AN ANALYSIS IN THE IMPLICATION OF THERMAL ENERGY DISTRIBUTION TOWARDS HUMAN COMFORT IN AN OFFICE SPACE

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Abstrak

Kajian ini bertujuan untuk menyiasat pengedaran tenaga haba terhadap prestasi seorang pekerja di sebuah bangunan pejabat. Hawa dingin adalah penting untuk mengekalkan keselesaan terma persekitaran dalam ruang tertutup, terutama untuk iklim di Malaysia. Untuk menyiasat sensasi berkesan haba daripada mereka yang bekerja dalam persekitaran yang tidak seragam, adalah amat penting untuk menentukan butir-butir pemindahan haba tempatan. Dalam konteks ini, tujuan kajian ini adalah untuk membandingkan antara haba keselesaan dan suhu tetapan penyaman udara. Suhu dikekalkan pada lima tahap yang berbeza iaitu 19, 21, 23, 26 dan 29^{o}C. Kajian ini telah dijalankan di dalam ruang alam sekitar di Universiti Malaysia Pahang. Hasil kajian menunjukkan bahawa suhu antara 21-29^{o}C dan kelembapan relatif antara 50-60% boleh memberi perubahan kepada tahap suhu kulit yang menunjukkan tahap keselesaan yang dialami oleh subjek.

Kata Kunci: Pengedaran terma, Keselesaan terma, Bangunan pejabat

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Abstract

This study aims to investigate thermal energy distribution on a worker's performance in an office building. Air conditioning is essential for maintaining environment thermal comfort in indoor space, especially for the climate in Malaysia. In order to investigate an effectual thermal sensation of those working in a non-uniform environment, it is very important to define the local heat transfer details. In this context, the purpose of this study is to compare between thermal comfort and temperature settings of air conditioning. The temperature was maintained at five different levels which are 19, 21, 23, 26 and 29°C. The study was carried out in the environmental chamber at University Malaysia Pahang. The result shows that the temperature settings between 21-29°C and relative humidity between 50-60% can give a difference to skin temperature level that indicates the level of comfort experienced by the subjects.

Keywords: *Thermal distribution, Thermal comfort, Office building*

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1.0 Introduction

Malaysia is located in a 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 (Qahtan et al, 2010). In such a climate, many of the buildings in Malaysia depend much on the air conditioning and mechanical ventilation (ACMV) systems to make sure that all the building occupants are comfortable being in that building.

Buildings differ in a number of ways: their individual physical form; the heating or cooling system provided and whether being used; the possibilities they offer for occupants to control their environment and the policies of management about whether there is a dress code and so on (Nicol & Humpreys 2002).

Laboratory experiments and field investigations are the two typical approaches to study the correlation, relationship, and action between each of the thermal comfort to human in Malaysian buildings and to find the impact of thermal comfort toward workers' performances in their workplaces. Field investigation is the most challenging approach because of the uncontrollable and unquantifiable variables in the actual workplace practices. However, this method may render the most convincing results as it provides the direct feedback from the occupants in the real situation of study area.

The aim of this study is to investigate the implication of thermal distribution to human comfort in the office building. The physiological factor of heart rate has been chosen as the main parameter. In recent years, a lot of studies have investigated the thermal comfort using physiological mechanisms such as vasodilation, vasoconstriction, sweating, and metabolic heat production. Before this, the predictive mean vote (PMV) model developed by Fanger 1970 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 used by preventing over-heating and excessive cooling. Past studies have proven that the mechanisms of thermal comfort could be understood only by using the knowledge of physiology (Charlie et al 2001).

2.0 Experimental Procedures

This paper will look into the details about the materials and the experimental test that have been adopted in conducting the study. It includes field of study, selected locations for study, subjects of the study, procedures of study and methods of data collection.

2.1 Materials

The experiments were carried out in an environmental chamber with the size of 3.6 m x 2.4 m x 2.4 m as illustrated in Figure 1 (a). In this chamber, a complete set of computer, system, desk and chair is provided as presented in Figure 1 (b). The thermal environment with different temperature settings (19, 21, 23, 26 and 29^{o}C) was maintained in the environmental chamber. Figure 2 shows the environmental chamber main switch controller used to maintain and adjust the temperature setting. The temperature was measured using controller in the environmental chamber. Each temperature could be set up and adjusted by using the switch box in the environmental chamber. The other thermal conditions including the air velocity (about 0.05±0.01 m/s) and 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 had been asked to avoid caffeine, alcohol, smoking and involvement in any intense physical activity to at least 12 hours before the experiment. All these may affect the result testing if not being controlled. Dress code for the test was also being emphasized whereby the subjects were reminded to wear loose smart casual attires. As for footwear, they must be comfortable office shoes.

Figure 3 shows the chest lead for heart rate measurement and helmet for skin temperature measurement. Electrodes connected by lead wives to the ECG machine were attached to the subject on their chest, wrist and leg. Before beginning the experiment, information about the components of a subject's physical condition including height, weight, age, BMI and gender was recorded as illustrated in Table 1. Table 2 shows the type of work the subject must follow during the measurements. There were three types of work being performed by the subject during the measurements namely thinking, sitting and printing. Each measuring session took 10 minutes in which the measurements of heart rate and skin temperature were recorded. The facility and type of tasks were set up to resemble a normal work operation of an office.

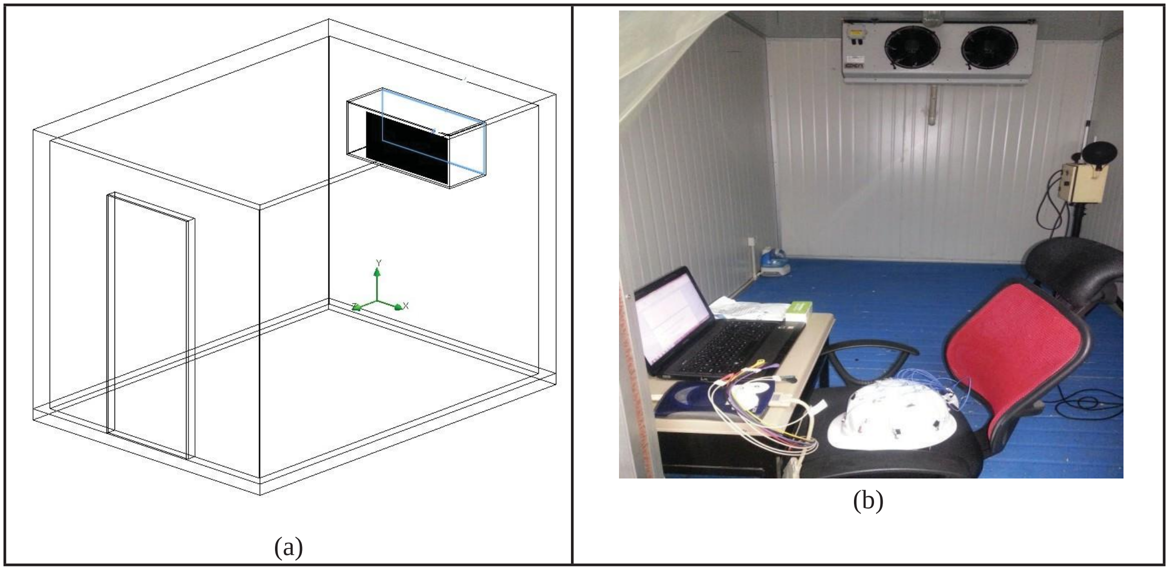
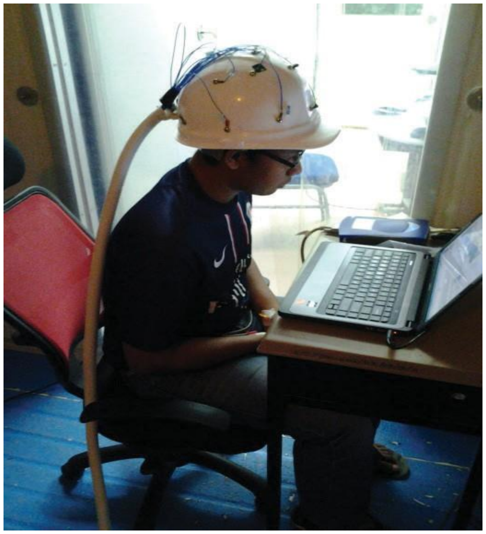


Figure 1: (a) Environmental chamber layout, (b) Interior view of the environmental chamber

Figure 2: Environmental chamber main switch controller

(a)



(b)

Figure 3 (a) One of the respondents for heart rate measurement (b) one of the subjects with the 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 specified time and metabolic rate

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

The measuring equipment selected for this study are also categorised into environmental and physiological. The measurements were recorded in the workplaces ergonomic simulator chamber WES-103 in University Malaysia Pahang (UMP) as the main study area.

3.0 Results and Discussions

Figure 4 presents the heart rate readings for each subject at different temperature settings. In Figure 4 (a), the higher heart rate reading for all subjects was 94.83 bpm at the 26^{o}C temperature setting. Besides that, the graph also shows that medium heart rate was 82 bpm at the 29^{o}C temperature setting. The lower heart rate was 76.67 bpm at the 23^{o}C temperature setting. The lower heart rate illustrated the comfort zone of temperature in the office. Previous study from Choi et al (2012), found that, heart rate reading is directly proportional to the temperature of office room. Lower heart rate of subject shows the higher comfort level of occupant in a particular temperature setting in the office building. Therefore the results indicate that the subject felt most comfortable when the temperature setting was at 21^{o}C.

The individual thermal comfort sensation shows a difference from each other due to environmental or physiological factors. These statements can be proven by conducting experimental test using ECG to get the reading of heart rate. Figure 4 (b) shows the lower heart rate reading at 29^{o}C while doing typing task at workstation and the higher heart rate reading at 23^{o}C. There are positive correlations between range of temperature and heart rate level. The room temperature had given significant effects on heart rate. From the result it can be seen that the most suitable temperature for a subject to do their typing task is 19^{o}C because the heart rate level on average was lower. It also shows that the subjects felt neutrally comfortable at 19^{o}C. ISO 7730 (1994) and ASHRAE Standard 55 (2004) defines the comfortable temperature range to be 18-28^{o}C. However, Hwang et al. 2006 argued that the comfortable temperature range is 20.1-28.4^{o}C in a classroom and suggested an edge temperature of 28^{o}C that will contribute to energy saving. Thus, as expected, there is a strong correlation between temperatures and comfort in the office based on the heart rate levels of the subjects while doing physical activities like typing.

Figure 4 (c) presents the correlation between temperature and heart rate of the six subjects while they were doing the printing activity or hard task. The higher heart rate reading shows the uncomfortable feeling of subject at normal air temperature. From the line graph, at the temperature setting of 26^{o}C the subject produces higher reading of heart rate while doing printing and moving around at their workstations. Thus, at the most suitable temperature of 23^{o}C, all the heart rate readings shown by the subjects were at a comfortable level which is 92 for 1.6 Met printing tasks.

Yao et al. (2007) found that several physiological (stress) indicators which may be increased by psychological reactions have shown the potential to be used in determining the heart rate variability which is 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 is unweighted average of mental performance and manual performance and is used to define the overall effect of thermal environment on human performance.

These findings further support the study by Jensen et al. (2009) 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. 6 shows the results of PMV and PPD obtained from the experimental analysis of thermal assessment in the environmental chamber. The results of PMV index at 19^{o}C show readings between -2.86 to -0.17. Other than that the PPD also shows a reading of 5.6% - 94.4% at the room temperature. Thus, the thermal comfort assessment for the environmental chamber can be regarded as the 19^{o}C based on 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 subjects are not comfortable to perform their office works when the room temperature is maintained at 19^{o}C. This is because they will be overcooled if they stay for eight hours in the office. Previous study by Ayako et al. (2009) which recorded overcooling effect found that there is no medical definition of the symptom of unusual feeling of coldness. However, a lot of people suffer from the unusual feeling of coldness at some body parts, such as hands, feet, and lower back, in winter and in a cold or an air-conditioned environment either at school, workplaces or colleges.

The results of PMV index at 21^{o}C show readings between -3.00 to 0.05. Other than that the PPD also shows reading around 5% - 99.42% in this study. Thus, the thermal assessment for the environmental chamber is regarded cool at 19^{o}C by following the thermal comfort scale. In conclusion, this range of room temperature (21^{o}C) is categorised as uncomfortable for office room temperature.

Additionally, 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 (1970). These indices attempt to correlate human thermal comfort with environmental conditions. Previous study on thermal comfort have found that, thermal comfort can also be corelated with workers' productivity, safety and health.

The study by Dua (1994) states that there are many symptoms workers can show when they feel uncomfortable at workplaces. These include signs of depression, stress and anxiety which may lead to decreasing performance indicated by increasing absenteeism and lower productivity.

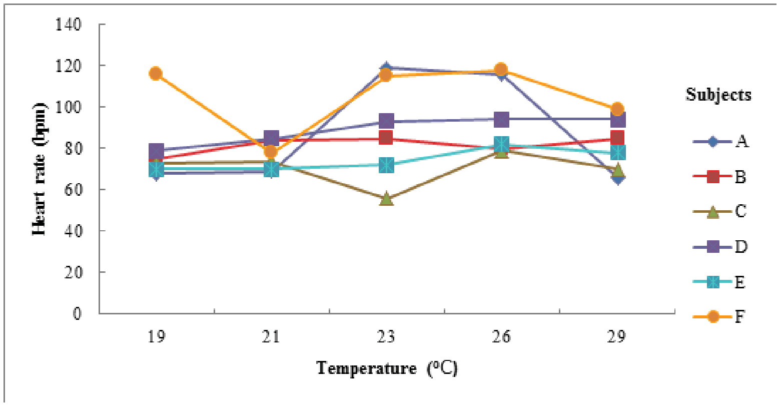
The results of PMV index at 23°C show reading between -0.39 to -0.9. Other than that the PPD also shows reading around 5% - 22.1% at this chamber. Thus, the thermal comfort assessment for this chamber is at a comfort zone when the temperature setting is 23°C by following the thermal comfort scale.

The results of PMV index at 26°C show readings of 0.93 to 1.59. Other than 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°C by following the thermal comfort scale. In conclusion, this range of room temperature (26°C) is categorised as uncomfortable for office room temperature because hot condition can lead to sweating workers.

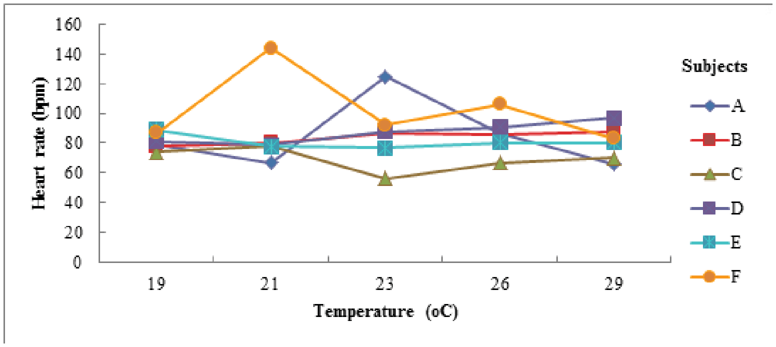
Literature suggests that, usually office workers face overcooling problems more frequently than overheating problems in office room. According to Shikdar and Sawaqed 2003, workers who do not feel comfortable will complain of discomfort and dissatisfaction at work and consequently reduce their productivity. Ismail et al. 2008 support this indication with their findings of an investigation undertaken in automotive paint shop. Their job satisfaction analysis reveals that sweat causing environment or exposure to heat will cause significant discomfort.

The results of PMV index at 29°C shows readings between 1.1 to -1.96. Other than that, the PPD also illustrates reading around 30.4% - 74.9% at this chamber. Thus, the thermal comfort assessment for the environmental chamber is regarded very hot and uncomfortable at 29°C by following the thermal comfort scale.

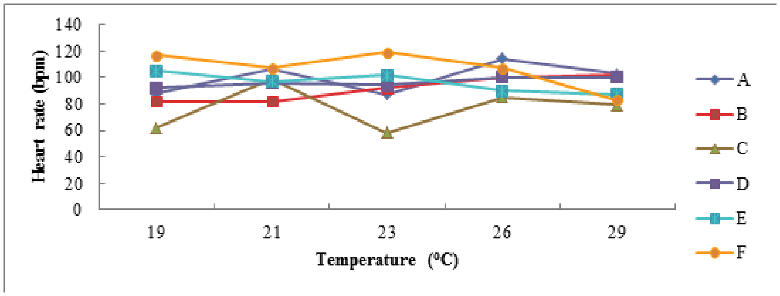
According to thermal sensation scale, the comfort zone of workplaces must be neutral or 0 of PMV reading. Thus, it can be concluded that the room temperature of 29°C is not comfortable for workers to perform their work tasks because they will feel overheating staying eight hours in their office rooms.



(a) 1.0 Met



(b) 1.2 Met



(c) 1.6 Met

Figure 4: **Heart rate readings for each subject at different temperature setting with three activity levels; (a) 1.0 Met, (b) 1.2 Met and (c) 1.6 Met.**

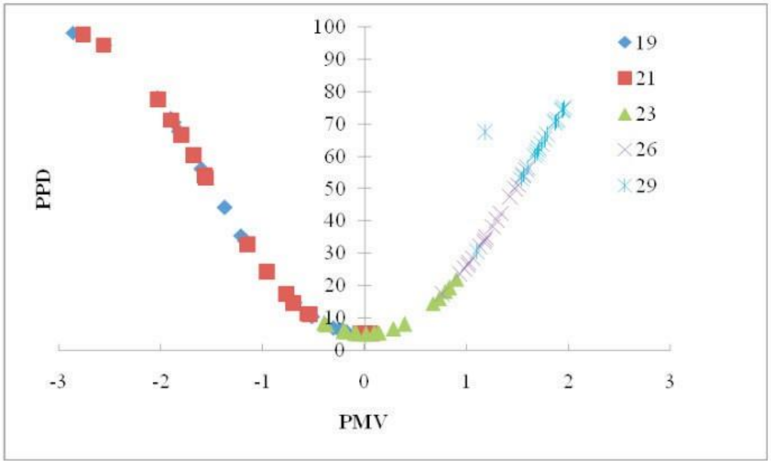
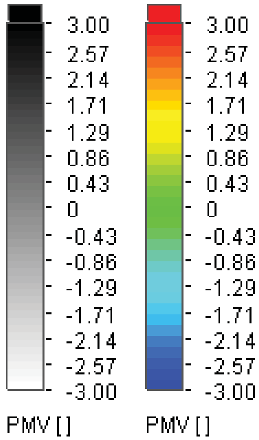
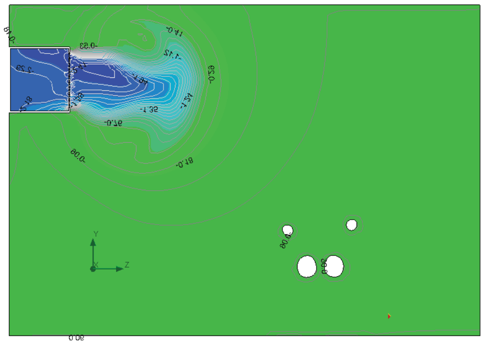
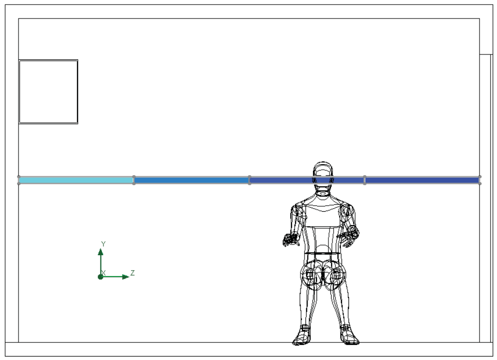
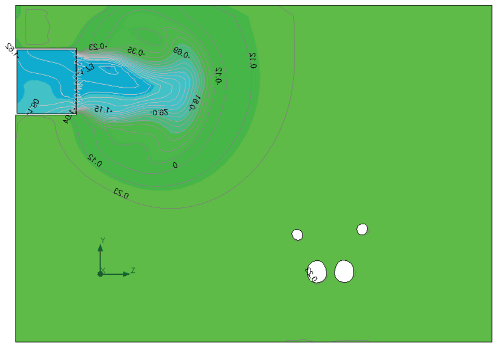
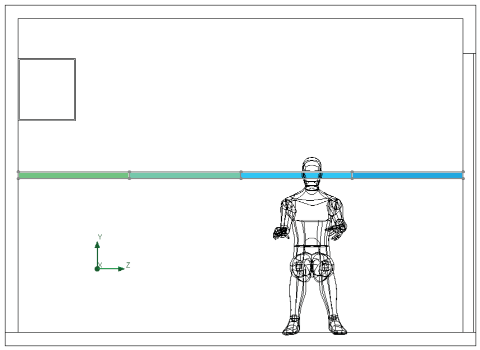


Figure 5: **The thermal comfort assessment based on five temperature settings in the environmental chamber**



Simulation	Experiment
19°C	
	
21°C	
	
23°C	

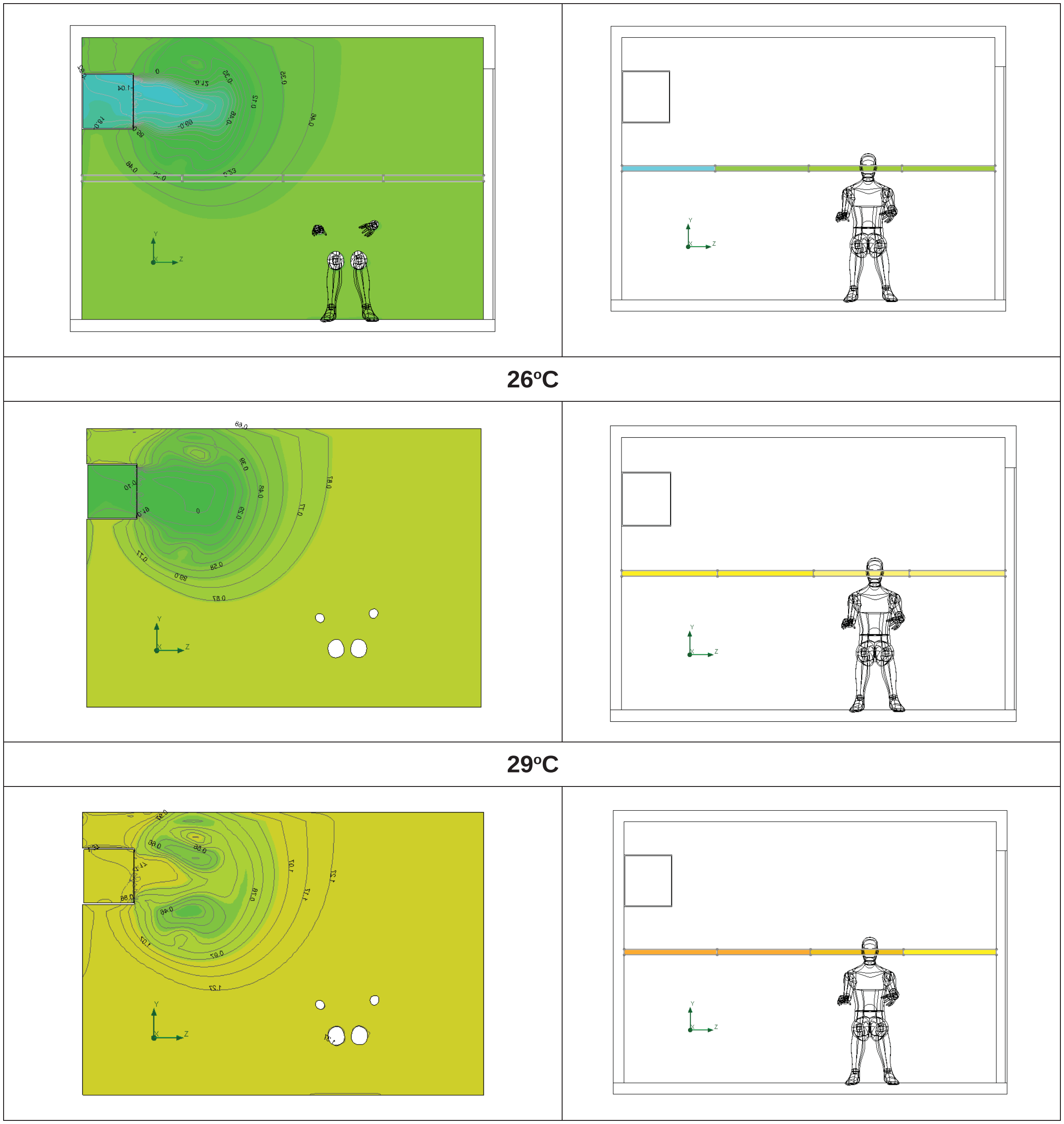


Figure 6: Effects of PMV values in the building by side views

4.0 Conclusions

It can be concluded that different heart rate readings have been recorded for different types of tasks at different temperature ranges. The experimental results show that the temperature range of 21-29^{o}C and relative humidity of 50%-60% provide different temperatures that indicate the levels of comfort experienced by the subjects. The most comfortable zone for an office room bears an air temperature of 23^{o}C. At this temperature, the heart rate level shown by subjects are at medium level, indicating that subjects are comfortable to do their office tasks and it leads to an increasing of performance and productivity. Lower relative humidity accelerates evaporation of moisture, thus lead the human body to feel overcooling. Therefore, when the air temperature is lower or higher the performance of subjects will decrease as based on heart rate reading of ECG and thermal comfort assessment of PPD and PMV.

As shown in this paper, it brings advantages over total volume conditioning in terms of improved thermal comfort. However, several topics still remain to be explored in order to ease practical application. The significant topics which can be drawn from this study is to investigate the correlation, relationship, and action between each of the thermal comfort toward human in Malaysian buildings and to assess effects of environment and physiological variables on human performance and productivity.

References

ASHRAE Standard 55, 2004. Thermal Environmental Conditions for Human Occupancy, ASHRAE Inc. Atlanta.

Ayako Y, Hiroko K, Kazuyo T. and Norio I., 2009. Interinduvidual differences in Thermal Comfort and the Responses to Skin Cooling in Young Women, *Journal of Thermal Biology*. Vol.37(1), p.p 65-71.

Charlie H.Z, Edward A. and Zhang H, 2001. "A Model of Human Physiology and Comfort for Assessing Complex Thermal Environments," Build Environment.Vol. 36 (6), p.p. 691-699.

Choi J.H, Loftness V. and Lee D.W, 2012. "Investigation of the Possibility of the use of Heart Rate as a Human Factor for Thermal Sensation Models," Building and Environment.Vol. 50, p.p. 165 – 175.

Dua J.K., 1994. Job Stressors and their Effects on Physical Health, Emotional Health and Job Satisfaction in a University. Journal Education Administration.Vol.32, p.p. 59-78.

Fanger P.O 1970. Thermal Comfort: Analysis and Applications in Environmental Engineering, Copenhagen, Danish Technical Press.

Hwang R.L, Lin T.P. and Kuo N.J, 2006. "Field Experiments on Thermal Comfort in Campus Classroom in Taiwan," Energy and Buildings. Vol. 38(1), p.p. 53-62,

Ismail A.R., Mansor M.R.A., Kim C.B., Tahir, M.M., Usman I.M.S., Sopian K., Ab. Rahman M.N., Sulong A.B. and Deros B.M 2008. "The Relation Between the Discomfort Level of Automotive Industries Operators Towards their Workstation Design and Work Environment," Journal of Achievement in Materials and Manufacturing Engineering.Vol. 31(2), p.p. 1-9.

ISO 7730, 1994. Moderate Thermal Environments: Determination of the PMV and PPD Indices and Specification of the Conditions for Thermal Comfort, International Standard Organization, Geneva.

Jensen K.L, Toftum J. and Friis-Hansen P, 2009. A Bayesian Network Approach to the Evaluation of Building Design and its Consequences for Employee Performance and Operational Costs," Building and Environment.Vol.44, p.p. 456-462.

Nicol J.F. and Humphreys M.A 2002. "Adaptive Thermal Comfort and Sustainable Thermal Standards for Buildings," Energy and Buildings.Vol. 34, p.p. 563–572.

Shikdar A.A. and Sawaqed N.M 2003. "Worker Productivity and Occupational Health and Safety Issues in selected Industries," Computers and industrial Engineering.Vol. 45(4), p.p. 563-572.

Qahtan, A.M., Keumala, N.I.M. and Rao, S.P 2010. "Occupant Satisfaction in Respect to Indoor Environmental Quality in Energy Efficient Certified Buildings in Malaysia". 16th International Conference of the CIB W104 Open Building Implementation on “Open and Sustainable Building”. Bilbao, Spain, CIB W104.

Yao Y, Lian Z, Liu W. and Shen Q, 2007. “Experimental Study on Skin Temperature and Thermal
Comfort of the Human Body in a Recumbent Posture under Uniform Thermal Environments,” Indoor Built
Environment.Vol.16(6), p.p. 505-518