperature and relative humidity levels in the preschool and primary schools are represented.

Results for Secondary and Primary schools are presented in two different groups because of their schedule, activities and students' age, both of them linked to metabolism and CO₂ emission levels.

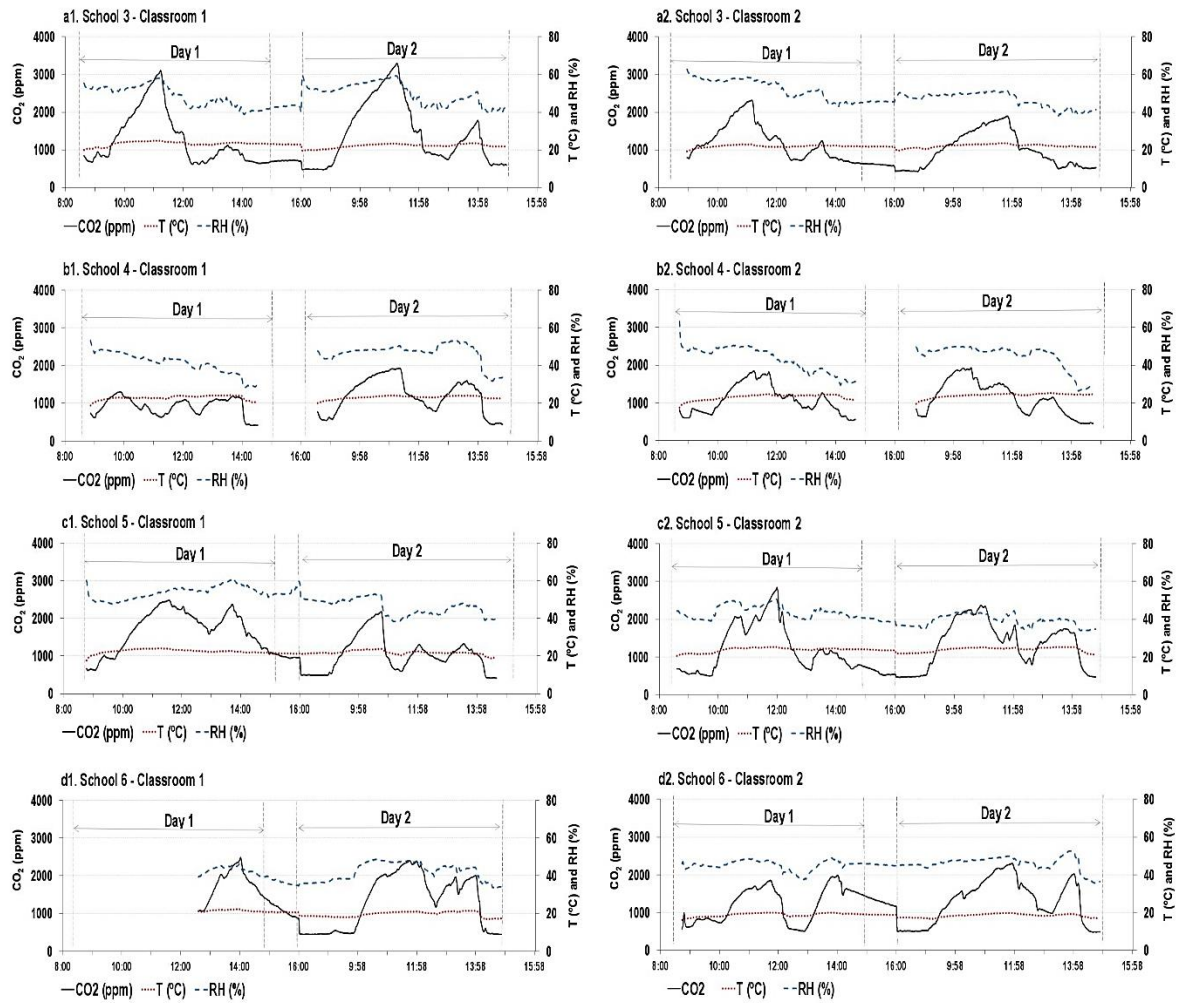


Fig. 18. Preschool and Primary schools results: CO₂, temperature and humidity indoor levels evolution

These results presented in Figure 18 are similar to the results obtained in Figure 17, being CO₂ levels between 500 ppm and 2500 ppm, relative humidity between 30% and 60% and air temperature around 20°C-25°C due to the heating system operation in the first hours in the morning.

Through the analysis of CO₂ levels is possible to identify classroom occupation. Thereby, in School 3, in day 1, there have been some activity either extracurricular or cleaning, etc... until 19:00. In addition, when the classroom is not occupied, CO₂ levels turn to the outdoor levels quickly with an adequate ventilation action, as is possible to appreciate in the graphics represented in Figure 18.

In Figure 19 are presented the evolutions of CO₂, temperature and relative humidity levels in secondary schools. Results are similar to the results obtained in Figure 18, being CO₂ levels between 500 ppm and 2500 ppm, relative humidity between 30% and 60% and air temperature around 20°C-25°C due to the heating system operation in the first hours in the morning.

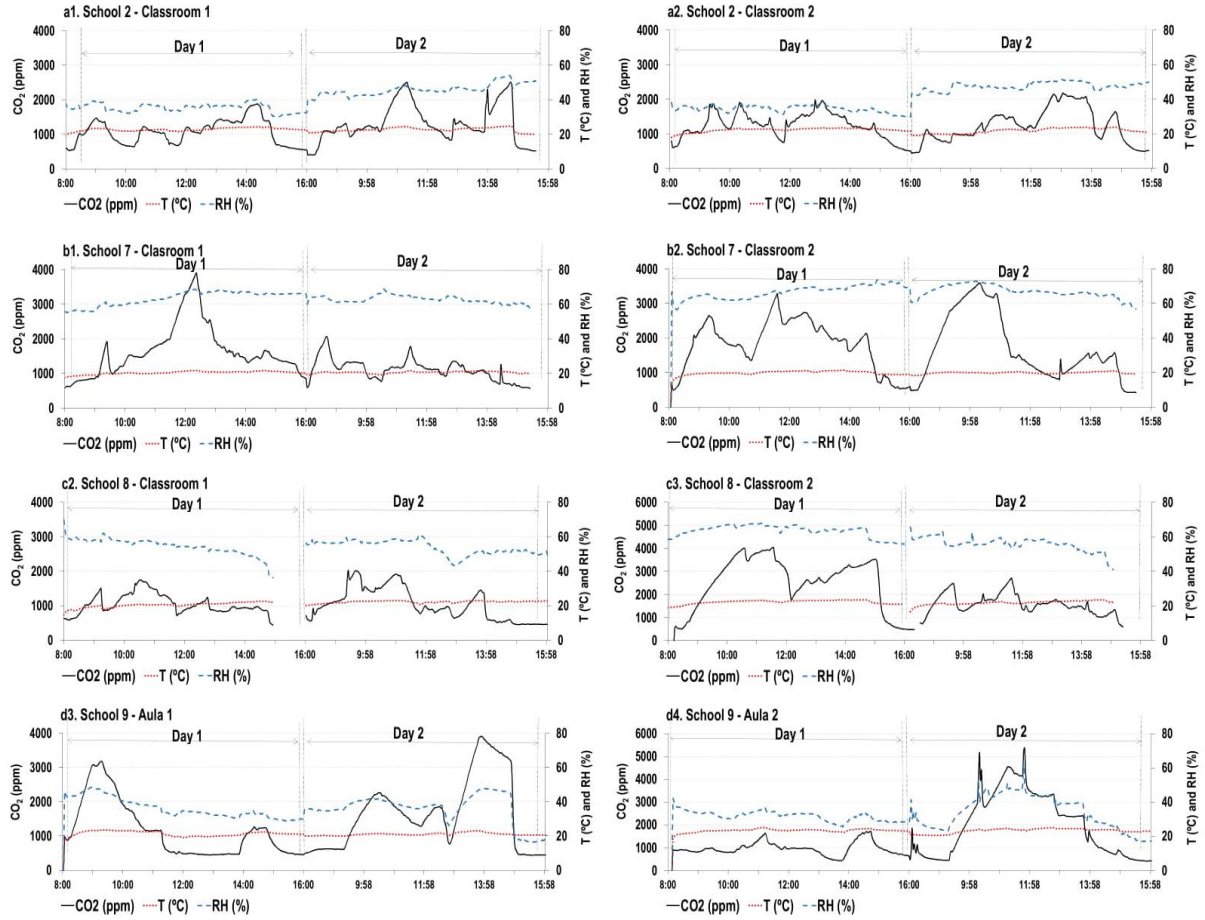


Fig. 19. Secondary schools results: CO₂, temperature and humidity indoor levels evolution

Results in Figure 19 are similar to those obtained in the primary schools in Figure 18. Main differences for secondary schools are the maximum CO₂ levels, reaching higher values at peaks, up to 4000 ppm, these levels are linked to students age. Relative humidity is similar, between 30% and 60% and indoor air temperature is maintained along the whole period in the comfort range, with values between 20°C and 25°C. Heating system operates to set temperature only in the first hours in the morning.

The obtained results, as expected, are quite different to those presented in other research works developed in colder climates, with buildings with high level of air-tightness and no occupants' habits regarding with airing the classrooms. For example, Clements-Crome suggested an usual level of 4000 ppm in UK schools [7]. In addition, WHO schools survey report [5] considered a CO₂ concentration level evolution represented in Figure 20 as representative of bad IAQ level.

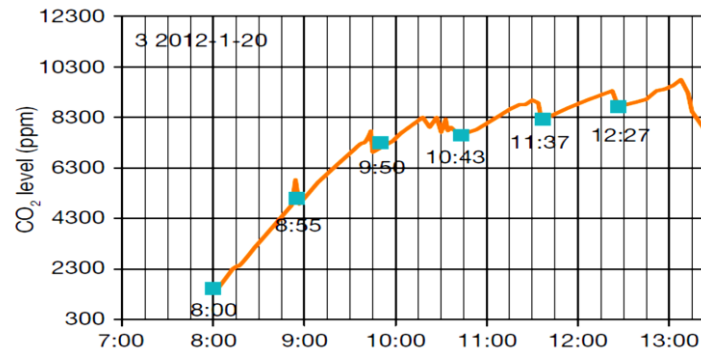


Fig. 20. Example of CO₂ accumulation in a classroom with poor ventilation (WHO Schools survey publication [5])

In the results of the experimental campaign presented in Figures 17, 18 and 19 there are some peaks around 2000-3000 ppm, but they are scarce and not continue, and they are related to specific events and not maintained along long periods. Therefore from these experimental data do not show coincidences with the UK studies evidences (4000 ppm) [7]. In Table 10 the concentration limits under different technical regulations are identified.

Table 10

Air pollutants concentration limits under technical regulations

Air pollutants concentration	Unit	Guideline	Exposure time and observation	Reference
CO ₂ *	ppm	<1000	Tolerance up to 1300	French school regulation [26]
	ppm	<1500	Mean concentration during occupied period.	UK's school regulation 2006 [27]
	ppm	<1000	Mean concentration during occupied period. Tolerance up to 1500 along 20 minutes.	UK's school regulation 2016 [28]
Particulate matter fractions				
PM 10	µg/m ³	<20 a	Annual mean	WHO [29]
		<50	24-hour mean	
PM 2.5	µg/m ³	<10 a	Annual mean	WHO [29]
		<25	24-hour mean	

* There isn't any specific regulation in Spain which indicates maximum CO₂ level in school buildings with free running or natural ventilation operation.

4. DISCUSSION

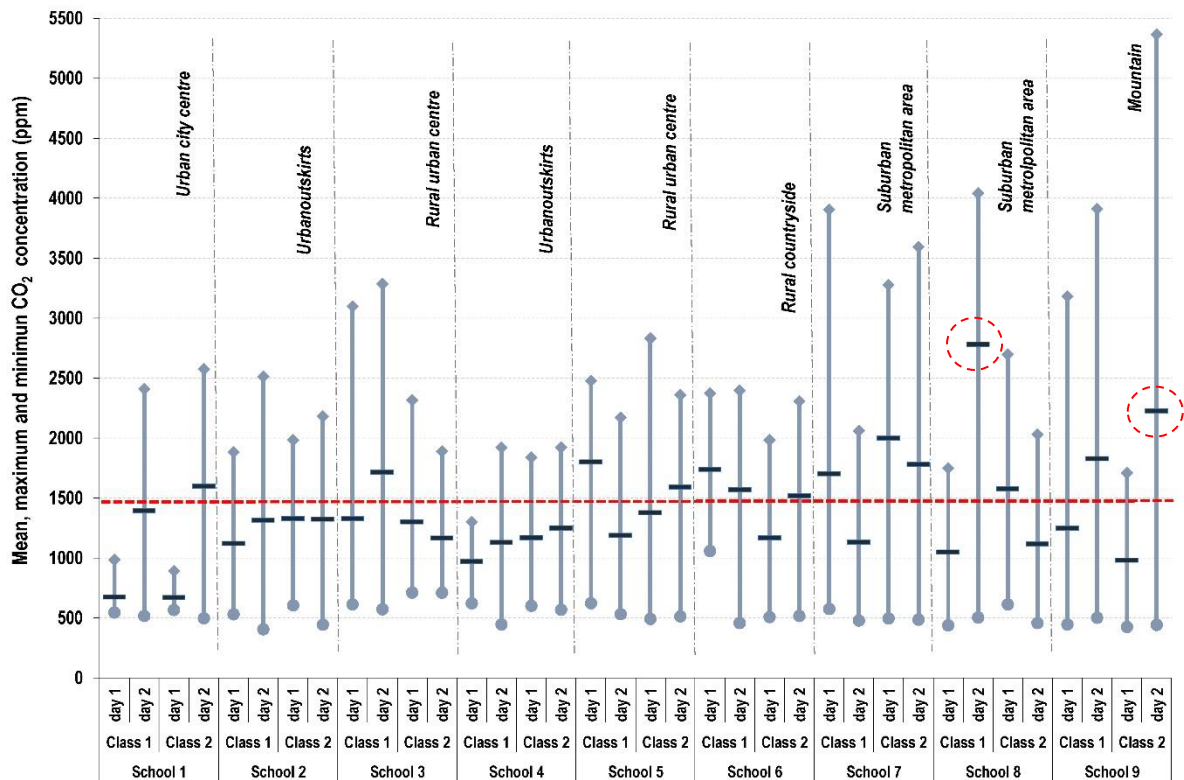
CO₂ is recognised as an appropriate marker of IAQ. The majority of the standards and regulations are still based on this approach and limit values for IAQ levels are directly related to pollution by persons, e.g. in terms of maximum CO₂ levels [1].

The results of the measurement campaign are compared with these technical regulations limits. Mean concentration deviation examples are analyzed in Table 11 and Figure 21.

The daily CO₂ mean concentration along the daily period of occupation in classrooms is represented in Figure 21.

Table 11Mean, maximum and minimum CO₂ concentration data

Measure	Maximum	Minimum	Average	Windows	Sunblind
S1C2d2	2574	497	1599.69	Depend on the hour	Slats/opened
S3C1d2	3284	572	1715.52		Slats/opened
S5C1d1	2476	622	1799.60		Roller closed until 12
S5C2d2	2360	512	1592.31	Only 10 minutes	
S6C1d1	2372	1057	1740.24	Depend on the hour	Roller mid closed
S6C1d2	2396	450	1567.85	2 opened	Roller mid closed
S7C1d1	3904	574	1702.48	Depend	Slats/depend hour
S7C2d1	3278	495	1996.63	Depend	Slats/depend hour
S7C2d2	3594	485	1781.32	Depend	Slats/depend hour
S8C1d2	4042	503	2782.64	Depend	Roller/depend
S8C2d1	2697	612	1575.65	Depend	Roller/depend
S9C1d2	3910	500	1828.10	Depend	Roller/depend
S9C2d2	5366	442	2227.00	Depend	Roller/depend

**Fig. 21.** Mean, maximum and minimum CO₂ concentration during lessons in schools.

From the total 36 days of the experimental campaign, there were 22 days (61.11%) in which mean CO₂ levels during the lessons were in all the period below the 1500 ppm average limit. CO₂ levels are represented for primary schools in Figure 22 and for secondary schools in Figure 23. They show CO₂ levels, number of occupants (right “y” axis) as well as the operation of the windows and openings along the represented period.

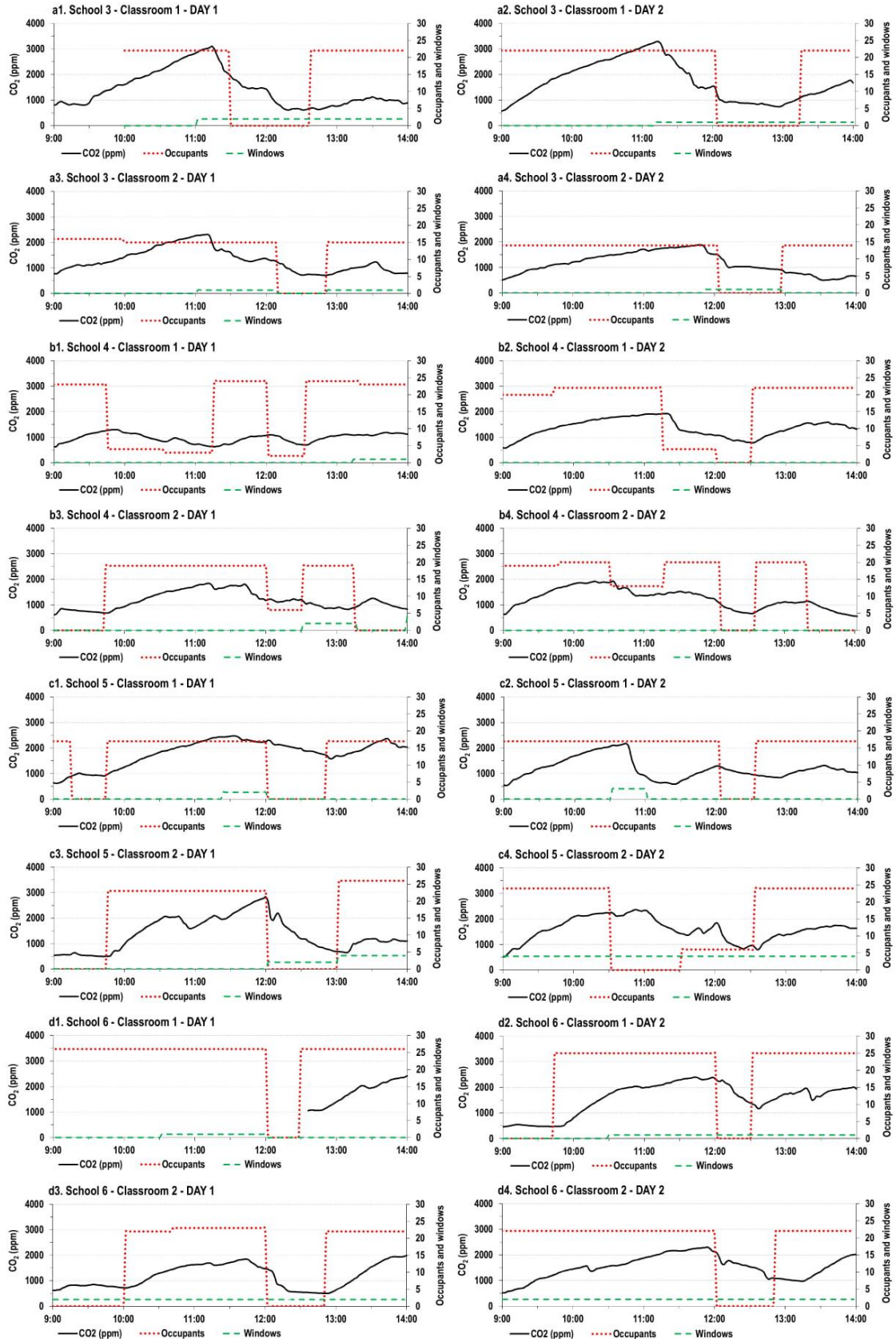


Fig. 22. Relationship between indoor CO₂ level evolution, occupation and airing openings in primary schools

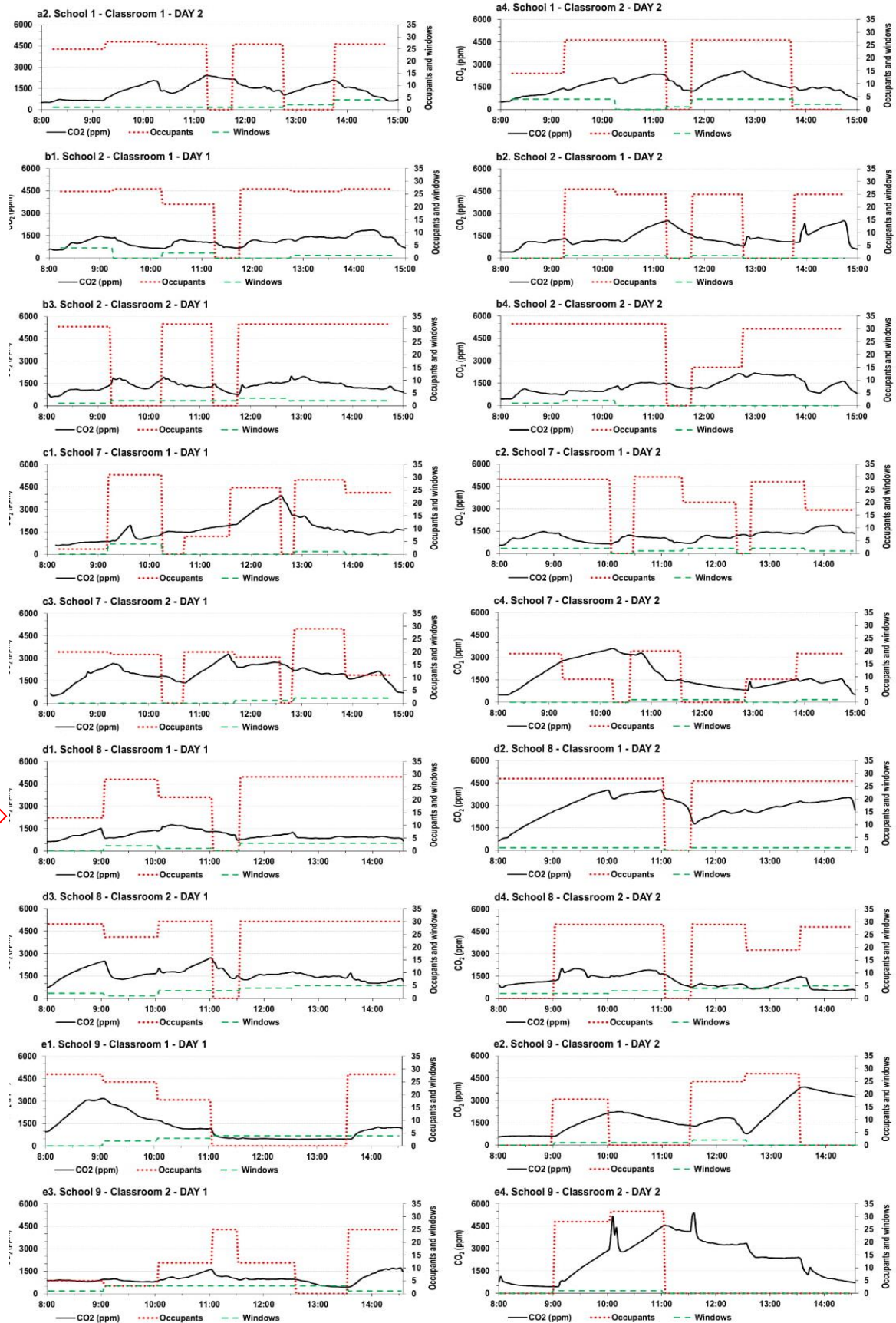


Fig. 23. Relationship between indoor CO₂ level evolution, occupation and airing openings in secondary schools

In the results presented in Figures 22 and 23, the evolutions of CO₂ levels, number of occupants and number of windows opened are represented. Direct relationship between occupation and increase of CO₂ concentration is clearly shown, as well as the effect of manually opening of windows, with the direct sudden effect on CO₂ levels when windows are opened. In all cases, the slope of the line is greater in the decrease than in the increase, so it is possible to observe the fast action of the airing effect and how it can be used for automated control if CO₂ exceeds some levels, i.e: 1000 ppm level.

Besides, there are two classrooms in which the CO₂ levels are not as high as it could be expected with high occupation, (School 4, Figure 22 and School 7, Figure 23). This probably could be due to that there were windows to corridors opened as it is shown (Figure 24), allowing effective cross ventilation.

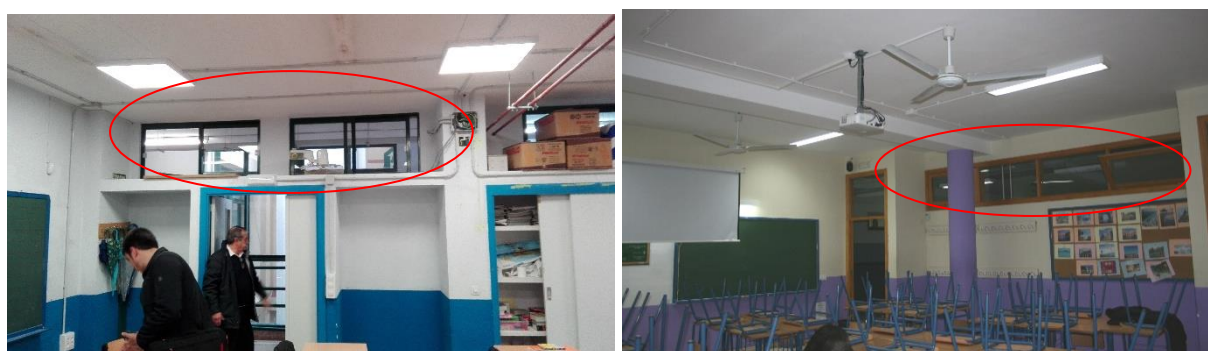


Fig. 24. Windows to corridor opened during measures. Left) School 4; right) School 7

4.1 Particles

The evolution of particles were measured in one classroom of each school in combination with CO₂ evolution analysis, in order to evaluate their evolution along the day as they are also affected by any ventilation strategy to be implemented. Particles sizes were evaluated in ten channels for a different range of particle size. The accumulated values of particulate matters, PM 2.5 and PM 10, are given in Table 11.

Table 11

Particulate matter fractions measurement (indoor and outdoor)

										SecHS	WHO
		*Sec	Sec	PS&P	PS&P	PS&P	PS&P	Sec	Sec&HS	&PT	limit
		School 1	School 2	School 3	School 4	School 5	School 6	School 7	School 8	School 9	(table 7)
PM10	µg/m ³	6.5	27.1	9.0	5.1	6.2	17.0	4.4	5.9	2.2	<50
Out PM10	µg/m ³	2.1	0.7	3.2	4.3	2.0	1.4	1.9	1.5	1.0	
PM _{2.5}	µg/m ³	4.3	11.8	4.0	3.1	2.8	6.0	2.6	3.8	1.3	<25
Out PM _{2.5}	µg/m ³	1.9	0.6	2.7	3.6	1.9	1.1	1.5	1.3	0.7	

*Sec: secondary level, PS&P: Preschool and primary level; HS High school; PT Professional Training

In Table 11 particulate matter levels are compared with WHO recommended levels. The results show that the measured indoor levels are always higher than the outdoor levels. PM 10 and PM 2.5 recommended limits are below 50 µg/m³ and 25 µg/m³ respectively in a 24-hour mean value (Table 9).

All the measures obtained in the classrooms were inferior to the maximum levels recommended considering the data included in Table 9.

Higher indoor levels were measured in School 2. Classroom indoor operation is given in Figure 22, and particles evolution is presented in Figure 25.

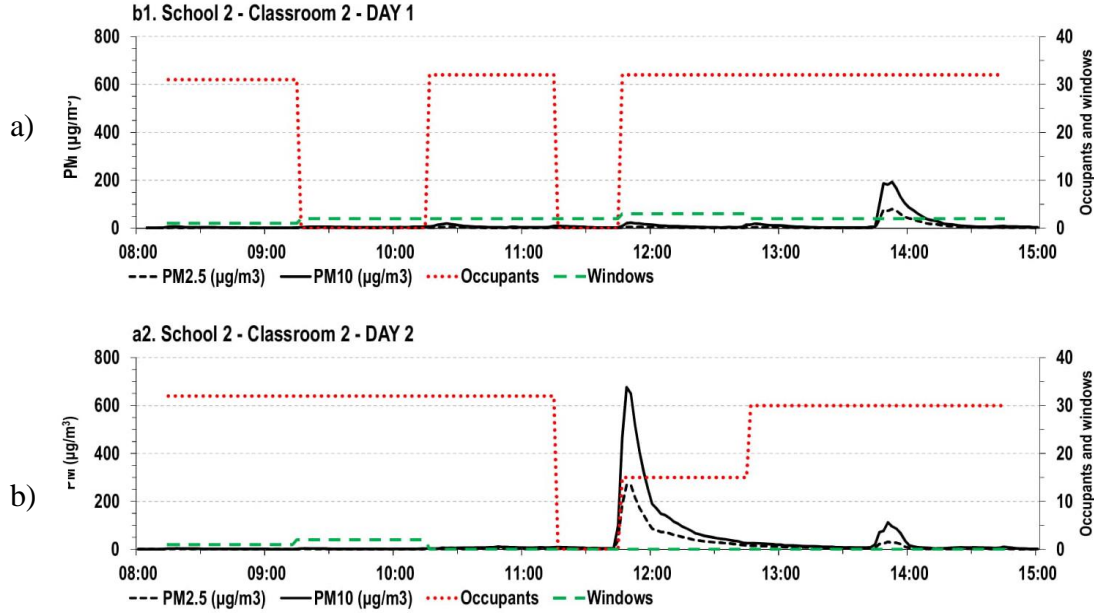


Fig. 25. Indoor particles level evolution in School 2: a) day 1; b) day 2

The relationship between indoor particles level, occupation and open windows in School 2 is represented in Figure 25. Peak values in day1 are obtained with a maximum occupation with 32 students and windows opened. Peak values for measures in day 2 were obtained with 16 students and windows closed. Outdoor levels are the lowest of all the analysed buildings (Table 9). Therefore, particles peak values are related to students' occupation and inlet activity when particles are suspended in the air because of the dust movement. In the second day, is given just after the midday break meanwhile in the first one at the beginning of the maximum occupation period.

These results agree with those obtained by Rufo et al. in Portugal, where by applying SINPHONIE project [30] recommendations obtained improvements in Indoor PM 2.5 and PM10 concentrations with no significant differences regarding outdoor PM concentrations.

With this data and with the focus on the indoor particles level, an adequate indoor particulate matter level is confirmed in the analysed school buildings, so with these levels of particles incoming, air filtration is not required.

5. CONCLUSION

This paper presents the characterization of indoor air quality in Mediterranean schools for natural ventilation designs. Natural ventilation systems (NVS) are of high interest in schools, because their specific characteristics daily and seasonal usage patterns and their high specific occupancy densities. These favourable characteristics for the NVS are reinforced in climates as the Mediterranean, with mild temperatures along the period of use.

The evaluation of classrooms IAQ is required for adequate NV designs. Meanwhile there are data of IAQ of schools in other climates, for the Mediterranean region there is a lack IAQ data in schools. To cover the knowledge gap, the results of the IAQ assessment campaign at the South of Spain are presented. The measurement campaign was designed to have a representative group of Mediterranean climate schools in six different types of locations. Its objective is to evaluate the IAQ situation in these mild climate school buildings in order to identify ventilation requirements and options able to guarantee IAQ standards. As these buildings are naturally ventilated, its operation and IAQ levels are studied from the approach of building design and location. The main conclusions of this work are the following:

- The measured indoor CO₂ levels are not similar to those presented in literature in research developed in colder climates in northern countries publications. This was an expected result. In the schools under analysis there are some peaks around 4000 ppm, but in most of the cases maximum value is around 2000 ppm, being more than 50% of the measures in the daily lessons below 1500 ppm. Comparing with the UK's ventilation regulation for schools, these levels could be in compliance with UK regulations of 2006 for the ventilation of school buildings but they are slightly deviated in comparison with the regulations of 2016.
- The ventilation in the schools studied was obtained by windows manually operated. CO₂ concentrations could be reduced and therefore improved, with automatic operation of the windows and using CO₂ level sensors, decoupling its operation from the action of the occupants. In any case, school staff must follow several ventilation recommendations, by airing the classrooms at least each break between lessons and at the end of the day, following Madureira et al. suggestions [31] after the analysis of 73 classrooms monitored in 20 public primary schools located in Porto. The effect of airing in the monitored classrooms has been shown as very effective with drastic reduction in CO₂ levels in a reduced period.
- The campaign was developed in the spring time, period of interest to analyse the potential for maintaining indoor air comfort conditions only with air renovations. The outdoor temperatures were between 10°C and 25 °C. It implies heating operation in the first hours of the day in some cases. The measures show that indoor temperature is maintained even when the heating system is switched off, mainly due to internal gains provided by the occupation level.
- The measured outdoor CO₂ levels remain in similar levels in all cases (between 450-500 ppm), but higher than those considered in regulations (UNE EN 13779).
- There is not an evidence of correlation between the urban location and indoor or outdoor measures.
- There is a correlation within indoor CO₂ levels, windows or doors openings and the number and age of the occupants. In addition, the ventilation rates are linked with the kind of sunblind: roller blinds or adjustable louvers, obtaining better ventilation rates with the second ones. Besides, there are better results, with lower CO₂ levels, when indoor windows from classrooms to corridor are opened, allowing cross ventilation.
- Regarding indoor particles measures, there is not a correlation between results obtained neither with the outdoor data nor with the indoor occupation level or with the ventilation operation. In any case, these levels seem to be related to particles suspension due to the occupants' activity.

- Considering the above, it is possible to conclude that an adequate indoor particulate matter level is confirmed in school buildings analysed, so the filtration of the incoming air with this purpose is not necessary. Thereby, WHO recommendations must be followed, controlling the sources as the priority strategy to maintain an adequate IAQ in schools.

School buildings' operation is discontinuous and heterogeneous, with frequent changes in the occupation level of the classrooms, of activity, etc... thus, ventilation strategies must allow the adaptation of its operation and the ventilation rates depending on the occupation and the schedule of each classroom.

From these values, NV opportunities are identified as promising solutions to improve the ventilation rates as a way to reduce the energy consumption in buildings, and taking advantage of climatic conditions in the school buildings design in a Mediterranean climate: wide practicable windows, cross ventilation to corridors opportunities, etc.

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Declarations of interest

None

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