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Indoor Air Quality and Thermal Comfort in University Classrooms in Southwestern Spain: A Longitudinal Analysis from Pandemic to Post-Pandemic

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Abstract: After the COVID-19 lockdown, the health authorities established strict protocols for ventilating indoor spaces and reducing contagion. Although the control of the disease allowed these measures to be relaxed, indoor air quality (IAQ) and natural ventilation (NV) are still essential. However, in certain climatic conditions, this can affect the thermal comfort of the occupants. This situation is relevant in educational buildings, where thermal discomfort can influence students' academic performance, especially during critical periods such as exams. In this context, this article explores how different NV strategies, both during and after the pandemic, affect the thermal comfort of students at a university in a Mediterranean climate zone. The analyses revealed that, despite the low temperatures and strict ventilation protocols due to COVID-19, thermal comfort during winter was higher than in spring and summer. These results led to an investigation into which variables could explain this phenomenon, detecting that the choice of clothing was crucial to achieving adequate comfort conditions. Regarding IAQ, ventilation was sufficient, even excessive, in some cases, especially during mandatory measures. In conclusion, it would be beneficial to establish ventilation protocols adapted to each environment and to advise students on individual strategies to improve their thermal comfort.

Keywords: indoor air quality; temperature; educational building; students; Mediterranean climate

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1. Introduction

1.1. Literature Review

Students spend a third of their day in school buildings [1]. As a result, indoor environmental quality (IEQ) in educational centres has been the subject of numerous investigations in different countries and climatic zones [2–5]. A key aspect of IEQ is indoor air quality (IAQ). The level of carbon dioxide (CO_2) is one of the most commonly used indicators for evaluating IAQ due to its relationship with human emissions [6]. Other pollutants, such as volatile organic compounds (VOCs) and particles (PM_{10}, $PM_{2.5}$), are also relevant, but measuring CO_2 is more common due to its ease [7,8].

The importance of having adequate IAQ levels has led to the development of various regulations and recommendations. At the European level, Standard EN 16798-3:2017 establishes criteria for IAQ in non-residential buildings, such as schools and universities [9],

and Standard ISO 16000-40:2019/Amd 1:2024 defines the requirements for its management [10]. The ASHRAE Standard 62.1 is the American benchmark in this area, establishing the minimum air renewal rates that help maintain pollutant levels [11]. Within the educational sphere, the United States Environmental Protection Agency (EPA) has developed the "IAQ Tools for Schools" programme to guide the evaluation and improvement of IAQ in educational centres [12].

Despite these regulations, several studies have shown that many classrooms have poor IAQ [13–17]. For example, Argunhan and Avci conducted a study at a university in Turkey and found that the measured values of CO_2 and particles were higher than required [18]. The same effect was observed in another study by Fuentes-Ferragud et al. in Spanish university classrooms [19]. These poor IAQ conditions fail to meet established standards and can affect students' well-being, health [20–22], and academic performance [23–25], as has been demonstrated in various studies. Thus, Chen et al. stated that moderate levels of CO_2 of up to 2100 ppm did not negatively affect cognitive performance, perceived indoor environment quality, or health symptoms in university students [26]. The same was demonstrated by Kozaki et al. [27]. Finally, Ahmed et al. showed that the cognitive performance of female university students improved with indoor temperatures between 20 and 23 °C and CO_2 levels of around 600 ppm [28].

On the other hand, since the notification of the first cases of COVID-19 at the end of 2019, the importance of having optimal IAQ conditions as part of the preventive measures against the spread of SARS-CoV-2 has been further emphasised [29], especially in times of high community transmission [30]. This paradigm led to implementing natural ventilation (NV) protocols in various environments, including university classrooms. However, the increased requirements for NV could compromise the thermo-hygrothermal conditions necessary to guarantee the thermal comfort of teachers and students in certain circumstances [31]. In this context, there is not much research addressing the direct influence of NV on thermal comfort in classrooms under strict preventive measures, as most universities continued without face-to-face teaching until the middle of the 2021–2022 academic year. Thus, the study by Aguilar et al. focused on evaluating the thermal perception of occupants during the winter in Spain. The results revealed that, although the CO_2 levels were adequate, most students were outside their thermal comfort zone [32]. This finding was repeated in the research by Miranda et al. [33]. Rodríguez-Vidal et al. analysed the performance of natural ventilation to improve air quality, comfort, and energy consumption [34]. During the pandemic, Alegría-Sala et al. quantified indoor air quality and thermal comfort in university environments, revealing that the recommendations were not always met in study spaces [35].

At the same time, other authors have focused on comparing environmental conditions in educational centres before and after the implementation of NV protocols due to COVID-19. For example, Rus et al. analysed the influence of ventilation measures and the use of masks on users' thermal comfort perception to compare the results with previous periods [36]. Similarly, Gómez Melgar et al. considered two different periods in 2018 and 2021 and compared the results obtained for thermal comfort and CO_2 concentration with various international standards. The results for 2018 showed that the comfort ranges were adequate, but the CO_2 concentrations were above 2000 ppm. On the contrary, in 2021, when the natural ventilation protocol for COVID-19 was activated, the CO_2 concentration was less than 700 ppm, reducing the building's performance in terms of comfort [37]. Similar results were observed by Ding et al. in a study carried out in the Netherlands [38].

However, it is crucial to point out that few studies have analysed the evolution from stricter protection measures to the progressive relaxation of health regulations and how these scenarios have influenced indoor air quality and the thermal comfort of university

students. De la Hoz-Torres et al. investigated the indoor environmental conditions of higher education buildings at a Portuguese and a Spanish university after the mandatory lockdown due to the pandemic. The results showed that, although air renewal was adequate and the average CO_2 concentration levels were low, students were not satisfied with the indoor environmental conditions [39]. Similarly, Romero et al. evaluated how some of the NV protocols implemented during the COVID-19 pandemic have endured over time, albeit relaxed, and their impact on thermal comfort in classrooms in a Mediterranean climate [40]. Finally, Pekdoğan and Avcı evaluated the comfort conditions of the students and determined the effect of the use of masks on the thermal sensation in the post-pandemic period. The results showed that the level of thermal comfort was adequate. Furthermore, the use of masks did not have a significant effect on thermal perception [41].

1.2. Research Gap, Novelty, and Paper Structure

As has become apparent in the literature review, during the COVID-19 pandemic, measures were adopted to mitigate the spread of the virus, such as the mandatory wearing of face masks in enclosed spaces. However, there is a lack of studies analysing the effects of the transition between the strict application of preventive measures and their progressive dismantling. Both in the most acute phase and in this intermediate stage, in which ventilation strategies and other mitigation actions have not yet been entirely relaxed, students' perception of environmental comfort may be affected. Beyond evaluating the efficiency of the measures adopted and their impact on users, the pandemic and post-pandemic scenarios provided a unique opportunity to analyse the effectiveness of ventilation in specific situations. This aspect has not been sufficiently addressed in the literature, highlighting the need to develop strategies for both conventional environments and future high-transmission situations.

In this context, assessments took on particular relevance, as the need to guarantee the integrity and fairness of the exams meant that they had to be carried out in person [42,43]. In addition, during assessment periods, classrooms tend to be more crowded, and students spend longer in them, which can affect the quality of the indoor environment [31], with potential repercussions on their academic performance during exams [44].

For all these reasons, this study aims to analyse the impact of natural ventilation on indoor environmental quality and the well-being of university students during face-to-face exams in a Mediterranean climate, comparing conditions at different stages of the pandemic. To this end, the following specific objectives are proposed: (1) to evaluate the thermal comfort and IAQ conditions in university classrooms during exams using in situ environmental measurements; (2) quantify the efficiency of natural ventilation by monitoring CO_2 concentrations and their relationship with perceived thermal comfort; (3) compare the evolution of environmental conditions between the acute phase of the pandemic (2021) and the stage of relaxation of measures (2022) to determine the effects of the progressive dismantling of mitigation strategies; (4) identify correlations between the most influential environmental parameters and their impact on students' perception of comfort; (5) propose strategies for optimising ventilation in educational environments to improve air quality and thermal comfort in conventional situations and high-transmission scenarios.

To address these aspects, the article is organised as follows: first, a literature review on IAQ and thermal comfort in educational environments is presented, emphasising the impact of NV strategies during and after the COVID-19 pandemic. Next, the research gap and the study's novelty are presented, highlighting the lack of work analysing the transition between strict ventilation measures and their progressive relaxation. The methodology used for data collection and analysis is then described. Subsequently, the results are presented

and discussed in different NV scenarios, including correlations between the most influential variables and case studies for a detailed evaluation. Finally, conclusions are drawn and recommendations are proposed to optimise ventilation in educational environments to balance IAQ and thermal comfort.

2. Materials and Methods

In this research, we have analysed how the mandatory ventilation measures during the pandemic and their subsequent relaxation in the post-pandemic period have affected the environmental conditions in universities throughout different seasons of the year. For this, after conducting different measurement campaigns, parameters regarding IAQ and thermal comfort were calculated and statistically analysed. Then, the results obtained were compared with the standards and case studies were developed to evaluate the evolution of the most significant variables over time. Finally, the main conclusions were drawn, the study limitations were identified, and lines of future research were proposed. The methodology followed is presented in Figure 1.

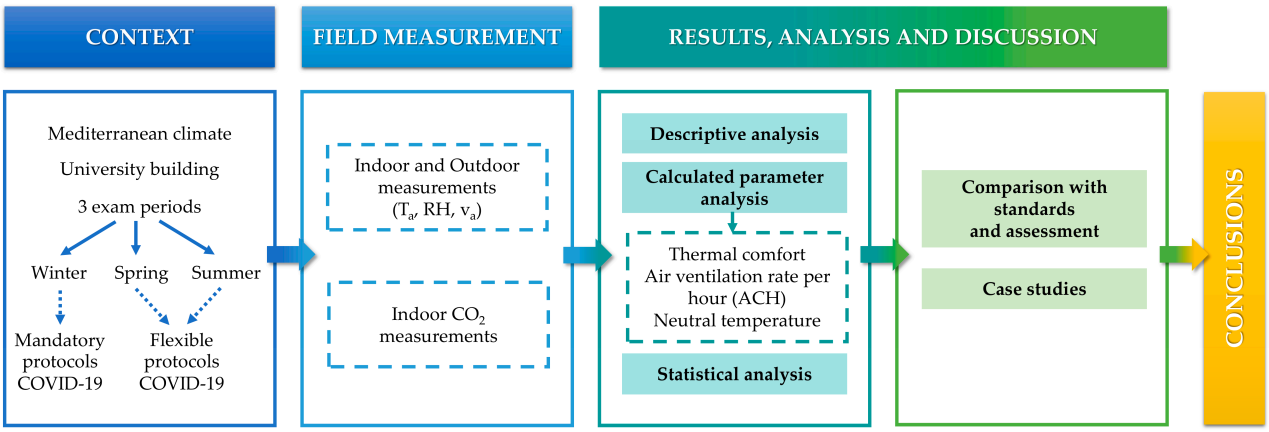


Figure 1. Methodological flow diagram.

2.1. Description of the Building and Selected Classrooms

A technical college located in southwestern Spain (38°53′2.5″–7°0′11″), an area with a Mediterranean climate (Csa) [45], was selected for this research. Winter is usually mild, with temperatures rarely below 6 °C. In summer, maximum temperatures are around 35 °C, with episodes of extreme heat reaching 41–42 °C.

The building chosen has a usable surface area of 11,418 m^2, distributed over four floors: basement, ground floor, first floor, and second floor. All the classrooms have exclusively NV. The interior divisions are made of concrete blocks with direct plasterboard partitioning. There is also a hot water radiator heating system which is used during the winter. Figure 2 shows the following: (a) the location of the building under study; (b) the main entrance, which faces east; and (c) the part of the building where all classroom windows are located, which have a north orientation.

To assess whether the university classrooms studied met the appropriate design criteria, the principal international guidelines were consulted, including the UNESCO Handbook for educational buildings planning [46], the ISO 21001:2018 standard for management systems in educational organisations [47], the ASHRAE 62.1-2019 [11] and 55:2023 [48] standards on ventilation and thermal comfort, and the Council of Educational Facility Planners International (CEFPI) Guidelines for Educational Facilities [49]. These standards address critical aspects such as proportion, layout, and orientation of educational spaces. In addition, they propose that classrooms should be designed to maximise indirect natural

light, ensure optimal thermal comfort, provide an ergonomic environment, and comply with accessibility standards.



(a) (b) (c)

Figure 2. (**a**) Location of the building, (**b**) Main facade of the building, (**c**) North façade.

The selected classrooms have a rectangular shape and surfaces ranging from 64.50 m^2 to 135.50 m^2, with a capacity to accommodate between 42 and 90 students. These dimensions offer between 1.50 and 1.76 m^2 per student, thus complying with standards [46], establishing a minimum of 1.50 m^2 per person to ensure comfort and mobility. With a width of 7.80 metres, optimal visibility and accessibility are ensured from any point in the classroom, while the height of 3 metres complies with CEFPI guidelines [49], guaranteeing adequate air volume and uniform light distribution. The distance of 2.5 metres between the blackboard and the first row of seats, as well as the 60 cm between rows, ensures an ergonomic and comfortable layout for students [46,49].

As for the windows, they are north-facing and located on the left side of the classroom to reduce uncomfortable shadows while students are writing [47]. This arrangement is crucial to avoid glare and overheating, optimising the entry of natural light without directly exposing students to solar radiation [11,48]. In addition, the windows occupy 25% of the exterior walls, complying with UNESCO guidelines [46], which suggest that the window area should cover between 20% and 30% of the exterior walls of the classroom. The windows are of sliding type, with 1.10 m and 2.05 m sashes, and are located 1 metre above the floor [49]. The blinds installed allow effective control of light and heat. Finally, the 3.60-metre-wide doors guarantee a quick and efficient evacuation, meeting the safety requirements demanded for classrooms of this capacity [47].

2.2. Context of Sample Selection

As mentioned above, this paper has analysed the evolution of NV measures since the start of COVID-19 and their impact on the thermal comfort of university students, focusing on the context of assessment exams. These cases are significant because the environmental conditions in the classroom can have an impact on academic performance [24,50]. In addition, there is a high variability of occupancy and time spent in classrooms, in contrast to face-to-face classes [31].

The pandemic led to the closure of Spanish universities on 16 March 2020. Upon resumption of face-to-face educational activities, including assessment exams, in September 2020, a World Health Organization (WHO) guidelines-based protocol was implemented to ensure safety, including mandatory face mask use, capacity control, and ventilation optimisation [51]. In this context, study period one includes examinations conducted between 11 and 29 January 2021. This period was selected due to the strict NV measures and lower outdoor temperatures. By March 2022, the acute phase of the pandemic had passed [52]. During this time, occupancy control became less stringent, and although ventilation was maintained, it was no longer mandatory. Under these conditions, study

periods two and three were selected, corresponding to the examination periods May–June 2022 (18 May to 6 June) and June–July 2022 (20 June to 8 July), respectively. In these periods, outdoor temperatures are higher and, a priori, more comfortable than in Period 1, a hypothesis that will be studied in later sections of this work.

On the other hand, the following criteria were considered for the exam selection: classrooms with more exams of all degrees and courses with different numbers of students on all building floors. Thus, after applying these criteria, 9 classrooms (69.20%) out of the 13 available in the building were analysed, and 50 out of the 200 planned evaluation exams were measured, distributed as follows: 18 samples in Period 1 (36.00%), 20 in Period 2 (40.00%), and 12 in Period 3 (24.00%).

In terms of the number of students tested, a total of 1082 students were tested over the three periods, distributed as follows: 297 in the first period (75.53% male and 24.47% female), 487 in the second period (78.64% male and 21.36% female), and 298 in the third period (82.21% male and 17.79% female). This gender distribution is typical of technical college [53–55].

The time students spent in the classrooms varied considerably due to the nature of the assessment tests, with students leaving as they completed their exams. On average, the exams lasted 2 h and 30 min, while the average time students spent in the classroom was approximately 2 h. The lengthiest exam lasted 4.5 h, while the shortest took only 1 h.

During the first period, teachers were advised that the exams should not last 2 h. This measure was implemented as part of the COVID-19 pandemic safety protocols to minimise the amount of time students spent in enclosed spaces and reduce the risk of contagion [51]. To avoid crowds, the exams were spread over three time slots: two in the morning at 08:00 and 11:30 and one at 16:30. In addition, it was suggested that students wait outside the building until the test started and were invited to enter progressively, following the teacher's instructions to take their assigned seats, thus maintaining a safety distance of 1.50 metres inside the classrooms.

In Periods 2 and 3, after the return to normality in the classrooms, the exams were limited to the morning shift, maintaining the two time slots of 8:00 and 11:30. On this occasion, students were allowed to wait inside the school until the teacher arrived in the corresponding classrooms. In some cases, if the classroom doors were open, students could enter as they arrived. The average waiting time in the building before the exams was approximately 20 min.

2.3. Equipment Used for the Assessment of Ventilation and Thermal Comfort Conditions

IAQ and ventilation conditions were assessed using a PCE-AQD 20 m (PCE Instruments), which measures CO_2 concentration in the range of 0 to 10,000 ppm. In addition, for indoor microclimate assessment, an HD32.1 thermal environment meter (Senseca, Padua, Italy), which measures air temperature (accuracy of $\pm 0.01^{\circ}$), relative humidity (accuracy of $\pm 0.1\%$ RH), and air velocity (accuracy of $\pm 0.05 + 0.5\%$ measure m/s), was used. The data were recorded and processed with DeltaLog 10 software (V1.1.0.11, Senseca, Padua, Italy). Outdoor environmental conditions were recorded using a Watchdog 2000 weather station (PCE Instruments, Albacete, Spain).

Environmental parameters and ventilation conditions were monitored at one-minute intervals during the examinations. The CO_2 meter, model PCE-AQD 20 (PCE Instruments, Albacete, Spain), was placed at the back of the classrooms, 1.50 m from the walls and 1 m from the breathing zone of the individuals [56]. The thermal environment equipment was placed in the centre of the rooms to provide a representative assessment of the microclimate during testing. Both devices were turned on 15 min before student entry to ensure stable

measurements. A representation of the classroom layout and the location of the equipment is shown in Figure 3.

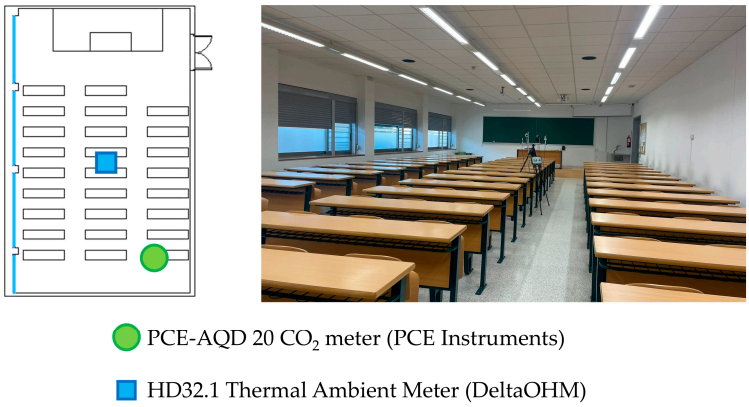


Figure 3. Location of measurement equipment in classrooms.

2.4. Assessment Methods and Reference Values

2.4.1. Thermal Comfort Study

Fanger's experiments for estimating thermal comfort were conducted in climate-controlled chambers, where groups of subjects were subjected to various environmental conditions while engaged in light or sedentary activities. Participants rated their thermal comfort, which allowed the development of the predicted mean vote (PMV) index, which predicts the average thermal sensation of a group [57]. The rating of each point on the PMV scale corresponds to one of the following options: cold (−3), cool (−2), slightly cool (−1), neutral (0), slightly hot (+1), hot (+2), very hot (+3). The recommended PMV range for thermal comfort is $-0.50 < \text{PMV} < +0.50$ [58].

To calculate the PMV it is necessary to consider, in addition to environmental variables, personal factors such as thermal clothing insulation and energy metabolism [57]. Both factors were calculated according to ISO 7730:2005 [58]. As all participants remained seated during the examinations, a metabolic rate of 70.00 W/m^2 (1.20 met) was applied.

In addition, the predicted percentage of dissatisfied (PPD) evaluates the dispersion of votes around the PMV obtained and reflects the percentage of individuals who would perceive the thermal sensation as unpleasant, either too cold or too warm. This factor is given by Equation (1).

$$PPD = 100 - 95 \cdot \exp\left(-0.03353 \cdot PMV^4 - 0.2179 \cdot PMV^2\right) \quad (1)$$

It is important to mention that, although Fanger's indices were initially designed for climate-controlled indoor environments, their application has extended to spaces with natural ventilation, such as classrooms [33,40,59–61]. In these contexts, it is essential to consider the appropriate design of spaces to maximise thermal comfort following established regulations and guidelines [50,62].

At the same time, to evaluate the NV effect, the thermal comfort level was analysed following the guidelines established in Regulation on Thermal Installations in Buildings (RITE) [63], ISO 7730 [58], ASHRAE Standard 55 [48], and EN 16798-1 [64].

Firstly, RITE establishes an operative temperature (T_{op}) in buildings of 21 to 23 °C in winter and 23 to 25 °C in summer, a relative humidity (RH) between 30 and 70%, and an air velocity (v_a) not exceeding 0.20 m/s [63]. The T_{op} calculation is given by Equation (2), where T_a is the air temperature (°C), T_{rm} is the mean radiant temperature (°C).

$$T_{op} = (T_a + T_{rm})/2 \quad (2)$$

On the other hand, ISO 7730:2005 establishes ranges of T_{op} and air velocity (v_a) according to the three categories of thermal environment. In this case, the selected category was "B", which implies a PPD < 10%. The T_{op} range for summer is 24.50 ± 1.50 °C, while for winter it is 22.00 ± 2.00 °C. As for v_a, the maximum allowed in summer is 0.19 m/s and in winter it is 0.16 m/s [58].

ASHRAE Standard 55-2023 establishes comfort temperature (T_c) ranges based on adaptability and a 90% level of acceptability (PPD < 10%, Category I). The limiting operative temperatures within this range are obtained by adding ±2.50 °C to the optimal comfort temperatures, defined by the equation given in (3), where T_{out} represents the average outdoor temperature, measured in °C [48].

$$T_c(ASHRAE\ 55) = 17.80 + 0.31 \cdot T_{out} \quad (3)$$

Finally, the model described in EN 16798-1:2020 applies to buildings with NV where occupants perform activities with a low metabolic rate. In this study, a normal expectation level (Category II) has been chosen, with a PPD of less than 10% and an acceptability range of ±3.00 °C around the T_c calculated by Equation (4) [64].

$$T_c(EN\ 16798-1) = 18.80 + 0.33 \cdot T_{out} \quad (4)$$

2.4.2. Indoor Air Quality Study

As mentioned, the most widely used IAQ is the CO_2 levels quantification, measured in parts per million (ppm) [65]. For educational buildings, ASHARE 62.1 sets different ventilation levels according to CO_2 concentration. Thus, the limit for good ventilation is 1000 ppm [11]. However, to reduce the spread of COVID-19, authorities recommended a maximum value of 800 ppm [66].

The air ventilation rate per hour (ACH) measures the air renewal in a space for one hour by introducing a volume of outdoor air equivalent to the room size [67]. Equation (5) was used to determine the ventilation rate [67–69], where c_0 is the initial concentration of CO_2 inside the classrooms, c_1 is the CO_2 concentration inside the classrooms at time t_1, t_0 is the start time of the measurement, t_1 is the final moment of the measurement (both in hours), and c_{out} is the average outdoor CO_2 concentration set at 450 ppm [33]. It should be noted that, before the study, measurements were taken of the CO_2 levels outside, in the vicinity of the building analysed. The results showed an average variability of less than 4%, so using a constant CO_2 value for the outside was decided [70].

$$ACH = \frac{-1 \cdot \ln\left(\frac{c_1 - c_{out}}{c_0 - c_{out}}\right)}{t_1 - t_0} \quad (5)$$

Simultaneously, EN 16798-3:2017 classifies IAQ into four categories (indoor air, IDA), according to the building's use, proposing an outdoor air flow rate per person. For classrooms, categorised as IDA 2, they recommend an air exchange of 12.50 L/s per person [9]. However, during the COVID-19 pandemic period, authorities recommended an airflow of 14.00 L/s per person [71]. Subsequently, ASHRAE Standard 241-2023 defined for classrooms that the minimum equivalent clean air flow per person in the infection risk management mode should be 20.00 L/s per person [72]. Expression (6) was used to determine the theoretical ventilation rate based on the values provided [67–69], where V is the volume of different classrooms.

$$ACH_{theoretical} = \frac{\left(\frac{\mathrm{L}}{\mathrm{s}} per\ person\right) \cdot (no.\ of\ people) \cdot \left(3600 \frac{\mathrm{s}}{\mathrm{h}}\right) \cdot \left(0.001 \frac{\mathrm{m}^3}{\mathrm{L}}\right)}{V(\mathrm{m}^3)} \quad (6)$$

Lastly, various guidelines for testing ventilation rates recommended between 5 and 6 air changes per hour for classrooms with an approximate surface area of 100 m^2 [69].

2.4.3. Statistical Analysis and Case Studies

The data collected for all variables were statistically analysed using IBM SPSS software (version 23.0). Pearson's correlation coefficient was used to assess the relationships between the different quantitative variables. This analysis allowed us to identify significant correlations between environmental conditions like CO_2 concentration, temperature, or air velocity, personal variables such as clothing, and classroom factors, including occupancy and window opening. The definition of Pearson's correlation coefficient, its interpretation, and the strength correlation scale (Table A1) are given in Appendix A.

According to the results obtained in the statistical analysis, the most representative tests that showed the strongest correlations of the parameters related to IAQ and thermal comfort were chosen. Thus, different case studies were used to independently assess how these variables evolved and behaved throughout the duration of these tests. For this purpose, cases were chosen that share specific characteristics, for example, classrooms with the same surface area, occupancy, window openings, etc.

3. Results and Discussion

This section of the paper begins with a descriptive analysis that provides an overview of the data collected over the different study periods. Variables such as the average occupancy of the classrooms, the available surface area per person, the degree of openness of the windows, and the level of thermal insulation of the students' clothing are described. Then, the classroom thermal comfort conditions are evaluated for the three periods analysed, starting with the results of both indoor and outdoor environmental parameters. Next, we examine how these conditions influence students' thermal perception, using the PMV and PPD indicators, and present a comparison between the calculated operative temperatures and different national and international thermal comfort standards. IAQ levels are then evaluated through CO_2 concentration and air change rates per hour (ACH) to analyse the evolution of the NV measures applied during the studied periods and compare them with various recommendations and regulations consulted. Finally, the statistical analysis results are presented to identify the most influential variables on thermal comfort and IAQ. Once identified, different case studies are presented to evaluate the evolution and behaviour of these variables over time in the most representative tests.

3.1. Descriptive Analysis

Regarding the average number of students per classroom, Figure 4a shows the evolution of the occupancy limitation measures. In the first period, the average occupancy was 1.50 times lower than in Periods 2 and 3, indicating that the capacity reduction protocol was no longer applied when moving from the acute phase of the pandemic to the surveillance and control phase. Likewise, the evolution in the occupancy ratio (OR), defined as the available surface area (m^2) per person, is shown in Figure 4b. The OR in the first period ranged from 3.47 to 27.10 m^2/person, whereas in Period 2, the range was much smaller (between 1.91 and 9.46 m^2/person). Based on these results, the evolution of occupancy restriction measures is evident. However, in Period 3, the OR increases again to between 2.95 and 19.36 m^2/person. In this case, this is a consequence of the fact that, due to the lower number of tests planned, the classrooms designated for the examinations were the largest of this university centre. In general, the area per person was in all periods larger than that reported in other studies before the pandemic, where the OR was around

2.00 m^2/person [73–76]. However, the results of this research are more in line with the ORs observed in work carried out during COVID-19 [77–79].

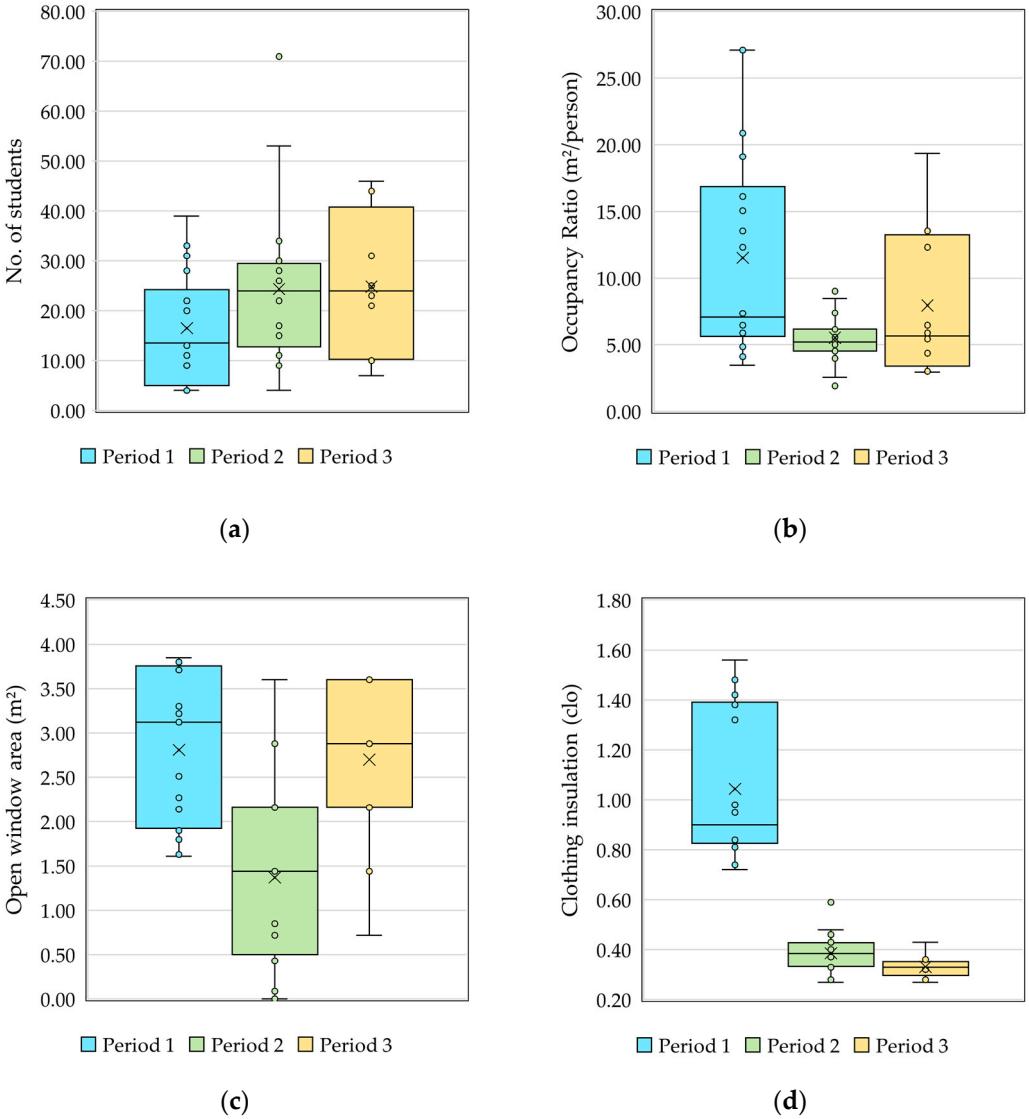


Figure 4. (**a**) No. of students, (**b**) Average occupancy density in m^2/person and (**c**) Average window opening in m^2, (**d**) Clothing insulation in clo, per period.

On the other hand, Figure 4c presents the window openings distribution (WO) by period. The average data reveal that ventilation measures were more stringent in Period 1 (2.81 m^2) compared to Periods 2 and 3 (1.37 and 2.70 m^2, respectively) despite the winter temperatures. This highlights the importance of such measures during the period of highest COVID-19 transmission [38,80,81]. It is noted that the strategy of encouraging NV persisted in classrooms during the transition from the acute to the surveillance phase, albeit in a less restrictive manner.

As shown in Figure 4d, the average thermal insulation of the students' clothing was determined following the ISO 7730:2005 Standard [58] and by direct observation, recording the participants' clothing at the time of the evaluation. In this way, in Period 1, the clothing insulation was 1.04 clo, while in Periods 2 and 3, it was reduced to 0.39 clo and 0.33 clo, respectively.

3.2. Thermal Comfort Evaluation

3.2.1. Indoor and Outdoor Environmental Parameters

Table A3 (Appendix B) shows the results of the indoor and outdoor environmental parameters measured in the different periods and the calculated values of T_{op}. The differences between the indoor and outdoor parameters are evident. Indoor air renewal was performed with continuous NV by opening doors and windows, so indoor environmental variables were influenced by this protocol [32,33,73]. This effect was most pronounced in Period 1, during the acute phase of the COVID-19 pandemic, when ventilation was intensified. In addition, the tests in this period were conducted under highly variable temperature conditions, due to the influence of a cold snap during the first half. Regarding relative humidity and indoor air velocity, the average values remained within the limits set by the standards [58,63].

3.2.2. Assessment of Thermal Comfort Results Using the PMV-PPD Indices

Figure 5 below shows the percentage distribution of the PMV categories by study period. The votes are concentrated between the thermal sensation "cool" and "slightly warm". During Period 1, despite low indoor temperatures and strict NV protocols, the highest percentage of thermal neutrality (61.11%) was noted. In studies conducted in winter during the COVID-19 pandemic, a prevalence of "slightly cool" has been observed in classrooms with natural ventilation and heating [33,36,82]. However, in studies conducted before the pandemic, the predominant PMV category was "neutral" [15,83–85].

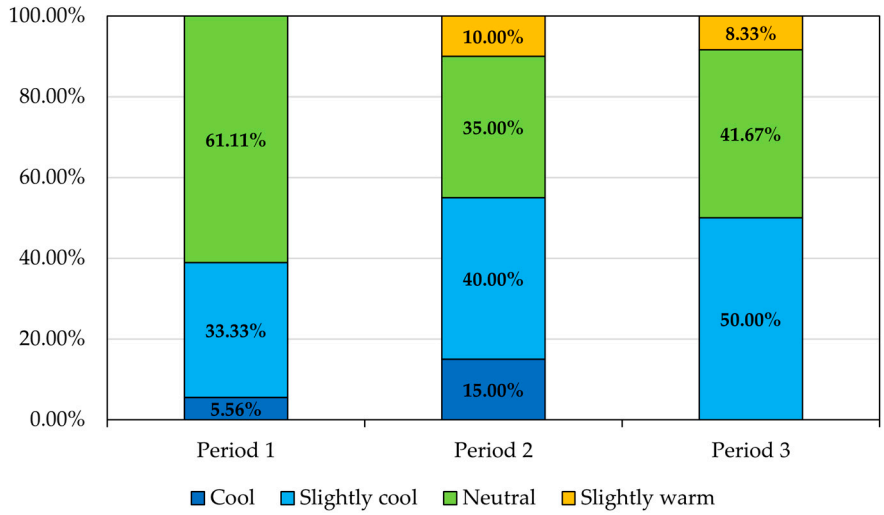
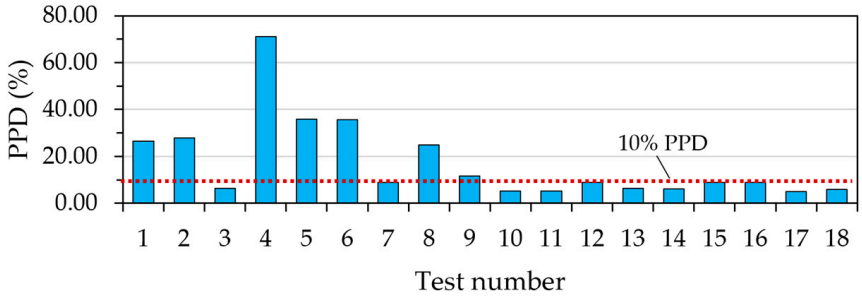


Figure 5. Distribution of PMV categories by period.

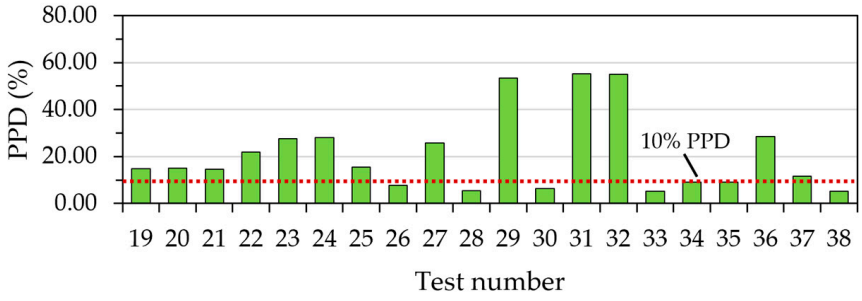
In Periods 2 and 3, although with milder weather conditions and the possibility to adjust ventilation measures, the predominant thermal sensation was "slightly cool" (40.00% and 50.00%, respectively). This contrasts with previous research that has observed a majority feeling between "slightly warm" and "hot" in this climate [84,86,87]. However, in some studies in air-conditioned classrooms, the calculated PMV is in the thermal neutrality zone, although with an inclination towards the "slightly cool" category [53,88].

Similarly, Figure 6 shows the percentage of dissatisfied (PPD) for the 50 tests performed in all periods. In Period 1 (Figure 6a), two phases can be seen in the results. Initially, when tests 1 to 9 were conducted, T_{out} were exceptionally low for this climate zone [33], directly affecting indoor climatic conditions due to the mandatory NV protocols. As a result, during this half of the period, PPD exceeded the 10.00% limit in most of the tests [58]. Test number 4 recorded the highest percentage of dissatisfaction, reaching 71.12%. In the second half of this period (Tests 10 to 18), climatic conditions normalised and, although winter low

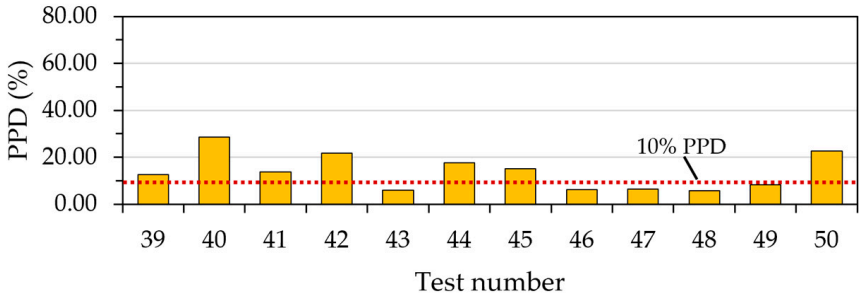
temperatures persisted, adequate thermal comfort levels were reported. As depicted in Figure 7, students during this period adapted their level of clothing (I_{cl}) according to the outside temperatures recorded, revealing a high correlation between both parameters (R^2 = 0.9126). Moreover, due to the strict ventilation protocols, the adaptability of clothing choice was reflected in the comfort observed. It is relevant to note that the clothing level in this study was higher than in other studies for similar conditions. Specifically, Torriani et al. [83] and Jowkar et al. [87] recorded thermal insulation of clothing around 0.90 clo, while de la Hoz-Torres et al. set it at 0.73 clo [89]. These results have suggested that students chose their clothing in anticipation of the expected low indoor temperatures during exams [87] to minimise any negative impact on their performance [90,91].



(**a**)



(**b**)



(**c**)

Figure 6. Distribution of the Percentage of Dissatisfied (PPD): (**a**) Period 1, (**b**) Period 2, and (**c**) Period 3.

On the other hand, during Periods 2 (Figure 6b) and 3 (Figure 6c), the majority of the tests (65.00% and 58.30%, respectively) were conducted in cold discomfort, despite average indoor temperatures of 24 °C. This could be partly due to the clothing level not being correctly selected. The average clothing insulation was 0.39 clo for Period 2 and 0.33 clo for Period 3. The discomfort experienced in some tests (tests 23, 24, 27, and 40) could also be related to the wide temperature range in which they were conducted [40]. Students chose clothing according to the weather conditions that were expected throughout the day. This effect was more pronounced

in the early morning tests. A poor clothing choice can generate significant deviations on the PMV scale (from 0.20 to 0.45 units) as a function of temperature [92]. As shown in Figure 7, the correlation between these parameters was lower compared to the previous case (R^2 = 0.3564 for Period 2 and R^2 = 0.5923 for Period 3). Also, based on the low slopes obtained in the regression equations (0.5724 for Period 2 and 0.4978 for Period 3), it was found that, for the variations in T_{out} observed in these two periods (between approximately 15.00 and 35.00 °C), the value of I_{cl} ranged only between 0.27 and 0.60 clo. Furthermore, differences in clothing habits from 15.00 to 20.00 °C (an interval in which temperatures coincide in all periods) have suggested that seasonal patterns may be more influential than a response to actual climatic conditions [89]. There is considerable variability when the clothing in this study is compared with that reported in previous studies. Thus, Guevara et al. reported an I_{cl} value of 0.85 clo when the outside temperature (T_{out}) was 18.60 °C and classrooms were naturally ventilated. At the same time, when the T_{out} range was between 23.00 and 27.50 °C and air conditioning systems were used, the clothing level recorded was 0.50 clo. However, cold discomfort was reported in these conditions [53]. For primary school children at T_{op} of 27.00 °C, Aparicio-Ruiz et al. observed clothing insulation values between 0.29 and 0.32 clo. In this case, a majority thermal sensation of "slightly warm" was detected [86]. For the same range of indoor temperatures, Balbis-Morejón et al. reported higher clothing values (between 0.50 and 0.57 clo), possibly due to the cooling [88].

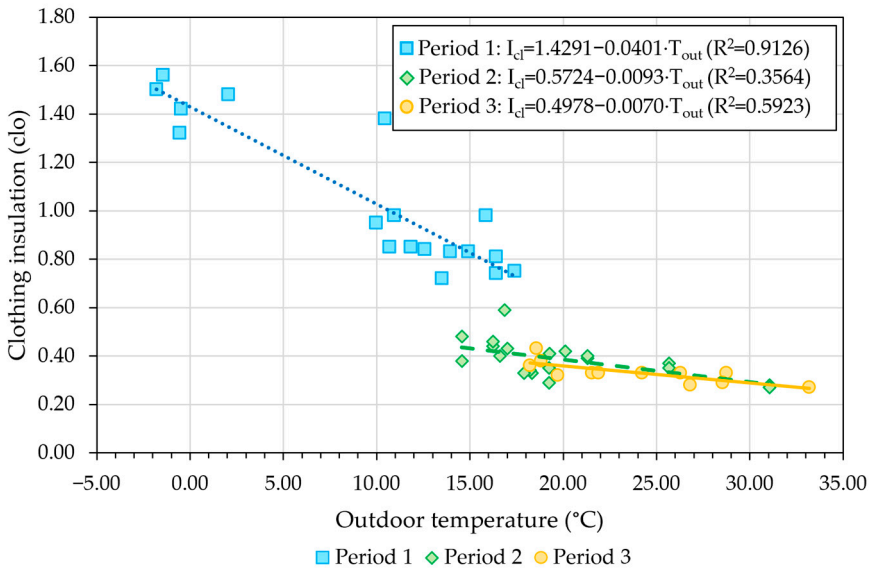


Figure 7. Clothing insulation in relation to mean outdoor temperature by period.

Finally, in the tests with a higher percentage of dissatisfaction (tests 29, 31, and 32), the higher air velocity recorded outside, and consequently inside the classrooms due to the windows opening, has played a crucial role in estimating the students' thermal discomfort. The strong influence of this parameter on PMV has been reported by several authors [93,94].

3.2.3. Thermal Comfort According to Different Standards

Figure 8 presents a comparative analysis between the T_{op} and the thermal comfort standards [48,58,63,64]. The results reveal significant variations in the comfort concerning the PMV distribution in Figure 5. It is important to note that the limits depicted in Figure 5 are based exclusively on the evolution of the operative temperature over the outdoor temperature. In contrast, the PMV depends on environmental (air temperature, radiant temperature, air velocity, relative humidity) and personal (metabolic rate, clothing insulation) combination factors [57].

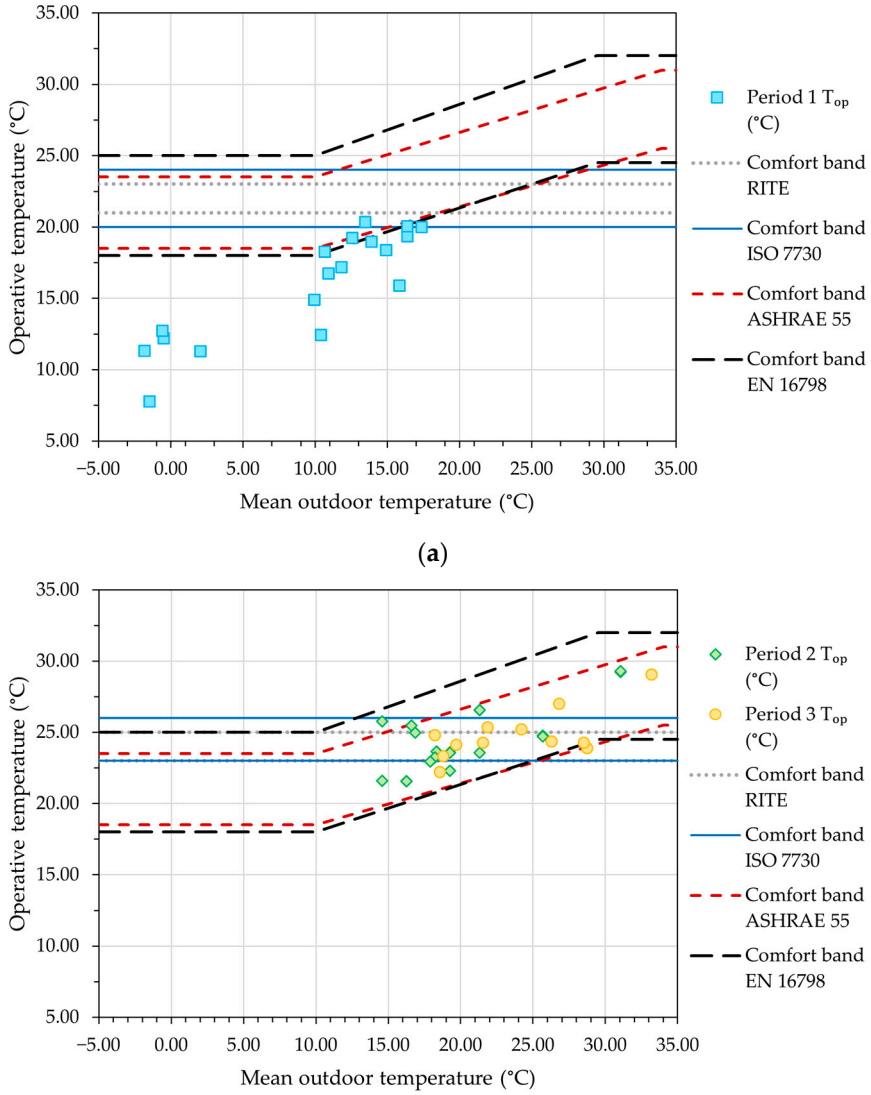


Figure 8. Comparison with Standards: (**a**) winter conditions (Period 1) and (**b**) spring and summer conditions (Period 2 and 3).

Practically all tests carried out in winter conditions (Figure 8a) were below the lower comfort limits. In this climatic scenario, RITE could be considered the most restrictive standard [63], as none of the tests met its thermal comfort range. In contrast, EN 16798-1:2020 had a wider comfort range, with 4 of the 18 tests (22.22%) performed in Period 1 falling within its limits [64]. These findings are consistent with previous studies conducted in educational buildings under the same conditions. For example, in the research carried out by Campano et al., operative temperatures around 19.50 °C were observed with outdoor temperatures close to 10.00 °C, both in heated and unheated classrooms. This could suggest that heating classrooms in these pandemic conditions would not have a sufficient effect [84]. In contrast, in mechanically ventilated classrooms, Ding et al. found no evidence of discomfort conditions as prescribed by the regulations consulted in their case [38]. On the other hand, Alonso et al. detected a discomfort rate in 99.00% of the tests, as indoor temperatures did not reach the lower comfort limits. At the same time, the same study also evaluated the environmental conditions in the classrooms before COVID-19. In this case, a large percentage of discomfort was experienced because the upper temperature limits were exceeded in many cases due to heating use [77].

For the spring and summer conditions depicted in Figure 8b, most of the tests were found to be within the limits of one of the standards. Both RITE [63] and ISO 7730:2005 [58] had more than half of the tests within their comfort ranges. In Periods 2 and 3, 5 tests out of the 32 performed (15.63%) were below their lower limits. Above the upper ranges (25.00 °C for RITE [63] and 26.00 °C for ISO 7730:2005 [58]), eight tests (35.00%) were found. Regarding ASHRAE Standards 55-2023 [48] and EN 16798-1:2020 [64], 90.00% of the tests met comfort conditions. These results do not differ significantly from other studies conducted during COVID-19 [79,84,95]. Similarly, no discrepancies were observed in pre-pandemic research [96–98].

The linear regression application to analyse the relationship between PMV and operative temperature enables an understanding of how occupant perception varies [53]. Using the resulting linear equation, it is possible to calculate the neutral temperature (T_n) and the temperature range in which the votes are within the comfort interval ($-0.50 < \text{PMV} < +0.50$) [57]. Figure 9 shows the linear regression of the PMVs for the three study periods, together with the PMV ranges for the three thermal environment categories defined by ISO 7730:2005 and the T_{op} limits for winter and summer conditions [58].

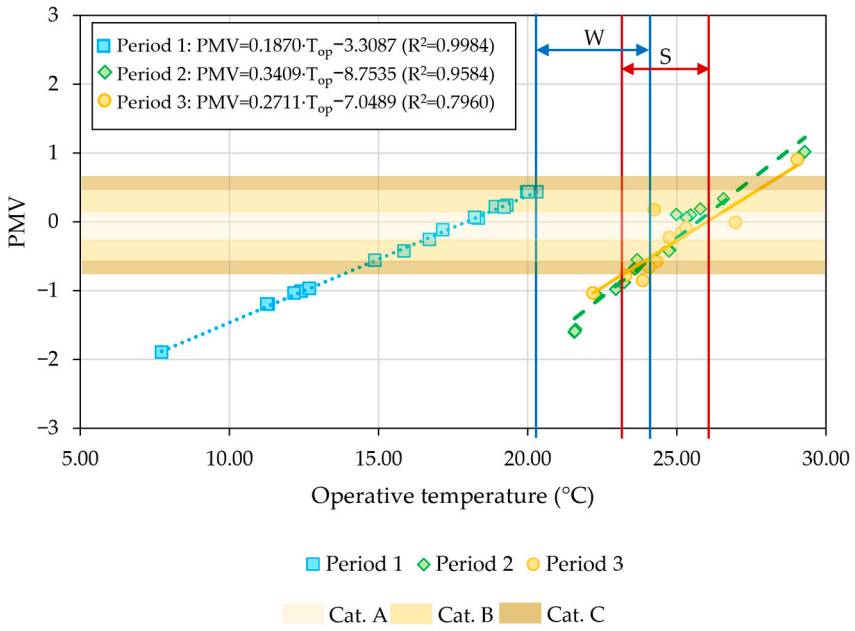


Figure 9. PMV vs. Operative Temperature according to ISO 7730:2005 Standard per period.

Regarding the T_{op} values recorded in Period 1, practically none were in the winter range. Nevertheless, 13 out of the 18 tests (72.22%) were within the comfort limits. As for the values for Periods 2 and 3, the temperature showed a narrower range than in the previous period. Here, 21.85% of the tests were outside the T_{op} range determined for the summer. Specifically, three tests were below the minimum temperature and four were above 26.00 °C, defined as the upper limit. In both periods, 18.75% of the tests were below the lower limit for category C of ISO 7730:2055, while 6.25% exceeded the upper limit [58].

Also, according to the results derived from the regression equations when PMV = 0, T_n has been estimated at 17.90 °C for Period 1, 25.70 °C for Period 2, and 26.00 °C for Period 3. In general, other works have reported neutral temperatures higher than that obtained for the winter season [15,84,99–101]. For example, the T_n obtained by Rus et al. for naturally ventilated classrooms with a heating system in operation was 24.44 °C [36]. Subsequently, after the mandatory ventilation protocols' elimination, Miao et al. evaluated IAQ and thermal comfort in classrooms in a Mediterranean climate zone. In this study, a neutral temperature of approximately 21.00 °C was calculated [102]. On the other hand, for spring climatic

conditions, a lower T_n than that calculated in the present study has also been observed. Aparicio-Ruiz et al. [86] recorded neutral temperatures around 22.00 °C. However, the T_n collected from other investigations carried out during the summer were very similar to that reported in this work [15,53,88,102]. Finally, the slopes of the PMV linear regression equations in Periods 2 and 3 were higher than in Period 1, suggesting a higher thermal sensitivity of pupils in spring and summer [15].

3.3. Indoor Air Quality (IAQ) Evaluation

3.3.1. CO_2 Concentration Levels

Figure 10 presents the CO_2 levels ranges, measured in ppm, for the three periods, along with the recommended limit for effective ventilation to reduce virus spread (800 ppm) [66]. This value has been used in other studies [33,77,103]. An average concentration of 1000 ppm has also been included as a recognised indicator [11]. The average CO_2 concentrations measured during the three periods were below the health limit of 800 ppm (554.48 ppm for Period 1, 675.83 ppm for Period 2, and 577.32 ppm for Period 3).

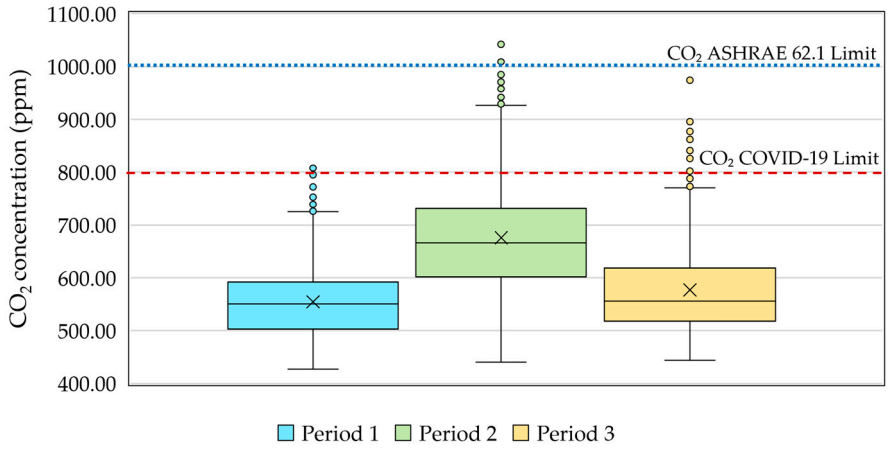


Figure 10. CO_2 concentration in ppm by period.

The lowest range of CO_2 (between 440.00 and 808.00 ppm) was observed in Period 1, remaining consistently below the safety threshold established during the COVID-19 pandemic, indicating the effectiveness of the NV measures. Previous studies in schools during the pandemic have reported similar CO_2 concentrations [33,35,67,104]. Thus, Villanueva et al. found average CO_2 levels of 539.00 ppm in preschool classrooms, 565.00 ppm in primary classrooms, and 661.00 ppm in secondary classrooms [105]. Aguilar et al. evaluated the impact of NV on the thermal perception of university students during the cold season. Their results showed that, in 90.00% of the classrooms evaluated, CO_2 concentrations were below 800 ppm (mean value of 566.40 ppm) [32]. Similarly, Alonso et al. compared IAQ in classrooms before and during the pandemic, observing a decrease of 300 ppm in weekly average CO_2 values when hybrid ventilation was used and a decrease of 400 ppm when NV measures were used [77]. However, in some cases, NV measures proved to be insufficient. In the case of investigations by Zemitis et al. [106] and Vassella et al. [107], the average CO_2 concentration was around 2000 ppm.

At the same time, the variability in values was significantly higher in Period 2 (between 440.00 and 1042.00 ppm), at times even exceeding 1000 ppm. These results would be consistent with the smaller area of open windows and higher classroom occupancy. During Period 3, CO_2 concentrations decreased compared to the previous period, ranging from

444.00 to 974.00 ppm. Although the average number of students remained the same, an increase in window openings was observed, possibly due to the slightly higher temperatures. In work carried out without the mandatory ventilation measures, higher CO_2 levels were observed than those obtained for these two study periods. For example, in rooms where windows were closed during monitoring, CO_2 concentration ranged between 1000 and 2000 ppm most of the time, as reported by Krawczyk et al. [75], Campano et al. [108], and Madureira et al. [109].

To continue, Figure 11 shows the percentage frequency of CO_2 measurements, classified according to the four categories of ASHRAE Standard 62.1 [11]. During Period 1 and Period 3, for most of the measurement time (78.65% and 68.61%, respectively), values between 400 and 600 ppm were recorded, indicating excellent ventilation levels. These data would show, on the one hand, the strict compliance with the mandatory ventilation measures during the most critical phase of COVID-19 existing in Period 1 of the study. On the other hand, as observed in Period 3, they would underline the acquired importance of maintaining good IAQ conditions. The range between 600 and 800 ppm had the highest frequency (63.14%) in Period 2. Although CO_2 levels were higher, the quality of ventilation would be very good. Overall, 85.80% of sampling time was below 800 ppm in all three periods [66]. In the study by Korsavi et al., 45.00% of the CO_2 measurements recorded in NV classrooms were below the upper limit given by ASHRAE Standard 62.1 (1000 ppm) [11,103]. In a similar investigation by Dascalaki and Sermpetzoglou, in 66.00% of the monitoring time points, 850 ppm was not exceeded, because windows and doors were kept open during peak occupancy hours [110]. Finally, Diaz et al. compared IAQ conditions in classrooms at different times of the year. During winter, with windows closed, it was observed that, most of the time (56.00%), CO_2 levels exceeded 1400 ppm. In contrast, during spring, when classrooms were naturally ventilated, CO_2 values remained below 800 ppm 80.00% of the time [73].

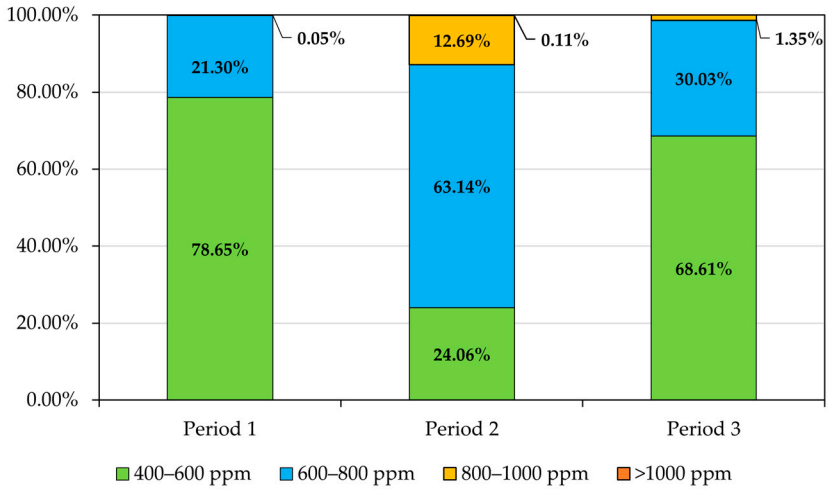
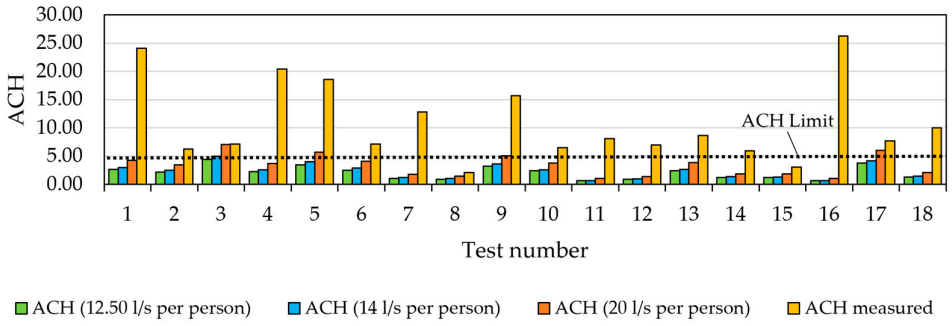


Figure 11. Distribution of CO_2 levels per period, according to ASHRAE 62.1.

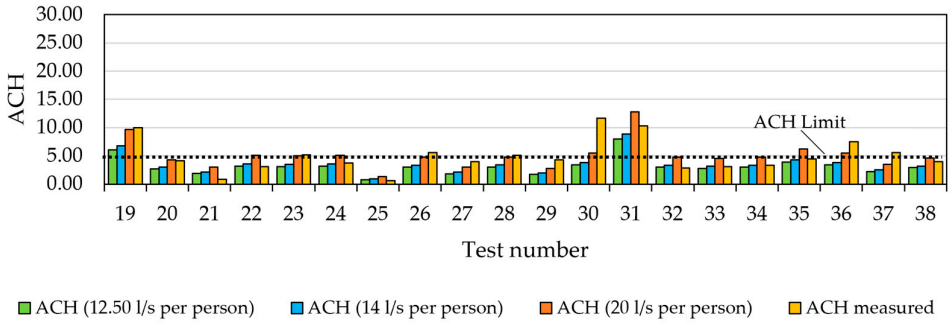
3.3.2. ACH by Natural Ventilation in Each Test

Figure 12 presents the ACH values calculated from experimental CO_2 measurements using Equation (5). In addition, air changes have been calculated according to the minimum theoretical ventilation flow rate (12.50 L/s per person) proposed by EN 16798-3:2017 for IDA category 2 buildings [9], as well as ACHs according to the air flows defined by the authorities during the COVID-19 pandemic (14.00 L/s per person) [71] and by the ASHRAE 241-2023 Standard (20.00 L/s per person) [72] using Equation (6). Experimental and theoretical calculations depend on the volume of the rooms studied and their occupation

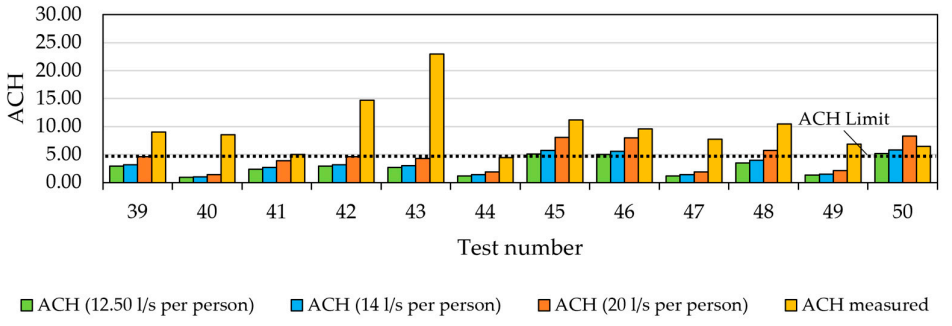
level. In addition, each test considers the surface area of windows and/or doors open to determine air changes. The recommended minimum ACH level for adequate ventilation is represented as well (black dotted line) [71].



(**a**)



(**b**)



(**c**)

Figure 12. ACH by test vs. minimum proposed by EN 16798-3:2017 (1000 ppm) and to reduce COVID-19 infections (800 ppm) to ensure an adequate ventilation level: (**a**) Period 1, (**b**) Period 2, and (**c**) Period 3.

In Period 1 (Figure 12a), it was observed that the ACH values obtained from the real CO_2 measurements in most of the tests were above the five minimum air renewals established by Allen et al. for classrooms [69]. Only two tests (8 and 15) had values slightly below 3 ACH, indicating potentially poor ventilation. However, when considering CO_2 levels, both tests had average concentrations below 550.00 ppm, indicating optimal IAQ according to this criterion. Also, these two tests were characterised by a very high occupancy ratio (OR) (20.88 and 27.10 m^2/person, respectively). This may indicate that the ACH indicator may not be adequate if taken alone when the occupancy of the enclosures is low. Therefore, it would be advisable to combine at least two ventilation-related parameters when concluding on IAQ [33]. Finally, when comparing the measured ACH values with

the theoretical values, it was observed that, in all cases, the minimum requirements for adequate airflow were exceeded [9,71,72].

A different scenario is observed in Period 2 (Figure 12b), in which the average ACH was 4.96. In 60.00% of the tests, there were five renewals per hour. Although CO_2 levels were higher than in the previous period due to the NV relaxation measures, they rarely exceeded 800 ppm. By this measure, IAQ could be considered as very good. However, discrepancies between the two assessment methods have again been reported. As in Period 1, the ACH indicator would not be entirely suitable for making air quality decisions in situations of higher occupancy [69]. Lastly, only the ACH values calculated for tests 21, 22, and 32 were below the theoretical values suggested by EN 16798-3 to avoid COVID-19 contagion [9,71]. The air changes measured in half of the tests were insufficient to guarantee the correct control of infectious aerosols given by ASHRAE Standard 241-2023 [72]. This is possibly due to a smaller open area in these cases.

For the Period 3 tests (Figure 12c), only test 44 was below the 5 ACH recommended, with the average ACH for the whole set being 9.71. It is worth noting that the CO_2 measurements taken during this period were found to be more in keeping with the indoor renewals achieved. In these tests, the average occupancy was like that reported by Allen et al. (25 students per 100 m^2) for the NV evaluation in classrooms [69]. Therefore, only when occupancy is in the average range should ACH be used to assess IAQ [33]. As in Period 1, higher window openings contributed to higher ACH values than the theoretical calculations. Last but not least, it is significant to note that the air changes for all the tests, except test number 50, exceeded the theoretical minimums recommended by the various standards consulted [9,71,72].

As in this study, the air renewals obtained by other authors depended on NV strategies and occupancy. Rey-Hernández et al. obtained an average of 3.86 ACH, which was insufficient due to the lack of cross-ventilation [67]. De la Hoz-Torres et al. obtained between 6.10 and 8.80 ACH with all windows open and between 4.60 and 8.40 ACH with partial opening [111]. However, both Hama et al. [112] and Abhijith et al. [113] reported lower ACHs (2.30 and 2.11, respectively) in naturally ventilated London primary schools.

In conclusion, it is essential to highlight the close relationship between IAQ and energy consumption, even in buildings that rely exclusively on natural ventilation [114], such as the university centre studied. Although there has been no direct measurement of energy consumption in this work, this relationship has been evident throughout Period 1 of the study. As mentioned above, implementing strict ventilation measures was crucial to reduce the spread of the virus during the COVID-19 pandemic, which indirectly influenced the building's energy consumption. Although natural ventilation does not use energy in the same way as mechanical ventilation systems, the prolonged opening of windows during cold months can increase heating demand as it attempts to maintain thermal comfort in classrooms [115]. In contrast, in periods with more favourable climatic conditions (Periods 2 and 3), it was possible to achieve a better balance between air quality and energy consumption. In these cases, natural ventilation can not only improve IAQ but also contribute to thermal comfort, thus reducing the need for additional energy expenditure [116].

3.4. Results of Statistical Analysis and Case Studies

As mentioned above, a Pearson correlation analysis was performed to assess the relationship strength (r) between variables. The closer r is to zero, the weaker the linear relationship [117]. Table 1 shows a summary of the results obtained in this statistical test for all periods, while the detailed results, broken down by study period, are presented in Table A2 in Appendix A. As can be seen, the most prominent factors for calculating thermal comfort (PMV) were operative temperature, air velocity, and clothing chosen by the

students. For IAQ conditions, defined by ACH and CO_2 concentration, two main factors were identified: window opening and occupancy ratio.

Table 1. Pearson correlation matrix for the set of all study periods.

Variables	OR	WO	CO_2	ACH	T_{op}	v_a	I_{cl}	PMV
OR	1							
WO	0.061	1						
CO_2	−0.629 **	−0.811 **	1					
ACH	−0.678 **	0.829 **	−0.749 **	1				
T_{op}	−0.175	−0.403 *	−0.322	−0.387	1			
v_a	−0.182	0.334	−0.651 *	−0.614 *	0.683	1		
I_{cl}	0.152	−0.074	−0.124	0.211	−0.849 **	0.204	1	
PMV	−0.132	0.132	0.419	−0.109	0.717 **	−0.613 *	−0.701 **	1

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

3.4.1. Case 1: Influence of Clothing Level on Thermal Comfort

In this first case (Figure 13), the influence of the clothing level chosen by the students on the PMV was assessed, and the variation in T_{op} was analysed. For this purpose, three tests were selected for each period studied, with an outside temperature of 18.00 °C. Window openings were similar in all cases (between 2.88 and 3.00 m^2).

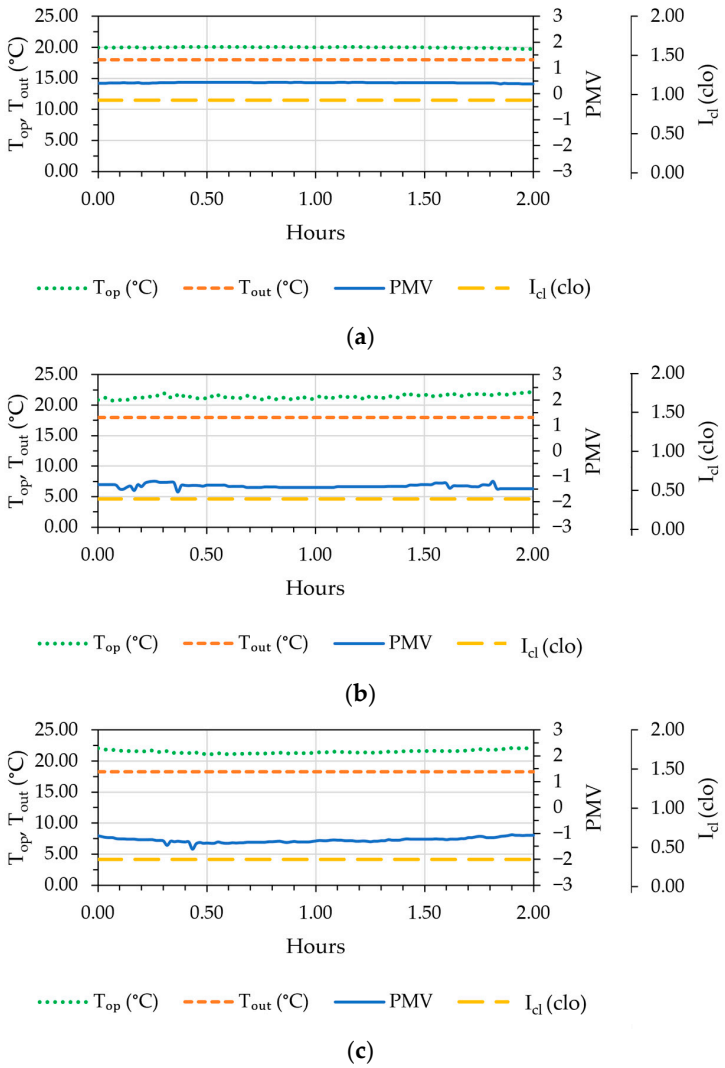


Figure 13. Influence of clothing level on thermal comfort: (**a**) Period 1, (**b**) Period 2, and (**c**) Period 3.

On the one hand, the difference between T_{out} and T_{op} is slightly smaller in Period 1 than in Periods 2 and 3. This would demonstrate that heating systems would not be sufficient to increase the temperature when NV protocols have been maximised [32,33]. On the other hand, it highlights the importance of clothing insulation during Period 1, where an average PMV of 0.43 was obtained for an I_{cl} of 0.83 clo. However, for the same conditions, the PMVs calculated for Periods 2 and 3 were between "cool" and "slightly cool" (−1.59 and −1.04, respectively) [58]. In both cases, the clothing selected was insufficient (0.46 clo for Period 2 and 0.43 for Period 3), again highlighting that clothing selection habits based on the season are more influential than choice based on actual temperatures [89].

3.4.2. Case 2: Influence of Indoor Air Velocity on Thermal Comfort

Figure 14 evaluates how indoor air velocity has affected thermal comfort levels in terms of PPD. Two tests were selected in similar classrooms with the same T_{op} (approximately 21 °C), window opening (1.44 m^2), occupancy (12 students), and I_{cl} (0.38 clo). In Figure 14a, it is observed that, when the v_a was high and underwent constant changes, the percentage dissatisfied (PPD) evolved proportionally to these changes. However, under similar conditions, when the air velocity is below the regulation values [58,63], the PPD remains constant within the comfort zone (Figure 14b). This phenomenon was observed in an experiment where air velocity was varied in classrooms, assessing its impact on the students' thermal comfort. Air velocities higher than 0.25 m/s generate thermal dissatisfaction and cold sensations [118].

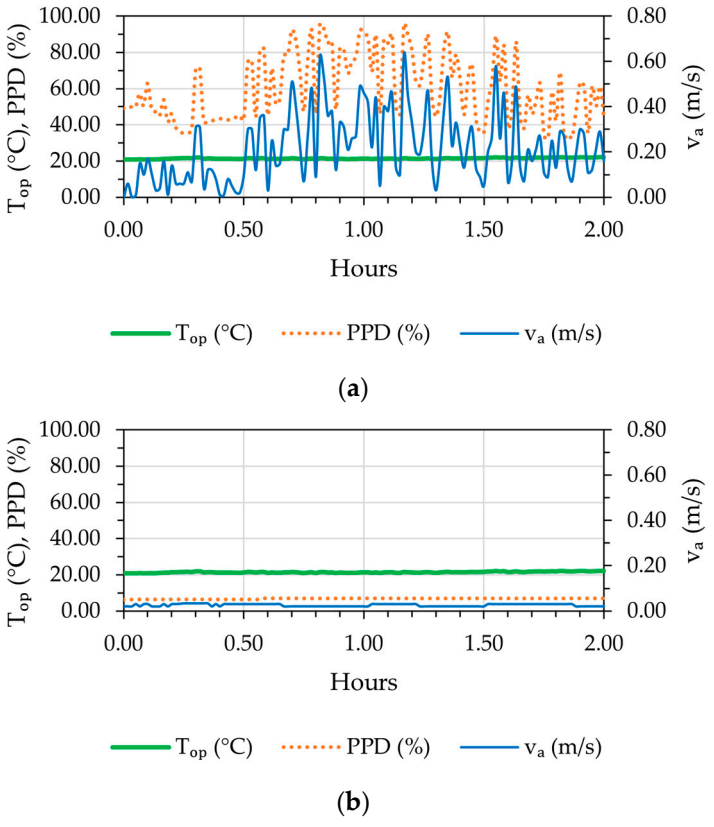


Figure 14. Influence of indoor air velocity on thermal comfort: (**a**) High air velocity and (**b**) Low air velocity.

3.4.3. Case 3: Influence of Window Opening on IAQ Conditions

In the third case study represented in Figure 15, ACH and CO_2 concentrations were evaluated as the NV strategies evolved. For this purpose, the same classroom and initial

occupancy (22 people) were selected, while the WO was 3.80 m^2 in Period 1, 0.10 m^2 in Period 2, and 2.00 m^2 in Period 3.

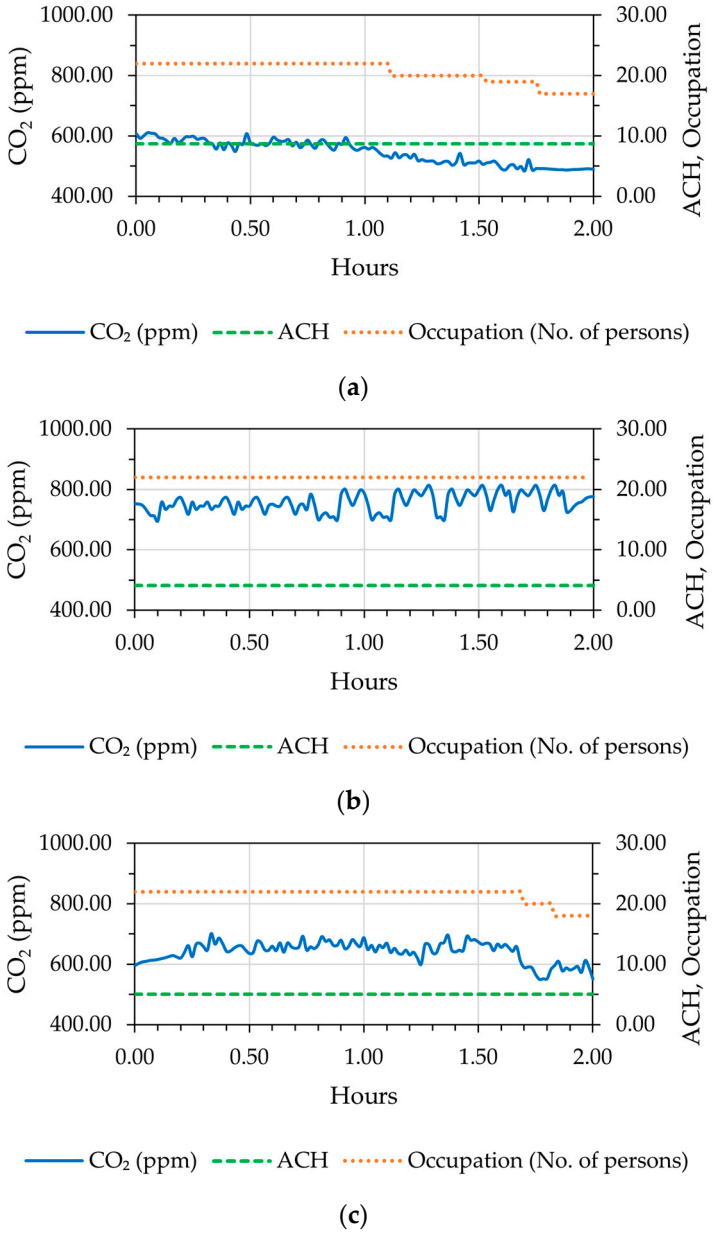


Figure 15. Influence of window opening on IAQ conditions: (**a**) Period 1, (**b**) Period 2, and (**c**) Period 3.

The test selected for Period 1 (Figure 15a) was conducted by maximising the window opening during COVID-19. The number of students remained constant during the first hour, gradually decreasing in the following hour as they finished the test. This evolution could also be observed in the CO_2 concentration. The maximum values recorded barely exceeded 600 ppm at specific times, the average level being 522.75 ppm. The air renewal rate produced was 8.65 ACH. These results would indicate optimal IAQ conditions [11,66,69,71].

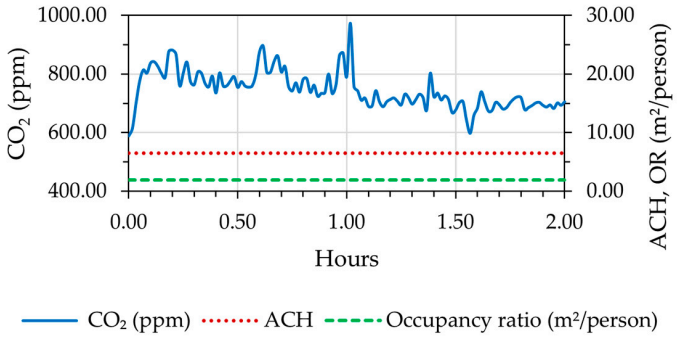
In Period 2 (Figure 15b), the window-opening strategy was relaxed, reflected in an increase of more than 200 ppm in CO_2 concentration, with an average level of 741.48 ppm. In previous studies conducted before and after the onset of the pandemic, evolutions in CO_2 levels were like those obtained in this study [77]. On the other hand, the air renewal rate was 4.11 ACH, which is slightly below the recommendations [69]. Based on these, the

IAQ could be considered good, although a larger window opening would be recommended to achieve the minimum required ACH [69].

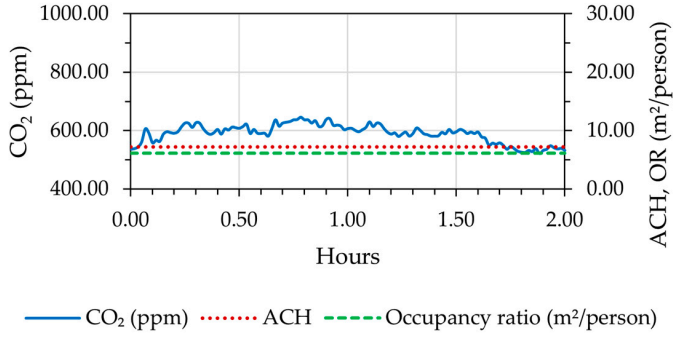
Finally, in Period 3 (Figure 15c), the windows were opened to favour thermal comfort conditions due to the higher temperatures recorded. In this way, an intermediate opening was observed, directly influencing IAQ. In this case, CO_2 levels increased slightly during the first 15 min of the tests and remained stable for an hour and a half (average concentration of 650.27 ppm). Subsequently, coinciding with the departure of some students, CO_2 decreased to below 600 ppm. The air renewals obtained were 5.03 ACH. According to these results, the IAQ in the classroom during the experiment was very good [11,69], suggesting that more flexible ventilation strategies than those implemented during the pandemic were effective in improving IAQ and thermal comfort [33].

3.4.4. Case 4: Influence of the Occupancy Rate on IAQ Conditions

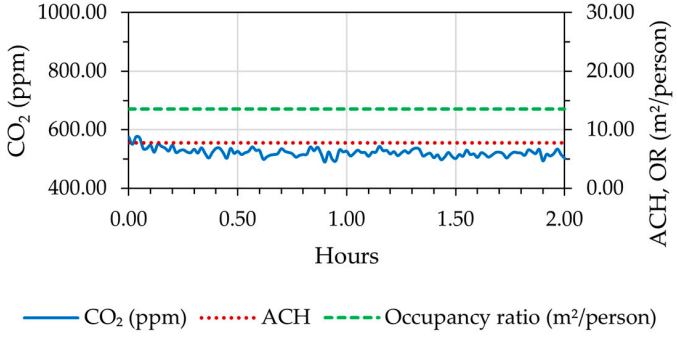
In this last case study (Figure 16), the relationship between IAQ and occupancy ratio was explored. Four average OR levels were established (very low: OR < 3, low: 3 ≤ OR < 10, medium: 10 ≤ OR < 20, and high: OR ≥ 20) and classrooms with the same area of open windows (3.60 m^2) were selected.



(**a**)

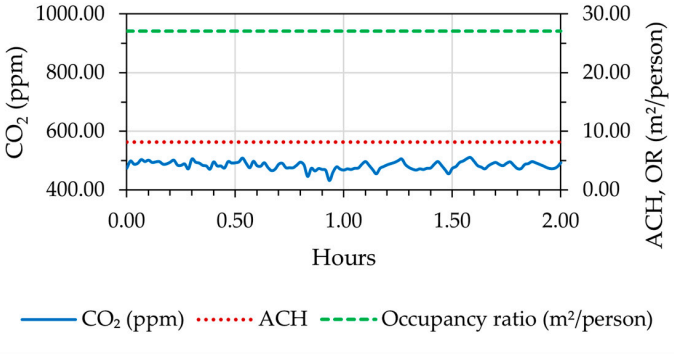


(**b**)



(**c**)

Figure 16. *Cont.*



(**d**)

Figure 16. Influence of OR on IAQ conditions: (**a**) Very low OR, (**b**) Low OR, (**c**) Medium OR, (**d**) High OR.

Looking at the CO_2 levels for very low ORs (Figure 16a), the first half of the test spent most of the time above the 800 ppm recommended to reduce COVID-19 infections [66]. During the second hour of the test, some students left the room, and CO_2 was reduced to below the limit. In line with the findings of this analysis, several studies have suggested that lower ORs lead to higher CO_2 concentrations [119–122]. For example, Korsavi et al. stated that ORs lower than 2.30 m^2/person were a potential reason for high CO_2 levels [103]. On the other hand, for low ORs (Figure 16b), CO_2 concentrations were around 600 ppm. In this case, the IAQ could be qualified as very good [11]. Finally, when the OR is higher than 10 m^2/person, the CO_2 evolution shown in Figure 16c,d is between 400 and 600 ppm. Thus, the IAQ would be considered excellent [11]. Based on these findings, the recommended OR for optimal CO_2 conditions in NV classrooms should be above 10m^2/person. Such a value would be well above the occupancy ratio recommended by Eurostat (2011), which is 2.00 to 3.10 m^2/person based on 20.80 + 2.00 students for the average size of classrooms in European countries [103,123]. As for the ventilation rate, in all selected tests, it was above the recommended 5 ACH [69].

4. Limitations and Future Work

This study investigated the impact of NV protocols on air quality and thermal comfort in university classrooms during and after the COVID-19 pandemic in a Mediterranean climate zone. The results, specific to the building studied, suggest the need to extend the research, exploring different ventilation contexts.

For the thermal comfort evaluation, the PMV and PPD indices have been used, which, although the most widely used methodology, do not consider the real thermal sensation perceived. Therefore, it would be appropriate to complement these studies with surveys assessing these aspects. The local thermal comfort assessment (draughts rate, asymmetric thermal radiation, temperature gradients, etc.) and the students' location influence in different areas of the classrooms are also aspects of interest. Research should also be conducted into how other environmental conditions, such as noise and lighting, influence students' comfort in educational spaces.

Although the use of CO_2 as a variable of analysis has advantages in simplicity, the possibility of measurement errors is highlighted. It is suggested to explore alternatives like injected gases and considering suspended particles for a more complete IAQ analysis. The 5 ACH target provides an approximate benchmark for the ventilation levels required to maintain good air quality. These targets are based on the ASHRAE 62.1-2019 occupancy density. However, to set appropriate limits, it is crucial to consider the various volumes and occupancy levels, as well as the airflow required according to

evolving regulations. Therefore, it is essential to establish more extensive guidelines to regulate this aspect comprehensively.

5. Conclusions and Practical Recommendations

The need to guarantee optimal indoor air quality (IAQ) conditions has become particularly important since the emergence of COVID-19. As a result, natural ventilation protocols have persisted in many cases, even after the most critical phases of the disease have been overcome. However, these measures could impact the thermal comfort of the student. This study determined the evolution of ventilation and its impact on environmental conditions during several exam periods in 2021 and 2022.

Based on this analysis, almost all the winter tests were below the lower limits of the standards consulted, while most of the spring and summer tests were within the comfort range. However, significant variations were found between these results regarding comfort calculated with the PMV-PPD indices. In Period 1, despite the low temperatures, thermal neutrality was high (61.11%) due to adequate clothing adaptation. Students dressed more warmly as they were aware of the low temperatures expected in classrooms due to mandatory COVID-19 ventilation protocols. On the other hand, in Periods 2 and 3, with milder temperatures and the option to adjust the NV measurements, most of the tests resulted in discomfort due to the cold (65.00% and 58.30%, respectively). The lack of adequate insulation in the clothing contributed to this problem. Choosing clothing based on the year's season had a more significant impact than selection based on actual temperatures. The highest recorded air velocity played a crucial role in the tests with the most considerable dissatisfaction.

The average CO_2 concentrations were below the COVID-19 limit (554.48 ppm for Period 1, 675.83 ppm for Period 2, and 577.32 ppm for Period 3), demonstrating the effectiveness of the ventilation measures. In most cases, ventilation rates were provided that exceeded the recommended threshold of 5 ACH for adequate ventilation. However, the air changes calculated for the tests in which window opening was minimised did not meet the requirements of ASHRAE Standard 241-2023. Similarly, it has been observed that this indicator may not be sufficient in high or low occupancy, so combining at least two parameters related to ventilation to assess IAQ is suggested.

Finally, after statistical analysis, it was found that the most influential factors in terms of IAQ conditions (CO_2 and ACH levels) were the open window area and the occupancy rate. Regarding thermal comfort (PMV), the most important parameters were the T_{op} and the insulation of the clothing.

Based on the observations made, the authors of this study suggest that it would be beneficial for educational buildings to establish specific natural ventilation protocols designed according to the environmental conditions and characteristics of the classroom to maintain adequate air quality conditions with the least possible impact on thermal comfort. These measures are essential to balance both factors, especially during periods with high rates of transmission of respiratory diseases, which tend to be more common in winter. Furthermore, the compromise between IAQ and thermal comfort in periods of milder temperatures could be significantly improved if there is adequate control over the choice of clothing, allowing occupants to better adjust to thermal variations without compromising ventilation. It is also advisable to change the timing of assessment exams when it is necessary to maximise natural ventilation measures, especially when weather conditions are problematic. The aim is to prevent this from affecting students' academic performance during these assessments. In addition to the proposed organisational measures, it is recommended that guides be published for students with advice on individual actions to improve their thermal comfort in the classroom, highlighting the importance of this

factor in the learning process. This advice would focus on aspects such as selecting appropriate clothing and consulting weather forecasts. Finally, it should be noted that this study's findings can be extrapolated to other environments, such as offices, where environmental factors and clothing conditions play an essential role in the well-being and work performance of the occupants. In addition, these results apply to contexts with similar conditions and climatic zones, where the variables studied may have a comparable influence on individuals' thermal perception and discomfort.

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Nomenclature

The following nomenclatures are used in this manuscript:

ACH	Air Ventilation Rate per Hour
c_{out}	Average Outdoor CO_2 Concentration (ppm)
CO_2	Carbon Dioxide Concentration (ppm)
VOC	Volatile Organic Compound
c_0	Initial Indoor CO_2 Concentration (ppm)
c_1	Indoor CO_2 Concentration at Time t_1 (ppm)
IAQ	Indoor Air Quality
I_{cl}	Level of Clothing (clo)
IDA	Indoor Air Category According to EN 16798-3:2017
IEQ	Indoor Environmental Quality
N	Observation Number
NV	Natural Ventilation
OR	Occupancy Ratio (m^2/Person)
p_a	Atmospheric Pressure (hPa)
PMV	Predicted Mean Vote
PM_{10}	Particulate Matter with a Diameter of 10 Micrometres or Less (μm)
$PM_{2.5}$	Particulate Matter with a Diameter of 2.5 Micrometres or Less (μm)
PPD	Predicted Percentage of Dissatisfied (%)
RH	Relative Humidity (%)
T_a	Air Temperature (°C)
T_c	Comfort Temperature (°C)
T_g	Globe Temperature (°C)
T_{op}	Operative Temperature (°C)
T_{out}	Outdoor Temperature (°C)
T_{rm}	Mean Radiant Temperature (°C)
T_w	Wet Bulb Temperature (°C)

t_0	Start Time of the Measurement (h)
t_1	Final Moment of the Measurement (h)
V	Volume of Different Classrooms (m^3)
v_a	Air Velocity (m/s)
WO	Open Window Area (m^2)

Appendix A. Statistical Analysis: Pearson's Correlation Coefficient

Appendix A.1. Methodology

Pearson's correlation coefficient is a test that measures the statistical relationship between two continuous variables [124]. This coefficient ranges from +1 to −1. A value of 0 indicates that there is no association between the variables, while a value greater than 0 indicates a positive association; that is, as the value of one variable increases, so does the value of the other. Finally, a value less than 0 indicates a negative association; that is, as one variable's value increases, the value of the other variable decreases. Table A1 shows the strength scale of Pearson correlations [117].

Table A1. This is a table caption.

0.01–0.19	No/negligible relationship
0.20–0.39	Weak relationship
0.40–0.59	Moderate relationship
0.60–0.79	Strong relationship
0.80–1	Very strong relationship

Appendix A.2. Methodology

The results of each correlation, by study period, are summarised in Table A2, which includes the following information: Pearson's correlation coefficient; statistically significant coefficients, indicated with one (*) or two (**) asterisks; the observation number in each case (*N*); and the strength of the correlation (*r*) (Table A1).

For Period 1, Pearson's correlation analysis revealed strong positive relationships between WO and ACH ($r = 0.843$). Lower CO_2 concentrations were found to have higher ACH ($r = -0.849$). Similarly, a high negative correlation was found between T_{op} with WO ($r = -0.657$), with ACH ($r = -0.695$), and with CO_2 ($r = -0.642$). This strong relationship between temperature and CO_2 levels has been reported by several authors [97,125,126]. Regarding PMV, an almost perfect negative correlation was identified with the operating temperature ($r = -0.975$) and with the I_{clo} selected by the students ($r = -0.966$). The square of the correlation coefficient (r^2) suggests that more than 93.00% of the variation in PMV is attributed to variations in operating temperature and clothing [127]. In addition, RH ($r = -0.571$), v_a ($r = -0.503$), and CO_2 showed moderate relationships with PMV, possibly influenced by constant ventilation through open windows during this period [125].

For Periods 2 and 3, the strongest correlations were observed for IAQ-related parameters. Specifically, in Period 2, the significant negative correlation between WO and CO_2 ($r = -0.833$) and the positive correlation with indoor air renewals ($r = 0.831$) stood out. The influence of T_{op} on PMV was lower compared to the cold season ($r = 0.672$ for Period 2 and $r = 0.789$ for Period 3). This change could be due to the milder temperatures, mostly within the comfort range [125]. Likewise, the effect of I_{clo} is also considerably smaller ($r = -0.633$ for Period 2 and $r = -0.695$ for Period 3). De la Hoz-Torres et al. found relationships between clothing and indoor environmental parameters located in the same ranges as those observed in this study [89]. Finally, it was observed that higher v_a were associated with lower PMV values in spring and summer ($r = -0.782$ for Period 2 and

$r = -0.701$ for Period 3), mainly due to the higher number of tests close to the regulatory limits [58,63].

Table A2. Pearson correlation matrices for each study period.

Period 1 (N = 18)										
Variables	**OR**	**WO**	**CO_2**	**ACH**	**T_{op}**	**T_{op}**	**RH**	**v_a**	**I_{cl}**	**PMV**
OR	1									
WO	0.062	1								
CO_2	−0.581 *	−0.789 **	1							
ACH	−0.645 **	0.843 **	−0.849 **	1						
T_{op}	0.183	−0.657 *	−0.642 *	−0.695 *	1					
T_{out}	0.135	−0.060	−0.187	−0.058	0.881 **	1				
RH	0.093	0.181	0.143	−0.073	−0.185	−0.118	1			
v_a	−0.073	0.426	−0.731 **	0.509 *	−0.494 *	−0.315	0.063	1		
I_{cl}	−0.149	−0.017	−0.149	0.258	−0.901 **	−0.970 **	−0.124	0.472 *	1	
PMV	−0.171	0.003	0.531*	−0.293	−0.975 **	−0.876 **	−0.571 *	−0.503 *	−0.966 **	1
Period 2 (N = 20)										
Variables	**OR**	**WO**	**CO_2**	**ACH**	**T_{op}**	**T_{op}**	**RH**	**v_a**	**I_{cl}**	**PMV**
OR	1									
WO	−0.006	1								
CO_2	−0.781 **	−0.833 **	1							
ACH	−0.709 **	0.831 **	−0.639 *	1						
T_{op}	−0.142	−0.657 *	−0.220	−0.118	1					
T_{out}	−0.046	−0.508 *	−0.179	−0.135	0.628 **	1				
RH	−0.101	0.179	−0.067	0.096	−0.175	−0.182	1			
v_a	−0.069	0.309	−0.516 *	0.613 *	0.705 **	0.503 *	−0.131	1		
I_{cl}	−0.045	−0.017	−0.172	0.125	−0.688 **	−0.711 **	−0.184	0.159	1	
PMV	−0.135	0.185	0.309	0.075	0.672 **	0.508 *	−0.285	−0.782 **	−0.633 **	1
Period 3 (N = 12)										
Variables	**OR**	**WO**	**CO_2**	**ACH**	**T_{op}**	**T_{op}**	**RH**	**v_a**	**I_{cl}**	**PMV**
OR	1									
WO	−0.010	1								
CO_2	−0.631 *	−0.805 **	1							
ACH	−0.650 **	0.825 **	−0.659 *	1						
T_{op}	−0.185	−0.389	−0.179	−0.181	1					
T_{out}	−0.186	−0.070	−0.124	−0.128	0.762 **	1				
RH	0.048	0.189	0.009	0.014	0.128	−0.149	1			
v_a	0.011	0.351	−0.568 *	0.501 *	0.392	0.414	−0.128	1		
I_{cl}	−0.063	−0.192	−0.128	−0.141	−0.770 **	−0.785 **	−0.160	0.183	1	
PMV	−0.104	0.168	0.387	0.095	0.789 **	0.646 **	0.204	−0.701 *	−0.695 **	1

** Correlation is significant at the 0.01 level. * Correlation is significant at the 0.05 level.

Appendix B. Indoor and Outdoor Environmental Parameters

Table A3. Indoor and outdoor environmental parameter values, by period.

Period 1											
Type	**Indoor**								**Outdoor**		
	T_a (°C)	**T_{rm} (°C)**	**T_{op} (°C)**	**T_g (°C)**	**T_w (°C)**	**RH (%)**	**v_a (m/s)**	**p_a (hPa)**	**T_a (°C)**	**RH (%)**	**v_a (m/s)**
Average	15.23	16.03	15.41	15.92	15.90	55.9	0.03	999.55	8.73	90.8	1.73
STD	4.24	3.58	3.89	3.77	3.95	10.20	0.05	5.54	6.89	7.79	2.44
Max	21.40	19.93	20.70	20.14	20.56	73.8	0.57	1006.35	17.89	99.0	10.24
Min	4.20	9.47	5.80	7.93	6.85	36.1	0.00	987.14	−2.17	71.0	0.00
Period 2											
Type	**Indoor**								**Outdoor**		
	T_a (°C)	**T_{rm} (°C)**	**T_{op} (°C)**	**T_g (°C)**	**T_w (°C)**	**RH (%)**	**v_a (m/s)**	**p_a (hPa)**	**T_a (°C)**	**RH (%)**	**v_a (m/s)**
Average	23.91	24.71	24.27	24.49	17.25	41.3	0.06	993.30	19.76	64.9	0.95
STD	2.60	2.01	2.35	2.16	1.93	9.96	0.10	3.21	4.92	9.78	0.74
Max	31.00	29.10	30.45	29.91	19.75	56.6	0.70	998.33	34.00	83.0	3.17
Min	19.90	22.25	20.65	21.60	13.71	25.2	0.00	987.23	12.28	50.0	0.00

Table A3. *Cont.*

Type	Period 3										
	Indoor								Outdoor		
	T_a (°C)	T_{rm} (°C)	T_{op} (°C)	T_g (°C)	T_w (°C)	RH (%)	v_a (m/s)	p_a (hPa)	T_a (°C)	RH (%)	v_a (m/s)
Average	24.38	24.99	24.62	24.89	17.70	43.6	0.04	994.02	22.69	58.4	0.85
STD	1.91	1.64	1.74	1.72	1.90	9.68	0.08	1.95	4.65	13.04	0.60
Max	31.60	28.84	30.75	28.99	20.43	58.7	0.88	997.10	34.67	87.0	3.17
Min	20.30	22.58	21.10	22.37	15.13	20.9	0.00	991.09	13.72	45.0	0.00

References

1. Almeida, R.M.S.F.; Ramos, N.M.M.; de Freitas, V.P. Thermal Comfort Models and Pupils' Perception in Free-Running School Buildings of a Mild Climate Country. *Energy Build.* **2016**, *111*, 64–75. [CrossRef]
2. Yang, D.; Mak, C.M. Relationships between Indoor Environmental Quality and Environmental Factors in University Classrooms. *Build. Environ.* **2020**, *186*, 107331. [CrossRef]
3. Nur Aishah Mohd Noor, S.; Ding, H.H. Indoor Environment Quality (IEQ): Temperature and Indoor Air Quality (IAQ) Factors toward Occupants Satisfaction. *IOP Conf. Ser. Mater. Sci. Eng.* **2020**, *864*, 012012. [CrossRef]
4. Kraus, M.; Nováková, P. Assessment of the Indoor Environment for Education. *IOP Conf. Ser. Earth Environ. Sci.* **2019**, *290*, 012144. [CrossRef]
5. Jamaludin, N.M.; Mahyuddin, N.; Akashah, F.W. Assessment of Indoor Environmental Quality (IEQ): Students Well-Being in University Classroom with the Application of Landscaping. *MATEC Web Conf.* **2016**, *66*, 00061. [CrossRef]
6. Lipinski, T.; Ahmad, D.; Serey, N.; Jouhara, H. Review of Ventilation Strategies to Reduce the Risk of Disease Transmission in High Occupancy Buildings. *Int. J. Thermofluids* **2020**, *7–8*, 100045. [CrossRef]
7. Figueroa-Lopez, A.; Oregi, X.; Almeida, M.; Hernández-Minguillón, R.J. Evaluation of Hygrothermal Comfort in Educational Centres by Monitoring Three Case Studies with Different Ventilation Systems in Vitoria, Spain. *J. Build. Eng.* **2023**, *65*, 105591. [CrossRef]
8. Di Gilio, A.; Palmisani, J.; Pulimeno, M.; Cerino, F.; Cacace, M.; Miani, A.; de Gennaro, G. CO_2 Concentration Monitoring inside Educational Buildings as a Strategic Tool to Reduce the Risk of SARS-CoV-2 Airborne Transmission. *Environ. Res.* **2021**, *202*, 111560. [CrossRef]
9. *EN 16798-3:2017*; Energy Performance of Buildings–Ventilation for Buildings—Part 3: For Non-Residential Buildings–Performance Requirements for Ventilation and Room-Conditioning Systems (Modules M5-1, M5-4). CEN: Brussels, Belgium, 2017.
10. *ISO 16000-40:2019/Amd 1:2024*; Indoor Air—Part 40: Indoor Air Quality Management System—Amendment 1: Climate Action Changes. CEN: Brussels, Belgium, 2024.
11. *ANSI/ASHRAE Standard 62.1-2019*; Ventilation for Acceptable Indoor Air Quality. ASHRAE: Atlanta, GA, USA, 2019.
12. Environmental Protection Agency (EPA). *IAQ Tools for Schools*; Environmental Protection Agency (EPA): Washington, DC, USA, 2009.
13. Samandi, E.; Shirazi, A.; Newton, S. Measuring the Fine Particulate Exposure Levels of Building Occupants Using Localized Sensors. *Build. Environ.* **2023**, *242*, 110403. [CrossRef]
14. Zhang, X.; Zhao, C.; Zhang, T.; Xie, J.; Liu, J.; Zhang, N. Association of Indoor Temperature and Air Quality in Classrooms Based on Field and Intervention Measurements. *Build. Environ.* **2023**, *229*, 109925. [CrossRef]
15. Wang, X.; Yang, L.; Gao, S.; Zhao, S.; Zhai, Y. Thermal Comfort in Naturally Ventilated University Classrooms: A Seasonal Field Study in Xi'an, China. *Energy Build.* **2021**, *247*, 111126. [CrossRef]
16. Shin, H.; Kang, M.; Mun, S.-H.; Kwak, Y.; Huh, J.-H. A Study on Changes in Occupants' Thermal Sensation Owing to CO_2 Concentration Using PMV and TSV. *Build. Environ.* **2021**, *187*, 107413. [CrossRef]
17. Chatzidiakou, L.; Mumovic, D.; Summerfield, A.J. What Do We Know about Indoor Air Quality in School Classrooms? A Critical Review of the Literature. *Intell. Build. Int.* **2012**, *4*, 228–259. [CrossRef]
18. Argunhan, Z.; Avci, A.S. Statistical Evaluation of Indoor Air Quality Parameters in Classrooms of a University. *Adv. Meteorol.* **2018**, *2018*, 4391579. [CrossRef]
19. Fuentes-Ferragud, E.; López, A.; Piera, J.M.; Yusà, V.; Garrigues, S.; de la Guardia, M.; López Labrador, F.X.; Camaró, M.; Ibáñez, M.; Coscollà, C. Indoor Air Quality and Bioaerosols in Spanish University Classrooms. *Toxics* **2024**, *12*, 227. [CrossRef]
20. Wargocki, P.; Sundell, J.; Bischof, W.; Brundrett, G.; Fanger, P.O.; Gyntelberg, F.; Hanssen, S.O.; Harrison, P.; Pickering, A.; Seppänen, O.; et al. Ventilation and Health in Non-Industrial Indoor Environments: Report from a European Multidisciplinary Scientific Consensus Meeting (EUROVEN). *Indoor Air* **2002**, *12*, 113–128. [CrossRef]

21. Fang, Y.; Luo, X.; Lu, J. A Review of Research on the Impact of the Classroom Physical Environment on Schoolchildren's Health. *J. Build. Eng.* **2023**, *65*, 105430. [CrossRef]
22. Lamberti, G.; Fantozzi, F.; Salvadori, G. Thermal Comfort in Educational Buildings: Future Directions Regarding the Impact of Environmental Conditions on Students' Health and Performance. In Proceedings of the 2020 IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe), Madrid, Spain, 9–12 June 2020; pp. 1–6.
23. Corgnati, S.P.; Filippi, M.; Viazzo, S. Perception of the Thermal Environment in High School and University Classrooms: Subjective Preferences and Thermal Comfort. *Build. Environ.* **2007**, *42*, 951–959. [CrossRef]
24. Villarreal Arroyo, Y.P.; Peñabaena-Niebles, R.; Berdugo Correa, C. Influence of Environmental Conditions on Students' Learning Processes: A Systematic Review. *Build. Environ.* **2023**, *231*, 110051. [CrossRef]
25. Brink, H.W.; Loomans, M.G.L.C.; Mobach, M.P.; Kort, H.S.M. A Systematic Approach to Quantify the Influence of Indoor Environmental Parameters on Students' Perceptions, Responses, and Short-term Academic Performance. *Indoor Air* **2022**, *32*, e13116. [CrossRef]
26. Chen, D.; Huebner, G.; Bagkeris, E.; Ucci, M.; Mumovic, D. Effects of Short-Term Exposure to Moderate Pure Carbon Dioxide Levels on Cognitive Performance, Health Symptoms and Perceived Indoor Environment Quality. *Build. Environ.* **2023**, *245*, 110967. [CrossRef]
27. Kozaki, T.; Matsuzawa, N.; Hyakutake, K. Effect of High Carbon Dioxide Level on Psychological Performance and Arousal Level. *Jpn. J. Ergon.* **2022**, *58*, 76–83. [CrossRef]
28. Ahmed, R.; Mumovic, D.; Bagkeris, E.; Ucci, M. Combined Effects of Ventilation Rates and Indoor Temperatures on Cognitive Performance of Female Higher Education Students in a Hot Climate. *Indoor Air* **2022**, *32*, e13004. [CrossRef] [PubMed]
29. Li, H.; Lan, Y.; Wang, Z.; Kong, X.; Fan, M. Experimental Study on the Cross-Infection Control Performance under Intervention Cascade Ventilation in the Post-Epidemic Era. *Sustain. Cities Soc.* **2024**, *102*, 105185. [CrossRef]
30. Zhang, R.; Li, Y.; Zhang, A.L.; Wang, Y.; Molina, M.J. Identifying Airborne Transmission as the Dominant Route for the Spread of COVID-19. *Proc. Natl. Acad. Sci. USA* **2020**, *117*, 14857–14863. [CrossRef]
31. Kim, H.; Hong, T.; Kim, J.; Yeom, S. A Psychophysiological Effect of Indoor Thermal Condition on College Students' Learning Performance through EEG Measurement. *Build. Environ.* **2020**, *184*, 107223. [CrossRef]
32. Aguilar, A.J.; de la Hoz-Torres, M.L.; Martínez-Aires, M.D.; Ruiz, D.P. Thermal Perception in Naturally Ventilated University Buildings in Spain during the Cold Season. *Buildings* **2022**, *12*, 890. [CrossRef]
33. Miranda, M.T.; Romero, P.; Valero-Amaro, V.; Arranz, J.I.; Montero, I. Ventilation Conditions and Their Influence on Thermal Comfort in Examination Classrooms in Times of COVID-19. A Case Study in a Spanish Area with Mediterranean Climate. *Int. J. Hyg. Environ. Health* **2022**, *240*, 113910. [CrossRef]
34. Rodríguez-Vidal, I.; Martín-Garín, A.; González-Quintial, F.; Rico-Martínez, J.M.; Hernández-Minguillón, R.J.; Otaegi, J. Response to the COVID-19 Pandemic in Classrooms at the University of the Basque Country through a User-Informed Natural Ventilation Demonstrator. *Int. J. Environ. Res. Public Health* **2022**, *19*, 14560. [CrossRef]
35. Alegría-Sala, A.; Clèries Tardío, E.; Casals, L.C.; Macarulla, M.; Salom, J. CO_2 Concentrations and Thermal Comfort Analysis at Onsite and Online Educational Environments. *Int. J. Environ. Res. Public Health* **2022**, *19*, 16039. [CrossRef]
36. Rus, T.; Moldovan, R.; Albu, H.; Beu, D. Impact of Pandemic Safety Measures on Students' Thermal Comfort—Case Study: Romania. *Buildings* **2023**, *13*, 794. [CrossRef]
37. Gómez Melgar, S.; Sánchez Cordero, A.; Videras Rodríguez, M.; Andújar Márquez, J.M. Influence on Indoor Comfort Due to the Application of COVID-19 Natural Ventilation Protocols for Schools at Subtropical Climate during Winter Season. *E3S Web Conf.* **2021**, *293*, 01031. [CrossRef]
38. Ding, E.; Zhang, D.; Hamida, A.; García-Sánchez, C.; Jonker, L.; de Boer, A.R.; Bruijning, P.C.J.L.; Linde, K.J.; Wouters, I.M.; Bluyssen, P.M. Ventilation and Thermal Conditions in Secondary Schools in the Netherlands: Effects of COVID-19 Pandemic Control and Prevention Measures. *Build. Environ.* **2023**, *229*, 109922. [CrossRef] [PubMed]
39. de la Hoz-Torres, M.L.; Aguilar, A.J.; Costa, N.; Arezes, P.; Ruiz, D.P.; Martínez-Aires, M.D. Reopening Higher Education Buildings in Post-epidemic COVID-19 Scenario: Monitoring and Assessment of Indoor Environmental Quality after Implementing Ventilation Protocols in Spain and Portugal. *Indoor Air* **2022**, *32*, e13040. [CrossRef]
40. Romero, P.; Valero-Amaro, V.; Isidoro, R.; Miranda, M.T. Analysis of Determining Factors in the Thermal Comfort of University Students. A Comparative Study between Spain and Portugal. *Energy Build.* **2024**, *308*, 114022. [CrossRef]
41. Pekdogan, T.; Avci, A.B. A field study on adaptive thermal comfort in a naturally ventilated design studio class in the post-pandemic period. *ALAM CIPTA Int. J. Sustain. Trop. Des. Pract.* **2022**, *2*, 80–86. [CrossRef]
42. Flores, M.A.; Barros, A.; Simão, A.M.V.; Pereira, D.; Flores, P.; Fernandes, E.; Costa, L.; Ferreira, P.C. Portuguese Higher Education Students' Adaptation to Online Teaching and Learning in Times of the COVID-19 Pandemic: Personal and Contextual Factors. *High. Educ.* **2022**, *83*, 1389–1408. [CrossRef]
43. Kharbat, F.F.; Abu Daabes, A.S. E-Proctored Exams during the COVID-19 Pandemic: A Close Understanding. *Educ. Inf. Technol.* **2021**, *26*, 6589–6605. [CrossRef]

44. Romero, P.; Valero-Amaro, V.; Rubio, S.; Miranda, M.T. An Analysis of Thermal Comfort as an Influencing Factor on the Academic Performance of University Students. *Educ. Sci.* **2024**, *14*, 1340. [CrossRef]
45. Beck, H.E.; Zimmermann, N.E.; McVicar, T.R.; Vergopolan, N.; Berg, A.; Wood, E.F. Present and Future Köppen-Geiger Climate Classification Maps at 1-Km Resolution. *Scince* **2018**, *5*, 180214. [CrossRef]
46. UNESCO. *Handbook for Educational Buildings Planning*; UNESCO: Paris, France, 1985.
47. *ISO 21001:2018*; Educational Organizations—Management Systems for Educational Organizations—Requirements with Guidance for Use. ISO: Geneva, Switzerland, 2018.
48. *ANSI/ASHRAE Standard 55-2023*; Thermal Environmental Conditions for Human Occupancy. ASHRAE: Atlanta, GA, USA, 2023.
49. CEFPI. *Guide for Planning Educational Facilitie*; CEFPI: Columbus, OH, USA, 1991.
50. Romero, P.; Miranda, M.T.; Montero, I.; Sepúlveda, F.J.; Valero-Amaro, V. Critical Review of the Literature on Thermal Comfort in Educational Buildings: Study of the Influence of the COVID-19 Pandemic. *Indoor Air* **2023**, *2023*, 8347598. [CrossRef]
51. WHO COVID-19 Safe Return to School 2020. Available online: https://www.fip.org/files/content/priority-areas/coronavirus/mo-resources/WHO_Update_26_re-opening_schools_.pdf (accessed on 13 March 2024).
52. Ministerio de Sanidad. *Real Decreto 115/2022, de 8 de Febrero, Por El Que Se Modifica La Obligatoriedad Del Uso de Mascarillas Durante La Situación de Crisis Sanitaria Ocasionada Por El COVID-19*; Ministerio de Sanidad: Madrid, Spain, 2022.
53. Guevara, G.; Soriano, G.; Mino-Rodriguez, I. Thermal Comfort in University Classrooms: An Experimental Study in the Tropics. *Build. Environ.* **2021**, *187*, 107430. [CrossRef]
54. Salas-Morera, L.; Ruiz-Bustos, R.; Cejas-Molina, M.A.; Olivares-Olmedilla, J.L.; García-Hernández, L.; Palomo-Romero, J.M. Understanding Why Women Don't Choose Engineering Degrees. *Int. J. Technol. Des. Educ.* **2021**, *31*, 325–338. [CrossRef]
55. Calvo-Iglesias, E.; Epifanio, I.; Estrade, S.; Mas de les Valls, E. *Gender Perspective in STEM Disciplines in Spain Universities*; Spain Universities: Barcelona, Spain, 2022; pp. 165–179.
56. WHO. *Methods for Sampling and Analysis of Chemical Pollutants in Indoor Air*; WHO: Copenhagen, Denmark, 2020.
57. Fanger, P.O. *Thermal Comfort: Analysis and Applications in Environmental Engineering*; Danish Technical Press: Copenhagen, Denmark, 1970.
58. *ISO 7730:2005*; Ergonomics of the Thermal Environment—Analytical Determination and Interpretation of Thermal Comfort Using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. ISO: Geneva, Switzerland, 2005.
59. Nico, M.A.; Liuzzi, S.; Stefanizzi, P. Evaluation of Thermal Comfort in University Classrooms through Objective Approach and Subjective Preference Analysis. *Appl. Ergon.* **2015**, *48*, 111–120. [CrossRef]
60. Papadopoulos, G.; Panaras, G.; Tolis, E. Thermal Comfort and Indoor Air Quality Assessment in University Classrooms. *IOP Conf. Ser. Earth Environ. Sci.* **2020**, *410*, 012095. [CrossRef]
61. Fabozzi, M.; Dama, A. Field Study on Thermal Comfort in Naturally Ventilated and Air-Conditioned University Classrooms. *Indoor Built Environ.* **2020**, *29*, 851–859. [CrossRef]
62. Zomorodian, Z.S.; Tahsildoost, M.; Hafezi, M. Thermal Comfort in Educational Buildings: A Review Article. *Renew. Sustain. Energy Rev.* **2016**, *59*, 895–906. [CrossRef]
63. Gobierno de España. *Real Decreto 1027/2007, de 20 de Julio, Por El Que Se Aprueba El Reglamento de Instalaciones Térmicas En Los Edificios (RITE)*; Gobierno de España: Madrid, Spain, 2007.
64. *EN 16798-1:2020*; Energy Performance of Buildings. Ventilation for Buildings. Part 1: Indoor Environmental Input Parameters for Design and Assessment of Energy Performance of Buildings Addressing Indoor Air Quality, Thermal Environment, Lighting and Acoust. CEN: Brussels, Belgium, 2020.
65. Cony Renaud-Salis, L.; Ramalho, O.; Abadie, M. Towards the Definition of an Indoor Air Quality Index for Residential Buildings Based on Long- and Short-Term Exposure Limit Values. *Int. J. Vent.* **2020**, *19*, 189–200. [CrossRef]
66. Ministerio de Sanidad. *Medidas de Prevención, Higiene y Promoción de La Salud Frente a COVID-19 Para Centros Educativos En El Curso 2020–2021*; Ministerio de Sanidad: Madrid, Spain, 2020.
67. Rey-Hernández, J.M.; Arroyo-Gómez, Y.; San José-Alonso, J.F.; Rey-Martínez, F.J. Assessment of Natural Ventilation Strategy to Decrease the Risk of COVID 19 Infection at a Rural Elementary School. *Heliyon* **2023**, *9*, e18271. [CrossRef]
68. REHVA. *Health-Based Target Ventilation Rates and Design Method for Reducing Exposure to Airborne Respiratory Infectious Diseases*; REHVA: Brussels, Belgium, 2022.
69. Allen, J.; Spengler, J.; Jones, E.; Cedeno-Laurent, J. 5-Step Guide to Checking Ventilation Rates in Classrooms. 2020. Available online: https://schools.forhealth.org/wp-content/uploads/sites/19/2020/10/Harvard-Healthy-Buildings-program-How-to-assess-classroom-ventilation-10-30-2020.pdf-EN.pdf (accessed on 13 March 2024).
70. Batterman, S. Review and Extension of CO_2-Based Methods to Determine Ventilation Rates with Application to School Classrooms. *Int. J. Environ. Res. Public Health* **2017**, *14*, 145. [CrossRef]
71. Ministerio de Sanidad. *Evaluación Del Riesgo de La Transmisión de SARS-CoV-2 Mediante Aerosoles. Medidas de Prevención y Recomendaciones*; Ministerio de Sanidad: Madrid, Spain, 2020.
72. *ASHRAE Standard 241-2023*; Control of Infectious Aerosols. ASHRAE: Atlanta, GA, USA, 2023.

73. Diaz, M.; Cools, M.; Trebilcock, M.; Piderit-Moreno, B.; Attia, S. Effects of Climatic Conditions, Season and Environmental Factors on CO_2 Concentrations in Naturally Ventilated Primary Schools in Chile. *Sustainability* **2021**, *13*, 4139. [CrossRef]
74. Clements-Croome, D.J.; Awbi, H.B.; Bakó-Biró, Z.; Kochhar, N.; Williams, M. Ventilation Rates in Schools. *Build. Environ.* **2008**, *43*, 362–367. [CrossRef]
75. Krawczyk, D.A.; Rodero, A.; Gładyszewska-Fiedoruk, K.; Gajewski, A. CO_2 Concentration in Naturally Ventilated Classrooms Located in Different Climates—Measurements and Simulations. *Energy Build.* **2016**, *129*, 491–498. [CrossRef]
76. Branco, P.T.B.S.; Alvim-Ferraz, M.C.M.; Martins, F.G.; Sousa, S.I.V. Children's Exposure to Indoor Air in Urban Nurseries-Part I: CO_2 and Comfort Assessment. *Environ. Res.* **2015**, *140*, 1–9. [CrossRef]
77. Alonso, A.; Llanos, J.; Escandón, R.; Sendra, J.J. Effects of the COVID-19 Pandemic on Indoor Air Quality and Thermal Comfort of Primary Schools in Winter in a Mediterranean Climate. *Sustainability* **2021**, *13*, 2699. [CrossRef]
78. Rodríguez, D.; Urbieta, I.R.; Velasco, Á.; Campano-Laborda, M.Á.; Jiménez, E. Assessment of Indoor Air Quality and Risk of COVID-19 Infection in Spanish Secondary School and University Classrooms. *Build. Environ.* **2022**, *226*, 109717. [CrossRef]
79. Gil-Baez, M.; Lizana, J.; Becerra Villanueva, J.A.; Molina-Huelva, M.; Serrano-Jimenez, A.; Chacartegui, R. Natural Ventilation in Classrooms for Healthy Schools in the COVID Era in Mediterranean Climate. *Build. Environ.* **2021**, *206*, 108345. [CrossRef]
80. Busato, F.; Cavallini, A. Window Opening or Mechanical Ventilation Systems for Italian Schools? Energetic Aspects, CO_2 Concentration and Infection Risk Assessment Based on the SARS-CoV-2 Data. *Buildings* **2023**, *13*, 1743. [CrossRef]
81. Konstantinou, C.; Constantinou, A.; Kleovoulou, E.G.; Kyriacou, A.; Kakoulli, C.; Milis, G.; Michaelides, M.; Makris, K.C. Assessment of Indoor and Outdoor Air Quality in Primary Schools of Cyprus during the COVID-19 Pandemic Measures in May–July 2021. *Heliyon* **2022**, *8*, e09354. [CrossRef]
82. Kuwahara, R.; Kim, H. Studying the Indoor Environment and Comfort of a University Laboratory: Air-Conditioning Operation and Natural Ventilation Used as a Countermeasure against COVID-19. *Buildings* **2022**, *12*, 953. [CrossRef]
83. Torriani, G.; Lamberti, G.; Salvadori, G.; Fantozzi, F.; Babich, F. Thermal Comfort and Adaptive Capacities: Differences among Students at Various School Stages. *Build. Environ.* **2023**, *237*, 110340. [CrossRef]
84. Campano, M.Á.; Domínguez-Amarillo, S.; Fernández-Agüera, J.; Sendra, J.J. Thermal Perception in Mild Climate: Adaptive Thermal Models for Schools. *Sustainability* **2019**, *11*, 3948. [CrossRef]
85. Mıhlayanlar, E.; Öztuna, S.; Büyükakın, K. Investigation of Thermal Comfort Conditions in Higher Education Facilities: A Case Study for Engineering Faculty in Edirne. *TEM J.* **2017**, *6*, 71–79. [CrossRef]
86. Aparicio-Ruiz, P.; Barbadilla-Martín, E.; Guadix, J.; Muñuzuri, J. A Field Study on Adaptive Thermal Comfort in Spanish Primary Classrooms during Summer Season. *Build. Environ.* **2021**, *203*, 108089. [CrossRef]
87. Jowkar, M.; Rijal, H.B.; Brusey, J.; Montazami, A.; Carlucci, S.; Lansdown, T.C. Comfort Temperature and Preferred Adaptive Behaviour in Various Classroom Types in the UK Higher Learning Environments. *Energy Build.* **2020**, *211*, 109814. [CrossRef]
88. Balbis-Morejón, M.; Rey-Hernández, J.M.; Amaris-Castilla, C.; Velasco-Gómez, E.; San José-Alonso, J.F.; Rey-Martínez, F.J. Experimental Study and Analysis of Thermal Comfort in a University Campus Building in Tropical Climate. *Sustainability* **2020**, *12*, 8886. [CrossRef]
89. de la Hoz-Torres, M.L.; Aguilar, A.J.; Costa, N.; Arezes, P.; Ruiz, D.P.; Martínez-Aires, M.D. Predictive Model of Clothing Insulation in Naturally Ventilated Educational Buildings. *Buildings* **2023**, *13*, 1002. [CrossRef]
90. Johnston, D.W.; Knott, R.; Mendolia, S.; Siminski, P. Upside-Down Down-Under: Cold Temperatures Reduce Learning in Australia. *Econ. Educ. Rev.* **2021**, *85*, 102172. [CrossRef]
91. Alberto, I.C.; Jiao, Y.; Zhang, X. Too Hot or Too Cold to Study? The Effect of Temperature on Student Time Allocation. *Econ. Educ. Rev.* **2021**, *84*, 102152. [CrossRef]
92. Tabaie, Z.; Omidvar, A.; Kim, J. Non-Uniform Distribution of Clothing Insulation as a Behavioral Adaptation Strategy and Its Effect on Predicted Thermal Sensation in Hot and Humid Environments. *Energy Build.* **2022**, *271*, 112310. [CrossRef]
93. Burzo, M.; Wicaksono, C.; Abouelenien, M.; Pérez-Rosas, V.; Mihalcea, R.; Tao, Y. Multimodal Sensing of Thermal Discomfort for Adaptive Energy Saving in Buildings. In Proceedings of the iiSBE Net Zero Built Environment 2014 Symposium, 2014, Gainesville, FL, USA, 6–7 March 2014.
94. Priya, G.; Nagaraju, K. Significance of Air Movement ForThermal Comfort in Educational Buildings, Case Study of a Classroom. *Int. Adv. Res. J. Sci. Eng. Technol.* **2016**, *3*, 88–93.
95. Burridge, H.C.; Bontitsopoulos, S.; Brown, C.; Carter, H.; Roberts, K.; Vouriot, C.; Weston, D.; Mon-Williams, M.; Williams, N.; Noakes, C. Variations in Classroom Ventilation during the COVID-19 Pandemic: Insights from Monitoring 36 Naturally Ventilated Classrooms in the UK during 2021. *J. Build. Eng.* **2023**, *63*, 105459. [CrossRef]
96. Almeida, R.M.S.F.; de Freitas, V.P. Indoor Environmental Quality of Classrooms in Southern European Climate. *Energy Build.* **2014**, *81*, 127–140. [CrossRef]
97. Vilcekova, S.; Meciarova, L.; Burdova, E.K.; Katunska, J.; Kosicanova, D.; Doroudiani, S. Indoor Environmental Quality of Classrooms and Occupants' Comfort in a Special Education School in Slovak Republic. *Build. Environ.* **2017**, *120*, 29–40. [CrossRef]

98. Corgnati, S.P.; Ansaldi, R.; Filippi, M. Thermal Comfort in Italian Classrooms under Free Running Conditions during Mid Seasons: Assessment through Objective and Subjective Approaches. *Build. Environ.* **2009**, *44*, 785–792. [CrossRef]
99. Liu, G.; Jia, Y.; Cen, C.; Ma, B.; Liu, K. Comparative Thermal Comfort Study in Educational Buildings in Autumn and Winter Seasons. *Sci. Technol. Built Environ.* **2020**, *26*, 185–194. [CrossRef]
100. Yang, B.; Olofsson, T.; Wang, F.; Lu, W. Thermal Comfort in Primary School Classrooms: A Case Study under Subarctic Climate Area of Sweden. *Build. Environ.* **2018**, *135*, 237–245. [CrossRef]
101. Ma, F.; Zhan, C.; Xu, X.; Li, G. Winter Thermal Comfort and Perceived Air Quality: A Case Study of Primary Schools in Severe Cold Regions in China. *Energies* **2020**, *13*, 5958. [CrossRef]
102. Miao, S.; Gangolells, M.; Tejedor, B. A Comprehensive Assessment of Indoor Air Quality and Thermal Comfort in Educational Buildings in the Mediterranean Climate. *Indoor Air* **2023**, *2023*, 6649829. [CrossRef]
103. Korsavi, S.S.; Montazami, A.; Mumovic, D. Indoor Air Quality (IAQ) in Naturally-Ventilated Primary Schools in the UK: Occupant-Related Factors. *Build. Environ.* **2020**, *180*, 106992. [CrossRef]
104. Aguilar, A.J.; de la Hoz-Torres, M.L.; Costa, N.; Arezes, P.; Martínez-Aires, M.D.; Ruiz, D.P. Assessment of Ventilation Rates inside Educational Buildings in Southwestern Europe: Analysis of Implemented Strategic Measures. *J. Build. Eng.* **2022**, *51*, 104204. [CrossRef]
105. Villanueva, F.; Notario, A.; Cabañas, B.; Martín, P.; Salgado, S.; Gabriel, M.F. Assessment of CO_2 and Aerosol (PM2.5, PM10, UFP) Concentrations during the Reopening of Schools in the COVID-19 Pandemic: The Case of a Metropolitan Area in Central-Southern Spain. *Environ. Res.* **2021**, *197*, 111092. [CrossRef] [PubMed]
106. Zemitis, J.; Bogdanovics, R.; Bogdanovica, S. The Study of CO_2 Concentration in A Classroom during the COVID-19 Safety Measures. In Proceedings of the E3S Web of Conferences, EDP Sciences, Tallinn, Estonia, 29 March 2021; Volume 246.
107. Vassella, C.C.; Koch, J.; Henzi, A.; Jordan, A.; Waeber, R.; Iannaccone, R.; Charrière, R. From Spontaneous to Strategic Natural Window Ventilation: Improving Indoor Air Quality in Swiss Schools. *Int. J. Hyg. Environ. Health* **2021**, *234*, 113746. [CrossRef] [PubMed]
108. Campano-Laborda, M.Á.; Domínguez-Amarillo, S.; Fernández-Agüera, J.; Acosta, I. Indoor Comfort and Symptomatology in Non-University Educational Buildings: Occupants' Perception. *Atmosphere* **2020**, *11*, 357. [CrossRef]
109. Madureira, J.; Paciência, I.; Pereira, C.; Teixeira, J.P.; Fernandes, E.d.O. Indoor Air Quality in Portuguese Schools: Levels and Sources of Pollutants. *Indoor Air* **2016**, *26*, 526–537. [CrossRef]
110. Dascalaki, E.G.; Sermpetzoglou, V.G. Energy Performance and Indoor Environmental Quality in Hellenic Schools. *Energy Build.* **2011**, *43*, 718–727. [CrossRef]
111. de la Hoz-Torres, M.L.; Aguilar, A.J.; Ruiz, D.P.; Martínez-Aires, M.D. Analysis of Impact of Natural Ventilation Strategies in Ventilation Rates and Indoor Environmental Acoustics Using Sensor Measurement Data in Educational Buildings. *Sensors* **2021**, *21*, 6122. [CrossRef]
112. Hama, S.; Kumar, P.; Tiwari, A.; Wang, Y.; Linden, P.F. The Underpinning Factors Affecting the Classroom Air Quality, Thermal Comfort and Ventilation in 30 Classrooms of Primary Schools in London. *Environ. Res.* **2023**, *236*, 116863. [CrossRef]
113. Abhijith, K.V.; Kukadia, V.; Kumar, P. Investigation of Air Pollution Mitigation Measures, Ventilation, and Indoor Air Quality at Three Schools in London. *Atmos. Environ.* **2022**, *289*, 119303. [CrossRef]
114. Jia, L.-R.; Han, J.; Chen, X.; Li, Q.-Y.; Lee, C.-C.; Fung, Y.-H. Interaction between Thermal Comfort, Indoor Air Quality and Ventilation Energy Consumption of Educational Buildings: A Comprehensive Review. *Buildings* **2021**, *11*, 591. [CrossRef]
115. Morawska, L.; Tang, J.W.; Bahnfleth, W.; Bluyssen, P.M.; Boerstra, A.; Buonanno, G.; Cao, J.; Dancer, S.; Floto, A.; Franchimon, F.; et al. How Can Airborne Transmission of COVID-19 Indoors Be Minimised? *Environ. Int.* **2020**, *142*, 105832. [CrossRef] [PubMed]
116. Park, B.; Lee, S. Investigation of the Energy Saving Efficiency of a Natural Ventilation Strategy in a Multistory School Building. *Energies* **2020**, *13*, 1746. [CrossRef]
117. Cohen, J. *Statistical Power Analysis for the Behavioral Sciences*; Academic Press: London, UK, 2013.
118. Cen, C.; Cheng, S.; Wong, N.H. Effect of Elevated Air Temperature and Air Velocity on Thermal Comfort and Cognitive Performance in the Tropics. *Build. Environ.* **2023**, *234*, 110203. [CrossRef]
119. Wargocki, P.; Wyon, D.P. Providing Better Thermal and Air Quality Conditions in School Classrooms Would Be Cost-Effective. *Build. Environ.* **2013**, *59*, 581–589. [CrossRef]
120. Stabile, L.; Dell'Isola, M.; Russi, A.; Massimo, A.; Buonanno, G. The Effect of Natural Ventilation Strategy on Indoor Air Quality in Schools. *Sci. Total Environ.* **2017**, *595*, 894–902. [CrossRef]
121. Mumovic, D.; Davies, M.; Ridley, I.; Altamirano-Medina, H.; Oreszczyn, T. A Methodology for Post-Occupancy Evaluation of Ventilation Rates in Schools. *Build. Serv. Eng. Res. Technol.* **2009**, *30*, 143–152. [CrossRef]
122. Ramalho, O.; Mandin, C.; Ribéron, J.; Wyart, G. Air Stuffiness and Air Exchange Rate in French Schools and Day-Care Centres. *Int. J. Vent.* **2013**, *12*, 175–180. [CrossRef]
123. European Comission. *Eurostat 2011. School Enrolment and Levels of Education*; European Comission: Brussels, Belgium, 2011.

124. Hauke, J.; Kossowski, T. Comparison of Values of Pearson's and Spearman's Correlation Coefficients on the Same Sets of Data. *Quaest. Geogr.* **2011**, *30*, 87–93. [CrossRef]
125. Haddad, S. Thermal Comfort in Naturally Ventilated Schools. In *A Field Study of Thermal Comfort in Iranian Primary School Classrooms*; University of New South Wales: Sydney, Australia, 2016.
126. Lazovic, I.; Stevanovic, Z.; Jovasevic-Stojanovic, M.; Zivkovic, M.; Banjac, M. Impact of CO_2 Concentration on Indoor Air Quality and Correlation with Relative Humidity and Indoor Air Temperature in School Buildings in Serbia. *Therm. Sci.* **2016**, *20*, 297–307. [CrossRef]
127. Nicol, F.; Humphreys, M.; Roaf, S. *Adaptive Thermal Comfort: Principles and Practice*; Routledge: London, UK, 2012; ISBN 9781136336485.

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