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Thermal Comfort Temperature Range for Industry Workers in a Factory in Malaysia

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ABSTRACT: *A field study was carried out to assess the comfortable conditions of the working environment of a production factory in Kuala Langat, Malaysia. Malaysia is a hot and humid climatic country with high average outdoor temperature of 23.7^{0}C - 31.3^{0}C and average humidity of 75% RH - 95% RH throughout a day. Heating, ventilating and air-conditioning (HVAC) system of a factory must be well-designed to provide comfortable conditions to the workers. Survey was conducted by randomly picking up the employees in the desired space. The air quality of the space that is temperature, humidity, CO and CO_2 level, as well as dust particles of the plant was measured. The workers' thermal satisfaction was studied by using seven-point thermal sensation scale proposed by ASHRAE standard 55 (2004). Adaptive model was employed to determine the neutrality temperature. The comfortable temperature range for the workers of the factory was determined to be from 21.5°C to 23°C with humidity of 45% RH to 60% RH.*

Keywords: *Malaysia, factory workers, HVAC, air quality, ASHRAE seven-point thermal sensation scale, adaptive model.*

I. INTRODUCTION

The number of HVAC systems of various buildings has been significantly increased for their growing importance along with the rapid industrialization of developing countries (Nicol and Roaf, 1996), (Szokolay, 1991). Study has shown that the energy use for HVAC has now become one of the largest sectors in energy consumption (Humphreys, 1976). Malaysia, a country located in south-east Asia, lies north to the equator with 7° latitude, has a tropical climate. Malaysia has a hot and humid weather all the time (de Dear and Brager, 2002). Hence consumption of energy is too high to produce comfortable air-conditioned (AC) environment for working space in the factories.

Nowadays, HVAC system is a primary concern in every building, since the energy consumption in electricity has the highest percentage in HVAC among all building services installations as well as electric appliances. HVAC system of a building plays an important role in providing a comfortable environment by controlling temperature, humidity, air motion, radiant sources, odour and noise of the space (Yamtraipat *et al*., 2005). Comfort is a major concern in a working space to provide satisfaction to all workers. Study has shown that the productivity level of employees is related to the level of thermal comfort (TC) (de Dear and Brager, 2002), (Abdul Rahman and Kannan, 1997). The humidity ratio is one of the major concerns in production especially for manufacture of semiconductors and foods, because the ambient humidity is around 80% RH. RH levels affect the respiratory system of human body and encourage the growth of harmful matter such as mold and mildew. Besides, many pests such as dust mites, bacteria, and viruses thrive at environment of high RH (Canter, 1983). Working environment above 32°C is considered as high temperature environment and environment with humidity above 60% RH can be considered as high humidity environment, based on the relationship between environmental temperature and human thermal balance (Mathews *et al*., 2001).

The main objective of this research is to find the desirable comfort temperature range for workers in a factory in Kuala Langat, Malaysia. Measurement of various aspects of TC for environment, namely temperature, air velocity, dust particle, CO_2 level contains and RH was done at the plant.

II. METHODOLOGY AND ESTIMATION

The methodology used in the study is as given below:

1. A factory was chosen and the details of all type of workers and room specifications were found out.
2. Field survey was conducted to find the TC temperature range for factory workers for different types of rooms. This includes measuring the data on temperature, air quality, and air flow characteristic. Survey-questionnaires were also distributed among the workers to have them expressed their comfort level.
3. All measurements of the factory were compared with standard comfort level of ASHRAE Standard 55 to find their suitability for warm humid tropical climatic conditions.

2.1 WARM HUMID TROPICAL CLIMATIC CONDITIONS

The study is focused on warm humid tropical climatic location near the equator. Such countries are Malaysia, Singapore, and Indonesia in South-East Asia. There is almost no distinction between summer, winter, autumn or spring in these regions. Basically, the whole year round is a permanent summer with high temperature, with the exception of periods during the wet season and places at higher altitudes. In many tropical regions, people identify two seasons: wet and dry. However, most places close to the equator are wet throughout the year, and seasons can vary depending on a variety of factors including elevation and proximity to an ocean. Even though it is situated at the equator it might not be the hottest region in the world, since the rainy and humid conditions cools down the air.

As for the study conducted in Malaysia, average temperature is around 27°C year round with heavy rains from November to February. The warmer months are not extremely hot, while the cooler months appear to be similar to warm summer conditions in this 4 seasonal country. Light clothes are worn throughout the year since the temperature difference between day and night is insignificant.

2.2 THE FACTORY ENVIRONMENT AND THE WORKERS

The factory environment considered in this research involve those workers who work in the production line in Malaysia, where their work is considered as light work and does not pollute the indoor air. The main concern is the increase of moisture or humidity due to the respiration of the workers and the temperature rise due to heat gain from building and machines. Such condition thus needs fresh or outdoor air to balance the indoor air content and quality. A "factory worker" here is classified as an employee who is directly involved in production related activities of the factory establishment excluding any work at supervisory or administrative level (Wijewardane and Jayasinghe, 2008).

The thermal perceptions of the occupants are affected by the factors such as demographics (gender, age, economic status), context (building design, building function, season, climate, semantics, social condition), and cognition (attitude, preference, and expectations). People interact with and change their environment in consistent with their past experiences, future plans and intentions, and hence their perception on TC could be affected by such factors too (Baker, 1993), (Oseland, 1994).

Therefore, one's satisfaction towards TC is not fixed. It could be calculated with some parameters given, but it does not apply for the whole life. It changes from time to time depending on the current and past experience, cultural and technical practices.

2.3 FIELD SURVEY

In the factory, survey was done in both office building and production line building. The production line building is identified as Semicond 1 (zone 1, production line), Semicond 1 (zone 2, production line) and Semicond 4 (first floor, production line). Survey was done first in the office building. There is high density of workers in this building and its temperature is a bit high compared to the manufacturing plant. The latter is of lower density of workers, but has many types of equipment that need low temperature to maintain their functionality. The location of the factory is at Kuala Langat, 2°55' N and 101° 28' E with average climatic data as shown in Table 1.

The office building together with its high density of workers, fluorescent lighting, electrical equipment such as computers and photocopy machine were selected during the survey. The idea is, this entire factory would increase the heat gain within the space, which has a significant effect on TC.

For the production line building, although the density of workers is lower but the number of equipments is so large which causes the area need a higher cooling effect to remove the heat generated by the equipments.

The TC of the workers had been determined by the survey-questionnaire that was distributed to the workers. Both male and female workers were selected for the questionnaire, because the number of male and female in this factory is almost the same. The seven point scale for comfort vote proposed by ASHRAE Standard 55 was used to determine the TC in the area. This would give a wide range for response in the research. 'Slightly cool', 'neutral', and 'slightly warm' were considered as thermally acceptable conditions.

The survey was conducted in a sunny day. The outdoor temperature varied from 31°C (10.00 am) to 32.6°C (3.45 pm). The maximum outdoor temperature was 40.3°C (11.50 am). The indoor temperature of Semicond 4 building varied from 21.6 to 22.5°C and that of Semicond 1 building varied from 20 to 23.4°C. This survey was using ASHRAE Standard 55 in determining the objective of the research. It is about indoor temperature and humidity at a certain area and a subjective survey which is the questionnaire. In this survey, many data had been collected on relative humidity, dry bulb temperature, mean radiant temperature, air flow rate, air velocity and particles in the space, etc. All the data were measured by digital equipments and were combined together in Microsoft Excel. Outdoor humidity was also recorded. The questionnaire survey was carried out at the same time when objective measurements were going on. Activity and clothing value for the workers were also evaluated according to ASHRAE Standard 55.

Table 1. The average climatic data for Kuala Langat with 2°55'N latitude 101°28'E longitude

Month	Mean daily temperature (°C)		Relative humidity (%)	
	Max	**Min**	**Min Mean**	**Max Mean**
January	31.9	25.9	82.6	98.6
February	32.8	26.3	81.2	98.2
March	33.0	26.6	82.5	98.4
April	32.8	26.8	84.9	98.4
May	32.7	27.0	84.3	98.2
June	32.3	26.7	83.9	98.1
July	31.9	26.4	83.4	97.8
August	32.0	26.4	83.1	97.9
September	31.9	26.2	84.6	98.3
October	31.7	26.2	85.5	98.7
November	31.2	25.9	86.9	98.9
December	31.2	25.8	85.7	98.9

Source: Director General Meteorological Services- Malaysia

III. RESULTS AND DISCUSION

3.1 FINDINGS

Seven point scale for comfort vote proposed by ASHRAE Standard 55 was used considering 'slightly cool', 'neutral' and 'slightly warm' as acceptable range for TC. In the questionnaire survey, for Semicond 1 – zone 1, 73% of occupants' vote for 'cool' condition on the scale is shown in Table 2. This result tells us that the workers were thermally distressed. For Semicond 1 – zone 2, 91.6% of the occupants' vote was for 'slightly cool' on the scale. For Semicond 4- level 1, 33% vote was for 'neutral', 25% vote for 'slightly cool', 25% vote for 'slightly warm'. This tells us that this area has acceptable thermal comfort conditions.

Table 2. Results of survey

Location	Average Temp (C^0)	(-3) Cold		(-2) Cool		(-1) Slightly Cool		0 Neutral		(+1) Slightly Warm		(+2) Warm		(+3) Hot		Number of Subjects
Semicond 1 (zone 1)	23.0	0	0%	11	73%	3	20%	0	0%	1	7%	0	0%	0	0%	15
Semicond 1 (zone 2)	21.5	0	0%	0	0%	11	92%	1	8%	0	0%	0	0%	0	0%	12
Semicond 4 (level 1)	23.0	0	0%	1	8%	3	25%	4	33%	3	25%	1	8%	0	0%	12

Humidity – 49.5-50.5%; metabolic rate – 1.7-2.2; clothing – 0.67 clo (Overalls, long-sleeve shirt, Lab Cot); average outdoor temperature – 34.2°C at 51.6% relative humidity.

3.2 VALIDATION WITH LARGER FACTORY

For validation purpose, another test was conducted in the production line (Semicond 4) with a larger workforce. The survey was carried out also on a working day representing the normal daily routine. Workers were asked to do their normal work, while indicating the comfort vote. On a typical day, the temperature range inside the factory was 21.6 ^{o}C to 22.5^{o}C from 10 a.m. to 4 p.m. Therefore, the temperature-changing rate was very small and that eased the task of questioning a large number of workers. Supervisors from the factory were informed about the procedure and requested to administrate the seven point scale comfort vote. The survey was conducted in a sunny day. The outside temperature range varied from 31^{o}C (10.00am) to 32.6^{o}C (3.45pm). The maximum temperature for outdoor was 40.3^{o}C (11.50 pm). With the large sample also, it was indicated that temperature in the range of 21.5 ^{o}C to 23^{o}C was acceptable by up to 80% of the occupants. This indicates that the prediction of the smaller sample tallies very well with the large sample. Thus, a temperature up to 23^{o}C can be considered acceptable for factory workers who are accustomed to warm humid tropical climatic conditions.

3.3 A COMPARISON WITH COMFORT MODELS

Adaptive models are applied to define the neutral temperature as a function of outdoor, indoor or both temperatures. Some of them present a higher accuracy in certain conditions and, as a result, these principal models were employed for this study. Auliciems and de Dear developed the relations for predicting group neutralities based on mean indoor and outdoor temperatures which were employed by the ASHRAE as shown in eq. (1). Other adaptive models have been also proposed by Humphreys (1976) and Nicol and Roaf (1996). Szokolay (1991) developed the model to determine the comfort zone in psychometric chart by determining neutrality temperature, using equation below to indicate the center point for comfort zone. Szokolay (1991) indicated also the range of about $\pm$ 2^{o}C about neutrality temperature. However, before applying these models, we must remember that occupants must be engaged in near sedentary activity (1-1.3 met).

$$T_n = 17.6 + 0.31T_o \quad (1)$$

where
T_n = Neutrality temperature [ºC], T_o = Arithmetic average of the mean daily minimum and mean daily maximum outdoor (dry bulb) temperatures for the month in question [ºC].

But, considering the tropical climate change that was possibly adapted, de Dear and Brager (2002) proposed the deviation of about $\pm$ 3.5^{o}C about the neutrality temperature, which gives the range of 7^{o}C.

From Table 3, on the day this research was conducted, the mean value of outdoor dry bulb temperature was about 34^{o}C, which gives the neutrality temperature to be 28^{o}C. This is relevant to the neutrality temperatures (24.6 ºC, 26.1 ºC and 27.4ºC) for Malaysia (Abdul Rahman and Kannan, 1997). The thermal sensation voting indicates that the acceptable comfort temperature for all workers is up to 23^{o}C, which is in the range proposed by de Dear and Brager (2002). This proves the applicability of their recommendation.

Table 3. Outdoor temperature and relative humidity

Time	Temperature	Humidity
10.00	31.0	57.7
11.10	34.2	50.1
12.10	37.0	48.3
12.40	39.4	45.8
15.00	30.8	52.2
15.45	32.6	55.2

Yamtraipat *et al*. (2005) conducted research about the acceptable comfort temperature of large number of respondents in different climatic regions of Thailand. The survey was conducted using different types of AC buildings from the private and public sectors. The highest mean indoor temperature for thermal acceptability of the subjects was 26^{o}C, 27.4 ^{o}C and 26.4^{o}C for zone H1, H2 and H3 respectively. They concluded that the recommended nationwide indoor set point for AC buildings in Thailand is 26^{o}C, which was accepted by most of the subjects in every climatic zone (80% of votes), and the appropriate relative humidity range should be between 50% and 60%. Since Malaysia is neighbor to Thailand, the climatic condition of these two countries is not much different as well. And, these values can be referred as benchmark to the acceptable temperature and RH. Based on thermal sensation voting at the factory in Malaysia, most of the staff felt comfort with the temperature of 22.6^{o}C, and humidity range of 45% RH to 55% RH which is not much different with the research done by Yamtraipat *et al*. (2005).

IV. CONCLUSION

From the study, it is revealed that the factory workers in clean room could feel reasonably comfortable up to a temperature of 21.5°C - 23°C with humidity of 45% RH to 60% RH. This is a very important finding, since this guideline can be used for establishing TC by introducing some features to the factory. A higher level of TC would increase the productivity of the factory.

Applications of findings are

Once the air quality and the temperature range for TC of factory workers in warm humid tropical climates is found, these can be used to promote some of the features to the factory to achieve the goal. Some of the examples are:

1. In order to reach the TC temperature range, the number of the machines must be controlled in every section of the factory. The machines in the factory may be treated as heated bodies in the factory and a good locating strategy should be considered as highly desirable.
2. A better clothing material for clean room would assure the workers to feel more comfortable. Clothing includes coveralls, shoe & boot covers, facemasks, gloves & disposable garments.
3. It would be necessary to ensure that the outdoor temperature remains relatively low. In this context, the use of plenty of vegetation is highly desirable. Thus, reservation of strips of sufficient width such as 10m or more between factories for planting multiple rows of trees can be recommended.
4. The use of plenty of insulation in the roofs and walls of factory buildings can be considered as extreme necessity, since the above upper limit of comfort will be valid only in the absence of heated bodies.

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