The relation between occupant's mood state and thermal sensation

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Abstract. Thermal comfort is mainly evaluated by the Fanger's Predicted Mean Vote/Predicted Percentage of Dissatisfied (PMV/PPD) method and adaptive thermal comfort approaches. PMV/PPD method takes four environmental (such as indoor air temperature, relative humidity, mean radiant temperature and air velocity) and two personal parameters (basic clothing insulation and metabolic rate) into account for calculations. On the other hand, adaptive approach adds human behaviours to the thermal comfort models. However, none of these models includes the effect of the mood state of the occupants on thermal sensation. To this aim, this study investigates the relationship between occupant's mood state and thermal sensation as a case study. Pre-test-Post-test Control (PPC) experimental design is conducted on the students in a university study hall in Turkey. Profile of Mood States (POMS) is used to examine the effect of mood state on the thermal sensation while the Actual Mean Vote (AMV) is obtained via developed mobile application. Simultaneously, the PMV is calculated in order to obtain the difference from the AMV. The results showed that there is a strong relationship between the mood state and thermal sensation. The outcome of this study would enlighten the HVAC engineers and specialists in order to understand the gap between PMV and AMV caused by the mood state.

Keywords. Profile of Mood States, Thermal Sensation, Psychology
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1. Introduction

Thermal comfort mainly depends on four environmental parameters such as indoor air temperature (T_i), relative humidity (RH_i), mean radiant temperature (T_r) and air velocity (v_a) and two personal parameters as basic clothing insulation (I_{cl}) and metabolic rate (met) [1]. International standards such as ASHRAE 55 [2] and ISO 7730 [3] still use Fanger's Predicted Mean Vote/Predicted Percentage of Dissatisfied (PMV/PPD) method as thermal comfort index [1]. The method uses the parameters above and runs seven-point thermal comfort scale from -3 (represents very cold scale) to +3 (represents very hot scale). In addition, zero (0) PMV value claims that the occupant is fully comfortable in a given environment. In other words, neutral thermal comfort, not thermal sensation, is obtained in an environment. Considering the definition of the thermal comfort in the ASHRAE 55 [2], as "*the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation*", it is obvious that thermal sensation not only depends on physiological parameters but also psychological ones. The side of the "State of the Mind" in the definition should be explained in detail. Recent studies showed that thermal sensation also depends on psychology, stress levels, culture and climate adaptation etc. [4-8]. For instance, Rohles [5] conducted an experiment with two different occupants in two different rooms with the same architectural configuration. However, there was a heater in one of the rooms and no heater was existed in another, however, both occupants were informed by the researchers as there was a heater in the room. According to the outcomes of the study, both occupants stated that they felt warm in the room. In another study by Turhan and Özbey [8], the effect of one of the psychological parameters; stress level was investigated on the thermal sensation of students. The authors stated that there was a strong relationship between the stress level and thermal sensation. Similar to the Turhan and

Özbey's study [8], Jones [9] considered that absence of psychological variables in thermal comfort models caused the gap between measured and actual thermal comfort since thermal sensation was highly related to the psychological variables as well as physical parameters. The effect of the psychological parameters especially increases in unconditioned or mixed-mode buildings. For instance, Singh et al. [10] concluded that the reason of the gap between thermal comfort and sensation was psychological parameters in unconditioned buildings.

Mood state is one of the affective states in psychology field [11]. For instance, Muller et al. [12] stated that in cold environments, occupants felt negative mood states and as a conclusion, were triggered to alter their human cognition, daily activities and wellbeing. Ibrahim et al. [13] conducted virtual settings-based experiments to investigate the effect of mood states on human evaluation of the thermal environment. The participants were requested to use the PANAS-X pre-mood test [14] before watching a video that targeted eliciting predetermined mood states: anger and happiness. By using linear models, the researchers concluded that happy and angry occupants voted different thermal sensation scale in the same environment. However, none of the studies included all of the mood states as a psychological rating scale used to assess transient and distinct mood states. The experiments in a real and living buildings are essential.

This study aims to investigate the relationship between occupant's mood state and thermal sensation with experiments conducted in a university study hall in Turkey.

2. Materials and Methods

The method of the study includes objective measurements, such as PMV, T_i, RH_i and T_r, and subjective measurements from online surveys in order to learn basic clothing insulation (I_{cl}) value, thermal preferences (AMV) and Profile of Mood States (POMS) score of the occupants.

2.1 design of experiments

The experiments are conducted in a Turkish university study hall in Csb climate zone according to the Köppen Geiger Climate classification [15]. The total capacity of the study hall is 912 occupants, however, the experiments are conducted in a 10 m^2 zone of the total zone (Fig.1). The average outdoor temperatures for the building location is -3.3°C and 14°C for winter and summer seasons, respectively [16]. In the building, there is no mechanical ventilation in the hall while the heating is obtained by four radiators with a fixed 22°C set-temperature value of each. Moreover, there is no mechanical system for cooling, thereby, the occupants prefer to open the doors for fresh air and cooling purposes.

A hundred two apparently healthy and normotensive male and female occupants are included in the study. As an example, Table 1 depicts the main characteristics of the occupants included in the experimental and control group. For the experiments, the study hall is used by students, researchers and academicians during experiments between 15th of July, 2021 and 1st of November, 2021. Occupants are selected from different majors such as Engineering, Architecture, Psychology and Fine Arts. Pre- and Post- Control (PPC) tests are conducted in the experiments. For this reason, the students are split into two equal groups (control and experimental groups). The experiments are conducted before and after activities. A total of 102 occupants is attended to the study. As a first step, permissions are taken from the Ethics Committee of the University and the occupants are informed of the aim and experimental procedures.

Tab. 1 - Main characteristics of the occupants in experimental and control groups.

Experimental Group			
Gender	Average Age	Age Range	Total Number
Male	24.1	18-67	35
Female	22.8	18-54	16
Total	23.5	18-67	51
Control Group			
Male	24.2	18-67	35
Female	22.6	18-54	16
Total	23.6	18-67	51

Then, the occupants are requested to rest for thirty minutes since high metabolic rates after arriving the study hall could affect their thermal sensations and mood states. Likewise, the authors ensure that the occupants never take caffeine based drinks and alcohol before the experiments by interview method. In the study, experiments are conducted on pre-and post- periods with one-hour time interval (Fig.1).

Fig. 1 - Snapshot of pre-and post-experiments.

The occupants are requested to use mobile application while environmental parameters are measured by objective sensors. The environmental parameters to be measured are chosen as PMV, T_i, T_o, RH_i, RH_o and T_r. All measurement devices are placed at 1.1 m above the ground. The list of measurement devices and their specifications are given in Table 2. The measurements are taken with 1-minute interval during experiments.

Tab. 2 – Measurement devices and specifications

Device	Model	Aim of the usage	Specifications
Thermal Comfort Sensor	Delta Ohm [17]	PMV, T_i,RH_i, T_r	Measuring range: -10-100 °C. Accuracy: ±0.1°C Resolution: 0.1°C
Temperature and Relative Humidity Sensor	Onset HOBO [18]	T_o and RH_o	Measuring range: −40-80°C Accuracy: <±0.5°C Resolution: 0.1°C

For the experiments such as obtaining mood state and/or thermal sensation, occupants should not be in close contact with other occupants since the mood state can be affected by occupants that stay close. For this reason, the experimental zone is isolated from the other occupants. On the other hand, occupants in control group do not study any major, instead, they are requested to read their favourite books with underlining the all sentences of the book. The reason of underlining sentences is to obtain same metabolic rate with experimental group. On the other hand, occupants in experimental group study their majors.

Finally, the metabolic rate of the students are assumed as 1.1 met regarding to seated-typing (65 W/m^2) position [2].

2.2 assessing mood state of occupants

In the study, Profile of Mood States (POMS) test is used to assess mood state of the occupants. The POMS test is a self-reported questionnaire in order to obtain mood state of the occupants developed by McNair et al [19]. The test includes 65 mood states which load on six different sub- scales such as depression, anxiety, fatigue, vigour, tension, and confusion. Total Mood Disturbance (TMD) is calculated by subtracting positive feelings from negative feelings. Negative feelings include the sum of the scores of Tension-Anxiety (TA), Anger-Hostility (AH), Depression-Dejection (DD), Fatigue-Inertia (FI), and Confusion-Bewilderment (CB), while the positive feeling is only represented by Vigor-Activity (VIG). After finding the value of the raw scores of the TMD, they are converted into normalized T-scores [19] with a mean equal to 50 and a standard deviation equal to 10 [20,21] by equation 1.

$$T - Score = 50 + \frac{10 \times (n-m)}{s} \quad (1)$$

Here, n represents the raw scores, m defines the mean, and s is the standard deviation [19, 22]. Increasing T-score could indicate a worsening of the mood. More information on the usage of the POMS in thermal comfort field can be found in [8]. One-tailed *t-test* is used in order to understand the relationship between mood state and thermal sensation. Experiments are conducted to verify null hypothesis (H0: $\tau i = 0$) below;

"There are no positive and significant relationships between mood state and thermal sensation".

The hypothesis is analyzed for occupants at a 5% significance level ($\alpha = 0.05$). The null hypothesis is assumed to be rejected if p-value is found to be lower than 0.05. Alongside the statistical tests, it is also worth to analyze effect size (d_{ppc}), which interprets practical significance, in order to assess the size of differences between experimental group and control group for repeated experiments. Detail information on the calculation of effect size is given in [8, 23, 24]. The SPSS statistical computer package is used to analyze the results [25].

2.3 development of mobile application

A mobile application is developed for smartphones and tablet computers to obtain subjective values such as AMV, mood state score and basic clothing insulation value. Four interfaces are developed for the study. In first interface, main characteristics (gender, nationality, weight and height etc.) of the occupants are asked while garments are simultaneously asked in order to calculate "clo" value of the occupants in the second interface. The occupants are requested to pick their garments in the list developed from the ASHRAE 55 clothing list [2]. Thus, the mobile application easily calculates basic clothing insulation value of the occupant. In third interface, the POMS test asks positive and negative feelings of the occupants by referring a scale where "0 star" means "not at all" and "5 stars" means "extremely". In final interface, the occupant is asked to fill the AMV section by selecting their thermal preferences from the ASHRAE 7-point scale which runs between cold (−3) and hot (+3). The collected data are then stored in a web-server. An example screenshot of the developed mobile application is depicted in Fig.2.

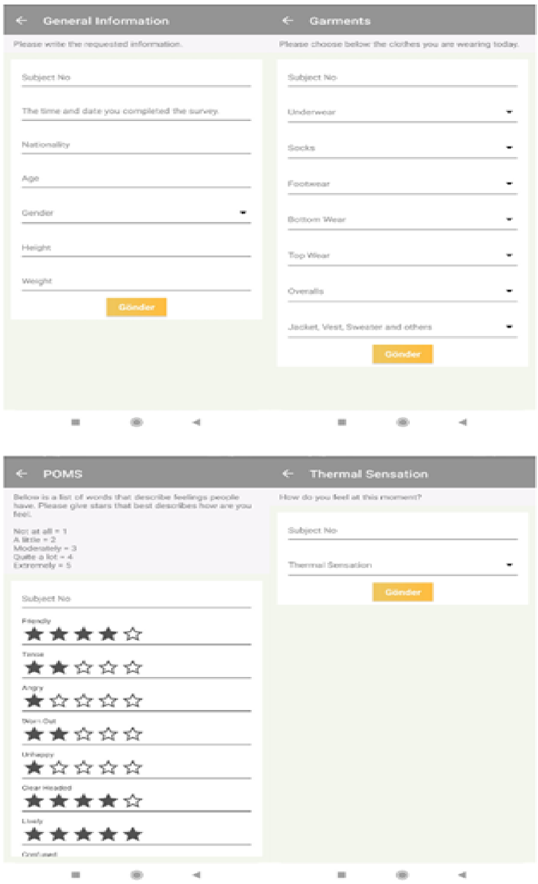

Fig. 2 – Example screenshot of the developed mobile application

3. Results and Discussions

The environmental parameters are measured during pre- and post- experiments and the results are depicted in Table 2.

Tab. 2 – The results of objective measurements during experiments

parameter	Average	SD
PMV	-0.47	0.38
T_i	23.8	2.4
T_o	24.1	4.6
RH_i	35.8	10.4
RH_o	30.9	10.1
T_r	23.9	2.1

The average PMV values are measured as -0.47 on the cooler side. Moreover, average indoor air temperature is obtained as 23.8°C. It is worth to remind that there are minor temperature and relative humidity differences between pre- and post-test experiments. However, this difference can be neglected in the study.

Fig.3 depicts the sub-scales of the POMS items on abscissa for both groups while their T-scores are represented on y-axis. The figure clearly indicates that T-scores of the negative mood states (TA+AH+DD+FI+CB) of the control groups are lower than the experimental groups for post-test results. In addition, positive mood states (VIG) of the experimental group are lower than control group. This result indicates that studying a major increases stress level as a conclusion of increasing negative mood states. On the other hand, total score of the positive mood states are declining while studying a major in a study hall. Total T-score of the experimental group is found as 52.7 and 68.4 for pre-and post-tests, respectively. The result shows that negative mood states are dominant compared to positive mood states for post-test data. Similarly, one can compare the pre- and post- tests results of control group. The figure depicts that total T-score of the control group does not differ for pre-and post- tests data. This result concludes that mood state of the control group does not change while the mood state of the experimental group worsens.

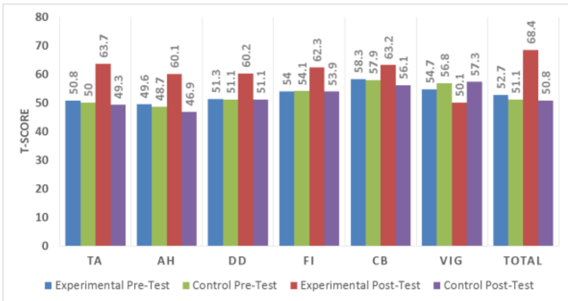

Fig. 3 – Pre- and Post- Tests T-scores for control and experimental groups

Table 3 represents the evaluation of the T-scores in POMS between control and experimental groups. There are no significant difference between two groups on the pre-test experiments. On the other hand, statistical results conclude that there are some significant differences between the control and experimental groups in the T-score of the POMS for the post-test. It is found that total T-score of the mood state is significant at 1% level, while other sub-scales are found to be significant at 5% level.

Tab. 3 –Scores of Profile of Mood States (POMS) in the control and experimental groups

Control versus Experimental groups				
Pre-Test	T-score	t-value	p-value	significance
TA	50±3	0.91	0.18	(-)
AH	49±4	0.80	0.21	(-)
DD	51±2	0.86	0.19	(-)
FI	54±3	0.61	0.27	(-)
CB	58±2	0.41	0.35	(-)
VIG	56±4	0.26	0.41	(-)
Total	51±3	1.21	0.11	(-)
Post-Test	T-score	t-value	p-value	significance
TA	61±4	1.91	0.03	**
AH	58±4	2.16	0.02	**
DD	56±3	2.17	0.02	**
FI	58±2	1.89	0.03	**
CB	60±1	1.91	0.03	**
VIG	54±2	1.93	0.03	**
Total	63±2	3.11	0.003	***

Note: *** = significance at 1%, ** = significance at 5%, (-) is considered as not significant

3.1 correlations of POMS score with AMV

Correlations of mood state with thermal sensation are summarized in Table 4. Pre-test and Post-test data of experimental group are used together in the correlation. The results represent that the AMV is highly correlated with the total T-score of the POMS (R^2 of 0.87). Furthermore, the parameter is found to be significant in 1%. Similarly, subscales of the POMS test including TA, AH, DD, FI, CB and VIG are correlated with the AMV at 5% interval. However, the effect of the VIG subscale is lower than the others. The reason could be the small variation of the VIG score in the post-test experiments. Studying the majors in a study hall lowers occupant's the VIG score and occupants prefer to be in similar T-score of the VIG. On the other hand, aversive mood states increase for the occupants (Fig.4).

Tab. 4 –Correlations between mood state and the AMV

Experimental group				
AMV	R^2	t-value	p-value	significance
TA	0.81	2.9	0.002	***
AH	0.84	2.9	0.002	***
DD	0.85	3.1	0.001	***
FI	0.79	2.1	0.019	**
CB	0.76	2.1	0.021	**
VIG	0.71	1.9	0.030	**
Total	0.87	3.1	0.001	***

The results also show the difference between the PMV and AMV values related to the mood states changes (Fig.4). For instance, at PMV= -0.4, the AMV of the occupants with the total T-score of 50, is -0.37. However, the occupants with the total T-score of 68 feels warmer (AMV=-0.21) than the normal ones. On the other side, if the positive mood state score increases (left hand-side in the figure), the occupants feel warmer (AMV=-0.32) again. The reason could be overproduction of "Adrenaline" which causes blood pressure increase.

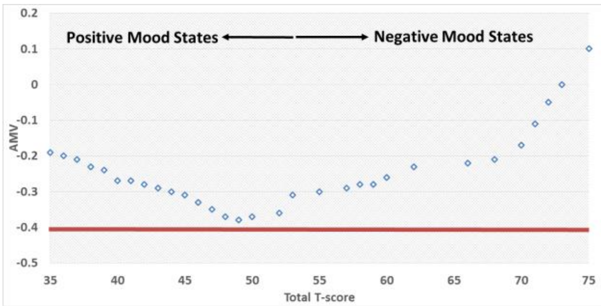

Fig. 4 – The change of the AMV related to mood state of the occupants on the same PMV value of -0.4.

3.2 effect size control

As a supportive analysis, effect size control is conducted for the study since statistical significance could be affected from different population parameters. For pre- and post-test control experiments, it is worth to conduct effect size control which indicates the size of differences between experimental group and control group [23]. The value under 0.2 means small effect, between 0.2 and 0.5 depicts medium effect and values above 0.8 represents large effects. Similar to the statistical results, effect sizes of the parameters show medium and large effects between control and experimental groups. Thereby, the results are considered as consequential.

Tab. 1 – Effect size control results

parameters	d_{ppc}
TA	0.65
AH	0.71
DD	0.86
FI	0.74
CB	0.77
VIG	0.56
Total	1.1

3.3 limitations

This study aims to show the relationship between the mood state of the occupants and thermal sensation. However, some limitations should be considered in the study. The first limitation is the number of the occupants used in the study. Only 102 occupants are participated in pre-and post-test experiments. A fairly large data sets are needed to verify the correlations above.

Moreover, due to the global pandemic of Covid-19, the occupants wear face masks which could affect thermal sensation and even their current mood states. Additionally, clothing insulation of the face mask is neglected in the study. As a further study, the effect of face mask on thermal sensation and mood states will be studied in detail.

Cultural differences may alter the personal selections in the POMS questionnaire and may affect the results directly. Even though, all occupants are selected as Turkish, the occupants may have different cultural background.

In the study, raw scores are subjected to T-score transformations with a standard scale of standard deviation and mean. Even though the results of Turkish occupants in the experiments obey this standard scale with a mean of 50 and a standard deviation of 10, larger data sets should be investigated.

This study is conducted at study hall of engineering department. Thus, female participants are lower than male ones. Female and male occupant size should be equal to verify the correlations.

Some potential moderating parameters such as age and gender could affect the results. However, these differences of T-score depending on gender and age, are not investigated in this study.

4. Conclusions

The relationship between occupant's mood state and thermal sensation is investigated with pre- and post-control experiment design strategy in this study. Statistical analysis results show that the AMV is related to the mood states of the occupants.

The present findings suggest that mood states of the occupants can increase the gap between the PMV and AMV. Thereby, researchers should take psychological parameters such as mood state into account while determining thermal sensation of the occupants.

Future research might investigate normative values of mood states for other specific populations.

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It is worth to note that this study is conducted under the Approval of Ethics Committee of Atılım University as result of meeting on 14.11.2019.

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Data Statement

The datasets generated during and/or analysed during the current study are not available because the project (Project Number: 120M890) is still in process but the authors will make every reasonable effort to publish them in near future.