







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

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Abstract

Post-epidemic protocols have been implemented in public buildings to keep indoor environments safe. However, indoor environmental conditions are affected by this decision, which also affect the occupants of buildings. This fact has major implications in educational buildings, where the satisfaction and learning performance of students may also be affected. This study investigates the impact of post-epidemic protocols on indoor environmental conditions in higher education buildings of one Portuguese and one Spanish university. A sensor monitoring campaign combined with a simultaneous questionnaire was conducted during the reopening of the educational buildings. Results showed that although renewal air protocols were effective and the mean CO₂ concentration levels remained low (742 ppm and 519 ppm in Portugal and Spain universities, respectively), students were dissatisfied with the current indoor environmental conditions. Significant differences were also found between the responses of Portuguese and Spanish students. Indeed, Spanish students showed warmer preferences (thermal neutrality = 23.3°C) than Portuguese students (thermal neutrality = 20.7°C). In terms of involved indoor factors, the obtained data showed significant correlations ($p < 0.001$) between acoustic factors and overall satisfaction in the Portuguese students ($\rho = 0.540$) and between thermal factors and overall satisfaction in the Spanish students ($\rho = 0.522$). Therefore, indoor environmental conditions should be improved by keeping spaces safe while minimizing the impact of post-epidemic protocols on student learning performance.

KEYWORDS

building management, built environment, indoor environmental quality, new-normal scenario, sensor monitoring

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1 | INTRODUCTION

The pandemic outbreak of COVID-19 has led to disruptions in human activities and the basic needs of the population worldwide. The rapid spread of the severe acute respiratory syndrome coronavirus-2 (SARS-CoV-2) has resulted in the suspension of many agricultural, industrial, and commercial activities, causing a negative impact on both the global industrial and economic sectors and a deterioration in the global economy.^{1,2} The adopted measures to limit the spread of SARS-CoV-2 have also profoundly affected the education sector worldwide. More than 1.5 billion learners (89.4% of the total enrolled learners) were affected by the closure of educational buildings when schools and higher education institutions were closed in 185 countries on April 2020.³ The southwestern European countries, namely, Spain and Portugal, were also severely affected by the COVID-19 pandemic. The strict lockdown measures were decreed on March 12 and 13 in Portugal and Spain, respectively.^{4,5} These measures included the closure of playgrounds, schools, and universities, and this situation lasted until early May in Spain and June 20 in Portugal.

Educational institutions faced these circumstances and took steps to suddenly change the teaching activities and start using online teaching methodologies. However, although this adaptation allowed the academic process to continue, teachers and students found it difficult to adapt to this new scenario. A recent research study concluded that 50.43% of the respondents of Spanish universities presented a moderate-to-severe impact of the outbreak.⁶ In light of these facts, educational buildings were reopened for some learning activities, during epidemic conditions, in order to mitigate the impact of online teaching on university communities. As a consequence, this process required implementing measures to protect the health, safety, and welfare of educational building occupants from the spread of SARS-CoV-2. Given that teachers, students, and staff spend long periods per day in these buildings, the first consideration to maintaining a healthy environment and reducing exposure risk is a dilution of pollutants within the indoor space. Although indoor air management will not stop the spread of COVID-19 on its own, it can reduce the number of people infected when occupants also follow measures to control and stop infection (e.g., the use of masks and practicing good hand hygiene).^{2,7-9}

International organizations also published guidelines in which ventilation was considered an important factor in the safety of indoor spaces. World Health Organization (WHO) guidelines recommended 1000 ppm as the CO₂ concentration limit.¹⁰ The Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA) recommended 8–10 L/s per person in meeting rooms and classrooms.¹¹ In addition, the guidelines drawn up by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) also suggested lowering the number of building occupants and increasing outdoor air ventilation. Additionally, they recommended that ventilation systems must be run at a maximum of 2 hr before and after occupancy for pre- and post-occupancy flushing.¹² Therefore, given the importance of ventilation in educational buildings, the contingency and action plan for COVID-19 established

Practical implications

- Although the application of post-epidemic protocols in higher education buildings has kept the mean CO₂ concentration levels under control by providing an effective air renewal, the implementation of these protocols affected the degree of satisfaction of indoor environmental variables that deserves to be considered.
- The main dissatisfaction causes indicated by the students are outdoor noise from several sources and low thermal comfort, which are clearly related to the application of the post-epidemic protocols, and therefore, they should be revised to be taken into consideration.
- Priorities for the revision of post-pandemic protocols should be focused on minimizing the interference in student learning with special care in those preferences of individuals in accordance with the climatic area that they live in.
- Well-defined patterns are identified for fine-tuning the final protocols in accordance with the specific circumstances, for example, prioritizing the improvement of acoustic conditions during mid-season should be considered in the case of the Azurém Campus, and minimizing the impact of thermal conditions in the case of the Fuentenueva Campus.

in engineering schools and faculties by Spanish and Portuguese universities also refer to ventilation among their defined measures. For example, the plan established by the University of Granada also considers the recommendation to ventilate before and after occupancy as a reopening measure for educational centers, and it even specified that “even if the weather conditions are adverse, ventilation must be carried out by means of natural ventilation through open windows and doors”.¹³ In addition, the “Plano de Contingência” (Contingency Plan) COVID-19 draw up by the University of Minho also stated “good ventilation and frequent air renewal must be ensured, for example, by opening doors and windows. If mechanical ventilation is used, it should be in extraction mode and never in recirculation mode”.¹⁴

Fortunately, the efforts of researchers and the rollout of effective vaccines have made society hopeful for a return to the “new normal.” On September 1, 2021, the proportion of the population who had received all the doses prescribed by the vaccination protocol in Portugal and Spain was 75.5% and 72.0%, respectively.¹⁵ Indeed, Portugal had the highest COVID-19 vaccination rate in the world in September.¹⁶ Consequently, given the percentage of vaccinated people in the university community compared with that for the 2020–2021 academic year, the COVID-19 contingency plans approved by the different faculties and engineering schools were adapted to allow for the highest possible attendance in the 2021–2022 academic year. The main objective was to ensure a safe, secure,

TABLE 1 Summary of the investigated buildings

Campus	Building	Number of surveyed students (<i>n</i>)	Average occupancy density (m ² /person)	Lighting system	Type of windows	Finish materials		
						Floor	Wall	Ceiling
Azurém (Portugal)	B1	42	1.3	Suspended and mounted fluorescent luminaire	Aluminum/metal glazed windows	Wood	Gypsum plaster	Acoustic plasterboard
	B2	49	1.2			Vinyl/wood	Gypsum plaster/wood	Plaster
	B3	81	1.2			Ceramic tile	Gypsum plaster/cork	Acoustic plasterboard
	B4	45	1.3			Vinyl	Gypsum plaster/wood	Acoustic plasterboard
Fuentenueva (Spain)	B5	111	1.1	Mounted fluorescent luminaire	Aluminum glazed windows	Terrazzo	Gypsum plaster	Registrable suspended ceiling
	B6	113	1.8			Natural stone	Ceramic tile	Registrable suspended ceiling

and suitable indoor space for full face-to-face attendance in a new-normal scenario of post-epidemic conditions.^{13,17} In this sense, except for the 1.5-micromanometer social distance, all the measures stated in the COVID-19 contingency plans remained in place in the educational buildings.

In this context, the start of the 2021–2022 academic year began with face-to-face learning and the application of a conditionally normal scenario. However, since these measures and protocols affect the indoor environmental conditions in this new-normal scenario, the occupant satisfaction and the indoor environmental quality (IEQ) of educational building may be affected by them. Increasing the amount of outdoor air affects indoor environmental factors (such as the background noise, air temperature, and relative humidity (RH)), and as a consequence, occupants' performance may be affected.^{18–21} Indeed, previous research studies concluded that a poor indoor environmental quality is associated with adverse health effects and illness, leading to student absenteeism.^{22,23} However, given the short time that has elapsed since society has suddenly been forced to adapt to the "new normal," very little research has been published related to the impact of the new post-epidemic protocols on the indoor environmental variables in educational buildings. To address this gap, the aim of this study was to analyze the satisfaction and perception of university students in this new scenario of post-epidemic conditions. For this purpose, a measurement campaign was conducted in educational buildings in Portugal (Azurém Campus, University of Minho) and Spain (Fuentenueva Campus, University of Granada). This study assessed the indoor environmental conditions and the sensation and satisfaction of the students with the indoor acoustic, lighting, and thermal conditions along with their subjective perception of the impact of these variables on their academic performance. The findings will support decision making for the redesign and development of protocols, thus minimizing student dissatisfaction and ensuring that educational centers are safe.

2 | MATERIALS AND METHODS

A questionnaire and IEQ monitoring were conducted at the Azurém Campus (University of Minho, Guimarães, Portugal) and at the Fuentenueva Campus (University of Granada, Granada, Spain). Field measurements were performed during the reopening of the educational buildings in the 2021/2022 academic year (during the period of September–November 2021).

2.1 | Educational building case studies

Guimarães is located in the northern part of Portugal (41°26'42"N - 8°17'27"W), and the climate belongs to Csb category according to the Köppen–Geiger climate classification. This area is characterized by cold and rainy winters and hot and slightly humid summers, with an average annual temperature range from 5 to 28°C. Granada is located in the southern part of Spain (37°10'41"N - 3°36'03"W),

and its climate is classified as Csa. Granada is characterized by cold winters (partly cloudy) and hot summers. The annual temperature varies from 0 to 34°C, and at certain times of the year, the thermal oscillation during the day is large, often exceeding 20°C in 1 day.

In both locations, an analysis of the characteristics of teaching and learning spaces was conducted to select representative classrooms on both campuses. For this purpose, building managers were asked to identify the different spaces used for undergraduate lecture classes of each campus. These classrooms used for the undergraduate students were chosen since they have the largest number of occupants. Among these classrooms, the measurement campaign was carried out in those ones with the dimensions, occupation, and layout representative of the spaces used for this activity in each of the buildings. The selection criteria were the same in both campuses. As a result of this process, 8 classrooms distributed in 4 buildings at the Azurém Campus and 7 classrooms distributed in 2 buildings at the Fuentenueva Campus were selected in the IEQ measurement campaign.

A summary of the selected buildings, classrooms, and number of surveyed students is shown in Table 1.

2.2 | IEQ sensors and experimental setup

The IEQ monitoring campaign was conducted during normal lessons (1.5–2 hr), during the mid-season (from September to November 2021) in both locations. Different indoor parameters were recorded during the IEQ measurement: air temperature (°C), radiant temperature (°C), RH (%), air velocity (m/s), CO₂ concentration (ppm), and light intensity (lux). In addition, the sound pressure level (dBA) in each classroom was measured. Table 2 shows a summary of the main characteristics of the used sensors. All parameters were measured in 1-min logging intervals. The sensors were placed in the middle of the classrooms, separated >1 m from the surrounding surfaces and at a height of 0.6 m.

Outdoor climatological data were taken from meteorological stations close to the study area. For the area of Portugal, the data were obtained from IPMA (Portuguese Institute for Sea and

Atmosphere),²⁴ and for the area of Granada, the data were obtained from AEMET (State Meteorological Agency)²⁵.

Additionally, based on the indoor air temperatures and radiant temperatures values obtained from the sensor monitoring campaign, the operative temperatures were calculated. This variable is used in Spanish and Portuguese legislation to define upper and lower limit requirements of thermal quality in the indoor environment. In the case of Spain, two ranges are defined. For the summer months (assuming 0.5 clo value and an estimated percentage of dissatisfied between 10% and 15%), the range (R_{S-S}) is from 23 to 25°C. For the winter months (assuming 1 clo value and the same estimated percentage of unsatisfied), the range (R_{S-W}) is from 21 to 23°C. The Portuguese legislation only establishes an annual range (R_p), which is wider than that established in the Spanish legislation, and sets the operating temperature limits from 20 to 25°C. The operative temperature values obtained from the field measurements were compared with the indoor thermal quality requirement ranges of each country.

2.3 | Data collection and analysis from questionnaires

A paper-based cross-sectional questionnaire was conducted in this study. The construction of the questionnaire involved the following steps: Firstly, the prototype questionnaire was built by the research group using the UNE-CEN/TR 16798-2:2019 Standard for the evaluation of the indoor environmental quality. Specifically, this study followed the recommended procedures and questionnaires given in this Standard for the systematic registration of subjective reactions of building occupants. The questionnaire was divided into sections containing items related to thermal, lighting, acoustic, and air quality indoor environment. These items followed the guidelines established in UNE-EN 10551:2019 for subjective assessment of physical environment. Subsequently, in order to validate the prototype questionnaire, a focus group comprised of an expert panel was conducted. A total of 8 experts participated in this process, including professors and students of the related disciplines in university

TABLE 2 IEQ sensor characteristics

Variable	Sensor	Range	Accuracy
Mean radiant temperature	FPA805GTS AHLBORN	–50 to 200°C	0.1°C
Air velocity	HD403TS2 Delta OHM®	0.1 to 5 m/s	±0.2 m/s + 3% f.s
Air temperature	FHAD 46-C41A AHLBORN	–20 to +80°C	Typical ±0.2 K at 5 to 60°C maximum ±0.4 K at 5 to 60°C maximum ±0.7 K at –20 to +80°C
Relative humidity	FHAD 46-C41A AHLBORN	0 to 98% RH	±2.0% RH in range from 10 to 90% RH ±4.0% RH in range from 5 to 98% RH
CO ₂ concentration	HOBO® MX1102	0 to 5,000 ppm	±50 ppm ±5% of reading
Light intensity	HOBO® MX1104	0 to 167,731 lux	±10% typical for direct sunlight
Sound pressure level	Imperum-R TECNITAX® Ingeniería	35 to 115 dBA	±1 dBA

degrees. As a result of this expert panel, the clarity of the formulation, and the adequacy of the specific vocabulary for the textual product were analyzed. The items related to Indoor Air Quality in the original UNE-CEN/TR 16798-2:2019 Standard were not used in our research because the experts mentioned the possible bias in the subjective assessment of this factor, since the students had to wear a face mask at any time during the lecture class. Finally, the results obtained from this process were analyzed and the questionnaires were set up.

The questionnaire was divided into a general information section, sections addressing the acoustic, lighting, and thermal comfort, and a section that addressed the overall evaluation of the IEQ. The general information section collected demographic data (such as the age and gender of the subjects), as well as the type of mask and clothing that the subjects were wearing during the survey. The clothes selected from a checklist by the participants were used to estimate the clothing insulation value (EN ISO 7730).²⁶ Based on these data, together with the operative temperature and the metabolic rate, the predicted mean vote (PMV) was calculated.

Regarding the IEQ questions, the thermal satisfaction vote (TSAV), lighting satisfaction vote (LSAV), and acoustic satisfaction vote (ASAV) were examined in the questionnaire based on a 7-point scale (from -3 for "very dissatisfied" to 3 for "very satisfied"). In addition, a 7-point scale was also used to examine the thermal sensation vote (TSV, from -3 for "cold" to 3 for "hot"), lighting sensation vote (LSV, from -3 for "very bright" to 3 for "very dark"), and acoustic sensation vote (ASV, from -3 for "very noisy" to 3 for "very silent"). Participants were asked to select the causes of dissatisfaction using a checklist covering the thermal, lighting, and acoustic situations.

Moreover, to examine the perceived interference/enhancement of the indoor environmental conditions on the performance of the students, the perceived thermal impact on learning performance (PTILP), perceived acoustic impact on learning performance (PAILP), and perceived lighting impact on learning performance (PLILP) were also assessed. For this purpose, the questionnaire included the following three direct questions: "Does the acoustic quality in your classroom space enhance or interfere with your ability to get your

academic work done?" "Does the lighting quality in your classroom space enhance or interfere with your ability to get your academic work done?" And "Does the thermal quality in your classroom space

enhance or interfere with your ability to get your academic work done?" A 7-point scale was used in these questions (from -3 for "interferes a lot" to 3 for "enhances a lot"). It should be remarked that this study subjectively evaluates the perceived impact of indoor environment on the performance of students.

Finally, two questions about the overall indoor environmental conditions were included in the questionnaire. The first one was about the overall satisfaction (OV1) (with a 7-point Likert scale from -3 for "very dissatisfied" to 3 for "very satisfied"). The last direct question (OV2) was "Please estimate how your productivity is increased or decreased by the environmental conditions in this building (i.e., thermal, lighting, and acoustics)." This was also graded with also a 7-point scale (from -3 for "decreases a lot" to 3 for "increases a lot"). The questionnaire was validated by a focus expert group prior to be applied to the respondents.

The field study followed the recommended procedures stated in Annex F of UNE-CEN/TR16798-2:2019 and ISO 10551:2019 in order to provide consistency, reliability of results, and meaningful comparison data obtained from investigation internationally. The questionnaire surveys were conducted during middle morning or middle afternoon, no just after arrival or after a lunch break. The questionnaires were filled out during the last 15 min of each lecture class to lessen the lecture disturbance. This decision was intended to maximize the exposure of the university students to the indoor environmental condition of the classroom since the survey was conducted at the end of the class (ensuring that the students had been sitting in the classroom for at least 1 hr and minimizing the influence of metabolic rate on the thermal evaluations by the students).

After the field measurement campaign, the collected data were analyzed to estimate the satisfaction, sensation and impact on the learning activities of the students with the indoor environmental conditions. The average satisfaction score was calculated for each question as an arithmetic mean of the votes obtained from each campus. Moreover, from the results obtained for the thermal, lighting, and acoustic satisfaction questions, the rate of satisfaction (RS) and dissatisfaction (RD) was calculated for each of the indoor environmental variables (see Equations 1 and 2):

$$\text{Rate of Dissatisfaction (RD)} = \frac{\text{"Very dissatisfied" votes} + \text{"Dissatisfied" votes} + \text{"Slightly dissatisfied" votes}}{\text{Total votes}} [\%] \quad (1)$$

$$\text{Rate of Satisfaction (RS)} = \frac{\text{"Very satisfied" votes} + \text{"Satisfied" votes} + \text{"Slightly satisfied" votes}}{\text{Total votes}} [\%] \quad (2)$$

academic work done?" "Does the lighting quality in your classroom space enhance or interfere with your ability to get your academic work done?" And "Does the thermal quality in your classroom space

In addition, the rate of interference (RI) and the rate of enhancement (RE) were estimated for each variable from the results obtained from the PTILP, PLILP, and PAILP questions (Equations 3 and 4):

$$\text{Rate of Interference (RI)} = \frac{\text{"Interfere a lot" votes} + \text{"Interfere" votes} + \text{"Slightly interfere" votes}}{\text{Total votes}} [\%] \quad (3)$$

$$\text{Rate of Enhancement (RE)} = \frac{\text{"Enhance a lot" votes} + \text{"Enhance" votes} + \text{"Slightly enhance" votes}}{\text{Total votes}} [\%] \quad (4)$$

2.4 | Statistical analysis

In order to determine whether there are significant differences between the probability distributions of the results for both campuses, a statistical analysis of the data obtained in the measurement campaigns was carried out. For this purpose, the probability distribution of the data was evaluated using the Kolmogorov–Smirnov test. Nonparametric test (the Mann–Whitney *U* test or the Kruskal–Wallis test) was applied to the non-normally distributed means of data in order to examine the statistical significance of the possible difference between both campuses. Furthermore, the Spearman correlation test was determined between: (1) the satisfaction and the interference on the learning performance for each IEQ factor; (2) the satisfaction of IEQ factor and the overall satisfaction; and (3) interference of each IEQ factor and the overall interference.

In addition, a tendency analysis was carried out on the obtained datasets. Linear and polynomial fits were used to assess the relationship between the values of the subjective and objective IEQ factors. IBM SPSS statistic (version 23.0) was used to perform all the statistical analyses.

3 | RESULTS

The general information of respondents is summarized in Table 3. A total of 440 students (217 from the Azurém Campus and 223 from the Fuentenueva Campus) participated in this field study. Since all the university students who participated in the surveys were sitting and listening to the lecturers during the measurements, a metabolic rate of 1.1 was met, as stated in ISO 7730.²⁶ On both campuses, the majority of respondents were between 18 and 25 years old (87.1% on the Azurém Campus and 91.0% on the Fuentenueva Campus), and most of them were wearing a surgical mask (90.3% and 70.4% on the Azurém Campus and Fuentenueva Campus, respectively).

Regarding the type of clothing the students were wearing, the value for the clothes was estimated using the conventional clo table

TABLE 3 General information

Variable		Response	
		Portugal	Spain
Age	n/a	9 (4.1%)	11 (5.0%)
	18–25	189 (87.1%)	203 (91.0%)
	+25	19 (8.8%)	9 (4.0%)
Sex	n/a	0 (0%)	1 (0.4%)
	Male	91 (41.9%)	144 (64.6%)
	Female	126 (58.1%)	78 (35.0%)
Type of mask	n/a	1 (0.5%)	6 (2.7%)
	FFP2	6 (2.8%)	39 (17.5%)
	Surgical	196 (90.3%)	157 (70.4%)
	Cloth	12 (5.5%)	17 (7.6%)
	Other	2 (0.9%)	4 (1.8%)

defined in ISO 7730.²⁶ Figure 1 shows the distribution of the clothing insulation values for the students from the Azurém Campus and the Fuentenueva Campus.

3.1 | Indoor environmental monitoring results

The results obtained from the sensor monitoring in both campuses are summarized in Table 4. The mean outdoor air temperature obtained during the measurement survey was very similar in both locations (18.6°C in Guimarães and 19.5°C in Granada). However, the range was wider in Granada (from 6.8 to 30.2°C) than in Guimarães (from 15.2 to 23.7°C). The difference between the mean operative temperatures during the survey in both locations was less than 1°C. As in the case of the outdoor temperature, the range of values measured at the Azurém Campus (max. 25.5°C and min 20.5°C) was narrower than that of those measured at the Fuentenueva Campus (max. 28.1°C and min 16.8°C).

Based on the data obtained from the field measurements, the PMV was calculated. Figure 2A shows the mean PMV values obtained in each classroom against the indoor operative temperature. Regarding the operative temperature values obtained from the Azurém Campus, most of them were in the range defined by the Portuguese legislation for indoor thermal quality (R_p). However, half of them were below the lower limit for category 4 stated by the UNE-EN ISO 7730:2006 Standard. With respect to the values obtained from the Fuentenueva Campus, the operative temperature had a wider range than the Azurém Campus. Only three of all the values are in one of the two ranges (R_{S-W} and R_{S-S}) established in the Spanish legislation. However, although some of these values are outside these ranges, they are in the categories defined by the UNE-EN ISO 7730:2006 Standard.

Figure 2B shows the operative temperature versus the outdoor temperature. The limits of the adaptive method defined in the UNE-EN 16798–1:2020 Standard are included in the figure. This method is used when thermal conditions can be regulated through the opening and closing of windows and doors, which is applicable during intermediate seasons (i.e., spring and autumn). On both campuses, the obtained values are in categories I and II, as defined in the Standard.

Regarding the RH, the mean indoor value was lower in Granada (38.3%) than in Guimarães (52.4%), and the indoor air velocity was similar in both locations. The CO₂ concentration level value in Guimarães (ranging from 400 to 1100 ppm) was higher than the values measured in Granada (ranging from 399 to 617 ppm). If both the average CO₂ concentration levels are compared with the recommended limit values stated in the international guidelines, it should be noted that the average level is below the limit recommended by the REHVA (800 ppm) and the WHO (1000 ppm). Therefore, although the maximum level measured at the Azurém Campus is 100 ppm above the WHO recommended limit, it is possible to state that the ventilation protocols were effective in most of the scenarios analyzed. In addition, the mean lighting value was

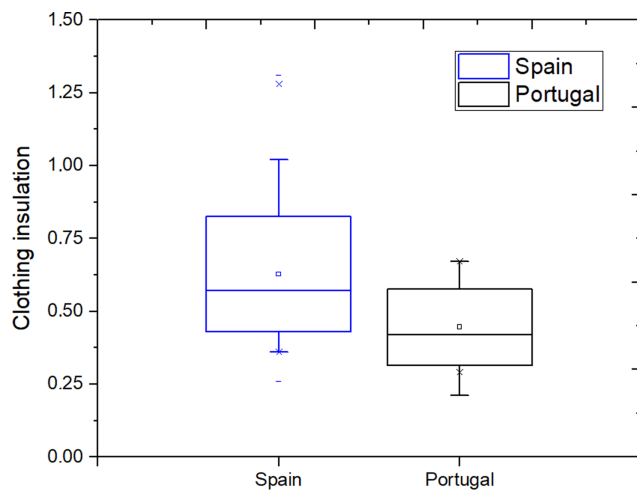


FIGURE 1 Distribution of insulation clothing values

301 lux in Guimarães and 434 lux in Granada. Finally, the average background noise sound pressure level L_{Aeq} value obtained at the Azurém Campus was 47.2 dBA, and at the Fuentenueva Campus, it was 49.7 dBA.

3.2 | Subjective indoor environmental evaluation

The results obtained from the analysis of the data collected in the field surveys are shown in this section. Figure 3 summarizes the TSAV, LSAV, and ASAV results obtained from the students on the environmental indoor conditions during the field survey. First, based on these results, it can be stated that the greatest difference in the RS between both campuses is in relation to the thermal environment. The RD was only 10% in the Azurém Campus, while in the Fuentenueva Campus, it amounted to 36%. In addition, regarding the results of the response from the students to their lighting and acoustic satisfaction, the obtained RS values are similar for the Azurém Campus and the Fuentenueva Campus (77% and 83% in the case of lighting RS, and 74% and 69% regarding acoustic RS, respectively).

The results regarding the response from the students for the TSV (Figure 4) show that the mean values were 0.41 in Guimarães and -0.05 in Granada. It should be noted that the students tended to feel neutral in both locations; in fact, no student at the Azurém Campus identified the indoor thermal environment as either cold or hot. At this campus, the sum of “cool” and “slightly cool” responses was 12%, and the sum of “slightly warm” and “warm” was equal to 41%. In contrast, the number of students who voted that the indoor space was “cold” and “hot” at the Fuentenueva Campus was 2% in both cases. The sum of the responses that indicate “cool” and “slightly cool” is higher than that obtained for the Azurém Campus (31%), while the sum of “slightly warm” and “warm” provides a value of 30%.

As stated in ASHRAE-55 (2004), when at least 80% of the votes from occupants are within the three central categories of the scale

(i.e., -1 , 0 , and 1), the indoor thermal environment is perceived as comfortable or acceptable. In this study, 79% and 70% of votes from the students are within the three central categories for the Azurém Campus and the Fuentenueva Campus, respectively.

With respect to the LSV responses from the students (Figure 5), the mean obtained values were 0.91 in Guimarães and 0.43 in Granada. A total of 61% of the students from the Azurém Campus indicated that lighting inside classroom was “dim,” “very dark,” or “dark.” However, only a 10% of the students indicated that the indoor lighting environment was “light,” “bright,” or “very bright.”

In the case of the Fuentenueva Campus, the results are very different than those from the Azurém Campus. Only 21% indicated that it was “dim,” “dark,” or “very dark.” It is worth noting that if these results are compared with the LSAV, the students were satisfied with these conditions even though they mainly rated the LSV as “neutral,” “dim,” and “dark” in both locations.

Regarding the responses from the students about the ASV (Figure 6), the results show a lower distribution of votes for “neutral” than for the TSV and LSV. The mean ASV values were 0.96 in Guimarães and 0.63 in Granada. The sum of the responses from students who indicated that the indoor acoustic environment was “very noisy,” “noisy,” or “slightly noisy” was 16% for the Azurém Campus. This value increased to 26% for the Fuentenueva Campus. The location of the campus and the activities that take place around them are aspects to consider when evaluating these results. The Azurém Campus is located in a larger area than the Fuentenueva Campus, and its educational buildings are surrounded by green spaces and landscaped areas. In contrast, the Fuentenueva Campus is located in the center of the city of Granada, a tramway crosses the campus, and its buildings are surrounded by main streets with a high volume of traffic.

In addition to an analysis of the sensation votes and satisfaction votes on the thermal, lighting, and acoustics of the indoor environmental conditions, the RI and RE of the PTILP, PLILP, and PAILP responses were analyzed (Figure 7). Regarding the Azurém Campus, the obtained results show that the environmental condition that most contributes to enhancing student performance in class is the lighting condition (RS = 77%) followed by the thermal condition (RS = 71%) and, to a lesser extent, the acoustic condition (RS = 67%). In fact, it is the acoustic condition that showed the highest RI value (20%).

Nevertheless, the responses obtained from the survey conducted at the Fuentenueva Campus show that the indoor environmental factor that generates the greatest interference with student learning performance is the thermal condition (RI = 36%) followed by the acoustic condition (RI = 23%) and, to a much lesser extent, the lighting condition (RI = 12%).

Regarding the overall environmental conditions (Figure 8), it should be noted that the RS for the students at the Azurém Campus (77%) was slightly higher than that for the students at the Fuentenueva Campus (71%). However, a different distribution was found in the responses given the OV2 question (Figure 9): 75% of students at the Azurém Campus indicated that their productivity

TABLE 4 Results obtained from the field measurements

Country	Indoor air temperature (°C)		Radiant temperature (°C)		Operative temperature (°C)		RH (%)		Air velocity (m/s)		CO ₂ (ppm)		Lighting (lux)		L _{Aeq} (dBA)	
	P ^a	S ^a	P	S	P	S	P	S	P	S	P	S	P	S	P	S
Max	25.6	28.0	25.4	28.5	25.5	28.1	69.7	50.1	0.08	0.09	1100	617	567	691	58.0	58.0
Min	20.5	16.3	20.5	17.3	20.5	16.8	28.7	28.1	0.01	0.01	400	399	112	316	38.6	43.6
Average	23.2	23.3	23.0	24.0	23.1	23.7	52.4	38.3	0.03	0.03	742	519	301	434	47.2	49.7
Median	23.4	25.3	23.2	25.8	23.3	25.6	54.9	37.6	0.02	0.01	791	517	277	377	45.7	47.8
SD	1.9	4.0	1.8	3.8	1.8	3.8	16.0	6.9	0.02	0.03	215	83	177	113	7.5	4.9

^aP indicates Portugal (Azurém Campus), and S indicates Spain (Fuentenueva Campus).

was at least slightly increased by the environmental conditions (i.e., thermal, lighting, and acoustic) in the building while they were doing the questionnaire. In contrast, this value increased to 48% in the Fuentenueva Campus. In addition, the percentage of students giving a neutral answer to this question was higher at the Fuentenueva Campus than at the Azurém Campus.

3.3 | Causes of dissatisfaction

Figures 10 and 11 show the main causes of dissatisfaction at the Azurém Campus and the Fuentenueva campus, respectively. Regarding the Azurém Campus, students were found to be dissatisfied with the thermal environment due to drafts (25%), the HVAC systems not working quickly enough (14%), slow air movement (13%), and humidity that was too high (13%). In relation to indoor lighting, the main causes of dissatisfaction were not enough daylight (29%), the space was too dark (26%), and not enough electric lighting (16%). Indeed, 71% of the causes of dissatisfaction were related to the lack or shortage of lighting in the classroom. This can be also observed in the data obtained during the field monitoring campaign on this campus (the minimum is 112 lux). In terms of acoustic dissatisfaction, students highlighted people talking in neighboring spaces (36%) and excessive echoes (30%) as the main causes. Other external noise represented only 11%. The opening of doors and windows influences indoor acoustic conditions. Almost 50% of the causes were related to this factor. In fact, noise from corridors and indoor/outdoor common areas was the main dissatisfaction cause. It should be noted that one-third of the dissatisfaction was caused by classroom architectural design (i.e., echoes). In addition, it should be noted that the mean sound pressure level (background noise) measured in the classrooms was above the level recommended by the WHO.

Among the causes of thermal dissatisfaction on the Fuentenueva Campus (Figure 11), we found that drafts were the primary cause, with a value of 26%. This cause was followed by hot/cold surrounding surfaces (16%) and high air movement (13%). Two of these three causes are closely related to the measure of increasing the air exchange ratio in the classroom through natural ventilation (opening doors and windows generate drafts inside a classroom).

Regarding the indoor lighting environment, students have identified shadow effect in their workspace (23%), too much brightness (18%), and too much electric lighting (17%) as being the causes of the most dissatisfaction. These causes are opposite to those indicated by the students at the Azurém Campus.

In terms of acoustic dissatisfaction, outdoor traffic noise accounted for about one-third of the votes among the causes of acoustic dissatisfaction (32%). Other external noise (25%) and people talking in neighboring spaces (22%) represented almost half of the causes of dissatisfaction. As pointed out in the previous section, the Fuentenueva Campus is located in the center of the city of Granada, so urban noises (e.g., traffic noise and noise from outdoor activities) influence the acoustic environmental conditions inside the

FIGURE 2 (A) Predicted mean vote PMV versus operative temperature and (B) operative temperature versus outdoor temperature. The black squares are from the Portugal dataset, and the blue squares are from the Spain dataset

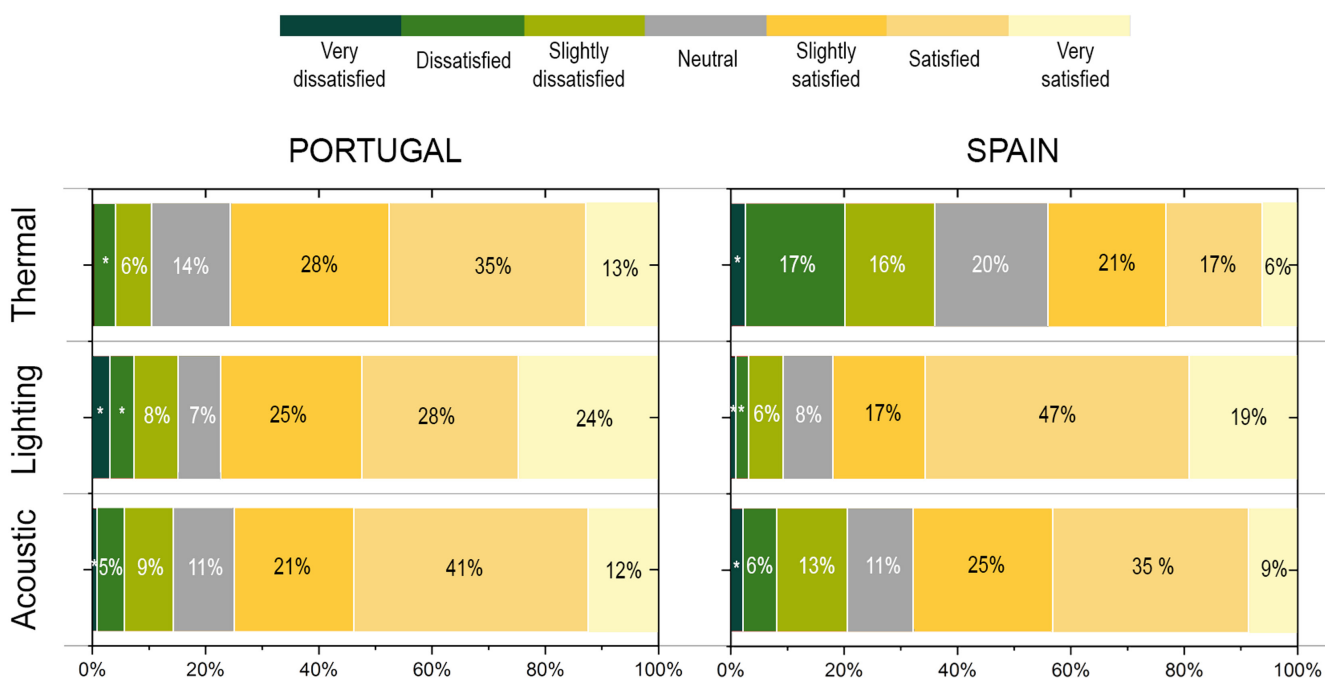
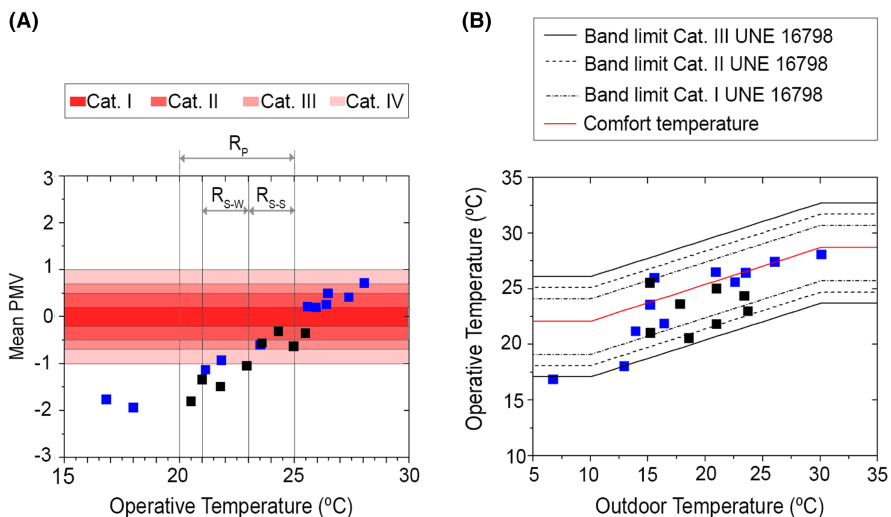


FIGURE 3 TSAV, LSAV, and ASAV values obtained in Portugal and Spain. * indicates the percentage is <5%

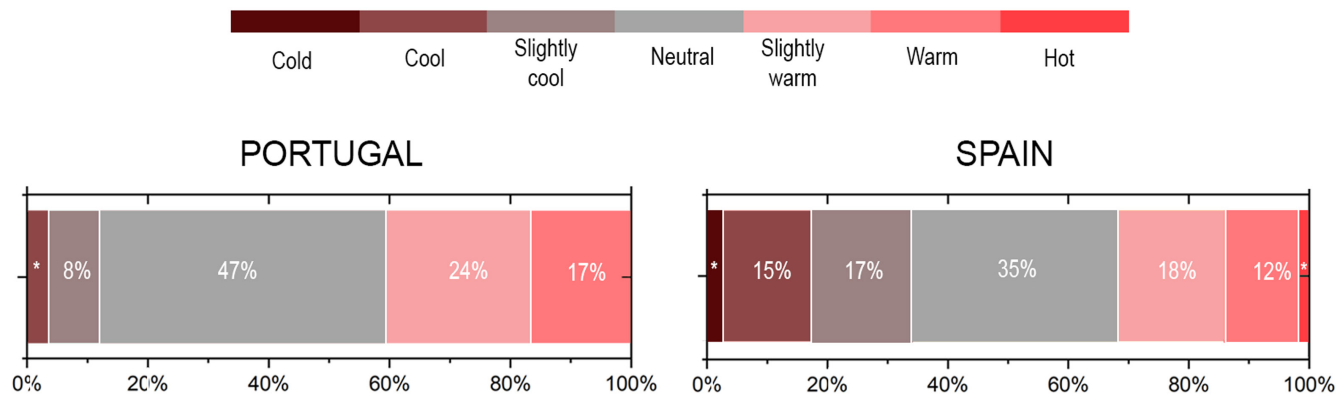


FIGURE 4 TSV values obtained in Portugal and Spain. * indicates the percentage is <5%

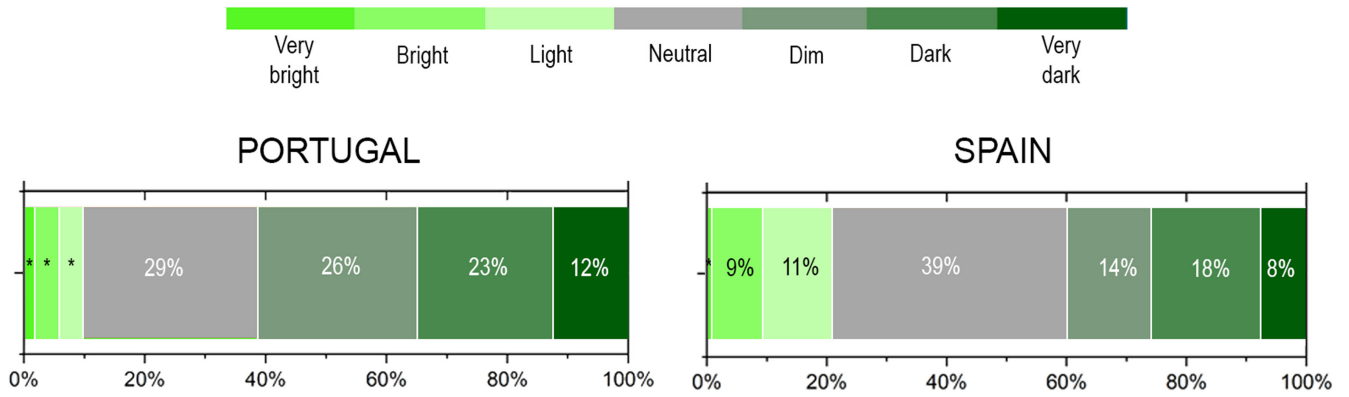


FIGURE 5 LSV values obtained in Portugal and Spain. * indicates the percentage is <5%

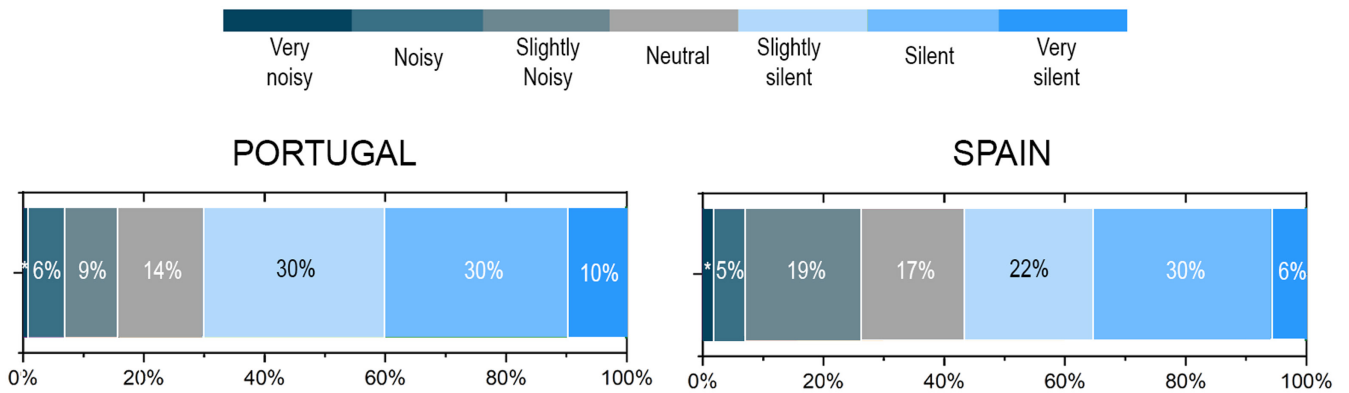


FIGURE 6 ASV values obtained in Portugal and Spain. * indicates the percentage is <5%

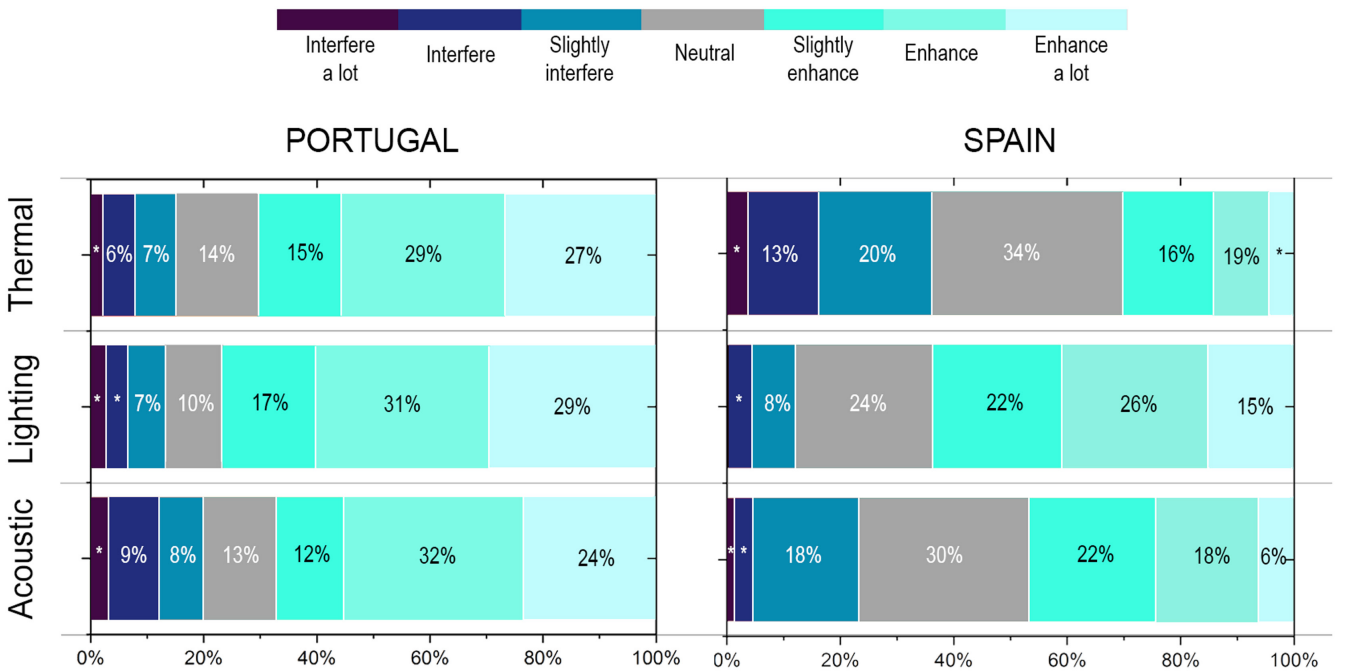


FIGURE 7 PTILP, PLILP, and PAILP values obtained for Portugal and Spain. * indicates the percentage is <5%

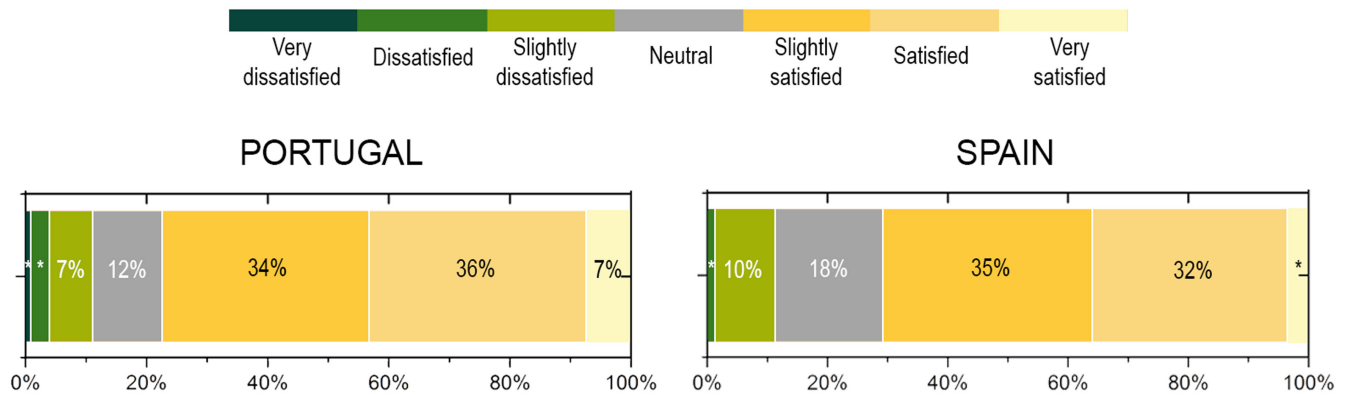


FIGURE 8 Overall satisfaction vote in Portugal and Spain. * indicates the percentage is <5%

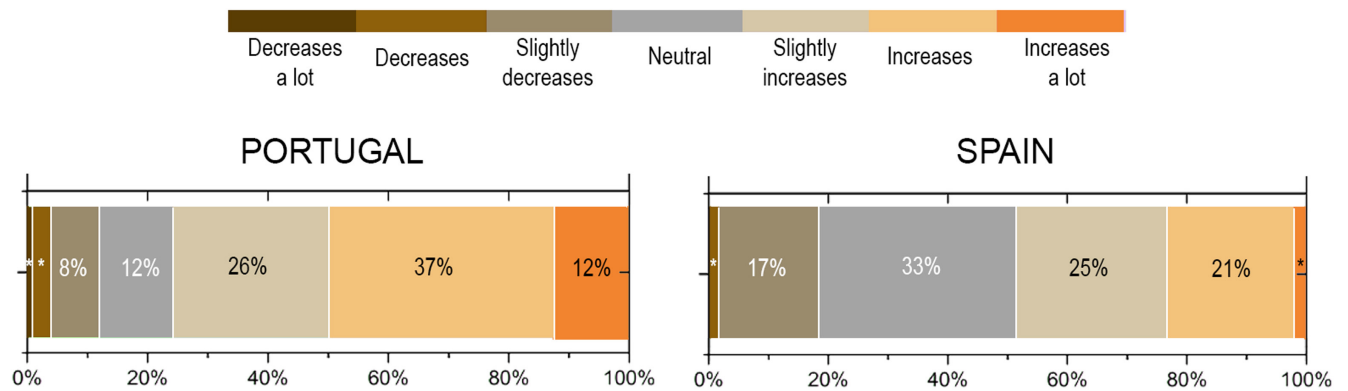


FIGURE 9 Perceived impact of thermal, lighting, and acoustic environmental conditions on the productivity of the students. * indicates the percentage is <5%

classroom. This fact is aggravated due to the increase in the natural air renewal rate in the classrooms.

3.4 | Statistical analysis

This section shows the results obtained from the statistical analyses. Firstly, regarding the significant difference between the data obtained from both campuses, the Kolmogorov–Smirnov test showed that the data did not meet the normal distribution. Therefore, the Kruskal–Wallis test was used to examine the statistically significant difference between the groups. The results showed a statistically significant difference between satisfaction, sensation, and performance interference of all IEQ factors for the different campuses ($p < 0.02$), with the exception of light satisfaction ($p > 0.05$) (see Table A1 in Appendix A).

Secondly, Figure 12 shows the relationship between the satisfaction ratings of each variable (i.e., the thermal, lighting, and acoustics) with its respective objective variable (i.e., the operating temperature, brightness, and sound pressure level).

The relationship between the TSAV and the indoor operative temperature is shown in Figure 12A. The resulting equations and coefficient of determination (R^2) for both Spain and Portugal are shown

in the scatter and Table A2 in Appendix A. A moderate relationship is shown for the Spain dataset ($R^2 = 0.52$; $p < 0.05$). The results show a higher thermal satisfaction when the operative temperature ranges from 21 to 27°C in both locations. However, the mean TSAVs were below 0 when the operating temperature was outside this range. A significant association between TSAV and indoor operative temperature was examined using the Spearman correlation (Table A5 in Appendix A). The results showed a relationship between both variables ($\rho = 0.305$, $p < 0.01$). However, the results obtained from the measurement campaign carried out in Portugal revealed an insignificant correlation between both variables.

The relationship between the mean LSAV and the mean lighting, and the relationship between the ASAV and the background noise sound pressure level are shown in Figure 12B,C, respectively (Table A2). In the case of lighting satisfaction, at the Azurém Campus, a nonlinear relationship was observed in the dataset (Figure 12B) that can be modeled as a polynomial fit. This may be due to the fact that too bright or too dark illuminance may cause discomfort. In the Fuentenueva Campus dataset (Figure 12C), no relationship was observed. A negative linear relationship was observed for acoustic satisfaction for both campuses. In fact, similar results were reported in previous studies for both variables.^{27–29} The same results were observed in the Spearman correlation test results, except for the

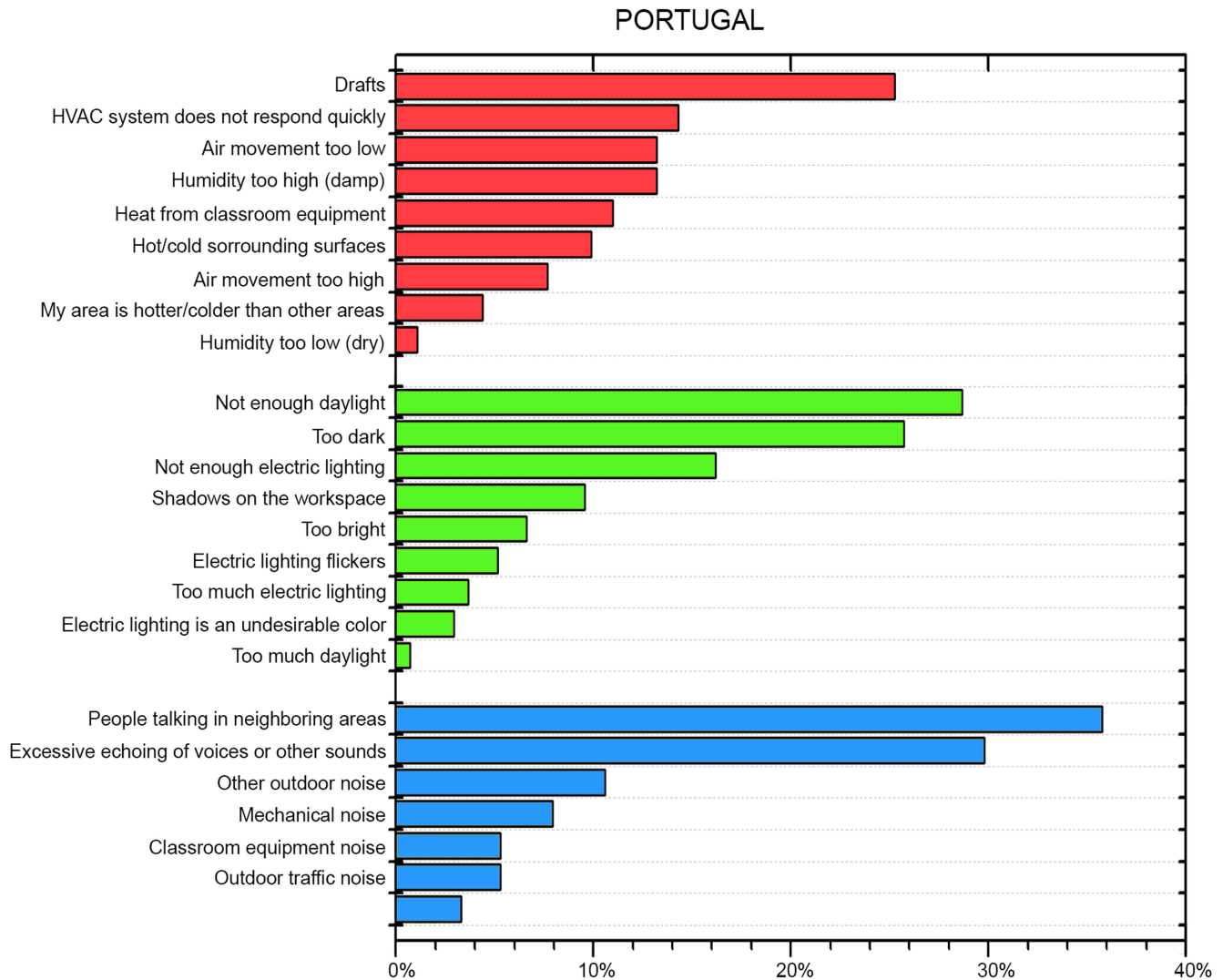


FIGURE 10 Causes of dissatisfaction in Portugal

relationship between ASAV and L_{Aeq} for Azurém Campus, showing a significant association between both variables ($\rho = -0.289$, $p < 0.001$; Table A5).

Similar results were found from the analysis of the relationships between the interference votes and each of the indoor environmental variables (Figure 12D–F and Table A2). The coefficients of determination were low in all the cases. Regarding the Spearman correlation test, the results indicated a significant association between PTILP and T_{op} ($\rho = 0.307$, $p < 0.001$) in the case of Spain (Table A5).

Since the operative temperature is the only indoor environmental variable that has shown a moderate–strong relationship with the TSAV and PTILP, the relationship between this variable and the TSV was analyzed. The results are shown in Figure 13.

As observed, the obtained coefficient of determination in Spain is much higher than that in Portugal. This value may be influenced by the fact that the range of measured operating temperature data at the Azurém Campus was much narrower than the range measured at the Fuentenueva Campus. However, previous

studies showed similar values for the coefficient of correlation since there was a high variability for the TSV in each indoor air temperature.^{30–32} Based on these results, the neutral temperature was calculated by a substitution of 0 for the TSV in both equations. Students from the Fuentenueva Campus had warmer preferences than the students from the Azurém Campus, since the neutral temperature obtained for the Azurém Campus (20.6°C) was lower than that obtained for the Fuentenueva Campus (23.3°C). In addition, the Spearman correlation coefficient between these variables revealed a moderate–strong correlation in Spain ($\rho = 0.533$, $p < 0.001$) and a significant association in Portugal ($\rho = 0.202$, $p = 0.003$).

Additionally, the relationships between question OV.1 and the thermal, lighting, and acoustic satisfaction votes were analyzed. The linear regression results are shown in Figure 14A–C and Table A3. The mean overall satisfaction vote obtained from Portugal shows a moderate relationship with the acoustic satisfaction vote ($R^2 = 0.68$, $p < 0.05$) and the thermal satisfaction vote ($R^2 = 0.58$, $p < 0.05$) and a weak relationship with the lighting satisfaction vote

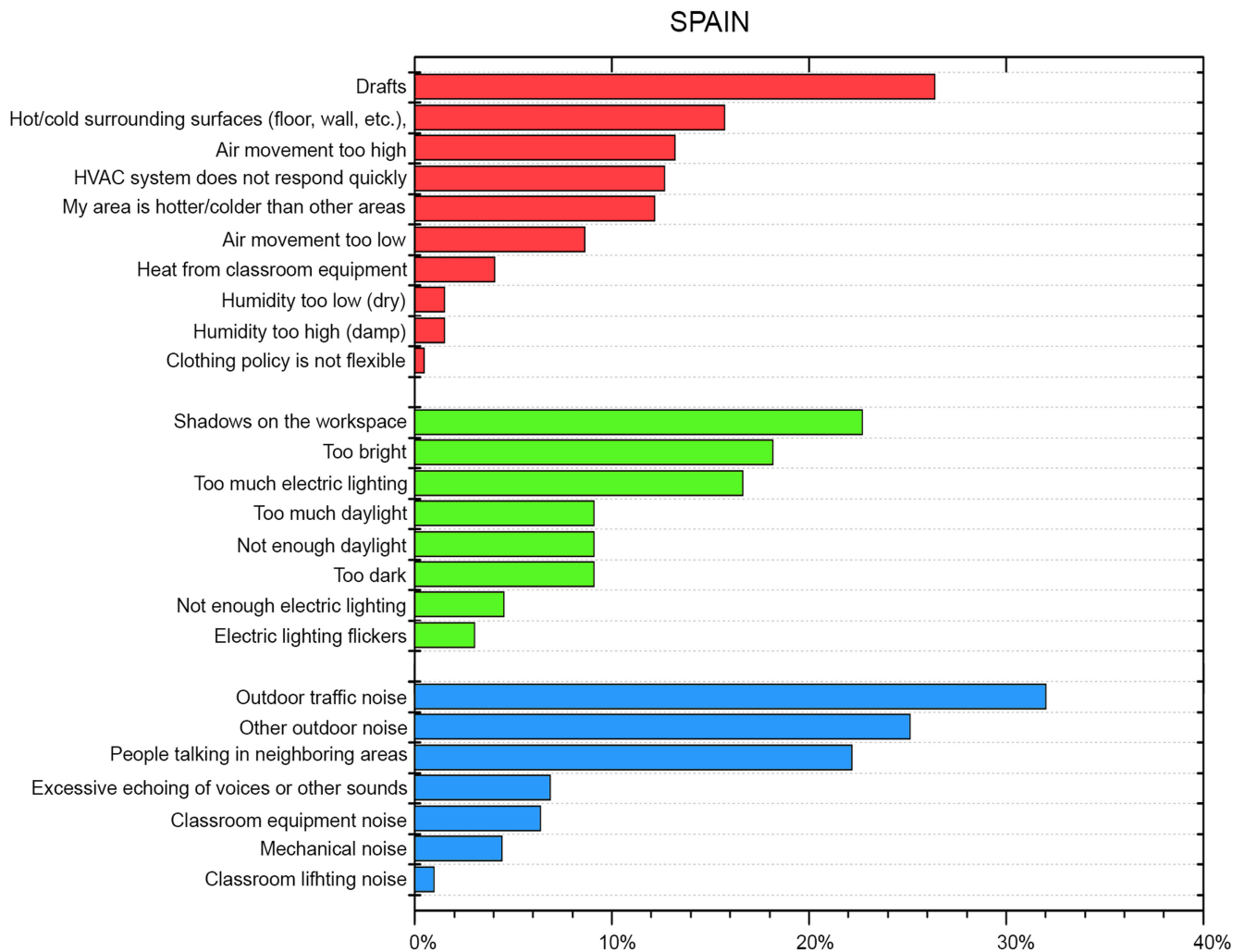


FIGURE 11 Causes of dissatisfaction in Spain

($R^2 = 0.36$, $p = 0.11$). In the case of Spain, the mean overall satisfaction vote results show a moderately strong relationship with the thermal satisfaction vote ($R^2 = 0.70$, $p < 0.001$) and a moderate relationship with the lighting satisfaction vote ($R^2 = 0.65$, $p < 0.01$). In fact, the Spearman correlation test indicated similar results: There was also a strong relationship between OV.1 and ASAV ($\rho = 0.540$, $p < 0.001$) in the case of Portugal, and between OV.1 and TSAV ($\rho = 0.522$, $p < 0.001$) in the case of Spain (Table A6). The results suggest that the satisfaction of Portuguese students was more influenced by the indoor acoustic conditions, while the satisfaction of the Spanish students was more influenced by the indoor thermal conditions.

The variation of the vote from the Portuguese students on the impact of general environmental conditions on their productivity is explained by the impact of the classroom acoustic conditions. This is indicated by a strong relationship between both variables ($R^2 = 0.89$, $p < 0.001$). In addition, there was a moderate relationship between the interference of the lighting and thermal conditions on student performance ($R^2 = 0.53$, $p < 0.05$ and $R^2 = 0.57$, $p < 0.05$, respectively). However, the Spearman correlation test provides closer

values for interference of acoustic ($\rho = 0.581$, $p < 0.001$), thermal ($\rho = 0.609$, $p < 0.001$), and lighting ($\rho = 0.546$, $p < 0.001$; Table A6).

Nevertheless, the analogous analysis of the responses obtained from the Spanish students at the Fuentenueva Campus shows a weak relationship with the indoor acoustic conditions ($R^2 = 0.13$, $p = 0.28$) and a weak-moderate relationship with the indoor lighting conditions. On the contrary, it shows a strong relationship with the impact of thermal conditions on student performance ($R^2 = 0.70$, $p < 0.001$). In fact, Figure 12D already shows a moderate relationship between indoor operative temperature and the impact on student performance. Spearman's correlation coefficients were closed for the three variables.

4 | DISCUSSION

Previous studies carried out in educational buildings during mid-season prior to the COVID-19 pandemic period found narrower ranges of variations for both variables (17.8–24.2°C and 37%–59% in Spain,³³ and 20–23°C and 30%–60% in North Portugal³⁴). Therefore,

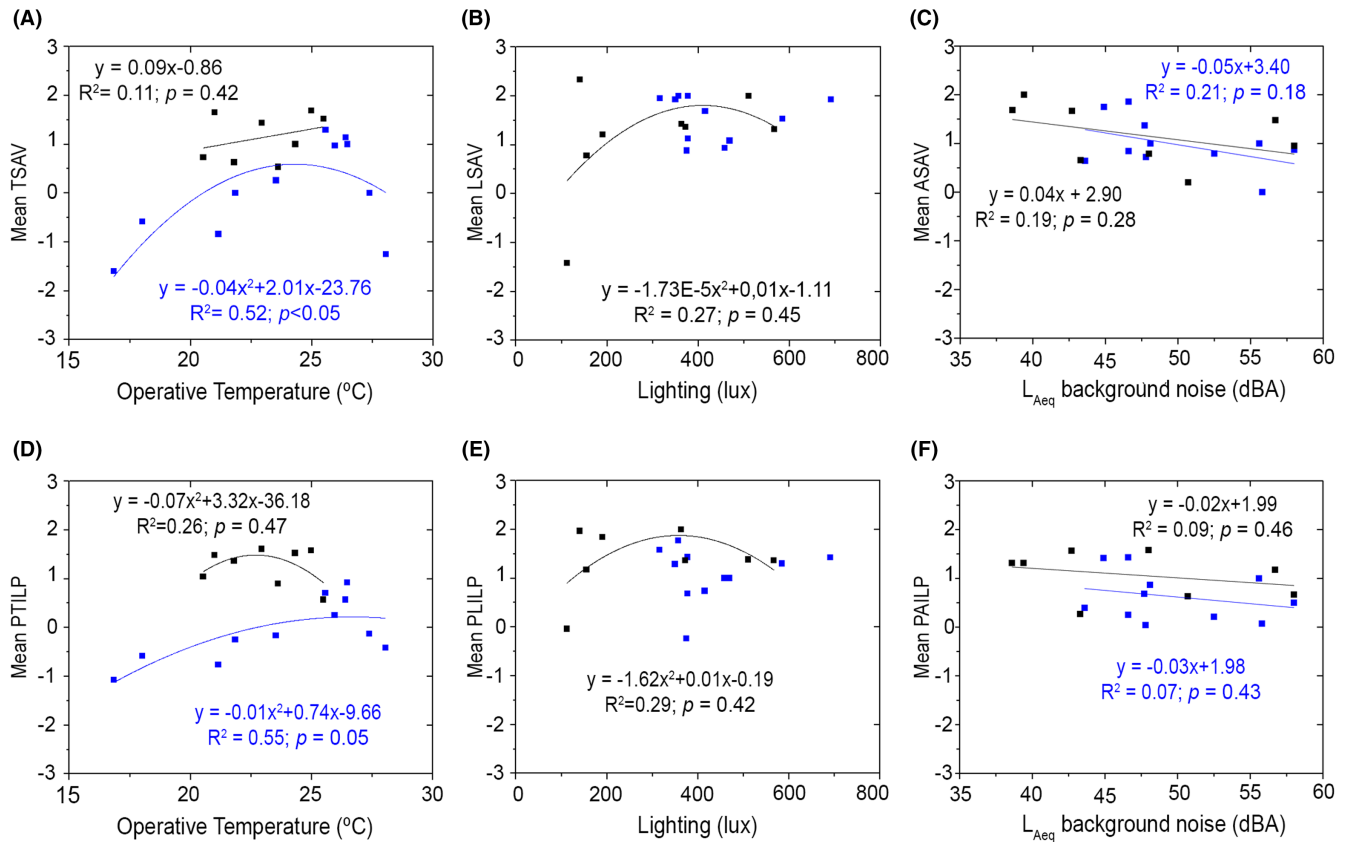


FIGURE 12 (A) TSAV versus operative temperature, (B) LSAV versus lighting, (C) ASAV versus background noise sound pressure level, (D) PTILP versus operative temperature, (E) PLIP versus lighting, and (F) PAILP versus background noise sound pressure level. The black squares indicate the Portugal dataset, and the blue squares indicate the Spain dataset. Statistical information is shown in Table A2 in Appendix A

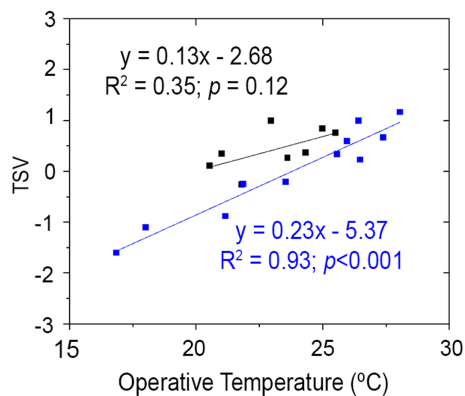


FIGURE 13 Linear regression of the TSV between indoor operative temperatures. Statistical information is shown in Table A4 in Appendix A

it is observed that the variation range of both variables is wider after the reopening of the educational buildings as a consequence of the natural ventilation strategy.

In addition, this ventilation strategy of opening of doors and windows improved the Indoor Air Quality inside the classrooms, as can be seen from the obtained CO₂ concentration levels. Both campuses had acceptable ventilation rates, with CO₂ concentrations ranging from 400 to 1000 ppm in Guimarães and from 399 to 617 ppm in

Granada. Other studies conducted during the pandemic found similar CO₂ concentration results.^{35–37} These values are lower than the CO₂ concentration reported by previous studies conducted before the COVID-19 pandemic; that is, Fernández-Aguera et al.³³ found that CO₂ concentration level ranged between 591 and 1995 ppm in educational buildings in South Spain, and Madureira et al.³⁴ reported that the 1000 ppm CO₂ concentration was exceeded during 70% of the occupation measurement time in educational buildings in North Portugal. Although these measures clearly improved the ventilation rates, they also caused an increase in background noise sound pressure levels inside the classrooms. Opening windows and doors for natural ventilation in classrooms does compromise the acoustic envelope insulation.³⁸ Indeed, an average of 47 and 49 dBA were obtained respectively in Guimarães and Granada. Both values are above the recommended limit stated by the WHO for teaching-learning spaces (i.e., 35 dBA).³⁹

The data obtained from the questionnaire showed significant differences between both campuses. Indoor acoustics and indoor lighting were the environmental variables with which Portuguese students were most dissatisfied. In contrast, Spanish students indicated that they were more dissatisfied with the indoor thermal environment.

Additionally, it should be noted that the Spearman correlation test revealed a strong relationship between OV.1 and

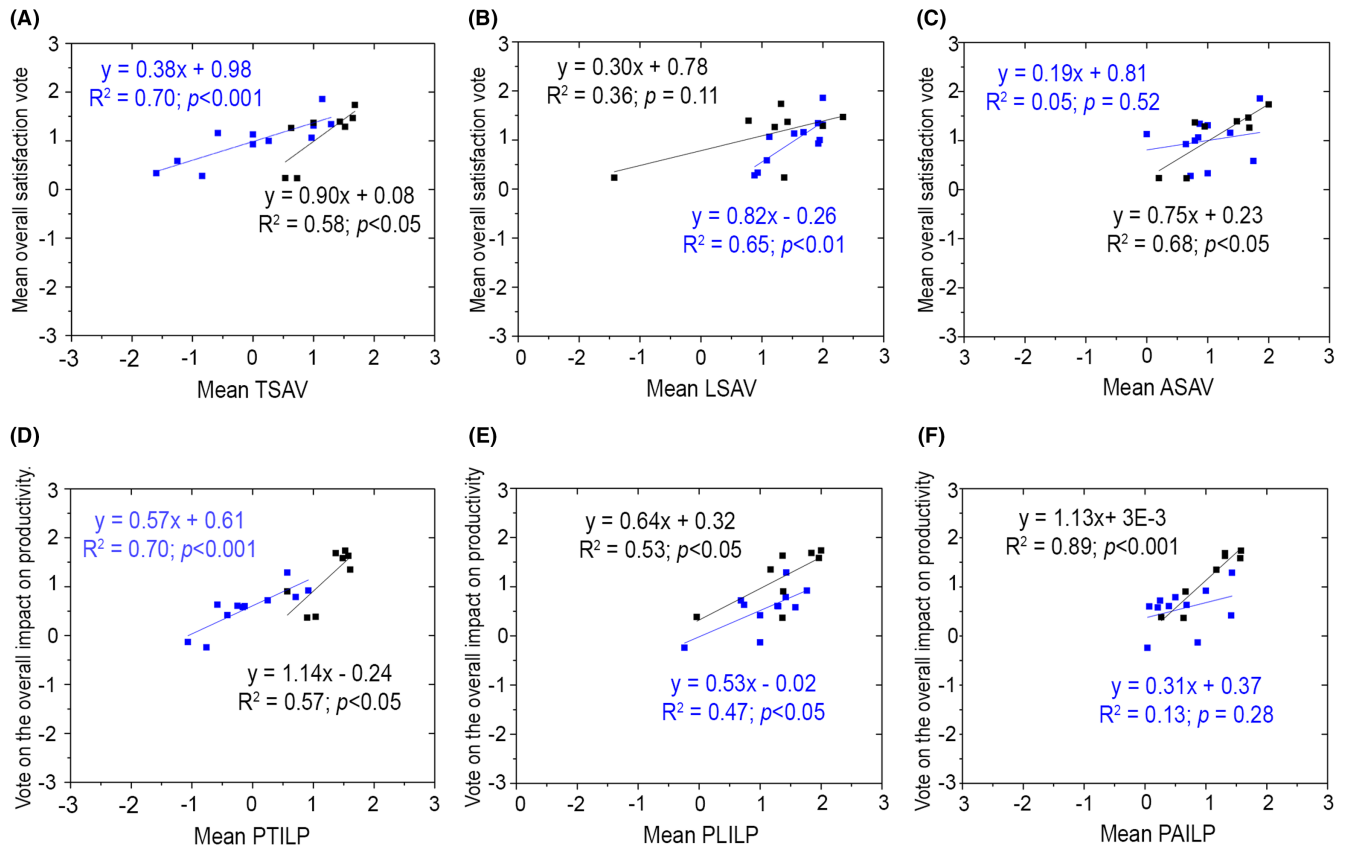


FIGURE 14 Linear regression of: (A) OV1 and TSAV, (B) OV1 and LSAV, (C) OV1 and ASAV, (D) OV2 and PTILP, (E) OV2 and PLILP, and (F) OV2 and PAILP. The black squares indicate the Portugal dataset, and the blue squares indicate the Spain dataset. Statistical information is shown in Table A3 in Appendix A

acoustic satisfaction in the dataset obtained from Portugal students ($\rho = 0.540$). In the case of Spanish students, a strong relationship was revealed by the Spearman correlation test between OV.1 and thermal satisfaction ($\rho = 0.522$).

Moreover, the variables that generated the greatest interference with the learning performance were the acoustic and thermal conditions for Portuguese and Spanish students, respectively.

The greatest cause of dissatisfaction indicated by the Spanish students related to the indoor thermal conditions was “drafts.” Although the mean air velocity value was below 0.1 m/s during the field measurement campaign, values close to it may result in a risk of cold airflow for students. In contrast, the Portuguese students reported that their greatest cause of dissatisfaction was the indoor acoustic conditions due to “people talking in neighboring areas.” These causes of dissatisfaction are clearly related to the measures implemented due to the COVID-19 pandemic. Although the measure of social safety distance (1.5 m) was already removed, natural ventilation (through doors and windows) is still in place. As a consequence, some students were closer to the windows and may be exposed to drafts, while the others claimed that they did not experience enough air movement.

Regarding the relationship between the subjective responses and thermal sensation, the thermally acceptable zone ranged from 21.0 to 27.0°C in both locations, and thermal neutrality was 20.7°C

at the Azurém Campus and 23.3°C at the Fuentenuueva Campus. It was found that students from the Fuentenuueva Campus had warmer preferences (neutral temperature = 23.3°C) than students from the Azurém Campus (neutral temperature = 20.7°C). Warmer climatic conditions prevailing in Granada compared with Guimarães may influence the warmer thermal preference in the Fuentenuueva Campus.

5 | RESEARCH LIMITATIONS

This study analyzed the impact of post-epidemic protocols implemented in higher education buildings through a sensor monitoring campaign that has been conducted simultaneously with a questionnaire survey to examine the perceived impact of indoor environment on students. Although environment surveys are tools widely used to evaluate the sensation and satisfaction of occupants, they also have shortcomings when assessing some aspects such as the emotional state of the occupants.⁴⁰ Future research should consider the development of new methodologies that will focus on analyzing the possible influence of these circumstances on students' behavior, emotion, and IEQ satisfaction, including the assessment of the impact on learning performance using the objective test (e.g., mathematical calculations, concentration ability tests).

Additionally, it should be noted that the target population in this study were young university students who may be not as sensitive to indoor environmental conditions as other groups (e.g., elder people⁴¹). Since this is our target population, the results should not be extrapolated to other population groups without further analysis and verification. Therefore, further research would be needed to expand this analysis to different populations (e.g., children or older adults) since their distinguishing features and characteristics may affect the reported results.

In addition, it is noteworthy that the indoor air temperature was close to the outdoor air temperature due to the continuous ventilation strategies. Therefore, there was not a significant thermal gradient since the indoor environmental condition is highly affected by the outdoor conditions. These factors influenced the natural airflow rate, which is generated by two driving forces (wind and temperature differences), and they may change quickly. Although the average air velocity obtained from the field measurements did not exceed 0.1 m/s inside the classroom, the students closest to the openings (windows or doors) could feel it. Therefore, the PMV method may be unreliable under these circumstances and it should be used as an orientative or reference value for this study, since the thermal sensation of the occupants has been directly measured through the thermal sensation vote obtained from the questionnaire survey.

6 | CONCLUSIONS

This study evaluated indoor environmental conditions during the reopening of educational buildings in the post-epidemic COVID-19 scenario following the implementation of the “new-normal” strategic measures in Spain and Portugal. Although post-epidemic protocols have provided effective air renewal and the mean CO₂ concentration levels remained below 900 ppm, the results suggest that their implementation have a significant impact on the degree of satisfaction with indoor environmental variables. The results of this study indicate that students are mostly dissatisfied with the acoustic and thermal conditions. In addition, the students indicated that these variables also affected their learning performance.

In addition, statistically significant differences were found between the preferences of the student from Fuentenueva Campus and the Azurém Campus: Spanish students indicated a warmer preference (neutral temperature = 23.3°C) than Portuguese students (neutral temperature = 20.7°C). In this sense, actions are needed to minimize the interference on students' learning performances considering the preferences of individuals. This research shows that the impact follows well-defined patterns that can be used for fine-tuning the final protocols that would be applied in these post-epidemic circumstances. For example, based on the results obtained in this research, the adaptation of the protocols during mid-season should consider prioritizing the improvement of acoustic conditions in the case of the Azurém Campus, and minimizing the impact of thermal conditions in the case of the Fuentenueva Campus. In any

case, post-epidemic measures implemented during conditional normality scenario in educational buildings should improve these indoor environmental conditions, keeping spaces safe while minimizing the impact of post-epidemic protocols on student learning performance.

AUTHOR CONTRIBUTION

María L. de la Hoz-Torres and Antonio J. Aguilar involved in the conceptualization, formal analysis, methodology, investigation, data curation, and writing of the original draft. Néelson Costa and Pedro Arezes involved in the conceptualization and methodology, contributed to resources, and wrote, reviewed, and edited the manuscript. Diego P. Ruiz and M^a Dolores Martínez-Aires involved in the conceptualization and methodology, contributed to resources and project administration, acquired funding, and wrote, reviewed, and edited the manuscript.

CONFLICT OF INTERESTS

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

DATA AVAILABILITY STATEMENT

Data are available upon request.

PEER REVIEW

The peer review history for this article is available at <https://publons.com/publon/10.1111/ina.13040>.

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REFERENCES

1. Marinello S, Butturi MA, Gamberini R. How changes in human activities during the lockdown impacted air quality parameters: A review. *Environ Prog Sustain Energy*. 2021:e13672. [10.1002/ep.13672](https://doi.org/10.1002/ep.13672)
2. Elsaid AM, Mohamed HA, Abdelaziz GB, Ahmed MS. A critical review of heating, ventilation, and air conditioning (HVAC) systems within the context of a global SARS-CoV-2 epidemic. *Process Saf Environ Prot*. 2021. [10.1016/j.psep.2021.09.021](https://doi.org/10.1016/j.psep.2021.09.021)
3. UNESCO. 1.3 billion learners are still affected by school or university closures, as educational institutions start reopening around the world. Available online: <https://en.unesco.org/>. Accessed 01 December 2021.
4. Portuguese Council of Ministers of March 12. (2020). *Medidas extraordinárias de resposta à epidemia do novo coronavírus [Extraordinary measures to respond to the new coronavirus epidemic]*. Government of Portugal. Available online: <https://www.portugal.gov.pt/pt/gc22/governo/comunicado-de-conselho-de-ministros?i=330>. Accessed 01 December 2021.

5. Sappal P. *Portugal starts mass testing for Covid-19 to help lift lockdown restrictions quicker & attract tourists back*. Euroweekly. Available online: <https://www.euroweeklynews.com/2020/04/23/portugal-starts-mass-testing-for-covid-19-to-help-lift-lockdown-restrictions-quicker-attract-tourists-back/>. Accessed 01 December 2021
6. Odriozola-González P, Planchuelo-Gómez Á, Iruetia MJ, de Luis-García R. Psychological effects of the COVID-19 outbreak and lockdown among students and workers of a Spanish university. *Psychiatry Res.* 2020;290:113108. [10.1016/j.psychres.2020.113108](https://doi.org/10.1016/j.psychres.2020.113108)
7. Fadaei A. Ventilation systems and COVID-19 spread: evidence from a systematic review study. *Eur J Sustain Dev Res.* 2021;5(2):em0157. [10.21601/ejosdr/10845](https://doi.org/10.21601/ejosdr/10845)
8. Nazaroff WW. Indoor aerosol science aspects of SARS-CoV-2 transmission. *Indoor Air.* 2021. [10.1111/ina.12970](https://doi.org/10.1111/ina.12970)
9. Bueno de Mesquita PJ, Delp WW, Chan WR, Bahnfleth WP, Singer BC. Control of airborne infectious disease in buildings: Evidence and research priorities. *Indoor Air.* 2021. [10.1111/ina.12965](https://doi.org/10.1111/ina.12965)
10. World Health Organization. *Air quality guidelines for Europe*. WHO Regional Office for Europe; 2000. Available online: https://www.euro.who.int/_data/assets/pdf_file/0005/74732/E71922.pdf. Accessed 26 September 2021.
11. REHVA. *COVID-19 Guidance. How to operate HVAC and other building service systems to prevent the spread of the coronavirus (SARS-CoV-2) disease (COVID-19) in workplaces version 4.1*. 2020. Available online: https://www.rehva.eu/fileadmin/user_upload/REHVA_COVID-19_guidance_document_V4.1_15042021.pdf. Accessed 20 October 2021
12. ASHRAE. *Building readiness*. Available online: <https://www.ashrae.org/technical-resources/building-readiness>. Accessed 1 November 2021
13. Universidad de Granada. *Plan de Contingencia. Plan de actuación COVID-19*. 2020. Available online: <https://covid19.ugr.es/informacion/plan-contingencia>. Accessed 25 November 2021.
14. University of Minho. *Plano de Contingência*. Publicado a 10 maio de 2021. Available online: <https://www.uminho.pt/PT/viver/COVID-19/Documents/PlanoContingenciaMaio2021.pdf>. Accessed 01 December 2021
15. Share of people vaccinated against COVID-19, Sep 1, 2021. Available online: https://ourworldindata.org/explorers/coronavirus-data-explorer?zoomToSelection=true&time=2021-09-01&facet=none&pickerSort=asc&pickerMetric=location&Metric=People+vaccinated+%28by+dose%29&Interval=7-day+rolling+average&Relative+to+Population=true&Align+outbreaks=false&country=ARE~PRT~CUB~CHL~ESP~SGP~KHM~URY~KOR~CAN~CHN~IND~USA~IDN~PAK~BRA~NGA~BGD~RUS~MEX~JPN~ETH~PHL~EGY~VNM~TUR~IRN~DEU~THA~GBR~FRA~TZA~ITA~ZAF~KEN~OWID_WRL. Accessed 1 November 2021
16. Euronews. *Portugal has the highest COVID-19 vaccination rate in the world*. Available online: <https://www.euronews.com/2021/09/23/portugal-has-the-highest-covid-19-vaccination-rate-in-the-world>. Accessed 01 December 2021
17. Despacho RT-87/2021. *Orientações para o funcionamento da UMinho no ano de 2021/22*. Available online: https://www.ics.uminho.pt/pt/Documents/Despacho_RT-87_2021.pdf. Accessed 01 December 2021
18. Daisey JM, Angell WJ, Apte MG. Indoor air quality, ventilation and health symptoms in schools: an analysis of existing information. *Indoor Air.* 2003;13(LBNL-48287):53-64. [10.1034/j.1600-0668.2003.00153.x](https://doi.org/10.1034/j.1600-0668.2003.00153.x)
19. Heracleous C, Michael A. Assessment of overheating risk and the impact of natural ventilation in educational buildings of Southern Europe under current and future climatic conditions. *Energy.* 2018;165:1228-1239. [10.1016/j.energy.2018.10.051](https://doi.org/10.1016/j.energy.2018.10.051)
20. Aguilar AJ, de la Hoz-Torres ML, Martínez-Aires M, Ruiz DP. Monitoring and Assessment of Indoor Environmental Conditions after the Implementation of COVID-19-Based Ventilation Strategies in an Educational Building in Southern Spain. *Sensors.* 2021;21(21):7223.
21. Lin S, Lipton E, Lu Y, Kielb C. Are classroom thermal conditions, lighting, and acoustics related to teacher health symptoms? *Indoor Air.* 2020;30(3):544-552. [10.1111/ina.12640](https://doi.org/10.1111/ina.12640)
22. Mendell MJ, Eliseeva EA, Davies MM, et al. Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools. *Indoor Air.* 2013;23(6):515-528. [10.1111/ina.12042](https://doi.org/10.1111/ina.12042)
23. Simons E, Hwang S-A, Fitzgerald EF, Kielb C, Lin S. The impact of school building conditions on student absenteeism in upstate New York. *Am J Public Health.* 2010;100(9):1679-1686. [10.2105/AJPH.2009.165324](https://doi.org/10.2105/AJPH.2009.165324)
24. Instituto Português do Mar e da Atmosfera. Available online: <https://www.ipma.pt/pt/index.html>. Accessed 1 November 2021
25. Agencia Estatal de Meteorología. Available online: <http://www.aemet.es>. Accessed 25 November 2021
26. UNE-EN ISO 7730:2006. 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 7730:2005).
27. Cao B, Ouyang Q, Zhu Y, Huang L, Hu H, Deng G. Development of a multivariate regression model for overall satisfaction in public buildings based on field studies in Beijing and Shanghai. *Build Environ.* 2012;47:394-399. [10.1016/j.buildenv.2011.06.022](https://doi.org/10.1016/j.buildenv.2011.06.022)
28. Tang H, Ding Y, Singer B. Interactions and comprehensive effect of indoor environmental quality factors on occupant satisfaction. *Build Environ.* 2020;167:106462. [10.1016/j.buildenv.2019.106462](https://doi.org/10.1016/j.buildenv.2019.106462)
29. Yang D, Mak CM. Relationships between indoor environmental quality and environmental factors in university classrooms. *Build Environ.* 2020;186:107331. [10.1016/j.buildenv.2020.107331](https://doi.org/10.1016/j.buildenv.2020.107331)
30. Nakano J, Tanabe S-I, Kimura K-I. Differences in perception of indoor environment between Japanese and non-Japanese workers. *Energy Build.* 2002;34(6):615-621. [10.1016/S0378-7788\(02\)00012-9](https://doi.org/10.1016/S0378-7788(02)00012-9)
31. Wang Z. A field study of the thermal comfort in residential buildings in Harbin. *Build Environ.* 2006;41(8):1034-1039. [10.1016/j.buildenv.2005.04.020](https://doi.org/10.1016/j.buildenv.2005.04.020)
32. Jowkar M, Rijal HB, Montazami A, Brusey J, Temeljotov-Salaj A. The influence of acclimatization, age and gender-related differences on thermal perception in university buildings: case studies in Scotland and England. *Build Environ.* 2020;179:106933. [10.1016/j.buildenv.2020.106933](https://doi.org/10.1016/j.buildenv.2020.106933)
33. Fernández-Agüera J, Campano MÁ, Domínguez-Amarillo S, Acosta I, Sendra JJ. CO₂ Concentration and occupants' symptoms in naturally ventilated schools in Mediterranean climate. *Buildings.* 2019;9(9):197. [10.3390/buildings9090197](https://doi.org/10.3390/buildings9090197)
34. Madureira J, Paciência I, Pereira C, Teixeira JP, Fernandes EDO. Indoor air quality in Portuguese schools: levels and sources of pollutants. *Indoor Air.* 2016;26(4):526-537. [10.1111/ina.12237](https://doi.org/10.1111/ina.12237)
35. Meiss A, Jimeno-Merino H, Poza-Casado I, Llorente-Álvarez A, Padilla-Marcos MÁ. Indoor air quality in naturally ventilated classrooms. Lessons learned from a case study in a COVID-19 scenario. *Sustainability.* 2021;13(15):8446. [10.3390/su13158446](https://doi.org/10.3390/su13158446)
36. Meiss A, Poza-Casado I, Llorente-Álvarez A, Jimeno-Merino H, Padilla-Marcos MÁ. Implementation of a ventilation protocol for SARS-CoV-2 in a higher educational centre. *Energies.* 2021;14(19):6172. [10.3390/en14196172](https://doi.org/10.3390/en14196172)
37. Gil-Baez M, Lizana J, Villanueva JB, 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. [10.1016/j.buildenv.2021.108345](https://doi.org/10.1016/j.buildenv.2021.108345)
38. Pinho P, Pinto M, Almeida RM, Lopes S, Lemos L. Aspects concerning the acoustical performance of school buildings in Portugal. *Appl Acoust.* 2016;106:129-134. [10.1016/j.apacoust.2016.01.002](https://doi.org/10.1016/j.apacoust.2016.01.002)

39. Berglund B, Lindvall T, Schwela DH & World Health Organization. Occupational and Environmental Health Team. (1999). *Guidelines for community noise*. World Health Organization. <https://apps.who.int/iris/handle/10665/66217>
40. Brink HW, Loomans MG, Mobach MP, Kort HS. Classrooms' indoor environmental conditions affecting the academic achievement of students and teachers in higher education: a systematic literature review. *Indoor Air*. 2021;31(2):405-425. [10.1111/ina.12745](https://doi.org/10.1111/ina.12745)
41. Xiong J, Ma T, Lian Z, de Dear R. Perceptual and physiological responses of elderly subjects to moderate temperatures. *Build Environ*. 2019;156:117-122. [10.1016/j.buildenv.2019.04.012](https://doi.org/10.1016/j.buildenv.2019.04.012)

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APPENDIX A

TABLE A1 Results obtained from the Kruskal–Wallis test to determine the significant differences between the data obtained in Portugal and Spain

	Satisfaction			Sensation			Interference		
	TSAV	LSAV	ASAV	TSV	LSV	ASV	PTILP	PLILP	PAILP
χ^2	49.910	2.048	5.537	15.377	16.480	5.629	77.394	14.648	25.144
<i>p</i> -value	<0.001	0.152	0.019	<0.001	<0.001	0.018	<0.001	<0.001	<0.001

TABLE A2 Statistical information of regression between subjective and objective variables

Input variables:		TSAV- T_{op}	LSAV-lighting	ASAV- L_{Aeq}	PTILP- T_{op}	PLILP-Lighting	PAILP- L_{Aeq}
Spain	R^2	0.521	—	0.210	0.548	—	0.070
	<i>p</i> -value	0.047	—	0.183	0.050	—	0.432
	S.E.	0.730	—	0.506	0.478	—	0.510
	<i>F</i>	4.595	—	2.077	4.474	—	0.677
Portugal	R^2	0.110	0.274	0.192	0.263	0.293	0.094
	<i>p</i> -value	0.422	0.449	0.278	0.466	0.420	0.461
	S.E.	0.487	1.144	0.603	0.386	0.652	0.497
	<i>F</i>	0.744	0.942	1.424	0.892	1.038	0.619

TABLE A3 Statistical information of regression between subjective and overall responses

Input variables:		OV1-TSAV	OV1-LSAV	OV1-ASAV	OV2-PTILP	OV2-PLILP	OV2-PAILP
Spain	R^2	0.699	0.654	0.047	0.699	0.467	0.129
	<i>p</i> -value	0.001	0.003	0.521	0.001	0.02	0.278
	S.E.	0.268	0.287	0.477	0.251	0.334	0.427
	<i>F</i>	20.906	16.982	0.447	20.899	7.897	1.335
Portugal	R^2	0.584	0.364	0.677	0.570	0.526	0.894
	<i>p</i> -value	0.027	0.113	0.012	0.030	0.042	<0.001
	S.E.	0.397	0.491	0.350	0.408	0.4286	0.199
	<i>F</i>	8.412	3.434	12.557	7.960	6.654	52.590

TABLE A4 Statistical information of regression between subjective and overall responses

Input variables:		TSV-T _{op}
Spain	R^2	0.930
	p -value	<0.001
	S.E.	0.250
	F	118.819
Portugal	R^2	0.353
	p -value	0.121
	S.E.	0.361
	F	3.269

TABLE A5 Spearman's correlation analysis between subjective and objective variables

Input variables:		TSAV-T _{op}	LSAV-lighting	ASAV-L _{Aeq}	PTILP-T _{op}	PLILP-lighting	PAILP-L _{Aeq}
Spain	ρ	0.305	-0.019	-0.044	0.307	0.026	-0.024
	p -value	<0.001	0.777	0.515	<0.001	0.694	0.719
Portugal	ρ	0.030	0.114	-0.289	-0.049	0.030	-0.129
	p -value	0.659	0.094	<0.001	0.474	0.665	0.058

ρ indicates Spearman's rho coefficient.

TABLE A6 Spearman's correlation analysis between subjective variables and overall responses

Input variables:		OV1-TSAV	OV1-LSAV	OV1-ASAV	OV2-PTILP	OV2-PLILP	OV2-PAILP
Spain	ρ	0.522	0.477	0.490	0.375	0.389	0.403
	p -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
Portugal	ρ	0.492	0.400	0.540	0.609	0.546	0.581
	p -value	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001

ρ indicates Spearman's rho coefficient.