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THE IMPACT OF COVID-19 VENTILATION REQUIREMENTS ON THE TEMPERATURE AND AIR QUALITY IN UNIVERSITY CLASSROOMS

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The current study analyzes educational buildings aiming to determine the long and short-term effects of the COVID-19 pandemic situation regarding the usage patterns and indoor environmental quality standards. Through monitoring campaigns in various classrooms, data has been gathered on temperature and indoor air quality which has made it possible to obtain a picture of the current situation in rooms with forced ventilation systems as well as in rooms where only natural ventilation is available. Results show that the CO2 concentration levels remain controlled regardless of the number of students in spaces equipped with mechanical ventilation; however, in classrooms where only natural ventilation is available, these values vary depending on the occupancy and, when attempting to maintain the recommended levels, indoor thermal conditions are greatly affected by the external weather. The factors with the greatest impact on comfort are airspeed and outside temperature, which in several cases have resulted in very low indoor temperatures that do not comply with the legally required limits.

Keywords: IAQ; temperature; Covid 19

IMPACTO DE LOS REQUISITOS DE VENTILACIÓN POR EL COVID-19 SOBRE LA TEMPERATURA Y LA CALIDAD DEL AIRE EN AULAS UNIVERSITARIAS

Este trabajo analiza edificios educacionales con el objetivo de entender los efectos derivados de la pandemia del COVID-19 con respecto a los patrones de uso y los estándares de calidad ambiental interior marcados por las autoridades. Se han recogido datos de temperatura y calidad del aire en aulas universitarias, lo que ha permitido obtener una fotografía de la situación actual tanto en espacios provistos de sistemas de ventilación forzada como en salas donde únicamente se dispone de ventilación natural. Los resultados muestran que, en espacios ventilados mecánicamente, la concentración de CO2 se mantiene regular independientemente del número de estudiantes; sin embargo, en aulas con ventilación natural, estos valores varían en función de la ocupación y, al intentar mantener los niveles recomendados, las condiciones térmicas interiores se ven muy afectadas por el clima exterior. Los factores con mayor impacto sobre el confort son la velocidad del aire y la temperatura exterior que en varios casos se ha traducido en temperaturas interiores muy bajas que no cumplen con los límites legales.

Palabras clave: CAI; temperatura; Covid-19

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1. Introduction

On March 11, 2020, the World Health Organization (WHO) elevated the health emergency caused by Covid-19 to an international pandemic due to the incessant increase in cases derived from the high transmission rate of the virus (Adhanom Ghebreyesus, 2020). In order to stop the spread, many countries declared a state of alarm and adopted extraordinary measures that affected the free movement of people and forced the closure of numerous businesses and institutions. In Spain, the imposition of lockdown started on the 15th of March and was maintained for 100 days, after which a de-escalation began full of new restrictions and recommendations. Many of these recommendations have been focused on ensuring correct Indoor Air Quality (IAQ) since the main route of transmission is through the air as Covid-19 is a viral disease that affects the respiratory system, (World Health Organization, 2020).

CO_2 concentration monitoring is one of the main methods to know the status of the IAQ. CO_2 is not considered a dangerous element for health and is only used as a factor to know the quality of the air, although there are studies that relate high concentrations of CO_2 with decreases in the speed of several cognitive functions (Du et al., 2020; Satish et al., 2012). Table 1 shows the levels of CO_2 requested in the Spanish Regulation of Thermal Installations in Buildings (RITE) based on the use of the spaces (Gobierno de España, 2007). It should be noted that the spaces covered by these recommendations refer to indoor environments for non-industrial use such as office buildings, public buildings (schools, hospitals, restaurants, theatres...).

Table 1. Indoor air quality categories according to the use of buildings specified by the RITE

Air quality	Environment type	Maximum level
IDA 1. Optimum	Hospitals, clinics, laboratories and nurseries.	350 ppm
IDA 2. Good	Offices, residences, reading rooms, museums, courtrooms, teaching classrooms and similar and swimming pools.	500 ppm
IDA 3. Regular	Commercial buildings, cinemas, theatres, function rooms, restaurants, coffee shops, bars, gyms, sports venues (except swimming pools) and computer rooms.	800 ppm
Right. Low		1200 ppm

Note: Maximum level indicates the CO_2 concentration (in parts per million by volume) above the outdoor air concentration.

It has to be noted that, even if the Spanish government has supported the values stated on the RITE (INSST, 2021; MITECO, 2020), several experts on the field, with the aim of ensuring safe indoor environments, have recommended that the CO_2 concentration levels on IDA 2 spaces should not exceed 600-800 ppm (Aireamos, 2021).

This classification groups buildings with different specifications, due to both their use and the installed ventilation systems. In many cases, this implies that, in order to maintain the suggested IAQ levels, windows must be kept open regardless of the outdoor climate which has a direct impact on the energy expenditure and the thermal comfort of the occupants. In fact, in the Real Decreto 486/1997 (MITES, 1997) the working conditions for workplaces are established and it is indicated that, in the case of sedentary jobs, the temperature must be between 17 ºC and 27 ºC and the relative humidity should not be lower than 30% or higher than 70%. These limits exist since health can be affected by exposure to both low and high temperatures.

In the case of low temperatures, it has been shown that once the temperature drops below 16 ºC, respiratory stress begins and cardiovascular stress starts when it drops to 12 ºC (Ormandy

& Ezratty, 2015). Being exposed to this stress leads to the consumption of a lot of energy and the deployment of high amounts of corticosteroids and other substances that are necessary in the short term but that in the long term can cause immunosuppression (McMichael et al., 2008), which leads to an increased risk of contracting infectious diseases.

The effects of exposure to high temperatures, contrary to what happens with low temperatures, can manifest themselves relatively quickly (McMichael et al., 2008). Heat increases the rate of dehydration and causes the circulatory system to vasodilate, increasing the risk of suffering a "heat stroke" (Bouchama & Knochel, 2002). It should be noted that a population can develop resilience to heat over time (Bobb et al., 2014), which means that the negative impacts vary depending on the region and community studied (Anderson et al., 2013; McGeehin & Mirabelli, 2001).

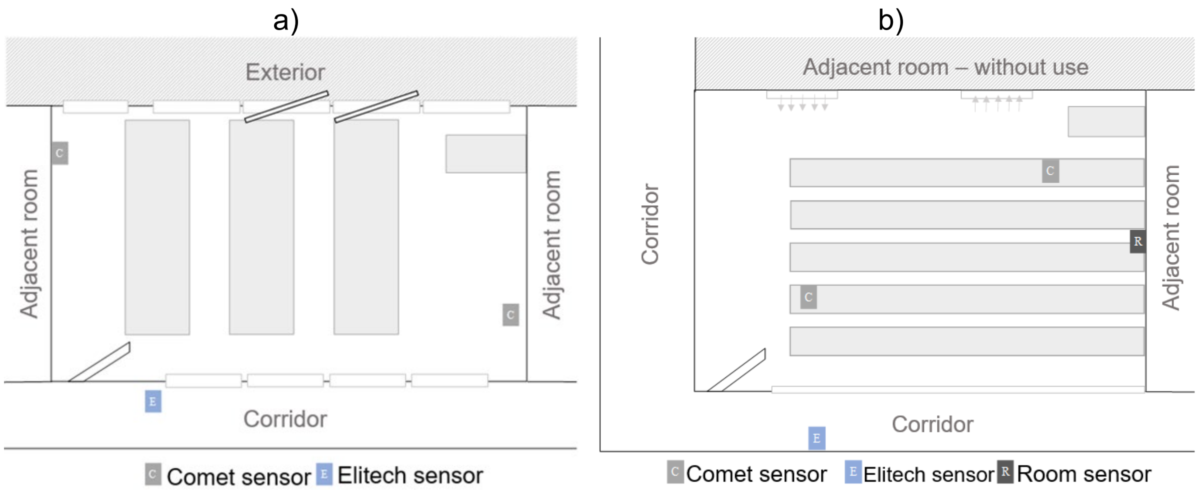
Furthermore, other studies have related human performance to temperature (Cui et al., 2013), suggesting that when temperatures departed from neutral (26 ºC), individuals experience an increment of negative emotions and have to spend more effort to maintain their performance.

With this knowledge as a background, the need to study the current conditions of Indoor Environmental Quality (IEQ) in university classrooms has been highlighted, for which a series of measurements have been carried out in different spaces of the Escola Tècnica Superior d'Enginyeria Industrial de Barcelona (ETSEIB) to verify if the ventilation measures stablished by the school and the government in schools, which asks to keep rooms ventilated is acceptable.

2. Methodology

For the measurements, two classrooms in the ETSEIB with different configurations and ventilation systems have been chosen.

Figure 1. Distribution and sensor displacement in (a) C1 and (b) C2



The first classroom (C1) is located on the tenth floor of the ETSEIB and has an area of approximately 48 m² and a volume of 140 m³. The heating of the room is carried out by the central heating system of the building, which is activated according to the daily hour and the outdoor temperature (see Table 2). The heating of the building can only be turned on or off in each floor, but it is not possible to regulate the flow, temperature, or control it by zones. Regarding the ventilation system, the only available option is natural ventilation.

This classroom is delimited by two other rooms of similar structure, a corridor and the façade that has five windows facing south-west, of which only two can be opened 15 degrees. These windows are quite particular, as they have the shaft in the centre (not the edge) as shown in Figure 1 (a). In addition, the wall that connects the classroom with the corridor has a door, four fixed windows and two grids for the heating supply. The vertical cladding is mainly made of solid brick with a layer of plaster. In C1, the student's tables and chairs (grey rectangles in Figure 1) are located in perpendicular to the windows and the corridor.

Table 2. Central heating operating conditions

Hour	Condition	Action
6:30 to 9:30	T_{out} < 16 ºc	On
	T_{out} < 17 ºc	Off
9:30 to 17:00	T_{out} < 14 ºc	On
	T_{out} < 15 ºc	Off
17:00 to 20:30	T_{out} < 15.5 ºc	On
	T_{out} < 16.5 ºc	Off
20:30 to 6:30$^{(+1)}$	Disconnection	Off

The second classroom (C2) is located in the basement and its dimensions are approximately 80 m² of surface and 240 m³ of volume. As shown in Figure 1 (b), C2 is surrounded by a corridor, another classroom with the same characteristics and an area that is out of use so it is not climatized. There are no windows to open while the separation with the corridor, in addition to the door to enter the classroom, is made up of a translucent glass partition. The rest of enclosures are made of plasterboard with a plaster finish. In C2, long strings of tables parallel to the corridor are placed for the students to attend the explanation of teachers, having the whiteboard and projection roll-out on the opposite location of the entrance of the room.

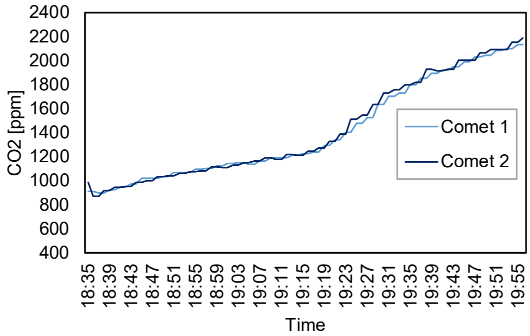
There is an air conditioning system that can be activated by the occupants but, even when it is turned on, it only works when the room temperature is outside of the temperature range of 21 ºC and 26 ºC. The temperature sensors that regulate the system are located in the false ceiling towards the centre of the classroom. This room also counts on a CO_2 sensor (R in Figure 1 (b)) linked to an automatic air renewal system that activates when the R sensor measures values over 750 ppm. The air vents of this system are located at the end of the room, above the blackboard, and it has to be noted that the extracted air passes through a heat recovery unit to acclimatize the outside air supply and it is then released to the corridor.

For the measurement of environmental variables with comparable conditions, it was decided to use two Comet sensors, model U3430, since they can log data without being plugged to the electrical power making it easier to place them in the rooms without disrupting the class. The data recorded by these sensors is the air temperature (T_{air}), the CO_2 concentration levels (CO_2), the relative humidity (RH) and the Dew Point. Additionally, an Elitech RC-5 temperature sensor was used to have information about the temperature outside the room, that is, of the corridor. The technical characteristics of the sensors are shown on the Table 3 and the location of the sensors is shown on Figure 1. In each of the conducted measurements, the Elitech sensor was hung in the corridor at approximately 2 metres from the floor to avoid disturbing traffic and maintaining a distance of 1.5 metres from the entrance door of the classrooms, preventing readings from being affected by the conditions inside classrooms. As for the Comet sensors, they were placed on different tables in the classroom with the additional goal of observing differences in CO_2 distribution within the classroom. In order to understand these differences in the readings of the sensors, an experiment was conducted in which both sensors were placed side by side and exposed to increasing levels of CO_2 concentration. The results obtained in this experiment show that when being placed together, the sensors readings have de same profile with slight differences derived from the accuracy of the devices (Figure 2)

Table 3. Technical characteristics of the C and E sensors

	Sensor	Measuring range	Resolution	Accuracy
Temperature (°C)	Comet Elitech	-20 – 60 -30 – 70	0.1	± 0.4 ± 0.5 (20-40) / ± 1 (rest)
CO_2 (ppm)	Comet	0 – 5000	1	± 50 + 3% from reading
Relative Humidity (%)	Comet	0 – 100	0.1	± 1.8

Figure 2. Accuracy test of Comet sensors in terms of CO_2 readings



Finally, a follow-up of the occupation and the activity or events carried out on the ventilation of the classroom needs to be carried out. This monitoring is done manually by the researcher, noting when people come in, when doors or windows open/close or when the air system is activated in each case. These notes later facilitate the interpretation of the variations of the measurements of the sensors. These data are collected with a frequency of one minute.

Table 4. Monitoring dates and weather conditions

Date	Classroom		Weather conditions	
	C1	C2	Mean temperature [ºC]	Relative Humidity [%]
2021/11/19	x	x	11.50	82
2021/11/23		x	12.30	80
2021/11/24	x		11.50	91
2021/11/26	x	x	9.40	67
2021/11/30		x	10.20	74
2021/12/01	x		10.90	69

Four measurements were carried out in each classroom between November 19 and December 1, 2021. The dates and the weather conditions of each measurement are presented in Table 4.

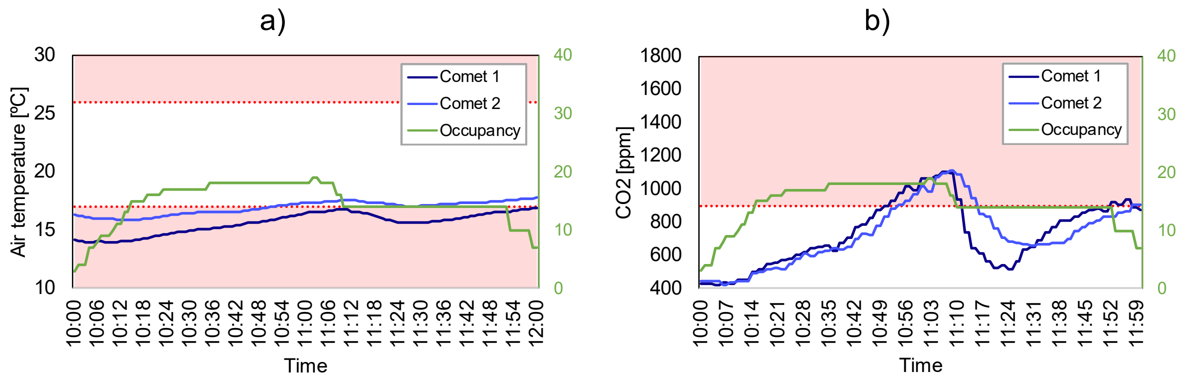
3. Results

By processing the data gathered from the measurements of each classroom, it can be observed how the existence of ventilation systems has a significant impact on the indoor temperature, and CO_2 concentration levels. Figure 3 and Figure 5 show the variations of the measurements made on November 26th, the day with the lowest outdoor temperature from the whole monitoring campaign.

Figure 3 allows us to observe how, even though it began at 19ºC, indoor temperature falls to 17ºC within the hour before the class begins because the window was kept open. Then during the interval between 10:00 and 10:09, coinciding with the entrance of students, cross ventilation is maintained, observing a notable drop in temperature falling well beyond the legal limit of 17ºC (reaching 14ºC). From this moment on, the door is closed and the CO_2 levels begin to rise caused by the breathing of the participants. It can be seen that once the window is closed, at 10:36, the concentration increases more rapidly. During this period temperature increases but it is unable to exceed 17 ºC. Between 11:09 and 11:24 there is cross ventilation again because the CO_2 measurements reached alarming values close to 1300ppm. This cross ventilation leads to a reduction of CO_2 levels and a second drop in temperature, moment in which some students decided to left the class visibly irritated. Since that moment, both temperature and CO_2 raised again when closing both door and windows.

Regarding the distribution of CO_2 and temperature within the classroom, it can be seen that the Comet 1 sensor has lower temperature readings, between 0.7 and 2.1 ºC lower than the Comet 2, and during the cross-ventilation period CO_2 levels decrease much faster, with differences of 305 ppm. These differences in temperature and CO_2 profiles are due to the fact that Comet 1 is closer to the window and due to the geometry of the windows and the position of the door, the ventilation flow crosses that area more easily impacting faster in the temperature and CO_2 changes.

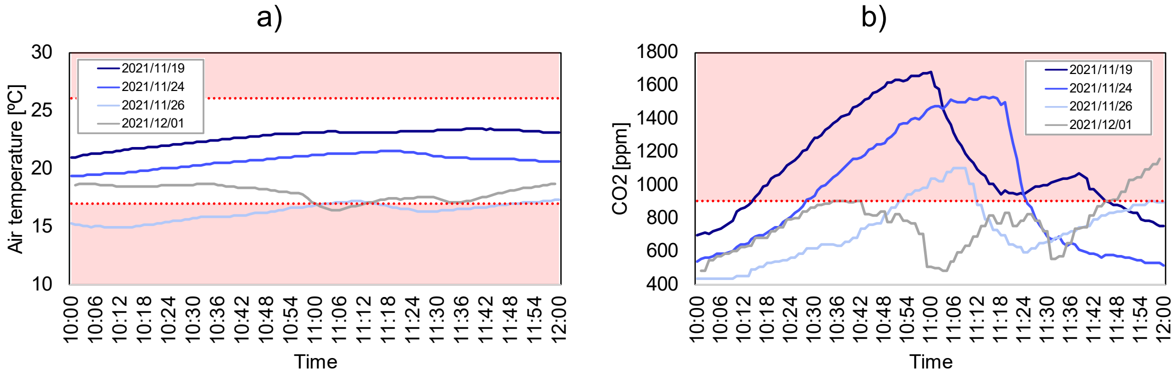
Figure 3. Recorded temperature (a) and CO_2 concentration (b) in C1 (November 26)



In summary, it can be noted how, the 26th November, C1 was unable to respect, at the same time the limits set by the local legislation in terms of temperature keeping the CO_2 concentration below 900 ppm, which is what the RITE marks as limit for classrooms (Table 1) but that it is still higher than what was stated as acceptable for COVID situations in close environments (Aireamos, 2021). Moreover, when everything is closed and considering the monitored occupation of the room (2/3 of its rated occupancy) the CO_2 ppm concentration increases at a ratio of 14.2 ppm/min, meaning that, departing from a totally ventilated room (400 ppm) in only 35 minutes the CO_2 concentration reaches the 900 ppm limit marked by RITE. Note also that, even having the windows open, if there is no cross ventilation (door open too) the CO_2

concentration still increases at a ratio of 7.2 ppm/min, which is half of what it occurs when the room is completely closed.

Figure 4: Recorded temperature (a) and CO_2 concentration (b) for the 4 days of study in C1

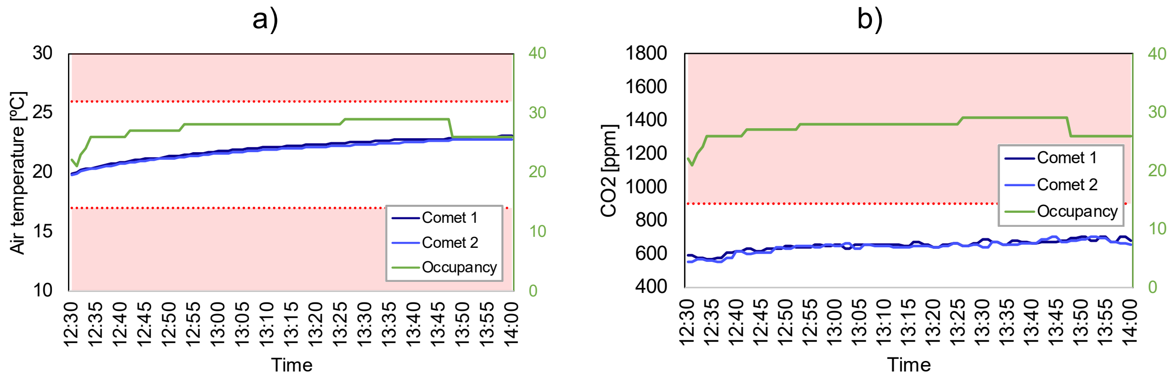


These measurements were repeated four days, which results are presented together in Figure 4. Considering the temperature range marked by the RITE in winter for this kind of installations between 21 to 23 ºC (Gobierno de España, 2007), it is observable that it is almost impossible to satisfy both the Temperature and air quality ranges simultaneously.

Effectively, 26th November was the most critical day, it was a cold-windy day outside with maximum wind gusts during the monitored period of 40.3 km/h (Meteocat, n.d.). Nonetheless, in those days when researchers were trying to satisfy the temperature ranges, CO_2 concentrations reached unacceptable values higher than 1500 ppm forcing them to open doors and windows for the sake of health considering the pandemic situation in which the study took place. Figure 4 shows how the CO_2 concentration ratio increase is rather constant at 15 ppm/min no matter the day when there's no cross ventilation.

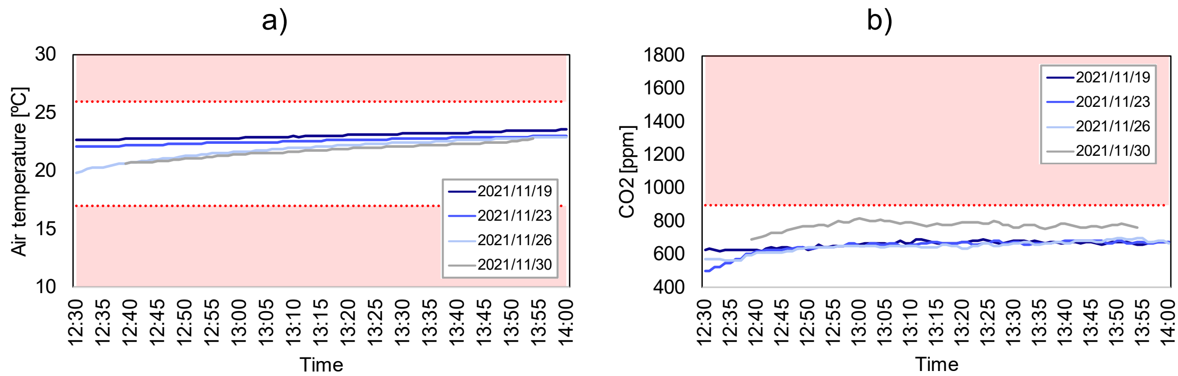
On the other hand, when looking at measurements in classroom C2 (Figure 5), which counts on both thermal and air ventilation management to ensure that temperature never falls below or above legal limits and, additionally, the room CO_2 sensor (R) forces the air ventilation system to activate when it reaches 750 ppm, even with higher occupancy, the CO_2 levels remain below 900 ppm during the whole lesson. Regarding the temperature, an increase is observed during the class hours (12:30 to 14:00) but since it does not exceed the 26 ºC fixed in the climate system, the cooling of the class does not turn on. In contrast to classroom C1, when comparing the readings taken from the two Comet sensors, the distribution of temperature and CO_2 remains uniform.

Figure 5. Recorded temperature (a) and CO_2 concentration (b) in C2 (November 26)



Similarly to C1, measurements in C2 were done in four days of class too, which are shown in Figure 6. It is interesting to see that, similarly to what occurred during the 26th November in C2, both temperature and air quality is maintained within the legality and, during most of the time, within the ranges suggested by the RITE as comfort boundaries in winter.

Figure 6: Recorded temperature (a) and CO_2 concentration (b) for the 4 days of study in C2



To summarize, Table 5 shows the percentages of time spent below 17 and above 26 ºC, outside the range of 21 and 23 ºC, above 900 ppm and complying with both temperature and air quality ranges set in the RITE simultaneously. When analysing the data set, the substantial disparity in the patterns followed by the two classrooms is underlined. On one hand, the classroom C2 only exceed the RITE limits when the temperature rises over 23 ºC since the classroom cooling systems does not activate until 26 ºC is reached, but the legal temperature restrictions are never exceeded and properly ventilated environments can be ensured.

On the other hand, in C1, the temperature and CO_2 conditions are seriously affected by external weather conditions and the actions of the occupants. In fact, its capability to stay within the RITE range is less than 11% of the time, be it because of staying too cold or because the concentration of CO_2 surpassed the limit of 900 ppm. It should also be noted that on two occasions the legally permissible temperature limits were exceeded been particularly striking the previously mentioned situation on 26th of November where 80% of the time the temperature remained below 17 ºC. It should be noted that although 26 November was a cold day, it was not the coldest day of the year and that the monitoring was carried out during the morning, so it is assumed that during other periods (such as night classes) the reached conditions could be even worse.

In addition, results indicate that, during the measured lessons, using cross-ventilation can reduce the CO_2 concentrations, however, since cross-ventilation is controlled by the occupants, other considerations might be prioritised. A very important factor when it comes to not maintaining cross-ventilation is the noise outside the classroom, which in many cases obstructs the performance of the activities in the classroom. In the case of classroom C1, the noise comes mainly from the corridor, by noise generated by people outside the classroom, and the traffic, as it is located next to the Diagonal avenue, one of the main arteries of Barcelona.

Table 5. Percentage of time below 17 ºC, outside the range between 21 and 23ºC, above 900 ppm and out of the ranges set in RITE for IAQ and temperature

Date	17 °C > T_i > 26ºC		21 ºC > T_i > 23 ºC		CO_2 > 900 ppm		Out of RITE ranges	
	C1	C2	C1	C2	C1	C2	C1	C2
2021/11/19	0%	0%	58%	49%	75%	0%	89%	49%
2021/11/23	-	0%	-	0%	-	0%	-	0%
2021/11/24	0%	-	66%	-	47%	-	93%	-
2021/11/26	80%	0%	100%	16%	18%	0%	100%	16%
2021/11/30	-	0%	-	12%	-	0%	-	12%
2021/12/01	10%	-	100%	-	16%	-	100%	-

Results show that only mechanical and controlled ventilation systems can ensure acceptable indoor conditions and that, to face future pandemic situations, school buildings should go in this direction.

Moreover, this study did not analyse the energy losses caused by the temperature reduction in those cases of cross natural ventilation. In those cases, most of the energy used to heat the classrooms is lost in few minutes when opening the windows.

As a consequence, future work should analyse and compare the energy efficiency of both natural and forced ventilation and to evaluate if the needed investment to install mechanical ventilation systems could be somehow recovered by not needing to spend so much energy (and money) because of the aforementioned energy losses when natural ventilation is used.

Finally, energy, IAQ and thermal comfort models could be used to maximize energy efficiency, safety and comfort in buildings.

4. Conclusions

This study highlights the effects that different ventilation systems have on the comfort conditions inside different university classrooms aiming to verify if the ventilation recommendations given by the authorities are acceptable not only from a pandemic point of view but also from an energy and comfort perspective.

It has been observed that natural ventilation is hardly capable to maintain the levels set by regulations in terms of CO_2 concentration and temperature simultaneously. In general, proper air renewal can only be achieved when cross ventilation is ensured, which has an influence over the temperature of the classroom. As a result, temperatures below 17°C were measured in the classroom without forced ventilation, an unsustainable situation that even forced some students to leave the class before it finished. Note that, legally speaking, this same decision could have been taken by the teacher, forcing the end of teaching lessons and, thus, making it impossible to cover the course expectations. This situation does not only impact the proper functioning of the course but it can also have negative effects on the health of students.

Moreover, the room without mechanical ventilation was almost unable to stay within the comfort margins marked by the RITE in this kind of buildings.

On the contrary, in the case in which mechanical ventilation is used, legal limits are respected at all times and measurements of both temperature and IAQ are most of the time within the ranges marked by the RITE.

Additionally, it has been seen that the conditions inside the non-mechanically ventilated classroom do not have a uniform distribution, leading to areas with more deficient ventilation even if cross-ventilation is ensured.

It must be taken into account that the present study includes a limited number of measurements, four per classroom, only two classrooms and during the winter season only. Therefore, increasing the study sample could allow to obtain more general conclusions. Nevertheless, these results show the importance of having mechanical or forced air ventilation and, additionally, of developing new systems to control indoor classroom conditions efficiently. For this reason, prediction models should be developed to provide information on the temperature and CO_2 concentration of the room without the need to collect large amounts of data and at a reduced computational cost.

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Communication aligned with the Sustainable Development Objectives

4 EDUCACIÓN DE CALIDAD

3 SALUD Y BIENESTAR

OBJETIVOS DE DESARROLLO SOSTENIBLE