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Orginal Article

Evaluating Thermal Comfort and Environmental Factors Using PMV-PPD Model: A Case Study in a Health Faculty in Yazd, Iran

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Abstract

Background: Thermal comfort is a multifaceted concept that is influenced by environmental factors such as air temperature, mean radiant temperature, air velocity, and relative humidity (RH). These elements significantly affect individual well-being and performance, particularly in office settings. Accordingly, this study investigated thermal comfort within a public health faculty.

Methods: This cross-sectional study was conducted in 2023 at a Health Faculty in Yazd, Iran. The study recorded the environmental parameters necessary for calculating the predicted mean vote (PMV) and predicted percentage of dissatisfied (PPD) on November 13th at 1 p.m. Calculations followed ISO 7730:2005 standards. Statistical analysis was performed using R version 4.3.3, with normality tested via the Shapiro-Wilk test. The Wilcoxon test was used for comparisons between two groups, while the Kruskal-Wallis test was utilized for multiple-group comparisons.

Results: The third floor exhibited a consistently higher temperature (24.1 °C), potentially causing discomfort. Although temperature, humidity, and thermal comfort indices varied across floors and corridors, the lack of statistical significance ($P>0.05$) suggests uniform environmental conditions. Most PMV values across floors fell outside the acceptable range ($-1<PMV<+1$), indicating general discomfort. PPD values were around 50% for all floors, except for the third floor, which had a PPD of 14%.

Conclusion: The study underscored the need for thermal comfort interventions in the health faculty building. A substantial portion of the building's occupants experienced thermal discomfort, potentially impacting their health and productivity. Addressing these issues is crucial for enhancing the overall environment and well-being of the faculty members and students.

Keywords: Predicted mean vote, Predicted percentage of dissatisfied, Thermal comfort, ISO 7730:2005, Fanger's model

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Introduction

Thermal comfort is a complex and multidimensional notion that is influenced by various factors such as cultural norms, social interactions, economic conditions, and climatic characteristics, all of which interact intricately with an individual's perception of comfort and satisfaction with their thermal environment (1). Environmental factors including air temperature, mean radiant temperature, air velocity, and relative humidity (RH) also significantly influence this concept (2). Thermal comfort significantly impacts health. Some adverse effects resulting from a lack of thermal comfort are heat stress, cold stress, and a weakened immune system, leading to an increased risk of illness (3,4). It also impacts well-being and productivity, especially in office settings (5,6), where it directly affects occupant satisfaction and indirectly contributes to issues like sick building syndrome (7). Designers have an essential role in fostering a balanced indoor climate by considering elements such as air temperature, humidity, radiation, and air movement (8). To enhance comfort in high-temperature conditions, the following strategies can be implemented: (1) Incorporating building design considerations that utilize materials with high thermal mass to regulate indoor temperatures and (2) Employing cooling strategies such as air conditioning, fans, or natural ventilation to lower air temperature, following the recommendations outlined in ASHRAE Standard 90.1 (9,10). However, achieving thermal comfort transcends mere regulation of room temperature; it involves a subjective, emotional connection with the environment (11).

The importance of thermal comfort extends beyond physical sensations, encompassing cognitive performance, emotional well-being, and overall satisfaction. In building environments, thermal comfort is crucial for both psychological and physical health, influencing morale, productivity, and individuals' willingness to engage with their surroundings. However, the relationship between thermal comfort and cognitive performance is intricate, with some measures showing minimal impact while others are significantly influenced by the thermal environment (12,13).

Energy consumption and thermal comfort are intrinsically linked. The significance of energy efficiency in heating and cooling structures cannot be overstated, as it plays a pivotal role in advancing sustainable development objectives. This underscores the crucial need to carefully adjust energy consumption patterns to strike a delicate balance between ensuring optimal levels of comfort and productivity for the occupants of these buildings(14).

The predicted mean vote (PMV) model, proposed by Fanger in the late 1960s (15), is widely used to assess thermal comfort levels in buildings (16,17). Based on experiments conducted in controlled climate chambers, the PMV model predicts thermal comfort by considering both personal and environmental factors (14). However, disparities have been noted between anticipated PMV values and actual thermal sensation ratings, particularly in warm climates (18,19). Empirical data analysis from naturally ventilated structures in Melbourne and Bangkok revealed discrepancies between predicted and actual thermal sensations, especially in warmer regions (14). The PPD index also shows the percentage of people who are dissatisfied with the thermal environment, and its value is derived from the PMV(20).

Investigating thermal comfort levels in hot climates has garnered attention from many researchers in recent years. Despite identified limitations, models like the PMV, grounded in the human heat balance principle, demonstrate a robust mathematical framework illustrating the interplay of factors affecting thermal comfort (14). Researchers in this field are still focused on adjusting or advancing these models (20), with efforts to refine them dating back to as early as 2002 and involving the integration of adaptive comfort concepts (21,22).

This study aimed to evaluate the impact of environmental factors on thermal comfort by applying the PMV-PPD model to identify potential disparities in thermal comfort across different floors and corridors of a public health faculty located in Yazd, a city characterized by an arid and hot climate, using the PMV-PPD model developed by Fanger.

The study was conducted in Yazd, Iran, a region with its own distinct climate and environmental conditions. This geographic specificity can provide unique insights into how local climatic factors influence thermal comfort in public buildings. Unlike many studies focused on hospitals or office buildings, this study targeted a health faculty building, providing insights into thermal comfort in educational and public health environments.

Materials and Methods

Study setting

This cross-sectional study was conducted on November 13, 2023, at 1 PM, at Shahid Sadoughi University, Faculty of Public Health, located in Yazd, Iran. Situated in the central region of Iran, Yazd has an arid and hot climate, characterized by coordinates of 31.89° N and 54.35° E, at an elevation of 1216 meters. The climatic conditions in Yazd adhere to the hot desert climate classification, designated as Köppen climate classification BWh (23, 24). This classification denotes Yazd's arid climate, featuring cool winters, hot summers, and a notable disparity between night and day temperatures.

Building description

The building utilized for this investigation (coordinates: 31.84° N, 54.33° E) is relatively new, having been operational for approximately nine years. It comprises four floors, with walls constructed primarily of brick. The inner section of the walls extends up to a height of approximately one meter and is composed of ceramic, while the rest is plastered. Additionally, the building features ceramic flooring and false ceilings constructed from compressed plastic, all in a light cream color scheme. It is equipped with a chiller-type central ventilation system, and the temperature inside the rooms is adjusted to the desired temperature using a thermostat. Its windows are double-glazed, consisting of two panes of glass, while the doors, mostly wooden, are frequently left open, helping to maintain constant conditions within the rooms and corridors.

Due to the architectural symmetry of the building, measurements were taken selectively on one side of the structure. Each floor of the building has two corridors (totaling eight corridors) lined with rooms. Within each corridor, measurements were conducted at three distinct locations: the beginning, middle, and end of the corridor. Moreover, sampling was performed at each location three times, resulting in a total of 36 samples from each distinct location.

Thermal comfort model

Data were collected using the QUESTemp 32 device to gauge a range of environmental parameters, including dry bulb temperature (T_d), wet bulb temperature (T_w), radiant temperature (T_r), RH, as well as both indoor and outdoor Wet Bulb Globe Temperature (WBGT) indices. PMV and PPD were calculated using equations 1-7. These meticulous measurements and analytical procedures significantly contributed to a holistic comprehension of the thermal comfort conditions prevailing within the designated setting, thereby providing invaluable insights for evaluating occupant comfort and overall well-being.

According to Fanger's model and ISO 7730:2005 (25), the PMV index is determined using the following equation (14,26):

$$PMV = \left[0.303 \times \exp\left(-0.036\left(M - W\right)\right) + 0.028\right] \times L, \quad (1)$$

In equation (1), the metabolic rate (M) is obtained from the ISO 7730 tables (26). W represents the effective mechanical power in watts per square meter, which is typically zero for most activities (27). The thermal load of the human body (L) is determined using the following equation (14):

$$L = (M-W) - 3.05\times10^{-3}\left[5733 - 6.99\cdot(M-W) - P_v\right] - 0.42\left[(M-W) - 58.15\right] - 1.7\times10^{-5}\times M\left(5867 - P_v\right) - 0.0014\times M\left(34 - T_d\right) - 3.96\times10^{-8}\times f_{cl}\left[\left(T_{cl}+273\right)^4 - \left(T_r+273\right)^4\right] + f_{cl}\times h_c\times\left(T_{cl}-T_d\right) \quad (2)$$

In this equation, the factors taken into account include the heat produced by the body through metabolic processes and external physical activity, as well as various mechanisms leading to heat loss such as convection, radiation, respiration, and evaporation. In Equation (2), the variables f_{cl}, h_c, and T_{cl} represent the clothing area factor, the convective heat transfer coefficient, and the temperature of the clothing surface, respectively.

The f_{cl} is determined as the ratio of the area covered by clothing on the body to the area of the body without clothing. This factor is closely linked to the thermal resistance provided by the clothing (14, 25, 26):

$$f_{cl} = \begin{cases} 1+1.29\times I_{cl} & if. \quad I_{cl}\le 0.078, \\ 1.05+0.645\times I_{cl} & if. \quad I_{cl} > 0.078, \end{cases} \quad (3)$$

I_{cl} represents the thermal resistance of clothing measured in Clo. Thermal resistance measures a material's or a component's resistance to heat flow. Thermal resistance of clothing is the fabric's capability to provide a thermal barrier between the human body and the surroundings (28). I_{cl} is obtained from ISO 7330 tables.

According to Fanger's model, the convective heat transfer coefficient from the human body (h_c) is determined using the following equation(14, 26):

$$h_c = Max\left(h_{c.free}, h_{c.forced}\right) \quad (4)$$

The convective heat transfer coefficients $h_{c.free}$ and $h_{c.forced}$ refer to free and forced convection modes, respectively (14, 26):

$$h_{c.force} = 12.1\sqrt{V_a} \quad (5)$$

V_a represents air velocity and is measured in m/s with an anemometer.
And,

$$h_{c.free} = 2.38(T_{cl}-T_a)^{0.25} \quad (6)$$

The clothing surface temperature (T_{cl}) is specified as (14, 26):

$$T_{cl} = 35.7 - 0.028(M-W) - 0.155 f_{cl} \begin{Bmatrix} (M-W) - 3.05\times10^{-3}\left[5733-6.99(M-W)-P_v\right] \\ -0.42\left[(M-W)-58.15\right] - 1.7\times10^{-5}M\left(5867-P_v\right) \\ -0.0014M\left(34-T_d\right) \end{Bmatrix} \quad (7)$$

The vapor pressure of the surrounding air (P_v) is calculated using a specific correlation(15,29):

$$P_v = \left(\frac{RH}{100}\right)\times\left(6.11\times10^{\left(\frac{7.5\times T_d}{237.3+T_d}\right)}\right) \quad (8)$$

Where RH is the air's relative humidity.

Moreover, according to the model developed by Fanger, the PPD index is calculated based on the following equation (26):

$$PPD = 100 - 95\cdot\exp\left(-0.03353PMV^4 - 0.2179PMV^2\right) \quad (9)$$

Statistical analysis

Descriptive and statistical analyses were performed utilizing R version 4.3.3. The Shapiro-Wilk test was employed to evaluate normality. Subsequently, the Wilcoxon unpaired test and the Kruskal-Wallis test were utilized to assess differences between groups, with the significance level set at <0.05. In instances where the Kruskal-Wallis test yielded significant results, supplementary post hoc analysis was conducted employing Dunn's test.

Results

Floor descriptions

The findings revealed several key aspects of the thermal environment across different floors. The third floor demonstrated the highest dry-bulb temperature (T_d) at 24.10 °C, while the second floor recorded the lowest at 22.70 °C. However, this difference was not statistically significant (Kruskal-Wallis test, $P=0.08$). In terms of wet-bulb temperature (T_w), the third floor again showed the highest values at 13.77 °C, with a significant difference observed between floors (Kruskal-Wallis test, $P=0.020$). Further analysis using Dunn's test with Bonferroni correction indicated a significant difference in T_w only between the first and third floors ($P=0.006$).

RH levels were highest on the third and second floors (17%), followed by the ground floor (16.33%) and the first floor (14.67%). No statistically significant difference in RH was detected between the floors (Kruskal-Wallis test, $P=0.261$). The third floor also demonstrated the highest radiant temperature (T_r), though this difference was not statistically significant (Kruskal-Wallis test, $P=0.064$).

For the WBGT, the third floor recorded the highest indoor ($WBGT_i$) and outdoor ($WBGT_o$) values, with readings of 17.10 °C and 17.00 °C, respectively. A significant difference was observed between floors for both $WBGT_i$ and $WBGT_o$ (Kruskal-Wallis test, $P=0.022$). Dunn's test with Bonferroni correction revealed significant differences for $WBGT_i$ and $WBGT_o$ only between the first and third floors ($P=0.007$).

The first floor had the highest absolute value for the PMV at -1.58, although no statistically significant difference was observed in PMV among various floors (Kruskal-Wallis test, $P=0.091$). Similarly, the first floor exhibited the highest value for the predicted percentage of dissatisfied (PPD) at 55.4%, but no significant differences were noted among different floors (Kruskal-Wallis test, $P=0.091$).

Detailed characteristics for each floor are provided in Figure 1 and Table 1.

Corridor descriptions

The findings indicated several key aspects of the thermal environment along the corridors. The end of the corridor exhibited the highest dry-bulb temperature (T_d) at 23.48 °C, followed by the middle (23.20 °C) and the beginning (22.77 °C). However, there was no statistically significant difference in Td along the corridors (Kruskal-Wallis test, $P=0.15$). Similarly, the wet-bulb temperature (T_w) recorded its highest values at the end of the corridor (13.07 °C), followed by the middle (12.97 °C) and the beginning (12.78 °C), with no significant difference observed along the corridors (Kruskal-Wallis test, $P=0.78$).

In terms of RH, the beginning of the corridor indicated the highest level (16.75%), with no significant difference detected along the corridors (Kruskal-Wallis test, $P=0.78$). The radiant temperature (T_r) was observed to be the highest at the end of the corridor (24.12 °C), but no significant difference was found in Tr along the corridors (Kruskal-Wallis test, $P=0.20$).

Regarding the WBGT indices, both indoor ($WBGT_i$) and outdoor ($WBGT_o$) values were highest at the end of the corridor (16.45 °C and 16.35 °C, respectively). However, no significant difference was observed along the corridors for $WBGT_i$ (Kruskal-Wallis test, $P=0.66$) or $WBGT_o$ (Kruskal-Wallis test, $P=0.77$).

The highest absolute value of the PMV was linked to the beginning of the corridor (-1.51), with no significant difference observed for PMV along the corridors (Kruskal-Wallis test, $P=0.14$). Similarly, the beginning of the corridor indicated the highest values for the PPD at 53.1%, though no significant difference was identified in PPD along the corridors (Kruskal-Wallis test, $P=0.14$). Detailed characteristics of the corridors are provided in Figure 2 and Table 2.

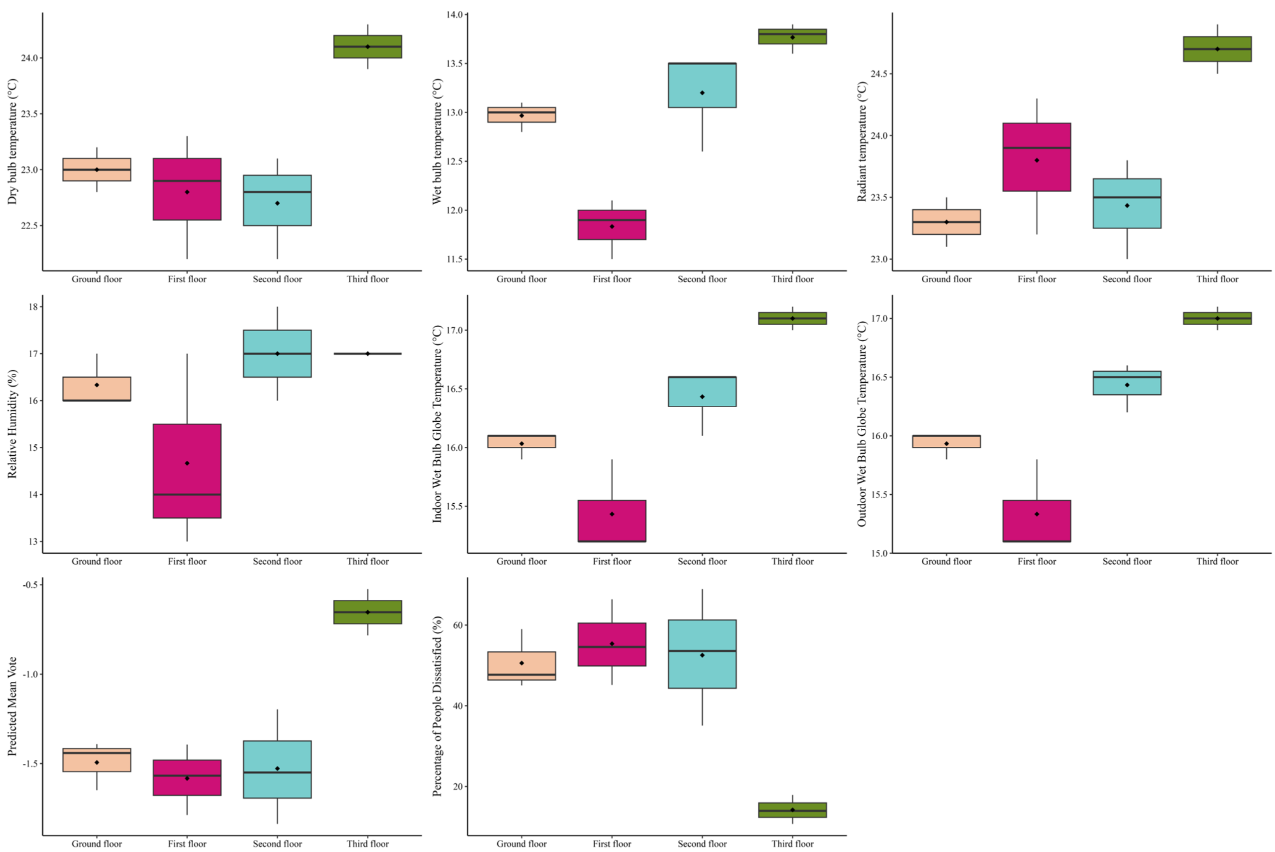

Figure 1. Boxplot of the environmental parameters on each floor

Table 1. Characteristics of each floor

	Ground floor	First floor	Second floor	Third floor	*P* value*	Overall
T_r (°C)						
Mean (SD)	23.30 (0.200)	23.80 (0.557)	23.40 (0.404)	24.70 (0.200)	0.064	23.80 (0.653)
Median [Min, Max]	23.30 [23.10, 23.50]	23.90 [23.20, 24.3]	23.50 [23.00, 23.80]	24.70 [24.50, 24.90]		23.70 [23.00, 24.90]
$WBGT_i$ (°C)						
Mean (SD)	16.00 (0.115)	15.40 (0.404)	16.40 (0.289)	17.10 (0.100)	0.022	16.30 (0.671)
Median [Min, Max]	16.10 [15.90, 16.10]	15.20 [15.2, 15.9]	16.60 [16.10, 16.60]	17.10 [17.00, 17.20]		16.10 [15.20, 17.20]
$WBGT_o$ (°C)						
Mean (SD)	15.90 (0.115)	15.30 (0.404)	16.40 (0.208)	17.00 (0.100)	0.022	16.20 (0.674)
Median [Min, Max]	16.00 [15.8, 16.0]	15.10 [15.1, 15.8]	16.50 [16.20, 16.60]	17.00 [16.90, 17.10]		16.10 [15.10, 17.10]
RH (%)						
Mean (SD)	16.30 (0.577)	14.70 (2.08)	17.00 (1.000)	17.00 (0)	0.261	16.30 (1.42)
Median [Min, Max]	16.00 [16.00, 17.00]	14.00 [13.00, 17.00]	17.00 [16.00, 18.00]	17.00 [17.00, 17.00]		17.00 [13.00, 18.00]
T_w (°C)						
Mean (SD)	13.00 (0.153)	11.80 (0.306)	13.20 (0.520)	13.80 (0.153)	0.020	12.90 (0.783)
Median [Min, Max]	13.00 [12.80, 13.10]	11.90 [11.50, 12.10]	13.50 [12.60, 13.50]	13.80 [13.60, 13.90]		13.10 [11.50, 13.90]
T_d (°C)						
Mean (SD)	23.00 (0.200)	22.80 (0.557)	22.70 (0.458)	24.10 (0.200)	0.080	23.20 (0.671)
Median [Min, Max]	23.00 [22.80, 23.20]	22.90 [22.20, 23.30]	22.80 [22.20, 23.10]	24.10 [23.90, 24.30]		23.10 [22.20, 24.30]
PMV						
Mean (SD)	-1.49 (0.137)	-1.58 (0.197)	-1.53 (0.321)	-0.65 (0.129)	0.091	-1.31 (0.438)
Median [Min, Max]	-1.44 [-1.65, -1.39]	-1.57 [-1.79, -1.39]	-1.55 [-1.84, -1.20]	-0.65 [-0.78, -0.52]		-1.42 [-1.84, -0.524]
PPD						
Mean (SD)	50.60 (7.41)	55.4 (10.6)	52.50 (16.90)	14.20 (3.59)	0.091	43.20 (19.80)
Median [Min, Max]	47.70 [45.00, 59.00]	54.6 [45.2, 66.4]	53.60 [35.10, 68.90]	14.00 [10.70, 17.90]		46.40 [10.70, 68.90]

Tr: Radiant temperature, WBGTi: Indoor Wet Bulb Globe Temperature, WBGTo: Outdoor Wet Bulb Globe Temperature, RH: relative humidity, Tw: wet bulb temperature, Td: dry bulb temperature, PMV: predicted mean vote, PPD: predicted percentage of dissatisfied.
* This is *P* value of the Kruskal-Wallis test, and the significant value is <0.05.

Relationship between PMV-PPD and other parameters

The correlation matrix presented in Figure 3 demonstrates significant interrelationships among environmental parameters and comfort-related variables. Radiant temperature (T_r) exhibited a strong positive correlation with dry bulb temperature (T_d) ($r=0.90$), PMV ($r=0.87$), and PPD ($r=0.87$), underscoring its pivotal role in influencing thermal comfort. The WBGT indices, both indoor ($WBGT_i$) and outdoor ($WBGT_o$) showed an almost perfect correlation ($r=0.99$).

Moderate correlations were observed between T_r and $WBGT_i$ ($r=0.58$), T_r and wet bulb temperature (T_w) ($r=0.54$), $WBGT_i$ and RH ($r=0.52$), and T_w and T_d ($r=0.64$). These moderate correlations suggest that while these variables are related, they do not exhibit the same strong association as those mentioned previously.

Conversely, RH demonstrates weak correlations with T_r ($r=0.02$), PMV ($r=0.28$), and PPD ($r=0.28$), indicating that RH has a relatively minor direct impact on these comfort parameters compared to other variables.

In summary, the correlation matrix highlights the dominant influence of radiant temperature on thermal comfort indicators and the strong coherence between different measures of WBGT, while also identifying the comparatively lesser role of RH in direct thermal comfort assessments.

Discussion

This study assessed the thermal comfort levels within a health faculty building in Yazd, Iran. Utilizing the PMV-PPD model, the study evaluated the impact of environmental factors such as air temperature, mean radiant temperature, air velocity, and RH on the thermal comfort of occupants.

An evaluation of thermal comfort indices and environmental parameters in the health faculty building in Yazd, Iran, revealed significant findings. Notably, the third floor consistently exhibited higher values for environmental parameters, yet occupants reported the highest comfort levels on this floor, as evidenced by the lowest scores for PMV and PPD. This finding is inconsistent with the study conducted by Kamar et al. which showed lower comfort levels correlated with higher values of environmental parameters (30). This

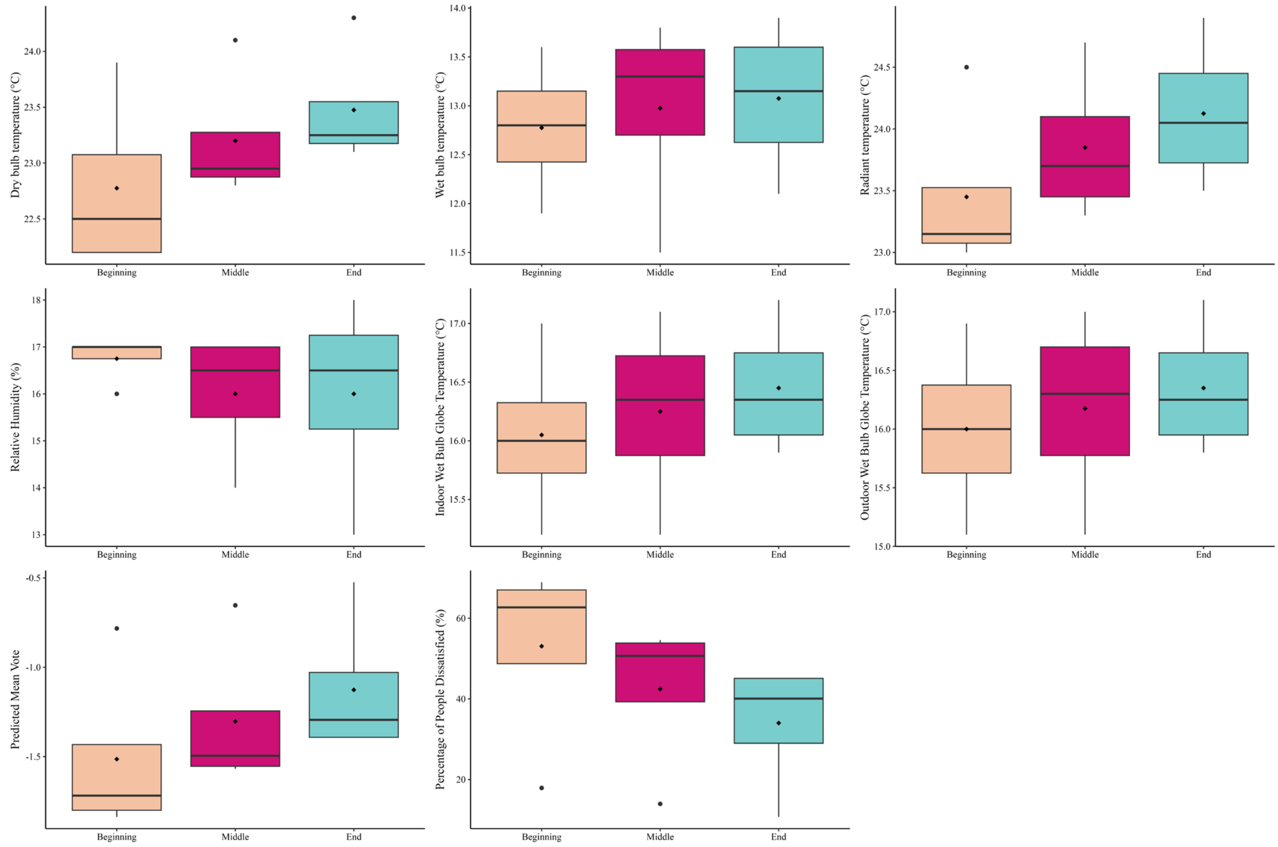

Figure 2. Boxplot of environmental parameters along the corridors

discrepancy may be attributed to differences in building types and their ventilation systems.

Although the first floor exhibited higher discomfort indicators, the lack of statistical significance implies a generally uniform thermal comfort across all floors. There are two possible scenarios: (1) the PMV/PPD model may underestimate thermal sensation for a specific subgroup on the first floor, similar to the reported underestimation of indoor thermal sensation in the PMV model compared to the thermal sensation vote (TSV) by Dhaka et al (31), and (2) potential issues with the air-conditioning system may contribute to localized thermal discomfort. However, further investigation of the first floor is warranted.

Analysis of the corridors revealed fluctuations that underscored the complexities of the building's thermal environment. Temperature, humidity, radiant temperature, and thermal comfort indices exhibited noticeable variations along the corridors. In some instances, these variances lacked statistical significance, indicating the need for further investigation. This is consistent with studies conducted by Niemann et al. and Azar et al. which showed fluctuations in environmental factors in office buildings (32,33).

A notable observation is that temperatures tend to be higher at the ends of the corridors, potentially due to airflow patterns, differences in ventilation and heating systems, or external heat sources. However, the lack of statistical significance suggests a relatively consistent temperature distribution across the corridors. This emphasizes the need to consider factors beyond temperature when assessing thermal comfort, as thermal comfort is a complex and multidimensional concept influenced by various factors, including cultural norms, social interactions, environmental factors, and climatic characteristics (14).

Higher humidity levels were usually found at the beginning of the corridors, which, together with other factors, can negatively affect thermal comfort, as observed by Jing et al (34). Despite this trend, the lack of statistical significance suggests that humidity levels are generally uniform across corridors.

There were no statistically significant fluctuations in WBGT, which is a measure of heat stress. However, due to higher dry and wet temperatures, WBGT indices peak at the corridor ends, indicating potentially higher heat exposure in those areas. Despite this, the overall uniformity across the corridors remains noteworthy.

Fluctuations in thermal comfort indices such as PMV and PPD did not achieve statistical significance. This suggests that occupants' perceived comfort remains consistent regardless of their position within the corridors. Coupled with the lack of statistically significant variations in environmental parameters, this implies a complex interplay of factors influencing thermal comfort

Table 2. Characteristics of each sampling point in the corridor

	Beginning	Middle	End	*P* value	Overall
T_r (°C)					
Mean (SD)	23.50 (0.705)	23.90 (0.619)	24.10 (0.613)	0.201	23.80 (0.653)
Median [Min, Max]	23.20 [23.00, 24.50]	23.70 [23.30, 24.70]	24.10 [23.50, 24.90]		23.70 [23.00, 24.90]
$WBGT_i$ (°C)					
Mean (SD)	16.10 (0.742)	16.30 (0.810)	16.50 (0.580)	0.771	16.30 (0.671)
Median [Min, Max]	16.00 [15.20, 17.00]	16.40 [15.20, 17.10]	16.40 [15.90, 17.20]		16.10 [15.20, 17.20]
$WBGT_o$ (°C)					
Mean (SD)	16.00 (0.753)	16.20 (0.826)	16.40 (0.580)	0.771	16.20 (0.674)
Median [Min, Max]	16.00 [15.10, 16.90]	16.30 [15.10, 17.00]	16.30 [15.80, 17.10]		16.10 [15.10, 17.10]
RH (%)					
Mean (SD)	16.80 (0.500)	16.00 (1.410)	16.00 (2.160)	0.782	16.30 (1.42)
Median [Min, Max]	17.00 [16.00, 17.00]	16.50 [14.00, 17.00]	16.50 [13.00, 18.00]		17.00 [13.00, 18.00]
T_w (°C)					
Mean (SD)	12.80 (0.714)	13.00 (1.02)	13.10 (0.793)	0.782	12.90 (0.783)
Median [Min, Max]	12.80 [11.90, 13.60]	13.30 [11.50, 13.80]	13.20 [12.10, 13.90]		13.10 [11.50, 13.90]
T_d (°C)					
Mean (SD)	22.80 (0.80)	23.20 (0.606)	23.50 (0.556)	0.150	23.20 (0.671)
Median [Min, Max]	22.50 [22.20, 23.90]	23.00 [22.80, 24.10]	23.30 [23.10, 24.30]		23.10 [22.20, 24.30]
PMV					
Mean (SD)	-1.51 (0.494)	-1.30 (0.437)	-1.13 (0.412)	0.143	-1.31 (0.438)
Median [Min, Max]	-1.72 [-1.84, -0.78]	-1.50 [-1.57, -0.65]	-1.29 [-1.39, -0.52]		-1.42 [-1.84, -0.52]
PPD					
Mean (SD)	53.10 (23.80)	42.50 (19.20)	34.00 (16.20)	0.141	43.20 (19.80)
Median [Min, Max]	62.70 [17.90, 68.90]	50.70 [14.00, 54.60]	40.10 [10.70, 45.20]		46.40 [10.70, 68.90]

Tr: Radiant temperature, WBGTi: Indoor Wet Bulb Globe Temperature, WBGTo: Outdoor Wet Bulb Globe Temperature, RH: Relative humidity, Tw: wet bulb temperature, Td: dry bulb temperature, PMV: Predicted Mean Vote, PPD: Predicted Percentage of Dissatisfied.
* This is the p-value of Kruskal-Wallis test, and the significant value is < 0.05.

as mentioned by Omidvar et al. in their study (14).

Examining thermal comfort conditions within the public health faculty building revealed concerning findings. The analysis of the PMV scores indicated a significant deviation from the preferred range of -1 to + 1, which signifies a comfortable thermal environment (35). Notably, only occupants on the third floor reported thermal comfort within this optimal zone.

Further evaluation using the PPD values provided clearer insights. Floors other than the third exhibited a concerning trend, as the PPD values consistently remained around 50%, resulting in a potential thermal dissatisfaction rate for roughly half the occupants on these floors. PMV values exceeding the recommended range on these floors further confirm this discomfort.

A study conducted in Kermanshah evaluated the thermal comfort levels within a hospital environment using the PMV-PPD model. The findings revealed a significant portion of the hospital experienced thermal discomfort, with conditions falling outside the acceptable comfort range defined by relevant standards. These discomfort levels were often associated with specific seasons and times of day (e.g., winter morning and summer noon), highlighting the need for adjustments in heating and cooling systems (27). Another study conducted surveys and field experiments in six office buildings in Tehran during the summer months and found that a significant number of offices did not meet the thermal comfort standards set by ASHRAE 55 and ISO7730 (36). Moreover, another study investigating thermal comfort among hospital staff in Isfahan, Iran, showed the units located on the underground floor required better design to facilitate natural ventilation and sufficient airflow to achieve optimal thermal comfort according to international standards (37). Consistent with these studies across diverse building types, including offices and hospitals, the present study identified a high prevalence of thermal discomfort. Employing a standardized PMV-PPD modeling approach, these studies, along with the present study, underscored the complex interplay between environmental factors, occupant characteristics, and building design in determining thermal comfort.

While some analyses did not yield statistically significant differences, the observed trends indicated a

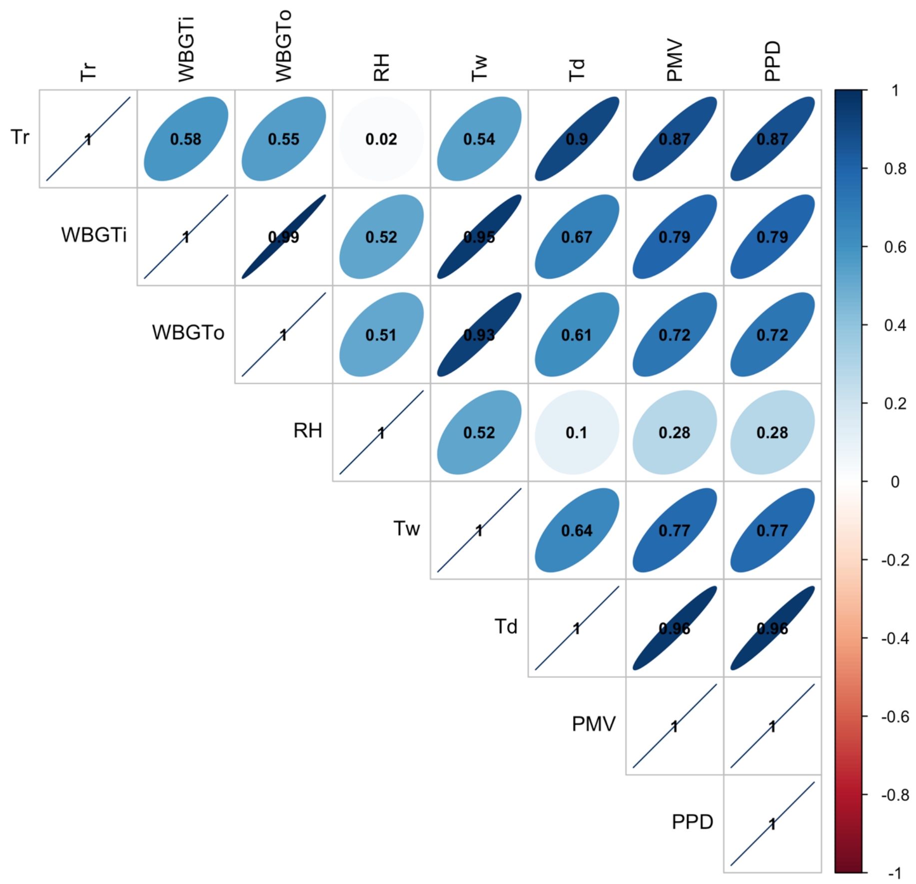

Figure 3. Correlation of PMV-PPD parameters

need for further investigation. These subtle variations could significantly impact specific occupant groups, such as those with high activity levels or minimal clothing. Understanding the underlying causes of these trends is essential for developing targeted interventions to enhance thermal comfort throughout the building.

To achieve statistically significant results, a more comprehensive data collection effort is required. This extended study should cover a longer timeframe and be compared with occupant surveys to identify potential discomfort zones. Thoroughly examining these subtleties will deepen our understanding of the building's thermal environment and allow us to devise a strategy to ensure a comfortable experience for all occupants of the health faculty building.

Conclusion

The third floor exhibited consistently higher temperatures; however, it surprisingly had the most comfortable occupants, as indicated by PMV and PPD scores. There were no statistically significant differences in thermal comfort across the various floors, suggesting uniformity despite variations in some parameters. The corridors displayed fluctuations in temperature, humidity, and thermal comfort indices although these variations often lacked statistical significance.

Overall, PMV scores indicated significant deviations from the ideal comfort zone, with only the third-floor occupants reporting comfortable conditions. PPD values revealed a concerning trend for all floors except the third, suggesting occupant dissatisfaction with thermal comfort. These findings underscore the importance of addressing thermal discomfort in indoor environments to enhance occupants' well-being and productivity.

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Competing Interests

The authors declare that they have no affiliations with or financial interests related to the subject matter or materials discussed in this research.

Ethical Approval

This study has the approval of Shahid Sadoughi University of Medical Sciences Ethics Committee number IR.SSU.SPH.REC.1403.134.

Consent to Publish

The authors consent to the publication of all content included in this manuscript.

Consent to Participate

Not applicable.

Data Availability Statement

All experimental results are presented in the manuscript, and additional results are available in the supplementary material.

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References

1. Houda M, Djamel A, Fayçal L. An assessment of thermal comfort and users' "perceptions" in office buildings - case of arid areas with hot and dry climate. Energy Procedia. 2015;74:243-50. doi: 10.1016/j.egypro.2015.07.589.
2. Fang Z, Feng X, Lin Z. Investigation of PMV model for evaluation of the outdoor thermal comfort. Procedia Eng. 2017;205:2457-62. doi: 10.1016/j.proeng.2017.09.973.
3. Hampo CC, Schinasi LH, Hoque S. Surviving indoor heat stress in United States: a comprehensive review exploring the impact of overheating on the thermal comfort, health, and social economic factors of occupants. Heliyon. 2024;10(3):e25801. doi: 10.1016/j.heliyon.2024.e25801.
4. Shen YH, Zheng JW, Zhang ZB, Li CM. Design and implementation of a wearable, multiparameter physiological monitoring system for the study of human heat stress, cold stress, and thermal comfort. Instrum Sci Technol. 2012;40(4):290-304. doi: 10.1080/10739149.2012.673193.
5. Kaushik A, Arif M, Tumula P, Ebohon OJ. Effect of thermal comfort on occupant productivity in office buildings: response surface analysis. Build Environ. 2020;180:107021. doi: 10.1016/j.buildenv.2020.107021.
6. Lamberti G, Salvadori G, Leccese F, Fantozzi F, Bluyssen PM. Advancement on thermal comfort in educational buildings: current issues and way forward. Sustainability. 2021;13(18):10315. doi: 10.3390/su131810315.
7. Ha H, Thi Hoa N, Tien Binh P. Simple method to improve the TCXDVN 306:2004 indoor climate standard for closed office workplaces in Vietnam. Sci Rev Eng Environ Sci. 2021;30(1):117-33. doi: 10.22630/pniks.2021.30.1.11.
8. Ambare A. Thermal comfort in built form. Int J Eng Innov Res. 2014;3(2):190-4.
9. de Abreu-Harbich LV, Chaves VL, Brandstetter MC. Evaluation of strategies that improve the thermal comfort and energy saving of a classroom of an institutional building in a tropical climate. Build Environ. 2018;135:257-68. doi: 10.1016/j.buildenv.2018.03.017.
10. Latha PK, Darshana Y, Venugopal V. Role of building material in thermal comfort in tropical climates–a review. J Build Eng. 2015;3:104-13. doi: 10.1016/j.jobe.2015.06.003.
11. Parsons S, Kriwoken LK. Thermal Mass, Thermal Comfort and Thermoregulation in Cool Temperate Climate Residential Buildings. Canberra: Australian and New Zealand Solar Energy Society; 2006.
12. Mueller ST, Tan YY, Flint I. Development and evaluation of a model of human comfort and cognitive ability for moderate differences in thermal environment. In: Stephanidis C, eds. HCI International 2019 – Late Breaking Papers. Cham: Springer; 2019. p. 395-401. doi: 10.1007/978-3-030-30033-3_31.
13. Senin MK, Mydin MA. Significance of thermal comfort in buildings and its relation to the building occupants. European Journal of Technology and Design. 2013;1(1):54-63.
14. Omidvar A, Kim J. Modification of sweat evaporative heat loss in the PMV/PPD model to improve thermal comfort prediction in warm climates. Build Environ. 2020;176:106868. doi: 10.1016/j.buildenv.2020.106868.
15. Ole Fanger P. Introduction of a basic comfort equation. ASHRAE Trans. 1967;73(2):1-20.
16. Ali SF, Sharma L, Rakshit D, Bhattacharjee B. Influence of passive design parameters on thermal comfort of an office space in a building in Delhi. J Archit Eng. 2020;26(3):04020017. doi: 10.1061/(ASCE)AE.1943-5568.0000406.
17. Kaushal AA, Anand P, Aithal BH. Assessment of the impact of building orientation on PMV and PPD in naturally ventilated rooms during summers in warm and humid climate of Kharagpur, India. In: Proceedings of the 10th ACM International Conference on Systems for Energy-Efficient Buildings, Cities, and Transportation. New York, NY: Association for Computing Machinery; 2023. p. 528-33. doi: 10.1145/3600100.3627034.
18. Doherty TJ, Arens E. Evaluation of the physiological bases of thermal comfort models. ASHRAE Trans. 1988;94(1):1371-85.
19. Kähkönen E. Draught, radiant temperature asymmetry and air temperature–a comparison between measured and estimated thermal parameters. Indoor Air. 1991;1(4):439-47. doi: 10.1111/j.1600-0668.1991.00008.x.
20. Khalil A, Bassuoni MM, Elsamadony MO, Raslan MA. Assessment of thermal comfort in operating rooms using PMV-PPD model. J Eng Res. 2020;4(12):51-62. doi: 10.21608/erjeng.2020.131508.
21. Ole Fanger P, Toftum J. Extension of the PMV model to non-air-conditioned buildings in warm climates. Energy Build. 2002;34(6):533-6. doi: 10.1016/s0378-7788(02)00003-8.
22. Song X, Yang L, Zheng W, Ren Y, Lin Y. Analysis on human adaptive levels in different kinds of indoor thermal environment. Procedia Eng. 2015;121:151-7. doi: 10.1016/j.proeng.2015.08.1042.
23. Humphreys MA, Fergus Nicol J. The validity of ISO-PMV for predicting comfort votes in every-day thermal environments. Energy Build. 2002;34(6):667-84. doi: 10.1016/s0378-7788(02)00018-x.
24. Sung H, Ferlay J, Siegel RL, Laversanne M, Soerjomataram I, Jemal A, et al. Global cancer statistics 2020: GLOBOCAN estimates of incidence and mortality worldwide for 36 cancers in 185 countries. CA Cancer J Clin. 2021;71(3):209-49. doi: 10.3322/caac.21660.
25. Mousighichi P. Comparison of Courtyards in Traditional Iranian Houses in Different Climates of Iran [dissertation]. İzmir Ekonomi Üniversitesi; 2023.
26. International Organization for Standardization (ISO). ISO 7730 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, Switzerland: ISO; 2005 .
27. Pourshaghaghy A, Omidvari M. Examination of thermal comfort in a hospital using PMV-PPD model. Appl Ergon. 2012;43(6):1089-95. doi: 10.1016/j.apergo.2012.03.010.
28. Zhang W, Huang Q, Wang Y, Li J. The predicted heat strain model considering wet and dynamic thermal insulation for

thermal protective clothing: modification and validation analysis. Text Res J. 2022;92(23-24):4563-75. doi: 10.1177/00405175221106227.
29. Cengel Y, Ghajar A. Heat and Mass Transfer: Fundamentals and Applications. 4th ed. McGraw Hill; 2011.
30. Mohamed Kamar H, Kamsah NB, Ghaleb FA, Idrus Alhamid M. Enhancement of thermal comfort in a large space building. Alex Eng J. 2019;58(1):49-65. doi: 10.1016/j.aej.2018.12.011.
31. Dhaka S, Mathur J, Brager G, Honnekeri A. Assessment of thermal environmental conditions and quantification of thermal adaptation in naturally ventilated buildings in composite climate of India. Build Environ. 2015;86:17-28. doi: 10.1016/j.buildenv.2014.11.024.
32. Azar E, Menassa CC. A comprehensive analysis of the impact of occupancy parameters in energy simulation of office buildings. Energy Build. 2012;55:841-53. doi: 10.1016/j.enbuild.2012.10.002.
33. Niemann P, Schmitz G. Impacts of occupancy on energy demand and thermal comfort for a large-sized administration building. Build Environ. 2020;182:107027. doi: 10.1016/j.buildenv.2020.107027.
34. Jing S, Li B, Tan M, Liu H. Impact of relative humidity on thermal comfort in a warm environment. Indoor Built Environ. 2013;22(4):598-607. doi: 10.1177/1420326x12447614.
35. Warey A, Kaushik S, Khalighi B, Cruse M, Venkatesan G. Data-driven prediction of vehicle cabin thermal comfort: using machine learning and high-fidelity simulation results. Int J Heat Mass Transf. 2020;148:119083. doi: 10.1016/j.ijheatmasstransfer.2019.119083.
36. Nasrollahi N, Knight I, Jones P. Workplace satisfaction and thermal comfort in air conditioned office buildings: findings from a summer survey and field experiments in Iran. Indoor Built Environ. 2008;17(1):69-79. doi: 10.1177/1420326x07086945.
37. Sajedifar J, Mirzaei R, Teimori GH, Mehri A, Azadbakht F, Choupani A, et al. Evaluation of thermal comfort in an Iranian educational hospital using PMV-PPD model. Biotechnol Health Sci. 2017;2017:e57653. doi: 10.5812/bhs.57653.