Indoor Temperature and CO2 in Educational Buildings during a Pandemic Winter in Spain

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ABSTRACT

Schools had covered special attention in the last year, due to their importance to organize daily work as well as since most of the children were still not vaccinated. Under this circumstance, the importance of air renewal to reduce the probability of COVID-19 contagion inside buildings was highlighted.

In Spain, educational buildings usually lack mechanical ventilation systems, so renovation of air is generated through the direct opening of windows. In such a way that its effectiveness can be analysed under winter conditions by the measurement of indoor CO_2 concentration and temperature. The work presented analyses both parameters: temperature and CO_2 data, monitored in 66 classrooms of 27 educational buildings in different climatic regions in Spain, during the winter of 2020-2021. According to the results, a modification of the thermal comfort conditions was observed with the increase of ventilation rates. The latter caused a decrease of CO_2 concentration and indoor temperatures, but also an increase of the energy demand that heating systems could not meet.

This paper provides an analysis of the data recorded during this difficult period in these classrooms, with the aim of highlighting the need for renovation of these buildings, which have enormous potential for improving their resilience, energy efficiency and indoor environmental quality.

KEYWORDS

Ventilation, carbon dioxide, comfort, COVID-19, schools.

1 INTRODUCTION

The air quality in educational centers is a relevant aspect for the health and learning process of children since it can greatly affect the activities they carry out. This aspect is especially influential in children aged between 7 and 10 years, the age group most prone to respiratory infections (Turanjanin *et al.*, 2014). Their performance depends mainly on mental concentration, directly linked to the level of fresh air circulating in the classroom (Branco *et al.*, 2015). During their stay in classrooms, children are exposed to numerous pollutants coming both from the outside air and from different sources inside the classroom (Pulimeno *et al.*, 2020).

Outdoor CO_2 concentration can vary from around 400 ppm (Apte, Fisk and Daisey, 2000), or somewhat higher in busy or industrial areas. However, the level of indoor CO_2 concentration depends on the users' breathing, in the level and period of occupancy, the amount of fresh air circulating in the classroom, its dimensions and the outdoor CO_2 concentration (Apte, Fisk and Daisey, 2000) (ASHRAE, 2022)

A high CO_2 concentration inside a classroom indicates insufficient ventilation of the space (Allen *et al.*, 2020). These values are used as indicators of indoor air quality, as well as a ventilation control method at different occupancy times (Kusiak and Li, 2009). The mean value of indoor CO_2 is used to assess the quality of ventilation with digital monitoring equipment (Wang *et al.*, 2014).

Ventilation is a fundamental aspect of indoor air quality (Viegas *et al.*, 2020). For correct ventilation, the interior air must be renewed by extracting or injecting it, either naturally or forced. Generally, in public spaces, mechanical systems are chosen to reduce, as far as possible, energy consumption (Kusiak, Tang and Xu, 2011). For this reason, optimization models are being developed, in which different variables are incorporated to optimize the systems.

Table 1: Values according to B.O.E., No. 64, 1971

Air supply	30-50 m^3/h by employee	Air renewal 6 times/h for sedentary jobs	Air renewal 10 times/h for physically strenuous jobs
Air speed	15 m/min for normal T^a	45 m/min in hot environments	
Temperature	17 to 22 ºC for sedentary work	15 to 18 ºC for ordinary work	12 to 15 ºC for physically demanding jobs
Relative humidity	40-60%	> 50% whether static electricity can be generated	

In Spain, most educational centers do not have mechanical ventilation systems, and ~~punctual~~ natural ventilation, which is carried out especially in winter, is insufficient to reach the reference levels (Guijarro Miragaya *et al.*, 2021). This ventilation through the windows, in addition to improving air quality, is directly associated with other comfort criteria such as thermal, acoustic, or visual comfort. The balance of all these factors will allow an adequate environment for learning.

Since 2013 the inspection of the air quality to achieve optimal comfort in the workplace it is mandatory in Spain. In this way, it is necessary to carry out an annual review of the duct network and of the environmental quality in buildings whose useful power is equal to or greater than 70kW, only individual dwellings are exempt (NTP 243:1987).

This concern has led to numerous studies on indoor air quality in spaces such as offices and schools during the last decades. In these studies, it has been detected that regular users present the symptoms of SBS, known as Sick Building Syndrome, such as irritation of the eyes, nose and throat, sensation of dry skin and mucous membranes, reddening of the skin, respiratory infections, cough, or difficulty breathing and concentrating, among others. They found that ventilation rates below 10 l/s per person can improve the appearance of SBS and increases to 20 l/s per person can significantly decrease the appearance of symptoms (Seppanen, Fisk and Mendell, 1999).

In the 1970s, ASHRAE published several studies recommending a fresh air rate supply of 34 m3/h per person and an absolute minimum of 8 l/s per person, recommending a ventilation rate of 10 l/s to conserve concentrations of CO2 below 1000 ppm.

Table 2: Values according to ASHRAE and RITE

	ASHRAE 2019	*RITE 2021*	
Air supply	Min. 25,5 m^3/h by p. in school classrooms	20 dm^3/s by person (IDA 1)	12,5 dm^3/s by person (IDA 2)
Concentration CO_2	-	350 ppm (IDA 1)	500 ppm (IDA 2)
Temperature	20 a 24 ºC in winter	23 a 25 ºC in summer	21 a 23 ºC in winter
Relative humidity	20-60%	45 a 60% in winter	40 a 50% in summer

Similarly, in Spain, the values described in table 2, are stipulated, based on the use of the building: nurseries (IDA 1) and teaching classrooms (IDA 2), where the recommended levels are marked to achieve the objectives established by the renewable energy promotion plan (BOE nº91, 2013) (BOE nº178, 2021)

2 OBJECTIVE

The aim of this study is to analyse the environmental quality in educational centers with different characteristics through CO_2, temperature, and RH indicators. The results allow analysing the behaviour patterns during this exceptional pandemic period, enlightening the rehabilitation needs of the educational buildings and their potential for improving their resilience, energy efficiency and indoor environmental quality.

3 METHODOLOGY

Twenty-seven buildings were analysed, monitoring 66 classrooms in four different climate zones in Spain (figure 1).

Figure 1: Image of one of the monitored classrooms in Madrid.

Table 3 presents the general data for the schools studied. Data collected during the periods from October 2020 to May 2021 and during the month of December 2021, coinciding with the COVID-19 pandemic, have been analysed.

Table 3: Summary of the educational centers

Center	Built Year	Province	Climate Zone DB-HE	Climate Zone Koopen
1	1954	Madrid	D3	Csa
2	1950	Madrid	D3	Csa
3	1982	Madrid	D3	Csa
4	1970	Madrid	D3	Csa
5	1950	Madrid	D3	Csa
6	1962	Madrid	D3	Csa
7	1939	Madrid	D3	Csa
8	1906	Madrid	D3	Csa
9	1910	Madrid	D3	Csa
10	1985	Madrid	D3	Csa
11	1996	Madrid	D3	Csa
12	1970	Madrid	D3	Csa
13	2000	Albacete	D3	BSk
14	1998	Zaragoza	D3	BSk
15	1984	Zaragoza	D3	BSk
16	1985	Sevilla	B4	Csa
17	1930	Sevilla	B4	Csa
18	1960	Sevilla	B4	Csa
19	1906	Córdoba	B4	BSh
20	1989	Navarra	D1	Cfb
21	1960	Navarra	D2	Cfb
22	1968	Navarra	D2	Cfb

23	1971	Navarra	D1	Cfb
24	1993	S. C. de Tenerife	A3	BSh
25	1982	S. C. de Tenerife	A3	BSh
26	1972	S. C. de Tenerife	A3	BSh
27	1980	S. C. de Tenerife	A3	BSh

The educational centres are in different provinces that encompass four different climate zones according to the Technical Building Code

The different measurements carried out during the experimental campaigns have been recorded by multiple experts through a web form, resulting in the following:

- General characteristics of each assessed classroom (tables 4-7).
- Data records from the continuous monitoring of air temperature (T), air relative humidity (RH) and carbon dioxide concentration (CO_2), all variables measured inside the classrooms during the periods mentioned above in section 2 (tables 8-11). Short periods of approximately one typical school week have been taken for the analysis. An example of one day is shown in Figure 2.
- Tests performed on the ventilation capacity of each of the classrooms, and ventilation strategies used (Table 12). The first test (E1) was conducted in 34 classrooms and consisted of measuring the time in minutes that CO_2concentration rise from 700ppm to 1000ppm. These tests were performed under conditions of occupancy with windows and doors closed (E1.1). And vice versa, record the time of decay of the CO_2 concentration from 1000ppm to 700ppm, when all doors and windows are opened (E1.2). The second test (E2), carried out in 17 classrooms, consisted of observing whether an average level of 700ppm was achieved (E2.1), considering the average air temperature of the classroom (E2.2) and the ventilation strategies used (E2.3).

4 RESULTS

4.1 Classroom features

The classrooms have been grouped according to the climate zones to which they belong, and the information is detailed in tables 4 to 7.

Table 4: Classroom features. Climate Zone D3

Center	Classroom	Orientation	Floor	Vol. (m^3)	Opening surface (m^2)	Nº Stud.	Age	Occupation (m^3/Nº Stud.)	Cooling Syst.
1	A	SO	B	67	0	7	15	9,6	1
	B	N	B	120	1,33	9	17	13,3	1
	C	N	1ª	141	2	15	14	9,4	0
	D	N	1ª	150	3	15	14	10,0	0
2	A	E	2ª	247	1,84	23	12	10,7	0
	B	E	2ª	206	1,08	19	8	10,8	0
	C	N	1ª	228	1,95	15	6	15,2	0
	D	E	1ª	241	1,84	17	4	14,2	0
	E	N	2ª	229	1,95	23	10	10,0	0
3	A	N	1ª	165	1,1	15	14	11,0	0
	B	N	B	165	1,1	14	13	11,8	0
4	A	SO	2ª	160	2	16	8	10,0	0
	B	NE	3ª	160	2	25	10	6,4	0
5	A	E	2ª	216	3,6	20	5	10,8	0
	B	N	3ª	338	6	20	10	16,9	0
	C	E	1ª	216	3,57	18	3	12,0	0
	D	S	2ª	144	3,57	20	5	7,2	0
6	A	N	1ª	165	2,73	17	13	9,7	0
	B	E	2ª	165	2,73	25	14	6,6	0
	C	E	2ª	165	2,73	17	15	9,7	0
	D	E	2ª	165	2,73	17	15	9,7	0
7	A	S	2ª	133	0,7	20	13	6,7	0

8	A	N	2ª	173	1,6	15	10	11,6	0
9	A	E	1ª	240	2,7	19	6	12,6	0
	B	N	1ª	166	2,7	13	6	12,8	0
	C	O	2ª	190	2,7	20	10	9,5	0
	D	E	B	240	2,7	20	5	12,0	0
	E	E	B	240	2,7	20	4	12,0	0
	F	O	1ª	190	2,7	20	9	9,5	0
10	A	N	1ª	120	1,6	20	14	6,0	0
	B	N	1ª	592	1,8	28	14	21,1	0
11	A	SE	B	626	4,8	15	23	41,8	0
	B	SE	B	630	6	17	23	37,0	0
	C	SO	B	448	0	17	23	26,4	0
	D	SE	1ª	403	4,8	27	23	14,9	0
	E	NE	1ª	340	0	45	23	7,6	0
	F	NO	1ª	263	3,6	16	23	16,5	0
12	A	N	1ª	809	0,91	75	21	10,8	0
13	A	N	1	151	2,5	24	16	6,3	0
14	A	S	2ª	6572	39,8	103	20	63,8	1
15	A	S	2ª	95	2,3	29	15	3,3	0
	B	SE	2ª	92	2,3	18	13	5,1	0
	C	N	2ª	184	2,3	28	16	6,6	0

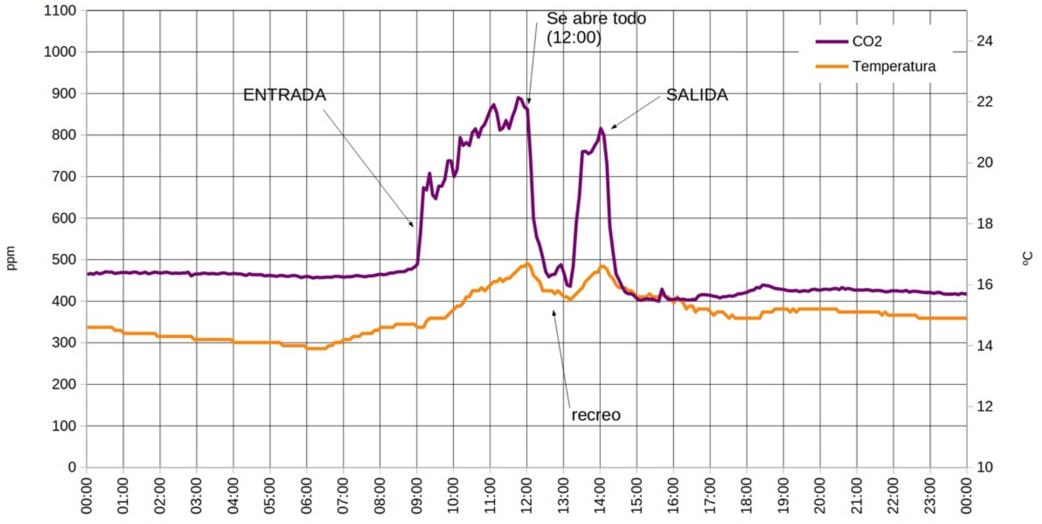

Figure 2: Example of one day recorded data for a classroom in Madrid.

Table 5: Classroom features. Climate Zone B4

Center	**Classroom**	**Orientation**	**Floor**	**Vol. (m^3)**	**Opening surface (m^2)**	**Nº Stud.**	**Age**	**Occupation (m^3/Nº Stud.)**	**Cooling Syst.**
16	A	S	1ª	207	7,9	22	14	9,4	1
	B	N	1ª	217	7,6	22	16	9,9	1
17	A	O	3ª	192	9,2	36	15	5,3	0
	B	E	3ª	193	9,2	26	15	7,4	0
	C	O	2ª	206	2,8	24	18	8,6	1
	D	E	2ª	226	5	24	28	9,4	1
18	A	S	3ª	324	2,5	33	20	9,8	1
19	A	E	3ª	184	3,6	8	16	23,0	0
	B	E	2ª	331	6,55	14	16	23,6	0

Table 6: Classroom features. Climate Zone D1-D2

Center	Classroom	Orientation	Floor	Vol. (m^3)	Opening surface (m^2)	Nº Stud.	Age	Occupation (m^3/Nº Stud.)	Cooling Syst.
20	A	SO	2ª	167	3,6	20	13	8,4	0
	B	NE	3ª	171	3,6	18	18	9,5	0
21	A	S	3ª	120	3	24	13	5,0	0
	B	S	4ª	135	3	18	16	7,5	0
22	A	E	3ª	238	2,3	18	13	13,2	0
	B	S	3ª	228	4,7	24	18	9,5	0
23	A	SO	1ª	161	2,5	25	14	6,5	0
	B	SO	3ª	163	3,4	20	18	8,2	0

Table 7: Classroom features. Climate Zone A3

Center	Classroom	Orientation	Floor	Vol. (m^3)	Opening surface (m^2)	Nº Stud.	Age	Occupation (m^3/Nº Stud.)	Cooling Syst.
24	A	O	1ª	168	3,3	15	12	11,2	1
	B	E	1ª	168	3,3	12	16	14,0	1
25	A	SO	1ª	203	2,5	18	10	11,3	0
	B	NO	1ª	195	3,74	17	12	11,5	0
26	A	O	1ª	157	2,8	22	7	7,2	0
	B	E	2ª	156	3,76	13	16	12,0	0
27	A	NE	2ª	166	2,1	24	8	6,9	0
	B	SE	2ª	180	2,1	24	10	7,5	0

4.2 Monitoring Results

Taking the local weather stations *AEMET* weather stations data as a reference, and the ranges of typical school hours (h.l) from 9:00h to 14:00h, we extract the data collected, for the different climatic zones, in tables 8 to 11.

Table 8: Experimental Results: CO_2 and T. Climate Zone D3

Center	Classroom	Period	School Days	Average CO_2 h.l. (ppm)	St.dev. CO_2 (ppm)	Average Tª int. h.l. (ºC)	Average Tª ext. h.l. (ºC)	Tª int.-Tª ext. (ºC)
1	A	16-20 Nov 20	5	577	167	18,2	15,4	2,8
	B	23-27 Nov 20	5	669	143	18,0	11,3	6,7
	C	30-4 Dec 20	5	547	83	16,7	10,0	6,7
	D	9-15 Dec 20	5	634	153	16,3	11,5	4,8
2	A	9-12 Nov 20	4	608	74	18,1	14,6	3,5
	B	9-12 Nov 20	4	619	104	17,8	14,6	3,2
	C	16-19 Nov 20	3	580	82	17,7	15,4	2,4
	D	16-20 Nov 20	4	691	81	18,8	15,4	3,5
	E	24-27 Nov 20	4	662	121	16,1	10,6	5,5
3	A	19 April 21	1	824	149	21,0	17,3	3,7
	B	19 April 21	1	884	106	19,0	17,3	1,8
4	A	27-3 Dec 20	4	443	30	15,7	10,5	5,2
	B	7-10 Dec 20	4	618	129	16,3	10,0	6,3
5	A	26-27 Jan 21	2	569	78	28,7	15,8	12,9
	B	28-1 Feb 21	3	607	122	22,4	12,1	10,4
	C	26 Feb 21	1	499	104	31,1	13,6	17,5
	D	27-29 Jan 21	3	453	93	22,0	13,2	8,8
6	A	9 Mar 21	1	-	-	-	11,6	-
	B	1-5 Mar 21	5	638	110	17,0	11,3	5,8
7	A	1-5 Mar 21	5	673	108	19,5	11,6	7,9
8	A	1-5 Mar 21	5	552	50	18,1	11,6	6,7
9	A	1-2 Dec 20	2	679	170	15,6	11,9	3,7
	B	1-2 Dec 20	2	601	134	14,3	11,9	2,3
	C	3-4 Dec 20	2	686	143	14,9	7,2	7,7
	D	3-4 Dec 20	2	783	236	15,8	7,2	8,5
	E	7-11 Dec 20	5	557	76	14,7	10,8	4,0

	F	7-11 Dec 20	5	615	95	15,1	10,8	4,3
10	A	1-5 Mar 21	5	674	212	21,1	11,6	9,5
	B	1-5 Mar 2021	5	589	61	14,7	11,6	3,1
11	A	15-20 Dec 21	4	573	50	12,2	11,1	1,1
	B	15-20 Dec 21	4	658	62	15,0	11,1	3,9
	C	15-20 Dec 21	4	611	29	16,8	11,1	5,7
	D	15-20 Dec 21	4	660	48	20,1	11,1	9,0
	E	15-20 Dec 21	4	526	15	21,1	11,1	10,1
	F	15-20 Dec 21	5	655	72	22,1	11,1	11,1
12	A	8 April 21	1	721	138	19,1	12,2	6,9
13	A	19-23 Oct 20	5	763	224	19,9	15,5	4,4
14	A	18-22 Jan 21	5	545	29	20,7	8,8	11,8
15	A	1-5 Mar 21	5	652	104	17,1	11,6	7,5
	B	1-5 Mar 21	5	624	120	19,0	11,6	7,4
	C	1-5 Mar 21	5	675	132	21,2	11,6	9,6

Table 9: Experimental Results: CO_2 and T. Climate Zone B4

Center	**Classroom**	**Period**	**School Days**	**Average CO_2 h.l. (ppm)**	**St.dev. CO_2 (ppm)**	**Average T^a int. h.l. (ºC)**	**Average T^a ext. h.l. (ºC)**	**T^a int.-T^a ext. (ºC)**
16	A	25-29 Jan 21	5	894	252	18,0	11,6	6,4
	B	-	-	-	-	-		
17	A	11-15 Jan 21	5	1691	580	16,3	9,8	6,5
	B	11-15 Jan 21	5	1400	555	10,8	9,8	1,0
	C	11-15 Jan 21	5	1159	380	10,7	9,8	0,9
	D	11-15 Jan 21	5	1865	484	17,5	9,8	7,7

Table 10: Experimental Results: CO_2 and T. Climate Zone D1-D2

Center	**Classroom**	**Period**	**School Days**	**Average CO_2 h.l. (ppm)**	**St.dev. CO_2 (ppm)**	**Average T^a int. h.l. (ºC)**	**Average T^a ext. h.l. (ºC)**	**T^a int.-T^a ext. (ºC)**
20	A	23-26 Mar 21	4	830	266	18,6	10,6	8,0
	B	23-26 Mar 21	4	932	409	18,0	10,6	7,4
21	A	1-5 Mar 21	5	1016	337	18,9	11,7	7,2
	B	1-5 Mar 21	5	725	171	17,4	11,7	5,7
22	A	1-5 Mar 21	5	1251	479	20,8	11,6	9,3
	B	1-5 Mar 21	5	983	278	19,3	11,6	10,6
23	A	1-5 Mar 21	5	1225	250	19,5	9,0	10,3
	B	1-5 Mar 21	5	937	352	19,5	9,0	10,6

Table 11: Experimental Results: CO_2 y T. Climate Zone A3

Center	**Classroom**	**Period**	**School Days**	**Average CO_2 h.l. (ppm)**	**St dev. CO_2 (ppm)**	**Average T^a int. h.l. (ºC)**	**Average T^a ext. h.l. (ºC)**	**T^a int.-T^a ext. (ºC)**
24	A	20-26 May 21	5	536	69	22,6	20,2	2,4
	B	10-14 May 21	5	511	79	25,4	20,2	5,3
25	A	8-14 April 21	5	649	134	22,1	19,8	2,3
	B	8-14 April 21	5	696	195	19,9	19,8	0,1
26	A	1-5 Mar 21	5	570	140	20,3	19,1	1,2
	B	1-5 Mar 21	5	626	153	19,1	19,1	0,0
27	A	15-19 Mar 21	5	497	48	20,6	20,2	0,4
	B	15-19 Mar 21	5	593	91	20,6	20,2	0,4

4.3 Tests

The data collected during the tests carried out can be seen in table 12.

Table 12: Test results

Center	**Classroom**	**E1.1**	**E1.2**	**E2.1**	**E2.2)**	**E2.3**
2	A	28	15	-	-	-
	B	50	20	-	-	-

	E	30	27	-	-	-
3	A	15	13	-	-	-
	B	9	4	-	-	-
5	A	22	6	Yes	29	Windows open 50%, doors open 100%
	B	40	8	No	22	Windows open 25%, doors open 100%
	C	37	3	Yes Yes	23	Windows open 50%, doors open 50%
	D	10	4	Yes	18	Windows open 50%, doors open 100%
6	A	12	3	Yes	15	Windows open 50%, doors open 100%
	C	9	3	Yes	18	Windows open 50%, doors open 50%
	D	11	5	Yes	17	Windows open 100%, doors open 100%
8	A	-	-	Yes	18	Windows open 100%, doors open 100%
9	A	19	12	-	-	-
	B	20	5	-	-	-
	D	24	15	-	-	-
	E	35	10	-	-	-
13	A	-	-	No	12	Windows open 100%, doors open 25%
18	A	15	10	-	-	-
19	A	19	3	-	-	-
	B	22	6	-	-	-
20	A	7	3	No	19	Windows open 25%
	B	7	11	No	19	Windows open 25%
21	A	5	6	No	19	Windows open 50%, doors open 100%
	B	4	1	No	19	Windows open 50%, doors open 100%
22	A	5	6	No	19	Windows open 25%, doors open 25%
	B	6	2	No	19	Windows open 25%, doors open 100%
23	A	7	5	No	19	Windows open 25%
	B	-	-	No	19	Windows open 25%
24	A	21	9	-	-	-
	B	18	12	-	-	-
25	A	13	14	-	-	-
	B	13	6	-	-	-
26	A	14	21	-	-	-
	B	44	5	-	-	-
27	A	8	12	-	-	-
	B	10	10	-	-	-

5 ANALYSIS AND DISCUSSION

Based on the results obtained, the relationship between the different parameters explained below is studied. It is worth mentioning at this point that since these are in-situ measurements, there are numerous variants that are not included in the analysis due to usage factors.

5.1 Temperature

Although the average temperatures inside the different climate zones are relatively close to the comfort ranges, the minimum values reached during school hours in each zone are very low: 12.2ºC (D3), 10.7ºC (B4), 17.4ºC (D1-D2), and 19.1ºC (A3). As can be seen, the values of the mildest winter climate zones (A3) are the highest recorded.

Moreover, in both A3 and D1-D2 the records are from periods closer to spring, unlike the data collected in D3 and B4, with most of their records in winter periods. In the case of the classrooms analysed in zone D3, the average between indoor and outdoor temperature is 6ºC.
So, we can see that, in some of the examples, the temperature difference between indoors and outdoors is greater than in others, so that some areas maintain a better hygrothermal comfort.

5.2 CO_2

CO2 concentrations are generally kept low in all classrooms, using natural ventilation as a strategy. The overall average is 697 ppm. This is below the 700 ppm reference values set as optimal during the pandemic (Organisation mondiale de la Santé and Organisation internationale du Travail, 2021)16, and well below the RITE reference values for teaching classrooms (900 ppm considering a reference value for outdoor CO_2 concentration of 400 ppm).

The classrooms that have recorded average values slightly above 900 ppm are the four classrooms in centre 17 in Seville (B4) and the classrooms in centres 20, 21, 22 and 23 in Navarra (D1-D2). It is also the classrooms in these two zones that have recorded the highest peaks, as shown by the standard deviation data. The average in zone D3 is 619 ppm, 1400 ppm in zone B4, 960 ppm in zone D1-D2, and 582 ppm in zone A3. Logically, the classrooms in climate zone A3 are the ones with the best data, both in terms of temperature and CO_2, as it is a very mild climate (Ramalho *et al.*, 2015).

5.3 Classrooms

If we eliminate case 14 from Zaragoza, which is an odd case within the sample in terms of size, we can see that in general there is a weak relationship between the number of pupils and the volume of the classroom, and there is a lot of dispersion in the data. The maximums are 41 m3/pupil and 64 m3/pupil, and the minimums are 5 m3/pupil and 3 m3/pupil. Nor does there seem to be a relationship between window area and classroom volume or number of pupils. In other words, in general, the number of pupils does not seem to be a design criterion for classrooms, neither for their volume nor for their window area.

Nor does there seem to be a direct relationship between indoor temperatures and the orientation or floor number of the classrooms. It is common in classrooms to use blinds to avoid glare or to allow better viewing of screens. This logically hinders the possible solar gain through the openings and reduces the air flow through windows.

As for the CO_2 generation rate, an average of 14 minutes was measured for the rise from 700 ppm to 1000 ppm, while the average for the fall is 7 minutes. There is also a large dispersion in these results, the maximum being 50 and 27 minutes respectively. The upward curves of CO_2 concentration are less steep than the downward curves.

These short times indicate the need to consider a trickle renovation, i.e., a small renovation that is taking place continuously. Opening both doors and windows is the most used strategy to keep CO_2 levels low. This is generating a cross-ventilation renovation by mixing air from other classrooms through common areas such as corridors. Therefore, it is also necessary to consider suction ventilation, thus avoiding the mixing of air between different school classrooms, by considering a strategic placement of these.

6 CONCLUSIONS

During the pandemic, different organisations have recommended increased ventilation to reduce the chances of infection inside schools. In the classrooms analysed, low baseline CO_2 levels have generally been achieved. This has been achieved at the cost of reduced indoor thermal comfort conditions, and increased energy consumption, the minimum temperatures recorded have been very low.

The design and use of the classrooms analysed does not respond to bioclimatic criteria, as no relationship is found between the data recorded and the volume of air or the surface area and orientation of windows.

The recorded data show the need for an energy rehabilitation of this type of buildings, including comfort and air quality criteria, using forced ventilation with heat recovery and CO_2 control.

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