Research Progress in Mechanical and Manufacturing Engineering Vol. 2 No. 2 (2021) 157-168
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RPMME

Homepage: http://publisher.uthm.edu.my/periodicals/index.php/rpmme
e-ISSN : 2773-4765

Study of Comfort Temperature for Bowling Activity at Bowling Centre of Batu Pahat Pacific Mall

Yeo Han Yong[1], Ahmad Fu'ad[1]*

[1]Faculty of Mechanical and Manufacturing Engineering
Universiti Tun Hussein Onn Malaysia, Parit Raja, 86400, MALAYSIA

*Corresponding Author Designation

DOI: https://doi.org/10.30880/rpmme.2021.02.02.020
Received 02 Aug. 2021; Accepted 27 Nov. 2021; Available online 25 December 2021

Abstract: The objective of this study is to predict the comfort temperature for bowling activities at bowling centre of Batu Pahat Pacific Mall. There are two types of methods for data collection in this study, which are physical measurement and human response methods. For physical measurement, it consisted of four environmental parameters that measured by the instruments VelociCalc® Plus device and KIMO® AMI 310 device, and two personal parameters are calculated through observation. While, human response method is based on the survey form. After the full data collection, the PMV values are calculated from each method. The relationship between air temperature and PMV value was predicted using correlation and regression analysis. Three different trend line equation of air temperature against predicted mean vote (PMV) was developed through SPSS software, and the equation which shows strongest relationship is chosen to predict the comfort temperature based on ASHRAE 55. Based on the result of correlation and regression analysis, the cubic polynomial equation was chosen to determine the range of comfort temperature for bowling activity because it has the highest correlation and regression coefficient. The cubic polynomial equation of physical measurement and human response methods was $y = -3.1447\ x^3 + 1.025\ x^2 + 4.3334\ x + 24.102$ and $y = -1.0399\ x^3 + 1.4269\ x^2 + 3.4184\ x + 23.827$ respectively. The minimum and maximum comfort temperature for physical measurement was 22.58°C and 26.13°C respectively, whereas the minimum and maximum comfort temperature for human response was 22.61°C and 25.76°C respectively. Based on the result obtained, the range of comfort temperature of Batu Pahat Pacific Mall bowling centre was acceptable because it was just slightly different with the ASHRAE Standard 55 (23.0°C to 26.0°C).

Keywords: Bowling Activity, Predicted Mean Vote (PMV), Comfort Temperature

1. Introduction

**Corresponding author: afuad@uthm.edu.my*

The term of “Comfort Temperature” or “Thermal Comfort” is a situation of being comfortable and satisfied with the surrounding temperature. It is the perception of contentment and well-being toward the current thermal environment. The comfort temperature in a building is significant as it could affect occupants’ health and productivity. Building system such as combinations of mechanical systems, control systems and thermal enclosure shall be designed to maintain the occupied space at indoor thermal condition [1]. As this could also avoid drifting environmental temperature which might affect the human health. When human expose themselves to the drifting environmental temperature, their bodies have to adapt to the inconsistent thermal condition and cause their thermoregulatory system being challenged [2].

Moreover, it is not easy to fulfil everyone’ satisfaction in a space due to the large variation in people characteristics which consist of both physiology and psychology. This is as result of different people have various environmental requirement of thermal comfort. Therefore, extensive laboratory and field data have been collected that provide the needed analytical data to determine thermal comfort temperature for occupants in a space [1]. Fanger (1972) developed the PMV model including six factors which divided to four environmental factors and two human body factors [3]. The four environmental factors are air temperature, mean radiant temperature, relative humidity and air velocity while two human body factors are clothing and metabolic rate which collected through observation. The metabolic rate is different for each other as it is based on current activity and surrounding condition. The metabolic rate is affected by a person’s body mass, blood flow, and fitness [4]. In this study, ASHRAE 55 standard is used as a principle to determine the thermal comfort based on PMV and PPD.

To evaluate the thermal comfort, PMV model is used as it uses the heat principles to relate the six factors for thermal comfort to mean response of people on ASHRAE thermal sensation scale. The results of the PMV model are shown on the 7-point ASHRAE scale of thermal sensation [5]. For bowling activity, it is very important for players in comfortable environment in order to have best performance. This is because a satisfactory indoor environment can provide occupants controllability, productivity, and health [6].

This study is conducted at bowling centre in Batu Pahat Pacific Mall to determine the comfort temperature for bowling activity. This is because there is no standard of comfort temperature for bowling activity that has been studied yet so this project is conducted to determine its comfort temperature. The comfort temperature is playing important role for indoor as it can affect the human’s activity performance as well as heath. If the surrounding temperature is too low (cold), it will cause human hypothermia. Cold exposure may result continuing hypertension due to activation of the sympathetic nervous system, increasing the risk of cardiovascular disease and cause sudden severity [7]. While if the surrounding temperature is too high (hot), it will cause human hyperthermia and heat stroke. Study by S. Tham et al (2020) shows that high indoor temperatures influence human health, especially respiratory health [8]. Hence, a standard comfort temperature should be determined through this study in order to maintain bowling players’ performance and health. The aim of this study is to determine the comfort temperature for bowling activity at Bowling Centre of Batu Pahat Pacific Mall.

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 Study Location

In this study, the study location is at bowling centre which is located at the Batu Pahat Pacific Mall. Bowling activity is a popular entertainment among adults. Most of people will play bowling ball whenever they are free. The surface area of the bowling activity area is 558.56m^2 62.80m of length and 8.90m of width, which included bowling equipment such as bowling ball roller machine and bowling ball storage rack. The type of ventilation in the bowling centre is HVAC system. The air-conditioners are located on the top of the room.

2.2 Equipment and Standard

There are two equipment explicitly used to measure the values of the parameters needed in this study. There are four parameters that are measured by these two devices, namely air temperature, air velocity, relative humidity and radiant temperature of the surrounding air. The instruments and devices are as follow: Figure 1/2

Figure 1: VelociCalc Plus Multiparameter Ventilation Meter 8386

Figure 2: KIMO AMI 310 with the Black Globe Thermometer

The standard is used to compare all measurement data with the standards. This is in also to ensure all the conditions of measurement following the guidelines of standard. The standard used in this study is Standard ASHRAE 55 and Malaysian Standard 1525 (2014) [9].

2.3 Methodology

2.3.1 Physical Measurement

Physical measurement method is the first part of the measurement method on environmental parameters by instruments. The parameters involved are air temperature, air velocity, relative humidity and radiant temperature. In this study, instruments such as VelocoCalc Plus Model 8386 and KIMO AMI 310 are used to the calculate the parameters. The telescopic sensor of instruments is adjustable to certain height from the floor. Therefore, it was adjusted according to the measurement height based on occupant's postures at 1.1m. The readings were recorded for further analysis in this study through this measuring equipment.

The measuring instruments and equipment must be pre-installed and allowed to adjust to the environment for 30 minutes. This is taken to ensure that the measurement equipment is completely adapted to the surrounding area and the accuracy of data. The method of measurements on the parameters must follow the standard guidelines form ASHRAE 55 during bowling activity.The case study location is at Batu Pahat Pacific Mall Bowling Centre. According to standard ASHRAE 55, the thermal environmental measurement should be taken at the location where the occupants are known to be or spend their time most. The measurements will be taken directly at the bowling centre during bowling activity as this will allow occupants to have sufficient time at the location. The parameters measured should be following the criteria of standard ASHRAE 55. If it is not possible to observe or estimate the occupancy distribution, the measurement locations must be at the centre of the zone or room. Besides it should be taken at 1.0 m (3.3 ft) inward from the centre of each of the room's walls. In the case of exterior walls with windows, the measurement shall be 1.0 m (3,3 ft) inward from the centre of the largest window.

2.3.2 Human Response

Human respond method is second part measurement method using evaluation of survey form. The survey form given the thermal sensation of the occupant consists of the seven-point scale from ASHRAE 55, where +3, +2, +1, 0, -1, -2, and -3. During the bowling activities or after bowling activities, the surveys were distributed to the occupants to prevent the influence of the outside temperature and allow the occupants to adapt the thermal conditions inside the bowling centre. This method was conducted following the standard guidelines from ASHRAE 55. The number of respondents needed to answer this survey form is at least 15. The survey form involves personal information of the bowling players and their related information to obtain clothing insulation and Predicted Mean Vote (PMV). The value of PMV is obtained by the average response of the users on the thermal sensation scale.

2.3.3 Data Collection

Data collection is characterized by standard validated techniques as the method of gathering, measuring and analyzing accurate insights for study. Once the pilot training was completed, the full data collection was conducted. There are two sets of data which are from physical measurement data and human response survey. To make sure the data is more reliable, 12 sets of data collection samples were made. The data collection took place in two sessions: afternoon session and evening session. The data was collected by recording all the readings shown by the measurement devices. The afternoon session started from 3p.m. to 5p.m. and the evening session started from 7p.m to 9p.m.

2.3.5 Data Analysis

The parameters were converted to the thermal environment according to the evaluation of thermal satisfaction by occupants after data collection. The parameters were transformed to estimate or determine the satisfaction of the comfort temperature of the bowling activity players during bowling activities at bowling centre of Batu Pahat Pacific Mall.

For physical measurement, the value of PMV is determined by inserting the six parameters such as air temperature, air velocity, relative humidity, mean radiant temperature, clothing insulation and metabolic rate into the equation. However, in this study, the PMV is calculated through CBE Thermal Comfort Tool because it is faster and easier compared with the equations 1 shown below. For the human response method, the PMV value was determined by calculating the average mean votes obtained from the survey on the thermal sensation scale.

$$PMV = [0.303e{-}0.036M + 0.028] \cdot \left[\begin{array}{l}(M - W) - 3.05 \times 10^{-3} \cdot [5\,733 - 6.99 \cdot (M - W) - pa] - 0.42 \cdot [(M - W) - 58.15] \\ -1.7 \times 10^{-5}\, M \cdot (5\,867 - pa) - 0.0014M \cdot (34 - t_a) - 3.96 \times 10{-}8 f_{cl} \cdot [(tcl + 273)^4 \\ - (\bar{t_r} + 273)4] - f_{cl} h_c \cdot (tcl - ta)\end{array}\right] \quad \text{(Eq.1)}$$

2.3.6 Correlation Analysis

Correlation is a bivariate analysis that calculates the strength or intensity of the relationship between two variables which are X and Y respectively. Sir Francis Galton (1877) presented the concept of correlation as the most significant contribution to the philosophy of psychology and technique in the mid of 19th century [10]. In statistics, the term correlation is used by researcher to determine an association, link, or any form of relationship, connection or correspondence between two or more random variables.

Pearson's correlation coefficient, R is the most frequently used correlation statistic for calculating the degree of the relationship between variables. This practical analysis takes values in the closed interval of ±1, which means the highest possible positive correlation value is +1, while the strongest possible negative correlation value is -1. The higher the coefficient is, thus, to each of these statistics, the higher the correlation it reflects [11]. The absolute value of Pearson's coefficient should be greater than 0.5 as it indicates lower correlation between two variables if the absolute R value < 0.5.

2.3.7 Regression Analysis

Regression analysis is used to model or predict the relationship between the dependent variable and one or more independent variables [12]. It can be used to determine the strength of the relationship between variables and to model the relationship between them in the future. Regression analysis involves many variations which are linear, multiple linear and non-linear. The most popular models are simple linear and multiple linear models. Nonlinear regression analysis is widely used for more complicated data sets in which the dependent and independent variables show nonlinear relationship form.

The basic principle component for regression is the diagnosis of multi-collinearity and the determination of the 'best' equation. The key factor regression analysis can be used to solve multi-collinearity disturbances to get accurate and simplified statistic effect through SPSS. The R^2 of the graph indicates the percentage of supporting the relationship and should be more than 0.5 in order to have high level of confidence towards the relationship [13]. The value of R^2 is in the range between 0 to 1, and the nearer the value to 1, the better the model it is.

3. Result and Discussion

3.1 Metabolic Rate

Through observation, there were five categories of bowling activities identified, which is seating, walking, lifting, standing and bowling. The method to categorize the bowling activity as one sample was by observing the player started from seating for preparation, walking to get the bowling ball, lifting the ball, walking to throwing position, standing for preparing the skills, start bowling, standing to wait for ball strike and walking back to the seat. According to the bowling rules, each games consists of ten frames therefore there are totally 10 samples were recorded for each game. Each sample of bowling activity was recorded based on time and listed in Table 1 below.

The calculation of met for bowling activities was done based on its categorized activities. The met for seating is 1.2, met for walking is 1.7 and met for lifting is 2.1, met for standing is 1.2 and the met for bowling is 3.0. The met for bowling is 3.0 met [14]. Based on results obtained, it showed each frame of the game was about 60 seconds which meant there was totally about 10 minutes per game with ten frames. Normally, it takes 10 minutes per player to bowl a single game averagely. The calculation of time-weighted average metabolic rate for bowling activities was shown below as well. Based on time-weighted average calculation, the metabolic rate for bowling activity is 1.68 met.

Table 1: Sample Time for Categorized Bowling Activities (s)

No. of Sample	Seating (s)	Walking (s)	Standing (s)	Lifting (s)	Bowling (s)
1	5.12	19.08	14.70	14.70	3.76
2	3.52	20.29	13.66	13.66	3.52
3	5.07	18.77	13.08	13.08	3.69
4	2.38	15.85	10.13	10.13	3.41
5	7.62	18.56	14.10	14.10	3.89
6	5.45	13.78	10.79	10.79	3.54
7	6.21	13.83	13.59	13.59	3.88
8	4.26	20.37	14.76	14.76	3.15
9	3.17	21.83	11.69	11.69	3.84
10	5.89	20.64	15.87	15.87	3.62
	Σ 48.69	Σ 183.00	Σ174.65	Σ 132.37	Σ 36.30

Time-Weighted Averaging of Metabolic Rate

$$M = \frac{\sum(\text{Activity Time} \times \text{Activity Met})}{\sum \text{Activity Time}} \quad \text{(Eq2)}$$

$$= \frac{1.2(48.69)+1.7(183.00)+2.1(132.37)+1.2(174.65)+3.0(36.30)}{48.69+183.00+132.37+174.75+36.30}$$

$$= 1.68 \text{ met}$$

3.2 Clothing Insulation

Through observation, the most popular clothing ensemble worn by bowling players for clothing insulation was a short-sleeved T-shirt without collar, thin straight trouser, ankle-length athletic socks, and shoes. In this study, the process that involved combining the garments specified in the garment insulation table was used to calculate the clothing insulation value. The fabric insulation of a short-sleeved T-shirt without collar was 0.08 clo, thick straight trouser were 0.24 clo, ankle-length athletic socks were 0.02 clo, and shoes were 0.02 clo, according to ASHRAE Standard 55. Thus, the total clothing insulation for bowling activity is 0.36 clo.

3.3 Physical Measurement Data

The physical measurement was conducted on two sessions which were afternoon session and evening session. The afternoon session was conducted from 3.00 p.m. to 5.00 p.m. while the evening session was conducted from 7 p.m. to 9.00 p.m. The details of the average physical measurement data for both sessions were shown in Table 2 below.

Table 2: Average Environmental Parameters and Calculated PMV Value Based on Physical Measurement Method

Set No.	Session	Air Temperature (ºC)	Air Velocity (m/s)	Relative Humidity (%RH)	Mean Radian Temperature (ºC)	PMV
1	Afternoon	23.0	0.03	60.9	22.9	-0.22

2	Afternoon	23.7	0.06	57.2	24.2	-0.14
3	Evening	22.5	0.12	56.7	23.3	-0.55
4	Evening	22.7	0.10	56.8	23.1	-0.49
5	Afternoon	24.5	0.07	57.0	26.1	0.08
6	Afternoon	23.3	0.06	53.4	24.8	-0.18
7	Afternoon	25.4	0.05	56.1	26.1	0.31
8	Afternoon	24.2	0.05	51.1	25.1	0.01
9	Evening	25.7	0.05	56.1	26.3	0.36
10	Afternoon	26.0	0.06	56.1	27.1	0.45
11	Afternoon	24.3	0.06	54.8	25.2	0.02
12	Afternoon	24.9	0.02	51.0	25.3	0.22

3.4 Human Response Data

For the human response method, the average voted PMV values from the respondents were shown in Table 3. The average voted PMV value for each session was calculated by dividing the sum of the thermal sensation scale by the total number of respondents. There were 12 sessions for the whole data collection.

Table 3: Average PMV for Human Response Method

Set No.	Number of Respondents	Sum of Thermal Sensation	PMV
1	15	-2.5	-0.17
2	17	-2.0	-0.12
3	20	-10.5	-0.53
4	16	-8.0	-0.50
5	15	+3.0	0.20
6	15	-2.5	-0.17
7	17	+6.5	0.38
8	16	+1.0	0.06
9	19	+9.0	0.47
10	15	+8.5	0.57
11	18	+3.0	0.17
12	16	+5.0	0.31
Total Respondents	Σ 199		

3.5 Correlation and Regression Analysis

For physical measurement method, Figure 3, Figure 4 and Figure 5 show the graph of air temperature versus PMV based on linear, quadratic and cubic polynomial. The highest correlation value, R for the physical measurement method was cubic polynomial followed by quadratic polynomial then linear polynomial with a value of 0.9948, 0.9930 and 0.9846 respectively. Meanwhile, for human response method, Figure 6, Figure 7 and Figure 8 shows the graph of air temperature versus PMV based on linear, quadratic and cubic polynomial. The highest correlation value, R for the human response method was also cubic polynomial followed by quadratic polynomial then linear polynomial with a value of 0.9918, 0.9914 and 0.9814 respectively. The highest regression value, R^2 for the physical measurement method was cubic polynomial followed by quadratic polynomial then linear polynomial with a value of 0.9897, 0.9861 and 0.9694 respectively. Meanwhile, the highest regression value, R^2 for the human response method was also cubic polynomial followed by quadratic polynomial then linear polynomial with a value of 0.9836, 0.9828 and 0.9632 respectively.

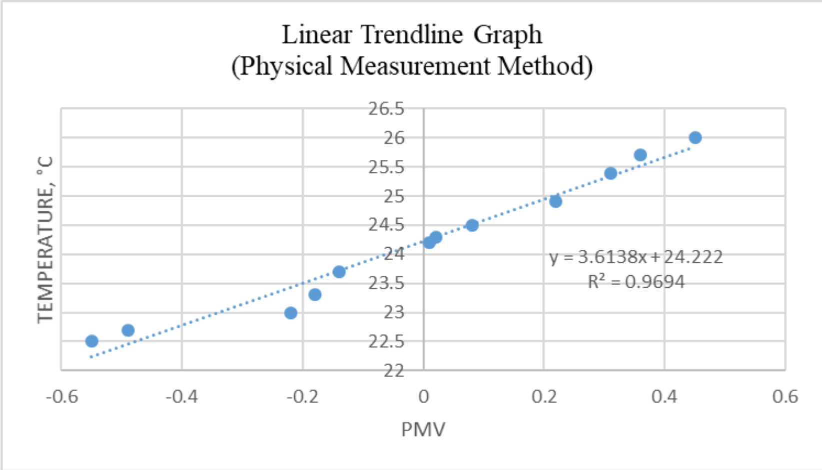

Figure 3: Graph with Linear Trend-line for Physical Measurement Method

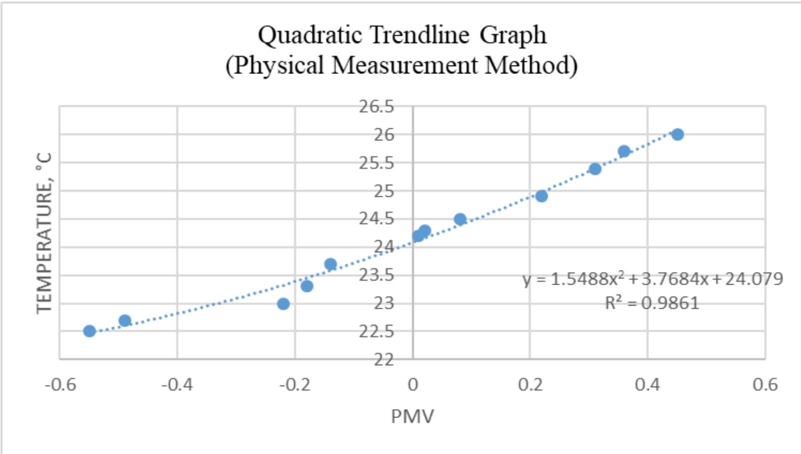

Figure 4: Graph with Quadratic Trend-line for Physical Measurement Method

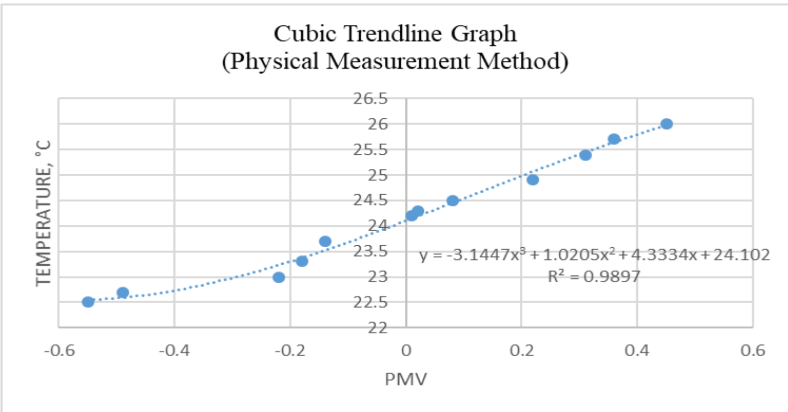

Figure 5: Graph with Cubic Trend-line for Physical Measurement Method

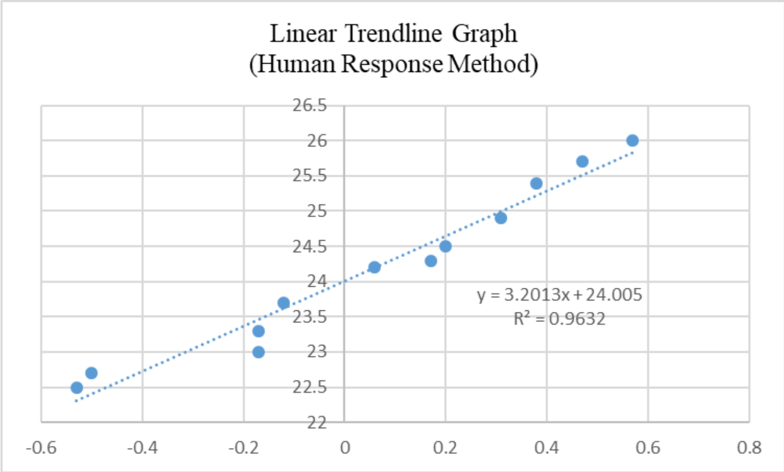

Figure 6: Graph with Linear Trend-line for Human Response Method

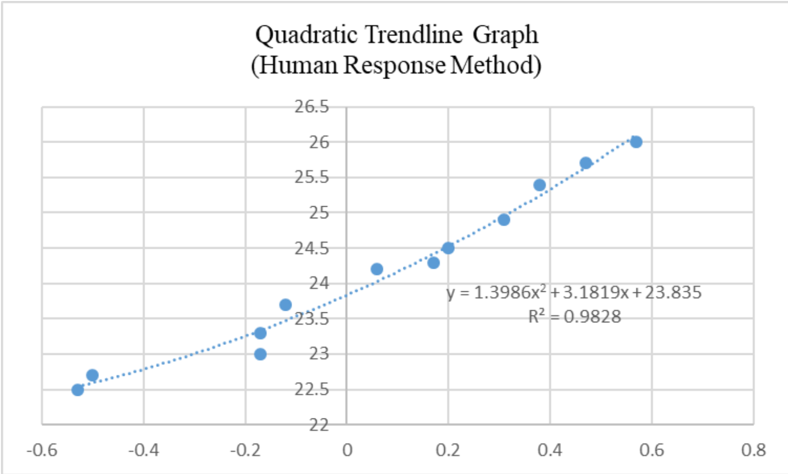

Figure 7: Graph with Quadratic Trend-line for Human Response Method

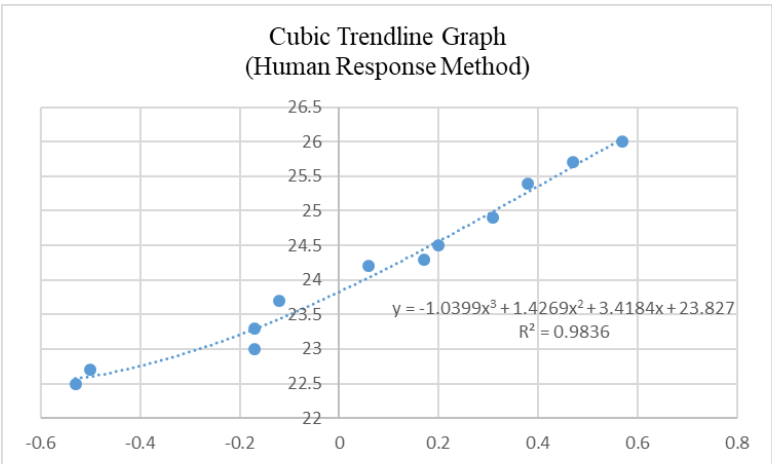

Figure 8: Graph with Cubic Trend-line for Human Response Method

Based on the data, the cubic polynomial had the highest correlation and regression coefficient value for both methods and showed the strongest relationship between two variables. Thus, the equation of cubic polynomial was chosen to determine the range of comfort temperature in the bowling centre, as greater sensitivity to thermal conditions was indicated by a larger regression slope value [15].

3.6 Comfort Temperature Determination

The cubic polynomial equation of physical measurement and human response methods was $y = -3.1447x^3 + 1.025x^2 + 4.3334x + 24.102$ and $y = -1.0399x^3 + 1.4269x^2 + 3.4184x + 23.827$ respectively. As a result, the comfort temperature ranges for physical measurement and human response methods were determined by inserting the ±0.5 PMV into the cubic polynomial equation, which +0.5 PMV as maximum temperature and -0.5 PMV as minimum temperature. Thus, the minimum and maximum comfort temperature of the Batu Pahat Pacific Mall bowling centre for physical measurement was 22.58℃ and 26.13℃ respectively. Meanwhile, the minimum and maximum comfort temperature for human response was 22.61℃ and 25.76℃ respectively. Based on the comfort temperature of each method, the difference on minimum and maximum comfort temperature was closely same. The difference for minimum and maximum comfort temperature of both methods were 0.03℃ and 0.37℃ respectively. The range of comfort temperature of Batu Pahat Pacific Mall bowling centre was slightly different with the ASHRAE Standard 55 (23.0℃ to 26.0℃). However, it was reasonable as the clothing insulation and average metabolic rate for bowling activities were difference with the office work. Besides, there was no large difference in the range of obtained comfort temperature compared with the ASHRAE 55 standard indoor comfort temperature. Most of the thermal comfort data is based on sedentary or near-sedentary physical activity levels, which are typical of office work [1].

4. Conclusion

In conclusion, the objective of this study on determining the comfort temperature for bowling activities at bowling centres of Batu Pahat Pacific Mall has been achieved. The two types of methods used to determine the comfort temperature in this study were physical measurement and human response methods. According to the results obtained, the minimum and maximum comfort temperature for physical measurement methods were 22.58℃ and 26.13℃ respectively, while the minimum and maximum comfort temperature for the human response was 22.61℃ and 25.76℃ respectively. The results obtained was slightly out of the range of 23.0℃ to 26.0℃ stated in ASHRAE Standard 55. However, it was reasonable because the clothing insulation and average metabolic rate for bowling activities were different from the office work. Moreover, the results obtained were not widely different from the standard indoor comfort temperature stated in the ASHRAE 55.

There are some recommendations that can be suggested for improvement in this study. The objective of these recommendations is to improve the quality and accuracy of the result in this study. For example, we can increase the set of full data collection in order to get more reliable and accurate data for analysis. Besides, we can increase the number of readings in order to get more accurate average results and add the number of sampling points for data collection. Lastly, controlled respondents to minimize the disparities in votes.

Acknowledgement

The authors wish to thank to the Faculty of Mechanical and Manufacturing Engineering, Universiti Tun Hussein Onn Malaysia that has supported on the accomplishment of research activity.

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