CREAM - Current Research in Malaysia Vol. 2, No. 2, April 2013: 43-59

Adaptive Fanger's Model for Optimum Thermal Comfort Setting for Lecture Halls in Malaysia

(Model Penyesuaian Fanger untuk Keselesaan Terma di Dewan Kuliah Malaysia)

PAU J.S., WILLIAM K.S. PAO, SHAHARIN A. SULAIMAN & E. HALAWA
Mechanical Engineering Department, Universiti Teknologi PETRONAS, Bandar Seri Iskandar, 31750 Tronoh, Perak, Malaysia.
william.paokings@petronas.com.my

ABSTRACT

Unnecessary air conditioning for thermal comfort causeds energy over consumption. As air conditioning has become irreversible, one of the solutions is to run air conditioners at minimal energy without sacrificing the comfort of occupants in air conditioned space. The approach to thermal comfort is the key to successful thermal comfort research. Fanger's model has been adopted by ASHRAE and ISO standards but its universal applications have been debated. In recent decades, adaptive model that regards humans as adaptive beings has been accepted. The static and deterministic nature of Fanger's model has limited its application in hot, humid countries, such as Malaysia. This research aims to integrate the theories of Fanger and adaptive model into a new model which is applicable in Malaysia by taking the case in lecture halls. The new Fanger's Adaptive Model is established through normalization of the thermal sensation distribution obtained in thermal chamber by Fanger. The PMV range of 80% satisfaction has been widened to -1.3 to +1.3 which adopted the theories of adaptive model, where humans have the ability to adapt to environment. The research also includes field observations on Malaysian students clothing and activity levels in lecture halls. Previous field study results which proposed 25.3°C comfort temperature for lecture halls in Malaysia together with the field observation results were used to verify the new model. About 95% of PMV falls within the new range at this comfort temperature. It is proven that Fanger's model is semi-adaptive and probabilistic and the integration of Fanger's Adaptive Model is more accurate in predicting thermal comfort in hot and humid climate.

Keywords: Thermal comfort, energy conservation, air-conditioning, adaptive model

ABSTRAK

Kelebihan pengunaan penghawa dingin untuk keselesaan terma menyebabkan kelebihan tenaga digunakan. Kehidupan selesa yang bergantung kepada penghawa dingin tidak dapat dipatahbalik. Olehitu, salah satu solusi bagi isu ini adalah menggunakan penghawa dingin dengan tenaga minimum tetapi tidak mengabaikan keselesaan manusia. Cara-cara memodelkan keselesaan terma adalah kunci kejayaan dalam bidang pengajian ini. Model Fanger telah digunakan oleh standard ASHRAE dan ISO tetapi pengunaannya secara global telah didebatkan. Dalam masa kebelakangan ini, model penyesuaian yang mengaitkan manusia sebagai subjek penyesuaian telah diterima oleh ramai pengaji. Ciri-ciri Model Fanger, iaitu static dan berketentuan telah menghadkan aplikasinya di Negara bercuaca panas dan lembap, seperti Malaysia. Pengajian ini berobjektif untuk mengintegrasikan teori Model Fanger dan Model Penyesuaian untuk mendapatkan satu model yang baru yang boleh diaplikasi di Malaysia, terutamanya di dalam dewan kuliah. Model baru, iaitu Model Penyesuaian Fanger ditubuhkan dengan menormalisasikan pengedaran sensasi haba seperti yang ditubuhkan oleh Fanger dalam ruang terma. Julat PMV untuk 80% kepuasaan telah diluaskan untuk mencapai –1.3 hingga +1.3. Ini telah mengintegrasikan teori Model Penyesuaian, iaitu manusia boleh menyesuaikan diri dalam suasana yang bertukar-tukar. Pengajian ini juga termasuk kajian pemerhatian dalam dewan kuliah di Malaysia untuk mendapatkan tahap pemakaian dan aktiviti dalam dewan kuliah. Pengajian lalu yang mencadangkan 25.3°C suhu keselesaan telah disahkan oleh pengajian ini. Terdapat 95% PMV jatuh dalam julat PMV baru (–1.3 hingga +1.3) berdasarkan suhu keselesaan ini. Ini telah membuktikan Model Fanger adalah separuh penyesuaian dan integrasi Model Fanger dalam Model Penyesuaian adalah lebih tepat dalam ramalan keselesaan terma di cuaca panas dan lembap.

Kata kunci: Penyesuaian, normalisasi, peratusankepuasan, suhukeselesaan, pemakaian

INTRODUCTION

Thermal comfort is the condition of mind, which expresses satisfaction with the thermal environment (ASHRAE, 1992). Humans' comfort has become a commodity and the lifestyles of having air conditioning might become an irreversible trend in modern life (Nicol, 2009). Air conditioning has used up a large amount of energy and this created another issue of energy over-consumption. One of the solutions is to run air conditioners at minimal energy and at the same time without sacrificing the comfort of occupants in air conditioned space(Nicol, 2009).

Fanger's model is based on thermodynamics'heat balance between human body and the environment. The parameters considered by Fangerare clothing insulation, metabolism rate, air temperature, radiant temperature, humidity and air velocity (Fanger and Toftum, 2002). ASHRAE and ISO have adopted Fanger's model in establishing the thermal comfort standards to be applied globally.

The universality of Fanger's model has been questioned as the model does not include culture, climate and social dimensions(Dear, 1996; Kempton and Lutzenhiser, 1992). These dimensions are difficult to be quantified as thermal comfort parameters. Adaptive model which is based on field experiment is said to better describe humans' thermal comfort as it indirectly include the three dimensions which not considered by Fanger. Humans' adaptive mechanism includes behavioral adaptations, physiological acclimatization and psychological adaptations (Fountain et al., 1996). Field studies conductedby researchers prove the inadequacy of Fanger's model in predicting thermal comfort, especially in tropical regions. Over-prediction of thermal comfort by Fanger's model in tropical regions causes unnecessary air conditioning energy. Adaptive model has gained its recognition in thermal comfort research when ANSI and ASHRAE Standard 55 and European Standard EN 15251 established adaptive standard in 2004.

Peoples from different background and culture dress up differently to suit the activities that they are doing and also to make themselves feel comfortable thermally. Malaysia has a diversity of culture with several ethnics living on this piece of land. Malay is the largest ethnic group in Malaysia, followed by Chinese and Indians. They dress up according to their own culture and habits. However, offices, schools, lecture halls and other locations set dressing requirements to their occupants. These constraint the clothing of building occupants and affecting the parameters to be studied in thermal comfort.

LITERATURE REVIEW

Fanger's Heat Balance Model

Fanger's model is based on the premises that optimum thermal comfort can only be achieved when all energy fluxes that affect the thermal balance of humans are taken into account and the deviation of energy balance from stable state shall be zero.According to Fanger, thermal comfort can be achieved when heat storage rate in body is zero (Becker et al., 2002). Fanger has determined the heat transfer mechanism into and out of human's body, comprising radiation from surroundings and energy-flux from human's body. The equations below show the energy entering and leaving the control volume of human body[1].

$$E_{in} = Atm + D_{if} + D_{ir} + E + R_{ef} \tag{1}$$

$$E_{out} = E_{res} + E_{sw} + C + E_{d} + R \tag{2}$$

The heat storage in human body is related to other heat terms,

$$S = M - W - E + R + C* \tag{3}$$

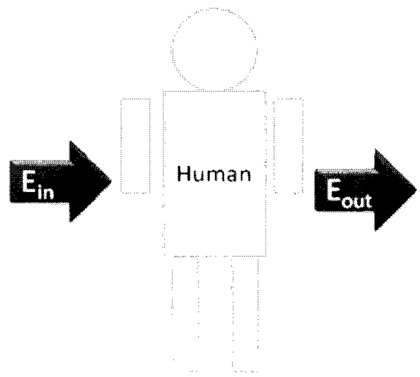

Figure 1: Fanger's heat balance model. A person will feel comfortable when the energy entering his body is equal to the energy exiting his body

Fanger had established two indices for thermal comfort which are predicted mean vote (PMV) and predicted percentage of dissatisfaction

[1] Atm is the long-wave atmospheric counter radiation; D_{if} is the diffuse radiation; D_{ir} is the direct solar radiation; E is the long wave radiation from surrounding areas; R_{ef} is the short-wave reflected radiation; E_{res} is the energy-flux by respiration; E_{sw} is the latent energy-flux by sweat evaporation; C is the convective and conductive heat flux; E_{d} is the latent energy-flux by vapor-diffusion; R is the long-wave radiation of humans.

(PPD) (Fanger, 1970). PMV expresses the quality of thermal environment as mean value votes of a large group of people on ASHRAE's 7-point thermal sensation scale (ASRHAE, 2003).

Table I: ASHRAE 7-Point Thermal Sensation Scale

Scale	Description
-3	Cold
-2	Cool
-1	Slightly cool
0	Neutral
1	Slightly warm
2	Warm
3	Hot

PPD is a mathematical function of PMV that describes the voting outside the three thermal satisfaction scale of ASHRAE (Nicol and Humphreys, 2002), as in Eqn. (4).

$$PPD(PMV) = 100-95 \times e^{-0.03353PMV4-0.2179PM} \quad (4)$$

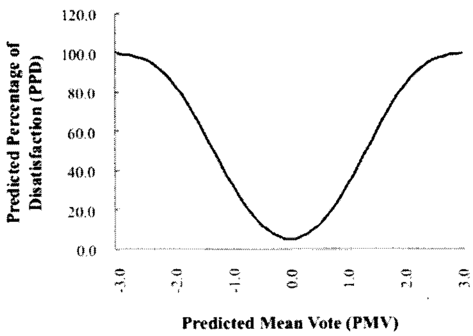

Figure 2: Predicted Mean Vote (PMV) and Predicted Percentage of Dissatisfaction (PPD) curve

The goal of air conditioning system is to approach PMV = 0 whereas PPD = 5 (Halawa, 1994). Fanger's model is regarded as partially adaptive as it accounts for physiological and behavioral adaptations such as clothing insulation and metabolism (Dear and Brager, 1998).

Universality of Fanger's Static Heat Balance Model

The universality assumption of ISO 7730 and ASRHAE Standard 55 which adopted Fanger's model has been challenged (Dear and Brager, 2011). Discrepancies of the predicted mean votes and actual mean vote from the data collected in field are due to clothing garments, chair insulation, inaccurate estimation of activity and metabolism rate, non-uniformities of measurement, and non-thermal factors, such as demographics(Dear and Brager, 1998). The standard shall be improved by considering the dynamic nature of human-surrounding interactions (Nicol, 2004). The discrepancies are also explained by the equations and non steady-state condition (Nicol and Humphreys, 2002).

Various field studies had shown that Fanger's heat balance theory failed to explain the comfort temperature range in the buildings with natural ventilation (Wong and Khoo, 2002). The field studies that conclude the above statement include researches conducted in Singapore, Indonesia, and the old Havana in Cuba (Wong and Khoo, 2002; Wong et al., 2002; Nicol, 2004; Gagge and Burton, 1941).

Adaptive Hypothesis

Adaptive hypothesis describes that a person's thermal expectations and preferences are affected by contextual factors and past thermal history. The contextual factors are climate, building and time (Nicol and Humphreys, 2002). People in warmer climatic zones prefer warmer indoor temperature thanthose in cold climatic zones (Dear and Brager, 1998). People will react in ways, either adjusting the environment or personal adjustment to restore their comfort when there is a change occurs.

Adaptive Model of Thermal Comfort

Adaptive model treats thermal recipients as active subject that interacts with the thermal environment. Their perception on thermal comfort is affected by past thermal history, cultural and technical practices (Dear and Brager, 1998). The adaptive model is a linear regression that relates indoor comfort temperature with outdoor air temperature and business culture, such as activities, dress code, etc (Mui and Chan, 2003).

$$T_{comf} = A \times T_{a,out} + B \qquad (5)$$

Adaptive mechanism includes behavioral adaptations, physiological acclimatization and psychological adaptations (Fountain et al., 1996). A person will change its personal variables such as clothing to adapt to thermal changes. Peoples show physiological adaptation by increased metabolic rate or sweating capacity and other physiological changes to adapt to the environment. Psychological adaptation is the change in people's expectation towards thermal environment (Dear and Brager, 1998). However, few literatures discuss on this adaptive mechanism.

Occupants in hot and humid climate will adapt to the environment naturally. Often, their daily adjustment to adapt to the thermal environment will become their habit in long terms. The ability to afford air conditioning is also another factor that influences occupants to be more tolerance towards the climate (Wong et al., 2002; Nicol, 2004; Gagge and Burton, 1941).

de Dear and Brager has presented the adaptive comfort chart by relating the indoor operative temperature (comfort temperature) to mean monthly outdoor air temperature, as shown in Figure 3. They claimed that the adaptive approach is more appropriate as it changes with results from the field survey automatically and it is independent on non-specific description of the season.

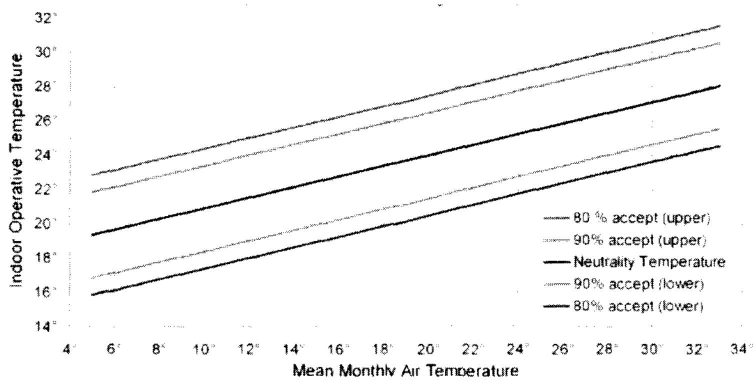

Figure 3: The adaptive comfort model as proposed by de Dear and Brager in 2001

Development of Adaptive Comfort Approach

Adaptive comfort approach has been developed since last decade. Some researchers constructed thermal comfort chart based on adaptive comfort approach in tropics country such as Thailand and Hong Kong as ASHRAE Standard cannot be applied in tropical country. For an example, Thailand has large climatic variation and thermal perception differs according to habits and regions (Khedari et al., 2000).

New adaptive comfort standard (ACS) has been established in 2001 for design, operation and evaluation of natural ventilated buildings which saves energy in air conditioning. ACS has adopted dry bulb temperature instead of utilizing outdoor effective temperature to characterize outdoor climatic environment. GIS mapping technology has proved ACS potential in saving energy (Dear and Brager, 1998). ISO 7730 PMV is be modified to improve its performance and accuracy in predicting the actual mean vote (Nicol and Humphreys, 2002). Extended PMV model has included expectancy factor, *e* into the PMV for the natural ventilation buildings in warm climate (Fanger and Toftum, 2002).

The discrepancy between actual thermal sensation vote and predicted mean vote in tropics classroom is shown in a study carried out in Hong Kong (Wong and Khoo, 2002). A new adaptive model (ACT) has been established in Hong Kong and a regressed linear relationship between outdoor temperature and indoor comfort temperature has been produced (Zhang et al., 2011).

The concept of air temperature thresholds to reduce the need for energy-intensive air conditioning in buildings has been introduced in 2011. By having a broad comfort/acceptable temperature, thus, less energy is required to maintain the indoor environment (Nicol, 2011).

Clothing and Thermal Comfort

Clothing can be described as the thermal resistance or insulation (Golman, 1981) and impedance to mass transfer (Parsons, 1993). Clothing can be regarded as mechanism of making a workplace environment and safer and healthier for workers. Clothing also represents a significant cultural development (Morgan and Dear, 2003), a projection of personality, mood, religion, sub-cult and other group affiliations (Dear and Brager, 2002). In terms of socio-economy, clothing is a code for organizational or corporate identity. Clothing is simply a layer of thermal insulation uniformly interposed between human's body surface and their immediate thermal environment (Fanger, 1970).

Remarkable clothing differences across buildings contribute to variations in predicting thermal comfort environment. The diversity of the clothing insulation in a building can be explained by various reasons, such as genders (Gut and Ackerknecht. 1993(, dress code regulations, response to outdoor environmental conditions(Dear and Brager, 2001), material culture(Morgan and Dear, 2003), comfort level, indoor environment, appropriateness to the job, desire to be fashionable, after-work activities (Dear and Brager, 2002). The focus of this research is on clothing insulation worn indoor affected by corporate dress codes and clothing insulation worn indoors affected by context/setting.

Climate and Thermal Comfort in Malaysia

Malaysia has hot humid climate with temperature ranging from 20°C to 32°C during daytime and 21°C to 27°C during night time with relative humidity around 75% (Fanger, 1985).

High energy is required for cooling buildings in hot and humid climate to provide a comfortable environment for occupants (Victor, 1963; Ismail et al., 2010). Field studies in Malaysia suggest a wider thermal comfort range for the hot and humid climatic zones than those proposed by international standards, i.e. ASHRAE Standard 55. This indicates that Malaysians are acclimatized to much higher environmental temperature(Ismail et al., 2009).

Malaysia, with fastest growing building industries worldwide, experienced increased energy demand in buildings. The average temperature for typical towns in Malaysia imply that air conditioning during office hours is a must for people living in hot and humid climate like Malaysia want to feel comfortable thermally during the day (Yau et al., 2011).

The prediction of neutral temperature for Malaysian lecture hall setting is 25.3°C (Yau et al., 2011). The comfort temperature obtained in lecture theatre in Singapore is 25.84°C (Cheong et al., 2003).

METHODOLOGY

The research issues are investigated by observing clothing behavior of subjects in a local university located in Perak, Malaysia. These observations were supplemented by a study on the imposed by university. Observations are made on the activities being carried out during in one to two hour lecture duration.

The method of clothing insulation estimation is based on the garment check-list defined in ASRHAE Standard 55P-2003 (ASHRAE, 2003). The effective insulation values are estimated by cumulatively summing subjects' clothing garment insulation as listed in the garments and effective insulation values in the standard (Dear and Brager, 2002).

$$I_{effective} = \Sigma_{j=n}^{j=n} I_{clo,j} \tag{6}$$

The distribution of individual thermal sensation votes for different values of mean vote established in ISO7730-2005 is normalized and expressed in normal distribution function in terms of predicted percentage of satisfaction instead of predicted percentage of dissatisfaction. PPD predicts the number of thermally dissatisfied persons among a large group of people while the rest of the group will feel thermally neutral, slightly warn or slightly cool. The distribution of individual thermal sensation votes for different values of mean vote has been established in ISO 7730-2005 (ISO, 2005) standard, as shown in Table III.

To obtain the 80% satisfaction requirement of as specified by ASHRAE and ISO Standard, the area under the normal distribution curve is integrated to obtain the satisfaction PMV scale.

The field studies result obtained in previous researches and the results of observations are computed to validate the new proposed thermal comfort model. All computations have been carried out using Microsoft Excel Visual Basic and Applications (VBA) functions.

Table III: Distribution of Individual Thermal Sensation Votes for Different Values of Mean Vote

PMV	PPD	Persons predicted to vote [a] %		
		0	-1, 0 or +1	-2, -1, 0, +1 or +2
+2	75	5	25	70
+1	25	30	75	95
+0.5	10	55	90	98
0	5	60	95	100
-0.5	10	55	90	98
-1	25	30	75	95
-2	75	5	25	70

[a] Based on experiments involving 1,300 subjects.

RESULTS AND DISCUSSION

Field Observations

In the lecture hall chosen for observation, the activities conducted by the occupants are light during the lectures. From Appendix A – Metabolism Rates for Typical Tasks in ASHRAE 55R-2003, the activities are classified as seating, reading or writing/seated quiet (Met = 1.0) and walking about (Met = 1.7).

The university requirements on students' attire during lecture are "smart casual". Due to cultural difference, Malay, Chinese and Indian ethnics and other races wear different clothing and they are listed as in Table IV. Besides, the clothing preferences in between genders are also considered.

Table IV: Observed Clothing Insulation Worn by Malaysian Students in Lecture Halls

	Male,	$I_{effective}$	Female	$I_{effective}$
Malay	Trousers, long sleeve shirt, socks, shoes, undergarments	0.65	Long sleeve shirtdress (thick), skirt (thick), undergarments, socks, shoes, scarf	0.87
Chinese	Trousers, short sleeve shirt, socks, shoes, undergarments	0.65	Straight trousers (thick), scoop neck blouse, shoes, socks, undergarments	0.36
Indians	Trousers, short sleeve shirt, socks, shoes, undergarments	0.65	Straight trousers (thick), scoop neck blouse, shoes, socks, undergarments	0.36
Others	Trousers, short sleeve shirt, socks, shoes, single-breasted (thin), undergarments	1.1	Straight trousers (thick), scoop neck blouse, shoes, socks, single-breasted (thin), undergarments	0.81

*The tolerance in the observation of clothing insulation is ±0.4.

Normalization of Predicted Mean Vote

As mentioned in ISO 7730, PMV-PPD curve is an inverted Gaussian distribution. To constrain the 80% satisfaction to fall within $-1 < PMV < +1$, the PPD function is expressed in quartic exponential function, as shown in Eqn. 4.

The transformation of PPD index to PPS index gives a bell curve, similar to normal distribution, as shown in Fig. 1. The curve can be represented by the Eqn. 7.

$$PPS(PMV) = 95 \times e^{-0.03353PMV^4 - 0.2179PMV^2} \qquad (7)$$

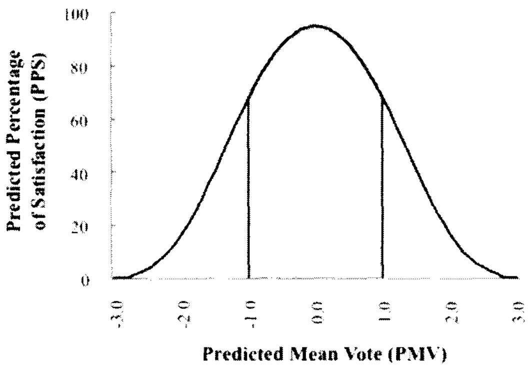

Figure 4: Predicted Percentage of Satisfaction (PPS) vs Predicted Mean Vote (PMV). 80% of satisfaction fall within the range of -1.0 < PMV < +1.0

The normalization of individual thermal sensation votes for different values of mean vote distribution has obtained a mean of 0 and standard deviation of 1.125. The normal distribution is illustrated in Fig. 5. However, in this model, 80% satisfaction falls within the range of -1.3 < PMV < +1.3. The equation that represents this curve is given in Eqn. 8.

$$PPS^{*}(PMV) = 0.355 \times e^{-0.395PMV^2} \qquad (8)$$

Normal distribution is a continuous probability distribution that has bell-shaped probability density function, known as the Gaussian function or as the bell curve, informally. A standard distribution will have mean equivalent to 0 whereas the variance is equivalent to 0. The result obtained from the normal distribution of PPS is non-normal distribution with variance greater than 1 even though the mean fall on 0.

The differences of intersection at 80% PPS(PMV) and PPS*(PMV) is due to the quartic exponential function in PPS(PMV). Based on adaptive hypothesis, people in warmer climatic zones prefer warmer indoor

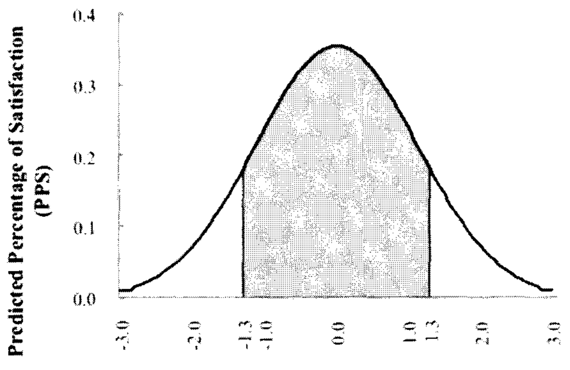

Figure 5: Normalized distribution of Predicted Percentage of Satisfaction (PPS) vs Predicted Mean Vote (PMV). 80% of satisfaction fall within the range of -1.3 < PMV < +1.3

temperature than those in cold climatic zones. This means that their PMV will be located beyond the limit of -1 < PMV < +1. Besides, people living in extreme climate countries will have higher tolerance in towards indoor thermal environment(Wong et al., 2002; Nicol, 2004). By transforming PPD(PMV) to PPS(PMV) and later normalize it to PPS*(PMV), the range of PMV for 80% satisfaction has been widen to -1.3 to +1.3.

Validation of PPD*(PMV) model by field observations

Using the metabolism rate and clothing insulation observed from field and assumptions on air velocity and relative humidity, PMV is calculated for proposed 25.3°C from Yau et al.'s field study. The air velocity of the lecture hall is assumed to be in the range of 0.15 to 0.5 and the relative humidity is in the range of 55% to 70%, based on Malaysian Standard, MS 1525: 2007.

About 95% of PMV values calculated based on the above setting and assumptions are in the range of ±1.3. Figure 6 illustrates the frequency of PMV values obtained.

The 5% of PMV that fall outside the range consist of the case high clothing insulation, high metabolism rate, low air velocity and at all relative humidity. The 5% also consists of the case low clothing insulation, low metabolism rate, high air velocity and low relative humidity. These cases are considered as worst case scenario in thermal comfort.

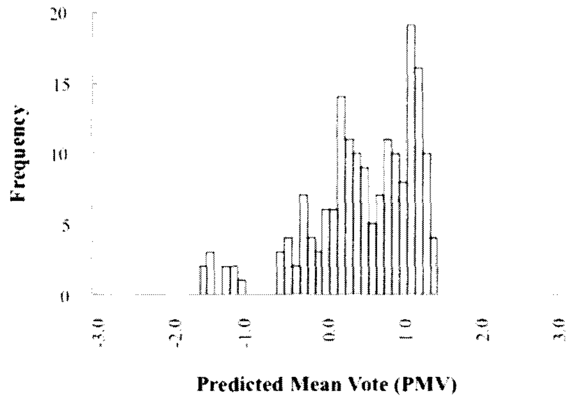

Figure 6: Distribution of Predicted Mean Vote (PMV) based on Malaysian lecture hall setting. 95% of PMV fall within the range of 1.3 < PMV < +1.3

CONCLUSION

Fanger's model is partially adaptive in its nature. Besides the six thermal parameters which will affect a building occupant's thermal comfort level, culture, habits and the three adaptive mechanisms have to be considered. Malaysia has hot and humid climate and high energy is used to provide comfortable thermal environment to the building occupants.

Original Fanger's model has over-estimated the level of dissatisfaction for tropical countries and caused much energy wastage in unnecessary cooling. Peoples in tropical countries are more satisfied with warmer temperature and have higher tolerance towards the thermal environment. This research have proposed and validated a new thermal comfort model, which is based on normalization of predicted mean vote. Using the results from previous research and the results of field observations, the new model of PPS*(PMV) has proven its validity in hot, humid climatic locations, such as Malaysia. The proposed temperature, 25.3°C by Yau et al. in their research was proven to be suitable for Malaysian lecture hall setting, with 95% PMV fall within the range of ±1.3.

This research has produced the integration of adaptive theories into Fanger's model through modifying Fanger's PMV-PPD indices and adopted field studies result into the modified indices.

ACKNOWLEDGMENTS

This research is funded by the Ministry of Higher Education Malaysia under the grant FRGS/1/2012/TKO7/UTP/45. The authors would like to acknowledge the financial support given by the MOHE.

REFERENCES

ASRHAE, *ASRHAE Standard 55: Thermal Environment Conditions for Human Occupancy*, American Society of Heating, Refrigerating and Air-Conditioning Engineers, 1992.

ASHRAE, *ASHRAE Standard 55P-2003: Thermal Environmental Conditions for Human Occupancy*, American Society of Heating Refrigeration and Air-conditioning Engineers (ASRHAE), 2003.

Becker S, Potchter O and Yaakov Y. Calculated and Observed Human Thermal Sensation in An Extremely Hot and Dry Climate. *Elsevier Energy and Buildings* 2002; 35: pp. 747-756.

Cheong KWD et al. Thermal Comfort Study of an Air-Conditioned Lecture Theatre in the Tropics. *Building and Environment* 2003; 38 (1), 63-73.

de Dear RJ, Fountain M and Brager GS. Expectations of Indoor Climate Control, *Elsevier Science* 1996; 24: pp. 533-536.

de Dear RJ and Brager GS. Developing an Adaptive Model of Thermal Comfort and Preferences. *Center for the Built Environment* UC Berkeley 1998; 104(1): pp. 145-167.

de Dear RJ and Brager GS. The Adaptive Model of Thermal Comfort and Energy Conservation in the Built Environment. *Int J Biometeorol* 2001; 45: pp. 100-108.

de Dear RJ and Brager GS. Thermal Comfort in Naturally Ventilated Buildings: Revisions to ASHRAE Standard 55. *Energy and Buildings* 2002; 34: pp. 549-561.

Fanger PO, & Toftum J. Extension of PMV Model to Non-Air-Conditioned Buildings in Warm Climates. *Energy and Building* 2002; 34: pp. 533-536.

Fanger PO. *Thermal Comfort.* New York: Mc Graw Hill. 1970.

Fanger PO. Energy and Building. In *Climate Responsive Building* 1985.

Fountain M, Brager GS and de Dear RJ. Expectations of Indoor Climate Control. *Elsevier Science* 1996; 24: pp. 614-626.

Gagge AP and Burton AC. *A Practical System of Units for the Description of Heat Exchange of Man with His Environment Science* 1941; 94: pp. 428-430.

Goldman RF. Evaluating the Effects of Clothing on the Wearer. *Elsevier Science* 1981: pp. 41-55.

Gut P and Ackerknecht D. Human Requirements Regarding Indoor Climate. *"Climate Responsive Building. Appproprite Building Construction in Tropical and Subtropical Regions,* St. Gallen, Switzerland, SKAT.

Halawa EE. Operative Temperature Measurement and Control. MSc Thesis 1994.

Ismail AR, Singh S and Goh CW. Thermal Comfort in a Closed Air Conditioned ICT Laboratory at Ungku Omar Polytechnic Malaysia. *National Conference in Mechanical Engineering Research and Postgraduate Students.* Universiti Malaysia Pahang 2010: pp. 555-563.

Ismail AR, Jusoh N, Zulkifli R, Sopian K and Deros BM. Thermal Comfort Assessment: A Case Study at Malaysian Automotive Industry. *American Journal of Applied Sciences* 2009; 6(8): 1495-1501.

ISO, International Standard 7730 (3): Ergonomics of the Thermal Environment – Analytical Determination and Interpretation of Thermal Comfort using Calculation of the PMV and PPD Indices and Local Thermal Comfort Criteria. *International Standard* 2005.

Kempton W. and Lutzenhiser L. 1992. "Introduction to special issue on Air-conditioning: The Interplay of Technology, Culture and Confort." *Energy and Buildings,* 18(3-4): 171-176.

Khedari J, Yamtraipat N, Pratintong N, Hirunlabh J. Thailand Ventilation Comfort Chart. *Elsevier Science: Energy and Buildings* 2000; 32: pp. 245-249.

Mui KW, Chan WT. Adaptive Comfort Temperature Model of Air Conditioned Building in Hong Kong. Permagon: *Building and Environment* 2003; 38: pp. 837-852.

Morgan C and de Dear RJ. Weather, Clothing and Thermal Adaptation to Indoor Climate. *Climate Research* 2003; 39(2): pp. 169-182.

Nicol JF, Humphreys MA. Adaptive Thermal Comfort and Sustainable Thermal Standards for Buildings. *Elsevier Science: Energy and Buildings* 2002; 34: pp. 563-572.

Nicol JF and Humphreys MA. Adaptive Thermal Comfort and Sustainable Thermal Standards for Buildings. *Elsevier Science: Energy and Buildings* 2002; 34: pp. 563-572.

Nicol JF. Cooling in a Low Carbon World. Energy and Buildings, *Building Research and Information* 2009; 37(4); pp. 345-347.

Nicol JF. Adaptive Comfort. *Building Research and Information* 2011; 39(2): pp. 105-107.

Nicol JF. Adaptive Thermal Comfort Standards in the Hot-Humid Tropics. *Energy and Buildings* 2004; 36(7): pp. 628-637.

Parsons KC. *Human thermal Environments: The Effects of Hot, Moderate and Cold Environments on Human Health, Comfort and Performance.* London: Taylor and Francis 1993.

Victor O. "Design with Climate". In *Climate Responsive Building* 1963.

Wong NH, Khoo SS. Thermal Comfort in Classrooms in the Tropics. *Energy and Building* 2002; 35: pp. 337-351.

Wong NH, Feriadi H, Lim PY, Tham KW, Sekhar C, Cheong KW. "Thermal Comfort Evaluation of Naturally Ventilated Public Housing in Singapore". *Pergamon: Building and Environment* 2002; 35: pp. 337-351.

Yau YH, Chew BT and Saifullah A. A Field Study on Thermal Comfort in Lecture Halls in the Tropics. *ISHVAC. Shanghai: ISI/SCOPUS Cited Publication* 2011: pp. 309 - 317.

Zhang H, Arens E and Pasut W. Air Temperature Thresholds for Indoor Comfort and Perceived Air Quality. *Building Research and Information* 2011; 39(2): pp. 134-144.