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The Impact of Thermal History on Buildings Occupants' Thermal Assessments in Air-Conditioned Office Buildings

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A b s t r a c t

The aim of this study was to investigate physiological factor that may affect worker performance in office building. Air conditioning is essential for maintaining environment thermal comfort in indoor the building, especially for climates such as Malaysia. To investigate of the thermal sensation of people located in no-uniform environment, it is very important to define the local heat transfer detail. In this context, the purpose was to make thermal comfort comparison between temperature settings of air conditioning. The temperature was maintained at five different levels which are 19, 21, 23, 26 and 29 oC. The study was carried out in environmental chamber at Univeristi Malaysia Pahang. The result shows temperature ranges between 21oC-29oC and relative humidity 50%-60% give difference heart rate level that indicates the level of comfort by subjects.

Keywords:

Thermal,
Office Buildings,
Air-Conditioned,
Environmental Chamber.

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1. Introduction

Malaysia is one of the countries located at hot and humid tropical region. The average mean temperature in a day ranges from 31.6 °C during the daytime to 24.6 °C, during the night. Also the humidity is uniformly high all through the year [1]. In such a climate, all the building in Malaysia depend more to the air-conditioning and mechanical ventilation (ACMV) systems to make sure all the building occupant feel comfort in that particle building.

Buildings differ in a number of ways: in addition to their individual physical form, they differ services; in what sort of heating or cooling system is provided and whether it is used; in the possibilities they offer for occupants to control their environment and in the policies of management about whether there is a dress code and so on [2].

Laboratory experimental and field investigation are the two typical approaches to study the correlation, relationship, and action between each of the thermal comfort to human in Malaysia building and to find the impact of thermal comfort toward workers performance in their workplaces. Filed investigation is the most challenging approach, because of the uncontrollable and unquantifiable variables in the actual workplaces practices. However, this method may render the most

convincing results as it provides the direct feedbacks from the occupants and we go through the real situation of study area.

The aim of this study was to investigate physiological factor that may affect worker performance in office building. The physiological factors have been choosing as a main parameter which is heart rate. In recent years, a lot of study investigated into the thermal comfort using physiological mechanisms such as vasodilation, vasoconstriction, sweating, and metabolic heat production. Before this, the predictive mean vote (PMV) model develop by Fanger [9] is popularly used to predict the thermal perceptions of a building's occupants. An estimated thermal sensation has been used to generate an optimal thermal sensation that would enhance human comfort and minimize energy use by preventing over-heating and excessive cooling. It is proving that the mechanisms of thermal comfort could be understood only by using the knowledge of physiology [3].

2. Experimental procedures

In this paper, will be discuss details about the material and experiment test that used to conduct the study. Its include field of study, locations selected for study, subjects of the study, procedure of study and method of data collection.

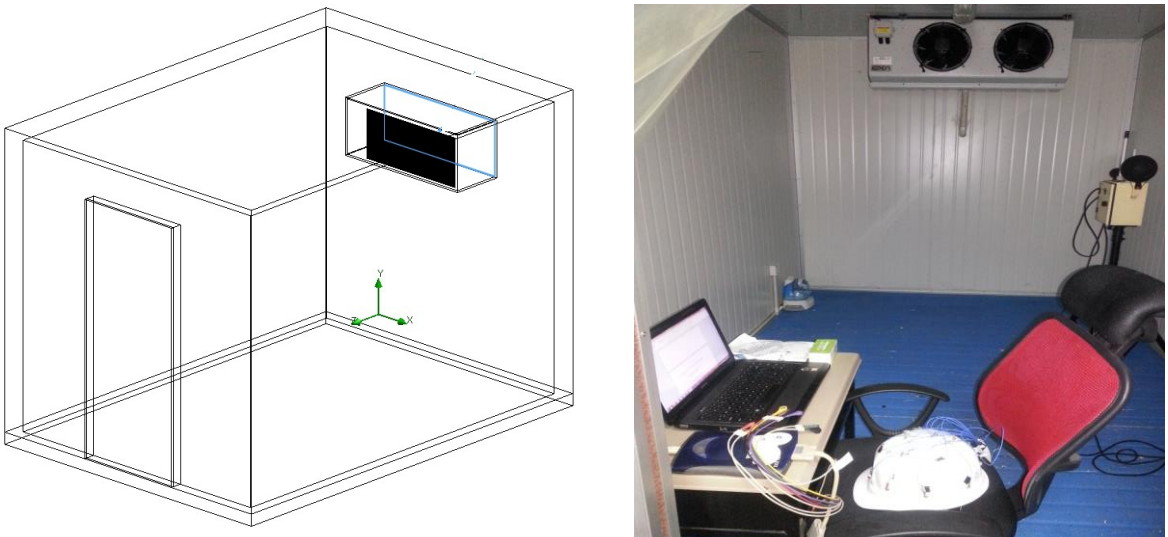
2.1. Materials

The experiments were carried out in a environmental chamber with the size of 3.6 m x 2.4 m x 2.4 m as illustrated in Fig. 1 (a). In this chamber complete set of computer, system, desk and chair as presented in Fig. 1 (b). The thermal environment with different temperature setting (19, 21, 23, 26 and 29 ^{o}C) in the environmental chamber. Fig. 2 shows the environmental chamber main switch controller to maintain and adjust the temperature. The temperature was measured using controller in the environmental chamber. Each temperature can be setting and adjusted by the switch box in the environmental chamber. The other thermal conditions including the air velocity (about 0.05±0.01 m/s) and the relative humidity (about 60±5%) were kept invariable throughout the experiments.

2.2. Experimental test

Six subjects were recruited to participate in this study. Subjects was asking to avoid caffeine, alcohol, smoking and in intense physical activity at least 12 hours. All such thing may affect the result testing if not control. Dress coat for test also be focused, the subject are remind to wear smart casual as long as loose, for shoes it must be comfortable and suitable to use in office.

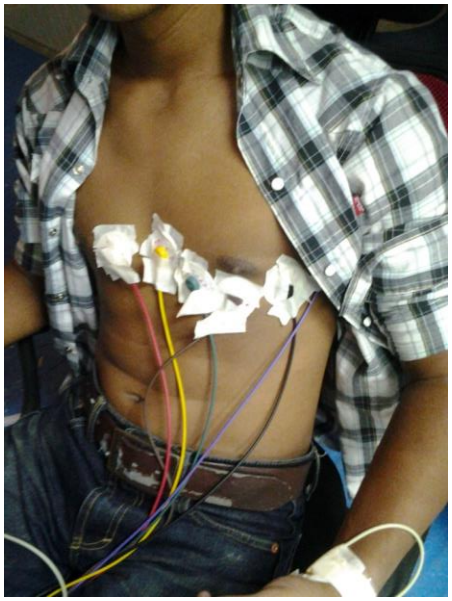
Fig. 3 shows the chest lead for heart rate measurement and helmet for skin temperature measurement. The subject was attached electrodes to their chest, wrist and leg and lead wires to the ECG machine. Before begin the experiment information about components of a subject's physical condition includes height, weight, age, BMI and gender was recorded as illustrated in Table 1. Table 2 shows the type of work the subjects must follow during measurement. There are three type of work includes thinking, sitting and printing which is the duration all works was 10 min. The facility and type of works was done like a model of an office.



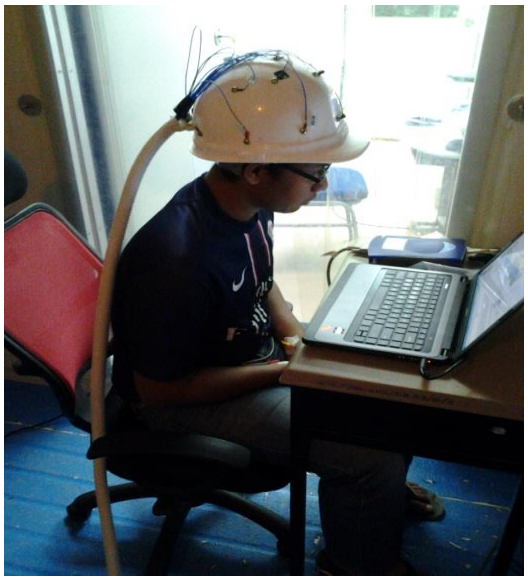
(a) (b)

Fig. 1: (a) Environmental chamber layout, (b) Interior view of the environmental chamber

Fig. 2: Environmental chamber main switch controller



(a)



(b)

Fig. 3: (a) One of the subject chest lead for heart rate measurement (b) one of the subject with helmet for skin temperature sensor

Table 1: List of subject's biography

Respondents	Sex	Age	Weight	Height	BMI
A	Male	22	80	165	29.4
B	Female	22	67	163	25.2
C	Female	26	55	154	22.3
D	Female	22	69	159	27.3
E	Male	25	64	170	22.1
F	Male	22	71	165	26.1

Table 2: Types of work with specification time and metabolic rate

Types of work	Duration	Metabolic rate (Met)
Thinking	10min	1.0
Sitting on chair while typing	10min	1.2
Printing	10min	2.5

Measurement equipment that selected to be used in this study also categories into to environmental and physiological. The measurement will conduct in the workplaces ergonomic simulator chamber WES-103 in University Malaysia Pahang as main of field of study area. For heart rate of respondent will be measure by using Electrocardiogram (ECG).

3. Results and discussion

Fig. 4 presented heart rate reading for each subject at difference temperature setting. In Fig. 4 (a), the higher heart rate for all subjects was 94.83 bpm at 26 ^{o}C temperature setting. Besides that, from the graph can see that medium heart rate was 82 bpm at 29 ^{o}C temperature setting. The lower heart rate was 76.67 bpm at 23 ^{o}C temperature setting. The lower

heart rate illustrated the comfort zone of temperature in the office. Previous study [4] found that, heart rate reading is directly proportional to temperature of office room. Lower heart rate of subject shows the higher comfort level of occupant in particular temperature setting in office building. Therefore, temperature setting at 21 ^{o}C subject more comfort at their workstation compares other temperature setting.

The individual thermal comfort sensation shows difference from each other due to environmental or physiological factor. These statements can be proven by conducting experimental using ECG and get the reading of heart rate. Fig. 4 (b) shows the lower heart rate reading at 29 Celsius while doing typing at workstation and the higher heart rate reading at 23 Celsius show by six subjects. The correlation between range of temperature and heart rate level are positively correlation. The room temperature had given significant effects on heart rate. From the result it can be seen that the most suitable temperature for office worker doing their typing task is 19 Celsius because heart rate level averagely lower and it shows the subjects feel neutrally comfort at 19 degree Celsius. According to ISO 7730 [5] and ASHRAE Standard 55 [6] define the comfortable temperature range to be 18-28^{o}C. However, Hwang et al. [7] was argued that the comfortable temperature range is 20.1-28.4^{o}C in classroom and come out with suggestion edge temperature of 28 ^{o}C that will contribute to energy saving. Thus, according to expected result, there is strongly correlation between temperatures toward comfortable in the office through heart rate level of subjects while doing physical activity like typing.

The Fig. 4 (c) presents the correlation between temperature and heart rate while doing printing activity or hard task by six subjects. The higher heart rate reading shows the uncomfortable of subject at air temperature. From the line graph, at temperature setting 26 Celsius the entire subject produces higher reading of heart rate while doing printing and movement at their workstations. Thus, the most suitable temperature at 23 Celsius, all the heart rate reading shows by respondents are at comfortable level which is 92 for 1.6 Met printing tasks.

Yao et al. [8] found that several physiological (stress) indicators which may be increased by psychological reactions have shown potential to be used in determined the heart rate variability was related to indoor air temperature and particulate matter suggesting effects on the autonomic nervous system. Moreover, as office tasks always include both mental tasks and manual tasks, thus, in this paper the experiment of ECG and temperature are unweighted average of mental performance and manual performance and is used to define the overall effect of thermal environment on human performance.

These finding further support study by Jensen et al. [9] that describes a method to evaluate the effects of temperature on occupants' performance during a year in a mechanically ventilated building. It can be used to compare different building designs in order to evaluate the best performing design according to total economy (cost of investment, energy cost and productivity of the occupants).

Fig. 5 shows the results of PMV and PPD obtained from experimental analysis of thermal assessment in environmental chamber. The results PMV index at 19 Celsius show reading between -2.86 to -0.17. Instead of that the PPD also shows reading around 5.6% - 94.4 % at this room temperature. Thus, the thermal comfort assessment for the environmental

chamber is very cool or overcooling at 19 Celsius by following the thermal comfort scale.

According to thermal sensation scale the comfort zone of workplaces must be neutral or 0 of PMV reading. Thus, it can be conclude that at 19 Celsius room temperature are not comfort for workers to perform their work task because they will feel overcooling if stay eight hour in office. Therefore, previous study done by Ayako et al. [10] recording overcooling effect found that there is no medical definition of the symptom of the unusual feeling of coldness. However, a lot of people suffer from the unusual feeling of coldness at some body parts, such as the hands, feet, and lower back, in winter and in a cold environment or an air-conditioned either at school, workplaces and collages.

The results PMV index at 21 Celsius shows reading between -3.00 to 0.05. Instead of that the PPD also shows reading around 5% - 99.42% at this study. Thus, the thermal assessment for the environmental chamber is cool at 19 degree Celsius by following the thermal comfort scale. As conclusion, this range of room temperature (21 Celsius) is categories as not comfort for office room temperature.

Furthermore, human thermal comfort will be influenced by psychological as well as physiological factors. Several comfort indices, such as PMV and PPD have been developed by father of thermal comfort such as Fanger and Nicol [11]. These indices attempt to correlate human thermal comfort with environmental conditions. Therfore, many previous study on thermal comfort found that, thermal comfort also corelated with workers productivity, safety and health.

Study by Dua [12] states that many symptoms can be shows by workers went they are not comfort at workplaces such as depression, stress and anxiety that may lead to decrease performance in workplaces went they are starting to dissatisfaction with their job, increasing absenteeism and lower productivity.

The results PMV index at 23 Celsius show reading between -0.39 to -0.9. Instead of that the PPD also shows reading around 5% - 22.1% at this chamber. Thus, the thermal comfort assessment for this chamber is at comfort zone went temperature setting is 23 Celsius by following the thermal comfort scale.

According to thermal sensation scale the comfort zone of workplaces must be neutral or 0 of PMV reading. Thus, from the result it prove that at 23 Celsius subjects are feel comfort to perform their office task such as typing, thinking and printing documents. The findings are supported by thermal standard references which state that according to ISO 7730 [5] and ASHRAE Standard 55 [6] define the comfortable temperature range to be 18-28^{o}C.

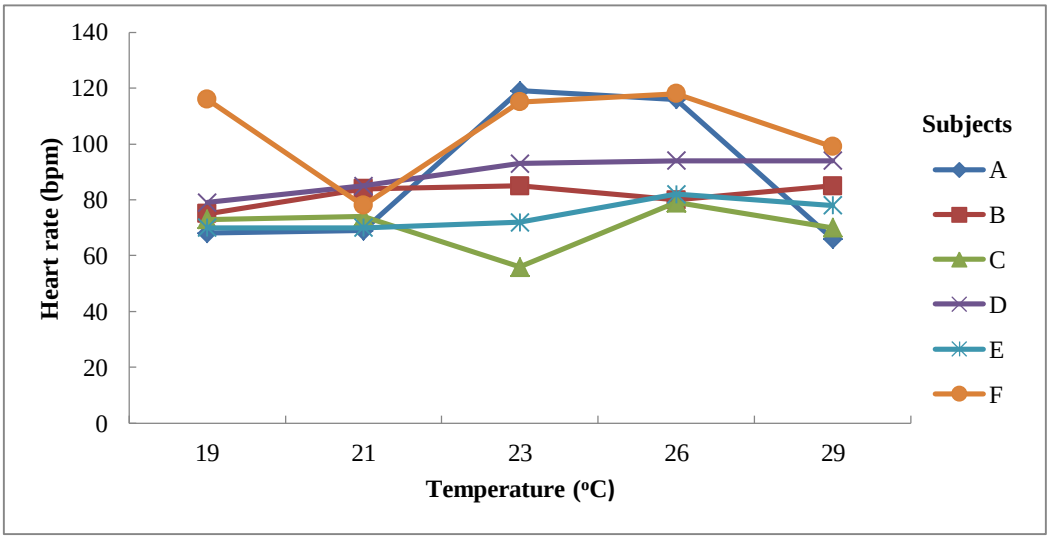
The results PMV index at 26 Celsius show reading 0.93 to 1.59. Instead of that the PPD also shows reading around 17.1% - 56% at this chamber. Thus, the thermal comfort assessment for the environmental chamber is slightly hot at 26 Celsius by following the thermal comfort scale. As conclusion, this range of room temperature (26 Celsius) is categories as not comfort for office room temperature because hot condition that leads to sweating among workers

Usually office workers will face overcooling problems and very rare finding the problems of heating in office room. According to Shikdar and

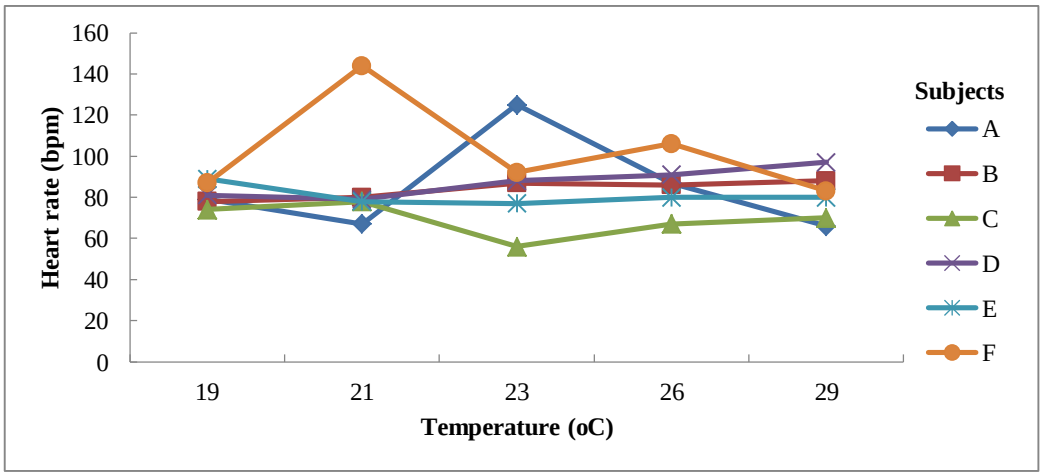
Sawaqed [13] workers are not comfort and keep complains of discomfort and dissatisfaction at work could reduce their productivity. Ismail et al. [14] supported by their finding study at automotive paint shop, working environment that caused sweating and exposure to heat will cause significant discomfort in the job satisfaction analysis.

The results PMV index at 29 Celsius shows reading between 1.1 to -1.96. Instead of that the PPD also illustrate around 30.4% - 74.9 % at this chamber. Thus, the thermal comfort assessment for the environmental chamber is very hot at 29 Celsius by following the thermal comfort scale.

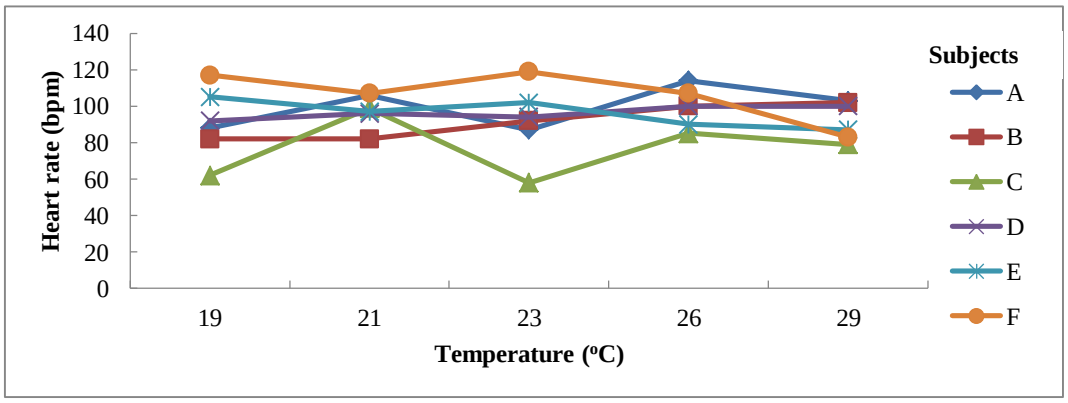
According to thermal sensation scale the comfort zone of workplaces must be neutral or 0 of PMV reading. Thus, it can be conclude that at 29 Celsius room temperature are not comforts for workers to perform their work task because they will feel overheating stay eight hour in their office room.



(a) 1.0 Met



(b) 1.2 Met



(c) 1.6 Met

Fig. 4: Heart rate reading for each subject at difference temperature with three activities level; (a) 1.0 Met, (b) 1.2 Met and (c) 1.6 Met.

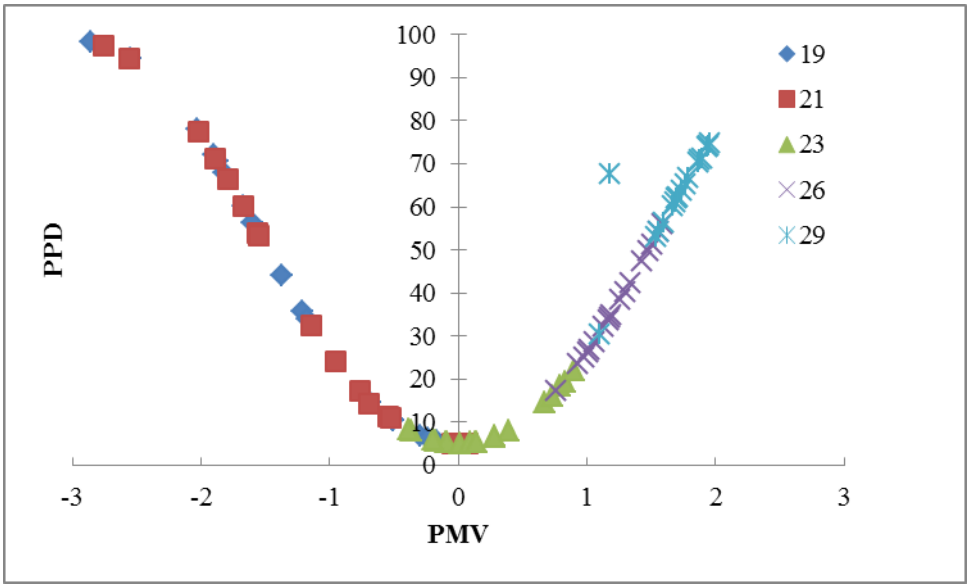


Fig. 5: The effect thermal assessment by five temperature setting in environmental chamber

Table 4: Average parameters for measurement in environmental chamber

Temperature (°C)	**Heart Rate (bpm)**	PMV	PPD
19	91.00	-2.69	47.85
21	97.83	-1.89	44.47
23	92.00	0.01	9.49
26	99.33	1.59	33.75
29	92.33	2.16	46.87

4. Conclusions

The most significant which can be drawn from this study to investigate the correlation, relationship, and action between each of the thermal comfort to human in Malaysia building and to assess effects of environment and physiological variables on human performance and productivity. Base on study, to find the most factors that lead to human performance and productivity depend on three results. Firstly, the subject's heart rate reading result from difference types of task at difference temperature ranges. Second, heart rate reading results from difference temperature range while doing multiple tasks. Lastly, conduct thermal comfort assessment of PMV and PPD.

According to experimental, found that temperature ranges between 21ºC-29ºC and relative humidity 50%-60% give difference heart rate level that indicates the level of comfort by subjects. The most comfort zone for office room air temperature is 23ºC. At this temperature the heart rate level shows by subject are at medium level, so that subjects are comfort to do their office task and may lead to increasing performance and productivity. Lower relative humidity accelerates evaporation of moisture, thus lead to human body to feel overcooling. Therefore, when the air temperature is lower or higher the performance of subjects will decrease and dropped base on heart rate reading of ECG and thermal comfort assessment of PPD and PMV.

Many previous study have indicate there is a significant relationship between heart rate and thermal condition based on these features, heart rate has the potential to be used as an index to illustrate the human thermal sensation. An analysis of the absolute level of heart rate data clearly showed a proportional relation to metabolic rate based on activity level. Data on all of the subjects shows significantly higher heart rates in the warm temperature and in the cool temperature at an activity level of 1.6 Met.

Acknowledgments

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