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Determination of Thermal Comfort Conditions of An Educational Building in Temperate - Humid Climate

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Abstract

The acceptable thermal comfort of the educational buildings will increase the efficiency of the occupants. In the scope of the study, three classrooms in different facades, sizes and heights were determined in a faculty building, in order to check the suitability of thermal comfort conditions of educational buildings. Measurements and surveys were carried out in the determined classrooms during a day in heating period.

The human is one of the important parameters that affects thermal comfort conditions. The temperature of the indoor environment varies according to the number of people in the environment because they generate heat depending on metabolic rate. Therefore, the field measurements were conducted occupied and unoccupied classrooms.

Classrooms when unoccupied were more comfortable than occupied according to measurement results. It is determined that the occupants are not satisfied with the thermal situation, but in general the environment allows the lesson to be understood and focused. In order to ensure thermal comfort, design parameters such as; the building layout, orientation, building form, internal planning and optical - thermophysical properties of building envelope should be determined properly. In addition, indoor air conditioning should be done according to occupant density and these design parameters.

Keywords: *Thermal comfort; pmv – ppd; educational building; classroom; temperate - humid climate.*

1. Introduction

One of the main functions of buildings is to protect us from negative environmental impacts. In developed countries, people spend on average 90% of their life indoors (Working Group For Sustainable Construction, 2004). Therefore, thermal comfort conditions should be appropriate to provide and maintain a healthy and comfortable living and to be more productive working. Ensuring that these buildings, which are the main purpose of education and training, are suitable for thermal comfort conditions will affect the attention, focus, perception and learning levels of students.

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Thermal comfort is the state of being satisfied with the thermal environment (ANSI/ASHRAE Standard 55, 2013). Thermal comfort depends on objective and subjective parameters. Subjective parameters consist of age, gender, subcutaneous fat (weight) and health. Objective parameters are analyzed under two main titles as personal (activity level and clothing insulation value) and environmental (air temperature, mean radiant temperature, relative humidity and air velocity) factors.

Since thermal comfort perception is different for each individual, specific indexes are developed to understand the general indoor thermal satisfaction of individuals. Fanger's 7-point thermal sensation scale is used to determine the thermal comfort level of the environment (Fanger, 2001). Based on studies and calculations from this scale, PMV (Predicted Mean Vote) and PPD (Predicted Percentage Dissatisfied) indexes have been developed. Based on these indexes, there are value ranges for determining thermal comfort in international standards such as ASHRAE-55 and ISO 7730 (ANSI/ASHRAE Standard 55, 2013; BS EN ISO 7730, 2015). There is a limited number of studies in the field of thermal comfort in educational buildings in the literature (Zomorodian et al., 2016, Barbhuiya and Barbhuiya, 2013, Yamtraipat et al, 2005, Mors et al., 2011.). However, the study in which the thermal comfort of classrooms is examined both according to the standards and the perception of the user is very few (Corgnati et al. 2007, Almedia et al. 2016).

The human body produces metabolic heat and increases the temperature of the indoor environment by respiration, radiation and convection. Other studies showed that an increasing number of occupants increase PMV on the hot side (Zoroğlu ve Gedik, 2017). Therefore, in the interior, there is a difference in terms of thermal comfort conditions between occupied and unoccupied. Classrooms are the places where students are collectively and within certain periods of time. In this study, thermal comfort condition compliance of classrooms in a faculty building at temperate-humid climate conditions was determined with objective (measurement) and subjective (survey) studies according to occupied and unoccupied classroom conditions.

2. Method

Educational buildings consist of units that have different thermal comfort due to variable occupant density and common space use. In addition, thermal comfort conditions in educational buildings play an important role in efficiency and health. In this study, in order to determine the suitability of the classrooms in terms of thermal comfort conditions, the study conditions were determined firstly. As a method, measurements and surveys were used. Results of measurements and surveys were analyzed and were evaluated according to ASHRAE 55 and ISO 7730 standards with a table and graphic methods.

2.1. Determination of Field Study Conditions

A field study was conducted on Yıldız Technical University, Faculty of Architecture, D-211, D-303 and D-409 classrooms in İstanbul that has temperate-humid climate. Measurement studies were conducted on both unoccupied (no occupant) and occupied (with occupant) classroom conditions. Parameters that affect thermal comfort were considered and measurements were conducted in 3 different classrooms on 13/12/2017 based on building orientation and classroom grades. In addition, D-211 was measured on 15/11/2018 as well (as this classroom has the highest discomfort class at full state on 13/12/2017).

Thermal comfort is determined by different methods. Most common practices are objective (measurement) and subjective (survey) methods. The use of both methods in the study is important in terms of comparing the results and determining the thermal comfort in the most accurate way.

During the measurements, the TESTO 480 measurement device shown in Figure 1 was used. The specified clothing insulation value and activity level are entered as input to the device. Device measures instantly changing air temperature, mean radiant temperature, relative humidity and air velocity. Based on these data, the device computes PMV and PPD results that are used for thermal comfort standards. According to these results, it is determined whether the environment is comfortable by comparing with the values given in standards.

Table 1. Physical Features of the Classroom

Classrooms	**Direction of classroom**	**Dimensions**	**Heating system and number of Radiator**	**Capacity (person)**
D-211	North and East Front (H: +3,14 m)	((14,70 m × 5,40 m) + (5,67 m × 2,36 m)) × 3,67 m two rectangular prism	Gas central heating systems, Cast iron radiator- 9 radiators	55-60
D-303	West Front (H: +7,85 m)	((14,90 m × 5,67 m) + (5,93 m × 0,7 m)) × 3,81 m two rectangular prism	Gas central heating systems, Cast iron radiator- 4 radiators	50-55
D-409	East Front (H: +12,80 m)	11,5 m x 5,50 m x (min 2,23m-max 4,07 m)	Gas central heating systems, Panel radiator- 3 radiators	35-40

In this subjective study, a survey study was conducted to determine occupant satisfaction. In the surveys, questions were asked to determine the occupants' thermal comfort. Surveys were conducted to students between lectures within class. Survey results were analyzed with SPSS program.

2.1. Determination of Measurement and Survey Conditions

Measurement points were determined by creating grids according to classroom size, furnishing and usage area. Measurement points were created 1 meter away from walls (The remaining space was divided into equal distances and dots were determined). To increase the accuracy of this study, 9 points in D-211 classroom, 8 points in D-303 class and 6 measurement points in class D-409 have been determined. Measurement points of D-211 classroom on the plan are shown in Figure 2. Classroom plan and measurement points for D-303 are presented in Appendix 1 and D-409 are presented in Appendix 2.

Before measurements, personal factors among objective parameters are inputted to the device. Activity level and clothing insulation values were determined based on ASHRAE 55 and ISO 7730 standards (ANSI/ASHRAE Standard 55, 2013; BS EN ISO 7730, 2015). Measurement conditions of the classrooms are shown in Table 3.

Figure 1. TESTO 480 thermal comfort measurement device

Table 2. Study Conditions and Measurement Days Weather Data

Method	**Measurement fields-Classroom**	**Measurement days and hours**	**Outdoor Weather Conditions**
Objective (Measurements) and Subjective (Survey)	YTÜ, Faculty of Architecture, İstanbul/Turkey - D-211, D-303, D-409	13.12.2017, 12.00 – 18.00	Air temperature 12 °C, Relative Humidity %79, Air Velocity 22 km/s, Cloudy Sky Conditions
	YTÜ, Faculty of Architecture, İstanbul/Turkey - D-211	15.11.2018, Unoccupied 10.10 - 11.20, Occupied 13.35 - 15.00	Air temperature 10 °C, Relative Humidity %87, Air Velocity 18 km/s, Cloudy Sky Conditions

Table 3. Measurement Conditions of the Classrooms

Point Number	Measurement Device Height	Measurement Type-Duration-Period	Activity Level	Clothing Insulation Value
D-211➜ 9 Point D-303➜ 8 Point D-409➜ 6 Point	1 meter	According to time 5 min 30 sec	1,2 met	0,7 clo

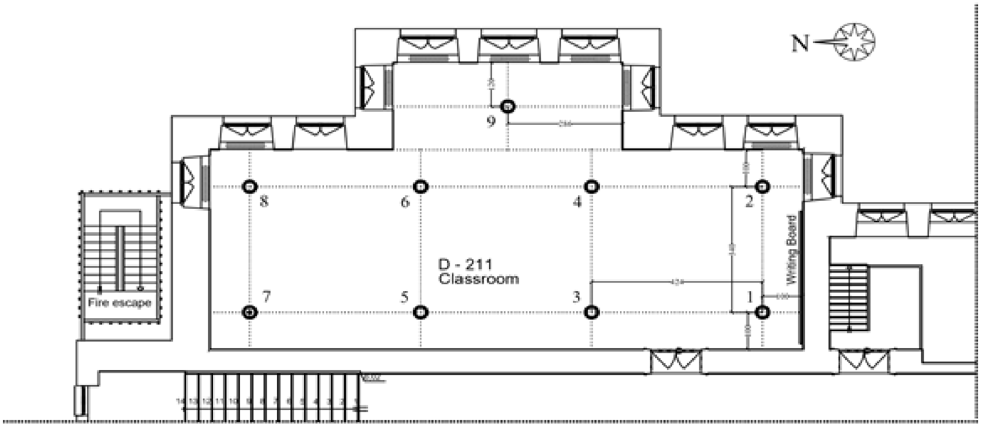

Figure 2. Measure points in plan

During survey study, clear and brief questions were asked to understand occupants' thermal comfort. Students were asked to assess the thermal comfort of the classroom in which they were involved. Subjective parameters for thermal comfort were asked as gender demographic questions. The subjective parameters that the thermal comfort depends on were asked as gender and demographic question. Question 1 was asked to understand thermal comfort levels based on 7-point thermal sensation scale. The second question is to determine whether the class's thermal comfort status allows students to focus on and understand the lesson. Accordingly, it will be inferred about the satisfaction of the users at the time of the lesson and whether thermal comfort affects the efficiency of the lesson. Finally, valid points in measurement study were marked on plan and students were asked to mark which point they were close to during lesson. The above mentioned study was to determine whether users who were at the same point with measurement study answered similarly to measurement results and to understand thermal comfort sensation differences between users at different locations.

PMV and PPD results were obtained from the measurement device. The survey questions were analyzed with the SPSS program. Obtained results were analyzed and evaluated with table and graphic methods.

3. Measurement Results

In the measurements made on 13.12.2017, the number of occupants was 35 in the D-303 classroom, 27 in the D-409 classroom and 42 in the D-211 classroom. There were 20 people in the D-211 classroom on 15/11/2018 measurements. Radiator heating systems were active during measurements. Windows in the classrooms were closed during measurements.

Electronic devices (lighting devices, projection device and laptop) were active in classrooms. In Figure 3, an example from the measurements is presented. Table 4 shows the PMV results of measurements made while occupied and unoccupied in classrooms.

In Figure 4, PMV measurement results of occupied and unoccupied classrooms were compared. When occupied and unoccupied classrooms were analyzed, occupied classrooms generally showed thermally discomfort. When the comfort level of classrooms was analyzed for measurement points, it was seen that points at the beginning of the measurement were within acceptable levels; however, these points were outside acceptable comfort level after the 4th point. Occupied and unoccupied situations of D-409 classroom and occupied situations of D211 classroom on two years were outside acceptable thermal comfort level.

Figure 3. D-211,Measurement when the classroom is occupied (15/11/2018)

Table 4. PMV measurement results for occupied and unoccupied classrooms

Measurement points	D-211				D-303		D-409	
	15.11.2018		13.12.2017		13.12.2017		13.12.2017	
	Occupied	Unoccupied	Occupied	Unoccupied	Occupied	Unoccupied	Occupied	Unoccupied
1	0,31	-0,23	0,39	0,37	0,15	0,01	**0,54**	0,42
2	0,34	-0,35	**0,58**	0,4	0,27	-0,03	**0,66**	**0,54**
3	0,47	0,05	**0,78**	0,41	0,33	0,03	**0,84**	**0,56**
4	**0,55**	0,22	**0,95**	0,41	0,44	-	**0,95**	**0,58**
5	**0,57**	0,26	**1,03**	0,44	0,37	-	-	**0,59**
6	**0,54**	0,35	**1,07**	0,31	0,45	0,44	**0,91**	**0,59**
7	0,49	0,37	**1,03**	0,45	0,43	0,39	-	-
8	**0,56**	0,36	**1,01**	0,6	-	0,41	-	-
9	**0,66**	0,48	**1,1**	0,65	-	-	-	-
Mean	0,49	0,17	**0,88**	0,45	0,35	0,21	**0,8**	**0,54**

*Limit value; -0,5<PMV<+0,5, --------- Limit Value Achieved, --------- Limit Value Not Achieved

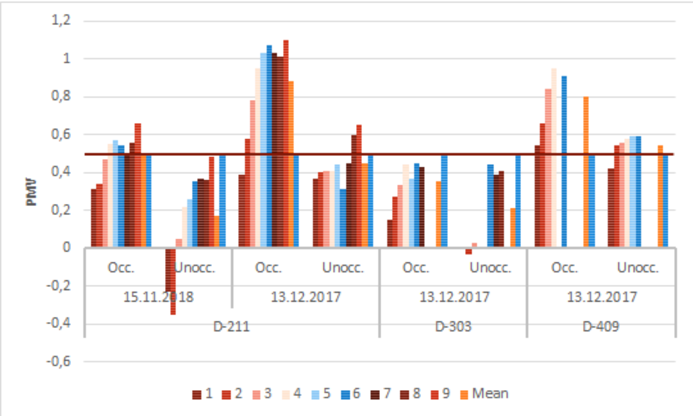

Figure 4. PMV - measurement points

In Figure 4, PMV measurement results of occupied and unoccupied classrooms were compared. When occupied and unoccupied classrooms were analyzed, occupied classrooms generally showed thermally discomfort. When the comfort level of classrooms was analysed for measurement points, it was seen that points at the beginning of the measurement were within acceptable levels; however, these points were outside acceptable comfort level after the 4th point. Occupied and unoccupied situations of D-409 classroom and occupied situations of D211 classroom on two years were outside acceptable thermal comfort level.

4. Survey Results

Thermal comfort surveys were applied between lessons after measurements. The occupants answered questions on gender, in-class location and thermal sensation. On surveys study dates, the number of occupants (students) and sex ratio is given in Table 5.

Table 5. Number Of Participants And Sex Ratio

		15.11.2018	13.12.2017		
		D211	**D211**	**D303**	**D409**
Number of participants		**18**	**39**	**32**	**24**
Sex	**Woman**	%44,4	%55,6	%62,5	%45,8
	Man	%55,6	%44,4	%37,5	%54,2

To understand the thermal comfort status of students, 7-point thermal sensation scale was applied and class distribution of answers is given in Figure 5.

To determine thermal sensations based on student location and to compare these results with measurement results, students were asked to mark the closest point given on the plan. Based on survey results, graphics that show the relationship between thermal sensation and location are given in Figure 6.

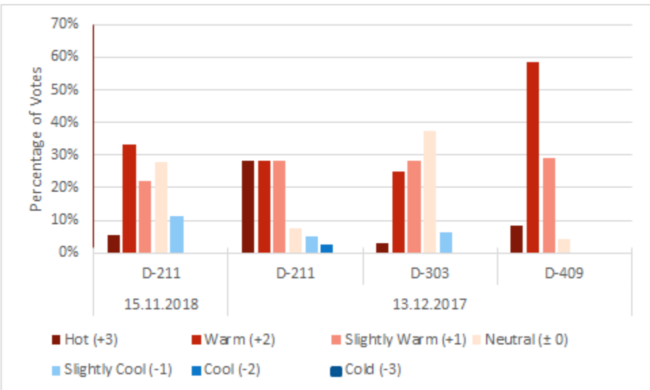

Figure 5. Thermal sensation votes- classroom

Table 6. Effect of Classroom Thermal Comfort on Education

Question 2	15.11.2018	13.12.2017		
	D211	D211	D303	D409
Yes	%88,9	%38,5	%93,8	%50
No	%11,1	%61,5	%6,3	%50
z				

Figure 6. Thermal sensation votes - measurement points

5. Discussion and Results

Measurement results were evaluated according to ASHRAE 55 and ISO 7730 standards. Acceptable thermal comfort levels range is +0,5> PMV > -0,5 according to standards (ANSI/ASHRAE Standard 55, 2013; BS EN ISO 7730, 2015). Measurement results were analyzed within this range.

When the measurement results were evaluated, PMV is on the hot side in all measurements as given in figure 4. Although the numbers of occupants were different, the occupied classrooms' PMV is higher than the unoccupied classrooms. Most of the occupants feel warmer than normal according to survey results as given in Figure 5.

D-409 was less comfortable than other classrooms at the unoccupied measurements. The highest percentage of occupants that felt warmer than neutral was in the D-409 classroom according to survey results. This could be explained by the fact that this classroom is on an attic and is equally heated via the same heating system with other classrooms. Additionally, another reason could be that volume of D-409 is 57% smaller than D-211 and 52% smaller than D-303.

PMV is on the cold side at some points in the D211 (15.11.2018) when classroom is unoccupied, according to measurement results. However, when these classrooms are occupied, the PMV is on the hot side at all points and most of the points are uncomfortable on the hot side. The classroom capacity is 58 people. In the case of 20 occupants in the classroom (approximately 35% of the classroom capacity was full), the PMV value was quite high on the hot side compared to unoccupied. While the D-211 class was occupied (42 people), the PMV was higher on 13.12.2017 than the 15.11.2018 in the measurements. According to survey results, the percentage of occupants that felt hotter than normal in D-211 classroom was higher on 13/12/2017 than 15/11/2018. It can be seen that when classrooms are at full capacity, the discomfort will increase on the hot side.

When measurement results were evaluated for locations, it was seen that PMV generally increased on the hot side towards the back part of the classroom. Measurement results showed that PMV was higher around areas closer to the radiator. However, survey results showed that occupants on the wall side felt hotter than occupants on the window side (closer to the radiator). In classrooms D-303 and D-211, some of the occupants sitting near the windows felt cool and slightly cool. This could be explained the heat transfer between the human body and cold window glass by radiation.

6. Conclusions

Human body temperature should be within certain levels for a healthy and comfortable life. Humans try to achieve heat balance with different methods in different environments. It is important that the interiors where most people spend most of their life are suitable for thermal comfort conditions. In educational buildings in which students are the main users, occupants’ satisfaction in terms of thermal comfort is important to increase efficiency.

In this study, indoor conditions (indoor air temperature, relative humidity, air velocity, PMV and PPD) were measured in three different classrooms located in the North and East, East and West facades of a faculty building in Istanbul with a temperate-humid climate.

Measurements were conducted twice during the same day while the classrooms were occupied and unoccupied. The measured values and PMV / PPD indices were compared with the ranges recommended in ASHRAE Standard 55-2013 and ISO 7730. Students' thermal sensitivities, thermal preferences and lesson focus levels were evaluated with the simultaneous surveys. The main results can be listed as follows;

• The indoor air temperature is higher than the limit values when the classrooms are both empty and full. Unnecessary heating of the classroom when empty, and the high level of heating again when the class population increases indicate that unnecessary consumption of heating energy. According to the location of the classrooms and the number of the occupants, the designing of heating systems and/or the control of the automation system will provide thermal comfort while reducing energy consumption.

• As the occupant density increased in classrooms, it was determined that the discomfort increased on the hot side.

• Stagnant air effect is observed since the air flow velocity is lower than the limit value when full and empty,

• Although the numbers of occupants were different, the occupied classrooms' PMV is higher than the unoccupied classrooms.

• Depending on the length of the measurement time and the length of the stay in the class; indoor air temperature, air humidity, PMV and PPD values were significantly increased at 3, 4, 5 and 6 measurement points.

• When the measurement results in the occupied and unoccupied classrooms were compared, the maximum moisture increase was observed in class D-303. D-409 showed 8%, D-211 5% and 4% moisture increase, while D-303 increased 39% humidity increase. The reason for this situation is the class D-303 was on the Western front and the measurement was carried out in the afternoon.

• When the survey results of the students using the classrooms were examined, the ‘warm’ option reached the highest value with 58% D-409, and in parallel, the students' focus on the lesson reached the lowest value with 50%.

As a result, acceptable thermal comfort conditions vary depending on the function of the volumes, the number of occupants and the duration time in the volume. One of the main sources of the problem is the continuous air conditioning of buildings with central systems all day long. Heating energy, which becomes unnecessary when classes are empty, causes uncomfortable when full. Therefore, especially in educational buildings where the number of people per unit area is high, air conditioning should be user-controlled or sensor. This situation may affect students' perceptions and affect the quality of education positively.

Thermal comfort conditions vary depending on locations, functions and number of the occupants. Therefore, these parameters should be considered during design. Architects and users should be aware of this issue and should be informed.

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