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Examining Thermal Comfort Levels and Physical Performance in Malaysian Settings: A Simulation Chamber Experiment

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Abstract

Thermal comfort refers to a situation where human feels satisfied with the environment's temperature. There is no absolute thermal comfort level that applies to all human, since it is a subjective situation that differ from one person to another. This study's objective is to identify Malaysian thermal comfort level and physical performances under simulation chamber experiment set-tings. Three young and healthy males with no medical issues were chosen as study respondents. There were four settings in this study; (i) 25°C with 70 RH, (ii) 34°C with 92% RH, (iii) 34°C with 74% RH and (v) 38°C with 83% RH . Respondents were required to imitate construction workers lifting task under the four environment settings. This study findings show a noticeable association between an increase in temperature towards heart rate level. As the temperature rises up, respondents mean and peak HR level also rises. Significant mean and peak HR were identified at 38°C for all respondents. In addition, respondents become fatigue and sluggish much faster at 38°C compared to 25°C and 34°C. The most notable decline in physical abilities was identified for Respondent A under 38°C setting. One possible reason for this situation is that respondent A Body Mass Index (BMI) is much higher than the two other respondents.

Keywords: Heat Stress, Construction Worker, Work Performance, Malaysia Construction Industry.

1. INTRODUCTION

Thermal comfort is a mental state which aids in expressing satisfaction with the thermal environment and is determined via subjective assessment (Wang et al., 2018). As a result, both the physical environment and psychological activities contribute to thermal comfort.

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Both the Adaptive and Static thermal comfort are emerged as the two prime categories in thermal comfort theory (Rupp et al., 2015). The most widely used thermal model for static thermal comfort is PMV (predicted mean vote, which Fanger developed in year 1970 (Omidvar & Kim, 2020). PMV was widely utilized for simulation studies in a climate chamber which imitate outdoor environment thermal conditions. Several studies have adapted climate chamber methodologies to explore construction workers thermal comfort level due to its flexibility in imitating outdoor environment and easier observational process (Song et al., 2016; Nicol & Roaf, 2017). Compared to observational studies at construction sites which is highly restricted by working hours, worker's movement, environment change, and on current practices, rather than what needs to be done, with clear cherry picking (some examples are given below) and many of the more blatant and insidious negative effects and impacts of mining not addressed. In a similar vein to the MMSD report, the Atlas advocates that the 'mining industry.

2. THERMAL COMFORT

Thermal comfort refers to a situation where a human feels satisfied with the environment temperature. There is no absolute thermal comfort level that applied to all human, since it is a subjective situation which differ from one person to another. Factory workers in India shown high thermal adaptation level compared to Indian office workers, where the mean values were at 32.2 °C with variations up to 9.5°C (Kumar et al., 2021). This indicates the factory workers can adapt up to 41.7°C during scorching summer season by only relying on behavioral changes and air velocity. Another study points out factory worker in India can adapt to 34°C without using the air conditioning system and only relying on air velocity with about 0.6 m s-1 (Wijewardane & Jayasinghe 2008). A study in Singapore found out overcooling as main source of thermal discomfort for office workers, which then lead to behavior such as wearing multiple layers of clothing while working (Chen & Chang, 2012).

Thermal comfort is also influenced by personal factors such as age, where children in primary schools have been reported to adapt with very high and low thermal condition in summer and winter (Lala et al., 2022). Nonetheless, the students only manage to adapt with high thermal environment after adjusting factors such as fan speed in summer and wearing very thick clothes in winter. Male and female in Italy show different thermal comfort level during winter and adapt different climate control method to overcome the coldness (Nico et al., 2015).

To ensure workers' productivity, a good thermal environment is essential. It has been claimed that poor thermal comfort has a significant negative impact on workers, causing things like lack of focus and decreased productivity. Sudden absence of air conditioning system due to breakdown, lack of maintenance or malfunction have shown to have major impact on workers productivity. In Hariz (2015) study, 40% of the workers become highly uncomfortable and losses the ability to multi-task and handing task on time when the HVAC system broke down. In addition, the workers state their work pace becomes much slower which then further delay their work schedule. Low Indoor Environment Quality (IEQ) reduces workers motivation and mood while working, thus, lead to a decrease in workers productivity within the range of 2.4% to 5.8% (Lamb & Kwok, 2016).

2.1 Construction Workers Productivity

There is no definitive method to measure the impact of external or internal factors towards construction workers productivity (CWP). This is due to the complex relationship between the influencing factors and CWP. On top of that, CWP itself is hard to measure since different construction task or job have different productivity scale and also use different resources. Thermal environment is one of significant factors known to have major impact on CWP. Thermal parameters like relative humidity, air temperature, wind velocity, clothing insulation, metabolic rate and mean radiant temperature influences on CWP and workers health were frequently examined.

Past studies have frequently associate thermal environment and CWP (Arif et al., 2016; Roskams & Haynes, 2019). Countries with extremely hot weather have significant implications to construction CWP. In China, construction workers productivity tremendously when the temperature rises above 34°C combined with wind speed of 1.3 m/s (Tang et al., 2021). At this stage, the construction workers start to become sluggish and working at much slower pace compared to temperature below 34°C.

Construction workers that wear cooling vest after doing medium-heavy task can hastily recover their thermal sensation and diminish loss of performance after working more than 150 minutes (Roelofsen & Jansen, 2022). On contrary, workers that don't use cooling vest will lost a lot of productivity after 120 minutes, plus, also being thermal discomfort. Li et al (2019) founds out different type of construction workers experienced difference thermal comfort level while working in summer, where the average WBGT can reach 35.8 and air temperature of 40°C and above. Construction workers like scaffolders and rig piler have much higher heart rate per minute and body core temperature compared to handymen and plumber that work inside a building.

2.2 Simulation Thermal Comfort Study

Experimental thermal comfort study mostly conducted in a climatic chamber, which have the capabilities to simulate outdoor environment to a certain extend. Researcher have branched from traditional field observational study to simulation study in a climatic chamber due to its advantages, such as ability to control temperature settings, air velocity, humidity, and observational infrastructure. On top of that, it's easier to conduct an experimental study in a setting that can be controlled since there are less unexpected interference compared to field observation, such as abrupt change in weather or workplace commotion.

Ismail et al (2020) experimental studies replicate construction workers task in a climatic chamber and comes to conclusion that relative humidity and air temperature influence individual work performances rate. The changes in skin temperature and heart rate become prominent at high air temperature, hence reducing subject concentration (Aziiz et al., 2020).

Sobarto et al (2019) founds out age have no influence on individual thermal comfort level and skin temperature at hands area have significant impact on the individual thermal sensation level. Air velocity is another key component for thermal comfort. A simulation study shows adjusting ambient air velocity increase individual thermal comfort level, equivalent to decreasing air temperature (Jia et al., 2022).

Clothing have cooling effect on the construction worker body. Yi et al (2017) experiment shown a cooling vest is best to be used after construction workers finish doing heavy task and not while doing the task. Cooling vest worn during rest period can effectively reduce workers heart rate and core temperature, thus reducing the chance for heart stroke to occur.

Even though climatic chamber can imitate outdoor environment climate, it can't replicate other factors that only existed in outdoor situation, such as gust of wind touching the skin or breeze of cool summer air. Thus, Predicted Mean Vote for individual on a field might be different compared to PMV in a climatic chamber that replicate the field environment (Bialek & Debska, 2022).

3. METHODOLOGY

This study adapted experimental methodologies and was conducted at a Climatic Chamber in Johor Bharu. The climatic chamber is called ESPEC and have the ability to regulate air temperature and air humidity to replicate outdoor environment. The experiment aims to replicate Malaysia construction site environment condition and construction task in the climatic chamber. Thus, investigating if there is any impact of elevating air temperature towards the study subject performances. Three young and healthy males with no medical issues were chosen as study respondents. Each respondent had been briefed on the experiment objectives and given their consent to join the experiment. Table 1 shown respondent's demographic profile

Participants	Age	Weight	Height
A	20	55.4	175.5
B	24	53.4	165.3
C	24	76.3	168.5

Table 1. Respondent Demographic Profile

There were four settings in this study; (i) 25°C with 70 RH, (ii) 34°C with 92% RH, (iii) 34°C with 74% RH and (v) 38°C with 83% RH . These four settings reflect construction site environment during noon (11am to 2 pm), where the temperature at its peak. Respondents were required to imitate construction workers lifting task through these four steps; (i) Lift a 10-kilogram box from Table A, (ii) carry the box to table B and then drop it there, (iii) lift the box back and (iv) carry it to Table A. Respondents need to repeat these four steps for 15 minutes for each environment settings.

Environment	Temperature (°C)	Relative Humidity (%)
A	25	70
B	34	92
C	34	74
D	38	83

Table 2. Climactic Chamber Environment Settings

Two aspects were recorded in this experiment. First, oxygen uptake volume was recorded through a face mask (Cortex MetaMax 3B) that covered the respondent nose and mouth. Second, recording of heart rate was via the sensor belt of heart rate, attached to the respondent body. The heart rate sensor will send information via Bluetooth and then processed by OmniSense™ 5.1 software. Besides that, researcher also observe respondent behavior from the aspect of movement, pace, reaction time, precision and stamina.

4. FINDINGS

Table 3 shown volume oxygen uptake for each respondent on each environment settings.

Environment Settings	Respondents	Heart Rate (BPM)		Mean Volume Oxygen Uptake (ml/min/kg)
		Mean	Peak	
25°C and 70 RH	A	120	128	11
	B	105	111	12
	C	91	98	8
34°C and 74 RH	A	123	136	10
	B	113	122	12
	C	91	99	8
34°C and 92 RH	A	128	137	11
	B	115	130	13
	C	101	115	9
38°C and 83 RH	A	149	162	13
	B	110	119	11
	C	102	118	9

Table 3. Volume Oxygen Uptake and Heart Rate

Respondent A have the highest BPM range of 120-149. Followed by respondent B with 105 to 115 and respondent C with 91 to 102. Meanwhile, mean volume oxygen uptake readings are fairly similar for respondent A (10-13) and respondent B (11-13). Respondent C have the lowest VO2 readings with 8-9. First setting represent Malaysia mean average temperature, which is around 25°C. Malaysia's mean relative humidity was 42% for dry season and can go up to 70% for wet seasons (MET, 2023). Thus, this study chooses 70% RH to reflect wet and cold outdoor environment, to match the 25°C temperature. In this setting, Respondent A mean HR was 120, followed by Respondent B with 105 and Respondent C with 91. Respondent A HR gradually increase above 120 from 10 minutes 15 seconds mark until 15 minutes, with highest HR reading at 128. On the other hands, Respondent B HR rise up after 6 minutes mark and start to settle down at 10 minutes. Respondent C on contrary shown lower HR average after 9 minutes mark until the experiment end.

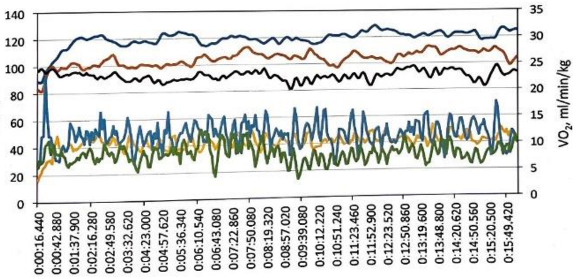

Figure 1:. 25°C with 70 RH

Second setting is 34°C with 74 RH, which reflects Malaysia highest average temperature environment from 1991 until 2020 (WBG, 2022). In this setting, mean HR for respondent A is 123, followed by respondent B with 113 and respondent C with 91. Respondent A HR peak is at 138, respondent B at 122 and respondent C at 99. Respondent C HR was stable for the entire 15 minutes, while respondent B HR seldomly goes higher than 120. On the other hands, Respondent A HR were mostly above 120 and stay above 130 after 11 minutes mark.

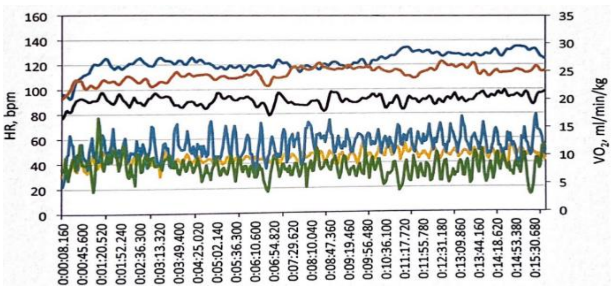

Figure 2: 34°C with 74 RH

The 34°C with 92 RH environment indicate high humidity conditions. Mean HR for respondent A is 128, followed by respondent B with 115 and respondent C with 101. Respondent A HR was above 120 from beginning of the experiment until the end, with highest HR recorded at 137. Respondent B HR was always above 100 with highest reading of 130. Respondent B HR start to spike up after 8 minutes mark and mostly went over 120 after that until the simulation end. Lastly, respondent C with the most stable HR, within the range of 90 to 115. Respondent C HR pace up significantly starting from 7 minutes 30 seconds until 15 minutes mark, where his HR went above 110 for 9 times.

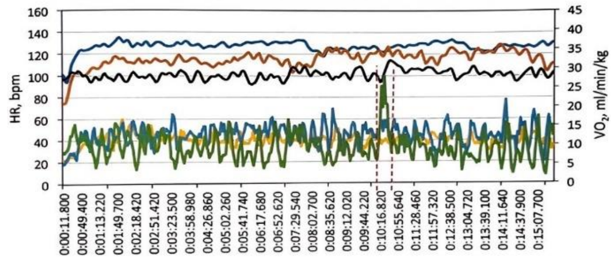

Figure 3: 34°C with 92 RH

The last environment setting is 38°C with 83 RH, which reflects extremely hot environment that rarely occurs in Malaysia due to factors such as northeast monsoon or El-Nino (Arnold, 2023). In this setting, Respondent A HR went above 140 after 3 minutes and reach 160 at 13.19 minutes. Respondent A HR steadily increased from 5 minutes and 44 second mark until the experiment end. On the other hands, Respondent B HR were mostly above 110 after 4 minute and 24 second mark and reach 119 at the end of the experiment. Respondent C HR fluctuates frequently around 95 to 110 range. Fatigue is noticeable for respondent C between 12 minutes to 14-minute mark where his HR never went below 105 and reach peak of 118.

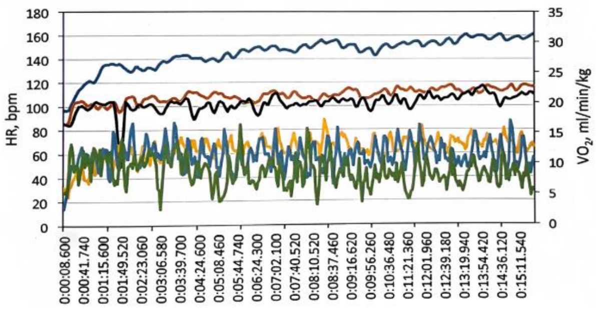

Figure 4: 38°C with 83 RH

6.1 Observational Findings

Respondents start to show sign of fatigue at 10 minutes mark for 25°C and at 7 minutes mark for 34°C and 38°C. This includes start to walk slowly from Table A to Table B, having difficulty to carry the load (box), and also start to throw down the box on top of the table instead of slowly laying it down. Fatigue signs become more prominent as the experiment goes on, to the point where its clear that their physical movement have become sluggish.

5. DISCUSSION

This study finding shows noticeable association between increase in temperature towards heart rate level. As the temperature rises up, respondents mean and peak HR level also rises. Significant mean and peak HR were identified at 38°C for all respondents. In addition, respondents become fatigue and sluggish much faster at 38°C compared to 25°C and 34°C. Increase in air temperature and relative humidity have been frequently associated with decrease in individual physical abilities (Aryal et al., 2017; Dutta et al., 2015; Karthick et al., 2022). For construction workers, performances and productivity have been observed to decline significantly when the temperature reaches extreme level, like 38°C and above for medium and high workloads (Bendak et al., 2022; Jouaret et al., 2020).

6. CONCLUSION

Moreover, significant association have been identified when the temperature is beyond individual perceived thermal comfort level (Gariazzo et al., 2023). Respondent mean and peak HR reading increase at higher rate when temperature changed from 34°C to 38°C, compared to 25°C to 34°C. Indicating respondents can still adapt with 34°C, however, become highly uncomfortable at 38°C. This is because 38°C and 83 RH setting can be considered a harsh environment for Malaysian that lives with average mean temperature of 25°C and maximum of 34°C. The most notable decline in physical abilities was identified for Respondent A under 38°C setting. One possible reason for this situation is respondent A Body Mass Index (BMI) is much higher compared to the two other respondent. Several other studies have also link the impact of worker BMI and decline in performance either under high temperature or over period of time (Karthik et al., 2019; Mohaptra et al., 2022).To summarize, respondents show sign of fatigue at 34°C and 38°C after 7 minutes of experiments. However, the increase in mean and peak HR was not significant at 34°C compared to 38°C. Moreover, respondents with high BMI showed very high mean and peak HR rate compared to the other respondents at 38°C and at one point goes beyond 160, which is over the safe threshold for medium and hard work intensity.

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