Predicting students' thermal sensation votes in university libraries taking into account their mood states

Dadi Zhang[1], Huiying (Cynthia) Hou[1*], Hayley, T.W. Tsang[1], Haifeng Lan[1], Kwok-Wai Mui[1], Ling-Tim Wong[1]

[1] Department of Building Environment and Energy Engineering, The Hong Kong Polytechnic University, Hong Kong, China
[*] *Corresponding email: cynthia.hou@polyu.edu.hk*

Abstract

This study examined the effect of mood states on students' thermal sensations within a university library comprising quiet and group study rooms. Through concurrent subjective and objective assessments over five consecutive workdays, this study investigated the influence of psychological factors, particularly mood states, in influencing thermal sensations. This study addressed a paucity of prior research in library settings where both independent and collaborative studies have been undertaken. Subjective data (i.e., personal information, thermal assessment and mood states) via questionnaires and objective data (i.e., air temperature, radiant temperature, relative humidity and air velocity) via on-site measurements were collected during five working days. Statistical analyses (ANOVA, t-test, correlations, regression) unveiled that male students and those with bad feelings (e.g., hostile, upset) reported significantly higher thermal sensation votes (TSV) ($p < 0.05$) compared to females and those with neutral/good feelings (0.4 - 0.5 difference out of 7). Two predictive models for TSV were developed for males and females, considering factors like body mass index (BMI), operative temperature and mood states. This research offers insights for designing specific study environments to improve thermal comfort, fostering students' well-being and guiding future initiatives in this area.

Keywords

Thermal comfort, Mood state, Students, University library, Study space

Introduction

Since more than one century, thermal comfort has been a research focus as a key element of indoor environmental quality, has always been a research focus.[1] Thermal comfort in study space is critical to students' health and learning performance.[2–4] Many studies over the last decade have reported on the effects of thermal comfort. Xiong et al.[5] found that uncomfortable thermal conditions can cause eyestrain, dizziness and accelerated respiration. Chang[6] discovered a link between thermal comfort and fatigue. Wargocki et al.[7] and Haverinen-Shaughnessy and Shaughnessy[8] demonstrated the negative effect of an uncomfortable thermal environment on students' school performance. Jiang et al.[9] and Lan et al.[10] developed mathematic models to show the impact of thermal comfort on occupants' performance. Despite the large number of studies on thermal comfort, the thermal conditions in study spaces are far from optimal, with more than 20% of occupants feeling dissatisfied with the thermal environment, particularly in subtropical or tropical areas.[11,12] Lan et al.[13] found that the number and spatial location of occupants have a significant impact on their thermal comfort. Given the significant negative effects of thermal discomfort on occupants' health and performance, more research is recommended to identify the factors that influence occupant thermal comfort and discover ways to improve it.

Regarding the research on thermal comfort in study spaces, most studies focused on classrooms in schools,[14–19] since classrooms are essential study spaces where regular education is provided. While, after class, libraries are the most common place (especially in universities) where students go after lecture for self-study and group work.[20] However, far fewer studies were conducted on thermal comfort in libraries. Previous research found that students who used libraries had a much lower dropout rate than those who did not use libraries.[21] To encourage students to go to libraries, many universities have renovated their libraries in recent decades, with the most popular methods including adding group study rooms, decorating the study spaces with artwork, increasing user seats, etc.[22] Although these renovations were done to accommodate students' preferences and needs, many university libraries still lack good thermal quality. For example, Akanmu et al.[23] found that the temperature and relative humidity in most units of libraries in Nigerian could not meet the related requirements, and Mohammadpourkarbasi et al.[24] reported that the majority of the occupants in the investigated library felt "slightly cool" or "cool". This might have unfavourable effects on students' experience and thereby reducing their visit frequencies and academic performance.[23]

Thermal comfort, according to ASHRAE Standard 55,[25] is a state of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation, implying the psychological effect on an individual's thermal comfort. To unified the quantification of thermal comfort, thermal sensation, as defined by ISO 7730[26] and ASHRAE standard 55[25] with a seven-point scale, has been commonly used by most related studies.[27,28] In recent years, mood states, as one type of psychological component, were identified to have an impact on human thermal sensation, and hence they have been incorporated in indoor environment preference judgment indicators in some studies.[29] Since thermal sensation has a significant influence on human task performance (e.g., work productivity, learning productivity),[30] some researchers have shed light on the mood state-thermal sensation relationships in education buildings to investigate how mood states affect students' thermal sensation. For example, Wang and Liu[31] investigated the relationships between students' emotional state and thermal sensation at a Chinese University and revealed that students' moods could affect their thermal perception during sitting and standing, but not during exercise. With the help of virtual settings, Ibrahim et al.[29] examined the effect of mood states on students' thermal sensation and confirmed that participants' thermal sensation was strongly influenced by their mood states. Similar results were also found by Turhan and Özbey.[32] They studied the effect of stress levels on university students' thermal sensations and showed that students' thermal sensations increased significantly with the increase in their stressful levels. Then, Özbey et al.[33] further demonstrated the impact of mood states on students' thermal sensation vote (TSV), and based on this, they suggested involving mood states as a quantitative variable in future thermal sensation models. In a recent study, Turhan et al.[34] compared occupants' thermal sensations collected in a field study with the predicted values calculated using Fanger's Predicted Mean Vote (PMV) model, and they introduced a "Mood State Correction Factor" (MSCF) to quantify the impact of mood on the differences between occupants' actual thermal sensations and PMV. This study indicated that PMV model was accurate for people with neutral moods, while it could cause larger error for occupants with extreme moods (e.g., very pessimistic/ Optimistic). Therefore, an updated model is needed to better predict peoples' thermal sensations.

According to previous research, environmental factors (i.e., T_a, T_r, v_a, Relative Humidity (RH))[35,36]and personal factors (i.e., age, gender, Body Mass Index (BMI), metabolic rate and clothing insulation)[35,37–39] were the most commonly studied factors that could influence occupants' thermal comfort. Yet, there have been very few studies on thermal sensation that considered mood states. According to the limited existing studies,[29-34] the impact of mood states on thermal sensation could be strong and hence should be considered together with other factors in TSV-related studies, as suggested in Figure 1.[29 32]

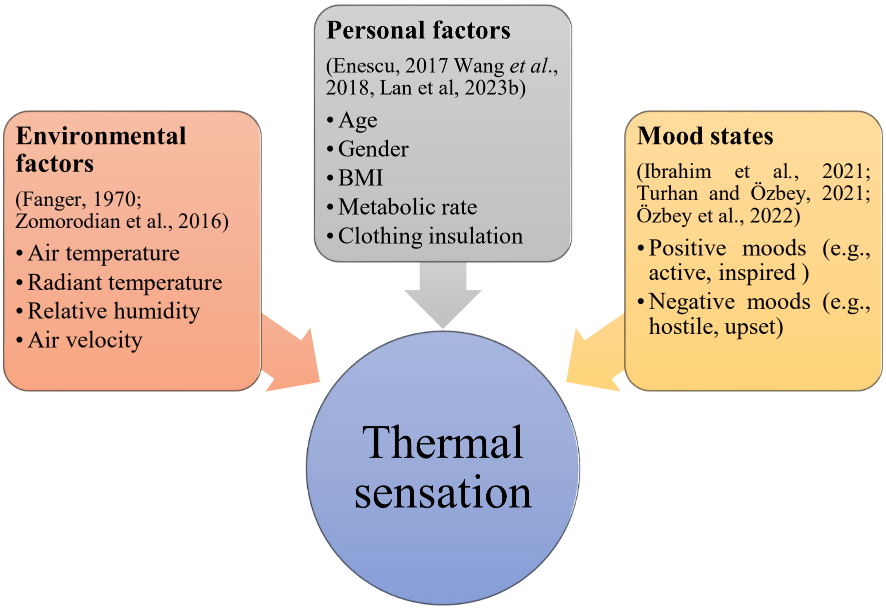


Figure 1. Factors that influence thermal sensation

Given the above-mentioned research gaps, this study aimed to investigate student' thermal sensation in a library indoor environment setting, considering environmental factors, personal factors and mood states at the same time. Specific research objectives are:

- To investigate the effects of the physical environment, personal characteristics and students' mood states on thermal sensation, separately
- To examine the combined effects of the physical environment, personal characteristics and mood states on occupants' thermal sensations

This work would provide fresh insights into the relationship between students' mood states and thermal sensation. Understanding the combined effects of the physical environment and mood states on students' thermal sensations could help create a comfortable and healthy thermal environment in learning spaces and further improve students' learning performance.

Methodology

Research design

A library is one of the most common places on campus where students conduct self-study and group work. Library indoor environment is critical in facilitating students' study and social activities while at university. The following factors influenced the selection of a university library for this study: (1), students with various personal characteristics (e.g., academic backgrounds, education level, nationality, etc.) were approached in the library. Involving students with different personal characteristics can help to enhance the sampling validity. (2), the library has multi-types of functional spaces, which allows for comparative analyses of thermal sensations in different indoor environment settings (e.g., quiet study space and group study space). (3), to investigate the mood states-thermal sensation relationship, the evaluation target (i.e., students) should be exposed to a specific environment for a period of time. A library setting was considered an appropriate setting for conducting mood state evaluation.

Figure 2 depicts the three research stages of this study: selection of the investigated study spaces, data collection and analysis. The following subsections provide detailed information about the research process.

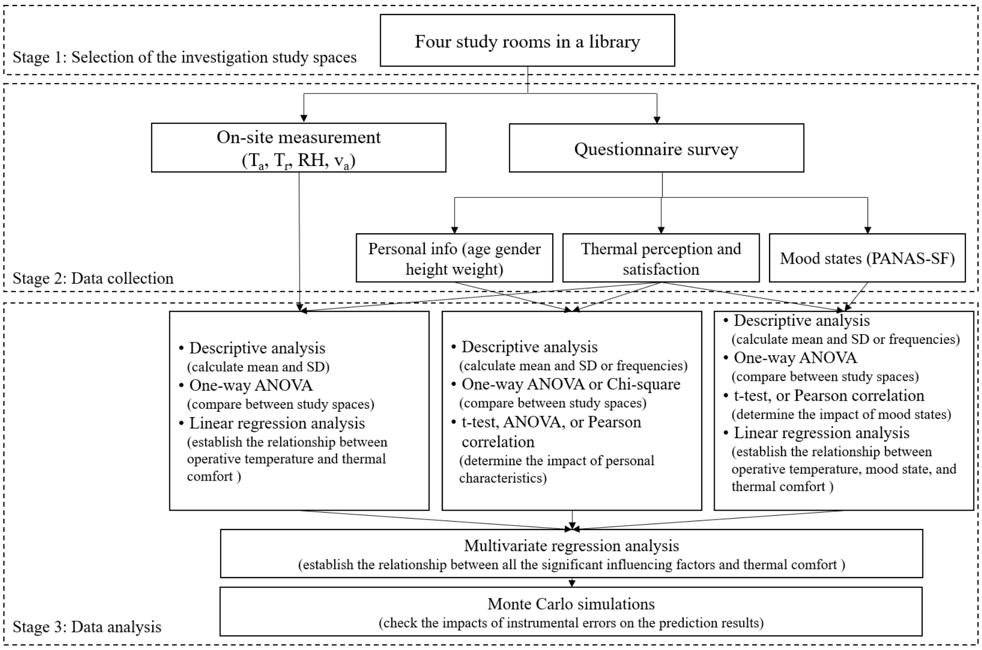


Figure 2. The research process of this study

Selected study spaces in the university library

This study was carried out in a university library which is a six-storey purpose-designed building. The building was established in 1972 and renovated in 2018. The whole building is mechanically ventilated with a all fresh air system. The total area of the library is 16,667 square metres, including four group study spaces and nine quiet study spaces with more than 3,900 study spaces. To involve more indoor environment conditions and enlarge the sample sizes, two quiet-study spaces and two group-study spaces on the first floor and sixth floor, respectively, were selected as the investigated places. The façades of the two study rooms on the sixth floor are glass, while there are concrete walls for the study rooms on the first floor hence no daylight shone through. The environmental conditions of the four study spaces are shown in Figure 3.

a) 1F Group-study space b) 1F Quiet-study space

c) 6F Group-study space d) 6F Quiet-study space

Note: the red circles mark the location of the IEQ loggers.
Figure 3. Environmental conditions in the investigated study spaces.

Data collection

From the 19th to the 25th of October 2022, both on-site measurement and questionnaire surveys were conducted. This study included eight researchers who were paired up to monitor each investigated study space (two researchers were responsible for one study space). For the measurements, T_a, T_r, RH, V_a and CO_2 concentration were continuously monitored using the integrated indoor environmental quality (IEQ) loggers from 9:00-18:00 every day in the investigation week. The accuracy and range of the sensors for T_a, T_r, RH, V_a were ±1°C (0-100 °C), ±2°C (0-100 °C), ±2% (0-100%) and ±5% of reading scale (0.2-20m/s), respectively. T_o was commonly used in thermal sensation studies, [24,40–42] because it can be seen as a combined index of air temperature, mean radiant temperature and air velocity was calculated using equation (1):

$$T_o = \frac{(T_r + T_a \times \sqrt{10v_a})}{1+\sqrt{10v_a}} \quad (1)$$

Four IEQ loggers were employed to measure and record the physical parameters in the four investigated spaces. Since all the investigated spaces were mechanically ventilated and the inlets were evenly distributed on the ceilings, the air temperature distributions were assumed to be uniform in these rooms. [43] Therefore, the loggers were located in the central location of each study space (according to the guidance on monitoring indoor environmental quality[44]) and should be able to represent the basic thermal conditions in these rooms. The measurement interval was set as one minute, and the real-time data was uploaded to a web server where all the data was stored and can be downloaded.

The questionnaire was adapted from the previously validated questionnaires on indoor environmental quality in educational buildings, such as the European SINPHONIE study[45] and a study performed by Bluyssen et al.,[46] and then adjusted for university students.[46] It included questions on students' general information (such as age, gender, weight and height), thermal comfort assessment and mood states. The thermal comfort assessment required students to indicate their perceptions of temperature and humidity, as well as their satisfaction with the thermal environment. The questions were as follows:

1) How do you perceive the temperature in this study room?
2) How do you perceive the humidity in this study room?
3) How satisfied are you with this thermal environment?

All of these questions were answered based on ASHRAE thermal comfort seven-point scale (from -3: Cold/Humid/Totally dissatisfied to 3: Hot/Dry/Totally satisfied). The Positive and Negative Affect Schedule Short Form (PANAS-SF) was used for the questions on mood state measurement because it has high internal consistency and strong reliability.[47] Students were asked to rate these mood states on a five-point scale (from 1: not at all to 5: extremely) based on their mood at the time completing the questionnaire. Compared with other mood measures (such as Profile of Mood States (POMS) with 65 items and The STAI (State-Trait Anxiety Inventory) with 40 items), PANAS-SF is briefer and simpler, including only 10 general mood items corresponding to five positive mood states (i.e., active, attentive, alert, determined and inspired) and five negative mood states (i.e., hostile, ashamed, upset, afraid and nervous). This relatively shorter questionnaire makes students more willing to participate in this survey, especially during their studying process.

The paper-based questionnaires were distributed at random to the university students after they stayed in the investigated locations for at least 30 minutes. During the investigation time, researchers remained in the investigated spaces and recorded the completion time for each questionnaire so that the subjective data could be linked to the measurement data in the analysis process. Before distributing the questionnaire, the researcher explained to each student the research purpose and the possible duration of the questionnaire survey. All the participants were asked whether they were willing to participate in the questionnaire survey or not, and only those who agreed were given the questionnaires. Each participant only filled out the questionnaire once. Furthermore, participants were informed that they could skip any questions that they did not want to answer and withdraw at any time if they did not feel comfortable answering the questions.

Data analysis

First, all the measurement data was imported to IBM SPSS Statistics 26.0.[48] The data screening process involves two steps: i) all the outliers of objective data were identified and eliminated using Z-scores; ii) all unreliable subjective data were identified based on the consistency between the answers to the perception and satisfaction questions. For example, in terms of thermal sensation, the scores of -3/ -2/ 2/ 3 were considered unsatisfied whereas the scores of -1/ 0/ 1 were considered satisfied with the thermal environment. As a result, for the respondent who selected -3/ -2/ 2/ 3 for the thermal sensation question but he/she indicated “satisfied” (i.e., scores 1-3) for the satisfaction question, his/her answer was treated as invalid, and then removed from the database.

Second, three mood indexes were created to synthesise students’ mood states: positive mood index, negative mood index and overall mood index. The positive mood index and negative mood index were calculated by adding the positive mood scores and the negative mood scores, respectively. The overall mood index was the normalized difference between the positive mood index and the negative mood index with a mean of zero and a standard deviation of five.

Third, after the calculation of the mood indexes, three sets of data – personal information (age, gender, height, weight), thermal perception and satisfaction, and mood state, were analysed in five steps (Stage 3 in Figure 2):

- The basic information (e.g. the mean and standard deviation (SD) of measurement parameters, students’ IEQ perceptions, satisfactions and mood states) were described using descriptive analysis;
- The differences in the investigated parameters between different study spaces were checked using one-way ANOVA (for continuous variables, such as weight, height and all the measured parameters) or Chi-square tests (for categorized variables, such as gender, age group, current feeling, etc.);
- The impact of personal characteristics and mood states on students’ thermal sensations and satisfaction were examined using two-tailed t-tests (for dichotomous variables, such as gender and mood state), one-way ANOVA (for variables with more than two categories, such as age, current feeling), and Pearson correlations (for continuous variables, such as BMI);
- Two thermal sensation models were developed using multivariate regression, taking all the significant influencing factors identified by the previous steps into account. For all the analyses, a p-value less than 0.05 was considered to be statistically significant.[49]
- Lastly, Monte Carlo simulations were conducted and two tornado plots were created to indicate the impacts of instrumental errors on the prediction results.

Results

Descriptive results

Participants. A total number of 259 questionnaires were collected and considered valid in this study. Table 1 presents the general information and mood states of the student participants, as well as the physical measurement data. As shown in the table, 54% of the participants were female students; 87% of the students were less than 25 years old; their average BMI was 21, which belongs to the normal weight defined by the World Health Organization (WHO; 18.5-24.9). 70% of them experienced positive events (such as receiving gifts); 61% of them experienced negative events (such as failed an exam) recently. Additionally, there were significantly more female students and more students (8% more than average) who experienced positive events recently on the sixth floor.

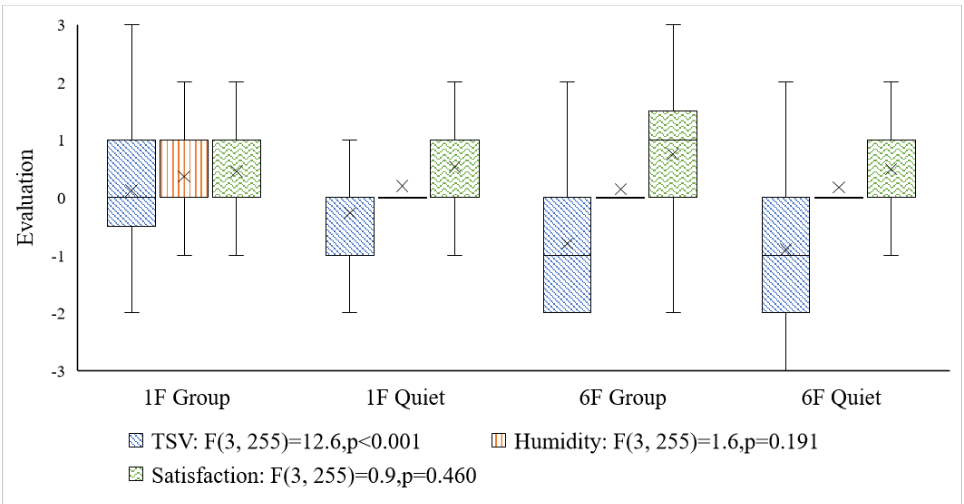
Table 1. Personal characteristics of the students

	All (N = 259)	1F Group-study (N = 57)	1F Quiet-study (N = 64)	6F Group-study (N = 69)	6F Quiet-study (N = 69)	P-value [c]
Personal characteristics						
Gender [a]						**0.001**
- female	140 (54)	21 (37)	34 (53)	42 (61)	43 (62)	
- male	117 (45)	35 (61)	30 (47)	26 (38)	26 (38)	
- unknown	2 (1)	1 (2)	0 (0)	1 (1)	0 (0)	
Age [a]						0.066
- 16-20	97 (37)	36 (63)	21 (33)	20 (29)	20 (29)	
- 21-25	130 (50)	19 (33)	31 (48)	42 (61)	38 (55)	
- 26-30	25 (10)	1 (2)	11 (17)	6 (9)	7 (10)	
- 30+	7 (3)	1 (2)	1 (2)	1 (1)	4 (6)	
Height (cm) [b]	169 (8)	171 (8)	169 (9)	169 (8)	167 (8)	0.158
Weight (kg) [b]	59 (12)	62 (11)	59 (14)	59 (10)	58 (12)	0.258
BMI [b]	21 (3)	21 (3)	21 (4)	20 (2)	21 (3)	0.546
Feeling [a]						0.073
- good	192 (74)	35 (61)	44 (69)	57 (83)	56 (81)	
- not so good	63 (24)	21 (37)	18 (28)	12 (17)	12 (17)	
- bad	4 (2)	1 (2)	2 (3)	0 (0)	1 (1)	
Positive events [a]	182 (70)	43 (75)	33 (52)	52 (75)	54 (78)	**0.002**
Negative events [a]	158 (61)	38 (67)	36 (56)	42 (61)	42 (61)	0.711
Physical measurement [b]						
T_a (°C)	26.0 (1.3)	27.2 (0.6)	26.7 (0.7)	25.9 (0.5)	24.2 (0.9)	**<0.001**
T_r (°C)	23.5 (1.6)	24.9 (0.6)	24.9 (0.7)	22.9 (0.8)	21.3 (0.4)	**<0.001**
T_o (°C)	24.4 (1.0)	25.2 (0.6)	24.9 (0.7)	24.3 (0.7)	23.2 (0.7)	**<0.001**
RH (%)	44.2 (3.0)	43.1 (3.6)	45.1 (2.9)	42.8 (1.8)	45.9 (2.1)	**<0.001**
V_a (m/s)	0.1 (0.2)	0.0 (0.0)	0.0 (0.0)	0.1 (0.1)	0.4 (0.1)	**<0.001**
Mood states [b]						
Active	3.1 (1.0)	2.9 (0.9)	3.2 (1.0)	3.2 (0.9)	3.1 (1.1)	0.257
Attentive	3.1 (0.9)	3.1 (0.8)	3.3 (0.9)	3.3 (0.9)	2.8 (0.8)	**0.005**
Alert	2.6 (1.1)	2.8 (0.9)	2.8 (1.2)	2.4 (1.1)	2.4 (1.0)	0.084
Determined	3.1 (1.0)	3.0 (0.9)	3.4 (1.0)	3.1 (0.9)	3.0 (1.0)	0.061
Inspired	3.1 (1.0)	2.7 (0.9)	3.1 (1.0)	3.3 (1.0)	3.1 (1.1)	**0.038**
Hostile	1.9 (1.1)	2.2 (1.2)	1.9 (1.1)	1.8 (1.0)	1.7 (1.0)	0.072
Ashamed	1.7 (1.0)	2.1 (1.1)	1.8 (1.0)	1.5 (0.8)	1.5 (0.8)	**0.001**
Upset	2.2 (1.1)	2.3 (1.2)	2.2 (1.2)	2.2 (1.1)	2.0 (1.0)	0.668
Afraid	1.9 (1.1)	2.0 (1.1)	1.9 (1.2)	1.9 (1.0)	2.0 (1.2)	0.916
Nervous	2.5 (1.2)	2.5 (1.2)	2.6 (1.2)	2.6 (1.2)	2.5 (1.2)	0.971
Positive mood	15.1 (3.5)	14.5 (3.2)	15.8 (3.7)	15.4 (3.4)	14.5 (3.6)	0.078
Negative mood	10.2 (4.0)	11.1 (4.3)	10.4 (4.4)	9.9 (3.4)	9.8 (3.7)	0.241
Overall mood	0.0 (5.0)	-1.3 (5.2)	0.6 (5.6)	0.6 (4.1)	-0.1 (5.0)	0.129

Note: a. the numbers are n (%) in each group values in each group, and p-values were obtained from Chi-square tests; b. the numbers are the mean (standard variation) values over the measurement period, and p-values were obtained from the one-way ANOVA tests; c. p-values less than 0.05 are in bold.

Thermal environments and thermal sensation. The second part of Table 1 shows the means and SDs of all the measurement parameters. There were statistically significant differences in these parameters between different study spaces. The temperatures on the first floor were significantly higher than on the sixth floor, while the RH, and V_a on the first floor were significantly lower than on the sixth floor. The lower temperature and high air velocity on the sixth floor might be due to the setting of the HAVC systems.

As shown in Figure 4, students' TSV differed significantly between different study spaces, with students on the 6th floor generally feeling colder than students on the 1st floor, which matches the measurement results. However, when it came to humidity perception and satisfaction with the thermal environment, students' votes were relatively unanimous, and no significant difference was found between the four study spaces. The average votes for these two indicators were all between 0 and 1, indicating that these students thought the study spaces were slightly dry and that the thermal environments were slightly satisfactory.



Note: the "×" represents the mean values.
Figure 4. Students' TSV, perceptions of humidity, and thermal satisfaction votes

Additionally, a power analysis was conducted for sample size estimation, based on the TSV collected from the four studied spaces. The results indicated that the effect size was 0.42, considered to be medium using Cohen's criteria;[50] the power was 0.99, meaning 99% chance of finding a statistically significant difference when there is one. With a significance criterion of $\alpha = 0.05$ and power = 0.8, the minimum sample size needed with this effect size is N = 88, with 22 in each study spaces. Thus, the obtained sample size of the current study (N = 259) is more than adequate to test the study hypothesis.

Mood states. In general, students' mood states were relatively upbeat. Figure 5 shows that more students selected "quite a bit" and "extremely" for positive moods (active: 36%, attentive: 33%, alert: 20%, determined: 36%, and inspired: 36%) than negative moods (hostile: 7%, ashamed: 7%, upset: 17%, afraid: 11%, and nervous：27%). In turn, more students chose "a little" or "not at all" to the negative moods (50%-79%) than positive ones (23-46%).

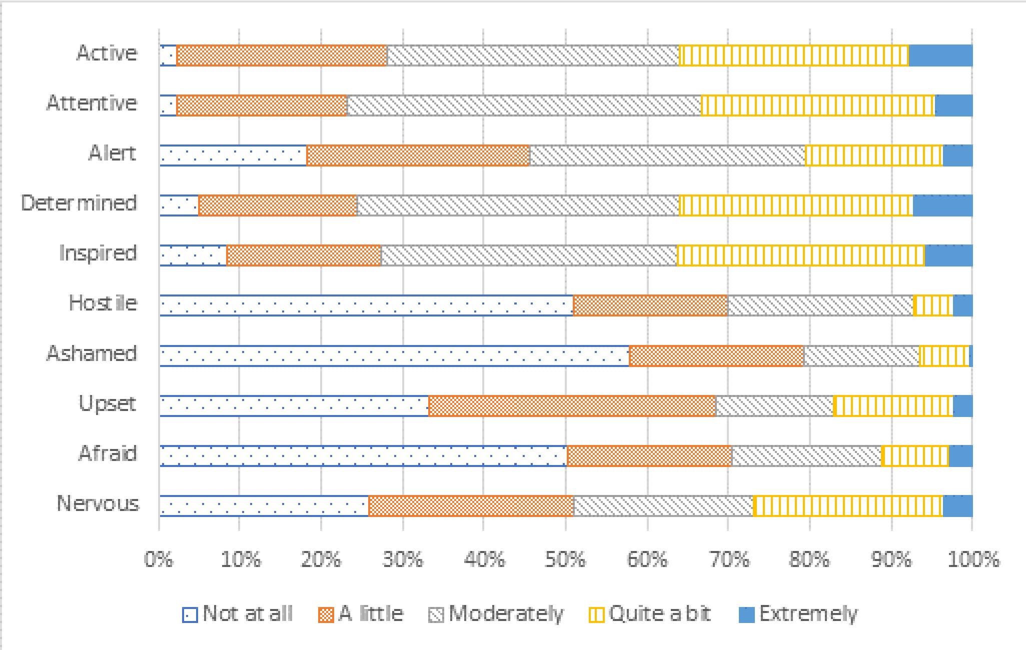


Figure 5. Students' indicated mood states.

When comparing students' mood states between different study spaces, as shown in Table 1, no significant difference was found for most types of moods, except attentive, inspired and ashamed. Students on the 6th floor quiet study room felt significantly less attentive, students on the 1st floor group study room felt significantly less inspired, and students in the 1st floor group study room felt significantly more ashamed. There was no significant difference in the positive and negative mood indexes between students from different study spaces. The values of their positive mood indexes were around 15, while those of their negative mood indexes were around 10. No significant differences in the overall mood index amongst students from different study spaces. The mean values of the overall mood indexes were all around zero, but all with wide fluctuations.

The effects of the three influence factors on students' thermal sensation

Operative temperature. According to the results of the statistical analyses (see Table 2), there was a significant positive correlation between T_o and students' TSV (β = 0.245, p <0.001), which was determined by *Equation (2)*, but the relationship was weak. According to the regression equation, the thermal neutral (TSV = 0) T_o was 25.9°C. However, no significant relationship was found between T_o and students' satisfaction votes, or between their TSV and satisfaction votes. This could be due to the T_o's limited range (21-26°C).

$$TSV = 0.282\, T_o - 7.295\ \ (21℃ < T_o < 26℃) \qquad (2)$$

Table 2. Analysis results about the relationships between T_o, TSV, and satisfaction votes.

	Relationship between	Unstandardized Coefficients (B)	R^2	Standardized Coefficients (β)	p-value
Original data	T_o and TSV	0.282	0.060	0.245	**<0.001**
	T_o and Satisfaction	-0.047	0.002	-0.039	0.530
	TSV and Satisfaction	0.126	0.011	0.122	0.051
Averaged T_o	T_o and TSV	3.215	0.889	0.943	**0.001**
	T_o and PD	/	0.993	0.800	**0.031**
	TSV and PD	-0.195	0.190	0.578	0.174

Note: results were obtained from regression analyses, and p-values less than 0.05 are in bold.

To emphasize and clearly illustrate the relationships between them, the percentage of dissatisfaction (PD) and averaged T_o of cases where students voted for the same thermal sensation were calculated, and the relationships between students' TSV and the averaged T_o/PD were established. As shown in Figure 6 and Table 2, there is a much stronger relationship between the TSV and T_o ($\beta = 0.943$, $p = 0.001$). For the PD, the majority of students were satisfied with the thermal environment (-1< satisfaction <1), even when they felt cold, only students who felt hot (TSV = 3) were dissatisfied with the thermal environment. Furthermore, based on the quadratic polynomial equation between T_o and PD shown in Figure 6, the T_o should be kept between 23.5-24.7°C to maintain a thermal comfort environment (i.e., PD less than 20%, according to ASHRAE 55).

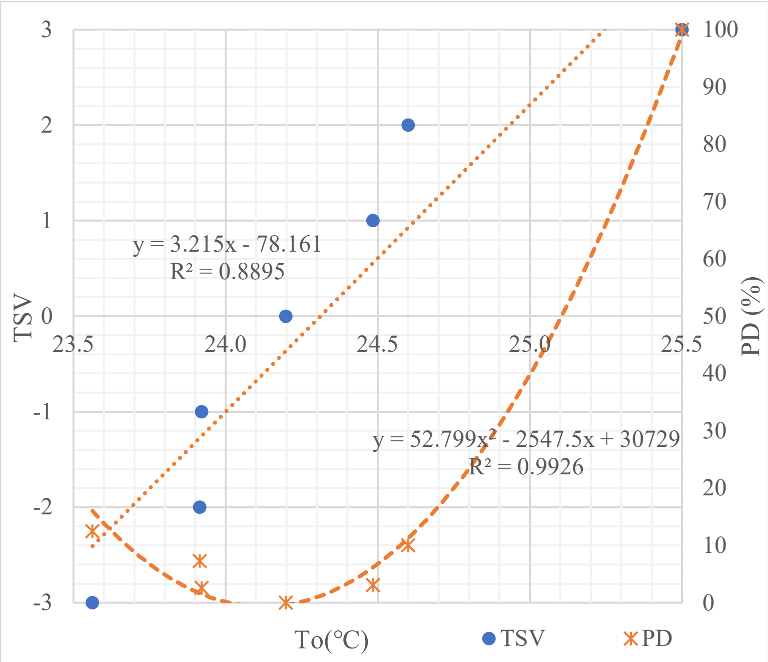


Figure 6. Relationship between T_o and TSV/PD

Personal characteristics. Regarding the effect of students' characteristics on their TSV and satisfaction, the results showed that "gender", "BMI", "current feeling" and "recent experience of positive events" had significant impacts on students' TSV, and "the current feeling" also had a significant impact on student's satisfaction with the thermal condition in the study spaces (see Table 3). Male students felt warmer than female students (medium effect: Cohen's d = 0.4); students with higher BMI felt warmer; students with positive feelings felt colder but were more satisfied with the thermal environment than students with negative feelings. Also, students who had recently experienced positive events reported feeling less cold than the others (medium effect: Cohen's d = 0.30).

Table 3. Impact of personal characteristics on thermal comfort.

Personal characters		TSV	p-values	Satisfaction	p-value
Gender [a]	Female	-0.7 (1.2)	**0.004**	0.6 (1.2)	0.922
	Male	-0.3 (1.0)		0.6 (1.2)	
Age [b]	16-20	-0.2 (1.1)	0.053	0.6 (1.2)	0.153
	21-25	-0.7 (1.1)		0.6 (1.1)	
	26-30	-0.7 (1.2)		0.6 (1.3)	
	30+	-0.3 (1.0)		0.3 (1.4)	
BMI [c]		r=0.216	**<0.001**	R=0.079	0.210
Feeling [b]	Good	-0.6 (1.1)	**0.004**	0.6 (1.2)	**0.026**
	Not so good	-0.3 (1.1)		0.6 (1.1)	
	Bad	1.0 (2.2)		-1.0 (1.4)	
	Yes	-0.2 (1.1)	**0.017**	0.8 (1.0)	0.090

Positive event [a]	No	-0.6 (1.1)		0.5 (1.2)	
Negative event	Yes No	-0.6 (1.1) -0.4 (1.2)	0.103	0.6 (1.1) 0.5 (1.2)	0.510

Note: a - results were obtained from independent t-tests, related Cohen's d values were reported in the text; b - results were obtained from the one-way ANOVA tests; c - results were obtained from the Pearson correlation analyses, and p-values less than 0.05 are in bold.

Mood states. Except for the negative moods of "active", "hostile", "upset" and "afraid", there was no significant difference in thermal comfort between students who reported strong feelings (quite a bit or extremely) toward the investigated moods and those who did not (see Table 4). Students who indicated "hostile" or "upset" felt significantly warmer than those who did not, whereas students who indicated "active" and "afraid" felt significantly more satisfied with the thermal environments. Besides, the values of Cohen's d of these analyses were between 0.3 - 0.5, indicating the medium effects of these moods.[50] Furthermore, the mean TSVs of students who felt "hostile" (0.0) or "upset" (-0.2) were significantly higher than students who had other moods; similarly, the mean satisfaction vote of students who felt "active" (0.8) and "afraid" (1.0) were also significantly higher than other students (see Table 4)

Table 4. Impact of mood states on students' thermal comfort

Mood states [a]	**TSV**				**Satisfaction**			
	yes [c]	**no** [c]	**t-value (p-value)** [b]	**Cohen's d**	**yes** [c]	**no** [c]	**t-value (p-value)** [b]	**Cohen's d**
Active (n = 93)	-0.6 (1.3)	-0.5 (1.1)	-0.70 (0.487)	-0.10	0.8 (1.3)	0.4 (1.1)	2.41 (**0.017**)	0.31
Attentive (n = 86)	-0.5 (1.2)	-0.5 (1.1)	0.45 (0.656)	-0.06	0.7 (1.3)	0.5 (1.1)	1.19 (0.237)	0.16
Alert (n = 53)	-0.4 (1.4)	-0.5 (1.1)	0.35 (0.724)	0.06	0.7 (1.3)	0.5 (1.1)	0.81 (0.422)	0.12
Determined (n = 93)	-0.6 (1.2)	-0.4 (1.1)	-1.42 (0.156)	-0.18	0.6 (1.3)	0.5 (1.1)	0.40 (0.693)	0.05
Inspired (n = 94)	-0.6 (1.2)	-0.4 (1.1)	-1.59 (0.113)	-0.21	0.7 (1.2)	0.5 (1.2)	1.11 (0.270)	0.14
Hostile (n = 19)	0.0 (1.3)	-0.5 (1.1)	1.97 (**0.050**)	0.47	0.9 (1.1)	0.5 (1.2)	1.28 (0.201)	0.31
Ashamed (n = 17)	-0.5 (1.0)	-0.5 (1.1)	0.074 (0.941)	0.02	0.8 (1.3)	0.5 (1.2)	0.73 (0.465)	0.18
Upset (n = 44)	-0.2 (1.3)	-0.6 (1.1)	2.15 (**0.033**)	0.36	0.5 (1.2)	0.6 (1.2)	-0.395 (0.693)	-0.07
Afraid (n = 29)	-0.2 (1.1)	-0.5 (1.1)	1.43 (0.153)	0.28	1.0 (1.3)	0.5 (1.2)	2.14 (**0.033**)	0.42
Nervous (n = 70)	-0.3 (1.1)	-0.5 (1.1)	1.28 (0.203)	0.18	0.6 (1.2)	0.6 (1.2)	0.30 (0.762)	0.04

Note: a. n was the number of students who reported strong feelings toward the corresponding mood. b. results were obtained from independent t-tests, and p-values less than 0.05 are in bold. c. "yes" represents the students who reported strong feelings (quite a bit or extremely), while "no" represents the students who did not.

The relationships between students' thermal comfort (i.e., their TSV and PD) and their positive/negative moods and general mood index were also investigated. Since the skewness and kurtosis of these parameters were around 0 and 3 respectively, they were considered normally distributed.[51] Significant relationships were found between students' TSV and their negative and overall mood indexes. As shown in Table 5, both relationships indicated that students with strong negative moods tended to feel hot, and the power values of these analyses were 0.71 and 0.81, indicating the tests could detect the statistically significant effect 70% or 80% of the time if the effect exists. However, no significant relationship was found between students' satisfaction votes and their mood indexes. The averaged values of students' mood indexes in cases where students voted for the same thermal sensation were then calculated.

Interestingly, students' positive mood score was found to be significantly related to their TSV in this way and the power of the test was higher (1.0), yet the implication was similar, namely, students with strong positive moods tended to feel cold. Nonetheless, no significant relationship between students' PD and their mood indexes was discovered.

Table 5. Impact of mood states on students' thermal comfort

	Mood indexes	TSV			Satisfaction/ Percentage of dissatisfaction (PD)		
		Correlation Coefficients (r)	p-value	Power	Correlation Coefficients (r)	p-value	Power
Original data	Positive mood	-0.082	0.188	0.37	0.100	0.108	0.484
	Negative mood	0.137	**0.028**	0.71	0.052	0.409	0.208
	Overall mood	-0.156	**0.012**	0.81	0.027	0.660	0.113
Averaged mood index	Positive mood	-0.776	**0.040**	1.00	-0.708	0.075	1.00
	Negative mood	-0.023	0.960	0.10	-0.737	0.059	1.00
	Overall mood	-0.589	0.164	1.00	0.184	0.694	0.91

Note: results were obtained from Pearson correlation analyses, and p-values less than 0.05 are in bold.

Development of an integrative thermal sensation model

According to the findings presented above, students' thermal sensation in the library was influenced by operative temperature, personal characteristics and mood states at the same time. To consider all the influencing factors, two multivariate regression analyses were performed to determine the combined effect of T_o, BMI and mood states for female students and male students separately. It should be noted that i) for personal characteristics, current feelings and positive event experiences were excluded because they were related to students' mood states; ii) for the mood states, the original overall mood index was selected as it represented all of the investigated mood states. Results of the regression analyses indicated good fits for both models: Female: $F(3, 133) = 2.865$, $p = 0.039$; male: $F(3,111) = 4.747$, $p = 0.004$. In other words, the T_o, BMI, and mood state index could significantly predict the students' TSV. Table 6 shows the detailed information about the two models.

Table 6. Impacts of gender, BMI, T_o and mood index on students' thermal sensation

Influencing factors	**Females:** F(3, 133) = 2.865, p = **0.039**				**Males:** F(3,111) = 4.747, p = **0.004**			
	Unstandardized coefficients (B)	Standardized coefficients (β)	p-values [a]	VIF [b]	Unstandardized coefficients (B)	Standardized coefficients (β)	p-values [a]	VIF [b]
BMI	0.059	0.106	0.215	1.025	0.083	0.211	**0.020**	1.003
T_o	0.254	0.211	**0.014**	1.009	0.230	0.217	**0.017**	1.012
Overall mood index	-0.019	-0.077	0.363	1.018	-0.022	-0.125	0.167	1.014

Note: a. results were obtained from linear regression analyses, and p-values less than 0.05 are in bold; c. VIF means the variance inflation factor.

The females' model indicated that only the T_o had a significant and decisive impact on students' TSV ($\beta = 0.2111$; $p = 0.011$), while the mood state index had the least and not statistically significant impact ($\beta = -0.077$; $p = 0.336$). To be more specific, for every degree increase in T_o, there was a 0.25 increase in female students' TSV; for every unit increase in BMI, there was a 0.06 increase in TSV; while for every unit increase in mood index, there was a 0.02 decrease in TSV. Regarding the males' model, both

T_o and BMI had significant impacts on students' TSV students, while comparing with them, the impact of mood state was still the least and not statistically significant. Specifically, for every degree increase in T_o, there was a 0.23 increase in male students' TSV; for every unit increase in BMI, there was a 0.08 increase in their TSV; while for every unit increase in mood index, there was a 0.02 decrease in TSV. Furthermore, the variance inflation factors (VIF) of all variables were less than 4, indicating that no multicollinearity was found amongst these variables. Based on the findings, the combined impact of T_o, BMI, and the overall mood index on students' TSV were evaluated using *Equations (3)* and (4) for female and male students separately.

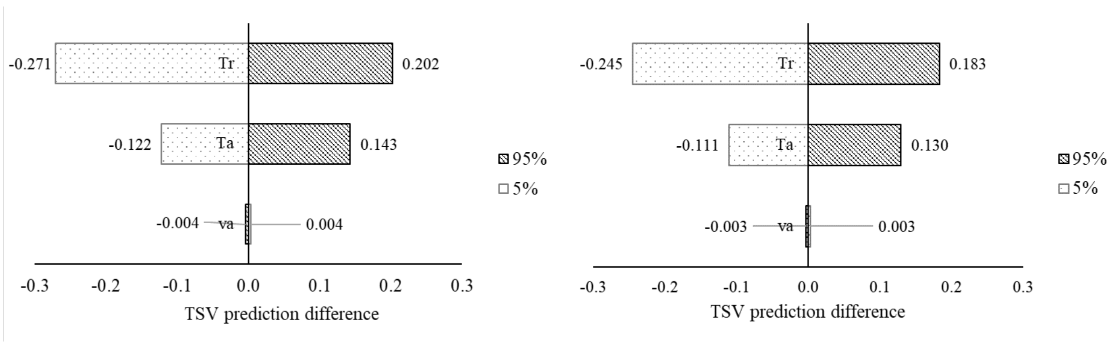
$$TSV = 0.254 \times T_o + 0.059 \times BMI - 0.019 \times Overall\ mood\ index - 7.883 \quad (3)$$

$$TSV = 0.230 \times T_o + 0.083 \times BMI - 0.022 \times Overall\ mood\ index - 7.539 \quad (4)$$

Impacts of instrumental errors on the prediction results

Given the fact that the devices used in the field study have certain instrumental errors, which might cause inaccuracy of the final TSV predictions. To check the impacts of the instrumental errors on the results, a series of Monte Carlo simulations were conducted. Detailed procedures were as follows: First, considering the measurement accuracy of the device (i.e., ±1℃ for T_a, ±2℃ for T_r and ±5% of reading value for v_a) and the actual measurement results are shown in Table 1. Three sets of normally distributed random numbers, with 'mean = 0, standard deviation = 0.6', 'mean = 0, standard deviation = 1.2', and 'mean = 0, standard deviation = 0.003' were generated to simulate the measurement errors of T_a, T_r, and v_a, respectively. The standard deviations were determined to make sure 95% of these values were within the device's accuracy ranges. Second, a new dataset with the main variables included in the TSV model was developed, where three new variables T_a', T_r' and v_a' were generated by adding the originally measured T_a, T_r and v_a with the simulated measurement errors, while the BMI, gender and mood states were kept the same since these were directly collected from the subjects' questionnaires and considered to be accurate. Third, using the newly generated variables, a set of new T_o can be calculated using Equation (1), and new TSVs were calculated using Equations (3) and (4). Lastly, two tornado plots were created to show the impacts of instrumental errors of T_a, T_r and v_a on the predicted TSV.

Figures 7 shows how much the instrumental errors affect the predicted TSV using the models were developed in the current study. Two less likely happened worse scenarios (with 5% occurrence probability) were considered. According to the graph, the measurement error of T_r was the most influential variable on the predicted TSV, while the measurement error of v_a had the least effect. The inaccuracy of measured T_r could cause as much as a 0.27 difference in the predicted TSV, which might be due to the relatively low measurement accuracy of T_r (±2℃).



a) Female b) Male

Figure 7. Tornado graphs comparing effects of instrumental errors on the predicted TSV.

Discussion

The effect of personal characteristics on students' thermal sensation

Personal characteristics factors, such as gender, BMI and mood factors (current feelings and recent experience of positive events) were found to have significant effects on students' thermal sensation. The effect of gender and BMI on students' thermal sensations were examined in previous studies. For example, female students tend to feel colder than male students,[18,52,53] and overweight students tend to feel hotter than normal or underweight students.[37,54]

Apart from the investigated factors, cultural differences and local climate also could affect students' thermal sensation.[55] For example, Kenawy and Elkadi[50] conducted a cross-national comparative investigation on people's thermal sensation and revealed significant impacts of cultural and climatic background on people' TSV. Specifically, they found that people originally from Asia (including Hong Kong) are more tolerant to heat stress than people from America, northwestern Europe and Australia. Therefore, the models developed by the current study (i.e., *Equations* (3) and (4)) should be applied carefully. For example, it may be only suitable for the young adults with similar culture and climate background. However, the methods used by the current study could be applied by future studies to develop other TSV models for people from different regions.

Thermal environment-thermal sensation relationships in the four study spaces

One of the innovations of this study lies in its research design – four study space with different indoor environments were treated as intervention. Data collection was conducted in these four study spaces for investigating the effect of thermal environment on students' thermal sensation. The four study spaces were located in the same building with mechanical ventilation. During the investigation week, the temperature, both T_a and T_r, recorded appeared to be significant different among the four study spaces. The temperature variation might be due to multiple reasons: number of students attended, interior design (study spaces on the 6^{th} floor has a higher ceiling and larger windows), etc. According to the collected data, the difference in temperature caused students different thermal sensations. For example, temperatures on the 6^{th} floor were relatively lower than on the 1^{st} floor (1F); correspondingly, students on the 6^{th} floor felt significantly colder than students on the 1^{st} floor.

To investigate the relationship between the T_o and students' TSV, a linear regression model was established. Based on the model, the neutral temperature of the investigated students was obtained as 25.9°C, which is 1.2°C lower than the neutral temperature identified by Jindal[41] in naturally ventilated classrooms. The difference between these two neutral temperatures shows conformity to the 1℃ difference in neutral temperature observed by Kwok[15] between naturally ventilated and mechanically ventilated study spaces. Due to the narrow temperature range of the environments investigated by this study, no significant relationship between the T_o and students' satisfaction was found. A polynomial regression model was established between the percentage of dissatisfaction (PD) and T_o, according to which, the lowest PD was achieved when T_o equals to 24.2°C. Although the established model was different from previous polynomial regression models developed by other researchers,[56–58] the temperature that corresponded to the highest satisfaction was within the range identified by these studies. These results implied the energy-saving potential of the investigated building because it is possible to increase the temperature set point in the investigated library by 1-3°C without sacrificing students' thermal comfort.

The effect of mood states on students' thermal sensations in study spaces

For the mood states-thermal sensation relationship, the results implied that students with good feelings felt cool and satisfied with the thermal environment, while students with bad feelings felt warm and unsatisfied with the thermal environment. This is consistent with the findings in Wong and Liu's [31] study - the subjects' TSVs and dissatisfaction rates were much higher under negative emotions. In addition, the current study also found that students who experienced positive events recently tended to feel neutral, while students who did not experience any positive events tended to feel cool. This result might be explained by the "restore" effect of positive events proposed by Gross et al.[59] that positive events could restore coping resources and help people to stay balanced, especially in adverse conditions.

Regarding the impact of mood states on students' thermal sensations, only two negative moods: "hostile" and "upset", were found to have significant positive impacts. Therefore, students who had these feelings felt relatively less cold than other students. This supports the results found by Ibrahim [29] that the negative feeling ("anger" in his case) could strengthen the warm feeling. Besides, the impact of "depression" on thermal sensation was reported by Özbey et al.[33] They revealed that depression could cause a difference in TSV as large as 0.3, which is similar to the finding of the current study that the average TSV of students who felt upset was 0.4 higher than the TSV of other students. According to psychosomatic studies, these negative moods could cause an increase in heart rate and metabolic rate,[60,61] which could further increase subjects' TSV. In addition, feeling "active" and "afraid" were found to be positively correlated with students' thermal satisfaction. In other words, the more "active" or "afraid" they felt, the more satisfied they were with the thermal environment. This might relate to human biological and psychological responses. According to Ward,[62] when people feel afraid, their bodies will release adrenaline and dopamine to keep them alert and these chemicals could make people feel pleasure and satisfaction. Although the same finding was not presented by any scientific study before, a related doubt that mood state might be related to subjects' satisfaction with the thermal environment was proposed by Wang and Liu,[31] and they suggested future studies to investigate the impact of mood states on people's thermal satisfaction.

Furthermore, to comprehensively evaluate the impact of moods, three mood indexes - positive mood index, negative mood index and overall mood index – were proposed in the current study. It was found that negative mood and overall mood indexes significantly correlated with students' TSV in study spaces, and students who had more negative moods tended to have higher TSV. This finding resonates with the results about the impact of current feelings mentioned in the section "The effect of personal characteristics on students' thermal sensation" and the impact of individual mood states mentioned in the above paragraph.

Combined effects of the physical environment, students' personal characteristics, and mood states on thermal sensation.

The combined impact of T_o, students' characteristics and their mood states, on students' thermal sensations, was reflected by two multivariate regression models (for females and males separately) that considered all the significant influencing factors, namely T_o, students' gender, BMI and overall mood index. The results implied that both models fit the data very well. According to these models, T_o has a decisive impact on female students' TSV, while both T_o and BMI have significant positive impacts on male students' TSV. This might be caused by the fact that the BMI of the investigated female students did not vary a lot (mean = 19.8; standard deviation = 2.0) and there was only one female student whose BMI exceeded 24.9, i.e., the upper limit of the normal BMI. On the contrary, male students' BMIs were relatively higher and covered a wider range (mean = 21.9; standard deviation = 2.7). Therefore, a more obvious impact of BMI on male students was identified. Moreover, the impact of mood states on students' TSV turned out to be not significant when all factors were considered together. This might be related to the fact that all students felt relatively positive during this study, and according to Ibrahim et al.[29] and Forgas and Bower,[63] when under positive moods, the ambient temperature plays the dominant role in determining subjects' thermal sensations. To confirm this result, more situations, including both different environmental conditions and different mood states, need to be investigated.

Limitations and future studies

Three limitations should be noted in this study. First, the current study only investigated one library building. Although four different study spaces with varying environmental settings were chosen and 259 students were surveyed, the temperatures in the studied spaces were quite similar. Because of the narrow temperature range of the investigated spaces, determining the impact of T_o on students' thermal sensations was difficult. Second, this study was limited by the relatively less investigated variables. Previous studies indicated that lifestyles (such as exercise and drinking alcohol) and some building-related indicators (such as window-to-wall ratios, building materials) could affect occupants' mood states and comfort.[64] However, they were not considered in the current study to control the questionnaire length and keep the attention of the students interacting. The last limitation is the short survey period. Third, the measurement device used in the current study has a relatively low accuracy, which might influence the prediction results. Given these constraints, future studies should involve more types of study spaces in various buildings (such as classrooms, lecture halls, etc.) using more accurate devices, and investigate dose-related, occupant-related and building-related indicators together.

Conclusion

The effects of physical thermal conditions, students' characteristics and their mood states on their thermal sensations were investigated in this study. Physical parameters were measured in four different study spaces in a library building over the course of one week, and 259 students' thermal sensations and mood states were collected. According to findings of this study, both physical environments and personal characteristics, as well as mood states, have a significant influence on students' thermal sensations and thermal satisfaction in the selected study spaces. Specifically, the male students and students with higher BMI tended to feel warmer than other students. The average TSV of students who had bad feelings (hostile and upset, in particular) was significantly higher than other students; and students who had good feelings or a strong feeling of fear were significantly more satisfied with the thermal environment.

In addition, this study established two integrated thermal sensation models, involving T_o, students' BMI and mood index for female and male students separately. Based on this, T_o has the greatest influence on students' TSV, while mood states have the least. This result, however, may be limited to the cases studied. Later studies would be required to confirm the findings by expanding the investigated buildings and periods. The findings of this study highlighted the importance of individual differences in thermal environment perception. Personalized heating, ventilation and air-conditioning systems should be developed in the future to better address this difference and increase occupant satisfaction.

Author Contributions

All authors contributed equally to the preparation of this manuscript.

Acknowledgment

This study was supported by grants from the Hong Kong Polytechnic University: Start-up Fund for New Recruits (Project ID: P0040305) and Policy Research Centre for Innovation and Technology (PReCIT) Seed Funding Scheme (Project ID: P0043831).

Declaration of conflict of interest: None

References

1. Fabbri K. A Brief History of Thermal Comfort: From Effective Temperature to Adaptive Thermal Comfort. In: *Indoor Thermal Comfort Perception*. Cham: Springer International Publishing, 2015, pp. 7–23.

2. Bluyssen PM. Health, comfort and performance of children in classrooms - New directions for research. *Indoor and Built Environment* 2017; 26: 1040–1050.

3. Lamberti G, Fantozzi F, Salvadori G. Thermal comfort in educational buildings: future directions regarding the impact of environmental conditions on students' health and performance. In: *IEEE International Conference on Environment and Electrical Engineering and 2020 IEEE Industrial and Commercial Power Systems Europe (EEEIC/I&CPS Europe)*. Madrid, 9-12 June 2020, pp. 1–6.

4. Wargocki P. Ventilation, thermal comfort, health and productivity. In: Mumovic D, Santamouris M (eds) *A Handbook of Sustainable Building Design and Engineering* . Second edition. | Abingdon, Oxon ; New York, NY : Routledge, 2018, pp. 209–225.

5. Xiong J, Lian Z, Zhou X, You J, Lin Y. Effects of temperature steps on human health and thermal comfort. *Build Environ* 2015; 94: 144–154.

6. Chang JH. Thermal comfort and climatic design in the tropics: An historical critique. *Journal of Architecture* 2016; 21: 1171–1202.

7. Wargocki P, Porras-Salazar JA, Contreras-Espinoza S. The relationship between classroom temperature and children's performance in school. *Build Environ* 2019; 157: 197–204.

8. Haverinen-Shaughnessy U, Shaughnessy RJ. Effects of classroom ventilation rate and temperature on students' test scores. *PLoS One 2015*; 10(8): e0136165. Epub ahead of print 28 August 2015. DOI: 10.1371/journal.pone.0136165.

9. Jiang J, Wang D, Liu Y, Xu Y, Liu J. A study on pupils' learning performance and thermal comfort of primary schools in China. *Build Environ* 2018; 134: 102–113.

10. Lan L, Wargocki P, Lian Z. Quantitative measurement of productivity loss due to thermal discomfort. *Energy and Buildings* 2011; 43(5): 1057–1062.

11. Mui K-W, Tsang TW, Wong L-T. Bayesian updates for indoor thermal comfort models. *Journal of Building Engineering 2020*; 29: 101117. DOI: 10.1016/j.jobe.2019.101117.

12. Fabozzi M, Dama A. Field study on thermal comfort in naturally ventilated and air-conditioned university classrooms. *Indoor and Built Environment* 2020; 29: 851–859.

13. Lan H, Hou H (Cynthia), Gou Z, Wong MS, Wang Z. Computer vision-based smart HVAC control system for university classroom in a subtropical climate. *Build Environ 2023*; 242: 110592. DOI: 10.1016/j.buildenv.2023.110592.

14. ter Mors S, Hensen JLM, Loomans MGLC, Boerstra AC. Adaptive thermal comfort in primary school classrooms: Creating and validating PMV-based comfort charts. *Build Environ* 2011; 46: 2454–2461.

15. Kwok AG. Thermal Comfort in Tropical Classrooms. *ASHRAE Trans* 1998; 104: 1031–1050.

16. De Dear R, Kim J, Candido C, Deuble M. Adaptive thermal comfort in Australian school classrooms. *Building Research and Information* 2015; 43: 383–398.

17. Wong NH, Khoo SS. Thermal comfort in classrooms in the tropics. *Energy Build* 2003; 35: 337–351.

18. Hwang RL, Lin TP, Kuo NJ. Field experiments on thermal comfort in campus classrooms in Taiwan. *Energy Build* 2006; 38: 53–62.

19. Fang Z, Zhang S, Cheng Y, Fong AML, Oladokun MO, Lin Z, Wu H. Field study on adaptive thermal comfort in typical air conditioned classrooms. *Build Environ* 2018; 133: 73–82.

20. Applegate R. The Library Is for Studying. Student Preferences for Study Space. *Journal of Academic Librarianship* 2009; 35: 341–346.

21. Murray A, Ireland A, Hackathorn J. The value of academic libraries: Library services as a predictor of student retention. *Coll Res Libr* 2016; 77: 631–642.

22. Shill HB, Tonner S. *Creating a Better Place: Physical Improvements in Academic Libraries*, www.libqual.org (1995).

23. Akanmu WP, Nunayon SS, Eboson UC. Indoor environmental quality (IEQ) assessment of Nigerian university libraries: A pilot study. *Energy and Built Environment* 2021; 2: 302–314.

24. Mohammadpourkarbasi H, Jackson I, Nukpezah D, Appeaning Addo I, Assasie Oppong R. Evaluation of thermal comfort in library buildings in the tropical climate of Kumasi, Ghana. *Energy Build 2022*; 268: 112210. DOI: 10.1016/j.enbuild.2022.112210.

25. *ANSI/ASHRAE Standard 55-2020*. Thermal environmental conditions for human occupancy. Attlanta: ASHRAE, 2020.www.ashrae.org (2020).

26. *ISO 7730: 2005. Ergonomics of the thermal environment - Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria*. Geneva: ISO, 2005.

27. Velt KB, Daanen HAM. Thermal sensation and thermal comfort in changing environments. *Journal of Building Engineering* 2017; 10: 42–46.

28. Fang Z, Liu H, Li B, Tan M, Olaide OM. Experimental investigation on thermal comfort model between local thermal sensation and overall thermal sensation. *Energy Build* 2018; 158: 1286–1295.

29. Ibrahim A, Ali H, Zghoul A, Jaradat S. Mood state and human evaluation of the thermal environment using virtual settings. *Indoor and Built Environment* 2021; 30: 70–86.

30. He Y, Chen W, Wang Z, Zhang H. Review of fan-use rates in field studies and their effects on thermal comfort, energy conservation, and human productivity. *Energy and Buildings* 2019; 194: 140–162.

31. Wang H, Liu L. Experimental investigation about effect of emotion state on people's thermal comfort. *Energy Build 2020*; 211: 109789. DOI: 10.1016/j.enbuild.2020.109789.

32. Turhan C, Özbey MF. Effect of pre-and post-exam stress levels on thermal sensation of students. *Energy Build 2021*; 231: 110595. DOI: 10.1016/j.enbuild.2020.110595.

33. Özbey MF, Çeter AE, Örfioğlu Ş, Alkan N, Turhan C. Sensitivity analysis of the effect of current mood states on the thermal sensation in educational buildings. *Indoor Air 2022*; 32(8): e13073. DOI: 10.1111/ina.13073.

34. Turhan C, Özbey MF, Çeter AE, Akkurt GG. A Novel Data-Driven Model for the Effect of Mood State on Thermal Sensation. *Buildings 2023*; 13(7): 1662. DOI: 10.3390/buildings13071662.

35. Fanger PO. *Thermal Comfort: Analysis and Application in Environmental Engineering*. Copenhagen: Danish Technical Press, 1970.

36. Zomorodian ZS, Tahsildoost M, Hafezi M. Thermal comfort in educational buildings: A review article. *Renewable and Sustainable Energy Reviews* 2016; 59: 895–906.

37. Wang Z, de Dear R, Luo M, Lin B, He Y, Ghahramani A, Zhu Y. Individual difference in thermal comfort: A literature review. *Build Environ* 2018; 138: 181–193.

38. Enescu D. A review of thermal comfort models and indicators for indoor environments. *Renewable and Sustainable Energy Reviews* 2017; 79: 1353–1379.

39. Lan H, Hou HC, Gou Z. A machine learning led investigation to understand individual difference and the human-environment interactive effect on classroom thermal comfort. *Build Environ 2023*; 236: 110259. DOI: 10.1016/j.buildenv.2023.110259.

40. Luo M, Cao B, Damiens J, Lin B, Zhu Y. Evaluating thermal comfort in mixed-mode buildings: A field study in a subtropical climate. *Build Environ* 2015; 88: 46–54.

41. Jindal A. Thermal comfort study in naturally ventilated school classrooms in composite climate of India. *Build Environ* 2018; 142: 34–46.

42. de Dear R, Brager GS. The adaptive model of thermal comfort and energy conservation in the built environment. *Int J Biometeorol* 2001; 45: 100–108.

43. Zhao W, Lestinen S, Mustakallio P, Kilpeläinen S, Jokisalo J, Kosonen R. Experimental study on thermal environment in a simulated classroom with different air distribution methods. *Journal of Building Engineering 2021*; 43: 103025. DOI: 10.1016/j.jobe.2021.103025.

44. *CIBSE TM68: Monitoring indoor environment quality*. London, The Chartered Institution of Building Services Engineers, 2022.

45. Schools Indoor Pollution & Health Observatory Network in Europe SINPHONIE - Final Report. European Commission (JRC Puhlication Repository), Publications Office of the European Union, JRC91160, EUR 26738 , OP LB-NA-26738-EN-N. Brussels, 2015. . DOI: 10.2788/99220.

46. Bluyssen P M, Zhang D, Kurvers S, Overtoom M, Ortiz-Sanchez M. Self-reported health and comfort of school children in 54 classrooms of 21 Dutch school buildings. *Build Environ 2018*; 138: 106-123. DOI: 10.1016/j.buildenv.2018.04.032.

47. Karim J, Weisz R, Rehman SU. International positive and negative affect schedule short-form (I-PANAS-SF): Testing for factorial invariance across cultures. In: *Procedia - Social and Behavioral Sciences*. 2011; 15: 2016–2022.

48. IBM Corp. IBM SPSS Statistics for Windows.

49. Thiese MS, Ronna B, Ott U. P value interpretations and considerations. *J Thorac Dis* 2016; 8: E928–E931.

50. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*. Academic press, Cambridge, Massachusetts, 2013.

51. Hair J, Black W, Babin B. *Multivariate Data Analysis: A Global Perspective*. 7th ed. Pearson Education, London, 2010.

52. Maykot JK, Rupp RF, Ghisi E. A field study about gender and thermal comfort temperatures in office buildings. *Energy Build* 2018; 178: 254–264.

53. Karjalainen S. Thermal comfort and gender: A literature review. *Indoor Air* 2012; 22: 96–109.

54. Rupp RF, Kim J, de Dear R, Ghisi E. Associations of occupant demographics, thermal history and obesity variables with their thermal comfort in air-conditioned and mixed-mode ventilation office buildings. *Build Environ* 2018; 135: 1–9.

55. Kenawy I, Elkadi H. The impact of cultural and climatic background on thermal sensation votes The impact of cultural and climatic background on thermal sensation votes AUTHOR(S). In: *PLEA 2013 : Proceedings of the 29th Sustainable Architecture for a Renewable Future Conference*. Munich, Germany, 10-12 September 2013. http://hdl.handle.net/10536/DRO/DU:30061646 (2013).

56. Cao B, Ouyang Q, Zhu Y, Huang L, Hu H, Deng G. Development of a multivariate regression model for overall satisfaction in public buildings based on field studies in Beijing and Shanghai. *Build Environ* 2012; 47: 394–399.

57. Mui KW, Chan WT. A new indoor environmental quality equation for air-conditioned buildings. *Archit Sci Rev* 2005; 48: 41–46.

58. Yang D, Mak CM. Relationships between indoor environmental quality and environmental factors in university classrooms. *Build Environ 2020*; 186: 107331. DOI: 10.1016/j.buildenv.2020.107331.

59. Gross S, Semmer NK, Meier LL, Kälin W, Jacobshagen N, Tschan F. The effect of positive events at work on after-work fatigue: They matter most in face of adversity. *Journal of Applied*

Psychology 2011; 96: 654–664.60. Johnston DW, Anastasiades P. *The relationship between heart rate and mood in real life.* J Psychosom Res 1990; 34(1):21-7.

61. Lin HP, Lin HY, Lin WL, Huang ACW. Effects of stress, depression, and their interaction on heart rate, skin conductance, finger temperature, and respiratory rate: Sympathetic-parasympathetic hypothesis of stress and depression. *J Clin Psychol* 2011; 67: 1080–1091.

62. Ward T. This is why getting scared can feel so good. *National Geographic*, https://www.nationalgeographic.com/science/article/why-fear-feels-good (2023, accessed 11 November 2023).

63. Forgas JP, Bower GH. Mood Effects on Person-Perception Judgments. *J Pers Soc Psychol* 1987; 53: 53–60.

64. Bluyssen PM. What do we need to be able to (re)design healthy and comfortable indoor environments? *Intelligent Buildings International* 2014; 6: 69–92.