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A Comparison of Students' Thermal Comfort and Perceived Learning Performance between Two Types of University Halls: Architecture Design Studios and Ordinary Lecture Rooms during the Heating Season

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Abstract: In classrooms, several variables may affect students' thermal comfort, and hence health, well-being, and learning performance. In particular, the type of learning activity may play a role in students' thermal comfort. However, most of the previous research has mainly investigated the thermal comfort of students in ordinary classrooms, while less attention has been paid to students' thermal comfort in classrooms with particular learning activities, such as architecture design studios, where students spend a long time and perform learning activities with high metabolic rates. For this purpose, we compared the thermal comfort and perceived learning performance of students majoring in architecture (n = 173) between two types of university halls, namely, design studios and typical lecture rooms (N = 15). We applied the classroom–comfort–data method, which included collecting physical, physiological, and psychological data from students and classrooms. Data were collected during the heating season (November 2021–January 2022) in a university building in Jordan. We conducted continuous monitoring combined with periodic measures for indoor temperature, relative humidity, mean radiant temperature, and air speed. Questionnaires, focus groups, and observations were also used to collect subjective data from students. The results showed statistically significant differences ($\Delta\mu = 3.1$ °C, $p < 0.01$, $d = 0.61$) in indoor temperature between design studios and lecture rooms. Only 58% of students' votes were within the ASHRAE 55-2107 recommended comfort zone. In design studios, 53% of students felt warm compared to 58.8% of students who had a cold sensation in lecture rooms. Students perceived themselves as more productive when they felt cooler. Our research's significance lies in its injunction that there must be a special thermal comfort guide for educational buildings that are adapted to the local environment and functions of the spaces, cooperatively.

Keywords: students' thermal comfort; perceived learning performance; design studios; university building; Middle East

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1. Introduction

Concepts such as healthy buildings [1,2], healthy school buildings [3], architecture and health [4], and building for well-being [5] have gained traction since the early 2000s. Such notions are regarded as having become "accepted components of educational buildings". These concepts are all fundamentally premised on the need to redress unfair, unequal, unhealthy, sick building syndrome and discomfortable indoor environments [6]. Additionally, in response to the recent COVID-19 pandemic, there has been an explicit recommendation to "further understand the links between educational buildings design, health and the indoor environmental quality (IEQ)" [7]. Students spend about 25% of their time inside educational buildings (e.g., schools, universities, and colleges), and therefore, the IEQ aspects such as indoor air quality [8], thermal [9], acoustic [10,11], and visual comfort [12] of educational buildings can affect students' health [13], well-being, and learning performance [14].

In particular, thermal comfort in classrooms is one of the main parameters of IEQ that may affect students' health and learning performance [15,16]. This is because the poor design of thermal environments in educational buildings can result in increasing thermal discomfort and health problems (e.g., muscle soreness, headache, and dizziness) [14,17]. It may also result in a rise in the energy use for the heating and cooling [9], which may lead to overheating in the winter [18] and overcooling in the summer [18,19].

In educational buildings, several variables can affect students' thermal perception including the duration of lecture [20], thermal adaptation strategies [21], psychological adaptation [22], educational level [23], students' gender [24,25], building operation mode [26], and climatic zone [27]. In addition, the type of learning activities carried out in classrooms can play a fundamental role in students' thermal perception, especially activities with a high metabolic rate [28]. For example, in the architectural field, students spend a long time in their design studios (e.g., 6–8 h per week) and they have a unique learning environment [29]. This is because architectural students have to perform intensive learning activities (e.g., designing, drawing, physical model making, research, and experimentation activities) with higher metabolic rates compared to students in typical lecture rooms, who usually have mild activities (i.e., passive sitting) with lower metabolic rates [30].

Given the complexity of educational buildings and the unavailability of design guides for classrooms [24], designers usually follow the most used international standards to design thermal environments in classrooms [31], while current regulations such as ASHRAE55-2017 [32] and ISO 7730-2007 [33] usually aim for neutrality and do not consider individual preferences and needs [34]. Further, although Fanger's model (PMV) was designed on the basis of experiments carried out on university students [35], researchers found some deviations between the predicted and observed thermal comfort, particularly in warm environments [7,18,36,37]. It has been argued that the thermal neutrality that is suggested by such standards is not necessarily the ideal setting for many people [38,39], since the perception of neutrality may vary between different climatic regions [18], seasons [40], age [9], gender [41], and cultural background [42].

Recently, a large and growing body of literature has investigated students' thermal comfort in educational buildings (see Section 1.1), while very few studies have examined the students' thermal comfort by considering students' learning activities conducted in the classrooms [43]. Conversely, the variation in learning activity types may have a significant influence on the perceived thermal comfort [20].

Thus, the current study was designed to compare students' thermal comfort and perceived learning performance in two types of university halls (i.e., architecture design studios (DS) and typical lecture rooms (LR)), where students have two different learning activity levels. The study was conducted in a university building in Jordan during the heating season and it attempted to consider the possible individual differences between students by applying the classroom–comfort–data method (CCDM) (the definition of the classroom–comfort–data method is expanded in Section 2) [22]. This method complements the data collection methods proposed by the existing international standards [32]. It is designed specifically to assess the thermal comfort of students in educational buildings.

1.1. Literature Review

In Table 1, we summarised twenty studies focused on students' thermal comfort over the last decade (2012–2022). Studies were classified on the basis of the educational building type (i.e., universities and schools). As shown in Table 1, nine of the analysed studies were focused on university buildings (i.e., ordinary lecture rooms) [44–52], while only one study investigated students' thermal comfort in different learning environments, i.e., design studios [53].

Table 1. Previous related research studied students' thermal comfort and learning performance in educational buildings.

Author, Year	Region	Climate	Season	Ventilation Type	Building Type	Class Rooms (n)	Students (n)	Monitored Days (n)	Outcomes
Sun et al., 2022	China	Cold	W	MV	University	1	587	4	TSV and TPV in the afternoon were significantly higher than those in the morning. Students' TSV was greatly affected by the pre-class activity.
Jiang et al., 2019	China		-	MV	University	1	25	-	Changing the room temperature by a few degrees Celsius can significantly impact students' self-reported TC.
Fabozzi and Dama, 2020	Italy	Temperate	S	M-M	University	16	985	-	In NV classrooms, the adaptive model was proven to be suitable for predicting students' comfort zone according to ASHRAE 55 Standard.
Bajc et al., 2019	Serbia	Temperate	W	M-M	University	1	240	19	No significant differences in thermal comfort perception between genders. Local thermal comfort is an important factor that can impact productivity.
Mishra and Ramgopal, 2015	India	Hot–humid	All seasons	NV	University	1	67	12	Regression neutral temperature was found close to 29 °C. 80% of occupant satisfaction was found for temperatures between 22 and 31.5 °C. Occupant adaptive actions mostly focused on clothing variation and fan usage.
Nico et al., 2015	Italy	Temperate	Spring	NV	University	2	126	1	A difference in thermal perception was found between women and men.
Tao and Li, 2014	China	Cold and subtropics	W	NV	University		640	-	A new adaptive equation was developed, which could be used to predict the thermal response in classrooms in subtropics region.
Fazio et al., 2020	Italy	Temperate	W	NV	University	3	959	-	Female students who had a slightly lower metabolism reported more acceptance for the warm thermal environmental.
Shi et al., 2022	China	Cold	W	MV	University	-	89		The PMV can predict the indoor thermal environment.
Jiang., et al 2018	China	Cold	W	MV	School	26	781	4	The comfort temperature of students in the classroom was found to be between 13.0 and 15.0 °C.
Wang et al., 2020	China	Temperate	S	MV	School	1	30	1	Learning performance was more efficiently when the TSV was "slightly warm".

Table 1. *Cont.*

Author, Year	Region	Climate	Season	Ventilation Type	Building Type	Class Rooms (n)	Students (n)	Monitored Days (n)	Outcomes
Chen et al., 2019	Taiwan	Temperate	S	NV	School	400	-	-	Building design parameter such window opening rate, ventilation rate, orientation, and external shading depth affected students' TC.
Bluyssen et al., 2018	Netherlands	Temperate	Spring	MV	School	54	1311	15	Physical building characteristics (e.g., location of school building, heating system, windows, and ventilation) can affect student TC.
Jiang et al., 2018	China	Cold	W	MV	School	1	12	60	Thermal discomfort caused by high or low temperatures had a negative impact on pupil learning performance.
Barrett, 2015	UK	Temperate	All seasons	M-M	School	153	3766	-	Individuality had an impact on students' thermal perception.
Gao et al., 2014	Denmark	Temperate	All seasons	MV	School	4	81	60	Perceptions of the indoor environment were more positive in the classroom that was ventilated by automatically operable windows with an exhaust fan in operation.
Turunen et al., 2014	Finland	Continental	S–S	MV	School	297	4248	-	Most frequently reported IEQ factors causing daily inconvenience in classrooms were noise and stuffy air or poor IAQ.
Wargocki and wyon, 2013	Denmark	Temperate	S	MV	School	10	380	7	The thermal and air quality conditions were below the recommended standards.
Puteh et al., 2012	Malaysia	Tropical	-	NV	School	-	-	-	Students have high level of awareness regarding the climate change.
Lee et al., 2012	Hong Kong	-	-	MV	School	4	340	90	TC, IAQ, and visual environment were the most reported aspects that can affect students learning performance.

Note: M refers to mechanical ventilation, M-M refers to mixed mode ventilation system, NV refers to natural ventilation, S refers to summer and W refers to winter, TC indicates thermal comfort, IAQ refers to indoor air quality.

Most research was concentrated in developed countries, such as Denmark [54], the Netherlands [52], Hong Kong [55], Italy [44,46,49], China [20,45,50,51,56], and the United Kingdom [57]. However, only two studies were in a developing country, i.e., India [27,48], whereas no evidence was reported from the Middle East region. However, there is an urgent need to address the students' thermal comfort issues in educational buildings in this region, due to the extreme climate conditions and the high energy consumption for cooling [19]. Over the last ten years, the majority of investigations had a field study design, with few laboratory studies [56]. Students' thermal comfort was assessed using subjective and objective methods. The physical measures of thermal conditions were continuous with a period of time ranging between one day [49] and three months [45]. The cross-sectional research design with repeated measures also was applied [51]. The sample size of investigated classrooms was usually higher in schools compared to the universities and ranged between one to sixteen classrooms. This could be referred to as the variation in learning strategies between schools and universities. The conducted studies covered buildings with three types of ventilation systems: mechanical [55,56,58–60], free-running [35,38,45,54], and mixed-mode ventilation systems [36,39,51].

Due to the complexity of assessing students' learning performance, it was noticeable that studies with a large sample size (n > 500) followed the subjective assessment approach by assessing students' attention [45,56,61], perception [56], impression [45], perceived health [14], comfort [60], adaptability [62], satisfactory level [27], self-reported learning performance [55], and the overall academic progress [57]. Conversely, students learning performance was assessed objectively in research with smaller sample sizes and included evaluation of students' test scores [45], productivity [47], the speed in task performance, and percentage of error [54]. However, the objective approach was more achievable in schools than in universities. Little research had combined the qualitative and quantitative approaches for evaluating students' learning performance [45,61].

On the basis of the findings of previous research, international standards, i.e., ASHRAE55, was found to overestimate students' thermal sensation in air-conditioned classrooms in winter. A field study conducted by Jiang et al. (2019) [45] reported an intensive use of energy for heating during the heating season in China, and students' comfort temperature ranged between 13.0 ± 1.01 °C and 15.0 ± 0.85 °C, which is comparatively lower than the recommended by the standards.

Several studies attempted to identify the most possible factors that may affect students' thermal comfort and hence learning performance. The building's physical characteristics were found to have a significant impact on the perceived thermal comfort. Bluyssen et al. (2018) showed that the location and orientation of the classroom can influence students' thermal comfort [14]. Similarly, Chen et al. (2019) found that ventilation systems and shading elements have a direct influence on students' thermal perception [49]. Other physical characteristics of classrooms were also found to have an impact on students' thermal comfort, such as openings' orientation and size [60], floor material [14,63], area and height of the classroom [49], and control over indoor temperature [64]. Students' thermal perception was affected also by physiological factors, including individuality [47,57] and gender [44,49,65]. Nico et al. (2015) reported more acceptability for warm thermal conditions among female students compared to male students [44]. Further, a certain scholar found that cultural background played a role in students' thermal perception, particularly in free-running educational buildings [48].

Overall, on the basis of the above literature studies, there were few amounts of research that investigated the students' thermal comfort in different learning environments. In addition, a lack of representative studies from the Middle East was clear, with recent evidence suggesting that there is excessive use of mechanical heating systems in educational buildings during winter, which may compromise students' thermal comfort and hence learning performance.

1.2. Research Objectives

In order to investigate the differences in students' thermal comfort and perceived learning performance between design studios and ordinary lecture rooms, we applied a holistic evaluation of multiple variables including the physical, psychological, and physiological aspects [21]. Data were collected from three main sources: (i) the building itself (physical measures), (ii) students (surveying), and (iii) the research team (observations), and this is the main innovation of this paper. The main objectives and applied research methods are illustrated in Table 2.

Table 2. Research objectives and applied research methods.

	Research Objective	Research method
1.	To assess and compare the indoor thermal conditions between the two types of university halls (i.e., DS and LR). Moreover, to investigate if the indoor thermal conditions in the two types of university halls comply with the recommended range by ASHRAE 55-2017 standard during the heating season.	Continuous on-site measurements of indoor thermal condition (i.e., T_a, T_r, RH, and V_a) for three months during winter + cross-sectional measures
2.	To compare students' thermal sensation vote (TSV), thermal preference vote (TPV), and predictive mean vote (PMV).	Surveying the same students within the two types of spaces using the ASHRAE 55 tool.
3.	To investigate thermal adaptation strategies adopted by students in their university halls.	Surveying students + focus groups + qualitative observations
4.	To assess and compare perceived learning performance between the two types of university halls (i.e., DS and LR).	Surveying the same students within the two types of university halls using the self-reported learning performance tool.

2. Materials and Methods

This study followed the within subjects' research design [66], as the surveyed students were the same within the two types of university halls (i.e., DS and LR). We distributed the survey in the selected university halls, and each student's survey was given a code (i.e., the first initials and birth date). This allows for the tracking of the same student in the two types of surveyed spaces. Thus, we controlled the effect of confounding variables (e.g., gender, age, studying year level, culture, nationality) [7]. Conversely, other variables that could not be controlled such as the students' mood toward the taught subject may have had a subtle impact on perceived learning performance.

In terms of assessing students' thermal comfort, the classroom–comfort–data method (CCDM) was used to assess students' thermal comfort [22]. The CCDM was developed in 2019 to complement the adaptive model in the ASHRAE 55-2017 standard by covering additional aspects (i.e., physiological and psychological) to expand and standardise the collection of information [22]. The CCDM was used in this study for its suitability and validity for gathering comprehensive thermal comfort data, particularly in field studies in educational buildings [21,22]. The data were collected between November 2021 and January 2022 to cover the coldest months in Jordan. The CCDM compromised three stages as follows (Figure 1):

i. The planning stage included preparation for the fieldwork activities such as building selection, sample size calculations, site visits, coordination with buildings' management and academic staff, design questionnaires, calibrating, and testing equipment.
ii. The data collection stage was developed to collect on-site records from three main sources: (i) the building (i.e., physical measurements); (ii) the students (i.e., thermal perception, perceived learning performance, physiological and psychological data); (iii) the research team or data collector, since they play a vital role during fieldwork by systematically inspecting on-site parameters related to the design of a surveyed building or students' behaviour.

iii. The data analysis and presentation stage phase involved data filtering, refining, and analysing. This stage allowed for identifying trends, patterns, and any potential inaccuracy in the collected data.

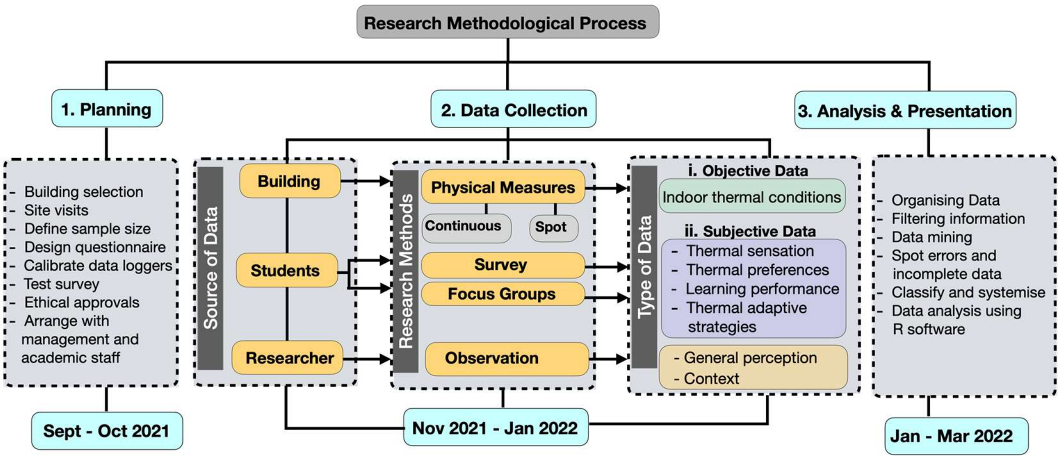

Figure 1. The research methodological framework and timeline.

2.1. University Halls Selection

To achieve the objectives outlined in Section 1.2, the study was conducted in a university building (i.e., Architecture and Design College) located in west-central Jordan (Figure 2a). The building was selected due to its suitability for this research since it consists of the two investigated types of university halls (i.e., architecture design studios and ordinary lecture rooms). It has a floor area of 1015 m^2 with seven stories. It was built and occupied in 2005. The building comprises 28 university halls and 7 computer laboratories. After multiple site visits, 15 university halls (i.e., representing 54% of the total number of university halls in the surveyed building) were selected within different vertical positions in the building (i.e., fourth floor, fifth floor, sixth floor, and seventh floor), aiming to ensure a good representation of the comfort conditions within the whole building.

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

Figure 2. (**a**) The surveyed university building in this study; (**b**) an example of the surveyed lecture rooms; and (**c**) an example of the surveyed architectural design studios.

The investigated halls have two different learning activity modes: (i) typical lecture rooms that have light learning activities with an average metabolic rate of 1.0 met and an average occupancy period ranging between 45 and 60 min/lecture (Figure 2b). (ii) Architectural design studios that are designed to assist architecture students in designing, research, and experimentation activities, with a higher average metabolic rate (1.4 met). Such design studios have a longer occupancy time compared to the typical lecture rooms, with an average of 3 h/lecture (Figure 2c), giving the chance to test any potential differences in students' thermal comfort between the two types of spaces.

The selected university halls were 80 m^2 on average with a 3.1 m height ceiling and a maximum occupancy rate of 22 students in design studios and 60 students in lecture rooms. All selected university halls were comparable in design characteristics and were distributed along corridors, almost sharing the same orientation (i.e., south), envelop materials, and design components. The only reported difference in the physical characteristics between surveyed halls was in the windows' glazing ratio since design studios have a larger average glazed ratio (62%) compared to the lecture rooms (33%) (see Table 3). There were no shading devices in all surveyed halls, except manually operated window blinds. All university halls have a mixed-mode ventilation system as each room is provided with five suspended electrical fans, which are used intensively during the cooling season from May to October. While the central heating system is turned on automatically between December and March. In April and November, the operable windows allow for natural ventilation. Students have control over the provided fans, while no control is available over the heating system. For anonymity and data sorting process, each university hall was given a unique ID, similarly for each surveyed student.

Table 3. The main characteristics of the investigated university halls in this study; ID refers to each surveyed university hall (N = 15).

Hall ID	Area (m^2)	Floor Level	Orientation	HVAC	Opening Area (m^2)	Glazing Ratio to Wall (%)	Max. Density (n)	Window Type	Window Numb. and Orientation	Open/Close Windows
DS1	86	4th	S	M.M	9.6	35.2	24	Sliding	2 S 2 W	√
DS2	84.5	4th	S	M.M	2.4	21.9	24	Sliding	2 S	√
DS3	61.4	4th	S	M.M	-	-	15	-	-	-
LR1	85.6	5th	S	M.M	9.6	35.2	63	Sliding	2 S 2 W	
DS4	84.1	5th	S	M.M	4.8	21.6	21	Sliding	2 S	√
DS5	84.5	5th	S	M.M	4.8	21.6	21	Sliding	2 S	√
DS6	66.2	5th	S	M.M	13.8	66.0	21	1 Hopper 4 Fixed	5 S	×
DS7	84.7	5th	S	M.M	9.6	35.2	26	Sliding	2 S 2 E	√
LR2	87	6th	S	M.M	9.6	34.0	63	Sliding	2 S 2 W	√
LR3	85	6th	S	M.M	4.8	21.0	63	Sliding	2 S	√
DS8	87	6th	S	M.M	4.8	20.7	24	Sliding	2 S	√
DS9	73	6th	S	M.M	15.1	64.3	22	1 Hopper 4 Fixed	5 S	×
DS10	69	6th	S	M.M	15	67.6	23	1 Hopper 4 Fixed	5 S	×
DS11	84.7	7th	S	M.M	4.8	21.9	24	2 Sliding	2 S	√
DS12	70.2	7th	S	M.M	14.7	67.6	20	3 Hopper 2 Fixed	5 S	×

Note: M.M refers to a mixed-mode ventilation system, DS refers to an architecture design studio, LR refers to a typical lecture room, S refers to the south, W refers to the west.

During the planning phase (September–October 2021), the research team conducted four meetings with the university administrative staff, and a full description and justification of the research was provided. The consent of the university representatives was given to conduct both the subjective and objective measures in the selected university halls. In addition, ethical approvals using the university protocols were gained. All related and supporting materials for our study were gathered during this stage, including the building's construction and architectural drawings, as well as the university functioning information (i.e., lecture schedules, university halls' use, students' learning activities, university hall capacity, and the number of students in each hall). Such information contributes to providing a comprehensive picture of the surveyed spaces.

2.2. Data Collection

The data were collected in the surveyed university halls between November 2021 and January 2022—these months represent the coldest months in Jordan. Table 4 illustrates the objective and subjective variables that were investigated in this study that contributed to more comprehensive data about students' thermal comfort and perceived learning performance (see Figure 1).

Table 4. The objective and subjective variables were investigated in this study to assess students' thermal comfort and perceived learning performance in the surveyed university halls ($N_{university\ halls}$ =15, $n_{students}$ = 173); * data were obtained from the Jordanian meteorological station.

Data Type	Aspect	Investigated Variable	Unit	Measuring Tool
A. Objective data	1. Indoor thermal conditions	Indoor air temperature (Ta)	(°C)	Temperature sensor Range: −29.0 to 70.0 °C Accuracy: 0.5 °C Resolution: 0.1 °C Time interval: 5 s
		Indoor relative humidity (RH)	%	RH sensor Range: 10 to 90% 25°C noncondensing Accuracy: 2% RH Resolution: 0.1% RH Time interval: 5 s
		Globe temperature (Tg)	(°C)	Black globe thermometer Ø 150 mm Range: −29.0 to 60.0 °C Accuracy: 1.4 °C Resolution: 0.1 °C Time interval: 5 s
		Mean radiant temperature (Tr)	(°C)	Temperature sensor Range: −29.0 to 70.0 °C Accuracy: 0.5 °C Resolution: 0.1 °C Time interval: 5 s
		Indoor air speed (Va)	ms^{-1}	1 inch|25 mm diameter impeller Range: 0.6 to 40.0 m/s Accuracy: larger of 3% of reading, least significant digit or 20 ft/min Resolution: 0.1 m/s Time interval: 5 s
	2. Outdoor thermal conditions	Outdoor air temperature (Tout) Outdoor RH (RHout)	(°C) %	General data collection *
B. Subjective data	3. Students' physiological factors	Metabolic rate	met	ASHRAE55-2017 and ISO 8996
		Clothing insulation Gender Age Nationality Education level Height Weight	clo (F, M) (Year) Jordanian, non-Jordanian BSC, MA M kg	ASHRAE55-2017 and ISO 9920
	4. Students' psychological factors	Students' thermal adaptation strategies	Environmental Behavioural Withdrawal from classroom	Survey + observation logbook

Table 4. *Cont.*

Data Type	Aspect	Investigated Variable	Unit	Measuring Tool
	5. Students' thermal comfort	Thermal sensation vote (TSV)	[−3, +3] 7-point scale	ASHRAE55 survey
		Thermal preference vote (TPV)	[−3, +3] 7-point scale	
		Predictive mean vote (PMV)	[−0.05, +0.5]	
	6. Students' perceived learning performance	Self-appraisal	5-point scale	Survey + focus group
	7. Architectural design	Building envelope materials, HVAC systems, windows ratio, control over temperature, type of windows, and building orientation		Observation logbook

2.2.1. Physical Measurements

In all selected university halls, we conducted two types of physical measurements for T_a, T_r, RH, and V_a: (i) Continuous measures for a total period of 75 days between November 2021 and January 2022. (ii) Cross-sectional measures, which were coincident with the time of each survey to capture students' thermal comfort and calculate the predictive mean vote. Measurements were conducted during the lecture time between 9:00 a.m. to 17:00 p.m. The Kestrel Meter 5400 heat stress tracker instrument was used to monitor all parameters [67] (Figure 3a), which is compliant with ISO 7726 [68] and ISO 7730 [33] standards. The equipment's details, range, and accuracy are illustrated in Table 4. The sample period was five seconds. In spot measures, the instrument was located close to the student's desk [69], and far away from any heat sources or radiation (e.g., computers, projectors, radiant heaters, and direct sunlight) (Figure 3b). Measurements were taken at a height of 1.1 m for standing students and 0.6 m for seated students in accordance with ISO 7726 [68]. For the continuous measurements, we selected a representative sample of locations [32] and we attempted also to cover the most extreme values of the thermal conditions (i.e., the occupied area close to a large glazed facade, corners, and the occupied area close to mechanical fans). In the case of exterior walls, the instruments were positioned 1.0 m inward from the centre of the largest window [32]. Figure 4 shows the location of equipment in the two types of university halls and the specific layout of the surveyed DS and LR.

Further, the local discomfort sources were investigated and the overheating from wide-glazed windows was observed as a source of local discomfort that could affect students' thermal comfort. All surveyed male students wore normal western clothes, and a good proportion (32%) of female students wore head ware (Figure 3c), which increased thermal insulation value by 0.03 clo [70]. The clothing thermal insulation level (clo) was calculated on the basis of ASHRAE 55-2017 and ISO 9920 [71]. The mean clo value was 0.91 ± 0.21 clo. The students' learning activities ranged between 1.00 met (i.e., sitting with passive work) in lecture rooms (Figure 3d) and 1.4 met (i.e., standing working) in design studios (Figure 3c). The metabolic rates of students were calculated on the basis of the standard tables provided by ASHRAE 55-2017 and ISO 8996 [30].

As the outdoor thermal conditions can influence the indoor thermal environment of the surveyed spaces, the outdoor temperature (T_{out}) and outdoor relative humidity (RH_{out}) during the field measurements period were obtained from a nearby weather station (i.e., Jordan meteorological department) [72]. Table 5 shows that the average daily mean of T_{out} ranged between 8.5 °C and 15 °C during the monitored period. The maximum temperature was 20 °C and reported in November, while the minimum T_{out} was reported in January (4 °C). The highest RH_{out} was recorded as 73% in January 2022, while the lowest was 49% in November 2021. Further, the heating degree days value (HDD) was calculated to be 873, while cooling degree days (CDD) were 0 since our study was conducted during the winter. The highest number of sunshine hours was reported in November 2021 (220 h), while the lowest (192 h) was in January 2022. The daily average solar radiation ranged between 4.5 and 5.6 kWh/m², which is considerably high compared to other regions in different parts of the world.

Figure 3. (**a**) The Kestrel Meter 5400 instrument; (**b**) the data logger positioned close to the students' desks; (**c**) students standing activities in architecture design studios; (**d**) students sitting with passive learning activities in the typical lecture room; (**e**) an example of focus group discussion done during the data collection stage.

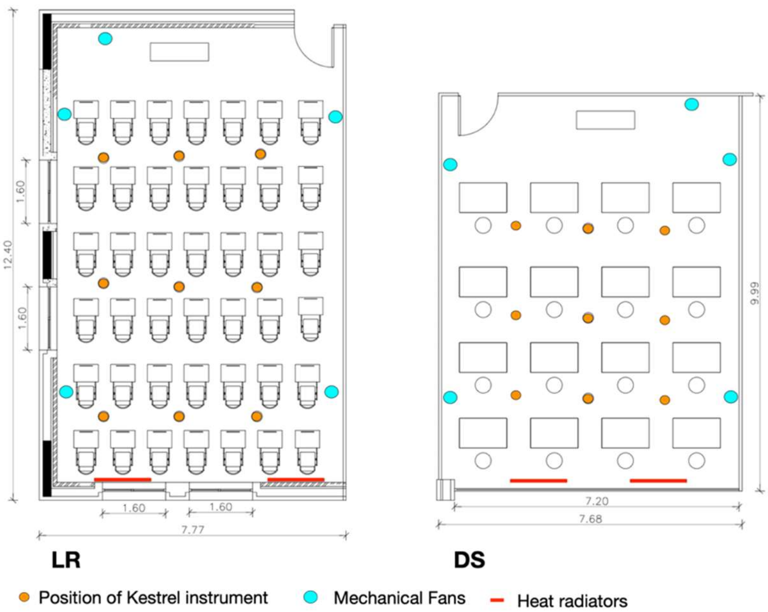

Figure 4. The layout of the two types of surveyed university halls: lecture rooms (LR) and design studios (DS).

Table 5. The daily mean outdoor temperature (T_{out}) and relative humidity (RH_{out}) recorded during the study periods between November 2021 and January 2022; annual heating degree days (HDD) and annual cooling degree days (CDD) were calculated using a base temperature (<18 °C and >18 °C, respectively).

Variable		**Month**		
		Nov	**Dec**	**Jan**
T_{out} (°C)	Max.	20.0	15.0	13.0
	Min.	10.0	6.00	4.00
	Mean	15.0	10.5	8.50
RH_{out} (%)	Max.	61	70	73.0
	Min.	49	60	65.0
	Mean	56	67	69.0
CDDs		0.0	0.0	0.0
HDDs		50	121	702
Sunshine hours (h)		220	190	192
Solar radiation (KWh/m^2)		5.60	4.90	4.50

2.2.2. Survey, Focus Groups, and Observations

During the planning stage, an estimation of the sufficient sample size was performed using the G*Power software [73]. The paired sample *t*-test was considered, assuming a moderate effect size of $d = 0.5$ and power of $\beta = 0.95$. The estimated sample size was 165 subjects. In this study, the survey was distributed to a convenience sample of 225 students, which resulted in 173 completed surveys being returned, thus representing a response rate of 77% and achieving the required sample size. This sample size is comparable to others used in previous thermal comfort studies in university buildings in different regions (see Table 1). The surveyed students' age ranged from 18 years to 26 years, and the mean age was 22 years ($\sigma = 0.01$). The sample comprised 81% of Jordanian students and 19% of non-Jordanian students. Female students' proportion (51%) was almost comparable to male students (49%) to reduce the effect of gender on the results. A full profile description of the participating sample is presented in Table 6.

Table 6. Comprehensive profile of surveyed students in this study; F refers to female students, M refers to male students, $n_{students} = 173$.

Gender		**Education Level**		**Nationality**		**Age (y)**	**Clo**	**Met**	**Height**	**Weight**
F	M	Bachelor	Master	Jordanian	Non-Jordanian	M ± SD	M ± SD	M ± SD	M ± SD	M ± SD
51%	49%	94%	6%	81%	19%	22 ± 0.01	0.91 ± 0.21	1.24 ± 0.27	169.3 ± 3.9	69.7 ± 4.6

The subjective data were gathered via a survey administered to full-time students only in order to obtain the same frame of reference and be in the same educational conditions [74].

The survey aimed to collect information about students' thermal perception, thermal adaptive strategies, and perceived learning performance. The questionnaire included 13 items with multiple questions that required a 5 min response time. It was originally designed in English and later translated into Arabic, which was the first language for most of the surveyed students. The Levantine Arabic dialect was provided particularly for TSV and TPV questions, targeting precise responses [7,18,75]. However, both versions of the questionnaire were combined with a consent form and distributed randomly by the research team. The paper-based questionnaire was provided with a QR code that was linked to a web version of the questionnaire to enhance the response rate [76]. The questionnaire had four main sections as follows (see Appendix A):

- The first section included five questions to collect information on students' physiological aspects (e.g., age, gender, height, weight, and nationality).
- The second section included four questions focused on students' thermal sensation votes (TSV), thermal preference votes (TPV), and clothes and physical activities adopted from ASHRAE 55-2017 [32].
- The third section evaluated students' perceived learning performance during lecture time using self-reported learning performance. It also evaluated the impact of indoor temperature on learning performance. In our study, the survey was used to assess perceived learning performance, since the use of objective tools such as students' test scores, speed in task performance, and percentage of error was challenging in our study, due to the university guides and restrictions.
- The fourth section aimed to collect data about students' thermal adaptive strategies.

Further, four focus group meetings were conducted with students between November 2021 and January 2022 in the surveyed university halls. Focus groups aimed to provide a dynamic interaction between students and the research team [77,78]. It also expanded the generated data through the questionnaires and provided powerful insights into students' perceptions and preferences [22]. Each focus group consists of five to eight students (Figure 3e), and the activities' duration averaged between 30 and 40 min, including 5 min introduction to the research. All meetings were recorded after gaining the student's consent, and later the recordings were transcribed and analysed [77]. To gain a holistic picture of students' thermal adaptation behaviour in their university halls and collect in-depth information [77], the research team recorded observations in the logbooks during the survey time.

2.3. Data Analysis Methods

The completeness of the dataset was examined and a few missing data points (i.e., 7) were detected; however, no systematic patterns of missing data were observed. The linear interpolation was used to estimate missing data points [79]. The normality of variables was inspected using the Shapiro–Wilk test and visual inspection of histograms. It was found that the p-value of the Shapiro–Wilk test was 0.09, and hence we assumed a normal distribution [80]. The significance level was set at 5%, and the characteristics of the sample were summarised using means (μ) and standard deviations (SD). The collected data were grouped into two categories according to the surveyed space (i.e., DS and LR). The data were analysed as follows:

- For continuous interval data, i.e., Ta (°C); Tr (°C); Va (ms^{-1}); and ratio scale data, i.e., RH (%), the independent sample t-test was used to test the difference in mean scores. In addition, the objective measures from surveyed university halls were compared to the recommended ranges of thermal conditions in the ASHRAE 55-2017 standard. Confidence intervals are reported together with the differences between groups. The effect size is reported using Cohen's well-known d metric, calculated using [81]:

$$d = (\mu a - \mu b)/s \quad (1)$$

  where μa represents the sample mean in one group, μb is the mean of the other group, and s is the pooled variance of the samples.

- For the ordinal variables, i.e., TSV, TPV, and perceived learning performance, the Wilcoxon rank sum test (i.e., Mann–Whitney test) was used, due to its applicability with the ordinal data [82]. Further, the power analysis was performed by calculating the effect size index, and Spearman rank correlation (Rho) was used to investigate the correlation between categorical variables [83].
- In comparing thermal comfort data, TSV was evaluated as "comfortable" within [−1 and +1] [32], whereas PMV was evaluated between [−0.5 and +0.5] [33], as is common in studies of this kind [84].
- The statistical analysis for our study was carried out using R software [85], including several packages, such as "interp" [79], "tidyverse" family [86], "comf" [87], and "cowplot" [88].

3. Results

This section presents the results of the data analysis. It first shows the results of physical measurements of thermal conditions in the surveyed university halls, and after it presents the results of students' thermal comfort, thermal adaptive strategies, and perceived learning performance.

3.1. Comparison of Thermal Conditions between DS and LR

Figure 5 shows the results of the continuous measurements of T_a, T_r, and RH between November 2021 and January 2022 classified on the basis of the monitored space type, i.e., design studios or ordinary lecture rooms. The mean indoor temperature varied over the monitored months. The maximum mean of T_a was reported in November (μ = 26.5 °C, SD = 2.4 °C), while the minimum was in January (μ = 21.9 °C, SD = 2.3 °C), with a difference of 4.6 °C. The continuous measures in all surveyed university halls show that T_a ranged between 29.4 °C and 16.9 °C, comparing this to the recommended range determined by ASHRAE 55-2017 standard for indoor temperature during the heating season [32]. The indoor Ta should range between 19.4 °C and 27.7 °C, and hence the indoor Ta in university halls failed the accepted range. Interestingly, there was a statistically significant difference in the monitored T_a (t (12,144) = −11.67, p = 0.01, d = 0.61) and T_r [t (11,345) = −13.89, p = 0.001, d = 0.55) between the design studios and lecture rooms over the monitored period (see Table 7). Surprisingly, the design studios showed higher mean scores of indoor T_a compared to the lecture rooms, with a difference of 5.3 °C, 2.9 °C, and 2.3 °C in November, December, and January, respectively.

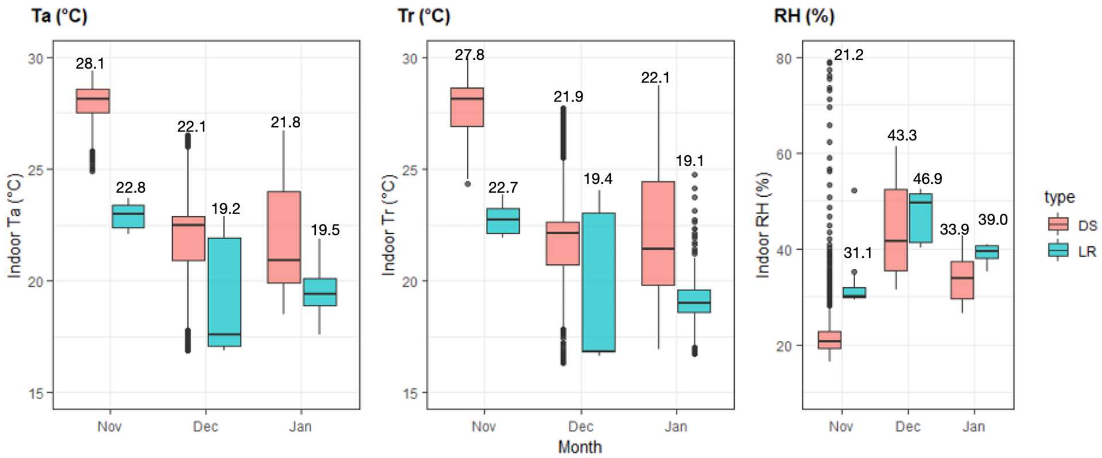

Figure 5. The monitored thermal conditions (i.e., Ta, Tr, RH) in the surveyed lecturer rooms between November 2021 and January 2022. Data were grouped on the basis of the university hall type; DS refers to the architecture design studio, LR refers to lecture rooms, whiskers indicate the minimum and maximum readings, black dots indicate the outliers, a bold black line indicate the median score, and the value beside each box-plot represents the mean score.

Table 7. Statistical analysis results (t-test) of the obtained continuous data in the architecture design studios (DS) and ordinary lecture rooms (LR) between November 2021 and January 2022, n = 13,145.

Variable	DS (μ ± SD)	LR (μ ± SD)	Δμ DS-LR	CI 99%		t	p-Value	Effect Size (d)	
Ta (○C)	25.5 ± 1.43	22.4 ± 1.01	3.10	0.12	1.20	−11.67	0.01 *	0.61	Large
Tr (○C)	25.3 ± 1.22	22.3 ± 1.1	3.01	0.85	0.96	−13.89	0.00 **	0.55	Medium
RH (%)	29.4 ± 11.7	32.5 ± 4.6	- 3.10	56.33	81.13	−10.88	0.00 **	0.41	Small

Note: * $p < 0.05$, ** $p < 0.001$.

Turning to the indoor RH, Figure 5 shows that the mean scores of RH in lecture rooms were higher compared to the design studios all over the monitored period. The Welch's unequal variances *t*-test suggests that there is a statistically significant difference in means of RH between design studios (μ = 29.4%, SD = 11.7%) and lecture rooms (μ = 32.5%, SD = 4.6%), with a small effect size (t (12,678) = −10.88, p-value < 10^{-3}; Δμ DS-LR = −3.1%; 95% CI [56.33, 81.13]; d = 0.41) (Table 7). The maximum RH was reported in November (82.4%) in design studios, therefore failing the recommended maximum value of RH identified by ASHRAE-55 of 80%.

Further, as our sample consisted of 13,145 readings that were obtained from 15 different halls over three months, the mixed-effects model was used to examine the differences in mean scores of temperatures between design studios and lecture rooms. The dependent variable was identified to be the indoor T_a, and the space type and month were identified as predictors. Results from the mixed-effects model show that the two significant predictors were found to be space type [Δμ = −3.1, 95% CI = −0.96 to −0.21], since the mean indoor temperatures were 3.1 °C lower in lecture rooms than in design studios. The month [Δμ = 4.6, 95% CI = −0.25 to 0.45] was also a significant predictor since the mean indoor T_a in November was 26.5 °C, higher than in December (21.9 °C) and January (21.5 °C). In addition, the analysis of the random effect shows that not all surveyed halls were the same, and slight differences in T_a and RH between all the individual surveyed halls were observed (see Figure 6). The reported indoor V_a was below 0.02 ms^{-1} in all surveyed halls, which complied with the recommended value in ASHRAE-55, 2017 [32].

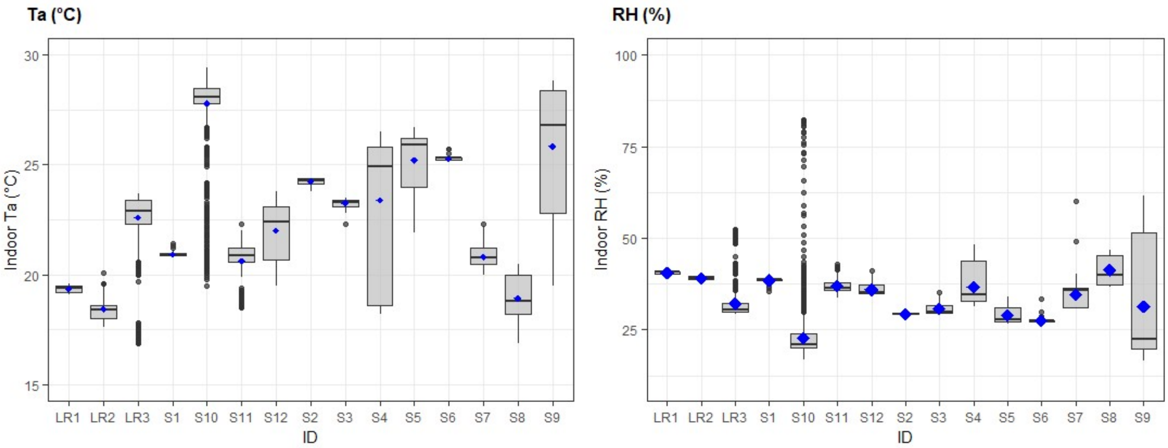

Figure 6. Box plots showing the difference values between the monitored Ta and RH among all surveyed spaces (each space has a unique ID; see Table 3). Whiskers indicate the minimum and maximum scores, black dots indicate outliers, blue square indicates mean score for each university hall; $N_{\text{surveyed halls}}$ = 15.

3.2. Comparison of Students' TSV, TPV, and PMV between DS and LR

Table 8 shows the overall distribution of the observed students' TSV and TPV, and it also shows the calculated PMV based on the spot measures for the six thermal comfort indicators (i.e., T_a, T_r, RH, V_a, met, clo) in both types of university halls (DS and LR). The PMV predicts that only 30.6% of votes fall within the ISO 7730 recommended range of [−0.5, 0.5] [33]. PMV predicts 78.6% of the overall votes on the warm side, contrary to the observed TSV. Figure 7a shows the distribution of students' thermal sensation votes. For the whole dataset, only 58% of students' TSV were within the ASHRAE 55-2107 recommended comfort zone between [−1 and +1] [32], hence failing the 80% ASHRAE 55 acceptability threshold. Surprisingly, 47% of the TSVs were on the warm side [+1, +3], while 26.5% of students felt cold [−1, −3].

Figure 7b shows the results of the distribution of students' TPV, and it can be seen that 36% of students preferred cooler indoor temperatures in their university halls than those provided, with only 25% of students preferring no change in their thermal environment; hence, the overall TPV did not meet the ASHRAE 55 recommendations.

Table 8. The distribution of students' votes that fell in the recommended comfort zone by ASHRAE 55-2017 standard for TSV and TPV and ISO 7730 standard for PMV; n_{DS} = 93, n_{LR} = 80.

Variable	TSV	TPV	PMV
(μ ± SD)	0.52 ± 1.56	−0.41 ± 0.01	0.81 ± 0.49
Recommended range	[−1, 1]	[−1, 1]	[−0.5, +0.5]
DS	56.8%	61.7%	25.1%
LR	64.7%	65.4%	52.9%
Overall	58.3%	64.7%	30.6%

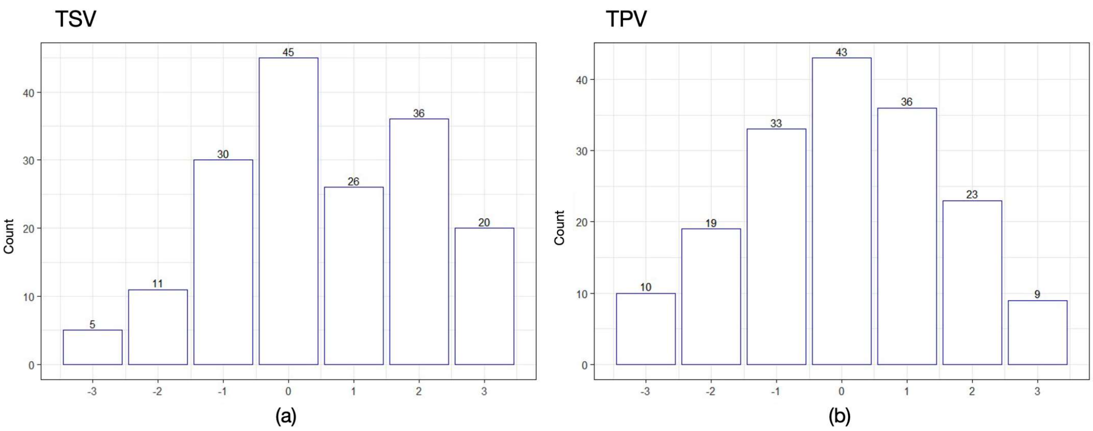

Figure 7. (**a**) The overall distribution of the thermal sensation votes (TSV) as reported by students and (**b**) the overall thermal preference votes (TPV) in the surveyed lecturer halls. The survey data are ordinal and are hence presented within [−3, +3]; the number above each column represents the count of votes; $n_{students}$ = 173, $N_{lecturer\ halls}$ = 15.

Figure 8 compares the results of TSV and PMV between the two types of surveyed university halls (i.e., DS and LR). The percentage of students who felt comfortable was higher in lecture rooms (64.7%), compared to the students in the design studios (56.8%). There was a variation in students' thermal sensations between the two types of surveyed spaces. For example, 53% of students in DSs felt warm, contrary to 58.8% of students in LRs who had a cold sensation. There was a statistically significant difference with medium effect size between mean scores of TSV between DS (μ = 0.78, SD = 1.56) and LR (μ = −0.54, SD = 1.33), (p-value < 10^{-3}; 95% CI [56.33, 81.13]; r = 0.51) (Table 9) and (Figure 8a). For PMV, there was no significant difference reported between the two types of surveyed spaces (Figure 8b).

Table 9. The results of the Mann–Whitney test. Mean and standard deviation values for DS and LR, difference, significance, and effect size.

		DS	LR				
Variable	**Reference Figure**	**(μ ± SD)**	**(μ ± SD)**	**Δμ DS-LR**	***p*-Value**	**Effect Size**	**(Spearman Rho)**
TSV	Figure 8a	0.78 ± 1.56	−0.54 ± 1.33	1.32	0.00 ***	0.51	(Medium)
TPV	Figure 7b	−0.81 ± 0.71	0.92 ± 1.01	−1.72	0.01 **	0.45	(Small)
PMV	Figure 8b	0.86 ± 0.46	0.61 ± 0.57	0.25	0.06 n.s.	0.06	(Negligible)
Perceived LP	Figure 10a	0.31 ± 0.01	0.67 ± 0.12	−0.36	0.01 **	0.62	(Medium)

Note: *** $p < 0.001$; ** $p < 0.01$; n.s. not significant.

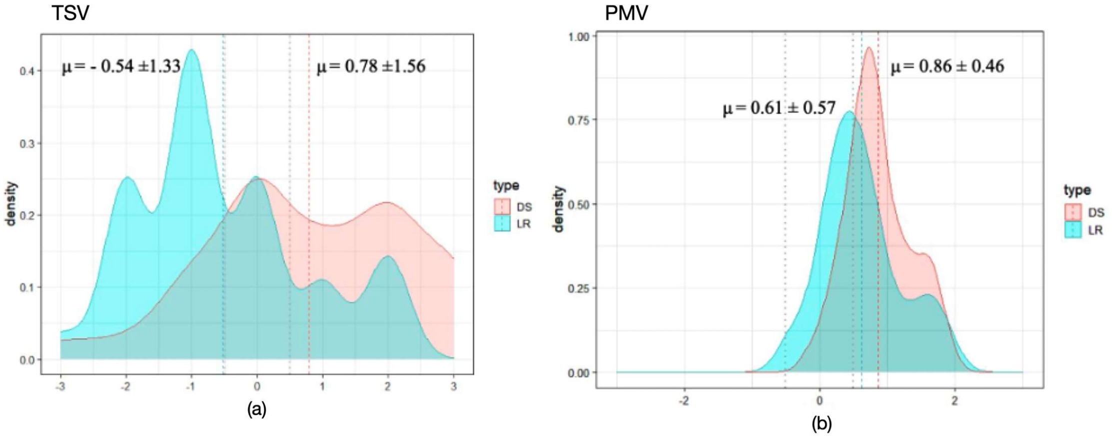

Figure 8. (**a**) Comparison of the observed TSV in design studios (DS) and lecture rooms (LR), and (**b**) the predictive mean vote (PMV) as predicted by Fanger's model ISO 7730 (2005). PMV data were calculated using spot measurements. The coloured dashed lines represent the mean score of variables, and the dotted grey line represents the recommended range by ISO 7730 [−0.5, +0.5]; $n_{students}$ = 173.

3.3. Students' Thermal Adaptive Strategies

To understand how students behave to increase their thermal comfort levels in their university halls, we investigated the thermal adaptive practices adopted by students during lecture time. Figure 9a shows the thermal practices that were classified into three groups: (i) environmental modifications to space (e.g., opening/closing windows, turning on/off fans or heater usage), (ii) behavioural adaptations (e.g., drinking cold/hot drinks, putting on/take off a piece of garment, changing position within the classroom), and (iii) withdrawal from space (e.g., leave lecture room). Results indicated that behavioural adaption was the most used practice among the surveyed students. For example, 70% of students heavily depended on removing or adding a piece of clothes to adjust their body temperature in their university halls.

In addition, 60% of the surveyed students reported that they were changing their location within the lecture room (i.e., sitting close to heat radiators or fans) to maintain their thermal comfort. This was more noticeable in design studios compared to lecture rooms, since the former has more flexible learning activities compared to the learning activities conducted in ordinary lecture rooms. Regarding the environmental modifications, opening/closing doors or windows was adopted by 34% of students, while leaving the lecture room had the lowest value of votes (8%), due to the classroom behavioural guides set by the university.

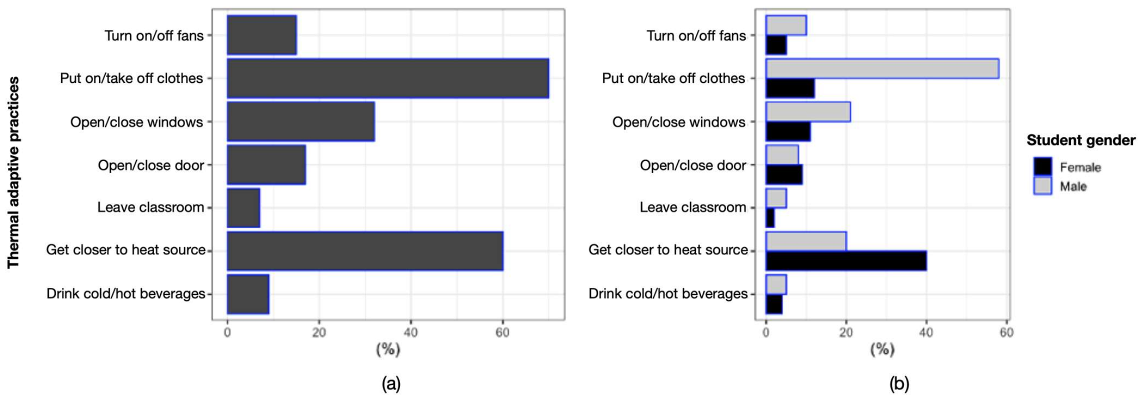

Figure 9. (**a**) The thermal adaptive strategies adopted by the surveyed students in their university halls to enhance their thermal comfort in their university halls as reported by students; $n_{students}$ = 173. (**b**) The thermal adaptive strategies followed by female and male students; the multiple choices were allowed per student, and hence columns do not add to 100%.

Further, we examined the variation between female and male students in terms of the adaptive strategies followed during lecture time. Figure 9b shows that the percentage of male students who adopted thermal adaptive strategies during lecture time was considerably higher compared to female students. The male students relied more on adjusting their clothing compared to female students, while the latter group preferred to get physically closer to heat radiators or fans to improve their thermal perception.

3.4. Comparison of Perceived Learning Performance between DS and LR

The perceived learning performance of students was evaluated using the self-reported learning performance questionnaire. Students' surveys were tracked over the two types of surveyed spaces. Figure 10a compares the overall mean score of the perceived learning performance of students grouped on the basis of the type of university hall. Interestingly, students in lecture rooms reported slightly higher mean scores of perceived learning performance (μ = 0.67, s = 0.01) compared to the students in design studios (μ = 0.31, s = 0.12). There was a statistically significant difference in the mean score of learning performance between design studios and lecture rooms (p-value < 10^{-4}; 95% CI [55.31, 71.42]; r = 0.62), with a moderate effect size (Table 9). However, the mean score of perceived learning performance of students in both types of surveyed spaces was close to the neutral midpoint (0), and hence they perceived themselves as broadly similar in design studios and lecture rooms.

Further, we asked students if the indoor temperature of the university hall could have an impact on their learning performance during lecture time. The results of students' responses are presented in Figure 10b. The indoor temperature was perceived as a factor that negatively affect the learning performance by 54% of surveyed students. Indoor temperature was perceived as reducing the learning performance for 49% of students in the surveyed halls. Surprisingly, 47% of those who were surveyed perceived their learning as low during the survey time. In addition, over half of the students (59%) agreed that the indoor temperature of their university halls needs to be improved.

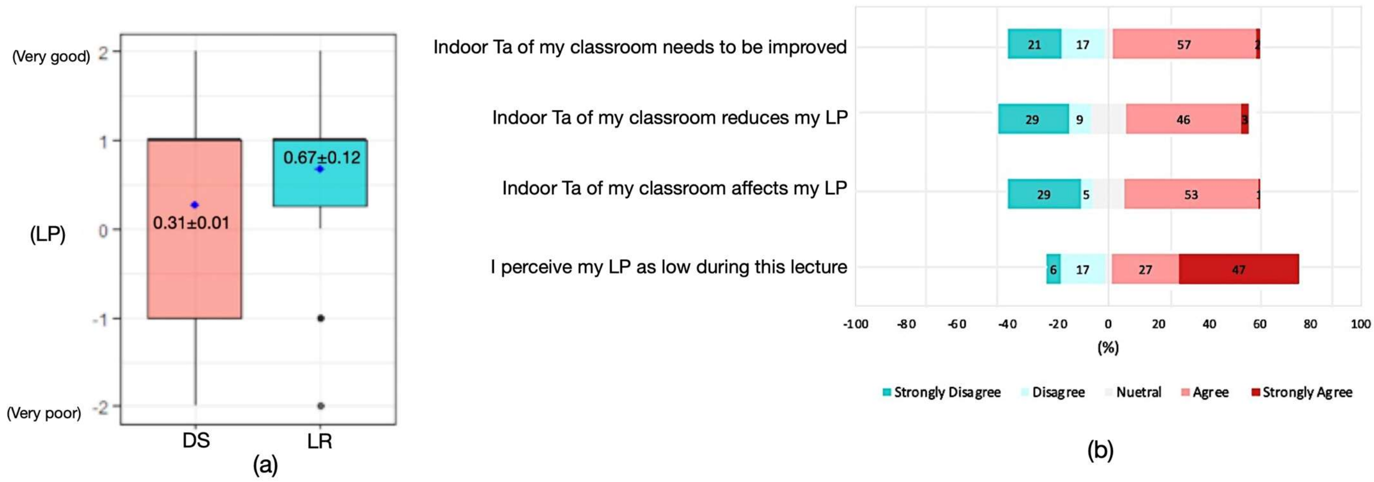

Figure 10. (**a**) Comparison of overall mean score of students' perceived learning performance between design studios (DS) and (LR); blue squares represent the mean scores. (**b**) The overall distribution of students' votes in terms of the impact of indoor Ta on a perceived learning performance level during lecture time; the scores span from strongly disagree (−2) to strongly agree (2), and (0) no opinion. To enable interpretation, the x-axis was mapped such that "0%" maps to "0" on the survey scale. Numbers on either side of "0%" can be used to judge the percentage of responses in each of the two categories below and above "0" on the survey scale.

4. Discussion

The findings were grouped and discussed into two themes: the objective findings obtained from the spot and continuous physical measures, and subjective findings that were gained from students through questionnaires, focus groups, and observations. Finally, we discussed the potential future developments of IEQ of classrooms.

4.1. The Physical Indoor Thermal Environment

On the basis of the evidence obtained from the physical measurements, both types of surveyed spaces, i.e., design studios and lecture rooms, did not meet the recommended range for indoor temperature and relative humidity determined by ASHRAE 55-2017 standard. Although both types of university halls were provided with the same heating system and located in the same direction (i.e., south) (see Table 3), there was an indicator of slight overheating in design studios (μ = 25.5, s = 3.2 °C) compared to lecture rooms (μ = 22.0 °C, s = 2.1 °C), with a difference of 3.5 °C overall in the monitored period. On the basis of the research team's observations, this variation in indoor temperature could be explained by three reasons. First, the physical characteristics of the university halls [60], since some of the surveyed design studios in this study have a south-facing fully glazed facade with an average area of 14.0 m^2 (see Figure 2c), with no provided sufficient shading devices. This may result in increasing the solar heat gain during the daytime [89], and hence the indoor temperature inside the design studios [63,90,91]. In contrast, the lecture rooms had smaller windows with an average area of 9.6 m^2 (Figure 2b), hence allowing for a smaller amount of heat gain.

Second, the students' activities varied between the two surveyed halls; for example, in design studios, students had higher learning activity levels (e.g., working standing, model making) with a high use of technology (i.e., personal laptops) compared to the passive learning activities conducted in lecture rooms (i.e., seating and listing to lectures), and a correlation between the indoor temperature and personal activity levels was suggested [20,91]. Third, according to the literature, students' respiration and heat dissipation may also increase the indoor air temperature in classrooms [53]. Since we observed more students in design studios compared to the lecture rooms during the survey time, this could also explain the slight difference in indoor temperature between the two types of surveyed spaces.

In addition to the physical measures, our focus groups provided some additional information. Students in design studios stated that they felt warmer in November compared to December and January; this was supported by our objective results obtained from the continuous measures of T_a (see Section 3.1). This can be referred to as the variation in the outdoor temperature since the mean of T_{out} in November was 15.0 °C compared to 10.5 °C in December and 8.5 °C in January. The impact of seasonal variations on students' perceived thermal comfort in mixed-mode buildings was observed in a similar study [40].

4.2. Thermal Sensation and Perceived Learning Performance of Students

The findings from physical measures were supported by the results of TSV and TPV obtained from the surveyed students. For example, in design studios, students had a higher warm thermal sensation than students did in lecture rooms, which indicated a possible overheating in such spaces. Interestingly, similar results were reported in a study conducted by the author in office buildings in Jordan during winter, as clear overheating in investigated buildings was reported, which indicated excessive energy use for the heating in buildings with mechanical heating systems [18]. In addition, our findings showed that only 58% of students' votes were within the ASHRAE 55-2017 recommended comfort zone, failing the 80% threshold suggested by the standard [32].

What is surprising is that we noticed that students in LR who had a higher percentage of cool thermal sensation (i.e., TSV ≤ -1) reported a higher mean score for the overall perceived learning performance (μ = 0.67, s = 0.01) (see Sections 3.2 and 3.4). Hence, we attempted to investigate any potential correlation between the observed thermal sensation and the perceived learning performance in both types of surveyed spaces. Surprisingly, we found a reverse linear relationship between the observed TSV and perceived learning performance ($p < 0.001$, $R^2 = -0.84 \pm 0.06$) in design studios and ($p < 0.001$, $R^2 = -0.87 \pm 0.11$) in lecture rooms (see Figure 11). Hence, it can be interpreted that students in this study perceived themselves as more productive in cooler environments during the heating season.

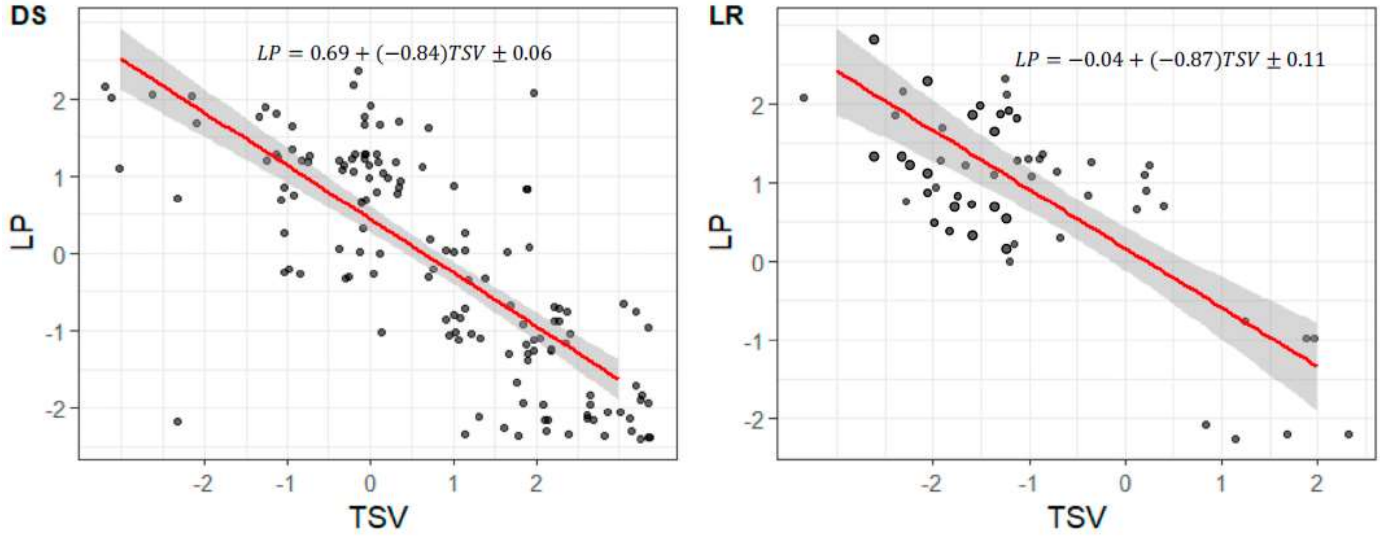

Figure 11. The suggested relationship between the observed thermal sensation votes (TSV) and perceived learning performance (LP) in design studios (DS) and lecture rooms (LR).

Such a finding was also reported in a similar study conducted in China [61], suggesting that the optimal learning performance of students was reported when students felt cool. However, their findings were obtained from school students that thermal comfort levels may differ from adults [23]. According to existing research, the influence of temperature on occupants' productivity has demonstrated that temperatures outside the comfort zone reduce occupants' performance. Scholars, such as Seppänen [92] and Wargocki [93], found that higher temperatures have a more negative impact on general productivity. However, although this research followed a within-subjects research design since each student was the same in the two surveyed spaces (i.e., DS and LR), hence minimising the effect of confounding variables (e.g., gender, culture, and nationality. etc.), other variables that could not be controlled such as the students' mood toward the taught subject may have had a subtle impact on perceived learning performance.

Regarding the followed thermal adaptive strategies by students, it was noticed that behavioural adaptive practices, such as clothing changing, taking cold/hot drinks, and fan usage, were the most adopted practices by students to enhance their thermal comfort. This finding was also reported by Kumar et al. (2018), who studied the different adaptive actions in a classroom in India and found that behavioural practices were the most commonly used by students to maintain their thermal comfort in free-running classrooms [94].

Students reported several factors that restricted their environmental adaptations. For example, in some design studios, the windows were sealed (see Table 3), and hence students did not have the option to open windows as a strategy to increase their thermal comfort when they felt warm. Students indicated also that during lecture time, opening the doors was not a proper option due to the high noise level coming from outside corridors where students stayed to wait for their lectures, especially during winter, when the outdoor cold temperature limits outdoor activities [21]. Moreover, students mentioned that in lecture rooms, hot or cold drink is prohibited, contrary to the situation in design studios, which have more flexible rules. Interestingly, female students had fewer options for adaptive strategies than male students (Figure 9b). For example, females generally have a lower chance of adjusting their clothes in public, which could be related to the local cultural and social restrictions [25]. However, students stated that none of the available thermal adaptive strategies was complete enough to achieve a satisfying thermal comfort status.

The discussion through focus groups revealed that students in design studios had higher perceived thermal comfort in the mooring lectures between 9:00 a.m. and 11:00 a.m.

compared to the afternoon, and this could be referred to as the high amount of gained solar radiation on the south facade between 12:00 p.m. and 15:00. A similar result was reported by Sun et al. (2022), who found that the time of lecture in university buildings affects the observed TSV of students [20].

4.3. Future Improvements of University Halls

In the last section of our survey, we asked students an open-ended question about what aspect of their indoor environment of university halls needs improvement. This question was designed to allow an insightful understanding of the actual improvement needs in such classrooms from users' perspectives. Surprisingly, 40% of students reported the heating system as an aspect that needs to be improved in their university halls (Figure 12). This was followed by windows' shading (17%) and cooling system (15%). It is important to bear in mind the possible bias in these responses since the obtained answers were during the heating season, which may influence students' priorities. Our findings reflect those of Lee et al. (2012) who also found that the thermal environment in university halls and school classrooms in Hong Kong was perceived by students as a major problem that needs to be improved [55]. Further, the ventilation systems, lighting, and furniture of university halls were also reported by students as aspects that need improvement.

Overall, our findings raise intriguing questions regarding how much the applied thermal comfort standards in educational buildings consider the variations in students' learning activity levels since it appears to be the case that there is no widespread awareness of the possible differences in the perceived thermal comfort between students in different types of classrooms. In addition, current thermal comfort standards widely use the neutrality point (i.e., neither cold nor hot) to assess people's thermal comfort [95], while neutrality in educational buildings could be affected by several factors including age, gender, cultural background, climatic region, and learning activity type. Further, our findings suggest that there is an excessive use of energy for heating in design studios, which may negatively affect students learning performance. Therefore, there is a need for more effective approaches to energy use to be utilised [96,97].

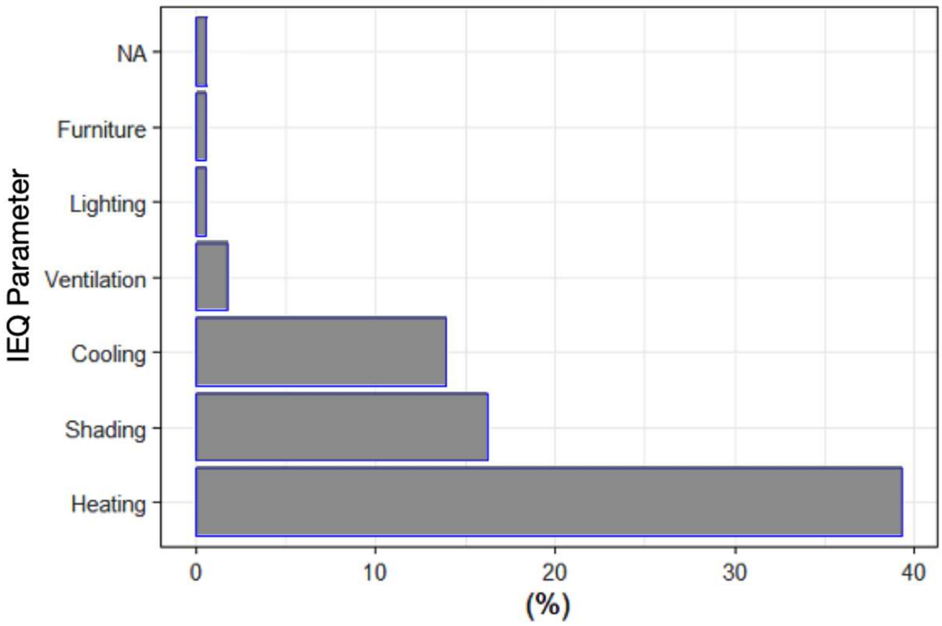

Figure 12. The indoor environment aspects in university halls that need to be improved from students' perceptions; $n_{students}$ = 173. Multiple choices were allowed per student, and hence columns do not add to 100%. NA represents nothing that needs to be changed or improved in terms of students' perceptions.

5. Conclusions

The exposure of students to unhealthy indoor environments can significantly affect students' thermal comfort and thus their health and learning performance. This paper attempted to advocate the crucial role of the thermal environment, on the basis of its significant impacts on students' thermal perception and perceived learning performance, by exploring the negative effects of poor thermal conditions. Providing a proper thermal environment is essential in educational buildings since students spend one-third of their day inside classrooms. Students' thermal comfort can be affected by several factors such as educational level, students' gender, physical characteristics of the classroom, and the type of learning activities carried out in classrooms. However, very limited research has examined the relationship between the students' thermal comfort and learning performance within different types of learning environments. Hence, this study was designed to compare university students' thermal comfort and perceived learning performance between two types of university halls, i.e., architecture design studios and ordinary lecture rooms in a university building in Jordan.

The thermal comfort data method was employed to collect objective data from 13 university halls and subjective data (e.g., students' thermal sensations, thermal preferences, thermal adaptive strategies, and perceived learning performance) from 173 students. The data were collected during winter over three months (November 2021–January 2022). The continuous physical measurements of thermal conditions showed that design studios had a higher mean indoor temperature score than the lecture rooms over the monitored period with a difference of 3.1 °C. More than half of surveyed students (53%) in DS had a warm thermal sensation, contrary to 58.8% of students in the LR who felt cool. It can thus be suggested that there was excessive heating use in the design studios. Only 58% of students' votes were in the recommended comfort zone by ASHRAE 55-2017 standard, hence failing the acceptable threshold of 80%.

Interestingly, students who had cooler thermal sensations reported a higher mean score of perceived learning performance ($\mu = 0.67 \pm 0.12$ on scale [-2, +2]). In terms of the thermal adaptive strategies, students heavily depended on behavioural adaptation strategies (e.g., adjusting clothes, drinking hot or cold beverages). There was a noticeable variation in thermal adaptive practices between male and female students due to cultural and social restrictions.

Overall, our findings indicated that the students' thermal comfort varied by the type of learning activity conducted in the classrooms. This paper highlights the need for a special thermal comfort guide for educational buildings adapted to the local environment and functions of the spaces, cooperatively. The thermal comfort in educational buildings is highly complicated, involving many actors, engaging with multiple contending forces, with highly intricate interactions between all these [98]. As a result, there is no single paramount paradigm around which to organise thought and action in this arena. Addressing such complexities requires a nuanced handling of educational buildings. It points to the need for the development of broadly based and coherent strategies and tactics for promoting health- and wellbeing-related outcomes, teased out in relation to the specifics of particular built environments [99]. Further research should investigate the proper approach for providing students with a comfortable thermal environment in their educational buildings and reducing the use of mechanical systems, contributing to greater energy savings.

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Appendix A Survey

We are evaluating your classroom to assess how well it performs for those who occupy it. This information will be used to assess areas that need improvement and provide feedback for similar buildings. Responses are anonymous. Please answer all the relevant questions

Classroom number: ID:		Time:	Date:	
Age: … … … … … … ..	**Gender** Female Male	**Level** First year Second year Third year Fourth year Fifth year	**Nationality** Jordanian Non-Jordanian	**Education Level** B.Sc. M.Sc.

1. At present, I feel حاليا انا اشعر							
English	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
Number	−3	−2	−1	0	+1	+2	+3
Arabic (Levantine)	بردان كتير	بردان	بردان شوي	مرتاح	مشوب شوي	دافئ	كتير مشوب
2. At present, I would prefer to be: حاليا انا افضل ان أكون							
English	Much cooler	Cooler	A bit cooler	No Change	A bit warmer	Warmer	Much warmer
Number	−3	−2	−1	0	+1	+2	+3
Arabic (Levantine)	ابرد كتير	ابرد	ابرد شوي	لا تغيير	ادفى شوي	ادفى	ادفى كتير

3. Your clothes at present: (Please tick)
Short-sleeve shirt/blouse
Long-sleeve shirt/blouse
Vest
Trousers/long skirt
Shorts
Dress
Pullover
Jacket
Long socks
Short socks
Tights
Tie

Boots
Shoes
Sandals
Head wear
Barefoot

4. What is your activity during the past 15 min? (Please tick)
Sitting (passive work)
Sitting (active work)
Standing relaxed
Standing working
Walking indoors
Walking outdoors
Other . . . .

5. Rate your learning performance in the classroom now

−2] Very Poor
−1] Poor
0] Acceptable
+1] Good
+2] Very Good

6. The current indoor air temperature in my classroom affects my learning performance

−2] Strongly Disagree
−1] Disagree
0] Neither Agree nor Disagree
+1] Agree
+2] Strongly Agree

7. Temperature in my classroom can reduce my overall productivity

−2] Strongly Disagree
−1] Disagree
0] Neither Agree nor Disagree
+1] Agree
+2] Strongly Agree

8. If you feel uncomfortable with the indoor temperature in the lecture room, which adaptive strategies you follow, select from the below answers:
   - Open/close windows
   - Turn on/off fans
   - Use heater
   - Drinking cold/hot drinks beverages
   - Putting on/taking off a piece of garment
   - Changing positions within the classroom
   - Leave lecture room
9. If you choose to improve any item in your classroom, what would it be?

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