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Thermal Comfort Assessment in Office under High air Conditioner Setting Temperature: A Review

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Abstract: Malaysia is located close to the equator and experience a hot and humid weather throughout the year. The hot outdoor and warm indoor condition has lead the building occupants on relying to the air conditioner to achieve comfort condition. This practices resulted to energy demand and high carbon emission. Necessary strategies is required to ensure the building occupants use the air-conditioner system efficiently.This study aimed to review the response of building occupants in higher set point temperature and the impact on the productivity. Furthermore, the relationship between comfort temperature with clothing insulation value and wind speed has been analyzed. The method for this review was a systematic review called Preferred Reporting Items for Systematic Review and Meta-Analyse (PRISMA). The first phase was journal identification where journals were collected based on keywords searching. The next phase was screening of journals and several conditions for eligibility and exclusion of journals were set. Data abstraction and analysis took place to compare and analyse data abstracted from the journals. As for the result, it was found that building occupants felt comfortable at 26°C set point temperature. Optimum productivity could be achieved when the preferred condition was "slightly cool" or "neutral". There are still lack of evidence that high setting air-conditioner temperature can provide thermal comfort especially in long working hour. Meanwhile, it was found that wind speed has stronger relationship with comfort temperature than the *clo* value with the coefficient of determination (R^2) of 0.72. It can be seen that adjusting wind speed was the main priority to achieve thermal comfort among occupants. As a recommendation, thermal comfort among occupants would be achieved in high set point temperature when fan with desired wind speed was implemented and positively affect productivity.

Keywords: Thermal Comfort, Fan, High Set Point, Productivity

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1. Introduction

Malaysia could be categorised as an equatorial as it was close to the equator and experience a hot and humid weather throughout the year. Based on Malaysia Meteorological Department, the maximum daily temperature in Malaysia was less than 35°C. An uprising issue especially in asian countries was that most of the building occupants adopt the air conditioner to beat the hot weather.

One of the way to achieve thermal comfort was by using air conditioner. Thermal comfort is defined by [23] as “that condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation”. Eventhough air conditioning system gave thermal comfort for occupants in a building, it also gave impacts on energy consumption [1]. A study from [2] stated that for every 1°C increase in set point temperature, roughly about 6% energy saving. The main impact of high set point temperature was to lessen energy consumption [3].

The interest towards the usage of air-conditioner doubles every year especially in hot climates [4]. Most of the office buildings in Malaysia are equipped with air-conditioner and it takes 57% of the energy consumption [5]. Previous study have shown that the temperature could be set higher to achieve optimum thermal comfort such as 28.6°C + fan assist at air speed 1 m/s [7], 28 °C + small fan [2]. It could be seen that the method of high setting temperature in “COOL BIZ” concept has a potential to be implemented in Asian countries. However, there were still less research to prove about the implementation. A study from [2] stated that for every 1°C increase in set point temperature, roughly about 6% energy saving. This shows potential of high setting temperature to reduce energy consumption. Therefore, a review on the thermal comfort assessment of individuals in an office under high air-conditioner setting temperature was conducted.

This paper presents the response of higher set point temperature (26°C to 28°C), the impact of high set point temperature to the productivity of occupants and the relationship between thermal comfort, clothing insulation as well as wind speed.

2. Materials and Methods

2.1 PRISMA

“PRISMA” or Preferred Reporting Items for Systematic Reviews and Meta-Analyses is “an evidence-based minimum set of items for reporting in systematic reviews and meta-analyses”[24]. Otherwise, it contain sub-items consisting the well-define stages of a systematic review such as developing eligibility criteria and describing information sources, search strategies, study selection processes, outcomes and data synthesis [8]. The methodology is used to analyse the thermal comfort of occupants in high air-conditioning setting temperature.

2.2 Resources

The resources for the review was mainly focused on a database of journals, which was Science Direct. It was the largest abstract and contain citation database of peer-reviewed literature from over 5000 publishers such as scientific journals, books and conference proceedings. Most researchers trust the contents in Science Direct, as it must be reviewed by an independent Content Selection and Advisory Board (CSAB).

2.3 Systematic review process

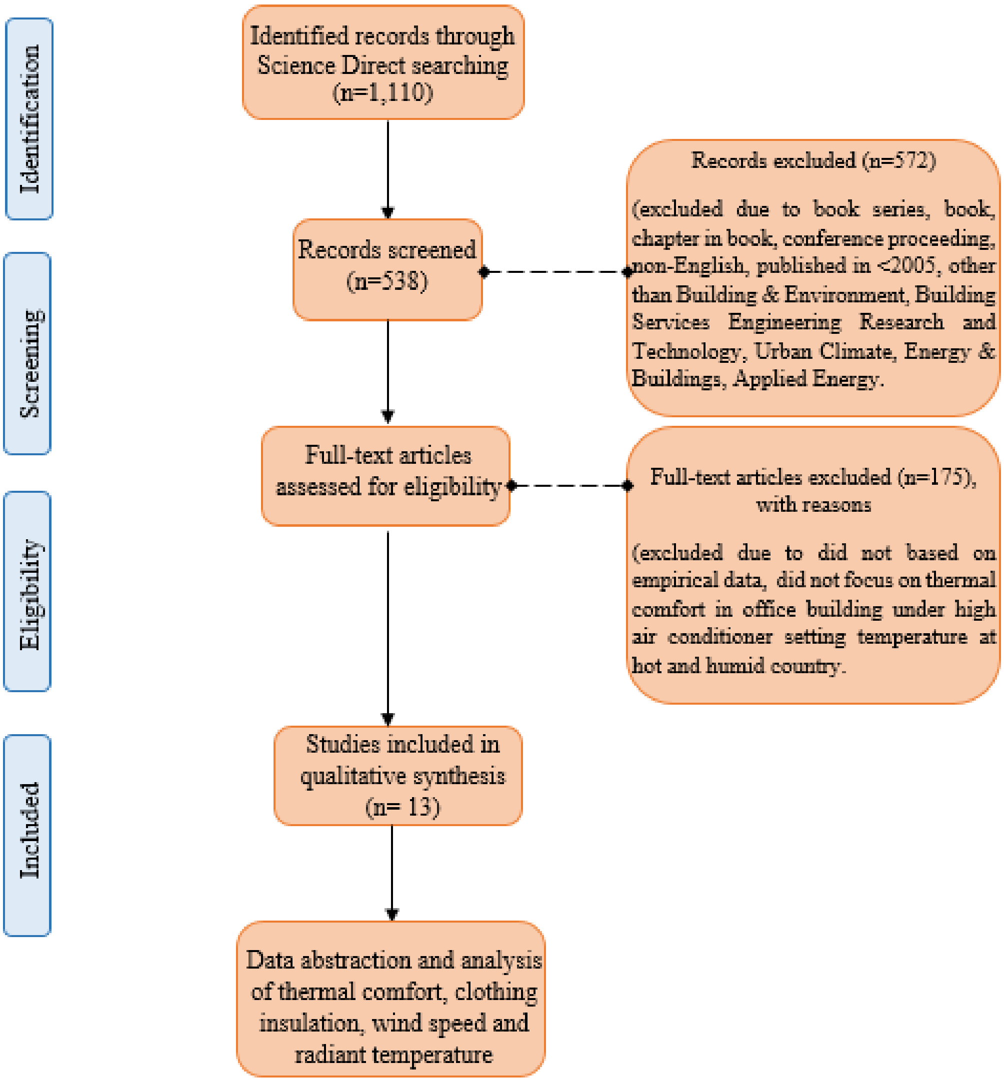


Figure 1: Systematic review process

2.3.1 Identification

It was where the researcher identify the correct journals before further analyse the data from every journals. The published papers found in Science Direct were based on several keywords such as thermal comfort, office, high air-conditioning temperature as well as hot and humid climate. Table 1 showed the keywords used as the information searching strategy. A total of 1,110 journals were extracted from this searching strategy.

Table 1: Information searching strategy

Database	Keywords
Science Direct (2005-2021)	((“thermal”)(“comfort”)(“in”)(“office”)(“under”)(“high”)(“air”)(“conditioning”)(“setting”) (“temperature”)) • Articles obtained: 121 articles ((“thermal”)(“comfort”)(“in”)(“office”)(“hot”)(“and”)(“humid”)(“country”)) • Articles obtained: 989 articles

2.3.2 Screening

Articles obtained from identification phase were screened for actual data extraction. After the screening phase, 363 journals needed to go through eligibility assessment.

Table 2: Eligibility and exclusion criteria

Criteria	Eligibility	Exclusion
Type of literature	Journal (research articles and reviews)	Book series, book, chapter in book, conference proceeding.
Language	English	Non-English
Timeline	2005-2020	<2005

2.3.3 Data abstraction and criteria

The remaining 13 papers were assessed and evaluated for data abstraction and analysis. By concentrating to the formulated question that responded on recommended temperature of occupant in office building under high air-conditioner setting temperature in hot and humid country, the data could be duplicated.

2.3.4 Included (thematic analysis)

Data comparison from every analysis of included journals were documented by using tabulation method for further understanding.

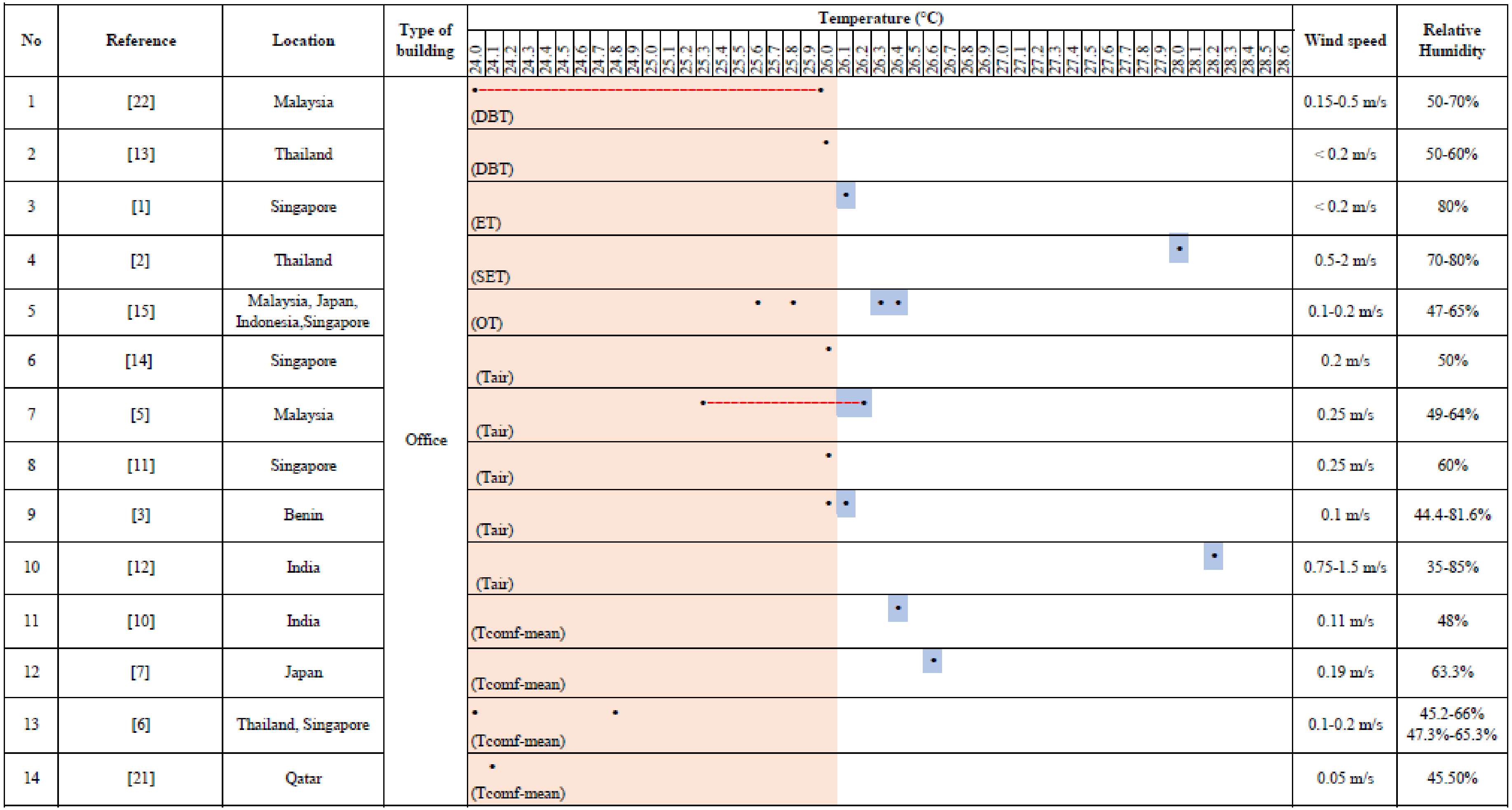
3. Results and Discussion

3.1 Response of occupants in high set point temperature

Thermal comfort could be indicated with human’s satisfaction in indoor spaces as most occupant spent 80% of the time indoor [9][10]. For hot and humid climate country like Malaysia, air conditioner played a vital role to maintain the comfort of occupants. The air-conditioner usage in commercial buildings especially offices took half of the energy consumption for a whole year [6]. The research for the implementation of higher set-point temperature has widen for greater energy saving [10]. In Figure 2, a review of a few journals regarding high set-point temperature in hot and humid country was included to analyse the response of higher set point temperature. As a benchmark condition, [22] was used as a baseline for the recommended set-point temperature.

The highest recommended temperature was from [11] where 86% of the subjects were comfortable at 28.2°C with a wind speed of 0.75-1.5m/s. This survey took place in India within the summer season by fully using evaporative cooling system. Adaptive behaviour was recorded and it is found that throughout the survey, the subjects tended to open the windows doors and switched on the fan. [10] stated that people would act (e.g.: change activity, clothing levels, open/close any opening, and switch on the fan) to maintain the thermal comfort.

[12] conducted a survey on thermal comfort in Thailand and the preferred dry bulb temperature by the participants were 26°C (PMV: 80% votes). The temperature was in the range of [22], which is 24°C to 26°C. The survey was conducted in 18 months and physical characteristic of subjects such as age, weight, height and clothing were collected. The same recommended set-point temperature (26°C) was recorded by [13] and [10] in Singapore where the climate is almost the same as in Thailand. The 6 weeks study from Lipczynska et al. [13] was aided with ceiling fan and the wind speed was 0.2m/s. With temperature set point of 26°C, the thermal acceptability of subjects increased from 59% to 91%, which was quite high. Otherwise, a study from [2] found that the recommended set-point temperature could be widen to 28°C with fan aided at the speed of 0.5-2m/s. This 4 hours study positioned a small electric fan with 15 cm diameter in front of every subject. The distance between the subject and the fan



No	Reference	Location	Type of building	Temperature (°C)	Wind speed	Relative Humidity
1	[22]	Malaysia	Office	(DBT)	0.15-0.5 m/s	50-70%
2	[13]	Thailand		(DBT)	< 0.2 m/s	50-60%
3	[1]	Singapore		(ET)	< 0.2 m/s	80%
4	[2]	Thailand		(SET)	0.5-2 m/s	70-80%
5	[15]	Malaysia, Japan, Indonesia,Singapore		(OT)	0.1-0.2 m/s	47-65%
6	[14]	Singapore		(Tair)	0.2 m/s	50%
7	[5]	Malaysia		(Tair)	0.25 m/s	49-64%
8	[11]	Singapore		(Tair)	0.25 m/s	60%
9	[3]	Benin		(Tair)	0.1 m/s	44.4-81.6%
10	[12]	India		(Tair)	0.75-1.5 m/s	35-85%
11	[10]	India		(Tcomf-mean)	0.11 m/s	48%
12	[7]	Japan		(Tcomf-mean)	0.19 m/s	63.3%
13	[6]	Thailand, Singapore		(Tcomf-mean)	0.1-0.2 m/s	45.2-66% 47.3%-65.3%
14	[21]	Qatar		(Tcomf-mean)	0.05 m/s	45.50%

Note: DBT= dry bulb temperature; ET= effective temperature; SET= standard effective temperature; T_{air}= air temperature; $T_{comf-mean}$= mean comfort temperature

Figure 2: Recommended set point temperature based on previous study

is quite near which is 30 cm. It was reported that there is no annoyingness among the subjects as high air movement up to 3 m/s was common among Thai citizen.

[14] conducted a field survey in four locations, which were Malaysia, Japan, Indonesia and Singapore. The highest and lowest temperature obtained were 26.4°C (Singapore) and 25.6°C (Malaysia) respectively. Malaysia followed the energy saving campaign and the minimum thermostat setting was 24°C. In addition, Singaporean Standard set the indoor operative temperature between 24°C to 26°C. Sikram [6] stated that the recommended set point in Thailand office was 24°C and it was the lowest of all studies. Main factor reported was clothing insulation where the workers adjusted the clothing to remain comfortable, as the temperature could not be adjusted.

In summary, based on the result in Figure 2, the preferred comfort temperature in office building were between 25.3°C to 26.2°C. Nevertheless, the result showed that there is still potential to implement the high air-conditioning setting temperature i.e., more than 26°C as shown by 50% of the literature review. It is believed that by carefully considering the setting of the other thermal comfort parameters such as indoor wind speed, the comfortable condition can be achieved. However, more documentations and studies are needed to justify the effectiveness of implementing high set-point temperature in Malaysia as it was still lacking [15].

3.2 Impact of high set point temperature on productivity

COOL BIZ concept originated from Japan suggested that set point temperature in office building should be increased to 28°C with lighter clothing to promote lower energy usage [16]. Implementation of high set point and the impact to office worker was not thoroughly discussed [16]. Table 3 showed a review on the impact of high set point temperature on building occupant's productivity.

Table 3: Review of impact on productivity under high set point temperature

Ref.	Test temp. (°C)	Impact			Reason
		Productivity	Actual Preferred Condition	Adaptive Measure	
[18]	22, 24, 26, 29, 32	Occupants performance at high temperature (>26°C) are low	Slightly cold to neutral	N/A	Slightly cold environment will make the occupants clear headed while warmer environment tends to have sleepy effect.
[13]	23, 26, 27	Increase in self-reported productivity such as alertness, level of concentration and work productivity at 26°C	Neutral	Operating ceiling fan (0.2 m/s)	The workers could adapt quickly to the environment condition within the thermal acceptability range
[2]	27 - 28	N/A	Slightly warm to slightly cool	Small fan (0.5-2 m/s)	Occupants' adaptability to high set point temperature depended on the culture.
[17]	16 - 28	Participants were best performed at 22°C	Neutral or slightly cool	N/A	High set point temperature could cause thermal discomfort and

					affect the productivity of participants.
[3]	25.7 – 28.7	Improved when fan is offered under comparison temperature without fan	N/A	Fan	Usage of fan can averagely extend neutral temperature.

[18] stated that the performance of occupants are lower in high set point temperature (≥ 26°C). Most occupants chose the preferred condition to be "slightly cold to neutral" as it could make the occupants avoid sleepiness. The changes in air temperature resulted to warm discomfort and could affect occupants' productivity and motivation. [17] were sharing the same statement where the occupants preferred "slightly cool" and "neutral" condition to boost the productivity. In this study, the occupants felt thermal discomfort when the thermal environment was too cold or too hot.

[17] stated that the change of thermal neutral condition resulted to decrement of productivity. Other than economic factor, human factor such as comfort, health and stress affected the productivity void in workplace [19]. Otherwise, decline in productivity happened when the temperature difference was too large even with the aid of fan [3].

In contrast, [13] reported that at the set point of 26°C, the productivity of workers increased with 0.2 m/s ceiling fan. The workers voted "neutral" for the preferred condition as most of the workers could adapt quickly to the environmental condition as long as it was within thermal acceptability.

[3] stated that productivity could be improved in high set point temperature when fan was offered to occupants. By this way, the neutral temperature could be extended. The result from this study found out that the main factor for occupants to use the fan were because of indoor or outdoor temperature, not because of the type and function of a building.

3.3 Relationship between thermal comfort, wind speed, and clothing insulation

Based on [23], clothing insulation, radiant temperature, metabolic rate and wind speed were the parameters to determine thermal comfort. However, the parameters that could be controlled were only clothing insulation and wind speed. In this study, a relationship between thermal comfort, clothing insulation and wind speed were analyzed to know whether thermal comfort was highly affected by clothing insulation or wind speed. The analysis for metabolic rate and radiant temperature were not conducted as there was a study stated that the assessment was conducted in controlled condition for metabolic rate (sitting: 1.0 *met*) [18] and radiant temperature was assumed to be the same as air temperature [2]. From selected journals, the data was abstracted and analyzed.

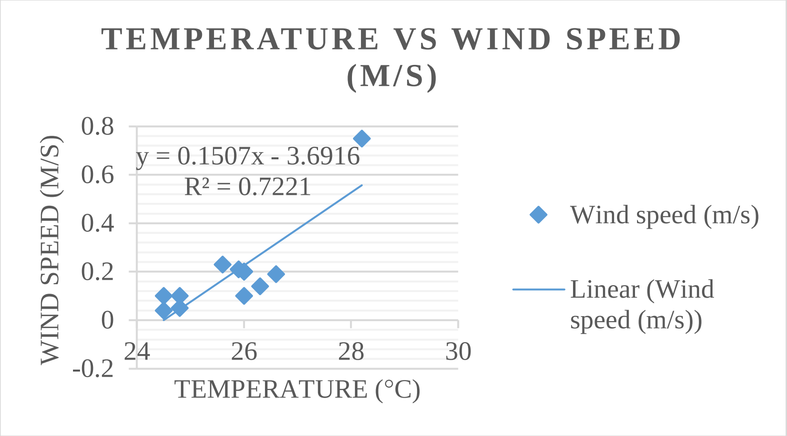


Figure 3: Linear relationship between preferred temperature and wind speed (m/s)

By using linear regression analysis, the relationship between thermal comfort, wind speed clothing insulation and radiant temperature could be determined. To understand the effect of windspeed towards thermal comfort, a scatter plot was drawn between preferred/neutral temperature and wind speed obtained from previous study. A quite strong correlation was found between temperature and wind speed (R^2 = 0.7721, y = 0.1507*x* – 3.6916) as illustrated in Figure 3. This indicated that the value of wind speed gave impacts on thermal comfort of occupants. Indraganti et al. [20] observed that the occupants in office building favoured elevated wind speed to reach desired thermal comfort. One of the approaches by the occupants to obtain high wind speed was by opening the windows [11], [14].

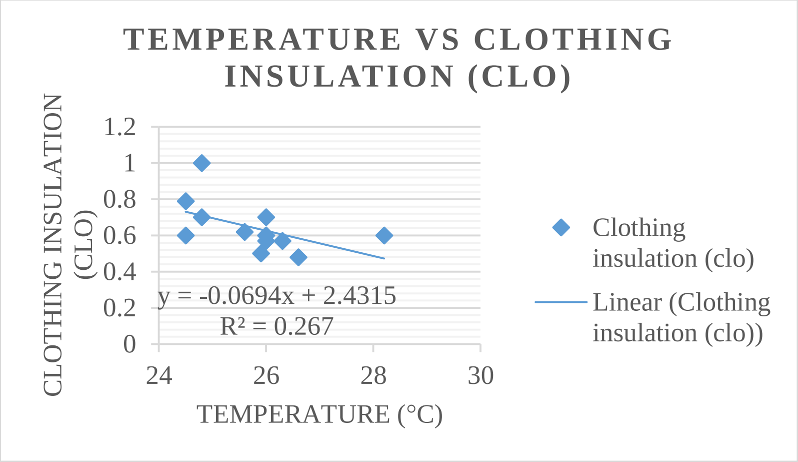


Figure 4: Linear relationship between preferred temperature and clothing insulation

On the other hand, Figure 4 showed a linear relationship between temperature and clothing insulation. A weak correlation has been recorded between temperature and clothing insulation based on the scatter plot (R^2 = 0.267, y = -0.0694*x* +2.4315). This indicated that clothing insulation has lower impact towards thermal comfort of occupants. [20] stated that clothing adjustment were made by occupants during the day in indoor temperature. In addition, it was recommended by Malaysia Standard [23] that the *clo* value for the occupants in elevated air speed to be in the range of 0 to 1.5 *clo*. [9] stated that adaptive behaviour towards the adjustment of clothing insulation of occupants in residential and office building has a significant different where the workers were restricted with formal attires. It was observed from both analysis that to overcome thermal discomfort at high temperature, adjusting the wind speed was the main priority to achieve thermal comfort of occupants compared to clothing insulation.

4. Conclusion

Based on the standard, the recommended temperature was between 24°C - 26°C. Most of the workers felt comfortable at 26°C. The highest set point temperature was 28.2°C with fan assists of 0.75 – 1.5 m/s. Workers agreed that optimum productivity was achieved when the preferred condition was "slightly cool" or "neutral". It was found that the building occupants could adapt with high temperature depended on the culture of certain countries. From the scatter plot, $R^2 = 0.7721$.It was found that adjusting the wind speed was the main priority to achieve thermal comfort of occupants compared to clothing insulation.

Future study needs to increase set point temperature up to 28°C in field measurement for future adaptation in building and optimum energy saving. Otherwise, productivity of the workers need to be recorded as evidence of the study as the researches about productivity in workplace are still lacking.

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