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A Review on Thermal Comfort Assessment in Malaysian Industries

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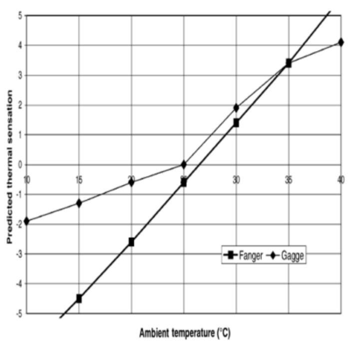
Graphical abstract



Abstract

In this world of advanced technology, many global organizations are realizing that the importance of their worker's comfort level towards their performance in order to be competitive. The studies in thermal comfort allow enhancing the understanding the importance of working environment among workers and occupants from various fields. This paper is focuses on reviews of the recent studies on thermal comfort assessments at the industries in Malaysia. The findings from other researchers' thermal comfort assessments at worldwide also reviewed together. This review would help the researchers, academicians and practitioners to take a closer look on how environmental factors affect human performance in industries and help to enhance the awareness on human comfort among all Malaysians.

Keywords: Thermal sensation; comfort; productivity; PMV; PPD

Abstrak

Dalam dunia teknologi maju, banyak organisasi global menyedari bahawa kepentingan tahap keselesaan pekerja mereka ke arah prestasi mereka untuk menjadi lebih kompetitif. Kajian keselesaan terma dapat meningkatkan pemahaman tentang kepentingan persekitaran kerja di kalangan pekerja dan penghuni dalam pelbagai bidang. Kertas kerja ini memberi tumpuan kepada ulasan kajian terkini pada penilaian keselesaan terma dalam industri di Malaysia. Hasil daripada penilaian keselesaan terma penyelidik lain di seluruh dunia turut dibincangkan. Kajian ini akan membantu penyelidik, ahli akademik dan para pengamal untuk memahami dengan lebih jelas tentang bagaimana faktor persekitaran mempengaruhi prestasi manusia dalam industri dan ia dapat membantu meningkatkan kesedaran tentang keselesaan manusia di kalangan semua rakyat Malaysia.

Kata kunci: Sensasi terma; keselesaan; produktiviti; PMV; PPD

1.0 INTRODUCTION

Thermal comfort strongly linked with the indoor air quality in a building and productivity [1, 2]. Field surveys confirmed that comfort temperature have close relation to the mean indoor temperature [3, 4]. Nicol and Humphreys (1973) suggested that such an affect could be the result of the feedback between the thermal sensation of subjects and their behavior [5]. Workplace environmental conditions, such as humidity, indoor air quality and acoustics have significant relationships with workers' satisfaction and performance [6, 7, 8]. Indoors air quality could have a direct impact on health problems and leads to uncomfortable workplace environments [9, 10, 11]. Productivity can be improved by comfort working environmental conditions [12].

The main purpose of ventilation system is to create optimal conditions for humans in indoor environments, taking into account their health, comfort, and productivity by providing air for breathing, for removing and diluting indoor pollutants, for adding or removing moisture, and for heating or cooling [13]. Occupants in a building will be troubled by adours and other possible contaminants and heat without ventilation [14]. Therefore, thermal comfort for naturally ventilated buildings should be the idealized criteria for evaluation [15]. Karyono (2000) stated that comfort conditions could be achieved with unnecessary cooling in air-conditioned buildings [16].

A good indoor climate is important to the success of a building because it not only makes the occupants feel more comfortable but also became important factor in energy consumption and its sustainability [17]. Rahman and Samad (2009) found that drop of 1°C would make significant difference in thermal comfort and also reduced energy consumption and money [18]. In another major study by Taylor *et al.* (2008) argued that a well-designed building should be able to provide good thermal comfort, while simultaneously having low energy consumption [19].

Ergonomic is highly associated with thermal comfort. According to Parsons (2000), ergonomic is defined as the application of knowledge of human characteristics to the design of systems [20]. Thermal comfort of human being is highly associated with the environment and physical appearances of each individual. The physical environment in principle includes all components making up an environment, and their interactions [21].

Besides that, Humphreys (1977) found that clothing was most strongly related to the air temperature and it has direct influences to the thermal comfort [22]. Clothing influence the heat exchange rate by convection and radiation, thus by naturally help to loss heat to the environment [23]. Clothing flexibility was a very effective way of maintaining thermal comfort, and more effective than any fixed clothing ensemble. As clothing flexibility increased, a higher cooling set point and a lower heating set point could be adopted without affecting thermal comfort, but realizing significant energy savings [24].

Heat stress is defined as the net load which a worker may be exposed from the combined contributions of metabolic heat, environmental factors and clothing requirements [25]. Heat strain is the overall physiological response resulting from heat stress. Human require energy to perform work and produce heat to maintain an internal body temperature at 37°C. The higher human's activity level the more heat will produce. When there is too much of heat produced, the body will sweat and causes discomfort [26]. On other hand, if too little heat is produced, the blood will be withdrawn from the hands and feet, skin temperature will fall and the individual will feel cold and uncomfortable [27].

Normally, Predicted Mean Vote (PMV) used as thermal sensation index of thermal comfort at the range of seven points scale. The PMV values are ranges from -3 to 3 as -3 (cold), -2 (cool), -1 (slightly cool), 0 (neutral), 1 (slightly warm), 2 (warm) and 3 (hot). Zero value or neutral vote represents the condition that most occupants feel thermally comfortable. PMV can be measured by air temperature, relative humidity, air velocity, air radiant temperature, occupants' clothing values and the metabolic rate due to activity [28, 29]. Thermal comfort dissatisfaction of the occupants usually estimated using Predicted Percentage of Dissatisfied (PPD). Even though the thermal sensation vote is neutral, the PPD value is at 5%. PPD less than 20% is considered good and that means 80% of occupants are satisfied with the thermal environment [30].

Jones (2002) found that there is a difference in predicted thermal sensation at corresponding temperature range between the models proposed by Fanger and Gagge especially at the lower temperature limits [31]. This can be clearly found in the Figure 1.

It is important to know that the comfort expectations of a tropical population and people from temperate or cold climate are different. According to Liping and Hien, (2009) previously Nicol and Humphreys (1973) had presented the results of field studies in the UK, India, Iraq, and Singapore [5, 15]. It is noted that temperatures well above 30°C are not considered uncomfortable in some cases. Li (2010) found that the ASHRAE Standard 55-2004 and ISO 7730-2005 comfort temperature range does not suit the Chinese local situation, although both of the standards are very useful reference materials [32]. There is a need to set up a thermal environmental conditions standard for China according to the local climate and human habitat. Meanwhile, Shukor (1993) stated that Malaysian thermal comfort zone within the temperature values of 24°C and 28°C [33]. On other hand, Mallick (1996) argued occupants feel uncomfortable at lower humidity and there is a decrease in comfort temperatures at higher humidity through his study in Bangladesh [34].

Study by Karjalainen (2007) found that females are tend to be more critical of their thermal environments, and are more sensitive to both cold and hot room temperatures [35]. The previous researches also reveals women adapt to work at higher temperatures compared to men [36, 37]. According Höppe (2002), most of the people spend their time at indoor and therefore steady state models are appropriate for thermal comfort assessments [38]. There is more reliable thermal comfort indices which is suitable for indoor environment allows most of the researchers prefer to conduct the indoor thermal comfort study to obtain more precise outcomes.

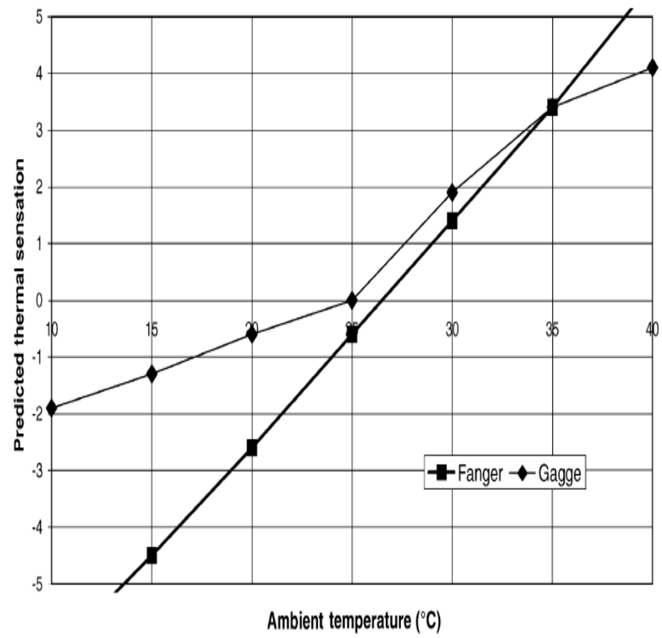


Figure 1 Comparison of prediction from the Fanger and Gagge models by Jones (2002) [31]

2.0 REVIEW OF THERMAL COMFORT STUDIES

Most of the industries in developing countries are concerned about improvement in the performance of workers, health and safety. Anyhow, the manufacturing industries are characterized with improper design of workplace, unpleasant environment, poor human-machine system design and inappropriate management programs [39]. The automotive industry is considered the single largest manufacturing sector in the world [40]. Malaysia has obtained much recognition regionally and internationally for its outstanding achievement in automotive industry since the first national car, the Proton Saga was introduced in 1985 [41]. In Malaysia, the automotive industry is broadly classified into two major sectors which are manufacture or assembly of motor vehicles and component and parts manufacturing such as body parts.

Recently, Ismail and colleagues have been actively conducted researches on thermal comfort assessment at Malaysian automotive industries. Their studies have been took place at various stations at automotive plant industries. They used both physical measurement and questionnaire survey methods in order to investigate the environmental factors influences and determine thermal comfort among the workers' and their productivity at each workstation. Their study at tire receiving station showed that workstation was not comfortable because the PMV index is around 1.07 to 1.41 and the PPD is 27% to 46%. That means about 54% of occupants are still likely to be satisfied with thermal condition.

Meanwhile, the PMV index at body assembly station was between the range of 1.76 and 2.1. As a result, the PPD value higher than tire receiving station with 65% to 81% [43]. This shows that the thermal sensation at body assembly was warm. Furthermore, the paint shop area considered as discomfort environment with PMV value was 2.1 and 2.8 with PPD value was 81.1% to 97.8% [44]. This showed that the paint shop areas' thermal sensation was warm and almost hot. In overall, the findings of the researches by Ismail and colleagues at Malaysian automotive industry reveals that paint shop area was the worst thermal comfort workstation among the measured workstations.

They concluded that low awareness on the importance of environmental ergonomics among industrial members and workers caused poor thermal comfort conditions in the Malaysian automotive industry. Therefore, serious attention is needed to emphasize on thermal comfort conditions at Malaysian automotive industry in order to provide better working environment for workers. As a result, it would help increase the productivity of workers at the Malaysian automotive industry. Further researches are recommended by optimizing the environmental parameters and setting up the working environment accordingly in order to improve the thermal comfort conditions in Malaysian automotive industry.

Ismail *et al*. (2009) have studied the dominance effects of environmental factors such as WGBT (°C), relative humidity (%) and illuminance towards the workers' productivity at Malaysian automotive industry [45]. Taguchi method was used to find the sequence of the dominant factor that contributing to the workers' productivity. The optimum level for the three environmental factors determined for optimum productivity. The multiple linear regressions were employed to obtain the equation model in order to represent the relationship of these environmental factors towards productivity. The study exposed that the dominant factors that contribute to the productivity at the body assembly production line is WBGT and illuminance.

The other studies by Ismail and colleagues (2010) show that the optimum environmental factors for thermal comfort manage to be predicted through Artificial Neutral Network's (ANN) analysis system which commonly used the method of best linear relationship. They managed to found the optimum value of production attained when the WBGT is 24.5°C, relative humidity is 54.86% and lighting value is 146.386 lux from the linear relationship [46, 47]. Through these optimum values, the optimum production rate has been achieved in one manual production line in company.

Ismail *et al*., (2011) conducted thermal comfort assessment at parcel and logistic industry in Malaysia [48]. The company primary activity is providing courier service covered Peninsular Malaysia, Sabah and Sarawak. The assessment conducted in the printing department. The clothing value is estimated 1.0 clo and metabolic rate is 93 W/m^2 for sedentary activity which based on ISO 7730 [49]. The results showed that PMV value ranging between 1.8 and 2.0 which indicates warm environment. As a result, the PPD values ranging between 67% and 76% exposed that more occupants likely to be dissatisfied with the workspace.

Thermal discomfort is a common feature in Brazilian work environments and that certainty affects the efficiency and the productivity of workers [50]. Another research demonstrate that the effect of hygro-thermal micro climate on the workers' performance. His study reveals that tasks with mainly physical activity performance depend upon metabolic heat [51].

Malik and Hanim (2009) have carried out study at two hotel lobbies which located at beach side and hill slope in Malaysia to determine whether the average air velocity can reduce the thermal discomfort [52]. The environmental factors such as air velocity, air temperature and relative humidity measured for one week by using BABUC environmental data logger. The Standard Effective Temperature (SET) is a temperature indicator that is used in this study as it takes the considerations of other climatic elements and not just relying on air temperature alone. Their study reveals that a drop of 1°C would make significant difference in thermal comfort and also reduce the energy consumption and costs. Both set of data are within the Malaysian thermal comfort zone within the value of 24°C to 28°C as mentioned by Shukor [34].

On the other hand, Jang *et al*. (2007) conducted an evaluation of the optimal temperature in each cabin of the Korean maritime patrol vessels [53]. Two methods were applied in this study, which are PMV/PPD and human factor. The ergonomic factors, human activities and clothing were surveyed in cabins of 250, 1000 and 1500 ton vessels in this study. PMV and PPD were calculated to find the optimal air temperature for each cabin. In this calculation, they assumed that the mean radiant temperature of environment factors was equal to the dry bulb air temperature, and the relative air velocity was 0.0 m/s. Since there were different crew members at various vessels with different activities, various optimum temperatures are obtained at each cabin. Based on human factors, the optimum temperature was 23°C and 29°C. The results showed that the wheelhouse and accommodation can save 6°C of energy in the case of PMV/PPD with demand controlled air conditioning.

The study by Toftum and Nielsen (1996) pointed out that regular complains of draught were received from the employees who are working at cool or cold environments [54]. In this study they have mentioned the previous study by Toftum (1994) who conducted a field study among employees at various industrial spaces showed the existence of a relationship between the general thermal sensation and local thermal discomfort caused by convective cooling of the skin [55]. In addition, they also figured out the findings of Kristensen and Christensen, (1983) at meat processing plants, a large number of complaints were received due to draught and coldness from the employees who are working at low temperature spaces [56].

Ajimotokan *et al*. (2009) has performed a study at a beverage bottling plant to investigate the influence of indoor environment on workers' health, comfort and productivity in Ilorin, Nigeria [57]. In their study, they have reviewed the previous researcher's findings as evidence to say that health, comfort and performance of adults improved at higher ventilation rates [58, 59, 60, 61, 62]. The study reveals that evidence from review of complaints showed that continuous environmental stress affected workers' performance and decreases the productivity. Overall, a large number of workers experienced the sign of discomfort related to the environmental factors in the workplace.

■3.0 CONCLUSION

The review on previous studies showed that there is a significant relation between environmental factors and human comfort. Based on the thermal comfort scenario in Malaysia, it shows that the awareness level on human comfort in industries is very low. There are insufficient researches on thermal comfort in Malaysian industry sectors. When compared to developed country, the managements and employers are paying more concern and priority to the human comfort at workplace at various fields. In conclusion, there is necessary to conduct more researches on the thermal comfort in various fields especially in industries to enhance the awareness level among all Malaysians.

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