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Study of the Effect of Different Building Material on Human Comfort: Case study in Naturally Ventilated Badminton Court

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Abstract: The objective of this study was to determine the effects of building materials towards comfort temperature in natural ventilated badminton court. This study provides a reference for engineer to make decision for a right choice of materials selection for a badminton court at a conceptual design stage to provide thermal comfort for badminton player by collecting data on 3 badminton court constructed of different materials which were zinc, half zinc and half concrete, and concrete to show the effects of materials on comfort temperature, and the comfort temperature was predicted through regression analysis on the graph of air temperature versus PMV. Based on the results for zinc material's badminton court, the comfort temperature range was between 26.71℃ to 28.20℃ while for the half zinc and half concrete material's badminton court, the comfort temperature range was between 25.06℃ to 27.86℃. Lastly, for concrete material's badminton court, the comfort temperature range was between 24.30℃ to 25.01℃. The study has shown that in naturally ventilated residential buildings, the building materials affect the human comfort. This study clarifies that concrete with low thermal conductivity reduces heat transfer from outdoor to indoor.

Keywords: Comfort Temperature Range, Building Material, Natural Ventilated

1. Introduction

In this era of rapid growth of population, the development of construction building become more significant. Under this context, the considerable growth of building sector is an opportunity to develop strategies to improve the thermal comfort without compromising the energy sustainability[1]. According to ASHRAE 55 [2], thermal comfort can be defined as the condition of mind which expresses satisfaction with the thermal environment. In other word, to have thermal comfort means that person feels neither too cool nor too warm. thermal comfort is based on people sensation which might different for each individual even though they are staying at the same place under same thermal conditions due to different metabolic rate [3]. Perception of thermal comfort of a person is based on two major factors which are classified as environmental factors and personal factors as well. The four environmental factors are air temperature, humidity, air velocity and radiant temperature while for the personal factors

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included metabolic rate and clothing insulation. Other than the six basic factors, other factors such building material, races, gender and other may give effect on thermal comfort. Material physical property such as such as density, state change temperature, specific heat, latent heat, specific gravity, thermal conductivity play an important role in natural ventilation. Thermal conductivity (k-value) will be mainly discuss in this study that acts as thermal property that describes its heat conduction capability of a material [4].

The Fanger model has been doubted about its accuracy and reliability when compare with the actual state of thermal comfort and found that Fanger model works well in only build environment with HVAC systems [5].In natural ventilated buildings, the model obtained from physical measurement is not suitable to apply due to the adaptive factor of occupant are dominant and have various options to adapt to a wider range of temperature [6]. For natural ventilated condition, the result obtained from experiments conducted automatically take into account of the physiological, behavioural, and psychological adaptions [7].

The comfort temperature range for non-residential buildings is 23.0°c to 26.6°c from Malaysia Standard MS1525 [8] (Malaysia DOS, 2014). However, there is no thermal comfort standard was established to measure the thermal comfort range due to large thermal adaptive factors existed in naturally ventilated buildings.

There are many difficulties with maintaining the thermal comfort of a sports facilities, especially in the aspect of overheating. Overheating is one of the more frequent problems that affects sports halls. This problem can be solved by using efficient ventilation causing air movement and heat removal.

Badminton is one of the most popular sports activities in Malaysia and people preferred play badminton to improve body health. Indeed, the demand of badminton court in Malaysia are quite significant and the thermal comfort in the badminton court is one of the remarkable issues that users concerned. Most of the badminton court is naturally ventilated building with blower. The materials used to build up the badminton court play an important role in provide the appropriate comfort temperature since many users preferred to play badminton in a cement badminton court rather than zinc badminton court. Thus, this case study will focus on the effect of thermal comfort on the different material's badminton court with naturally ventilated system.

2. Materials and Methods

The materials and methods section, otherwise known as methodology, describes all the necessary information that is required to obtain the results of the study.

2.1 Locations of Research

This study involves three badminton court to conduct the survey. First location which is Dewan Besar Kampung Baru Air Kuning Selatan that made up of zinc material is located at countryside area in Negeri Sembilan, with geographical coordinates2°30'32.0"N and 102°28'47.7"E. The approximate floor area is about 780.39 m^2. The second location which is Centre Point Badminton Court (Huang Du) that upper part of building made up with zinc and lower part of building made up of concrete is located at Melaka. The geographical coordinates is2°11'52.6"N and 102°15'15.4"E. The approximate floor area is about 716.52m^2. The third location which is Dewan Badminton MSN which made up of concrete is located at Melaka with geographical coordinates 2°16'12.5"N, 102°18'09.7"E. The approximate floor area is about 1257.83m^2.

2.2 Equipment

Figure 1 shows the measuring equipment used is thermometer to measure the air temperature inside the badminton court. The thermometer used is been calibrated to ensure the accuracy and sensitivity of the device. The sensitivity of the mercury thermometer is ±0.5 °C as smaller sensitivity can response faster to surrounding temperature change.

Figure 1: Mercury thermometer

2.3 Data Collection

The human response method is carried based on thermal environment survey form filled by the badminton court users. To avoid and minimize the sampling error, the survey form is expected to distribute and access by at least 8 badminton players for each session, but the sample size depends on the number of badminton players at the time of conducting survey. In order to obtain various data, this survey is conducted during cool, neutral and hot weather. The data collected is carried out in 3 times sessions which are morning session, afternoon session and also evening session. The data collected is exceeded 15 sets to obtain a more accurate result. The survey form consists of thermal sensation votes (TSV) that were cast on a modified seven-point thermal sensation scale based on ASHRAE Standard 55 [2].The thermal sensation scale had been modified to 13 voting scale to improve the sensitivity of the scale. The scale included from cold to hot which are -3, -2.5, -2, -1.5, -1, -0.5, 0, +0.5, +1, +1.5, +2, +2.5 and +3. At the same time, the air temperature is measured using the thermometer and the point of measured is referred the standard as well. The same process is repeated for the other two badminton court and thus the data collection process is considered as completed. Only the subjects that have been playing badminton for at least 30 minutes are considered in the survey in order to minimize fluctuations of thermal sensation.

2.4 Data Analysis

After conducting the data collection for human respond method, the PMV value is obtained by calculating the average mean votes for each session based on the thermal sensation scale from the survey. The PMV value obtained for three different building material's badminton court is used to carry out regression analysis by using Microsoft Excel. The relationship between temperature and PMV is determined by develop the equation from the polynomial trendline through regression analysis. There are three different polynomial trendlines which are linear, quadratic and cubic, and the best fit trendline is chosen. The equation developed from the best fit trendlines is used to obtain the range of the comfort temperature. This equation is used to identify the comfort temperature range of badminton courtthe PMV range for moderate class is setup as $-0.5 < PMV < +0.5$[9].

3. Results and Discussion

3.1 Predicted Mean Vote (PMV)

The 16 set of data was successfully collected for each badminton court. The morning session was carried out at 9 a.m. to 11 a.m. while the afternoon session was carried out between 1 p.m. to 2 p.m. and 3 p.m. to 5 p.m. For the evening session, the data start to collect at 7 p.m. to 9 p.m. The average PMV for each session was obtained by dividing the sum of thermal sensation vote by number of respondents.

Table 1 shows the summary table for PMV values for first location of study. There were 188 respondents participate in this survey, 128 of them were male and 60 of them were female. The range of thermal sensation vote was between +1.5 to +3.0.

Table 1: Summary table for PMV values of all sessions for Dewan Besar Kampung Baru Air Kuning Selatan

Set No.	Session	Air Temperature (°C)	Number of Respondents	Sum of Thermal Sensation Vote	PMV
1	Morning	29.1	13	28.0	2.15
2	Morning	29.7	12	27.0	2.25
3	Afternoon	31.0	13	30.5	2.35
4	Afternoon	32.2	10	25.5	2.55
5	Evening	33.5	14	37.5	2.68
6	Evening	29.3	15	32.5	2.17
7	Morning	28.5	15	29.0	1.93
8	Morning	29.6	12	26.5	2.21
9	Afternoon	34.4	9	24.5	2.72
10	Afternoon	32.4	10	26.0	2.60
11	Evening	28.3	11	21.0	1.90
12	Evening	27.8	10	17.0	1.70
13	Morning	30.5	12	27.0	2.25
14	Afternoon	33.5	11	29.5	2.68
15	Evening	30.9	11	26.0	2.36
16	Evening	28.3	10	18.0	1.80

Table 2 shows the summary table for PMV values for second location of study. There were 219 respondents participate in this survey, 149 of them were male and 70 of them were female. The range of thermal sensation vote was between +1.5 to +3.0.

Table 2: Summary table for PMV values of all sessions for Centre Point Badminton Court (Huang Du)

Set No.	Session	Air Temperature (°C)	Number of Respondents	Sum of Thermal Sensation Vote	PMV
1	Morning	27.8	15	26.0	1.73
2	Morning	30.1	16	36.5	2.28
3	Afternoon	29.8	15	32.5	2.17
4	Afternoon	28.5	11	21.5	1.95
5	Evening	30.2	16	35.5	2.22
6	Evening	28.5	12	22.5	1.87
7	Morning	30.3	15	34.5	2.30
8	Morning	31.1	15	36.0	2.40
9	Afternoon	33.0	10	25.5	2.55

10	Afternoon	33.8	11	29.5	2.68
11	Evening	31.7	12	29.0	2.42
12	Evening	29.3	18	38.5	2.14
13	Morning	28.8	15	29.5	1.96
14	Afternoon	33.4	10	26.0	2.60
15	Evening	30.4	14	32.5	2.32
16	Evening	29.6	14	30.5	2.18

Table 3 displays the summary table for PMV values for third location of study.There were 233 respondents participate in this survey, 164 of them were male and 69 of them were female. The range of thermal sensation vote was between +1.0 to +2.5.

Table 3: Summary table for PMV values of all sessions for Dewan Badminton MSN

Set No.	Session	Air Temperature (°C)	Number of Respondents	Sum of Thermal Sensation Vote	PMV
1	Morning	24.8	15	21.5	1.43
2	Morning	27.2	20	39.5	1.98
3	Afternoon	26.7	12	22.5	1.87
4	Afternoon	25.4	10	16.5	1.65
5	Evening	26.9	12	23.0	1.92
6	Evening	25.1	15	22.0	1.47
7	Morning	27.3	14	28.0	2.00
8	Morning	26.0	14	22.5	1.61
9	Afternoon	30.0	10	22.5	2.25
10	Afternoon	30.8	12	28.5	2.38
11	Evening	28.7	13	27.5	2.12
12	Evening	26.3	19	35.0	1.84
13	Morning	25.8	16	31.5	1.66
14	Afternoon	30.4	10	23.0	2.30
15	Evening	27.4	21	42.5	2.02
16	Evening	26.5	20	31.5	1.85

3.2 Correlation and Regression Analysis

The data obtained for three badminton court are further analysed by using correlation and regression method. The Microsoft Excel used as a tool to carry out the correlation and regression analysis. The point of air temperature and PMV are scattered and three polynomial trendlines were used which are linear, quadratic, and cubic and the equation was generate respectively along with coefficient of determination, R^2.

The graph of linear, quadratic, and cubic for first location of study which is Dewan Besar Kampung Baru Air Kuning Selatan was shown in Figure 2, Figure 3, and Figure 4. The graph of linear, quadratic, and cubic for second location of study which is Centre Point Badminton Court (Huang Du) was shown in Figure 5, Figure 6, and Figure 7. While the graph of linear, quadratic, and cubic for third location of study which is Dewan Badminton MSN was shown in Figure 8, Figure 9, and Figure 10.

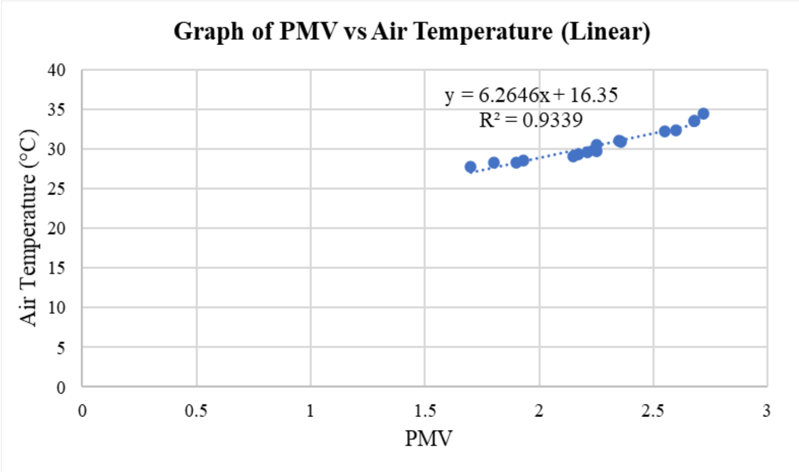

Figure 2: Linear Graph of PMV versus Air Temperature for Dewan Besar Kampung Baru Air Kuning Selatan

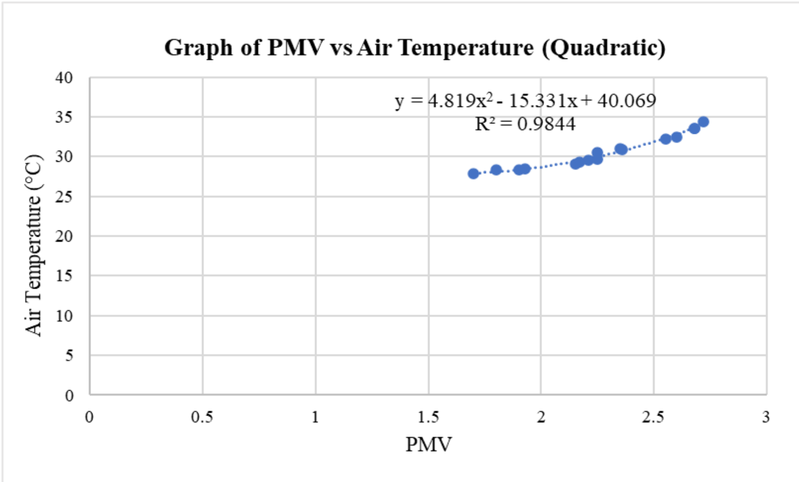

Figure 3: Quadratic Graph of PMV versus Air Temperature for Dewan Besar Kampung Baru Air Kuning Selatan

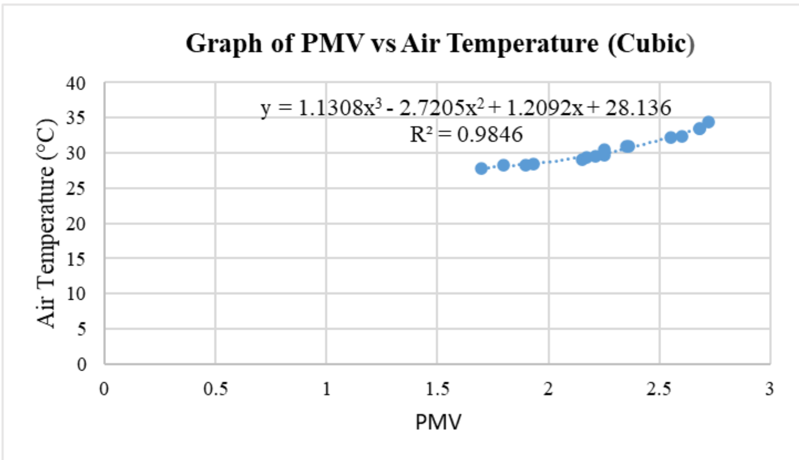

Figure 4: Cubic Graph of PMV versus Air Temperature for Dewan Besar Kampung Baru Air Kuning Selatan

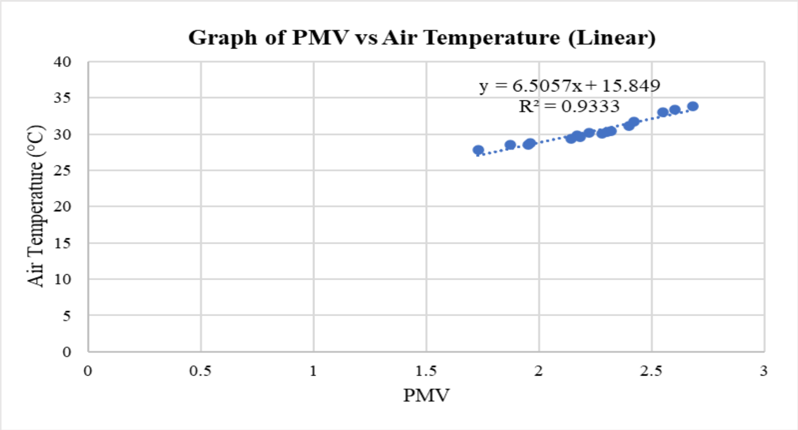

Figure 5: Linear Graph of PMV versus Air Temperature for Centre Point Badminton Court (Huang Du)

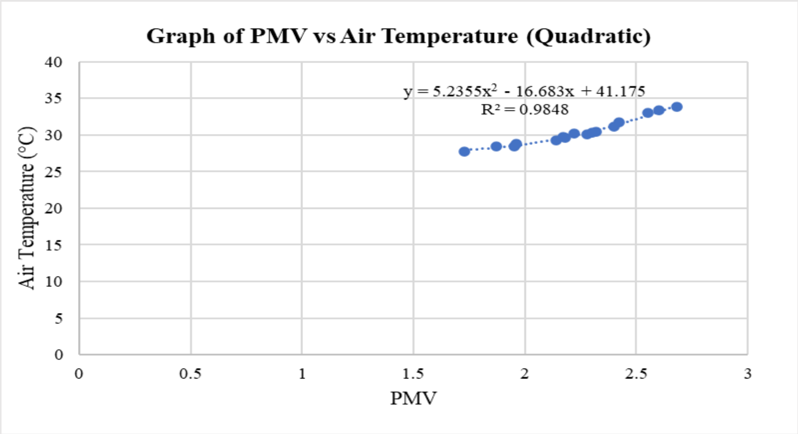

Figure 6: Quadratic Graph of PMV versus Air Temperature for Centre Point Badminton Court (Huang Du)

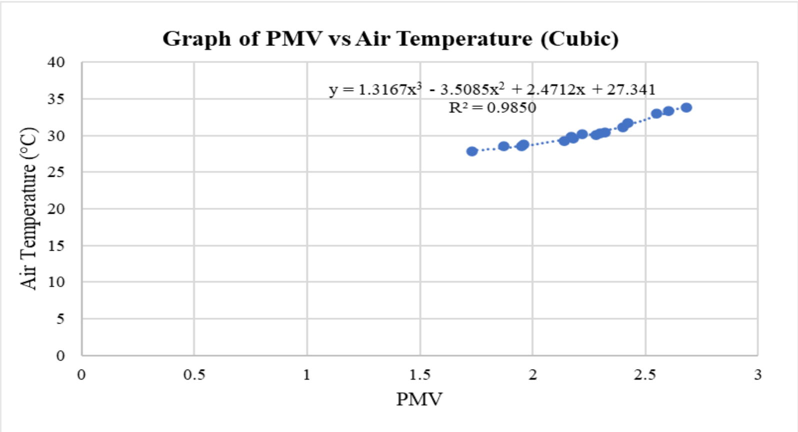

Figure 7: Cubic Graph of PMV versus Air Temperature for Centre Point Badminton Court (Huang Du)

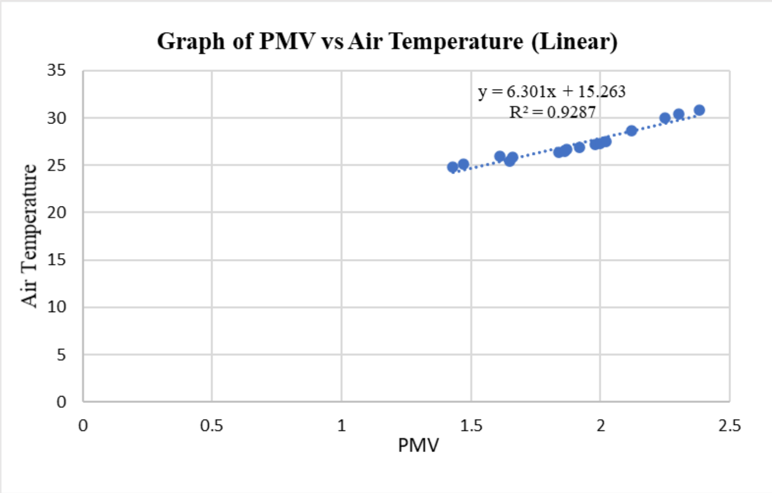

Figure 8 Linear Graph of PMV versus Air Temperature for Dewan Badminton MSN

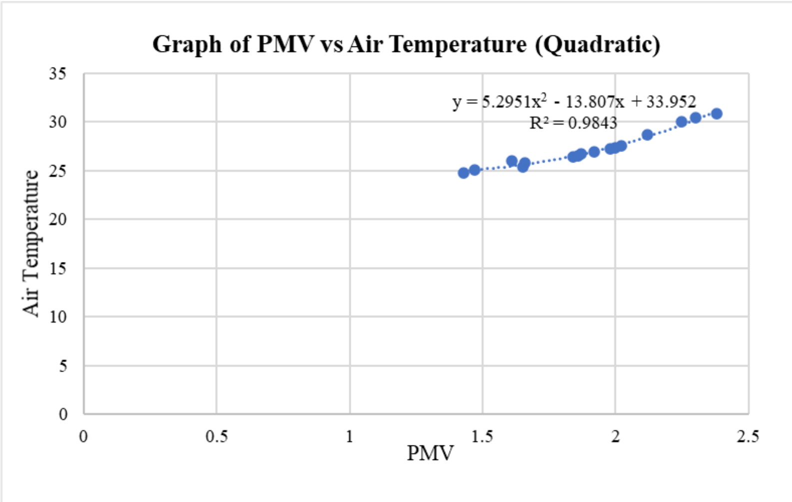

Figure 9: Quadratic Graph of PMV versus Air Temperature for Dewan Badminton MSN

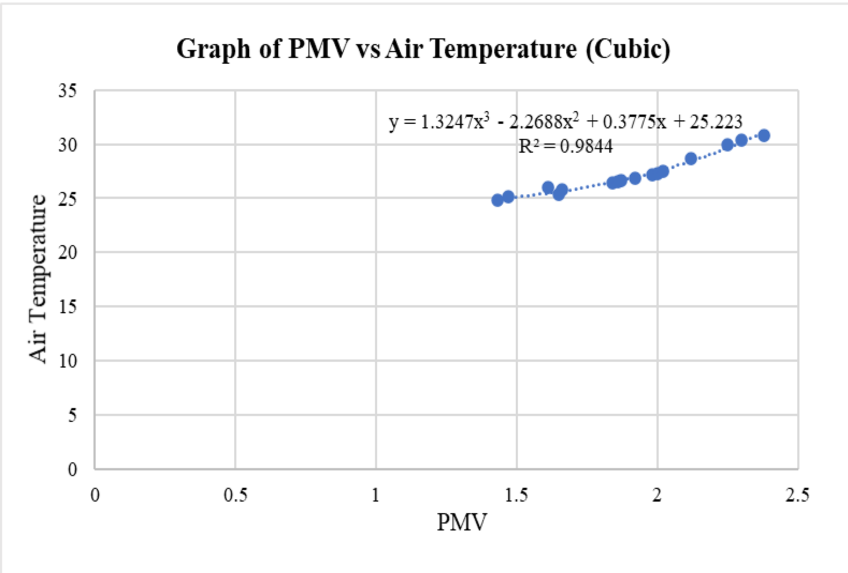

Figure 10: Cubic Graph of PMV versus Air Temperature for Dewan Badminton MSN

As from the graph above shown, the coefficient of R^2 for cubic graph is the highest among linear and quadratic as well as the coefficient of R for three badminton court. For Dewan Besar Kampung Baru Air Kuning Selatan, the highest R^2 was cubic followed by quadratic then linear with a value of 0.9846, 0.9844, and 0.9339. While the R value was obtained by squared root the R^2, the R also showed a descending value which are 0.9664, 0.9922, and 0.9923. For Centre Point Badminton Court (Huang Du), the highest R^2 was cubic followed by quadratic then linear with a value of 0.9333, 0.9848, and 0.9850. The R value was 0.9661, 0.9924, and 0.9925 for cubic, quadratic, and linear respectively. For Dewan Badminton MSN, the R was 0.9844, 0.9843, and 0.9287 while R was 0.9922, 0.9921, and 0.96237 for cubic, quadratic, and linear respectively.

The R-squared measure the goodness of fit for regression models. The cubic graph showed the highest R^2 value represent that it has the stronger relationship between air temperature and PMV. The equation from the cubic graph was chosen to determine the range of the comfort temperature.

3.3 Prediction of Comfort Temperature

The ASHRAE Standard 55 [2] mentioned that comfort temperature range can be determined by inserting the PMV= -0.5 into the equation for minimum comfort temperature and PMV= +0.5 into the equation for maximum comfort temperature and this was used as a tool to obtain the comfort temperature range in badminton court.The general form of a cubic polynomial equation is

$$y = ax^3 + bx^2 + cx + d \qquad \text{Eq. 1}$$

The unknown x was substitute by the PMV values for three different cubic polynomial equations to obtain comfort temperature. The equation from cubic graph for first location of study was $y = 1.1308x - 2.7205x^3 + 1.2092x^2 + 28.136$. The comfort temperature range was between 26.71℃to 28.20℃ after substituting the PMV limit. The equation from cubic graph for second location of study was $y = 1.3167x^3 - 3.5058x^2 + 2.4712x + 27.431$ and the comfort temperature range was between 25.06℃to 27.86℃. Lastly, the equation from cubic graph for second location of study was $y = 1.3247x - 2.2688x^3 + 0.3755x^2 + 25.223$ and the comfort temperature range was between 24.30℃ to 25.01℃.

Based on the result obtained in this study, the Dewan Badminton MSN showed a lower comfort temperature range compare with the badminton court for Dewan Besar Kampung Baru Air Kuning Selatan and Centre Point Badminton Court (Huang Du). This was because the Dewan Badminton MSN which build up with concrete (0.8 W/mk) has low thermal conductivity than zinc (112.2 W/mk). Concrete is widely used as the interior and exterior materials for buildings because it has the low thermal conductivity compare with other construction materials [10]. Various studies clarify that concrete with low thermal conductivity not only reduces the heat transfer but also contribute to the minimization of energy consumption in buildings [11]. The building material was a structure that isolates the outdoor environment to affect the indoor environment and thus it plays an important role in affecting cooling and heating loads [12]. The higher conductivity construction material in this study which is zinc was assumed to be transfer heat easily in the form of conduction, convection, and radiation to the indoor of the badminton court compared with the concrete. As the result showed the concrete provided the most thermal comfort following by concrete-zinc and the zinc provide the least thermal comfort to the building.

4. Conclusion

In conclusions, the main objective which is to study effect of different building materials on human comfort in badminton court which located in Melaka and Negeri Sembilan was successfully achieved. The subjective assessment was adopted in this study in order to obtain the comfort temperature range in natural ventilated badminton court. The result of this study showed that the comfort temperature range for first badminton court which made up with zinc material was between 26.71°C to 28.20°C. While for second badminton court which made up with zinc at upper part of building and concrete at the bottom part of the building, the comfort temperature range was between 25.06°C to 27.86°C. For the third badminton which made up of concrete material, the comfort temperature range was between

24.30°C to 25.01°C. The comfort temperature for higher thermal conductivity material (zinc) was showed a higher result with compare with the lower thermal conductivity material (concrete). However, the indoor thermal comfort was depending on many factors not only the construction materials, but also the gender, climates, etc. Therefore, the design of the buildings in term of construction material was essential to obtain a thermal comfort by saving the energy consumptions.

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