Adaptation Time Model Based on Difference in Gender

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Abstract

Thermal comfort is the state of mind in which a person feels physically comfortable with the temperature and humidity in their environment. Adaptation time refers to the amount of time it takes for a person to become comfortable in a new thermal environment. This study aimed to investigate the effects of gender on adaption time. A total of 10 participants, 5 males and 5 females, were recruited and exposed to different thermal environments under controlled conditions. The thermal comfort of the participants was evaluated using the ASHRAE 55 standard and the 7-point thermal sensation scale. The results of the study revealed that females had a lower thermal comfort level, a longer adaptation time, and higher PMV response compared to males.. This study also determine the relationship between the adaptation time and temperature difference for males and females. The equation for the males adaptation time is t_m= 1.65+5.23(ΔT) with the value of R and R^2 are 0.859, 0.794. For females, the equation for the adaptation times is t_f=0.92+5.89(ΔT) with the value of R and R^2 are 0.881, 0.776. These findings suggest that males and females may have different physiological responses to thermal environments.

1. Introduction

Thermal comfort is the state of mind in which a person feels physically comfortable with the temperature and humidity in their environment. Adaptation time refers to the amount of time it takes for a person to become comfortable in a new thermal environment [1]. The two are related because the longer it takes for a person to adapt to a new thermal environment, the less comfortable they will feel in that environment. Factors that can influence adaptation time include the rate of change of temperature and humidity, as well as individual factors such as age, gender, and clothing. Thermal comfort is a complex phenomenon that depends on a variety of environmental and personal factors. Environmental factors include temperature, humidity, air movement, and mean radiation temperature. Personal factors include clothing insulation, metabolic rate, and individual tolerance levels [2]. Adaptation time, also known as acclimatization time, is the amount of time it takes for a person to adjust to a new thermal environment. Factors that can influence adaptation time include the rate of change of temperature and humidity, as well as individual factors such as age, gender, and clothing [3].

2. Materials and Methods

Thermal comfort assessment is usually done by surveys. ASHRAE 55 is a standard developed by the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) for thermal environmental conditions for human occupancy. It provides guidelines for acceptable ranges of temperature, humidity, air movement, and other factors that affect thermal comfort. The survey typically includes questions about the person's thermal sensation, such as "How do you feel in terms of temperature?" and "How do you feel in terms of warmth or coolness?". Respondents are asked to select a number from the scale that best represents their current thermal sensation. The standard includes a survey method for assessing thermal comfort, which uses a 7-point thermal sensation scale ranging from -3(Cold) and +3 (Hot), while 0 (Neutral) [4]. The thermal sensation scale is a way of measuring a person's perception of their thermal environment and is used to gather data on the subjective comfort levels of building occupants. The thermal comfort assessment with 5 females' respondent and 5 males respondent take place in Bilik Seminar Makmal Aerodinamik in Universiti Tun Hussein Onn Malaysia (UTHM.

Fig 1 *UTHM Aerodynamic Laboratory Seminar Room*

2.1 Materials

Based on Figure 2 (a), the Velocicalc plus multi-parameter ventilation meter simultaneously measures and logs several ventilation parameters. Based on the model, these hand-held sensors can detect air velocity, indoor air temperature, and humidity. While Figure 2 (b), mercury thermometer is used to measure outside temperatures. Next Figure 2 (c), the software used is CBE thermal comfort tools. The CBE Thermal Comfort software uses a combination of input data and mathematical models to calculate thermal comfort levels in a building. Input data includes information about the building's design, such as the location of windows, the type of HVAC system, and the number of occupants. This software then uses this information to calculate the predicted mean vote (PMV). Lastly, Figure 2 (d) SPSS (Statistical Package for the Social Sciences) is a software package used for statistical analysis. It can be used to analyze data related to thermal comfort, such as data collected from surveys or experiments measuring people's perceptions of temperature, humidity, and other factors that affect comfort in indoor environments.
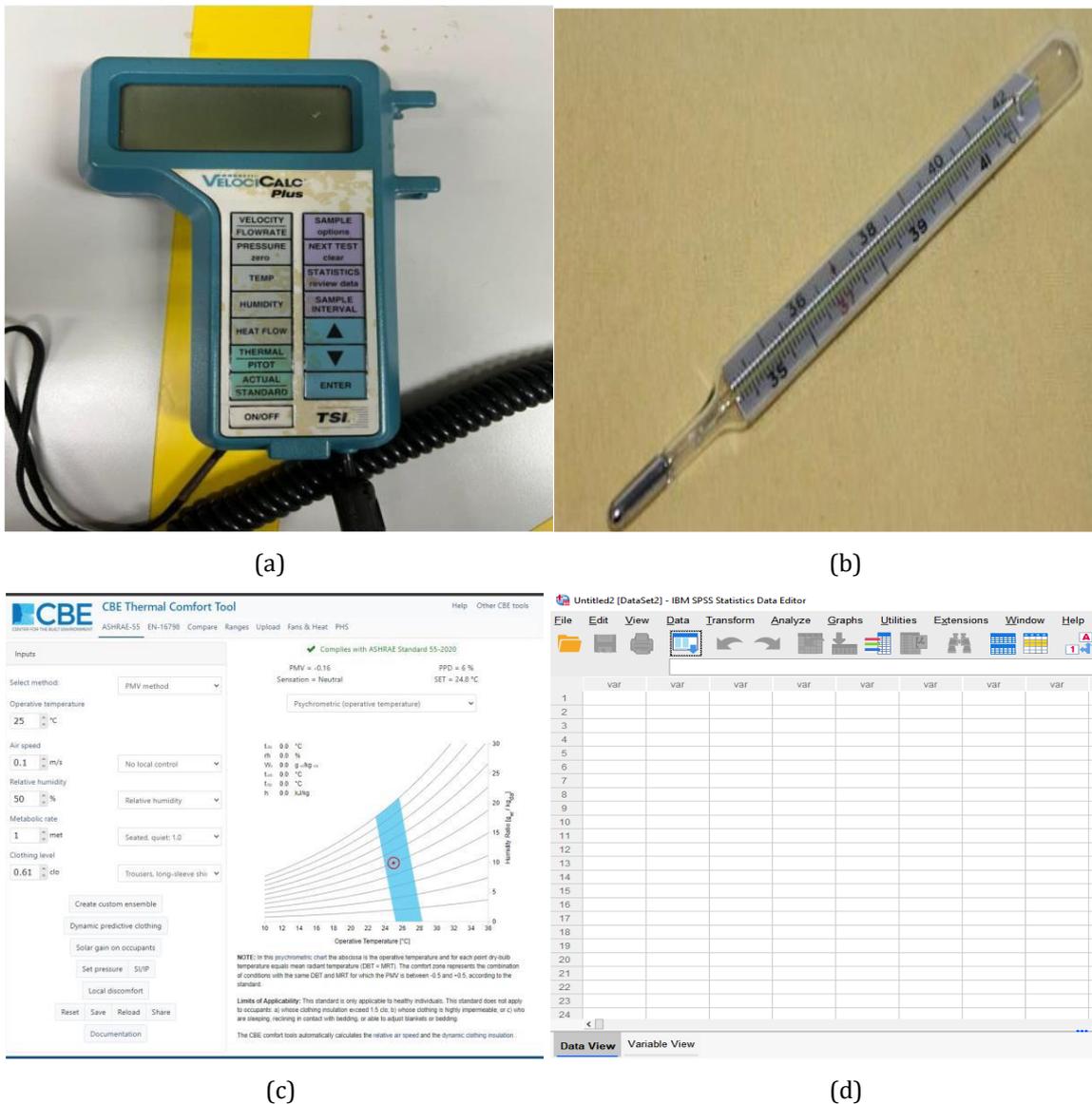
(a)

(b)

(c)

(d)

Fig 2 *(a) Velocicalc Model:8386-M-GB. (b) Mercury thermometer. (c) CBE thermal comfort tools. (d) IBM SPSS*

2.2 Methods

Both qualitative and quantitative methods are used when collecting thermal comfort survey data because they each have their own advantages and can provide different types of information. Quantitative methods involve collecting numerical data, such as temperature and humidity readings, and using statistical analysis to identify patterns and trends [5]. This type of data is useful for identifying specific issues and measuring the effectiveness of interventions. For example, a quantitative survey may ask occupants to rate their comfort level on a 7-point thermal sensation scale and then analyze the results to see how many falls within the ASHRAE 55-defined comfort zone. Combining both methods can provide a more complete understanding of the thermal comfort issues and can help to identify both the specific problems and the underlying causes. For example, if a quantitative survey shows that a particular space is consistently too warm, a qualitative survey can help to identify the reasons why, such as lack of shading or poor ventilation. [6]. The experiment setup was held in the Bilik Seminar Makmal Aerodinamik, with 5 males' students and 5 females' students as a respondent for the thermal comfort assessment. The respondents were given out a modified version of ASHRAE 55 Standard survey that is suitable for the Bilik Seminar Makmal Aerodinamik. A tool was used, VelociCalc (MODEL: 8386-M-GB), to collect the 4 parameters that are required to calculate Predicted Mean Vote (PMV) which are air temperature, relative humidity, air speed and Mean Radiant Temperature (MRT). In these cases, the surrounding surface as the same as the air, the MRT is assumed can be to be equal to air temperature and does need to measure [7] However, if the surrounding surfaces have significantly different temperatures, then the MRT should be measured and used as an input in the PMV calculation. While it is known that to calculate the PMV needs 6 parameters, the other two parameters can be collected through the survey, which are Metabolic Rate (met) and

Clothing Level (clo)[8]. Furthermore, there are 10 different sets of temperature that were set up in the air-conditioned Bilik Seminar Makmal Aerodinamik. Outside the building temperature was also taken by using a thermometer before starting the survey. This is due to get the temperature difference between the indoor temperature and outside temperature. Here the step by step for every 10 different set of temperature for thermal comfort assessment:

i.   Set up the air conditioning system and VelociCalc (MODEL: 8386-M-GB) in the Bilik Seminar Makmal Aerodinamik to desired temperature, ranging from the lower limit which 20 °C to upper limit 29 °C. The sliding room must be closed all the time. For a cooler temperature, it takes a long time to reach its lowest point, it can take up to 1.5 hours to wait before starting the survey since it takes longer time to adapt to a lower temperature.

ii. Before respondent started entering the room, the outside temperature was measured by using a mercury temperature. After that, all respondents were required to sit and limit their activity only to writing, reading, scrolling the phone or using a laptop. Respondents are forbidden to do heavy activities, as that can change their metabolic rate. As for clothing level, they are not allowed to highly insulate their body with too many clothes as that affects the clo values. A greater 1.5 clo value must not exceeded based on ASHRAE 55 – 2017.

iii. The respondents were given out the modified ASHRAE 55 surveys through Google Form. The respondent will answer the survey and vote PMV on the 7-thermal-sensation scale ranging from -3 (Cold) to -3 (Hot) that was developed by Povl Ole Fanger. They will vote based on their thermal sensation whether they felt cold, neutral or hot every for every 10 minutes and they required to stay there from 1.5 hours to 2 hours. Those data later will be analyzed by using CBE Thermal Comfort tools and Microsoft Excel.

iv. Repeat the same step 1 and 3 with different set of temperature.

3. Results and Discussion

In this assessment, the pilot test for the room temperature for Bilik Seminar Makmal Aerodinamik was set to 24° C. The reason why 24° C is suited to become pilot test is because the Predicted Mean Vote (PMV) is close to 0. The respondent should feel neutral in that room according to the ASHRAE 55 standard, a temperature of 24°C is within the range of temperatures that is considered to be comfortable for most people when the air is still, and the humidity is low. If they are voting for a larger scale rather than 0, which is whether more than -2 (Cool) or 2 (Warm), it means they are voting not seriously, or they did not understand the 7 thermal sensation scale given in the survey. It is important to briefly the respondent on how the 7 thermal sensation scale should work [9]. So, before the assessment was conducted, they need to know how to vote on the 7 thermal sensation scale based on their thermal preferences. However, thermal comfort is a complex concept that depends on many factors, such as air speed, humidity, and clothing insulation. Therefore, 24°C can be considered as one of the comfort temperature ranges, but it doesn't guarantee that it will be comfortable for everyone. Other than that, for the thermal comfort assessment, the clothing level (clo) value all respondents are free to what to wear, but not too highly insulated for every set of temperature. The clo values later are chosen the highest majority clo value will be set for each set of temperature. For the metabolic rate (met) is 1.2 met since the activities are limited for the respondent. Thanks fully for 1st assessment, all respondent was understood and given a satisfied result. Hence, the 1st pilot data can be used as 1st raw data of thermal comfort assessment. Table 1, Table 2, Table 3 and Table 4 below shows the 1st thermal comfort assessment raw data in Bilik Seminar Makmal Aerodinamik. This table is a completed 1 set of raw data to represent 24°C after being transferred from the survey and being analyzed in Microsoft Excel.

Table 1 *The parameters set for the 1st thermal comfort assessment.*

PILOT TEST 1 at 24 °C					
Respondent	Temperature Outside	Temperature AirCond	Met Rate	Clo Value	Average Temperature
5 males & 5 Females	29	24	1.2	0.57	23.57

Table 2 *The males vote over time for each 10 mins over 2 hours collected in the 24°C survey*

Males Vote Over Time	R1	R2	R3	R4	R5	Avg Male PMV
10	-0.5	-1	-0.5	-1	-1	-0.8
20	-0.5	-1	-0.5	-1	-0.5	-0.7
30	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
40	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
50	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
60	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
70	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
80	0	-0.5	-0.5	-0.5	-0.5	-0.4
90	-0.5	-0.5	-0.5	-0.5	0	-0.4
100	-0.5	-0.5	0	-0.5	-0.5	-0.4
110	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
120	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5

Table 3 *The females vote over time for each 10 mins over 2 hours collected in the 24°C survey*

Females Vote Over Time	R1	R2	R3	R4	R5	Avg Female PMV
10	-1	-1	-1	-1	-1	-1
20	-1	-0.5	-1	-0.51	-0.5	-0.7
30	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
40	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
50	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
60	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
70	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
80	0	-0.5	-0.5	-0.5	-0.5	-0.5
90	-0.5	-0.5	-0.5	-0.5	-0.5	-0.4
100	-0.5	-0.5	0	-0.5	0	-0.4
110	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5
120	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5

Table 4 *The analyzed data from the 1st survey thermal comfort assessment*

| Time (Min)	Av (m/s)	Temp (°C)	Rh%	PMV	Avg Male PMV	Avg Female PMV	Male Difference	Female Difference
10	0.09	23.80	72.90	-0.61	-0.80	-1.00	0.19	0.39
20	0.08	23.20	71.10	-0.54	-0.70	-0.70	0.16	0.16
30	0.08	23.70	74.60	-0.5	-0.50	-0.50	0.00	0.00
40	0.08	23.20	71.80	-0.55	-0.50	-0.50	0.05	0.05
50	0.08	23.40	74.60	-0.52	-0.50	-0.50	0.02	0.02
60	0.08	23.40	73.50	-0.55	-0.50	-0.50	0.05	0.05
70	0.08	23.70	76.20	-0.53	-0.50	-0.50	0.03	0.03
80	0.09	23.60	75.60	-0.52	-0.40	-0.50	0.12	0.02
90	0.09	23.90	77.70	-0.51	-0.40	-0.40	0.11	0.11
100	0.08	23.70	75.50	-0.5	-0.40	-0.40	0.10	0.10
110	0.09	23.50	74.40	-0.56	-0.50	-0.50	0.06	0.06
120	0.08	23.70	76.40	-0.53	-0.50	-0.50	0.03	0.03
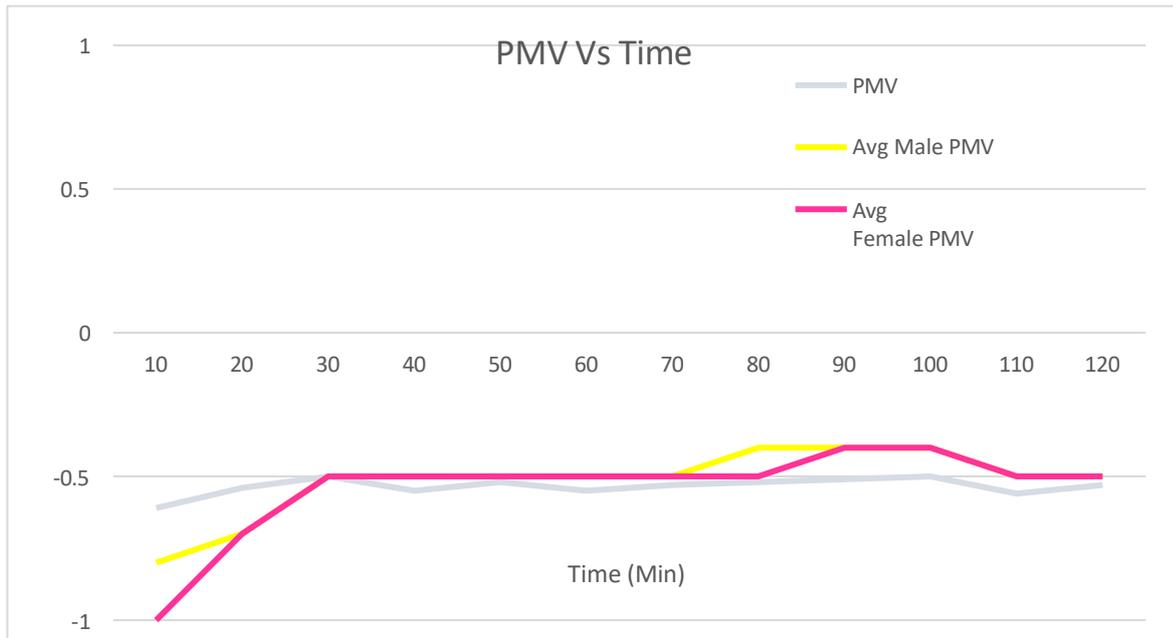
Fig 2 *The plotted Graph PMV Vs Time for 24 °C temperature set*

In Figure 2, 120 minutes long for the 1st thermal comfort assessment is completed. From this graph, it shows how vary is the PMV values between predicted PMV, average males PMV and average females PMV with each other's. There is a difference between males and females in term of thermal comfort preferences that can be observed from this graph, see at 1st 10 minutes, average males vote a lower PMV compared to females, this is because women tend to feel cooler than men in cooler environments. This is due to several physiological and behavioral factors, including differences in body fat distribution, metabolic rate, and hormonal levels. Women have a higher percentage of body fat and a lower metabolic rate than men, which means they generate less heat and are more sensitive to changes in temperature. Hormonal differences, such as the presence of estrogen, can also affect a woman's perception of temperature. [10]

The adaptation time for both males and females can be determined after analyzing the 10 thermal comfort that were done before. There are two assumptions made before determining the time taken for the adaptation time to the surrounding temperature for both males and female:

i   The difference of Predicted PMV and vote PMV must not less or more than 0.5 from both males and female respondent and should be approximately with each other's.
ii   The PMV line for both males and females show a pattern that close to the line with the Predicted PMV lines.

Table 5 below shows the adaptation time between males and females, from the lowest temperature which is 20 °C to the maximum temperature reach in the Bilik Seminar Makmal Aerodinamik which 29 °C. From the table below, both males and females have a different adaptation time at certain temperature that was set in the room. Based on Table 5, both male and female adaptation time is used in SPSS (Statistical Package for the Social Sciences) to analyze the data based on Model Summary, and Scatter Plots Graph to see best fit line for model. The "Model Summary" table provides information about the overall fit of the model, such as the R-squared value and the adjusted R-squared value. R-squared is a measure of how well the model fits the data, with a value of 1 indicating a perfect fit and a value of 0 indicating no fit. The adjusted R-squared considers the number of independent variables in the model and is a better measure of the model's ability to predict the dependent variable. Next is by develop graph adaptation time taken males against temperature difference in the scatter plot. A Scatter Plot Graph in SPSS is a type of graph that is used to show the relationship between two variables. It is a graphical representation of a set of data points, where each point represents the value of one variable plotted against the value of another variable. Hence, let's start with the Model Summary below based on Table 6 and Table 7 for males and females:

Table 5 *Adaptation Timetable Between Males and Females*

No	Set (ºC)	T_o (ºC)	Ti (ºC)	ΔT(ºC)	Male Adaptation Time (min)	Female Adaptation Time (Min)
1	20	29.3	19.88	9.42	60	70
2	21	29.5	21.07	8.43	60	70
3	22	29.5	21.98	7.52	50	50
4	23	32	23.01	8.99	40	40
5	24	31	23.57	7.43	30	30
6	25	31	24.91	6.09	20	30
7	26	31	25.91	5.09	20	20
8	27	30	27.09	2.91	20	20
9	28	29.7	27.92	1.78	10	10
10	29	29	28.7	0.3	10	10

Table 6 *Model Summary of Adaptation Time Male against Temperature Difference from SPSS*

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Male	0.859a	0.794	0.705	10.48869

a. Predictors: (Constant), temperature difference
b. Dependent Variable: male

Table 7 *Model Summary of Adaptation Time Female against Temperature Difference from SPSS*

Model Summary[b]				
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
Female	0.881a	0.776	0.752	11.80524

a. Predictors: (Constant), temperature difference
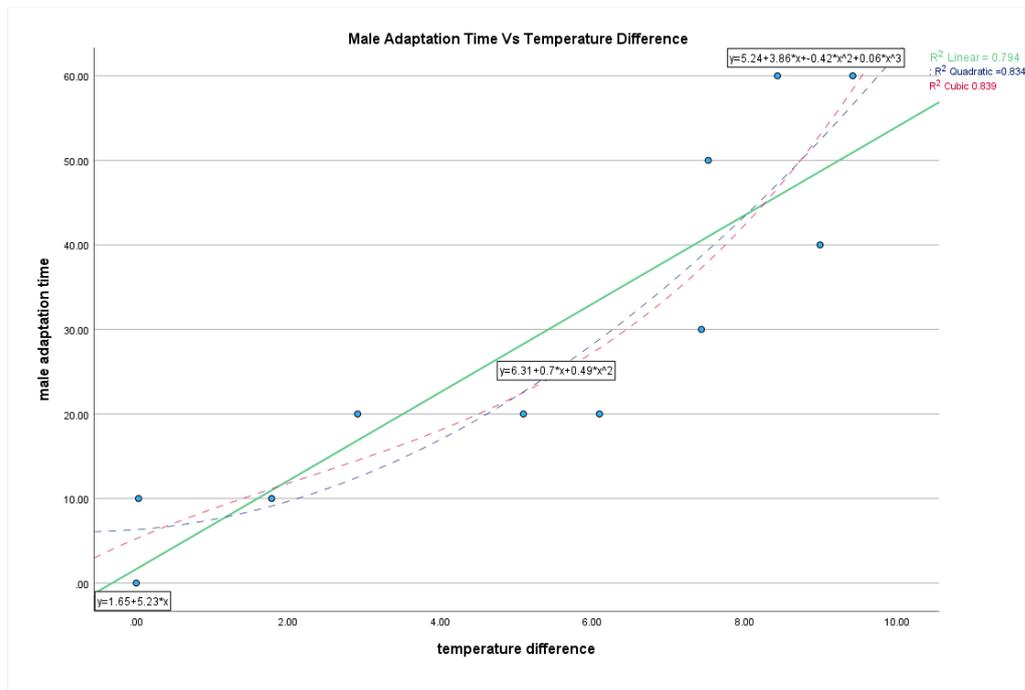b. Dependent Variable: female

Fig 3 *A scatter plot between the adaptation time male against temperature difference in SPSS*
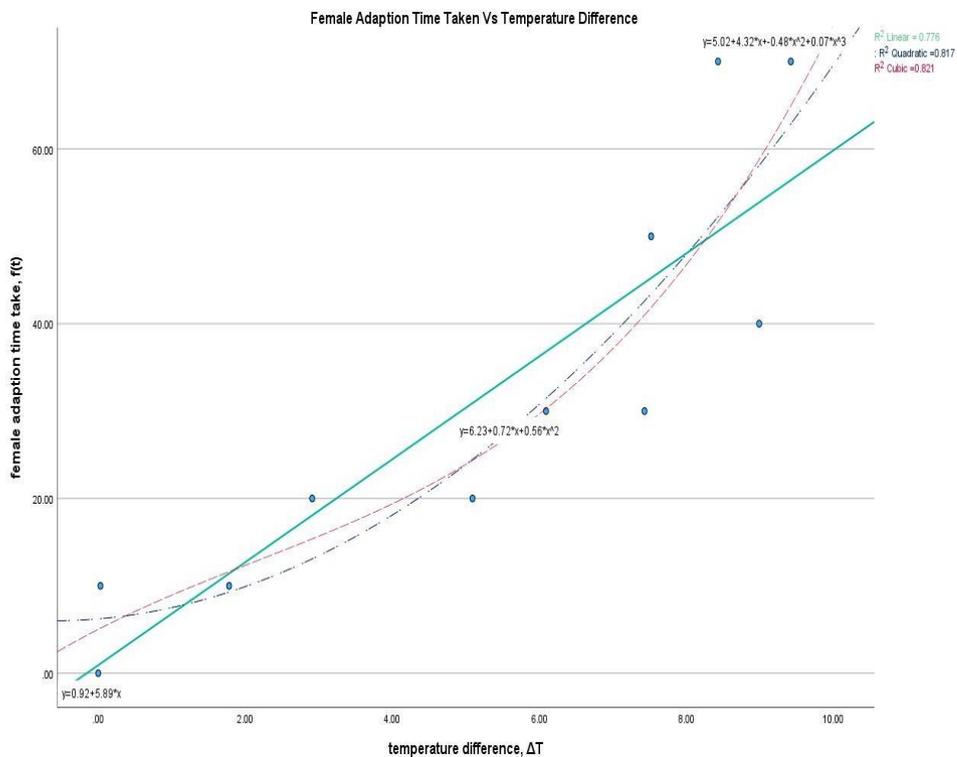

Fig 4 *A scatter plot between the adaptation time female against temperature in SPSS*

Figure 3 and Figure 4, shows a scatter plot between the adaptation time against temperature. Cubic curve line give the highest R squared value compared to straight line and quadratic curve line. The highest R squared means the best fit line for this model. However cubic line is not suitable for this relationship. For cubic relationship when the rate of change between the two variables is not constant, therefore, one variable will accelerate the rate of change for another variable. Meaning that the larger the temperature difference the more drastically adaptation time is taken. Hence, linear graph is the chosen relationship for male and female adaption time against temperature. The relationship between the two variables can be described by a straight-line equation, where the slope of the line represents the rate of change of one

variable with respect to the other.

Overall, males and female's respondent given a difference outcome in terms of their thermal preferences. This thermal comfort assessment shows that both males and females' respondent given same pattern for the relationship between adaptation time taken against temperature difference which is a linear relationship. In other words, as the independent variable (x) increases, the dependent variable (y) will also increase. This causes the graph result in Figure 3 and Figure 4 is a straight line when plotted on a graph. Hence the adaption time model for males and females is given by the following equations:

For male, the linear equation is

$$t_m = 1.65 + 5.23(\Delta T)$$

For female the linear equation is:

$$t_f = 0.92 + 5.89 (\Delta T)$$

4. Conclusion

In conclusion, from the male and female adaptation equation, the significance difference between males and female's adaptation time can be determine. For male respondents, the equation represents the adaptation time is $t_m = 1.65 + 5.23(\Delta T)$ and if the temperature difference is 5 °C, the adaptation time is 27.8 minutes. While for female adaptation time if, $t_f = 0.92 + 5.89 (\Delta T)$ and if the temperature difference is 5 °C, the adaptation time is 30.37 minutes. Meaning that with 5 temperature difference between outside temperature and indoor temperature when conduct thermal comfort assessment in Bilik Seminar Makmal Aerodinamik, it would take 27.8 minutes for male to adapt to that temperature compared with females which takes 30.37 minutes.

Based on this information, one possible hypothesis is that there is a difference in the time it takes for male and female respondents to adapt to changes in temperature. Specifically, regarding adaptation time between males and females is that females have a longer adaptation time compared to males. This means that it takes longer for females to become comfortable in a new thermal environment compared to males. This difference in adaptation time can be attributed to the physiological and hormonal differences between the sexes, and it highlights the need to consider gender when designing thermal comfort interventions. Furthermore, the results suggest that females may require more time to adapt to changes in thermal environments and that interventions that aim to improve thermal comfort for females should take this into account. Additionally, the study also found that the ASHRAE 55 standard and the 7 thermal sensation scale were effective tools for measuring thermal comfort and adaptation time. The results of this study contribute to the growing body of research on gender differences in thermal comfort and adaptation time and have implications for the design of thermal comfort interventions in buildings and other indoor spaces. Overall, it is important to consider the gender-specific differences in thermal comfort and adaptation time when designing buildings, HVAC systems and other thermal environments to ensure that they meet the needs of all occupants.

Acknowledgement

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