Title: Impact of COVID-19 protocols on IEQ and students' perception within educational buildings in Southern Spain.

Authors: Antonio J. Aguilar[1], María L. de la Hoz-Torres[1*], Lamberto Oltra-Nieto[2], Diego P. Ruiz[1] and Mª Dolores Martínez-Aires[2].

Affiliation:

[1] Department of Applied Physics, University of Granada, Av. Severo Ochoa s/n, 18071 Granada, Spain.

[2] Department of Building Construction, University of Granada, Av. Severo Ochoa s/n, 18071 Granada, Spain.

* mlhoz@ugr.es - Author to whom correspondence should be addressed.

Abstract

The COVID-19 pandemic has highlighted the fact that air quality is essential in buildings. In the case of educational buildings, teaching activities were moved to an online format during the 2020/2021 academic year, with only activities such as exams remaining face-to-face. This strategy required the development of protocols to ensure that classrooms were safe spaces. This study assesses the impact of these protocols in the indoor environmental conditions of educational buildings in Southern Spain. For this purpose, a measurement campaign was carried out at the Fuentenueva Campus of the University of Granada. The results show that the protocols have guaranteed effective ventilation. However, other indoor environmental variables have also been affected, including the satisfaction of users during exams due to temperature, relative humidity (RH) and noise. The highest levels of satisfaction were related to indoor lighting, while the highest levels of dissatisfaction were related to the indoor thermal environment. Among the main causes of dissatisfaction were draughts and outdoor noise, directly related to natural ventilation protocols

during the pandemic. Based on these findings, current pandemic protocols should be revised and redesigned to minimize the impact on student satisfaction and perceived learning performance from the identified environmental sources in this research.

Keywords: Indoor environmental quality, educational buildings, building management**,** occupants' satisfaction, IEQ monitoring, natural ventilation.

Introduction

Indoor air quality (IAQ) has received growing attention in recent years due to its short and long-term impacts on occupants' health and well-being (Camacho-Montano, Wagner, Erhorn-Kluttig, Mumovic, & Summerfield, 2019; Wargocki et al., 2002). Considering the pollutant concentrations in indoor air (Brelih & Seppänen, 2011; EPA, 2013) and the fact that people tend to spend approximately 90% of their time indoors, the built environment is an important element in its occupants' health and pollutant exposure (Odeh & Hussein, 2016; WHO, 2014). Ventilation measures, such as ensuring an adequate ventilation rate (VR), provide an outdoor airflow that removes or dilutes indoor-generated pollutants and improve IAQ. Ventilation standards and guidelines in European countries, and elsewhere, state that building ventilation is mandatory in order to ensure a satisfactory IAQ level and a healthy indoor built environment (ECA, 2017). However, maintaining an acceptable IAQ is a challenge in highly occupied environments such as educational buildings, where teachers, students and staff spend long periods of time (at least five hours per day) (Choe et al., 2022; ECA, 2017).

Nevertheless, despite the fact that good indoor environmental conditions are essential to providing a healthy, safe, productive and comfortable space, previous research studies have documented inadequate indoor environmental quality (IEQ) in educational buildings (Almeida & De Freitas, 2014; Daisey, Angell, & Apte, 2003; Teli, James, & Jentsch, 2013; Toftum et al., 2015; Van Dijken, Van Bronswijk, & Sundell, 2006). In view of the serious consequences of poor IEQ on students, in recent years previous research has been conducted with the aim of analysing the impact of natural ventilation on indoor environmental conditions in educational buildings. These research works were performed in pre-pandemic scenario. Thus, Sarbu and Pacurar (Sarbu & Pacurar, 2015) conducted a study to evaluate thermal comfort by subjective (using questionnaires) and objective (physical variables) measurements in two naturally ventilated classrooms in the Polytechnic University of Timisoara. They found that the average CO_2 concentration was 1450 ppm and 670 ppm in winter and summer respectively. The reason that this CO_2 concentration was lower in the summer season was that the windows were opened more often than they were in winter. Similar results were found in Italian natural ventilated classrooms by Stabile, Dell'Isola, Russi, Massimo and Buonanno (2017) and UK ventilated classrooms by Korsavi, Montazami and Mumovic (2020a, 2020b).

Previous studies also concluded that indoor air quality was strongly affected by the adaptive behaviors of the occupants. Regarding the driving factors related to the window-opening behavior in natural ventilated classrooms, Stazi, Naspi, Ulpiani and Di Perna (2017) concluded that students tend to suffer from poor air quality during heating season due to the students' prioritization of satisfying thermal perceptions. Indeed, Stazi affirmed that indoor and outdoor temperature are the main factors driving window-opening behaviors, while CO_2 concentration is not a stimulus. Similar conclusions were obtained by Duarte et al. (2017) and Heracleous and Michael (2019) in educational buildings in Portugal and Cyprus, respectively.

However, building occupants' behaviours and natural ventilation strategies have been modified as a results of the COVID-19 pandemic. The IAQ and indoor CO_2 concentration have recently been highlighted since teaching-learning spaces have become high risk environments for the transmission of Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2). Since this is an infectious virus that is mainly airborne, students or teachers could potentially be infected by inhaling a virus-containing aerosol generated when an infected individual exhales, speaks, shouts, coughs or sneezes (Greenhalgh et al., 2021). This fact makes it critical to manage IAQ in classrooms. Moreover, the COVID-19 pandemic has impacted the opinion in buildings engineering regarding healthy buildings (Awada et al., 2021) and has showed up the importance of ventilation (Gil-Baez et al., 2021).

In these circumstances, the closure of educational buildings was a measure taken by governments all over the world, in order to contain the virus transmission, in response to the COVID-19 outbreak. Despite the fact that learning activities were moved off-campus through the implementation of digital tools, this change posed difficulties of adaptation for teachers and students. This decision has affected more than 1.5 billion students worldwide and has had a severe impact on the learning process (Debbarma & Durai, 2021). Research conducted by Odriozola-González, Planchuelo-Gómez, Irurtia and Luis-García (2020) showed that 50.43% of the respondents at a Spanish University presented a moderate to severe impact of the outbreak. Therefore, Educational Institutions decided to return to face-to-face delivery of some academic activities (e.g. exams and assessments) in order to minimise the impact of the situation on their communities. Consequently, the return to the classroom required the implementation of measures to ensure a safe indoor environment for students and teachers.

In this regard, while the selection of an appropriate ventilation strategy in naturally ventilated classrooms can provide effective ventilation and low levels of CO_2 concentration, it also has an impact on all other indoor environmental variables. Ventilation levels affect indoor air temperature, air quality and acoustic parameters and they also impact, in a more indirect manner, the learning performance and capacity of students (Aguilar, de la Hoz-Torres, Martínez-Aires, & Ruiz, 2021; Daisey et al., 2003; Chryso Heracleous & Michael, 2018). IEQ factors have been associated with student learning and achievements, as well as illness and adverse health symptoms, leading to student absenteeism (Berman et al., 2018; Durán-Narucki, 2008; Eide, Showalter, & Goldhaber, 2010; Haverinen-Shaughnessy, Shaughnessy, Cole, Toyinbo, & Moschandreas, 2015; Mendell & Heath, 2005).

Recent research conducted during the COVID-19 pandemic scenario has evaluated the impact of natural ventilation protocols in the indoor physical environmental variables of classrooms in regions with similar climate conditions. Thus, in Villanueva et al. (2021) was assessed indoor air conditions in 19 schools (pre-school, primary and secondary) and it was found that most classrooms met the increased ventilation conditions through natural ventilation systems, although a total of 5 (26%) classrooms were found to exceed the recommended CO_2 concentration limit value (700 ppm) set by the COVID protocols. In a related research, Gil-Baez et al. (2021) evaluated environmental conditions in schools with natural ventilation systems during the COVID-19 pandemic. The results showed that natural ventilation systems can ensure adequate indoor air quality without compromising comfort conditions in mild weather conditions. However, these previous research studies have not conducted an evaluation of student satisfaction and sensation based on direct methods (i.e. surveying occupants) during the COVID-19 scenario. Therefore, with the aim of complementing this issue, the problem statement of the present work is to analyse the influence of COVID-19 protocols through the use of direct methods (sensor monitoring and a field survey campaign) in educational buildings to drive conclusions from the impact of these protocols on the indoor environmental conditions.

In addition, it should also be borne in mind that exam period has an important impact on the student body in any academic year. From the analysis of the evolution of the pandemic event, it is observed that new peaks of the crisis caused by COVID-19 may occur during exam periods. In order to prevent the spread of COVID-19 in university spaces, the IEQ of teaching-learning spaces should be assessed during exams after the reopening of educational buildings. However, a very limited research has been conducted during extreme events such as the COVID-19 pandemic, which had analyzed the impact of the application of these extraordinary protocols on the indoor environmental conditions in educational buildings. In this sense, the objective of this study is to evaluate the indoor environmental quality of teaching-learning spaces and the impact of COVID-19 protocols on students' perception and satisfaction during exams after the reopening of educational buildings. For this purpose, an on-site monitoring campaign and a questionnaire survey were conducted simultaneously during two periods of exams on Fuentenueva Campus at the University of Granada.

Methodology

Study area and building description

The Fuentenueva Campus is located in Granada, Andalusia (37°11′ N, 3°36′ W). This Campus is sited in the urban part of the city. Granada has a Mediterranean climate with hot and dry summers and cool damp winters. It is also characterised by strong daily and seasonal variations in temperature (AEMET, 2021) . The daily average temperatures and RH is 34°C and 37% in the hottest month (July) and 13°C and 72% in the coldest (January). However, night temperatures can drop to ~1°C in the coldest month.

Ten classrooms were selected in three educational buildings of the Fuentenueva Campus, for this research study. The ventilation system of the buildings is based on natural ventilation. All classrooms have manually operated windows on at least one side (see Figure 1 in the supplementary material online). The classrooms were selected according to the reopening plan of the University of Granada (UGR, 2020). The characteristics of the classrooms are shown in the Table 1 in the supplementary material online. The heating system was operating during the study and none of the classrooms had air conditioning equipment or mechanical ventilation systems. The guidelines for the return to face-to-face activity were based on maximising occupancy while respecting the 1.5 m distance rule between users. In addition, priority was given to classrooms with natural cross ventilation between doors and windows.

COVID-19 protocols in teaching-learning spaces

As in many countries, a COVID-19 protocol were adopted in the teaching-learning spaces with the aim of maintaining a sufficient fresh air supply to obtain a low virus level concentration and therefore preventing virus transmission. Specifically, the University of Granada approved a plan (UGR, 2020) based on the recommendations of the Ministry of Health of the Spanish Government (2020) and taking into account the current status of these spaces, as was stated in the WHO (2015) report. In this context, the COVID-19 protocols implemented during the examination period included: physical distancing (at least 1.5 m), wearing a face mask, handwashing, maintaining healthy facilities and increasing natural ventilation. In fact, the Ministry of Health of the Spanish Government (2020) recommended that the ventilation rate should be at least 12.5 litres/second per person in teaching-learning spaces. Since an increase of the ventilation rate is required, two strategies can be adopted: natural ventilation (increasing the flow of outside air through windows and doors according to the characteristics of the classroom) or mechanical ventilation (by increasing system capacity). In the case of educational buildings in Southern Spain, as in most European countries, classrooms are naturally ventilated (WHO, 2015) and thus the contingency and action plan for COVID-19 drawn up by the universities considered these circumstances. In this sense, the plan drawn up by the University of Granada (similar to others from European educational organisations) stated the following protocol in classrooms for the academic activities: one hour before the start of classes, all windows and doors were opened. This configuration was maintained during the face-to-face teaching-learning activities. Finally, the windows remained opened for one hour after the end of the activities. In addition, it also stated that one of the measures of ventilation required for the reopening of educational centres was: "even if the weather conditions are adverse, ventilation must be carried out by means of natural ventilation through open windows and doors" (UGR, 2020).

Data collection

In order to assess the IEQ factors in classrooms during the exams, objective (on site monitoring) and subjective (questionnaire survey) data collection were carried out. A measurement campaign was performed between January and July 2021. The campaign was divided into two monitoring periods: P1 (during the 3rd wave of COVID-19 infections, a period when restrictions on citizens were in place) and P2 (between the 3rd and 4th wave of infections, during a period of relaxation of the measures and reopening of educational centres).

Questionnaire survey

In this study, university students who were performing face-to-face academic activities during both periods were selected. The subjective responses of the participants were collected through a questionnaire. The used questionnaire comprised five parts: 1) General information, 2) Acoustic comfort, 3) Lighting comfort, 4) Thermal comfort, and 5) Overall comfort. These questions and the 7-point Likert scale with 0 as neutral is based on the UNE–CEN/TR 16798-2:2019 scale and the questionnaire was validated by an focus expert group prior to be applied to the respondents.

In 'General information' (1), respondents answered questions about their age, sex and type of mask used during the exam session. In parts 2), 3) and 4), they responded to questions about their satisfaction, sensation and performance interference, in terms of acoustics, lighting and thermal environmental conditions. A 7-point Likert scale was used to evaluate IEQ. The satisfaction ratings ranged from 'very satisfied' (+3) to 'very dissatisfied' (-3). For sensation, the range for acoustic was from 'too quiet' (+3) to 'too noisy' (-3), for light from 'too bright' (+3) to 'too dark' (-3) and for thermal from 'too hot' (+3) to 'too cold' (-3). For interference assessment, the range was from 'enhances a lot' (+3) to 'interferes a lot' (-3). In addition, participants reported possible causes of dissatisfaction and interference for each of the variables analysed. Participants could select one or more causes of dissatisfaction. Finally, part 5) evaluated the overall satisfaction and interference (acoustic, lighting and thermal). The questions contained in the questionnaire are provided in Table 2 in the supplementary material online.

In addition, clothing insulation was annotated by the researchers during the survey time using a checklist from UNE 7730 Standard. Based on these data, clothing insulation was then calculated following Tables C.1 and C.2 in the UNE 7730 Standard.

IEQ monitoring

In addition to the questionnaire survey, IEQ sensor monitoring was carried out during the face-to-face exams. The duration of the measurement was between 1.5 and 2.0 hours, according to the exam duration. For this purpose, temperature (ºC), relative humidity (%), air speed (m/s), lighting (lux), CO_2 concentration (ppm) and sound pressure level (dBA) were measured. All variables were measured in 1 minute intervals. Table 1 shows the characteristics of the sensors used. The sensors were placed around the classroom close to the students, 0.6 m above the floor and with a separation >1 m from surrounding surfaces.

Table 1. Sensor characteristics.

Sensor	Variable	Range measurement	Accuracy
HOBO® MX1102	Temperature	0 to 50°C	±0.21°C
	RH	1 to 90%	±2%
	CO_2	0 to 5,000 ppm	±50 ppm ±5% of reading
HOBO® MX1104	Light	0 to 167,731 lux	±10% typical for direct sunlight
HD403TS2 Delta OHM®	Air velocity	0.1 to 5 m/s	± 0.2 m/s + 3% f.s.
Imperum-R TECNITAX® Ingeniería	Sound pressure level	35–115 dBA	± 1 dBA

Outdoor climatological physical data were obtained from a meteorological station located at the Cartuja Campus of University of Granada. The data were provided by the State Meteorological Agency of Spain (AEMET) .

Statistical analysis

The statistical analysis focused on analysing the existence of differences between the probability distributions for both periods (P1 and P2), age, sex and different types of masks. The normality of the data was checked by goodness-of-fit tests (P-P probability plots and the Kolmogorov-Smirnov test). Regarding normal distributions, the parametric paired t-test was used. For the rest, the non-parametric Mann-Whitney U test was used. Levene's test for equality of variances was used to check the homoscedasticity requirement during the performance of the paired t-test. In addition, a study of the correlations between the different variables was carried out. Parametric Pearson correlations was used in the analysis. SPSS software (v. 23.0) was used in the statistical analysis.

Results

On-site IEQ monitoring

Table 2 shows the objective values obtained from the sensors during IEQ measurements in the periods P1 and P2. As can be seen, the mean outdoor temperature in P1 was 12.2ºC (± 4.6ºC), while the indoor temperature was 18.4ºC (± 2.1ºC). In contrast, the mean outdoor and indoor temperature was 26.3ºC (± 6.1ºC) and 27.4ºC (± 2.0ºC) respectively in P2. Regarding RH, in P1 it was 46.3% (± 9.8%) and in P2 it was 34.5% (± 7.5%).

The values defined by Spanish state regulations (RITE, 2007) in the winter season are 21-23ºC and RH between 40-50%, and in the summer season 23-25ºC and RH between 45-60%. From the analysis of these values, it can be concluded that indoor temperature was outside the comfort range defined in state regulations in P1, while the RH was within the defined ranges in the same period. The same case can be observed in P2 for both mean indoor temperature and RH. Similar results have been shown in previous studies carried out in educational buildings in a Mediterranean climate during the COVID-19 pandemic. Gil-Baez et al. (2021), found indoor temperatures ranging from 18.61º to 24.41ºC inside classrooms, while HR values ranged from 32.42% to 67.90%.

For air velocity, the mean value obtained was 0.11 m/s (± 0.08 m/s) in P1 and 0.08 m/s (± 0.04 m/s) in P2. The air velocity is moderate given the natural ventilation strategies implemented in the classrooms. Regarding CO_2 concentration, the average levels obtained were low (517 ppm and 440 ppm in P1 and P2, respectively). These levels are derived from the protocol established for COVID-19 spread control (the limitation of occupancy inside the classrooms and 1.50 m social distance, combined with natural cross ventilation between doors and windows). The values are far below the recommendations established in international guidelines, such as those indicated by the WHO (2000) and RITE (2007) (i.e. 1000 ppm and 900 ppm, respectively) .

The mean lighting values in the P1 and P2 periods were 351 lux and 527 lux, the latter being higher due to the higher number of sunshine hours. Finally, with respect to the indoor acoustic environment, the continuous sound pressure level (L_{Aeq}) during the exams in P1 and P2 was 57.0 dBA and 54.5 dBA, respectively. In this sense, there were unusually high values for the academic activities being carried out (exams). This was evident, since keeping the windows and doors open causes an increase in background noise levels derived from traffic (in an urban area of Granada), as well as the rest of the activities occurring around the University.

Table 2. Main values obtained for the IEQ measurements during the 2 periods

	Indoor Temperature (ºC)		**Outdoor Temperature (ºC)**		**HR (%)**		**Air velocity (m/s)**		**CO_2 (ppm)**		**Lighting (lux)**		**L_{Aeq} (dBA)**	
Period	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2	P1	P2
Max	21.6	29.3	21.8	33.7	62.6	48.3	0.28	0.16	668	576	506	815	62.6	64.3
Min	15.6	22.0	7.5	16.7	27.9	24.5	0.03	0.01	401	397	310	221	51.6	49.8
Average	18.4	27.4	12.2	26.3	46.3	34.5	0.11	0.08	517	440	351	527	57.0	54.5
Median	18.1	27.8	10.7	25.0	47.9	35.3	0.08	0.08	510	428	356	558	56.5	53.7
SD	2.1	2.0	4.6	6.1	9.8	7.5	0.08	0.04	83	46	134	185	2.9	4.1

Questionnaire survey responses

General information

A total of 491 questionnaires were obtained during the measurement campaign, of which 57 (12%) were discarded due to incompleteness, resulting in a total of 434 valid questionnaires (222 corresponding to P1 and 212 corresponding to P2). Table 3 shows the general information from the participants. The age range of the majority of the survey respondents was between 18 and 25 years, with a similar distribution in both periods (71% and 87% in P1 and P2, respectively). This age range is usual among undergraduate students. In terms of the distribution of men and women, they are similar in both periods (65-59% and 35-41%, respectively). Since students were siting during face-to-face exams, this is considered a sedentary activity and the metabolic rate is assumed to be 1.2 met. In addition, the median insulation clothing value obtained in P1 and P2 were 0.74 clo and 0.57 clo respectively, with a difference between periods of 0.17 clo. Figure 1 shows the clothing insulation values of students during the survey time in periods P1 and P2.

Table 3. General information from questionnaire survey participants.

Variable		**Responses**	
		P1	**P2**
Age	n/a	5 (2%)	9 (4%)
	18-25	157 (71%)	184 (87%)
	+25	60 (27%)	19 (9%)
Sex	Male	144 (65%)	125 (59%)
	Female	78 (35%)	87 (41%)
Type of mask	n/a	4 (2%)	0 (0%)

FFP2	136 (61%)	85 (40%)
Surgical	61 (27%)	101 (48%)
Cloth	16 (7%)	20 (9%)
Other	5 (2%)	6 (3%)

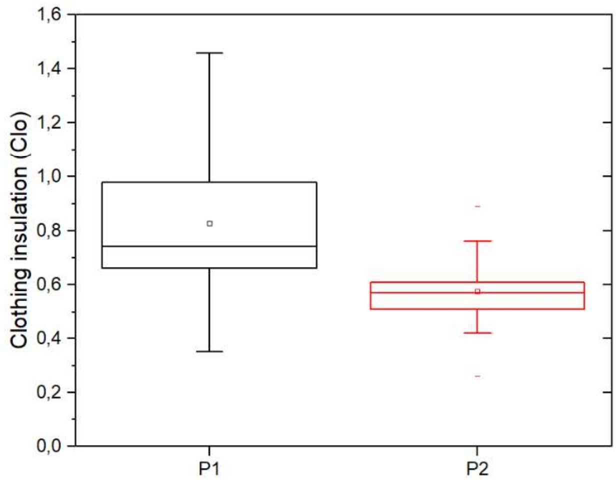

Figure 1. Clothing insulation values in P1 and P2.

Regarding the use of masks, there is a clear difference between P1 and P2. During the first period, the use of FFP2 type masks was the most common (61%) compared to surgical (27%). However, during the P2 period, the percentage of users using surgical masks (48%) was higher than that using FFP2 (40%). It should be noted that Granada was facing the 3rd wave of the COVID-19 pandemic during P1, compared to P2, when it was at a plateau prior to the escalation of the 4th wave.

Indoor acoustic environment

Figure 2 shows the results obtained during P1 and P2 in relation to the indoor acoustic environment. As can be seen, the results of question acoustic satisfaction show a low percentage of dissatisfaction (the sum of very dissatisfied, dissatisfied and slightly dissatisfied) of 27% in P1 and 12% in P2. This was in contrast to 64% and 80% of satisfied (the sum of slightly satisfied, satisfied and very satisfied) in both periods, respectively.

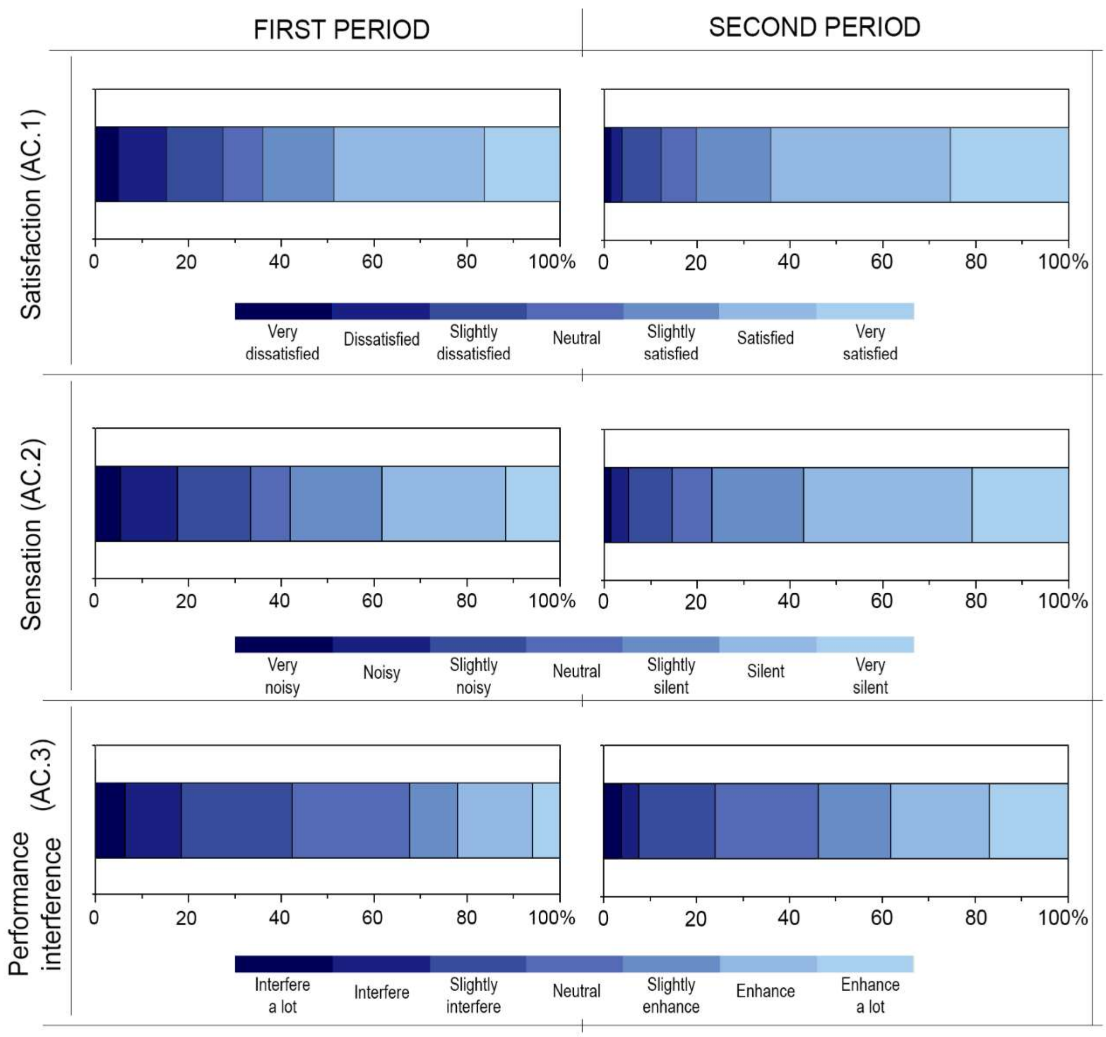

Figure 2. Distribution of votes for indoor acoustic environment questions.

Regarding the results obtained in acoustic sensation, only 18% in P1 and 5% in P2 considered the noise level in the classroom to be noisy or very noisy. Consequently, regarding the perception of the interference of the noise factor with student performance, 42% indicated (in question AC.3 about acoustic impact on task performance) that the noise interfered with them (considering the sum of interferes a lot, interferes and interferes a little) in P1, and 24% in P2. Figure 3 shows the causes of dissatisfaction with the indoor acoustic environment. It should be noted that, in both P1 and P2, the sum of the three main causes of dissatisfaction (>70%) came from noise sources outside the classroom (i.e. outdoor traffic noise, other outdoor noise and people talking in neighbouring areas).

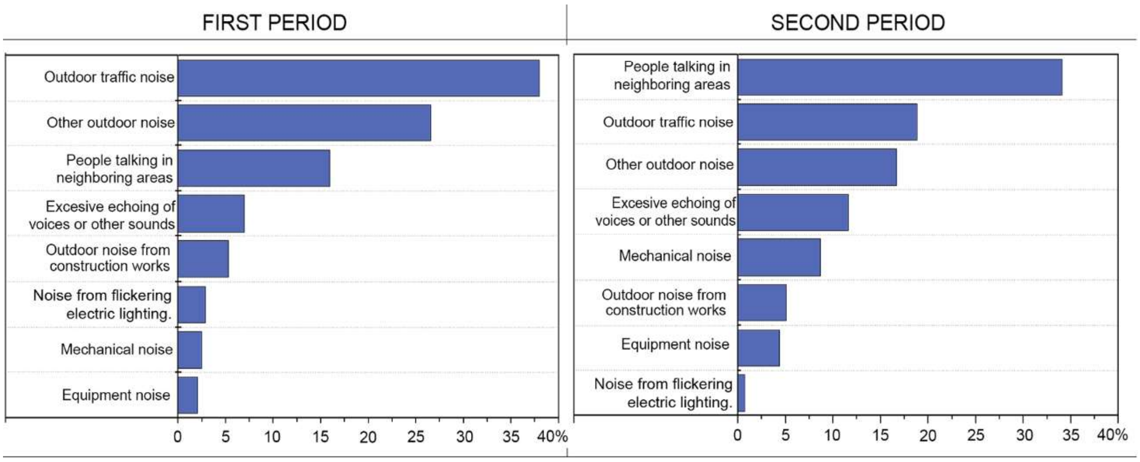

Figure 3. Analysis of the dissatisfaction causes regarding the indoor acoustic environment.

Indoor lighting environment

The obtained results related to indoor lighting environment showed that 89% of respondents were satisfied with the interior lighting in P1, increasing to 93% in P2 (Figure 4). In the case of lighting sensation, 18% and 15% of respondents indicated that the environment was too dark in P1 and P2, respectively; with 0% indicating that the lighting environment was too bright in both cases.

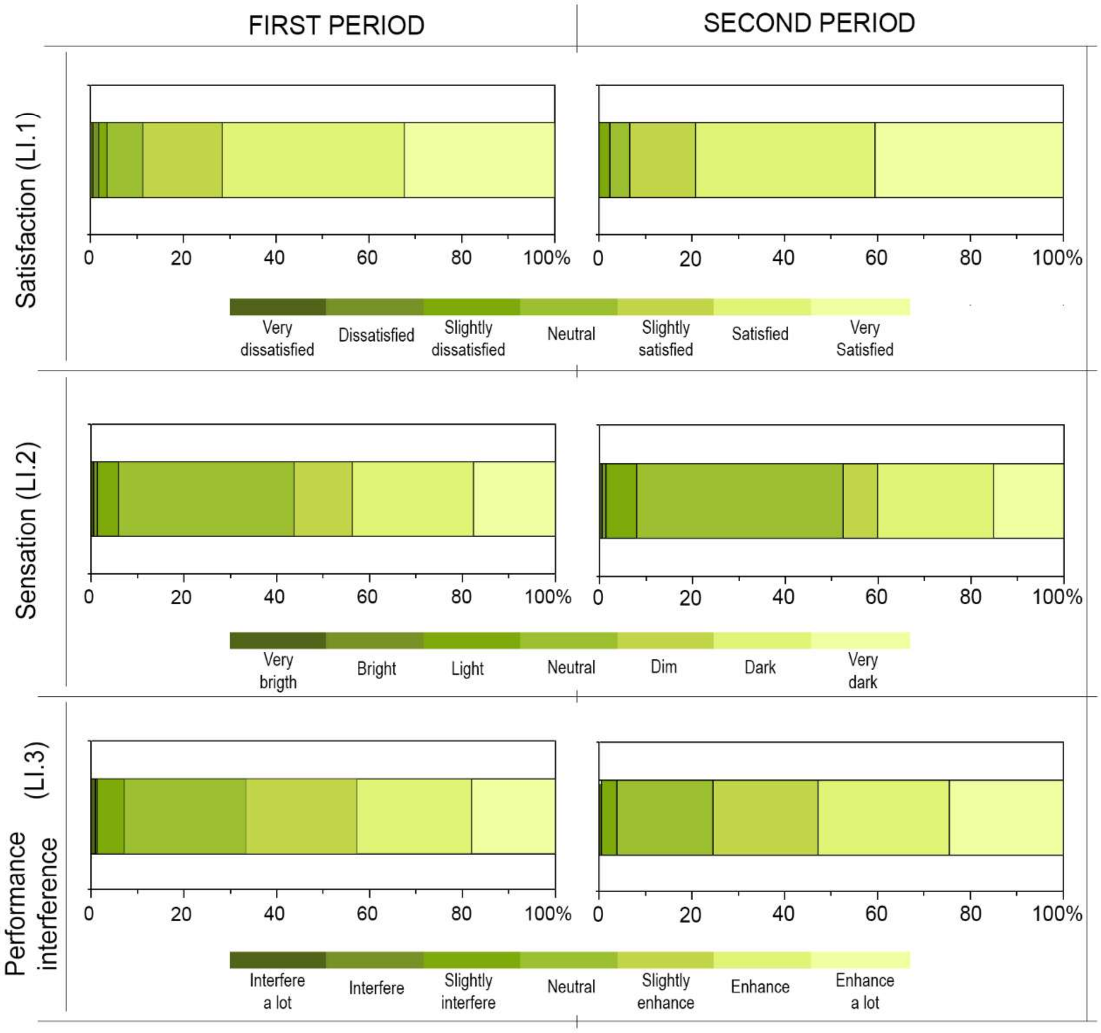

Figure 4. Distribution of votes for indoor lighting environment questions.

In addition, regarding the interference of the lighting environment with the students' performance, 7% indicated that it interfered with the activity in P1, compared to 3% of students that indicated that it interfered in P2. Among the causes of dissatisfaction (Figure 5), insufficient daylight is the most frequently indicated in both periods (25% in P1 and 19% in P2); followed by "electric lighting is an undesirable color" (16%) in P1 and "shadows on the workspace" (19%) in P2. It should be pointed out that the protocol implemented as a consequence of COVID-19 had no impact on classroom lighting. The opening of doors and windows and the distribution of students in the classroom during exams did not change the interior lighting of the classroom.

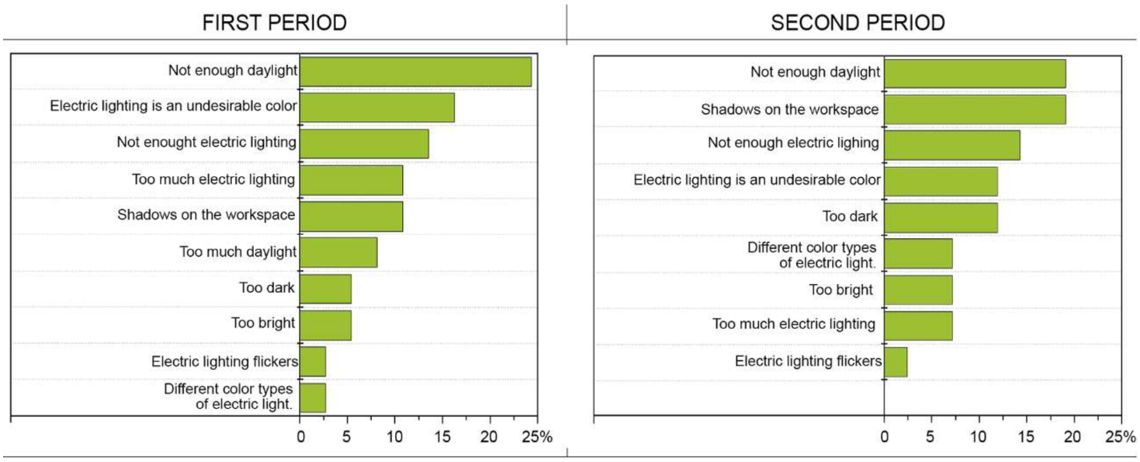

Figure 5. Analysis of the dissatisfaction causes regarding the indoor lighting environment.

Indoor thermal environment

Figure 6 shows the results obtained in the questionnaire survey concerning the thermal environment inside the classrooms. It should be noted that of all the different factors analysed, thermal environment is the only one that provides opposite responses in the two periods. The dissatisfaction rate was 53% and satisfaction rate was 31% in P1, compared to 17% and 66% in P2, respectively.

Regarding thermal sensation in P1, 28% indicated cool-cold and 33% slightly cool. In P2, on the contrary, 24% indicated warm-hot and 27% slightly warm. This is due to the fact that P1 coincided with the winter season and P2 with the spring-summer season. As for the evaluation of interference performance, 53% of the respondents indicated that the indoor thermal environmental condition interfered at least slightly during P1. By contrast, in P2, 49% indicated that the indoor thermal environment improved their ability to perform their work.

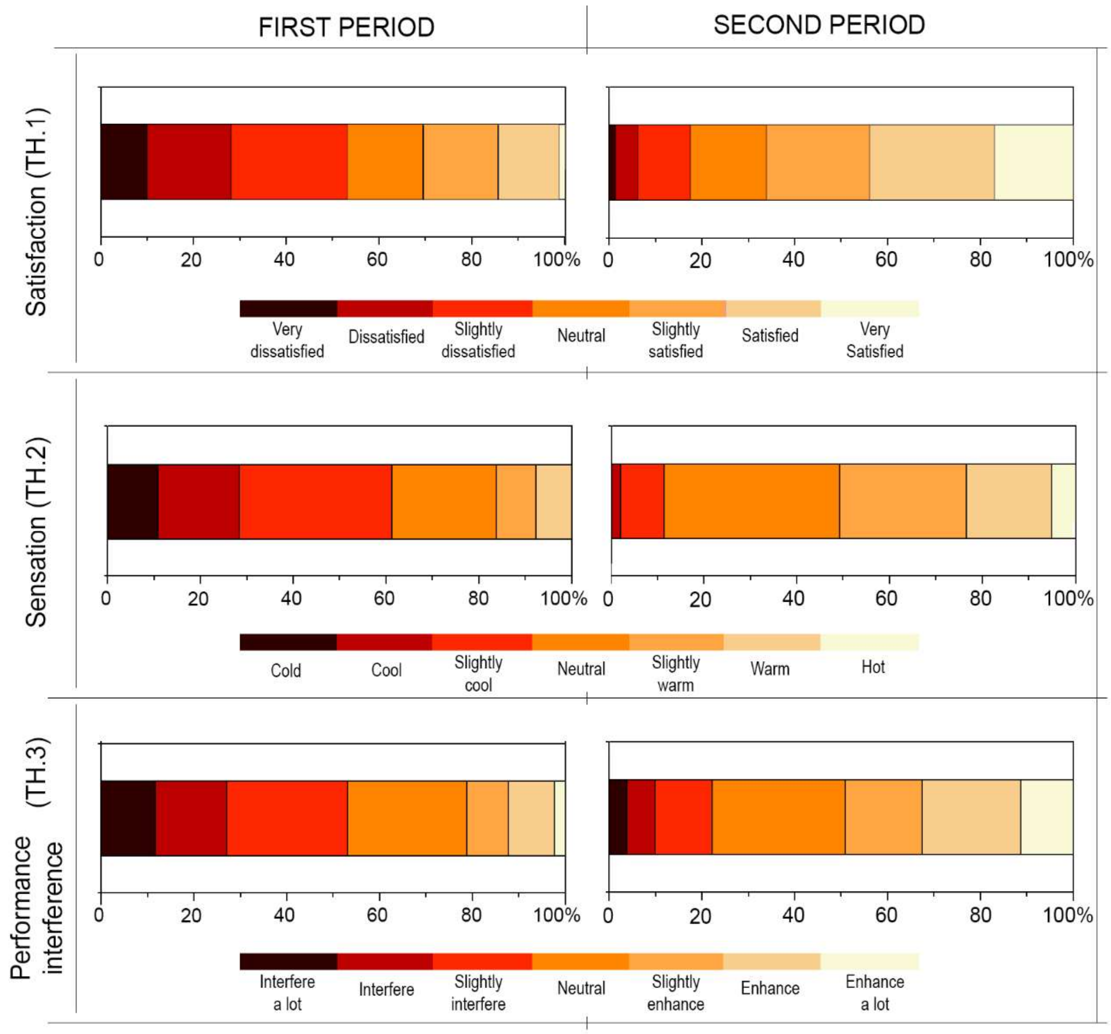

Figure 6. Distribution of votes for indoor thermal environment questions.

Figure 7 summarises the main causes of dissatisfaction with the indoor thermal environment. It can be seen that, in both periods, drafts are the main cause of dissatisfaction. This cause is especially important in P1, constituting one third of the votes among the causes of dissatisfaction. The second most-voted cause was that the air movement was too high (16%). Both causes are directly related to the COVID-19 contingency plan measures (keeping doors and windows open). The next cause is related to the heating system not responding fast enough (14%). In this sense, the facilities are not designed to meet the demands of this new pandemic situation.

During P2, drafts account for about a quarter of the votes indicated among the causes of thermal discomfort (22%). This cause is followed by 'surfaces around me are warmer/cooler' (14%) and 'the air movement is too low' (14%). In this sense, the social distance (at least 1.5 m) caused the students to be evenly distributed throughout the classroom. Therefore, some students were closer to the windows than the rest. This fact resulted in some students being more exposed to air currents than others were and, therefore, were more exposed to solar radiation.

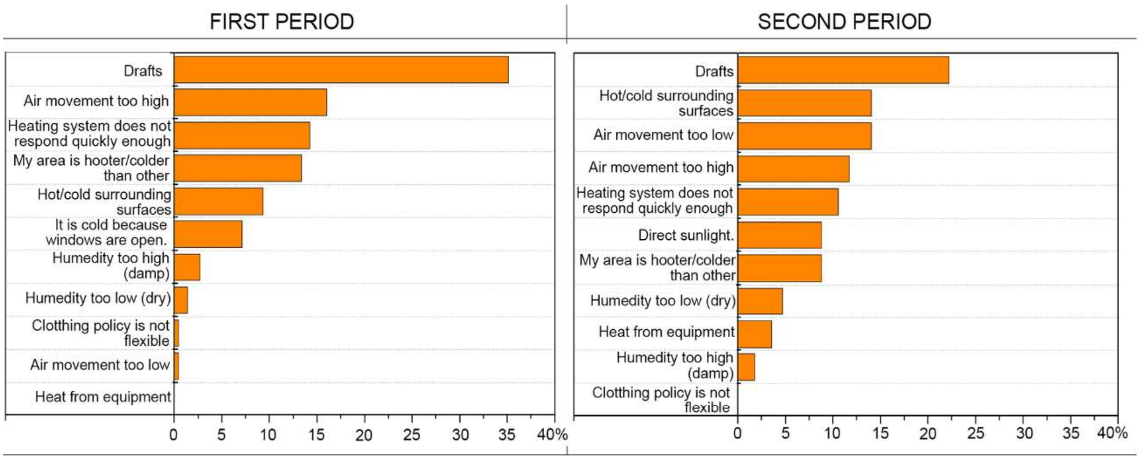

Figure 7. Analysis of the dissatisfaction causes regarding the indoor thermal environment.

Overall satisfaction

Finally, Figure 8 shows the overall satisfaction of students with the indoor environment. The results show that 65% of the respondents were satisfied with the overall IEQ in the classroom in P1 while, during P2, the overall satisfaction rose to 87%. Moreover, only 36% indicated that the IEQs were an improvement during P1, compared to 68% in P2. Furthermore, the results show that during P1 (corresponding to the winter season), the opening of doors and windows to achieve good ventilation was more dissatisfying than P2. In this regard, during P1, 31% of the responses indicated that their productivity was decreased by the indoor environmental conditions.

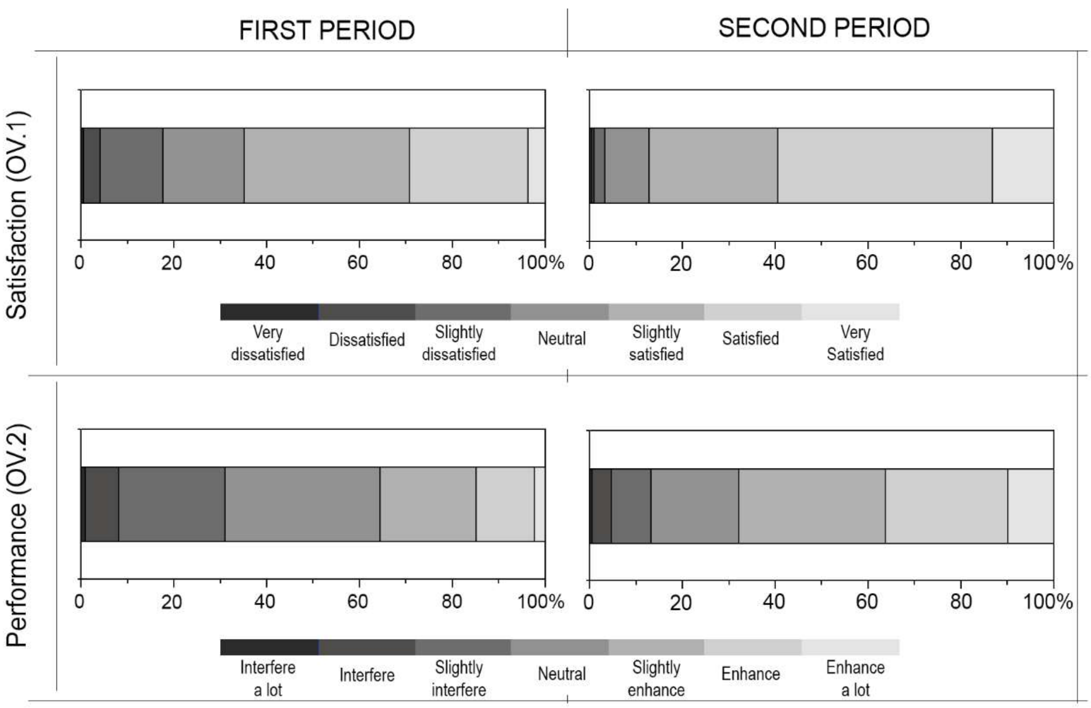

Figure 8. Distribution of votes for overall indoor environment conditions.

Statistical analysis and correlations

Firstly, since the measurement campaign was carried out in two different periods (P1 and P2), a t-test was conducted, in order to determine if there was a significant difference in the response obtained between the two periods (data provided in Table 3 in the supplementary material online). The obtained results about the indoor acoustic, thermal and lighting environment showed that the difference between the mean values of satisfaction, sensation and performance interference were statistically significant (con $p<0.000$ in all the cases), with the exception of lighting sensation, whose mean values were not significantly different between periods ($p=0.175$).

Regarding the overall indoor environment, the results obtained show that there were significant differences between the mean values of overall workspace satisfaction (OV.1) and overall impact on task performance (OV.2) ($p<0.001$ in both cases). In addition to the previous analysis, it was found that no significant differences were observed in the sex distribution in both periods. Moreover, no significant differences were observed in any of the variables' distributions according to sex.

Secondly, since it was found that the surgical mask and the FFP2 mask were the ones most used by the students, a t-test was performed to determine if there are differences between the answers provided according to the type of mask used. The results show that there are significant differences in acoustic satisfaction (p<0.001), acoustic sensation (p<0.001), acoustic impact on task performance (p=0.003) and thermal satisfaction (p=0.009).

Finally, the values obtained from the correlation analysis are shown in Figure 9. On the one hand, the results suggest that the overall satisfaction of students during exams (OV.1) is conditioned by multiple factors. It is worth noting the positive relationship with AC.2 (ρ=0.66, p<0.001), in which it can be seen that a quiet environment contributes to increasing overall satisfaction and improved student performance.

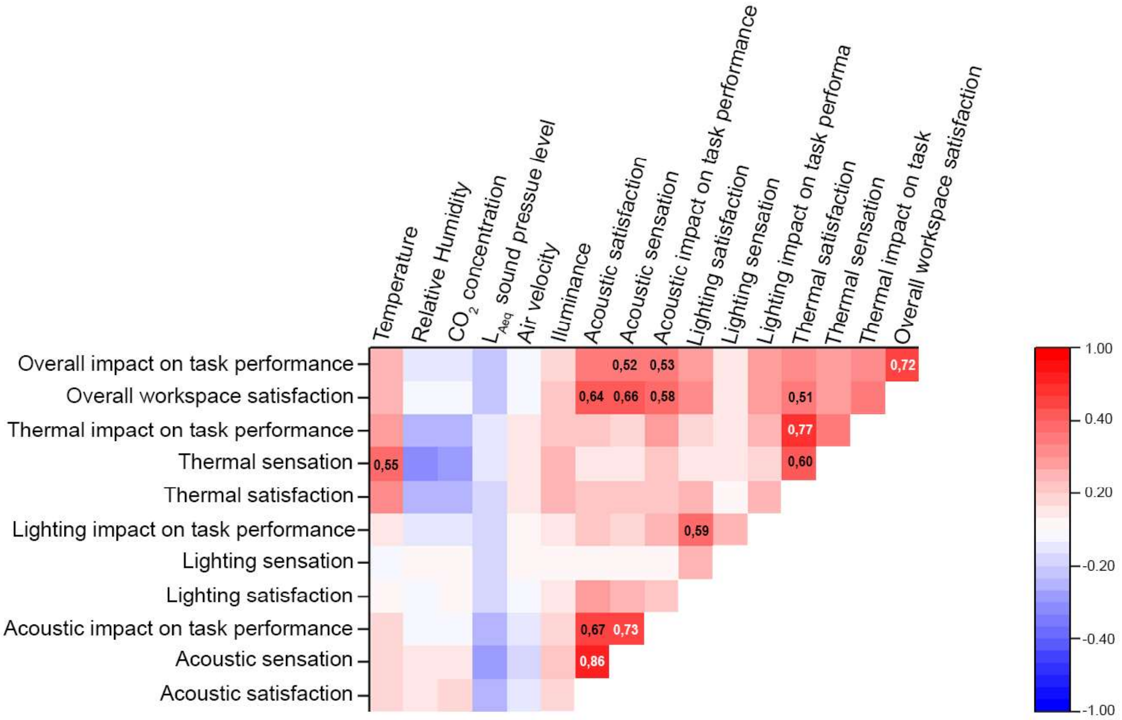

Figure 9. Correlation analysis.

Moreover, overall workspace satisfaction (OV.1) shows a moderate correlation with thermal environment satisfaction (TH.1) (ρ=0.51, p<0.001). These correlations suggest that the indoor acoustic environment, as well as the thermal environment, have a greater influence on overall satisfaction than the variables related to the lighting of the indoor environment. In addition, in relation to OV.2 performance, the only variable with a moderate correlation was the indoor acoustics (AC.2) (ρ=0.52, p<0.001).

On the other hand, in relation to thermal satisfaction and thermal sensation, it is observed that, in the range of temperatures in which the measurement campaign was carried out, there is a positive relationship between the interior temperature and the students' thermal satisfaction and sensation with it (ρ=0.44, p<0.001 and ρ=0.55, p<0.001, respectively). In contrast, a negative relationship is obtained between the acoustic satisfaction and acoustic sensation with the L_{Aeq} sound pressure level, the quieter the environment, the more satisfied students are with it (ρ=-0.31, p<0.001 and ρ=-0.35, p<0.001, respectively).

Figure 10 shows the relationship between thermal, acoustic and lighting sensation votes with the indoor temperature, sound pressure level and lighting, respectively. As can be seen, with the exception of the relationship between TSV and temperature, the obtained coefficients of determination (R^2) are quite low. Previous research reported that the individual differences between subjects affect the high variability of sensation votes and this result in a low coefficient of determination (Jowkar, Rijal, Montazami, Brusey, & Temeljotov-Salaj, 2020). From these results, the neutral temperature obtained was 23.2 ºC. The differences between the neutral temperature and the average indoor temperature obtained in P1 (18.4 ºC) was -4.81 ºC and in P2 (27.4 ºC) was +4.2 ºC. Regarding the acoustic sensation votes, students considered that L_{Aeq} above 60 dBA were noisy. Finally, regarding the lighting sensation votes, the range of lighting values measured in this study (200-800 lux) were considered as a bright environment.

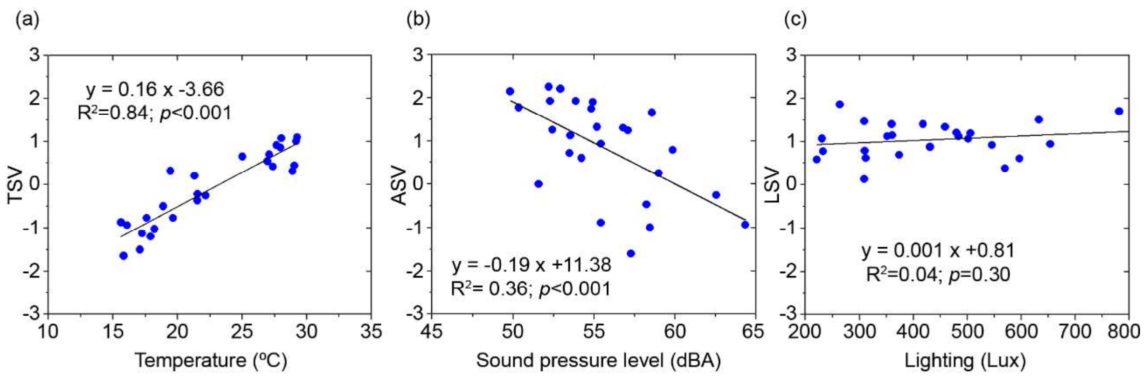

Figure 10. (a) Relationship between TSV and temperature. (b) Relationship between ASV and sound pressure level. (c) Relationship between LSV and Lighting.

Discussion

The results highlight that the natural ventilation strategies were effective since the average indoor CO_2 concentration level was 517 ppm in P1 and 440 ppm in P2. If these values are compared with other results found in other studies carried out during the COVID-19 pandemic period in similar climatological regions, it is observed that similar low concentration values were also reported in studies conducted in educational buildings (Miranda, Romero, Valero-Amaro, Arranz, & Montero, 2021; Villanueva et al., 2021). In contrast, Gil-Baez et al. (2021) reported higher CO_2 concentrations (between 969 - 2919 ppm). These values were higher since, unlike our study, the windows and doors remained closed during part of the time of the study. The same reason explains that the results obtained in our study differ from those found by other research carried out in Southern Spain prior to the COVID-19 outbreak. So, Fernández-Agüera, Campano, Domínguez-Amarillo, Acosta and Sendra (2019) conducted on sited measurements in classrooms and found CO_2 concentration values above 1000 ppm, with higher values during winter season due to the ventilation strategy (windows and doors were closed in the around 60% of the classrooms analysed).

In terms of the indoor air temperature and RH, in our research it was measured an average temperature of 18.4 ºC (ranged from 15.6º to 21.6º) and an average HR of 46.3% (ranged from 27.9% to 62.6%) in P1, while in P2 it was 27.4 ºC (ranged from 22.0º to 29.3º) and 34.5% (ranged from 24.5% to 48.3%), respectively. These values are similar to those obtained for other authors in the period of the COVID19 pandemic (Gil-Baez et al., 2021; Miranda et al., 2021) but they are quite different from the pre-pandemic time period. Indeed, Fernández-Agüera et al. (2019) reported values between 37 - 59 % and temperature values between 17.8 - 24.2 ºC during mid-season, and between 44 - 64 % and 19.2 – 22.7 ºC respectively during winter season).

The average air velocity was 0.11 m/s (ranged between 0.03 - 0.28m/s) in P1 and 0.08 m/s (0.01-0.16) in P2. Miranda et al. (2021) reported lower values in their measurement campaign conducted in winter season (air velocity ranged from 0.003 to 0.12). These results are in accordance with the ventilation strategy adopted in each case.

Regarding the indoor acoustic environment, the L_{Aeq} was 57.0 dBA in P1 and 54.5 dBA in P2 respectively. Previous field tests developed by the authors (de la Hoz-Torres, Aguilar, Ruiz, & Martínez-Aires, 2021) showed that natural ventilation strategies through opening windows and doors affect the indoor acoustics quality during the teaching process. In fact, it was found that background noise level can be increased between 6.4 dBA and 12.6 dBA in contrast to the same scenarios with closed doors and windows.

With regard to the data obtained from the occupant surveys, it is interesting to note that the average overall satisfaction was 65% during P1 and 87% during P2. The highest percentage of dissatisfied students in both periods is related to the indoor thermal conditions (53% in P1 and 17% in P2). The continuous natural ventilation by opening doors and windows has conditioned the indoor temperature of the classroom, resulting in wider temperature ranges in both periods than the values reported in studies carried out before the COVID-19 pandemic (Fernández-Agüera et al., 2019). Before the implementation of the epidemic protocols, students could open and close windows freely. However, during the pandemic, windows had to be kept open even if outdoor environmental conditions were adverse. Furthermore, from the obtained results, it was observed that students were more satisfied with a slightly warm environment versus a cooler environment. This is reflected by the fact that the percentage of dissatisfied students is higher in the season when the average indoor temperature was lower (winter, i.e. P1). In comparison to P1, natural ventilation during P2 can lead to an improvement of the indoor thermal environment, since ventilation can regulate the indoor temperature. Previous studies reported improvement of the indoor thermal environment through natural ventilation. Heracleous and Michael (2018) concluded that, since classrooms in Southern European countries have been diachronically naturally ventilated, natural ventilation strategies can improve thermal comfort in intermediate seasons (fresh outdoor airflow is welcomed by the occupants in the classrooms). However, measures to reduce the risk of overheating must be adopted in the warmer periods (Duarte et al., 2017).

It is also interesting to note that the clothing insulation values obtained in both periods (0.74 clo in P1 and 0.57 clo in P2) are similar to the values reported in a previous study conducted before COVID-19 pandemic (0.56 clo in warm seasons and 0.77 clo in winter season) (Wang, Kim, Xiong, & Yin, 2019). If the obtained values are compared with those reference clothing insulation values set in the Spanish state regulation (RITE, 2007) for sedentary activities (1.2 met), it is found that the clothing insulation value obtained during P2 is similar (RITE states a 0.5 clo value for the warm season) but the value obtained in P1 is lower (RITE states a 1.0 clo value for the cold season). In this sense, the high percentage of dissatisfied students in P1 may be influenced by both factors: (1) students were dressed with inadequate clothing insulation and (2) the temperature inside the classroom was lower as a result of the implemented COVID-19 protocols.

In addition, it should be noted that wearing a face mask may affect the thermal comfort of students. In fact, previous research have showed that the type of mask and the ambient temperature affect thermal comfort (Zender-Świercz, Telejko & Galiszewska, 2021; Milošević et al., 2022).

It is also remarkable that the second indoor environmental condition with the highest percentage of dissatisfied students was the acoustic conditions. This percentage was much higher in the first period (P1) than in the second (P2). In fact, if the L_{Aeq} values are compared between both periods, it can be observed that the average level in P1 (57.0 dBA) is also higher than the average level obtained in P2 (54.5 dBA). Since the academic activities in which the measurement campaign was conducted were exams, where the activity does not require teacher/student interaction, noise can be an important factor in student performance. In this sense, there is a relationship between the protocol implemented to ensure effective ventilation of the classroom (all doors and windows open during the academic activity) and the L_{Aeq} level inside the classroom. External noise sources contribute to increasing indoor L_{Aeq} noise levels to a greater extent than in pre-pandemic conditions (closed windows and doors). This fact is conditioned by the location of the university campus in the centre of the urban part of Granada. Previous studies have already highlighted that noise pollution is a problem in educational buildings in large cities (Ali, 2013; Chiang & Lai, 2008; Shield & Dockrell, 2004), so this is exacerbated by the measures implemented as a result of the COVID-19 pandemic.

In summary, acoustic and thermal conditions have influenced the student's satisfaction. Indeed, the statistical analysis results have shown a moderate-high relationship between the overall students' satisfaction with acoustic satisfaction and with thermal satisfaction (ρ=0.64; p<0.001 and ρ=0.51; p<0.001, respectively). Since pandemic protocols and ventilation strategies influence environmental conditions, their modification and adaptation could provide safe and secure spaces for the people and the environment. It should bear in mind that the percentage of students dissatisfied with the indoor environmental conditions in classrooms after implementing the COVID-19 protocols was higher in P1 than in P2. This fact suggests that pandemic protocols should be rethought and different strategies should be designed to adapt them to each seasonal period. Adaptations to improve indoor thermal conditions have to be prioritized during cold season since it was one of the major causes of students' dissatisfaction. The redesign process of ventilation protocols should give priority to ensuring an indoor temperature close to the neutral temperature (23.3ºC). Additionally, given the influence of acoustic conditions on overall student satisfaction, this process has also to prioritize providing suitable acoustic conditions during both time periods, avoiding high noise level values that have been rated by students as noisy (60.0 dBA).

Finally, this research shows that a COVID-19 ventilation strategy based on continuous natural ventilation through windows and doors provides effective air renewal and low CO_2 concentrations, but it does not ensure a minimum IEQ and occupant satisfaction. In addition, it should be taken in into account that natural ventilation strategies based only in the subjective physical response of students are not able to provide a minimum IAQ during severe conditions (winter and fall), so a ventilation strategy based on only those subjective data is not suitable

(Stabile, Dell'Isola, Frattolillo, Massimo, & Russi, 2016). In view of these facts, the selection of the ventilation strategy based on taking into account both an effective air renewal for low CO_2 concentrations and IEQ factors for occupant satisfaction becomes essential in this process and pandemic protocols should consider these findings in the process of redesigning ventilation strategies.

Limitations

The measurement campaign conducted in this study was carried out only during the months when face-to-face activities took place in educational buildings in the academic year 2020-2021. These activities only included exams, since all the other learning activities were moved off-campus (on line) in order to prevent the virus transmission. Therefore, the obtained results should not be extended without further analysis to other seasons or scenarios where different ventilation strategies could have been implemented (i.e. windows are not continuously opened or the classroom is mechanically ventilated).

Additionally, it should be noted that this measurement campaign has been conducted in university educational buildings. Further research will be needed in order to expand these results to other types of educational buildings and scenarios, since their characteristics may be different (spaces with less surface area, higher occupancy density, ventilation systems, etc.).

Conclusion

The situation arising from the pandemic caused by COVID-19 has led to an increased interest in achieving a good IAQ in the indoor built environment. The characteristics of educational buildings (high occupancy density and natural ventilation systems in most of the spaces) result in challenging conditions for building engineers and managers. These circumstances have led to the implementation of protocols to increase the air change rate in classrooms through the opening of windows and doors. Consequently, in addition to IAQ, the other IEQ factors have been affected by these measures, providing values very different from those expected under normal operating conditions.

This research shows that the implemented protocols have had an impact on student satisfaction regarding the indoor built environment. Although ventilation strategies have provided effective air renewal, it is clear that they have also disturbed indoor environmental conditions in classrooms, and not always in the sense of an IEQ improvement. In this sense, it should be noted that academic activities such as exams provide stress to students, which in turn can be also affected by poor IEQ conditions in classrooms. The obtained results show that pandemic protocols should not only prioritise ensuring a good IAQ but also the rest of IEQ factors by considering how the extend of this condition and its potential to disturb the student performance could be. In view of these facts, and given that most educational building in Europe are naturally ventilated, the finding of the current study could be successfully used to define and redesign the ventilation pandemic protocols of educational building in countries with similar climatic conditions (e.g. Mediterranean climate). Future research studies should address the development of systems and devices combined with redesigned safety protocols that ensure not only that indoor spaces are safe but also that they maintain acceptable levels of satisfaction in relation to IEQ. This is crucial in order to make buildings resilient and minimise the impact of pandemics on the learning process of future generations.

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