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Impact of Pandemic Safety Measures on Students' Thermal Comfort—Case Study: Romania

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Abstract: The indoor environmental quality of a building has attracted everyone's attention since a worldwide pandemic was declared and forced people indoors. After several months, people were able to return to their usual activities, but with strict safety measures added due to the circumstances. This paper focuses on the impact of safety measures on students' thermal comfort, a case study performed in a continental climate zone, during the winter. The methodology used involved the collection of both quantitative and qualitative data. Descriptive statistics and frequencies alongside correlations and cross-tabular methods were used to analyze the collected data. The results indicated that the predicted mean vote (PMV) underestimated students' thermal perception. A difference of 1.5 °C was found between the operative neutral temperature of the PMV and students' thermal sensation votes while wearing masks. Likewise, a lower neutral operative temperature was found for students wearing masks than for those without masks. Students wearing masks preferred a slightly cooler environment and a significant difference was found ($p = 0.001$) between students' thermal comfort votes. All of these findings indicate that there is a potential for energy savings without affecting students' thermal comfort.

Keywords: thermal comfort; university classroom; masks; PMV; TSV; temperature; humidity

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1. Introduction

The indoor environmental quality performance (IEQ) inside buildings significantly contributes to the health, well-being, productivity of the building's occupants, and energy consumption and lifecycle costs [1]. According to many studies, working or studying in a comfortable environment improves not only well-being but also satisfaction, productivity, and learning [2], while few symptoms of discomfort could lead to significant reductions in the work performance [3,4]. In addition to these, analyzing the influence of indoor environmental quality on energy consumption is useful for architects and engineers when undertaking building renovations to satisfy the comfort requirements of the occupants [5].

Educational buildings have a higher population density, compared to residential or commercial ones, in which occupants spend a lot of their daytime. Furthermore, these buildings represent a large share of the building stock and usually have high energy consumptions [6–8]. Therefore, studies on IEQ and energy performance in educational buildings received an increased attention from the research community during the past few years [8,9]. Studies showed that an occupant's perception of IEQ is influenced by different connected parameters, depending on thermal comfort, indoor air quality (IAQ), and visual and acoustic comfort [9–11]. Thermal comfort represents a key component of indoor environmental quality. The term "thermal comfort" has received various definitions such as: "the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation" [12] or "comfort or neutral temperature can be reached when the largest number of participants are satisfied" [13]. Based on previous studies, thermal comfort affects both the study efficiency and the academic performances of students [9]. To evaluate the levels of thermal perceptions of the students, predicted mean votes (PMVs) and predicted percentage of dissatisfied (PPD) are applied [14], with the following acceptable conditions for thermal comfort: PMV ranging from −0.5 to +0.5 and PPD smaller than 10% [9].

Before the COVID-19 pandemic, studies on indoor thermal comfort in educational buildings revealed that student's perception of the thermal environment could be affected by the density of the classroom, the age, their physiological and psychological characteristics, or the capacity to respond correctly to questionnaires [9,15]. Other studies showed that the environment of educational buildings affects student's thermal comfort and learning efficiency, while enhancing the level of thermal comfort improves the academic performance of students [16,17]. A field study performed in Hong Kong revealed students' preference for a cooler thermal environment with a comfortable temperature range between 21.56 °C and 26.75 °C, compared to the ASHRAE comfort range (23–27 °C). The authors highlighted the need to evaluate and correctly modify the comfort range depending on the climate zone [18]. Another investigation, this time from India, established the thermal acceptability limits on standard effective temperatures (SETs) between 23.42 °C and 26.56 °C for 80% of subjects [19]. All mentioned studies performed in educational buildings emphasized the importance of ensuring a proper, healthy, and productive environment, while different climate zones and occupants' adaptability should be considered in the evaluation.

Starting in 11 March 2020, the World Health Organization (WHO) declared the COVID-19 (caused by the SARS-CoV-2 virus) outbreak as a pandemic [20] and crucial preventive measures to reduce the risk of contagion were imposed, particularly in indoor spaces: hygiene measures, interpersonal distances, use of face masks, and increased ventilation rates [21]. All of these COVID-19 protocols highlighted the necessity of proper IEQs and stimulated engineers and researchers to find solutions to ensure an adequate IEQ without compromising occupants' thermal comfort or increasing energy consumption [15].

Some studies that have focused on the IEQ in times of COVID-19 concluded that implementing COVID-19 protocols in educational buildings in Spain and Portugal to keep a safe IEQ affects students' satisfaction (thermal conditions and acoustic) and learning performance. Consequently, the authors proposed that some of the COVID-19 protocols for indoor environmental conditions should be adapted [22]. The influence of face masks on thermal comfort of students in a university library in China highlighted that the environmental parameters should be adjusted to improve thermal comfort because students wearing masks had greater requirements for environmental comfort than students without masks and preferred colder temperatures [20]. The effects of natural ventilation on thermal comfort during examination in higher education centers in winter conditions in Spain revealed an increase in the dissatisfaction rate for outside temperature below 6 °C, so the authors outlined the necessity to establish strategies for ventilation depending on the climate zone [21]. Pandemic protocols should be improved to reduce the dissatisfaction rate of students (thermal and acoustic comfort: draught and outdoor noise related to natural ventilation) and to minimize the impact on learning performance [23,24].

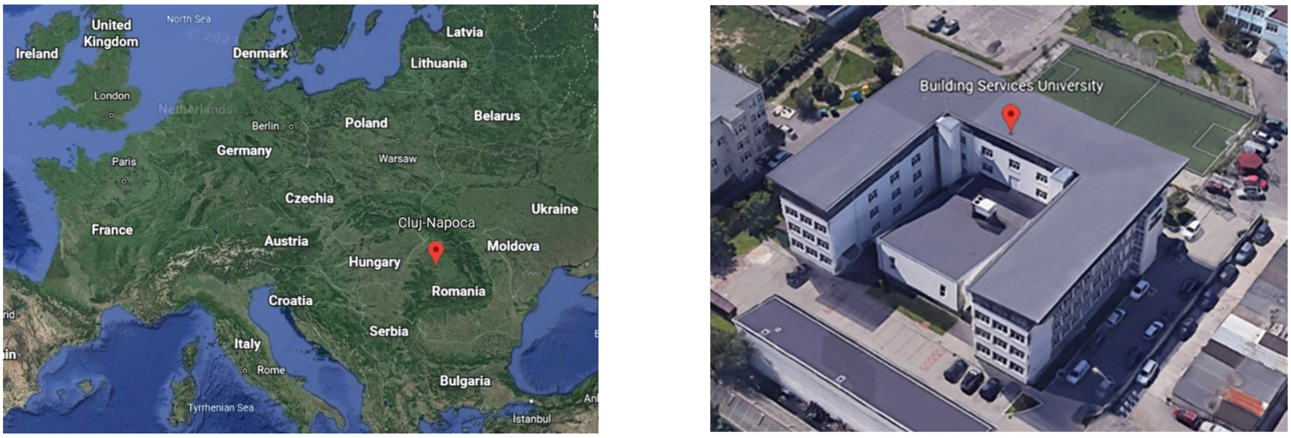
In view of the global epidemiological situation and in order to avoid the future closures of educational buildings, further research is needed to adapt the indoor environmental quality to medical protocols and to different climate zones but also considering the reduction in energy consumptions, while ensuring students' comfort and ability to concentrate, learn, and perform.

The aim of the present research is to fill the gap in the scientific literature regarding the impact of COVID-19 protocols on the thermal comfort of students in a continental climate zone. The present study analyzes the influence of face masks on students' perception of the indoor environmental parameters and thermal comfort during winter. In addition to face masks, another COVID-19 protocol, namely social distancing, was used. The specific objectives of this paper are to investigate whether students can easily adapt their thermal comfort under COVID-19 protocols, to search correlations between students' perception and environmental parameters, to examine whether age and body mass index (BMI) have an influence on students' perception, and to identify possible energy savings.

2. Materials and Methods

2.1. Climate Conditions and Site Description

The experiments were carried out in one of the teaching buildings of the Technical University of Cluj-Napoca, located in the central east of the city of Cluj-Napoca (Figure 1), Romania. The climate of the area is classified as Dfb by the Köppen-Geiger system [25], also known as a hemi-boreal climate, a subtype of the continental climate. The mean temperature during the summer in the warmest month is below 22 °C, while during winter the average temperature in the coldest month is far below −3 °C. A specific feature of the area is that the city is located between the hills and during the cold months it is quickly affected by fog, which can be very persistent.



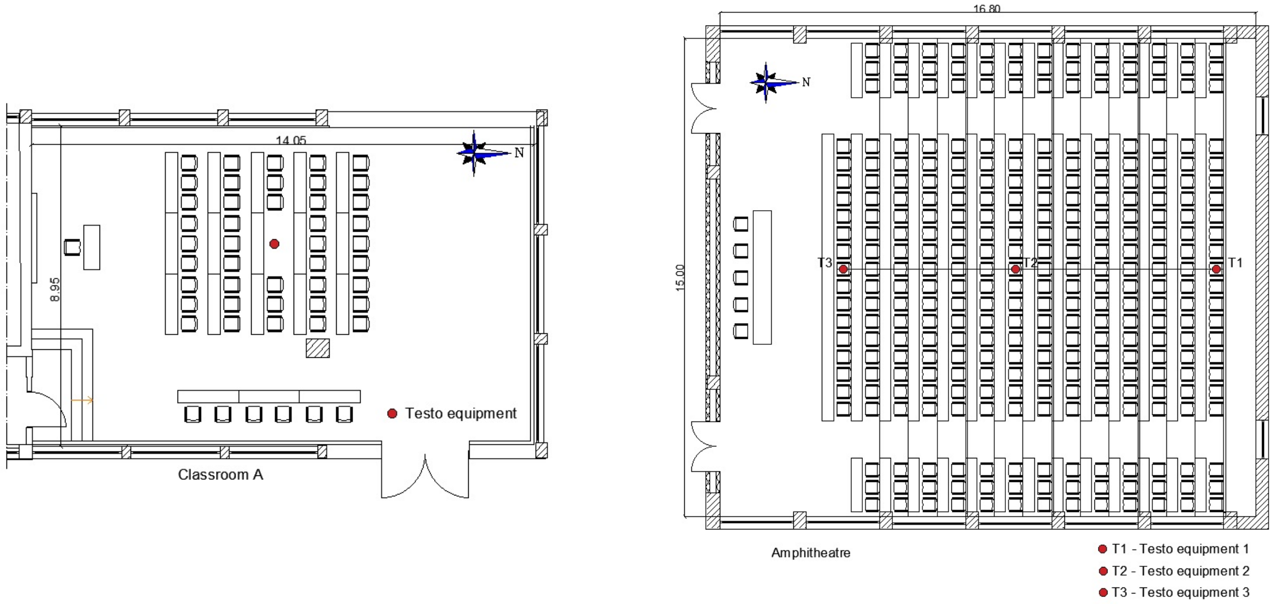
(**a**) (**b**)

Figure 1. Location of the investigation site: (**a**) In Europe; (**b**) Google Earth picture of the Faculty of Building Services Engineering.

The building in which the experimental campaign occurred was built in the early 1980s and had a major retrofit between 2005 and 2008. A metal-structure third floor was added on top of the existing brick and the cement two-story building. A new isolated roof was added and all windows were replaced with new ones made of PVC frames with double glazing. All of the building services, including the heating system, electrical and lighting system, and plumbing system were replaced or retrofitted.

The measurements were conducted in two classrooms located on the ground floor of the building. The classrooms have three exterior walls and similar orientations. The differences between them are related to their capacity, area, heating, and ventilation system. Classroom A, a teaching laboratory, has a capacity of 52 seats, an area of 126 m^2, and a volume of 504 m^3. Classroom B, an amphitheater, has a capacity of 300 seats, an area of 252 m^2, and a volume of 1134 m^3. Classroom A has a natural ventilation system and is heated through wall-mounted fan coil units placed under the windows. The thermal agent (water) is prepared by the building's thermal plant and delivered to the fan coil units by floor/wall mounted pipes. Classroom B has its own heating, ventilation, and air conditioning (HVAC) system supplied by an air treatment plant (rooftop plant). The thermal agent (air) is circulated through ventilation tubes, mounted in the ceiling, to diffusers.

Figure 2 shows the floor plan of the classrooms and the placement of the equipment used in the experiments.



(**a**) (**b**)

Figure 2. Floor plan of the classrooms with the position of the measurement equipment: (**a**) Classroom A; (**b**) Amphitheater.

2.2. Research Methodology

Both field studies were performed in the cold season at the end of January during students' written examinations.

The first field study, made in Classroom A, was in 2020 before the COVID-19 pandemic reached Romania, when no masks were required for students' safety. There were two written examinations scheduled in Classroom A, one starting at 10:00 and the second at 12:00. Measurements were performed in both written examination periods. In each session, 24 students participated in the written examination, thus totaling 48 subjects.

The second field study was performed in Classroom B in 2022 during the fifth wave of COVID-19, when social distancing and masks were necessary. Students were placed two seats away from each other and an empty row was left between them. Due to safety protocols imposed and the amphitheater's large capacity, there were scheduled examinations all day long. However, the same timeframes were chosen, as presented earlier (from 10:00 and 12:00), to investigate the thermal environment. A number of 129 students were enrolled in this measuring session (64 students from 10:00 and 65 from 12:00, respectively).

All of the subjects involved (namely 177) in this research were students of the bachelor cycle of the Faculty of Building Services Engineering and participated voluntarily.

The research methodology used in this study was to combine two types of measurements for each recording session, one objective performed with technical equipment and one subjective by means of a questionnaire filled in by the students involved in the study.

2.3. Objective Measurements

The objective measurements, in both classrooms, included indoor environment recordings of the air temperature, radiant temperature, relative humidity, and air velocity with a Testo 480 climate measuring instrument. The instrument's probes offer high measurement reliabilities with the technology of eliminating uncertain measurements. Thus, the determined calibration data in the probe generates a zero-error display. The investigation probes are designed in agreement with ISO 7726 [26] requirements. The probes used with the Testo 480 digital instrument have the following features:

- Temperature in the range between 0 and +50 °C with an accuracy of ±0.5 °C;
- Relative humidity on a scale from 0 to +100% RH with a precision of ±1.8%;
- Air velocity in the range between 0 and +5 m/s with an accuracy of ±0.03 m/s.

Since classroom B is an auditorium and has tiered seats, three measuring devices were installed to record the environmental parameters: the Testo 480 (named T2) was settled in the middle of the occupied area, a Testo 435 (named T1) was placed in front of the classroom, and a Testo 174 (named T3) was set in the back. The Testo 435 measures temperatures in between −50 °C and +150 °C with an accuracy of ±0.5 °C and relative humidity on a scale from 0 to +100% RH with a precision of ±1.5%, while the Testo 174 records temperature in the range between −30 and +70 °C with an accuracy of ±0.5 °C.

The placement of the equipment inside the classrooms was carefully chosen after the analysis of ASHRAE Standard 55 [12] recommendations. Thus, as it can be seen in Figure 1, the measuring devices were placed to cover the occupied area at a height of 1.1 m.

The students were evenly distributed in the classrooms so that a distance of at least one meter was kept away from the instrument to prevent local influences. The windows and doors were kept closed and the parameters were recorded every 5 min until the exam finished (around 11:30 for the exam that started at 10:00 and 13:30 for the one that started at 12:00).

According to ASHRAE Standard 55, the metabolic rate for the typical task, written examination, is 1.1 met. Students' garment insulation was determined through the observation method and the data are presented in Table 1.

Table 1. Observed and adopted garment insulation.

Garment Description	Value [clo]
Underwear	0.12
Calf-length socks	0.03
T-shirt	0.08
Long-sleeve sweater	0.36
Trousers	0.24
Boots	0.10
Total	0.93

The collected data of clothing insulation and metabolic rate were inputted into the Testo 480 instrument to determine the PMV.

2.4. Subjective Measurements

For a realistic and complete picture of classrooms' indoor thermal environment, we considered that both qualitative and quantitative data were required. Consequently, subjective measurements were essential to our research. All students were asked to fill in an anonymous questionnaire a half-hour after the start of the investigation. Through this, we could evaluate and interpret the perceived and preferred indoor thermal environment and thermal comfort.

The survey was divided into two sections. The first part collected students' anthropometric data, such as weight, height, and age. The second section included questions regarding students' perception and preference of the indoor thermal parameters and thermal comfort. This part of the questionnaire was drafted in accordance with the recommendations of ISO 10551 [27]. For students participating in the field measurements during the fifth wave of COVID-19, an extra question was added to the questionnaire regarding their concern to contact the virus from the university. Table 2 presents the evaluation scales of the perception of indoor parameters.

2.5. Data Analysis

The IBM SPSS 20.0 [28] statistical package was used to analyze the collected data. We assessed the descriptive statistics of the quantitative data and the frequency of the qualitative data for both cases when the students were with or without facial masks. Linear regression was used to analyze the relationship between the quantitative (PMV) and qualitative (TSV) main indices.

Through correlation coefficients (depending on data type), the relation of indoor thermal parameters with the subjective votes of students with and without masks were examined.

Statistical tests were employed to investigate whether there are differences between PMV and TSV. Collected data (both quantitative and qualitative) were tested for normal distribution. A lack of normality in the distribution of data was found; therefore, non-parametric tests were applied to determine significant differences. All of the applied tests had a statistical significance of 0.05 and a confidence interval of 95.0%.

Table 2. Evaluation scales of the indoor parameters.

Scale	**−3**	**−2**	**−1**	**0**	**1**	**2**	**3**
Thermal sensation vote (TSV)	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
Humidity perception vote (HPV)	Too dry	Dry	Slightly dry	Neutral	Slightly humid	Humid	Too humid
Air velocity perception vote (APV)	Too still	Still	Slightly still	Just right	Slightly breezy	Breezy	Too breezy
Thermal preference (TPV)		Much cooler	A bit cooler	Just right	A bit warmer	Much warmer	
Thermal comfort vote (TCV)				Very comfortable	Comfortable	Uncomfortable	Very uncomfortable
COVID-19 concern		Very high	High	Neutral	Low	Very low	

3. Results

All of the students involved in the investigation were male with an average age of 21.82 ± 3.19 years. The mean height of the subjects was 173.8 ± 19.58 cm, while the mean weight was 74.68 ± 17.57 kg. Based on the students' self-reported height and weight, the body mass index (BMI) was determined. Students were divided into three BMI subgroups: normal weight ($18.5 \leq \text{BMI} \leq 24.9$), overweight ($25 \leq \text{BMI} \leq 29.9$), and obese ($\text{BMI} \geq 30$).

3.1. Quantitative Data

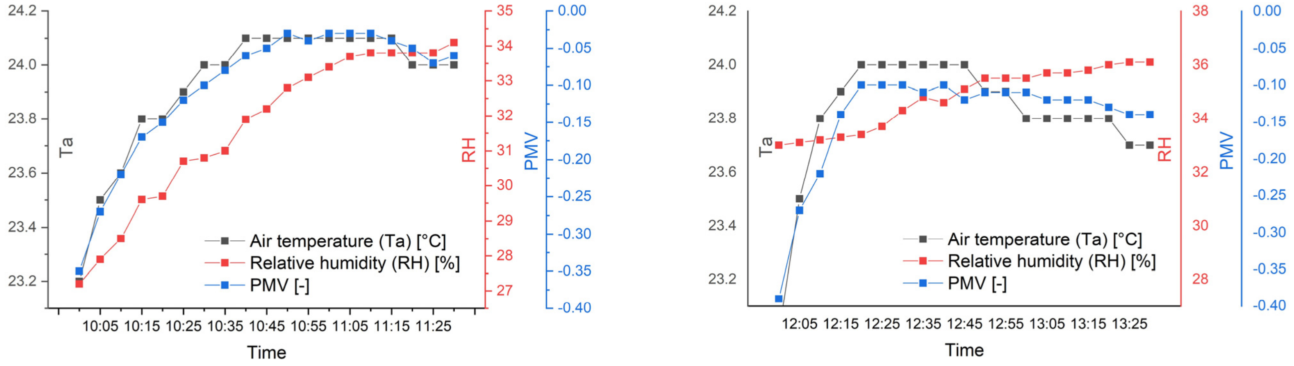
The results obtained during the measuring protocols of the indoor thermal environment parameters are summarized in Table 3. For classroom A, the mean air temperature, relative humidity, and air velocity were 23.9 °C, 31.7%, and 0.11 m/s, respectively. For classroom B, the mean recorded values of the air temperature for the Testo 435 (T1) was 22.99 °C, for Testo 480 (T2) was 23.3 °C, and for Testo 174 (T3) was 23.6 °C.

Table 3. Descriptive statistics of the indoor thermal environment parameters and PMV.

Item	**Classroom A**				**Classroom B**					
	Ta [°C]	**RH [%]**	**Va [m/s]**	**PMV [-]**	**Ta1 [°C]**	**Ta2 [°C]**	**Ta3 [°C]**	**RH [%]**	**Va [m/s]**	**PMV [-]**
Mean	23.9	31.7	0.11	−0.11	22.99	23.3	23.6	28.37	0.11	−0.33
SD	0.27	2.12	0.001	0.09	0.55	0.56	0.57	2.36	0	0.10
Min	23.0	27.2	0.11	−0.38	21.8	22.3	22.4	23.9	0.11	−0.61
Max	24.1	34.1	0.12	−0.03	23.7	24	24.3	30.5	0.11	−0.16

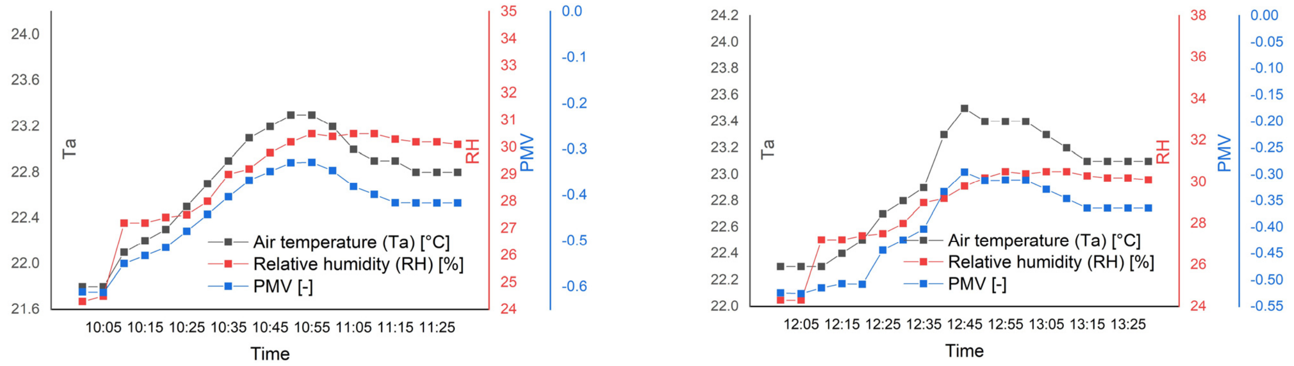
The outside climatic conditions of the investigated periods were very similar. In 2020, the outdoor temperature during the day had a minimum value of 0 °C and a maximum value of +4 °C, while in 2022 the temperature ranged between −0.5 °C and +4 °C.

In order to adequately characterize the environmental conditions observed inside the classrooms, in Figures 3 and 4 the evolution of the indoor air temperature is presented, with the relative humidity and the PMV obtained experimentally (Ta, RH, and PMV) over time (i.e., between 10:00 and 11:30, and 12:00 and 13:30, respectively).



(**a**) (**b**)

Figure 3. Evolution of air temperature, relative humidity, and PMV over time inside classroom A: (**a**) exam started at 10:00; (**b**) exam started at 12:00.

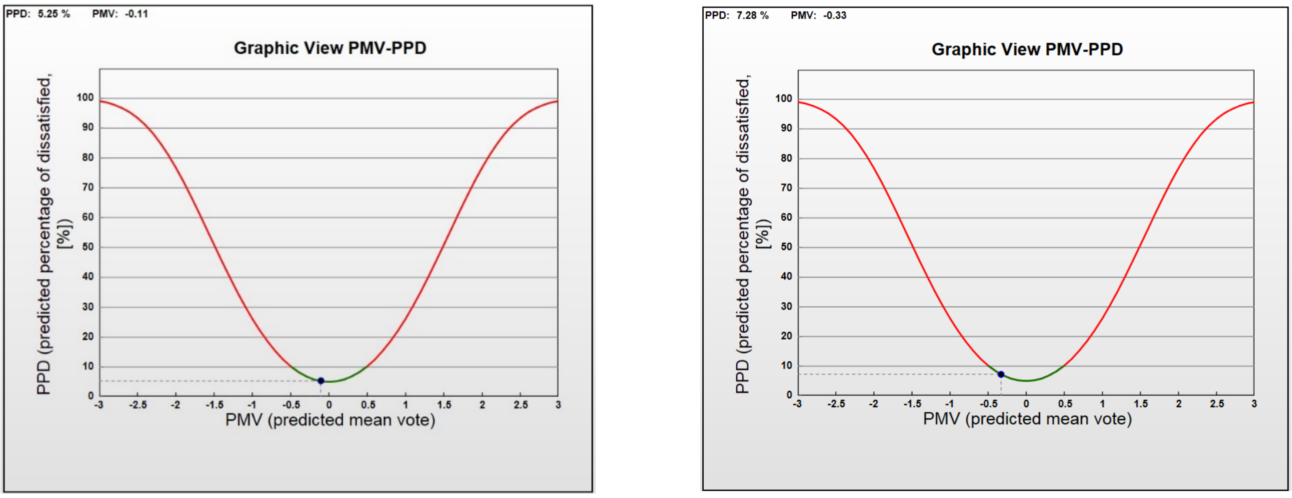


(**a**) (**b**)

Figure 4. Evolution of air temperature, relative humidity, and PMV over time inside classroom B: (**a**) exam started at 10:00; (**b**) exam started at 12:00.

To have a realistic picture of the indoor thermal environment inside each classroom, the same reference interval for the air temperature, the relative humidity, and the PMV was tried to be maintained. From Figures 3 and 4, it can be observed that slight differences appear between the two classrooms.

Figure 5 shows a graphic view of the PMV mean value with the predicted percentage of dissatisfied (PPD) computed by the Testo 480 climate measuring instrument.



(**a**) (**b**)

Figure 5. Graphic view of PMV-PPD: (**a**) without masks; (**b**) with masks.

The PPD is under 10% in both graphs and the PMV is in the thermal comfort range (−0.5 to +0.5). However, the negative values of PMV indicate the direction from a "Neutral" to a "Slightly cool" thermal environment.

3.2. Qualitative Data

Based on the subjective scales presented in Table 2, Figure 6 emphasizes the students' perception of the thermal sensation vote (TSV), air velocity perception vote (APV), and humidity perception vote (HPV) with and without face masks.

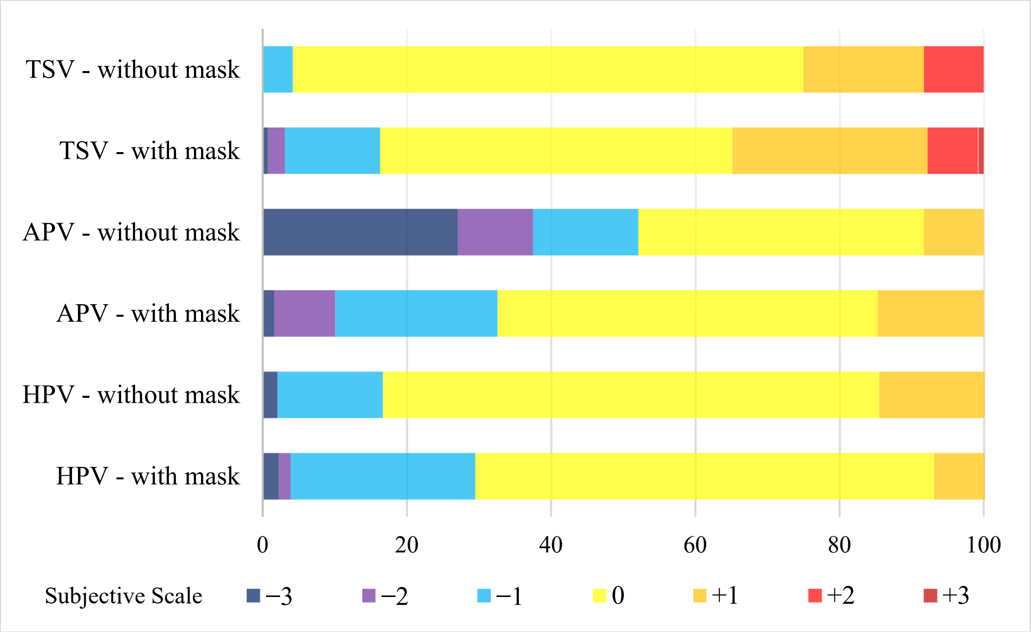


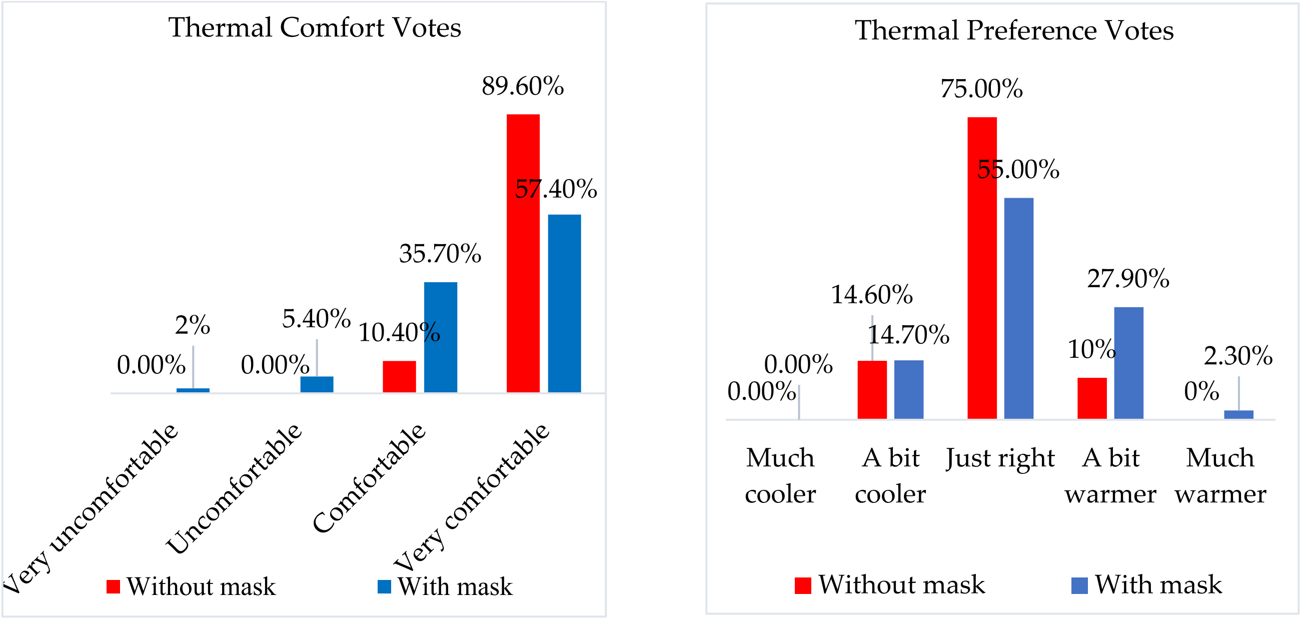
Figure 6. Perceived indoor thermal environment: TSV from "cold" (−3) to "hot" (+3), APV from "too still" (−3) to "too breezy" (+3), HPV from "very dry" (−3) to "very humid" (+3). Schemes follow the same formatting.

The frequency of students' TSVs without wearing facial masks reflects the perception of a "Neutral" (70.8%) to "Slightly warm" (16.7%) environment. The thermal sensation votes, when the students were wearing masks, were almost similar: "Neutral" (48.8%) and "Slightly warm" (27.1%). The mean TSV value without masks was 0.29, with a standard deviation (SD) of 0.680.23 (SD = 0.93) with masks, respectively. Most subjects perceived the humidity without and with facial protection as "Neutral" (68.8% and 63.6%, respectively). The mean value of HPV before the pandemic was −0.06 (SD = 0.69) and −0.29 (SD = 0.72) during the fifth wave of COVID-19. The majority of students' air velocity perception votes before and during the pandemic were around the "Just right" (39.6% and 52.7%, respectively) and "Slightly still" (14.6% and 22.5%, respectively) environment. The mean value of APV without facial masks was −1.08 (SD = 1.39) and −0.29 (SD = 0.87) with facial masks, respectively.

Figure 7 depicts the distribution of students' thermal comfort votes and thermal preference votes.

The mean value of TCV for the year 2020 measurements session was 0.1 with SD = 0.309, while for the year 2022 it was 0.51 with SD = 0.674. All of these data points, along with the ones presented in Figure 6, show that students are "Very comfortable" with the indoor thermal environment.

Just like TCV, more than half of the students enrolled in the research stated that their thermal preference votes were "Just right". The mean value of TPV of students without masks was −0.04 (SD = 0.504), and 0.18 (SD = 0.701) for the students with masks.



(**a**) (**b**)

Figure 7. Frequencies of TCV and TPV: (**a**) Thermal Comfort Votes; (**b**) Thermal Preference Votes.

The results from the question related to the COVID-19 concern of contacting virus from the university showed a mean value of −0.102 with SD = 1.289. The answers "Very high" and "High" from the survey received 17.2% and 19.5%, respectively, of the votes, while "Neutral" obtained 35.9% of the votes.

3.3. Predicted Mean Vote and Thermal Sensation Vote

The students were asked in each recording session to fill in the questionnaire a half-hour after entering the classroom, namely at 10:30 and 12:30. The calculated operative temperature (T_{op}) at the time that the occupants completed the survey had the same values in classroom A and in classroom B. Therefore, the mean values of PMV and TSV were plotted, for both classrooms, as a function of the operative temperature in Figures 8 and 9. The slopes of the resulted regression equations can be assessed as students' sensitivity to the air temperature [29]. For the case when students were without masks (classroom A), the slopes of the linear regression of the PMV and TSV were 0.346 unit/°C and −0.569 unit/°C, respectively. For classroom B, where subjects wore masks, the slopes of PMV and TSV were 0.185 unit/°C and −0.711 unit/°C, respectively. The differences in the slopes of the linear fits of the quantitative and qualitative indices denote that students' thermal responses were less sensitive than the one achieved from the PMV model, results that are consistent with a previous study [30].

The mean values of TSV, in both study cases, were higher than the PMV models; therefore, the neutral temperature was determined from the regression equation (Table 4), considering the range of temperature where the votes were within $-0.5 < TSV < 0.5$.

For the neutral operative temperature (when TSV = 0), a difference of 1.5 °C was obtained between PMV and TSV in classroom B. Overall, the temperature range of TSV was narrower than the one defined by PMV, especially in the case when students wore facial masks. One can deduce that the subjects wearing face masks were less sensitive to the temperature changes.

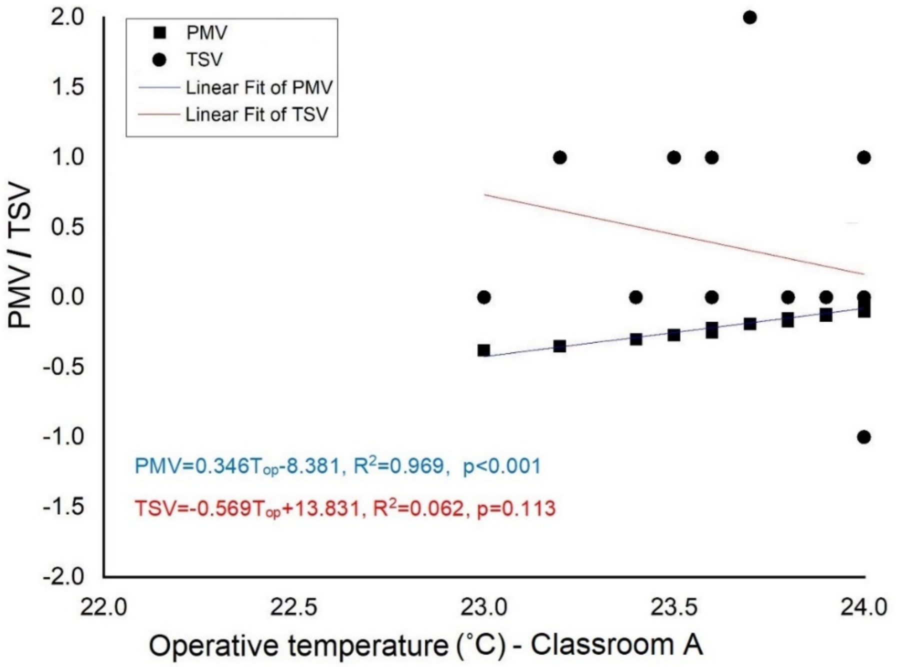


Figure 8. Linear regression of the mean PMV/TSV in relation to T_{op} for Classroom A.

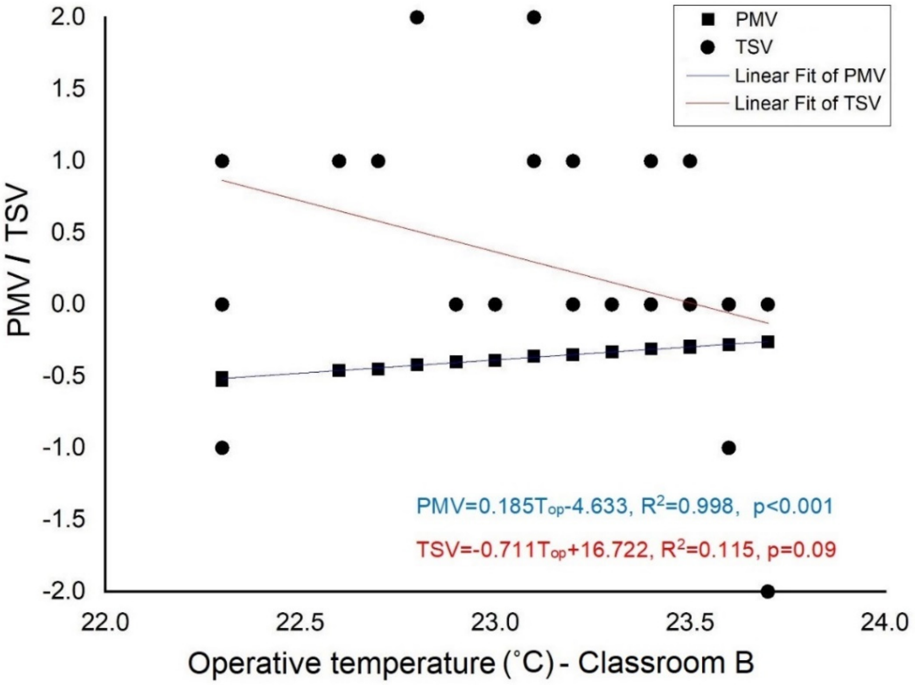


Figure 9. Linear regression of the mean PMV/TSV in relation to T_{op} for Classroom B.

Table 4. Regression models of PMV and TSV.

Case	Regression Model	Temperature Criterion (°C)		
		TSV = −0.5	TSV = 0	TSV = 0.5
Without masks	PMV = 0.346Top − 8.381, R2 = 0.969, $p < 0.001$ TSV == −0.569Top + 13.831, R2 = 0.062, $p = 0.113$	22.77 25.18	24.22 24.31	25.66 23.43
With masks	PMV = 0.185Top − 4.633, R2 = 0.998, $p < 0.001$ TSV = −0.711Top + 16.722, R2 = 0.115, $p = 0.09$	22.34 24.22	25.04 23.52	27.75 22.88

4. Discussion

4.1. Analysis of Quantitative Versus Qualitative Data

The key factor in achieving occupants' thermal comfort, especially in the cold season, is the air temperature with a direct effect on the thermoregulation of the human body [31,32]. In addition, the relative humidity has a strong impact on peoples' thermal comfort. Low levels of humidity lead to dryness of the mucous membrane, while high levels impede the evaporation of moisture from the surface of the skin [33–35]. At the same time, the air velocity contributes to a comfortable environment perception by increasing the convection and humidity evaporation from the skin or by decreasing clothing insulation [36].

Almost all recorded values of the indoor environment parameters during the field studies complied with the international and national thermal comfort standards [12,37–39], in which the recommended temperature range is between 20 °C and 24 °C, the relative humidity is between 30% and 70%, and the air velocity is less than 0.2 m/s.

From Table 3 it can be observed that, in classroom B the mean relative humidity (28.37%) failed to meet the recommended interval; however, when wearing facial masks, 63.6% of students perceived the relative humidity as "Neutral", while only 25.6% of students perceived it as "Slightly dry". Due to this non-compliance with standards, correlation analysis was performed to identify the best association of the quantitative data with the qualitative data (Table 5).

Table 5. Correlation between quantitative versus qualitative data.

Qualitative Data		**Quantitative Data**					
		Air Temperature		**Relative Humidity**		**Air Velocity**	
		Correlation					
		Spearman's Rho Coefficient	***p*-Value**	**Spearman's Rho Coefficient**	***p*-Value**	**Spearman's Rho Coefficient**	***p*-Value**
Thermal sensation vote (TSV)	Without masks	−0.326 [1]	0.046	−0.300	0.068	−0.058	0.728
	With masks	−0.467 [1]	0.016	−0.110	0.578	0.206	0.292
Humidity perception vote (HPV)	Without masks	−0.510	0.760	−0.231	0.162	−0.267	0.105
	With masks	0.150	0.464	0.109	0.580	−0.059	0.765
Air velocity perception vote (APV)	Without masks	−0.351 [1]	0.031	−0.351 [1]	0.031	−0.119	0.476
	With masks	0.241	0.235	0.406 [1]	0.032	0.430 [1]	0.022
Thermal comfort vote (TCV)	Without masks	0.042	0.801	−0.076	0.651	−0.048	0.774
	With masks	−0.116	0.571	−0.241	0.217	−0.165	0.403
Thermal preference vote (TPV)	Without masks	0.094	0.575	0.166	0.318	0.011	0.925
	With masks	0.337	0.092	−0.102	0.604	−0.205	0.295

[1] $p < 0.05$.

By looking at the results from the correlation analysis (Table 5), it can be observed that more than half of the qualitative data had a low negative relationship (Spearman's rho coefficient is lower than 0.3) with the quantitative data and did not present significant differences, except for some limited cases. The low negative correlation indicated that the changes of the indoor environmental parameters have a weak opposite impact on students' perception votes.

A medium negative relationship with significant differences ($p < 0.05$) was revealed in the case of the air temperature and TSV in both classrooms. In addition, significant differences with the medium indirect intensity were obtained in the case of APV and quantitative data (air temperature and relative humidity) in classroom A. Similar results for the APV versus relative humidity and air velocity with significant differences ($p < 0.05$), yet with a medium positive relationship, appeared in classroom B when students had facial masks. This means that students' perception of air movement was correlated with the relative humidity and air velocity and its direction was influenced by face masks.

The investigation continued with the correlation analysis between the main quantitative index of the indoor thermal environment (PMV) and the qualitative one (TSV). In the case when students were without masks, Spearman's rho coefficient presented a weak to a medium negative correlation (rho = −0.361) with significant differences (p = 0.026), while for the case when students were with masks, Spearman's rho coefficient (rho = −0.481) showed a medium negative correlation with significant differences (p = 0.013). The medium negative correlation demonstrated that any change in the quantitative index reflects in a moderate opposite direction of the qualitative index.

Since a medium correlation with significant differences was revealed between the air temperature and thermal sensation votes, we further investigated if TSV was correlated with TCV and TPV. The results of the analysis are presented in Table 6.

Table 6. Correlation between students' subjective responses.

Correlations	Qualitative Data	Outcomes	Thermal Comfort Vote (TCV)		Thermal Preference Vote (TPV)	
			Classroom A	Classroom B	Classroom A	Classroom B
Kendall's Tau-b	Thermal sensation vote (TSV)	Coefficient p-value	0.136 0.332	−0.107 0.180	−0.437 [2] 0.001	−0.443 [3] <0.001
Spearman's Rho	Thermal sensation vote (TSV)	Coefficient p-value	0.142 0.337	−0.121 0.173	−0.459 [2] 0.001	−0.448 [3] <0.001

[1] $p < 0.05$, [2] $p < 0.01$, [3] $p < 0.001$.

The analysis showed that TCV, regardless of whether students wore face masks or not, was weakly positively correlated with TSV. In the case of thermal sensation votes and TPV, in both classrooms a moderate negative correlation appeared with significant differences ($p < 0.05$). The outcomes point out that a modification of students' TSV, whether they wore face masks or not, has a medium effect on the opposite direction of TPV.

4.2. Diferences between PMV and TSV

The results showed that PMV underestimated students' thermal sensation and the discrepancy was significant. The mean values of PMV and TSV revealed a difference of 0.4 for classroom A (students without masks) and 0.56 for classroom B (students with masks), respectively.

The Shapiro-Wilk test applied to the PMV and TSV samples presented a lack of normality in the data distribution ($p < 0.05$); therefore, the Wilcoxon non-parametric test was employed. The outcomes of the non-parametric test presented significant differences between the samples: $p < 0.001$ when students were without masks and $p = 0.012$ when students with masks, respectively. The results emphasized that PMV cannot predict the thermal sensation of students regardless of if they are wearing facial masks or not.

The differences between PMV and TSV could be influenced by many factors, such as metabolic rate, clothing insulation, subjects' personal circumstances, and maybe face masks. Considering that the metabolic rate and clothing insulation were correctly estimated, consistent with similar studies [15–17], we excluded them as a potential factor affecting the discrepancy between PMV and TSV. Previous studies [40–42] revealed that Fanger's PMV-PPD model cannot precisely predict occupants' thermal sensation since is does not consider their continuous adaptation to the indoor environmental conditions in order to achieve thermal comfort. This accommodation is influenced by the psychological, physiological, and social aspects of each occupant. The most common factors related to a subjects' personal circumstances associated with the fact that students were into examination were stress and concentration. Studies showed [3–45] that people with increased levels of stress or intense concentration tended to perceive the indoor air temperature as higher than it actually was.

Recent studies emphasized that wearing facial masks creates discomfort and subjects preferred cooler temperatures [20,22,46]. Similar results are outlined from the present research. The non-parametric test applied to TPV samples did not show significant differences, although the mean value of students' TPV with masks was 0.18 compared to −0.04 for those without masks. Statistically significant differences ($p = 0.001$) were yielded when students' TCV were compared. Students without masks declared in a higher rate (89.6% compared to 57.4%) that they were "very comfortable" with the indoor thermal environment.

4.3. Statistical Analysis of Students' Subjective Votes According to Age and BMI

Previous studies reported that age and body mass index can influence subjects' responses to the indoor thermal environment [47,48]. In this sub-section we investigated, through Somers' d non-parametric test, the measure of association between age and BMI, as independent variables, and the qualitative data (TSV, HPV, APV, TCV, TPV, and COVID-19 concern) as dependent variables. According their age, students were divided into two groups, under and over 20 years old, while subject were split into three subgroups according to BMI: normal weight, overweight, and obese. The resulted values of the non-parametric test are presented in Table 7.

Table 7. Somers's d-values and approximate significance for age.

Age				
Subjective Votes	**Students without Masks**		**Students with Masks**	
	Somers's d			
	Value	**Approx. Sig.**	**Value**	**Approx. Sig.**
Thermal sensation vote (TSV)	0.034	0.771	0.058	0.170
Humidity perception vote (HPV)	−0.078	0.414	0.075	0.227
Air velocity perception vote (APV)	0.064	0.553	0.028	0.530
Thermal comfort vote (TCV)	−0.139	0.050	−0.031	0.479
Thermal preference vote (TPV)	0.146	0.181	0.016	0.758
COVID-19 concern	-	-	0.408	0.200
Body Mass Index				
Subjective Votes	**Students without Masks**		**Students with Masks**	
	Somers's d			
	Value	**Approx. Sig.**	**Value**	**Approx. Sig.**
Thermal sensation vote (TSV)	0.002	0.988	0.036	0.643
Humidity perception vote (HPV)	0.215	0.098	−0.195 [1]	0.016
Air velocity perception vote (APV)	−0.077	0.529	−0.066	0.409
Thermal comfort vote (TCV)	−0.087	0.482	0.014	0.863
Thermal preference vote (TPV)	−0.052	0.502	0.008	0.915
COVID-19 concern	-	-	0.093	0.310

[1] Sig. < 0.05

The results of the cross-tabular method showed a low association with no significant differences between the age groups regardless of wearing or not wearing facial masks. Similar outcomes were found in the BMI case with only one exception. A low negative association with significant differences was revealed for HPV when the subjects wore facial masks. A detailed analysis according to the body mass index and humidity perception is provided in the boxplot of Figure 10.

The variation of HPV of overweight and obese students fluctuated from "slightly dry" to "neutral", while for the normal weight subjects the votes were in line with "neutral". Given the votes, it seems that, while wearing facial masks, normal weight students had a better adaptation to the humidity of the indoor environment, even though the mean value of this parameter was slightly below (28.37%) the standards' recommendations.

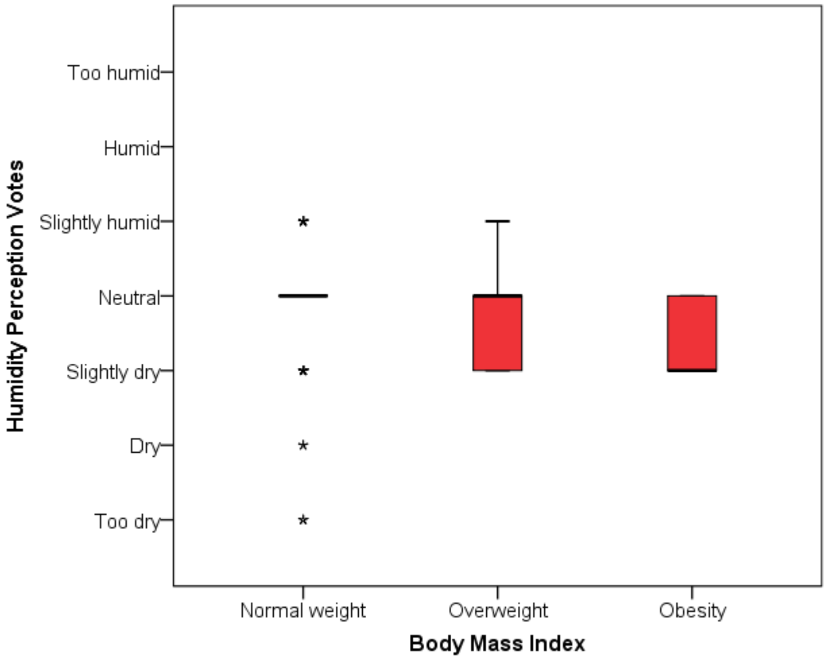


Figure 10. Boxplot of BMI and HPV of students with masks.

4.4. Potential for Energy Saving

Nowadays, when we are facing increased energy demands for heating and an emerging crisis of energy availability, without mentioning the effects of greenhouse gases emission on climate change, all of the attention is focused on energy savings potential. It is imperative to search and implement innovative methods to reduce the energy consumption of buildings.

In terms of energy savings for a building, the indoor air temperature plays a crucial role [49,50]. One intervention that is within reach to almost every user is to reduce the indoor air temperature without affecting occupants' thermal comfort. Recent studies conducted on different types of buildings highlighted that, by reducing the indoor air temperature by one degree, there is a potential of energy saving between 5 and 7.5% of the annual heating load [49,51–53]. A field investigation performed in offices and schools outlined that the acceptable range of the temperature variation should not exceed ±1 K [54]. Other research emphasized students' adaptability to cooler environments during winter [30,55,56].

The present investigation showed that PMV underestimates occupants' thermal perception regardless of their wearing a face mask or not. A difference of 1.5 °C was revealed between the operative neutral temperature of PMV and TSV when students had masks. In addition, when wearing masks, students prefer slightly cooler thermal environments.

Based on these findings, we can assume that by reducing the indoor air temperature by one degree there is a potential for energy savings without affecting students' thermal comfort.

4.5. Limitations and Further Studies

The limitations of the present investigation arise from the measurements period, which included only one season, winter, and only the continental climate zone. In addition, a larger sample of students would have been desired to empower the results. However, the data collected in this research allowed us to perform an adequate statistical analysis. Likewise, the type of facial masks worn by students was not considered in the study. Another limitation that could be considered is the gender imbalance of the study population, i.e., only male subjects participated in the experiments. Future investigations on this topic are needed for different seasons and climate zones to confirm our findings, since the requirements of wearing facial masks are still imposed in many countries. In addition, it is desirable to keep searching for methods to reduce the energy consumption of buildings based on subjects' activity and behaviour without affecting their thermal comfort.

5. Conclusions

This is a comparative field study on the influence of masks on students' indoor thermal environment perception during examination in the heating season in a continental climate zone. The potential of energy savings based on the findings are also discussed. The following conclusions are outlined from this research:

- PMV underestimated the thermal sensation votes of students whether they did or did not wear masks;
- For students without masks, the neutral Top was 24.31 °C, while for those with masks was 23.52 °C;
- A difference of 1.5 °C was found between the operative neutral temperature of PMV and TSV in the case when students had masks. For this situation, a potential for energy savings was identified;
- Students' APV was medium correlated with the relative humidity and air velocity and its direction was influenced by face masks;
- A significant difference ($p = 0.001$) was found between students' TCV. Students without masks declared in a higher rate (89.6% compared to 57.4%) that they felt "very comfortable" with the indoor thermal environment;
- Age did not seem to influence the indoor thermal environment perception of students. A low negative association with significant difference ($p = 0.016$) was revealed between the body mass index and students' humidity perception votes when subjects wore masks. It seems that, while wearing facial masks, normal weight students have a better adaptation to the humidity of the indoor environment.

Therefore, the research fulfils the main goal and come to improve the body of knowledge of the scientific literature addressing the impact of safety measures on students' thermal comfort during winter in a continental climate zone.

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