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Research Article

Assessment of student thermal comfort perception of spaces in education building with different ventilation strategies after COVID-19

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ABSTRACT

Environmental comfort directly affects student learning. With the rapid increase in educational buildings, thermal comfort conditions, student performance, and work efficiency are very important. The impact of COVID-19 has changed comfort expectations in assessing indoor air quality. This study investigates the thermal comfort of students from different regions in classrooms with different ventilation systems in summer and winter. The research presents statistically the results obtained from questionnaires and measurements of environmental variables. Surveys and field measurements were conducted from February 2021 to June 2022. The measurements included indoor environmental parameters, such as dry bulb and globe temperature, relative humidity, indoor airflow speed and CO_2 concentration. The subjective investigation was carried out using 635 particular questionnaires regarding their thermal senses, thermal preferences and the comfort conditions of the environment to determine the percentages of dissatisfaction. Approximately 82% of students in the naturally ventilated classrooms and 80% in the air-conditioned classrooms were comfortable. The average indoor comfort temperature estimated by the adaptive comfort method in naturally ventilated spaces was found to comply with ASHRAE 55 standards in both summer and winter. Another important finding is the differences in the thermal sensations of the students, especially for the winter period, as they come from various climatic regions of Türkiye.

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INTRODUCTION

With the effect of the pandemic (COVID-19), improving indoor air quality is now of greater importance for user comfort. Indoor Environmental Quality (IEQ) can be achieved with adequate thermal comfort, indoor air quality, visual and acoustic comfort [1]. Building designers are required to achieve the IEQ with the lowest possible energy use. The relationship between thermal comfort and energy consumption is critical for providing a comfortable and efficient living environment in buildings [2]. Heating,

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cooling and ventilation systems generally provide thermal comfort, but these systems consume significant amounts of energy [3, 4]. Strategies are needed to decarbonize the building stock by improving building energy performance without compromising occupant comfort [5]. Changes in local climatic conditions and temperature increases are observed due to energy consumption and increased emissions. Temperature increases obstruct thermal comfort, and air conditioning is generally considered the leading solution. Therefore, developing innovative ventilation and HVAC systems solutions is essential in sustainable building design [6]. In this way, both energy savings can be achieved, and the comfort of building users can be increased [7].

IEQ affects not only health and comfort but also building occupants' working and learning efficiency. In educational buildings, students and instructors spend most of their time in classrooms, studios, laboratories, etc. Therefore, investigating the thermal comfort of the school building is an important research topic. In addition, a significant part of the energy demand is related to indoor thermal comfort. Financial and energy restrictions, especially in school buildings, can harm students' learning performance and health [8]. ISO 7730 [9] defines thermal comfort as a "state of mind that expresses satisfaction with the thermal environment" ASHRAE Standard 55 [10] defines thermal comfort as a state of mind that expresses satisfaction with the thermal environment and is determined by subjective evaluation. In addition to this definition, Szokolay [11] defines it as a state of mind that requires subjective evaluation. These definitions include factors other than physical or physiological characteristics.

Thermal comfort varies depending on user activities, emotional states, personal and environmental factors [12]. Six parameters are used in the assessment of indoor thermal comfort. These parameters are divided into two: environmental and personal. The range of indoor comfort parameter values is defined in categories in EN 15251 [13]. Environmental factors: Air temperature is essential as it determines convective heat dissipation [14]. Air movement accelerates convection and creates a cooling effect as it increases evaporation from the surface. Air humidity has a negligible effect on thermal comfort, but high humidity restricts evaporation from the skin, while too low humidity causes the skin to dry out. The mean radiant temperature is the average temperature of all visible surfaces within the room from a user's point of view [1]. Personal factors: Clothing is the thermal insulation of the body and is measured in clo units [15]. The metabolic rate depends on factors such as food, drink, body shape, etc., and may impact thermal preferences due to the body's heat production effect [11].

Various studies on thermal comfort have been carried out in different countries of the world. Jiang et al. [16] analyzed the thermal comfort levels of students in controlled and uncontrolled environments during the winter season. It created an adaptive thermal comfort model based on students' behaviors affected by the external thermal environment. Merabtine et al. [17] studied thermal comfort for students of different age groups in the foyer area and the energy consumption of a two-story educational building. Pereira et al. [18] evaluated thermal comfort and indoor air quality in a school building. The results of PPD and PMV values were verified by comparing them with the data obtained from the survey. In his study of the indoor environment quality of different schools, De Giuli et al. [19] conducted a study on the indoor environmental quality of different schools. They found that students were not satisfied with the indoor conditions during the summer months. Aparicio-Ruiz et al. [20] investigated the thermal comfort of three classrooms in a school building. The study shows that the different models applied are inconsistent, and different strategies should be developed. Dorizas et al. [21] found that most students in different schools during the spring semester preferred a cooler environment, according to experimental measurements. Corgnati et al. [22] concluded that students prefer warm classrooms in winter and a more neutral indoor environment in other seasons when it is less cold. Similarly, Verma et al. [23] observed that there were slight differences in the values of experimental and survey data. Shrestha et al. [24] conducted a study on the thermal sensation of students in school buildings. The study shows that most students adapt to the ambient conditions and feel comfortable. Rodríguez et al. [25] addressed physiological and psychological variables in addition to physical and environmental factors. They concluded that little relationship exists between temperature, thermal sensation, and thermal comfort preferences in studying students of different age ranges. Similarly, Katafygiotou et al. [26] assessed indoor thermal conditions. The study found that air temperature and relative humidity were often insufficient for spaces.

Energy consumption has been increasing over time due to developments in the sectors. For this reason, the building's energy consumption and thermal comfort must be at optimum values with the proper efficiency studies. Kükrer and Eskin [27] found an increase in annual energy consumption while reducing user dissatisfaction. Hwang et al. [8] used different methods to evaluate different design parameters of the building envelope. Their study proposed school building envelope design criteria for balancing energy use and thermal comfort. Park et al. [28] analyzed the energy performance and thermal comfort of an educational building with a shading system. They concluded that cooling energy consumption decreases and thermal comfort increases when phase change material is applied to the shading system. Yu et al. [29] and Huh and Brandemuehl [30] used a multi-objective optimization to balance the energy use and thermal comfort of a building. However, Taylor et al. [31] found that more than 10% of users were dissatisfied when energy efficiency was achieved in classrooms using a multi-objective optimization. Li et al. [32] concluded that using RSM (Response Surface Method) for the optimal combination of different parameters in a school building results in energy savings of about 4% and increased environmental comfort.

In recent years, researchers from different parts of the world have carried out various studies on thermal comfort in educational buildings. Table 1 lists studies on thermal comfort in educational buildings over the past 20 years. This table contains information about the level of education in the studies, the country's location, the seasons, the age range, the ventilation type, the number of surveys and the number of schools [33-50].

While many existing studies have examined thermal comfort and indoor air quality, few have examined changes in comfort expectations in spaces with different ventilation strategies post-COVID-19. While previous research often focused on a single system type, this study provides more comprehensive information across naturally ventilated and air-conditioned classrooms. Furthermore, the study makes a unique contribution by considering the thermal comfort of students from various climatic regions of Türkiye. This emphasizes the influence of regional habits on thermal comfort.

The primary purpose of this study is to determine the thermal comfort feeling of students by examining the thermal comfort conditions of spaces with different ventilation strategies in both winter and summer after COVID-19. We consider different spaces of a university building with both an objective and subjective approach. In addition, the students' thermal sensation results were compared with the thermal comfort conditions of different regions where they had previously lived and got used to. Questionnaires constitute a subjective approach to thermal comfort, while the measurements constitute an objective approach based on the standards EN ISO 7730 and ASHRAE-55. In addition, the environmental conditions were evaluated by comparing their compliance with ASHRAE 55 and EN 15251 standards. This article seeks answers to two primary research questions (RQ): Do spaces with different ventilation strategies

Table 1. Previous thermal comfort research on classrooms in education buildings

Level	Year	Researcher	Location	Season	Age group	Vent. type	Sample size	School size
SE	2003	Kwok and Chun [33]	Japan	Summer	-	NV, AC	74	2
SE, U	2007	Corgnati et al. [34]	Italy	Spring, Autumn, Winter	14-22	NV	427	5
U	2009	Yao et al. [35]	China	Spring	mean 22	NV	3621	1
PE	2009	Zeiler and Boxem [36]	Netherlands	Winter	-	AC, NV	-	14
U	2011	Cao et al. [37]	China	Summer, Winter	17-25	AC	206	1
PE, SE	2012	Liang et al. [38]	Taiwan	Whole year	12-17	NV	1614	2
PE	2013	Haddad et al. [39]	Iranian	Autumn, Winter	10-12	NV	794	30 class
U	2013	Barbhuiya and Barbhuiya [40]	England	Winter	-	-	-	1
PE, SE	2013	Alfano et al. [41]	Italy	Summer, Winter	11-18	NV	4416	6
PE	2013	Pereira et al. [42]	Portugal	Winter, Spring	14-15	NV, AC	-	1
SE	2014	Modeste et al. [43]	Cameroon	Dry, Rainy season	15-29	NV	1545	6
SE	2014	Pereira et al. [18]	Portugal	Spring	15-18	NV	45	1
PE	2014	Teli et al. [44]	England	Spring, Summer	7-11	NV	2990	2
PE	2014	Katafygiotou et al. [26]	Cyprus	Whole year	-	NV, AC	-	1
KG, PE, U	2016	Almeida et al. [45]	Portugal	Spring	4-22	NV	487	6
U	2018	El-Darwish and El-Gendy [46]	Egypt	Spring	-	NV, AC	90	3
PE, SE	2018	Jindal [47]	India	Monsoon, Winter	10-18	NV+ fans	640	1
U	2018	Merabtine et al. [17]	France	Whole year	17-22	-	41	1
SE	2019	Papazoglou et al. [48]	Greece	Winter	16-18	NV	19	1
PE	2020	Jiang et al. [16]	China	Winter	9-16	NV, AC	1126	13
PE	2020	Heracleous and Michael [49]	Cyprus	Summer, Winter	12-15	NV	317	1
U	2021	Kükrer and Eskin [27]	Türkiye	Spring, Autumn	-	AC	-	1
PE, SE	2021	Rodríguez et al. [25]	Colombia	Spring, Autumn	7-16	NV	314	2
PE	2021	Shrestha et al. [24]	Nepal	Spring	13-15	NV	2454	8
PE	2021	Aparicio-Ruiz et al. [20]	Spain	Summer	10-11	NV, AC	2010	1
U	2022	Pekdogan and Avci [50]	Türkiye	Spring	18-21	NV	42	1

Note: NV - natural ventilation; AC - air conditioning, U- university; PE- primary education; SE- secondary education; KG-kindergarten.

after the pandemic comply with comfort standards when thermal comfort is evaluated (RQ1)? Moreover, does the effect of the climate region where students from different regions of the country live on user thermal comfort differ (RQ2)? To address these research questions and achieve the objectives, the remainder of this article is organized as follows: The first section explains the method section, which includes thermal comfort models, Balikesir's climate, a description of the building, field measurements and instruments used for the survey and survey questions. The next chapter includes the findings and discussion section explaining the indoor and outdoor environment, subjective evaluation, evaluation of the cultural influence, predicted mean vote and thermal sensation vote and adaptive thermal comfort model results. Finally, the article concludes by discussing the study results and recommendations.

METHODOLOGY

In evaluating the user thermal comfort of different spaces in the selected university building, surveys, heat balance (PMV/PPD), and adaptive comfort model methods were used. These methods are two common approaches used in current comfort standards. When we examined the flow chart of the study, the literature review and commonly used thermal comfort models were first examined. Afterwards, the spaces belonging to different ventilation strategies to be examined in the study were determined. Survey questions, experimental equipment and area measurements were applied to evaluate user thermal comfort subjectively and experimentally in the selected spaces. As a result of these analyses, statistical models of the study were created, and the study results were compared (Fig. 1).

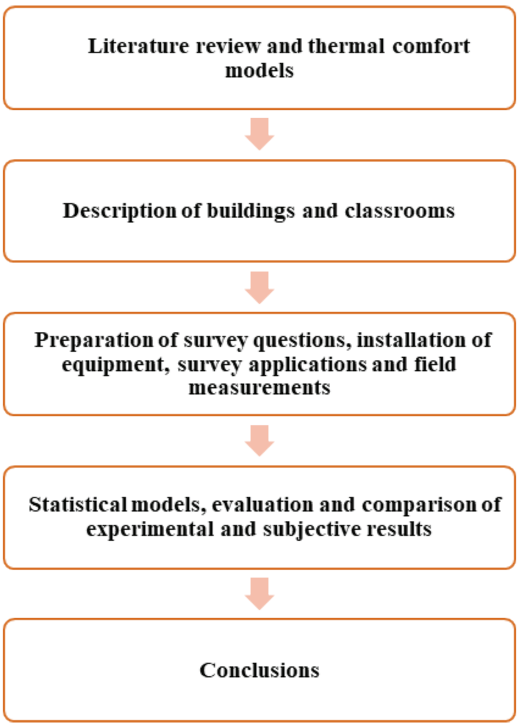


Figure 1. Flow chart of the method of the study.

Thermal Comfort Models

Detailed research on thermal comfort has been conducted for several decades. Two models are used to evaluate thermal comfort: the Heat balance model and the Adaptive thermal comfort model developed by Fanger in 1970 [51]. These models form the basis of current thermal comfort standards. The first model is suitable for air-conditioned buildings where users have no control. The heat balance approach was developed by Fanger, which produced the predicted mean vote (PMV) and predicted percentage dissatisfied (PPD) model. PMV can be determined by the Equations 1 and 2 [51].

$$\begin{aligned} PMV = (0.303e^{-0.036M} + 0.028))\{(M - W) \\ -3.96E^{-8} f_{cl}[(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] \\ - f_{cl} h_c (t_{cl} - t_a)] - 3.05[5.733 - 0.007(M - W) - P_a] \\ - 0.42[(M - W) - 58.15] - 0.0173M(5.867 - P_a) \\ - 0.0014M(34 - t_a)\} \end{aligned} \quad (1)$$

$$\begin{aligned} t_{cl} = 35{,}7 - 0{,}028 * (M - W) - I_{cl} * \{3{,}96 * 10^{-8} \\ * f_{cl} * [(t_{cl} + 273)^4 - (\bar{t}_r + 273)^4] \\ + f_{cl} * h_c * (t_{cl} - t_a)\} \end{aligned} \quad (2)$$

Where M is metabolic rate of the occupant (W/m^2 the body surface area), W is mechanical power by the occupant, f_{cl} is the surface area of the body with clothes, t_{cl} is clothing surface temperature (°C), T_a is temperature of air (°C), t_r is mean radiant temperature (°C), P_a is partial pressure of water vapour (P_a).

The PPD equation, which is a function of PMV, is calculated as follows:

$$PPD = 100 - 95e^{(-0.03353PMV^4 - 0.2179PMV^2)} \quad (3)$$

Fanger defined the PMV scale between cold (mark −3) and warm (mark +3). At this scale, ideal thermal comfort conditions are achieved with PMV equal to zero. Limit values are defined in ISO 7730 [9] and EN 15251 [13] standards. These values are presented in Table 2.

Table 2. The classification is based on ISO 7730 and EN 1525 standards

Category	Thermal state of the body as a whole	
	PPD	PMV
I	≤6	-0.2 < PMV < +0.2
II	≤10	-0.5 < PMV < +0.5
III	≤15	-0.7 < PMV < +0.7
IV	>15	PMV < -0.7 or PMV > +0.7

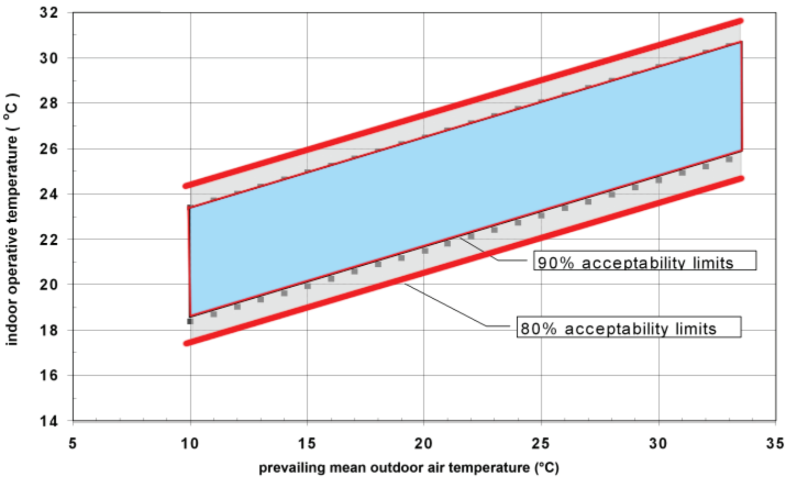


Figure 2. Adaptive thermal comfort graph according to ASHRAE standard 55–2017 [10].

The adaptive thermal comfort model is most suitable for naturally ventilated buildings and interacting with the environment. In ASHRAE 55–2017, this model defines acceptable thermal environments for areas where no mechanical cooling system and no heating system are working; users have metabolic rates ranging from 1.0 to 1.3 met and clothing insulation in the 0.5 to 1.0 clo range. The adaptive thermal comfort model is a linear regression equation directly relating the indoor comfort temperature in Equations 4 and 5 to the outdoor temperature. Acceptable indoor operating temperatures will be determined from Figure 2 using 80% acceptability limits [10].

The following equations corresponding to the acceptable operative temperature in accordance with the ranges in Figure 2 are used [10]:

$$\text{Upper 80\% acceptability limit Tc (°C)} = 0.31\text{Tpma(out)} + 21.3 \quad (4)$$

$$\text{Lower 80\% acceptability limit Tc (°C)} = 0.31\text{Tpma(out)} + 14.3 \quad (5)$$

Where T_c is indoor comfort temperature, $T_{pma(out)}$ is the prevailing mean outdoor dry bulb temp (°C).

For this study, the calculation of the operative temperature (T_o) is shown in Equation 6:

$$To = A * T_a + (1 - A) * T_r \quad (6)$$

Where T_o is the Operative temperature, T_a is the air temperature, and T_r is the mean radiant temperature. A is a parameter estimated from the relative air velocity. Values depending on the air velocity of parameter A are given in Table 3 [48].

Table 3. Estimation of (A) parameter for mean radiant temperature calculation

Velocity (m/s)	< 0.2	0.2 - 0.60	> 0.6
A	0.5	0.6	0.7

The Climate of Balikesir

Balikesir is between 39°40’ north latitudes and 26°28’ east longitudes of Türkiye. The provincial borders are dispersed within both the Marmara and Aegean Regions. According to Köppen Geiger climate classification, Balikesir is in the Csa climate zone [52]. Three climates are seen together in Balikesir—Mediterranean in the Aegean coast, Marmara in the north and continental climate in the interior regions. The temperature difference is low in the summer and winter periods on the coasts. In the interior, the difference is significant. In the mountainous eastern region, winters are harsh, and summers are cool [53]. The average temperature throughout the year is around 20.2°C. The coldest month is January (average maximum of 4.6°C), and the hottest month is July (average maximum of 24.8°C). In winter, there is much more rainfall than in summer. The difference between the driest and wettest month of the year is 77 mm. The prevailing wind direction is north. The relative humidity of Balikesir, on the other hand, is the highest, with 80% in December compared to the monthly average fog and humidity rates. The lowest humidity rate is in July at 53% [54].

Description of the Building

The Faculty of Engineering and Architecture, located at the Cagis Campus of Balikesir University, was chosen for this study. The building was built in 1993, consisting of rectangular blocks extending in the northwest and southeast directions. The total area of the building is 20.000 m^2. Approximately 85% of this area is heated, and approximately 17% is cooled. In Table 4, the material components and U values of the building elements are shown.

The building offers office spaces, a lecture hall, seminar rooms, meeting rooms, classrooms, laboratories, cafes, and study areas for users from different departments. The floor plan of the existing building where the experimental study was carried out is given in Figure 3.

Table 4. U-values of the building components

Building components	Specifications	U value (W/m²K)
External wall	30 mm cement mortar exterior plaster 190 mm vertical hole brick 20 mm cement mortar interior plaster	1.287
Terrace roof	6 mm polymer bitumen waterproofing membrane 0.005 mm lining 50 mm slope concrete 120 mm slab concrete 20 mm cement mortar plaster	3.42
Internal wall	20 mm cement mortar plaster 85 mm horizontal hole brick 20 mm cement mortar plaster	1.843
Ground	15 mm ceramic floor tile 60 mm levelling concrete and mortar 3 mm waterproofing membrane 100 mm lean concrete 35 mm sand 150 mm blockage	1.014
Window	6 mm glass 13 mm air gap 6 mm glass	2.708

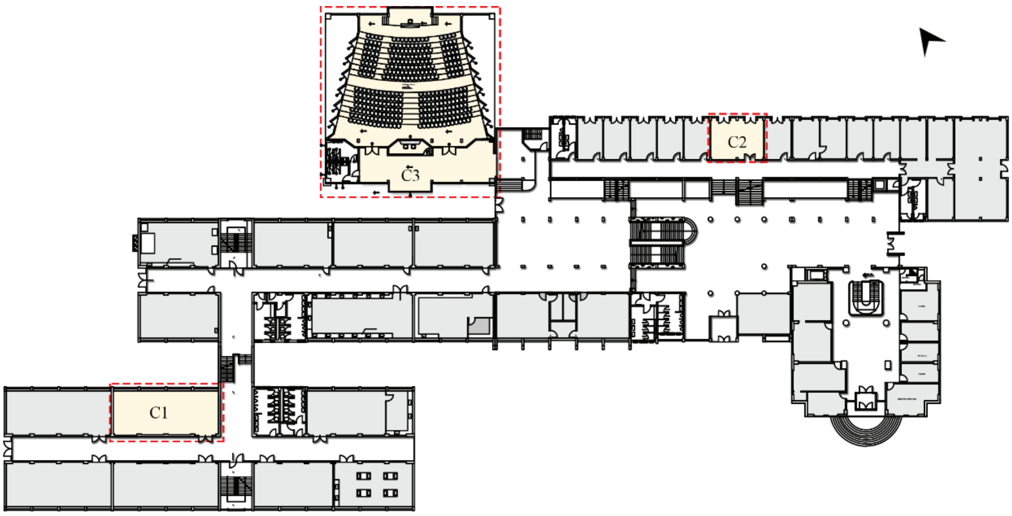


Figure 3. The floor plan of the existing building where the study was carried out.

In the building, the classroom (C1), design studio (C2) and lecture hall (C3) used for educational purposes with different ventilation strategies were examined (Fig. 4). Among the spaces examined, NV is used in the classroom heating system, NV+AC is used in the design studio, and AC is used in the lecture hall.

The examined spaces are on different floors and have been chosen as east-oriented. While the classroom and design studio plan type are rectangular, the amphitheater plan is trapezoidal. In addition, the dimensions (floor area and height) of the examined spaces differ.

Questionnaire Survey

The subjective approach consisted of students completing the questionnaires at specific times during a regular class period. The respondents were university students aged

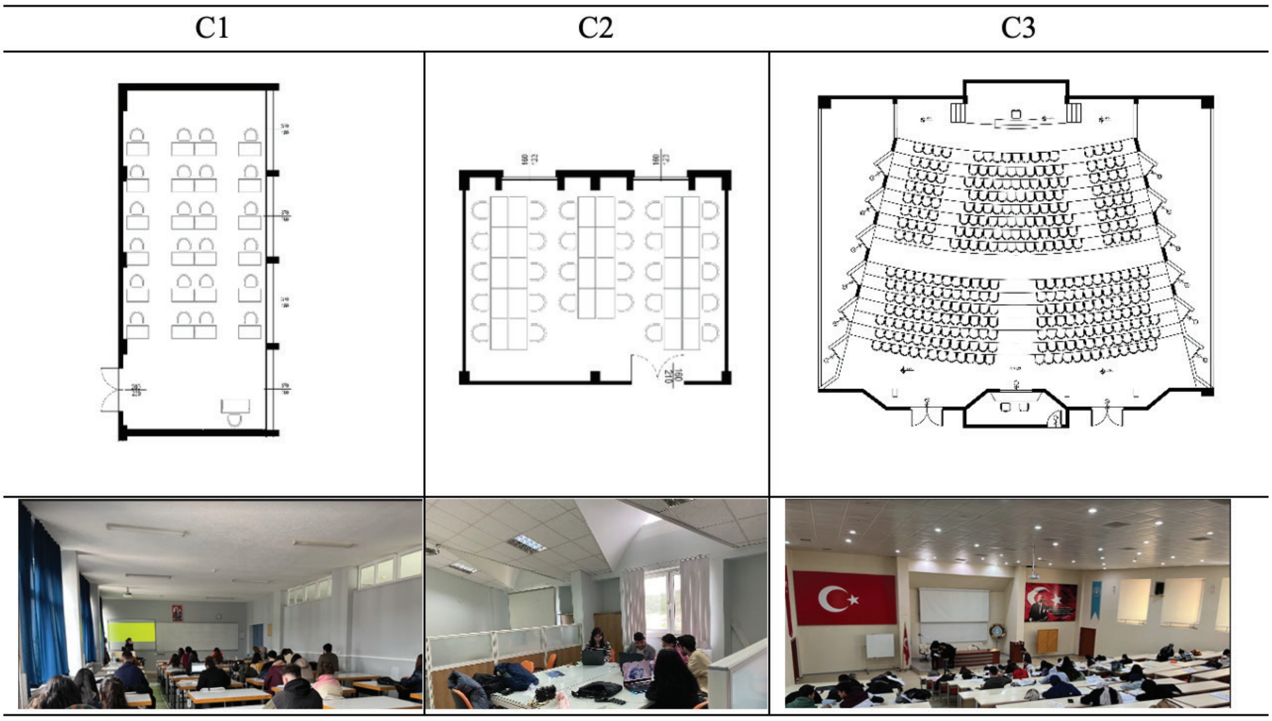


Figure 4. Plan and view of the three studied spaces.

19-27 years. The necessary equipment for the measurement was placed in the classroom center at the beginning of the class period, and the questionnaires and measurements were made. Before starting the surveys, the questions were explained so the students could easily understand them. There are 11 different questions in the questionnaire. Thermal comfort conditions are determined by analyzing the answers to the question "How do you perceive the ambient temperature during the time you are in the environment?" on the 7-scale scale proposed by Fanger [51]. The scale levels by the ASHRAE standard for the evaluation of the analysis are listed in Table 5.

The first questions of the questionnaire consist of personal (gender, age) and general (whether windows, doors and lighting are open or closed) questions. In the next section, questions were asked about how the students felt in terms of thermal, how they wanted their environment to change in terms of thermal, the environment's temperature level, the air velocity in the environment and the humidity rating. In the last part of the survey, the most influential factor on the comfort of the environment consists of questions

Table 5. Scales used in the questionnaire survey

Parameter	**Scale**						
Thermal sensation vote (TSV)	**-3** cold	**-2** cool	**-1** A bit cool	**0** neutral	**+1** A bit warm	**+2** warm	**+3** hot
Thermal preference vote (TPV)	**-3** A lot colder	**-2** colder	**-1** A bit colder	**0** No change	**+1** A bit warmer	**+2** warmer	**+3** A lot warmer
Thermal acceptability (TA)		**1** Acceptable		**2** neutral		**3** Unacceptable	
Air velocity sensation (AVS)	**-3** Very still	**-2** Moderately still	**-1** Slightly still	**0** Neutral	**+1** Slightly moving	**+2** Moderately moving	**+3** Much moving
Humidity sensation (HS)	**-3** Very dry	**-2** Moderately dry	**-1** Slightly dry	**0** Neutral	**+1** Slightly humid	**+2** Moderately humid	**+3** Very humid

about the dress situation and the region of Türkiye from which the students come. A total of 635 questionnaires were administered to 96 students in both terms. The values specified in ASHRAE 55 and ISO 7730 were used for the participants' metabolic rates and clothing conditions. The data obtained from the questionnaire were used to calculate the AMV (Actual Mean Vote) and APD (Actual Percentage Dissatisfied) values. The calculation of these values is shown below according to ISO 10551 (Equation 7 and Equation 8) [55]:

$$AMV = \frac{\sum_{mi} Q_m \cdot n_i}{\sum_i n_i} \quad (7)$$

$$APD = 100 - 95e^{(-0.03353PMV^4 - 0.2179PMV^2)} \quad (8)$$

Where, (Q) is the value representing questionnaire vote (-3, -2…+3), m and n is the number of students answered at the questionnaire, i.

Field Measurements and Instruments Used for the Survey

Indoor temperature comfort parameters: Indoor air temperature, globe temperature, CO_2 density, relative humidity and airflow velocity were measured with the Testo-480 (Fig. 5) device. The layout of the indoor measuring points of the device is shown in Figure 5. A HOBO data logger is housed inside a box in the shaded area to take outside temperature

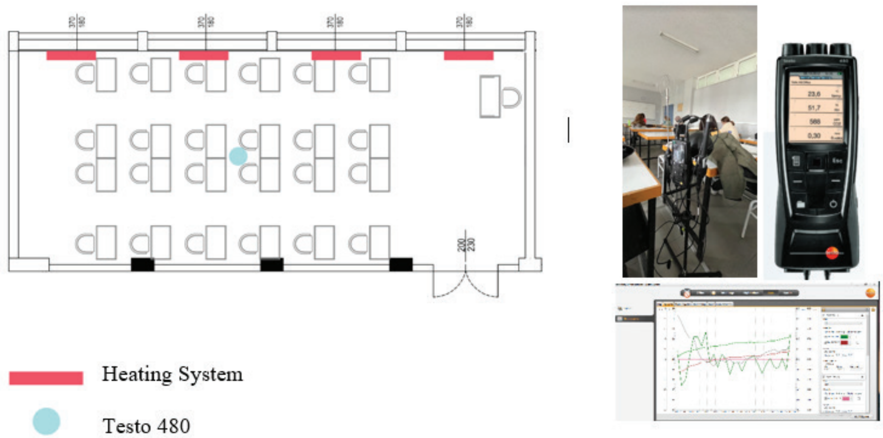


Figure 5. Testo 480 and the position of the device in the room.

Table 6. Instruments used in the field survey

Parameters	Equipment	Measuring Range	Accuracy	Photographs
Indoor air temperature, CO_2 concentration and humidity	IAQ probe (Testo 480)	0 to +50°C 0 to 100 %RH 0 to +10000 ppm CO 2 +700 to +1100 hPa	±0.5°C ± (1.8 %RH +0.7% of m.v.) ± (75 ppm CO 2+3 % of m.v.) 0 to +5000 ppm CO_2 ± (150 ppm CO_2 +5 % of m.v.) 5001 to +10000 ppm CO_2 ±3 hPa	
Outdoor air temperature	HOBO external temp/rh data logger	-20° to 70°C (-4° to 158°F) 1% to 95% (noncondensing)	±0.21°C from 0° to 50°C ±2.5% from 10% to 90% typical to a maximum of ±3.5% including hysteresis at 25°C (77°F); below 10% and above 90% ±5% typical	
Air velocity	Turbulence probe (Testo 480)	0 to +50°C 0 to +5 m/s +700 to +1100 hPa	±0.5°C ± (0.03 m/s +4% of m.v.) ±3 hPa	
Globe thermometer	Black-ball thermometer (Testo 480)	0 to +120°C	Class 1	

readings. It is to place the measurement points in a way protected from external factors.

Table 6 shows the equipment used to measure indoor and outdoor weather variables and their details. Measuring equipment was placed on tripods to continuously measure indoor air temperature, relative humidity, CO_2 density, air velocity and sphere temperature. During the measurement, the device was positioned in the middle of the measurement area and at the height of 1.1 m from the ground as specified in ASHRAE-55, ISO 7726 and EN ISO 7730 [56]. In total, 635 questionnaires were administered to 96 students. The results were evaluated separately as heating and cooling periods. The measurements were taken 5 minutes after the device was placed in the classroom, taking into account the time the

Table 7. Statistics of the thermal comfort indices and environmental parameters

			T_a(°C)	T_g(°C)	T_o(°C)	RH(%)	V_a(m/s)	Icl(clo)	T_{op}(°C)	CO_2 (ppm)	PMV
C1	Winter	Mean	18.4	18.7	10.5	44.1	0.11	0.95	18.61	1274	-1.29
		Min	15.7	16	2	38.3	0.04	0.8	15.9	712	-2.05
		Max	20.8	20.5	15	59	0.2	1.15	20.7	1882	-0.15
		s	1.58	1.42	3.77	7.84	0.04	0.18	1.48	341	0.49
		μ	0.36	0.32	0.86	1.80	0.01	0.10	0.34	78.3	0.11
		μ_{norm}	%1.9	%1.7	%9.5	%4.1	%9	%5	%1.8	%6.1	%1.8
	Summer	Mean	25.62	26.41	23.06	46.64	0.1	0.5	26.1	822	0.3
		Min	21.3	22.4	17	41.3	0.05	0.35	21.94	655	-0.42
		Max	27.7	29.8	28	52.4	0.21	0.55	28.96	1160	1.11
		s	2.57	2.61	3.49	3.4	0.05	0.1	2.58	157.32	0.53
		μ	0.66	0.67	0.9	0.87	0.01	0.06	0.66	40.62	0.13
		μ_{norm}	%2.6	%2.5	%3.9	%1.8	%12.5	%3	%2.5	%4.9	%2.1
C2	Winter	Mean	21.6	22.1	11.5	34.34	0.05	1	22	1192	-0.46
		Min	18.6	19.6	4	28.1	0.01	0.8	19.18	960	-1.19
		Max	23.5	23.5	12	45.4	0.15	1.1	23.5	1636	-0.05
		s	1.93	1.41	2.32	6.25	0.03	0.15	1.63	313	0.41
		μ	0.41	0.30	0.49	1.33	0.008	0.09	0.34	66.7	0.09
		μ_{norm}	%1.9	%1.4	%5.8	%3.8	%14.5	%4.5	%1.6	%5.8	%1.5
	Summer	Mean	24.11	25.7	25.1	45.81	0.43	0.45	24.9	747	0.34
		Min	21.7	23	18	39.1	0.06	0.37	22.4	625	-0.57
		Max	26.7	28.4	33	50.9	1	0.55	27.75	987	1.08
		s	2.26	2.60	7.17	4.04	0.34	0.09	2.34	125.51	0.59
		μ	0.65	0.75	2.07	1.16	0.10	0.05	0.67	36.23	0.17
		μ_{norm}	%2.7	%2.9	%8.2	%2.5	%22.9	%2.5	%2.7	%4.8	%2.8
C3	Winter	Mean	19	19.4	8.03	37	0.11	0.9	19.26	739	-1.2
		Min	15.6	14.9	2	23	0.06	0.7	15.36	683	-0.44
		Max	21.2	22.2	12	43.9	0.2	1.15	21.64	794	-2.48
		s	1.80	2.37	2.59	7.33	0.05	0.23	2.06	27.79	0.63
		μ	0.32	0.43	0.46	1.32	0.01	0.13	0.37	4.99	0.11
		μ_{norm}	%1.7	%2.1	%5.7	%3.5	%7.3	%6.5	%1.9	%0.67	%1.8
	Summer	Mean	23.51	23.67	24.9	46.27	0.067	0.5	23.63	918	-0.3
		Min	18.4	18.7	18	41.2	0.05	0.4	18.6	798	-1.22
		Max	27.2	27.5	29	52.7	0.1	0.6	27.4	1003	0.5
		s	4.31	4.22	4.95	5.49	0.01	0.1	4.27	61.32	0.77
		μ	1.36	1.33	1.56	1.7	0.004	0.06	1.35	19.4	0.24
		μ_{norm}	%5.8	%5.6	%6.2	%3.7	%7.4	%3	%5.7	%2.1	%4.1

T_a: Indoor air temperature; T_g: Indoor globe temperature; T_o: Outdoor air temperature; RH: Relative humidity; V_a: Air velocity; Icl: clothing insulation; T_{op}: Operative temperature; PMV: Predicted Mean Vote; s: Standard Deviation; μ: Standard Uncertainty; μ_{norm}: Normalized Standard Uncertainty.

device entered the regimen, and measurements were made for 15 minutes until the end of the lesson. In addition, measurements and surveys were carried out during the lessons to ensure the validity of the measured data.

RESEARCH FINDINGS AND DISCUSSION

Indoor and Outdoor Environment

HOBO data loggers were used for outdoor data, and Testo 480 instruments were used for indoor data. All received data were transferred to an Excel table in a computer environment. The collected data were analyzed using Python and statistical software (IBM SPSS 26 and Minitab). In addition, calculations of thermal comfort indicators (PMV and PPD) were taken from the Testo 480 instrument. In this study, the environmental parameters and thermal comfort indicators collected for the summer and winter months of the classroom, design studio and amphitheater are shown in Table 7. Table 7 shows the statistical results of the measured values (mean, maximum, minimum, standard deviation, standard uncertainty, and normalized standard uncertainty) for the different spaces.

Within the scope of this study. experimental measurements were made to evaluate the users' thermal comfort. Many different devices were used during the measurements, and uncertainty analysis is necessary for the accuracy of the measurement results. The uncertainty of a measurement result reflects the need for more precise knowledge of the value of the measured substance. Uncertainty is measured by the standard deviation of the measurement (Equation 9). The standard deviation measures how far the values deviate from the mean (average), while the Standard Uncertainty (Standard Error of the Mean) measures the average variation in the measurements (Equation 10). Accordingly, the Standard Error of the Mean should be reported as the uncertainty of our measurement [57].

$$s = \sqrt{\frac{1}{n-1}\sum_{i=1}^{n}(x_i - \bar{x})^2} \quad (9)$$

$$\mu = \frac{s}{\sqrt{n}} \quad (10)$$

Where $\bar{x}$ is the mean, x_i is the individual measurements, s is the standard deviation, μ is the standard uncertainty of the mean, and n is the number of measurements.

Table 7 shows that there are differences between the measurements of the venues. The Normalized Standard Uncertainty (μ_{norm}) gives a relative measure of uncertainty that can be useful for comparing and interpreting uncertainties between measurements. For example, in space C1, the Normalized Standard Uncertainty value of the indoor temperature measurements was calculated to be 1.9%. This value indicates that the uncertainty is approximately 1.9% of the measured value, and the smaller this value is, the higher the precision of the measurement. Analyzing the measurements, it can be seen that the air velocity measurement has the highest uncertainty. Similarly, Ribeiro et al. [58] performed an uncertainty analysis of PMV and found that airspeed measurement is the primary source of uncertainty in PMV calculations. Due to COVID-19, the distribution of various parameters, such as indoor air flow rate and indoor temperature, were different, especially in naturally ventilated classrooms. "Opening windows" was a joint action used by users in naturally ventilated classrooms. This

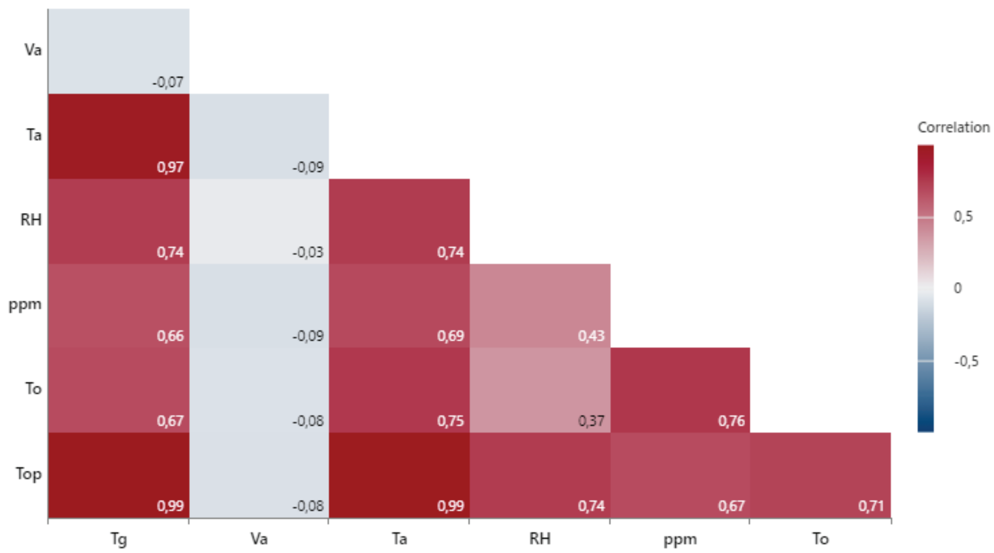


Figure 6. The relationship between the T_{op} and other environmental parameters.

situation has been an essential factor in the change in the average air speed in the classrooms. Especially in the summer, the high temperature and humidity make the users feel more comfortable thanks to the increased airspeed.

In addition, the correlations between Top and the values of environmental parameters such as T_a, T_o, RH, V_a and T_g were examined during the measurements (Fig. 6). Significant correlation values were found, especially between T_{op}, T_g, and T_a.

By examining correlations, it becomes easier to predict changes in thermal comfort based on changes in environmental parameters. For example, suppose an increase in outdoor temperature is strongly associated with an increase in operative temperature. In that case, steps can be taken to reduce the impact of hot weather on indoor comfort. Correlations between operative temperature and other environmental parameters provide essential data for optimizing comfort conditions. In addition, due to the high correlation coefficient of T_{op}, T_{op} can be selected as an independent variable for adaptive comfort models, which is commonly used in international standards [59].

Subjective Evaluation

The distribution of thermal sensation votes (TSV) according to the number of students is shown in Figure 7, respectively. By the ASHRAE seven-point scale, the students were asked, "How do you feel the warmth of the environment you are in?" TSVs were calculated by asking the question. The data were evaluated separately for both summer and winter months for students in the classroom (C1), design studio (C2) and lecture hall (C3). For the winter TSV results of C1 space, 99 (70.2%) out of 141 questionnaires were in the comfort range (between -1 and 1). For the summer, 77 (84.7%) of 91 surveys were in the comfort range. C2 space was in the comfort range in 69 (84.3%) of 80 questionnaires for winter and 49 (92.4%) of 53 questionnaires for summer. Similarly, 121 (63%) of 192 questionnaires for the winter month and 65 (83.3%) of 78 questionnaires for the summer questionnaires were within the comfort range.

The distribution of collected thermal preference votes (TPV) according to the number of students is shown in Figure 8. TPVs of students; "What kind of temperature change do you prefer during your time in the environment?" It was calculated with the question.

For the three different spaces, in winter, most students indicated that they preferred "No change" and their environment to be warmer. In summer, on the other hand, students preferred their environment to be cooler. Looking at the relationship between TSV and TPV, 32% of the students

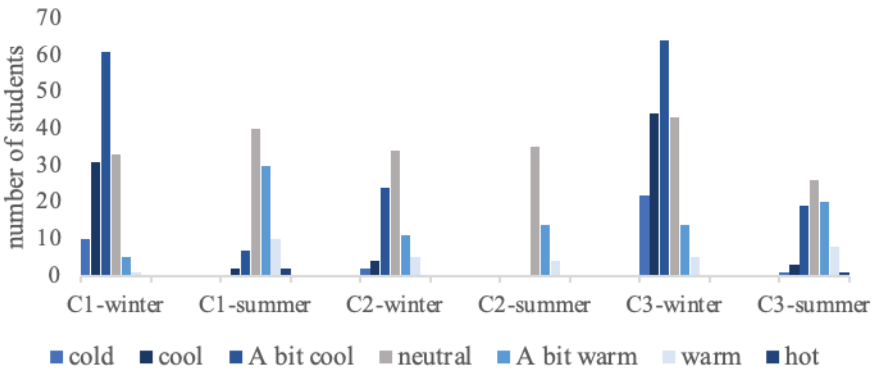


Figure 7. Distribution of thermal sensation responses during the field study.

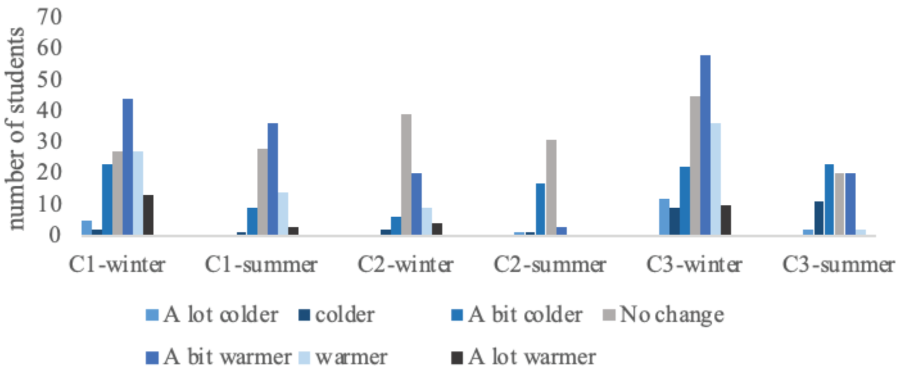


Figure 8. Distribution of thermal preference responses during the field study.

preferred "No change" for their "Neutral" thermal senses in winter; 28.6% of the students who identified as "Slightly cold" preferred "Slightly warmer" conditions, 16% of the students who identified as "Cold" preferred "Warmer" conditions, and 6% of the participants who identified as "Very cold" preferred "Much warmer" conditions. For "Neutral" thermal sensations in summer, 41% of the students preferred "No change"; 31% of the students who identified as "Slightly warmer" preferred "Slightly warmer" conditions, 8.6% of the students who identified as "warmer" preferred "Cooler" conditions, and 2% of the participants who identified as "Very cold" preferred "Much warmer" conditions.

Statistical characteristics of thermal sensation and thermal preferences for different spaces are given below (Table 8). Overall, Table 8 shows that the average thermal sensation rating for space C2 indicates that most of the students felt comfortable and did not prefer an environment that was too different from their current environment. For spaces C1 and C3, the average thermal sensation rating indicates that students felt a little uncomfortable but did not prefer an environment that was too different from their current environment. In addition, the average AVS and HS ratings in C1, C2, and C3 are close to neutral, indicating that students feel comfortable in the environment.

In this study, thermal acceptability is the question "What is the temperature of your environment?" measured from the answers given to the question. In the C1 environment, approximately 65% of the students feel comfortable in the winter and 95% in the summer. In the C2 environment, approximately 85% of the students feel comfortable in the winter and 34% in the summer. In the C3 environment, approximately 48% of the students feel comfortable in winter and 65% in summer (Fig. 9). The low thermal acceptability, especially in the C2 summer period, maybe because it is located on the top floor. Because it is known that the building envelope is in direct contact with the sun's rays in the summer months.

Table 8. Descriptive statistics of subjective thermal sensation and preference variables

Variables		Winter				Summer			
		Mean	s	Min	Max	Mean	s	Min	Max
C1	TSV	-1.03	0.97	-3	2	0.49	0.94	-2	3
	TPV	0.67	1.41	-3	3	-0.31	0.99	-3	2
	AVS	0.17	0.87	-2	2	-0.07	1.06	-3	3
	HS	-0.12	0.68	-3	2	0.25	0.65	-1	2
C2	TSV	-0.21	1.03	-3	2	0.41	0.63	0	2
	TPV	0.5	1.04	-2	3	-0.35	0.70	-3	1
	AVS	-0.3	0.56	-3	2	-0.11	0.99	-3	3
	HS	-0.13	0.65	-2	1	0.33	0.67	-1	2
C3	TSV	-1.01	0.95	-3	3	0.14	1.1	-3	3
	TPV	0.43	1.4	-3	3	-0.34	1.02	-3	2
	AVS	-0.09	0.99	-3	3	0.01	0.86	-2	3
	HS	-0.2	0.87	-3	3	0.44	0.92	-1	4

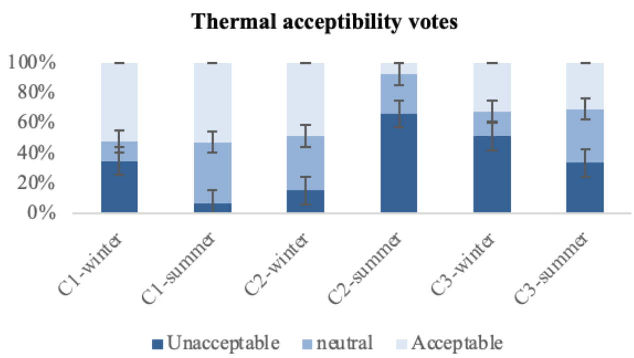


Figure 9. Distribution of acceptability responses during field study.

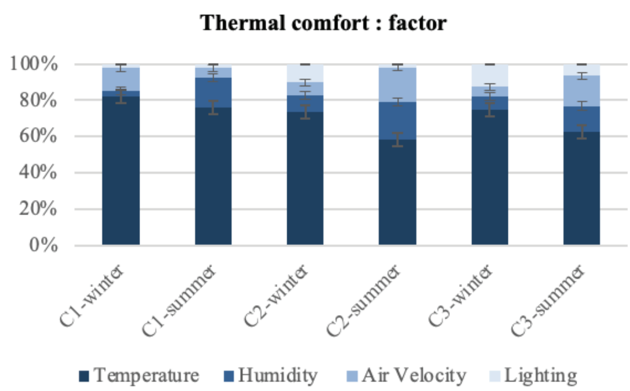


Figure 10. Distribution of the factors that most influenced students during the measurements.

The factor affecting thermal comfort, "Which factor do you think is the most affecting you in your environment?" It was measured from the answers given to the question (Fig. 10).

In general, temperature is the factor that most affects thermal comfort for all places and seasons. This result reveals the importance of the temperature factor in determining thermal comfort perception.

Evaluation of the Regional Influence

Balikesir, partly in the Southern Marmara Region and partly in the Aegean Region, has coastlines on both the Marmara and Aegean Seas. For this reason, the number of students coming from the Aegean and Marmara Regions is higher than the other regions. Using the ArcGIS program, the density analysis of the students according to the regions was performed, and then the average TSV values of both terms were shown on the map (Fig. 11).

According to the average TSV values of the winter period, students in regions where the winter season is generally cold are more satisfied with their environment. It was concluded that students from the Marmara Region, especially in the summer period, were more dissatisfied with the environment and preferred a cooler environment. In this study, the effect of the regional factor on thermal comfort is more pronounced, especially in the winter period.

Predicted Mean Vote and Thermal Sensation Vote

In order to compare TSV and PMV values, the operative temperature range of C1, C2 and C3 environments was considered. Operative temperature is an important method used for thermal comfort analysis [60, 61]. Table 9 shows the regression model of the mean values of PMV and TSV at indoor operative temperatures for both summer and winter periods. In addition, the regression models, correlation coefficients (r^2) and comfort temperatures (T_n) of TSV and PMV for all periods are given in Table 9. PMV and TSV were the dependent variables, and operative temperature was the independent variable. The significance value of the results was taken as $p<0.05$. Neutral or comfort temperature is the operative temperature calculated when PMV and AMV values are zero. Neutral temperature is

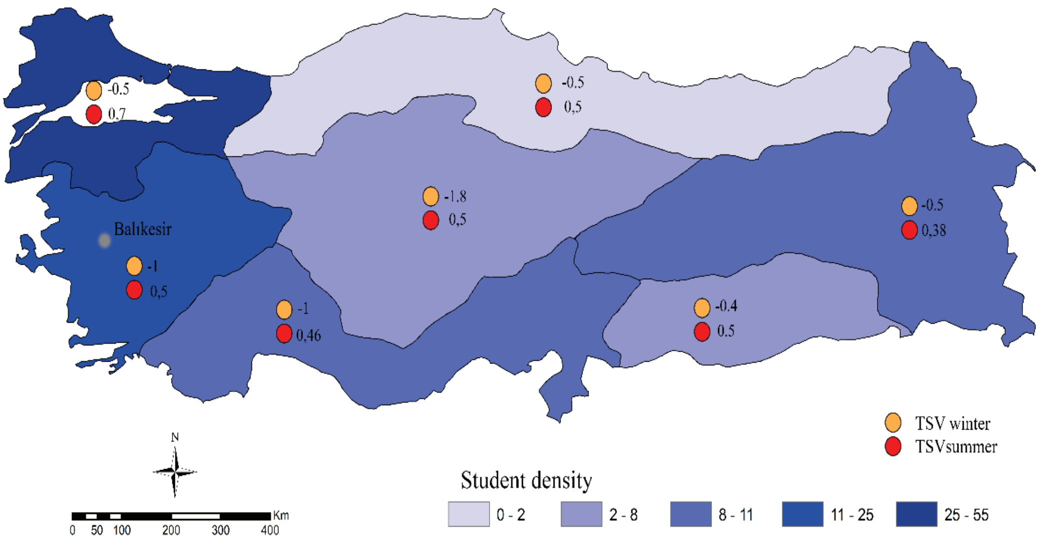


Figure 11. Density and average TSV values of the students participating in the survey by region.

Table 9. Regression models, neutral temperature and coefficient of determination for all periods

		Winter			**Summer**		
Variables		**Regression models**	T_n	r^2	**Regression models**	T_n	r^2
TSV	C1	$TSV=0.07T_{op} - 2.35$	31.8	0.09	$TSV= -0.09\ T_{op} +2.83$	32.4	0.26
	C2	$TSV=0.29\ T_{op} - 6.48$	22.3	0.89	$TSV= -0.03\ T_{op} +1.25$	41.6	0.17
	C3	$TSV=0.27\ T_{op} - 6.33$	23.4	0.86	$TSV= 0.17\ T_{op} - 3.7$	21.8	0.91
PMV	C1	$PMV=0.27\ T_{op} - 6.27$	23.6	0.66	$PMV= 0.19\ T_{op} - 4.54$	24.6	0.78
	C2	$PMV=0.25\ T_{op} - 5.94$	23.8	0.98	$PMV= 0.25\ T_{op} - 5.85$	23.4	0.96
	C3	$PMV=0.3\ T_{op} - 7.01$	23.3	0.97	$PMV= 0.18\ T_{op} - 4.56$	25.3	0.99

taken as "slightly cold", "neutral", or "slightly warm" on the ASHRAE scale.

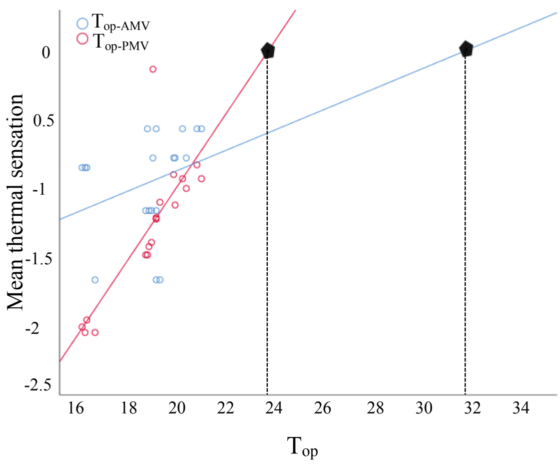
Quantifying the subjective and empirical data collected is always a challenge. Larger data sets may be needed to obtain a more concrete regression analysis. When we look at the studies in the literature, the sample size varies between 19 and 2990. C1 for the winter period (Fig. 12(a)); It is seen that the AMV and PMV graphs intersect when the operative temperature is between 20–21°C. After the operative temperature intercepts, the AMV graph rises steadily and predicts students' thermal sensation better than the PMV graph. The PMV model predicts colder sensations for operative temperatures than the actual rating. Students are not as sensitive to the indoor environment as PMV predicts. The Tn temperatures measured and calculated according to the survey results were 23.6°C and 31.8°C, respectively. Operative temperatures should be between 20°C and 24°C for the winter period according to ISO 7730. The calculated temperature was outside the standard range. According to the survey results, the students' thermal perceptions are 'cold', and the indoor conditions are unsuitable for thermal comfort during winter. The survey results show that the students want a warm environment (Table 8).

For the C1 space summer term (Fig. 12(b)), It is seen that the AMV and PMV graphs intersect when the operative temperature is between 26–28°C. It is seen that the slopes of AMV and PMV are in opposite directions after the operative temperature intersects. The measured temperature is different from the students' thermal perception. The Tn temperatures measured and calculated according to the survey results were 24.6°C and 32.4°C, respectively. Operative temperatures should be between 23°C and 26°C for the summer period according to ISO 7730. The calculated temperature was outside the standard range. According to the survey results, the students' thermal perceptions are ''a little warm," and the indoor conditions are normal in terms of thermal comfort for the winter period. The survey results show that the students want a somewhat cold environment (Table 8). Similarly, López-Pérez et al. [62] calculated a neutral operating temperature of 25.6°C in naturally ventilated spaces, outside the recommended range according to ISO 7730.

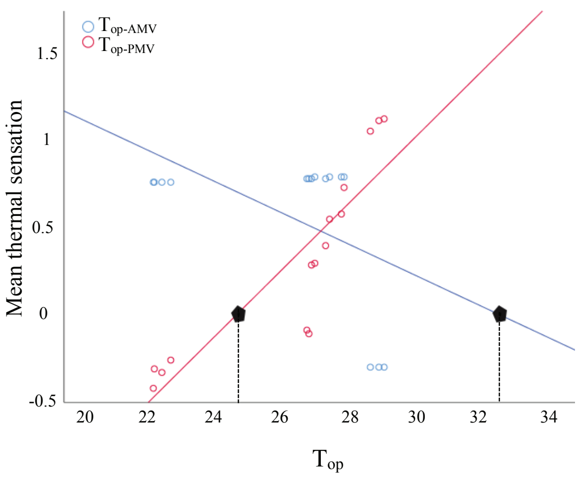
C2 is for winter (Fig. 13(c)); the PMV model shows sensations similar to actual voting for operative temperatures. Students are more sensitive to the indoor environment than the PMV model. The Tn temperatures measured and calculated according to the survey results were 22.3°C and 23.8°C, respectively. The calculated values are by the standards. Similarly, survey results confirm that students would like a slightly warmer environment (Table 8). That is, current temperatures meet participant preferences.

C2 is for the summer period (Fig. 13(d)). It is seen that the AMV and PMV graphs intersect when the operative temperature is between 26–28°C. The PMV model predicts colder sensations for operative temperatures than the actual rating. Students are not as sensitive to the indoor environment as PMV predicts. The Tn temperatures measured and calculated according to the survey results were 23.4°C and 41.6°C, respectively. The measurements have an extensive comfort range, and the calculated values do not meet the comfort conditions. However, the survey results show that students feel a little warmer (Table 8). In this case, current temperatures remained high according to participant preferences. These findings are consistent with those of López-Pérez et al. [62].

Similarly, Jindal [47] conducted a study on the PMV and PPD scale for students of different age groups. He concluded that the PMV and PPD models failed to predict the thermal sensations of students in naturally ventilated classrooms. Papazoglou et al. [48], in their research on the sensation of thermal comfort in students of different age



(a)



(b)

Figure 12. Observed thermal sensation votes and predicted thermal sensation votes for C1.

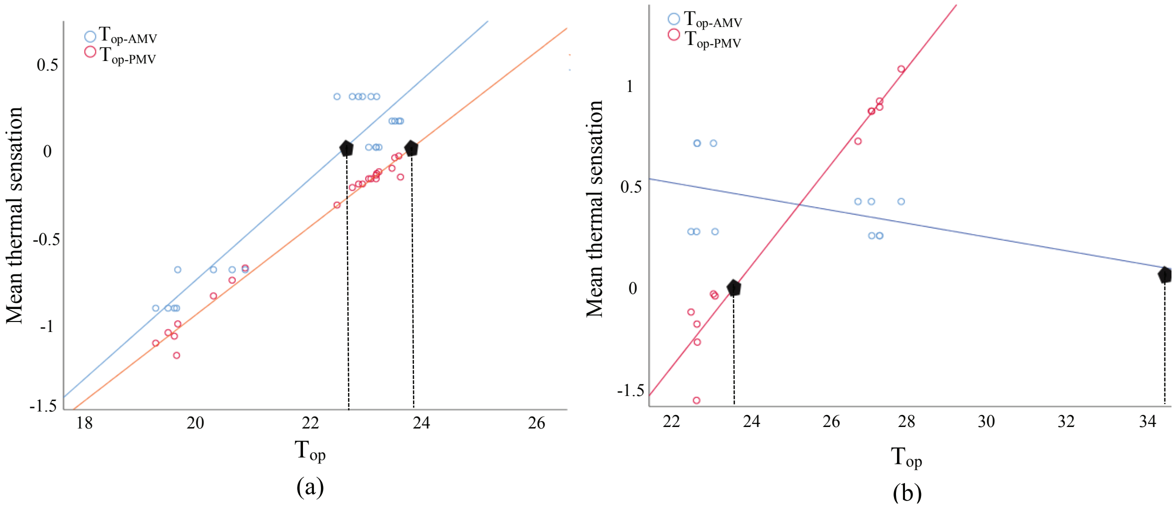


Figure 13. Observed thermal sensation votes and predicted thermal sensation votes for C2.

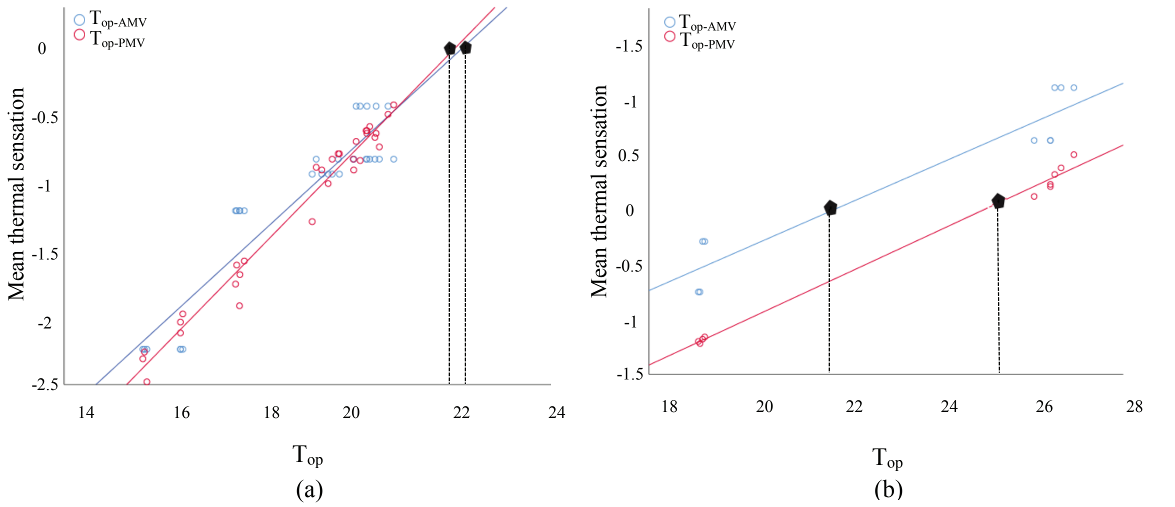


Figure 14. Observed thermal sensation votes and predicted thermal sensation votes for C2.

ranges in a school building, concluded that there were differences between experimental data and survey results.

C3 for the winter period (Fig. 14(e)); It is seen that the AMV and PMV graphs intersect when the operative temperature is between 20–22°C. The PMV model shows similar sensations to actual voting for operative temperatures. The T_n temperatures measured and calculated according to the survey results were 23.3°C and 23.4°C, respectively. The calculated values are by the standards. Similarly, when the survey results are taken into account, it is seen that the students want a somewhat warm environment (Table 8). That is, current temperatures meet participant preferences.

C3 space for the summer period (Fig. 14(f)); the PMV model predicts colder sensations for operative temperatures than the actual rating.

The Tn temperatures measured and calculated according to the survey results were 25.3°C and 21.86°C, respectively. The calculated temperature was outside the standard range. However, according to the survey results, the students' thermal perceptions are 'a little warm', and they want a 'a little cold' environment (Table 8). López-Pérez et al. [62] showed that in the space with AC mode, the linear regression line has a higher slope than expected for the summer season. They confirmed that the increase in the slope according to the TSV scale is due to the high proportion of people dissatisfied with the environment.

Adaptive Thermal Comfort Model

With the adaptive comfort approach, building users can adjust physiologically, psychologically and behaviorally according to environmental conditions [63]. In ASHRAE 55–2017, the Adaptive thermal comfort model is applied

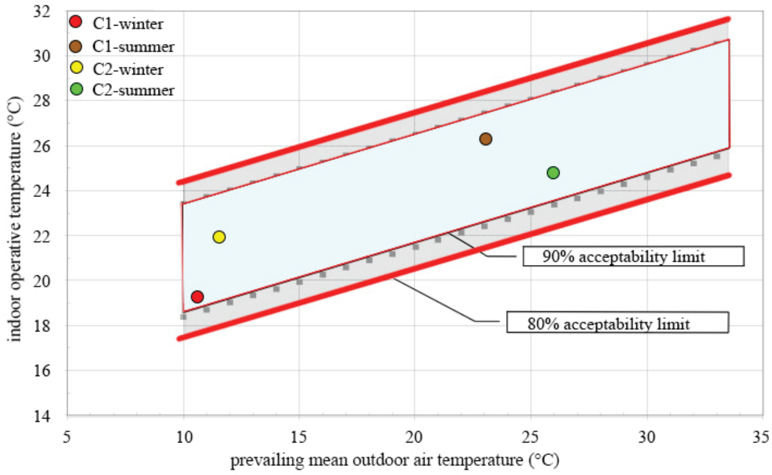


Figure 15. Acceptable operative temperature ranges for naturally conditioned C1 and C2 spaces [10].

for areas that are controlled by the user, naturally conditioned, where the mechanical cooling system and heating system do not work, the users have metabolic rates ranging from 1.0 to 1.3 met, and the clothing insulation is between 0.5 and 1.0 clo. The adaptive chart shows the acceptability comfort limits of 80% and 90% of the operative temperature (80% acceptability limits = operative temperature: 21.4 to 28.4°C and 90% acceptability limits = Operative temperature: 22.4 to 27.4°C) [64]. The input variable in the adaptive model in Figure 1 is prevailing mean outdoor air temperature $t_{pma(out)}$. This temperature is based on the arithmetic average of the mean daily outdoor temperatures over some days. At its simplest, $\overline{t_{pma(out)}}$ can be approximated by the climatically average monthly mean air temperature from the most representative local meteorological station available. The $\overline{t_{pma(out)}}$ equation is shown in Equation 11 [10]:

$$\overline{t_{pma(out)}} = (1 - \alpha)t_{e(n-1)} + \alpha t_{rm(n-1)} \quad (11)$$

Where α is a constant between 0 and 1 that controls the speed at which the running mean responds to changes in weather (outdoor temperature). Recommended values for α are between 0.9 and 0.6, $t_{e(n-1)}$ is the mean daily outdoor temperature for the day before the day in question, and $t_{rm(n-1)}$ is the running mean temperature for the day before the day in question (n – 1).

This model is not used in average outdoor temperatures below 10°C and above 33.5°C [10]. The study used average airflow velocity values by ASHRAE 55 standards. Figure 15 shows the winter and summer results for naturally ventilated spaces C1 and C2 during the study period. Results were obtained using data collected during the study for C1 and C2 environments. The results of the study comply with ASHRAE 55-2017 standards. The results are within the acceptable range of 90%. Similarly, according to the survey results of the students' thermal perceptions, it is seen that it is 'a bit hot' in the summer period and 'a little cold' in the winter period (Table 8). In other words, the ASHRAE 55 standard meets the comfort preferences of students. Pekdogan and Avci [50] investigated the adaptive thermal comfort conditions in the architectural design studio of an educational building in Türkiye. The results were similar to the results of this study and showed that the thermal comfort level was within 90% of acceptability limits according to ASHRAE Standard-55. These findings align with De Dear et al. [65] and López-Pérez et al. [62] in an educational building. Heracleous and Michael [49] examined indoor thermal comfort conditions and the effect of natural ventilation on thermal comfort in different periods. The study showed acceptable comfort results for users during the winter period but outside the comfort zone for the summer period. Adaptive thermal comfort models are based on the principle that building users can adapt to an environment through physiological, psychological and behavioral adjustments [66]. As a result, the adaptive thermal model in this study shows good prediction accuracy for naturally ventilated spaces C1 and C2 in educational buildings.

CONCLUSION

This study conducted a thermal comfort field study for three different spaces in a university building with different ventilation strategies in both summer and winter. A questionnaire-based study was conducted to collect subjective and objective data from building occupants. The study results were statistically analyzed using both PMV and adaptive comfort models based on the thermal comfort standards of the collected environmental parameters and questionnaires. Using adaptive strategies in naturally ventilated environments during summer makes students feel more comfortable and improves indoor air quality. During the study period, students' thermal preferences in all classes were slightly cooler in summer and slightly warmer in winter. There were differences in the acceptability of the comfort level of the student's environment. Especially in the C2 class summer period and the C3 class winter period, the comfort level needed to be at the desired level. In addition, it was confirmed that the effect of the cultural factor on thermal comfort is more pronounced, especially in the winter period, and students from colder regions feel warmer in the environment. Another important finding is that temperature is the most important factor affecting student comfort.

In summary, the study presented here shows that the thermal sensations of the students and the measured experimental data differ in some periods. Students' thermal sensations are within an acceptable comfort range. In this study, students' thermal comfort temperature range in naturally ventilated spaces fits the upper and lower limits of the Adaptive comfort model. However, adjustments should be made to accurately reflect their thermal sensations, especially for the neutral temperature range. There has been a significant increase in the number of educational buildings and students in Türkiye, especially in recent years. Therefore, it is predicted that quality education and better IEQ will significantly increase student performance. Professional groups, such as architects, engineers, etc., must show interest in this issue. This interest may contribute to improving knowledge in the field of indoor environmental quality for future studies and designing healthier and more comfortable educational environments for students.

NOMENCLATURE

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers.
CO_2	Carbon Dioxide.
IEQ	Indoor Environmental Quality
HVAC	Heating, Ventilation, and Air Conditioning.
Clo	Clothing insulation.
ISO	International Organization for Standardization.
RSM	Response Surface Method.
PMV	Predicted Mean Vote.
PPD	Predicted Percentage of Dissatisfied.
NV	Natural Ventilation
AC	Air Conditioning System.
U.- university	PE- primary education; SE- secondary education; KG-kindergarten.
M	Metabolic rate of occupant (W/m^2 the body surface area).
W	Mechanical power by the occupant.
f_{cl}	Surface area of the body with clothes.
t_{cl}	Clothing surface temperature (°C).
T_a	Temperature of air (°C).
t_r	Mean radiant temperature (°C)
P_a	Partial pressure of water vapour (Pa).
Met	Metabolic rates.
T_c	Indoor comfort temperature.
$T_{pma(out)}$	Prevailing mean outdoor dry bulb temp (°C).
T_{op}	Operative temperature (°C).
T_a	Air temperature (°C).
A	Air velocity of parameter (m/s).
C1	Classroom.
C2	Design Studio
C3	Lecture hall
TSV	Thermal sensation vote.
TPV	Thermal preference vote.
TA	Thermal acceptability.
AVS	Air velocity sensation.
HS	Humidity sensation.
AMV	Actual Mean Vote.
APD	Actual Percentage Dissatisfied.
s	Standard Deviation.
μ	Standard Uncertainty.
μ_{norm}	Normalized Standard Uncertainty.
T_n	Neutral (comfort) temperature (°C).
R^2	Coefficient of Determination.
t_{rm}	Running mean temperature (°C).

AUTHORSHIP CONTRIBUTIONS

Authors equally contributed to this work.

DATA AVAILABILITY STATEMENT

The authors confirm that the data that supports the findings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

CONFLICT OF INTEREST

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

ETHICS

There are no ethical issues with the publication of this manuscript.

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