Thermal comfort study at Dewan Sultan Ibrahim, UTHM

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Abstract. Thermal comfort is very important, especially in an auditorium. This study focusing on the sensation of thermal comfort at Dewan Sultan Ibrahim (DSI), UTHM. A person’s perception of thermal comfort is affected by environmental and personal parameter. The objectives of this study are to determine the responses of occupants regarding thermal comfort at DSI, field measurement on environment parameter, and compare with Industry Code of Practice on Indoor Air Quality 2010 (ACT 514) by DOSH (ICOP IAQ 2010 (Act 514)), Code of Practice on Indoor Air Quality for Air-conditioned Building (SS554:2009) Singapore (COP IAQ Singapore (SS554:2009)), and America Society of Heating, Refrigerating, and Air-Conditioning Engineers Standard 55-2010 (ASHRAE Standard 55-2010). Measurement was done by using 4 in 1 Meter Kit device, while the subjective measurement was carried out by distributing questionnaire. Measurement of environment parameter shows the average temperature of 24°C and relative humidity, 65.17%. Metabolic Rate is 1.0 met and average clothing insulation is 0.49 clo. Based on the analysis of Predicted Mean Vote (PMV) and Percentage People Dissatisfied (PPD), the occupants perceived their thermal conditions as comfortable.

1. Introduction
A healthy and comfortable thermal environment of indoor workspace helps the users to improve their work efficiency by maintaining various comfort related parameters within the desired range. This research was carried out at the main hall DSI, UTHM to determine the sensation of thermal comfort in the building based on responses of the occupant and through the field measurement. DSI usually have high heat load which is a transient of nature as occupants come and go, from the lighting and generally have full or nearly full occupancy. Thus, it may cause overheating due to excessive heat gain and lead to the dissatisfaction and unhealthy environment. Problem found when the thermal condition in an auditorium either in comfort or discomfort environment, it will give negative influence on activity held and it has to be considered [1]. Undesirable thermal conditions can lead to occupant dissatisfaction which in turn has an adverse effect on their health, productivity and performance [2].

The objectives of this study are to determine the responses of occupants regarding thermal comfort at DSI, measure the personal and environment parameter, and to compare thermal comfort in DSI based on the standard.

Scope of the study mainly focuses on the thermal comfort of the main hall at DSI. The questionnaires were distributed to respondents among student who attend an event to indicate their thermal condition. Perdicted Mean Vote (PMV) and Percentage People Dissatisfied (PPD) were used to predict the thermal sensation and degree of discomfort of the occupants. The measurement was carried out by using 4 in 1 Meter Kit. ICOP IAQ 2010 (ACT 514), COP IAQ Singapore (SS554:2009), and ASHRAE Standard 55-2010 were used to compare the data collected.
All the data were analyzed in the form of graph and pie chart by using SPSS version 21 and Microsoft Excel. From the environment parameter, PMV and PPD for the building were analyzed using CBE Thermal Comfort Tool.

2. Literature Review
Humans always strive and aware of creating a thermal comfort condition [3]. Hence, creating a comfortable thermal condition is one of the most important parameters to be considered when designing a building. It is due to the effect that will occur when the surrounding condition is not in discomfort condition.

ASHRAE defined thermal comfort as “the condition of mind that expresses satisfaction with the thermal environment” [4]. The emphasis is on the condition of mind. It is a psychological phenomenon which is it will influence individual differences in mood, personality culture, and another individual, organizational and social factor [5].

While the definition from the World Health Organization (WHO) defines thermal comfort as “a condition when people are satisfied with thermal environment” and also declares that “health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity” [6].

2.1. Body Heat Exchange
There are four modes of heat exchange between the body and its environment which is evaporation, convection, radiation and conduction. Figure 1 show modes of body heat exchange. Convection occurs due to heat transmission from the body when air contact with skin or clothing and then raises and replaced by cooler air in a continuous process. Radiation is energy motion, in the form of stream or waves of particles. Radiation reacts between the human body and surrounding through sun, open air, sky, window and walls. The third mode is evaporation that the process takes place when water from the liquid state back into the water cycle as atmospheric water vapor [7]. During the evaporation, water will absorb heat and as normal human being will lose about one liter of water a day in perspiration [8]. Conduction depends on the temperature difference (ΔT) between the body surface and the object the body is in contact with [9].

![Figure 1. Modes of body heat exchange.](image)

2.2. Factors Affecting Thermal Comfort
There were three factors affecting thermal comfort which is an environmental factor, personal factor and other factors. To determine the environmental factor in thermal comfort, there are four factors should be considered which is air temperature (T), relative humidity, air velocity (AV) and mean radiant temperature (MRT) [10]. Air temperature is considered as the air surrounding the body and measured in degree Celsius (°C) [11]. Minimum temperature different during day is between 20°C to 32°C and at
the night between 21°C to 27°C [12]. Surrounding temperature is the main factor to give comfort to the individual. From that, the occupant will express the sensation of thermal comfort.

Relative humidity is the second factor that affects comfort. It is related to the measurement of moisture in the air. Refer to ICOP IAQ 2010 (Act 514), accepted relative humidity is ranged of 40% to 70%.

Air velocity (AV) is also important to balance heat transfer from the body. Human is more comfortable in a warm humid environment if the air movement is high [13]. The acceptable range for air velocity is between 0.15 to 0.5 m/s. Factor affect thermal comfort as illustrated in Figure 2. The last factor under environment is mean radiant temperature (MRT). It is defined as the uniform surface temperature of an imaginary black enclosure in which an occupant would exchange the same amount of radiation heat as in the actual non-uniform space.

Personal factor such as clothing and metabolic rate are taken into account of thermal comfort [14]. The thickness of clothing will cause heat stress to the body. Therefore, the choice of clothing must be suited to an environmental condition. The unit uses to describe the thermal insulating quality of the clothing worn is the Clo, where 1 Clo is equal to 0.155 m2K/W. The activity level of human affects thermal comfort. While a person does any type of work or physical activity, the body transforms the chemical energy stored in it to heat and mechanical work [15].

Age, gender and health condition also the other factor that affects thermal comfort. The metabolic rate of women is lower than men. Men usually involve more in physical activities compared to women. Other factors that affect thermal comfort are health condition. If occupants in a good health condition, they felt comfortable.

![Figure 2. Factor affect thermal comfort.](image)

2.3. Comfort Assessment

Comfort can be observed by using two measurement methods which are the physical and subjective measurement. Data collected from subjective measurement was interpreted by using PMV and PPD method. PMV is a prediction of the mean value of thermal sensation votes of a large group of people in given environment. PMV is an index that represented on the thermal sensation scale, which is T, RH, MRT, and AV. Clothing and metabolic rate also calculated in determining the PMV. Fanger 1970 has been developed the theory of PMV and it is most representative thermal comfort model [16].

PPD is the average response of a large group of people. Given the subjective nature of comfort, there will actually be a distribution of satisfaction among a large group of people. To know the comfort level, PPD less than 20% is considered as a good condition and that means 80% of occupants are satisfied with the thermal environment [17].
2.4. Standards
Standard is very important to determine appropriate thermal conditions. Three standards being compared, ICOP IAQ 2010 (ACT 514) by DOSH, COP IAQ Singapore (SS554:2009), and ASHRAE Standard 55-2010 [18] [19] [20].

| Parameter                  | ICOP IAQ 2010 (ACT 514) | COP IAQ Singapore (SS554:2009) | ASHRAE-55 2010 Standard |
|----------------------------|--------------------------|---------------------------------|--------------------------|
| Air temperature, T (°C)    | 23-26°C                  | 24-26°C                         | 23-26°C                  |
| Relative humidity, RH (%)  | 40-70%                   | <62%                            | 20-60%                   |
| Air velocity, AV (m/s)     | 0.15-0.50 m/s            | 0.10-0.30 m/s                   | <0.15 m/s               |

3. Methodology
The methodology is defined as rules from which specific methods or procedures may be derived to interpret or solve the different problem within the scope of particular disciplines. A flow chart showing the experimental activities of the study which was used is illustrated in Figure 3. Subjective measurement was carried out by distributing questionnaire to respondents among student while the measurement was done by using 4 in 1 Meter Kit device.

![Figure 3. Methodology chart.](image-url)
4. Results & Discussions

4.1. Questionnaire

The questionnaire was distributed on 31st August 2016 to 100 respondents of first year students for 2016/2017 that attended orientation program in DSI. The respondents consist of 50 male and 50 female with age range between 20 to 23 years old.

Figure 4 shows the number of votes on the perception of the respondent to thermal sensation at DSI. Majority of them (80%) feel comfortable with the thermal sensation in the auditorium. They vote for neutral (0), satisfied (-1), little comfort (-2) and comfort (-3) while being in the auditorium for almost 1 hour.

![Figure 4. Methodology chart.](image)

Figure 5 shows the respondent’s perception of thermal comfort in DSI. About 89% of the respondents felt that DSI is comfortable because the air conditioning system work properly on that time and if refer to the measurement of a physical parameter, all data is in acceptable range as discussed in 4.2.2.

![Figure 5. Methodology chart.](image)

4.2. Questionnaire

In order to determine the environmental parameter, three factors were measured which include the air temperature, humidity and air velocity. Before conducting the measurement, the sampling point was
determined based on ICOP IAQ 2010 (ACT 514) as shown in Figure 6. It is divided into three sections and each section consists of three points which are point 1, 2 and 3.

Figure 7 shows the average temperatures in DSI. The highest temperature was at point C1, C2 and C3 with 25°C, 24.5°C and 24.9°C, respectively. The temperature in Section B is lower compared to Section A and C. During the measurement, the seat at section A was occupied by the female occupants while in section C was male occupants. Different with section B because this section was located at the middle seat between male and female. Based on the observation, section C was fully being seated by men and their metabolic rate was bit higher than female. Regarding ASHRAE 55 Standard, metabolic rate for sitting activity is 1.0 met. Based on research, women’s total energy expenditure which is the number of calories burned for metabolic needs, including breathing, blood circulation, digestion and physical activity, is around 5 to 10 percent lower than men’s [21].

Figure 8 shows the relative humidity at DSI. The highest average of relative humidity is at point A1 (67.5%) then it drops to 67.4% at point A2 and dramatically decreases to 63.9% at point A3. Measurement at point A3 located under the balcony of first floor and the diffuser located just 2 m from measurement point so the temperature is low and humidity was decreased. From the observation before conducting the measurement, outdoor weather is sunny and heat from outside was transfer through
building materials. Therefore it can conclude that heat transfer from building material affects the humidity inside the auditorium. If the temperature increased, the relative humidity should decrease [22].

Air velocity of every point in DSI is same which are 0 m/s because the ventilation system used is fully mechanical and location of the diffuser is located 9m from the respondent, so the air velocity is slow. Refer to the research by Siu K. B. at F2 Examination Hall at UTHM, air velocity in the hall was 0 m/s due to the hall used fully mechanical ventilation [23].

Figure 8. Methodology chart.

4.2.1. Effective Temperature
Figure 9 is about the temperature measured and thermal sensation voted by respondents in order to get the effective temperature that suitable for the auditorium in DSI. It is defined that the index which correlates the effects of air temperature, relative humidity and air velocity on the human body which produces of warmth or coldness as produced under the given conditions. The linear line presented the relationship between temperature and thermal sensation. Based on the correlation, the effective temperature in the auditorium is 27°C. Compared to ICOP IAQ 2010 (ACT 514), the temperature is slightly out of range. Refer to 4.3, result for PMV is 0.8 and located in between neutral and slightly warm.

Figure 9. Methodology chart.

4.2.2. Comparison Data With Standard
Table 2 shows the comparison of data collected with the standard. The temperature at DSI is 24°C. Refer to the standard, temperature and relative humidity in acceptable range. Air velocity in DSI is 0 m/s
because ventilation system is fully mechanical and distance between the diffuser and respondents is 9m so that the air velocity is slow. Based on ASHRAE 55-2010, range for air velocity is <0.15 m/s.

Table 2. Data Comparison with Standard.

| Parameter               | Result At DSI | ICOP IAQ 2010 (ACT 514) | COP IAQ SINGAPOR (SS554:2009) | ASHRAE 55-2010 |
|-------------------------|---------------|--------------------------|-------------------------------|----------------|
| Temperature, (°C)       | 24            | 23-26                    | 24-26                         | 23-26          |
| Relative Humidity (%)   | 65.17         | 40-70                    | <62                           | 20-60          |
| Air Velocity (m/s)      | 0             | 0.15-0.50                | 0.10-0.30                     | < 0.15         |
| Predicted Mean Vote     | -0.45         | -                        | -                             | -0.5 TO        |
| Predicted Percentage Dissatisfied (%) | 9%           | -                        | -                             | <20%           |

4.3. PMV and PPD

From the environment measurement, PMV and PPD for DSI were analyzed using CBE Thermal Comfort Tool. The PMV is -0.45 and percentage of people dissatisfied is 9%.

Table 3. Data Comparison with Standard.

| Parameter               | Average Data |
|-------------------------|--------------|
| Air Temperature, (°C)   | 24           |
| Mean Radian Temperature, (°C) | 25.32     |
| Relative Humidity, (%)  | 0            |
| Air Velocity, (m/s)     | 65.17        |
| Metabolic Rate, (met)   | 1.0          |
| Clothing Insulation, (clo) | 0.48      |
| PMV                     | -0.45        |
| PPD, (%)                | 9%           |

Based on the ASHRAE 55 Standard, PMV value is between -0.5 to +0.5. Thus, PMV in this auditorium is not achieved the ASHRAE 55 Standard. PPD less than 20% is considered as good [17]. Based on the result of CBE Thermal Comfort Tool, PPD in this auditorium is 9% and it shows that the occupants are satisfied with the thermal condition.

From the questionnaire survey, thermal sensation scale is used to determine PMV and PPD. The PPD index determines by a number of respondents expressed their discomfort level on 7 points thermal comfort sensation scale. Followed expression from Pourshaghagy and Omidvari (2012) [24]:
Table 4. Data Comparison with Standard.

| Very Uncomfortable | Uncomfortable | Less Satisfied | Just Satisfied | Satisfied | Little Comfort | Comfort |
|--------------------|---------------|----------------|----------------|-----------|----------------|---------|
| +3                 | +2            | +1             | 0              | -1        | -2             | -3      |

| Dissatisfied = 20% | Satisfied = 80% |

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PPD = \frac{\text{The Number of Respondent having Discomfort Level}}{\text{Total Number of Respondent in any section}} \times 100
\]  

\[
PPD = 6\% + 5\% + 9\% = 20\%
\]

Figure 10 illustrates the PPD against PMV. There are 20% occupants dissatisfied with the thermal comfort in this auditorium. The result of the mean vote was 0.8 and located in between neutral and slightly warm zone.

5. Conclusions

All objectives of this study are achieved. Majority of the respondents vote for comfortable in Dewan Sultan Ibrahim. From the measurement analysis, the average of the parameter measured was in accepted range except for air velocity due to DSI is fully mechanical ventilation and during measurement, all doors in the auditorium were close and the diffusers are located 9 m from measurement point. In conclusion, the thermal comfort sensation in Dewan Sultan Ibrahim is comfortable and in good condition. But, to ensure the thermal sensation in the auditorium is constant, several actions should be taken and implemented such as from the maintenance aspect. Scheduled maintenance should be conducted to make sure all system especially air conditioning system always in good condition. The materials used for constructions affect thermal comfort level of the occupants. Therefore, it is important
to consider the materials used before the construction started. Last is the environment parameter measurement should be carried out during sunny and rainy day to identify the parameter differences.

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