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Understanding Knowledge Level of The Thermal Implication and Its Effects Towards Physiological State in Construction Sector

Ahmad Rasdan Ismail[1,*], Nor Kamilah Makhtar[2], Raemy Md Zein[3], Nor Kamaliana Khamis[4], Darliana Mohamad[5]

[1] Mechanical Engineering Department, Faculty of Engineering, Universiti Teknologi PETRONAS, 32610 Seri Iskandar, Perak, Malaysia
[2] Department of Educational Planning and Research, Institute of Teacher Education, Campus Kota Bharu, Kota Bharu, Kelantan, Malaysia
[3] National Institute of Occupational Safety and Health (NIOSH), 43650 Bandar Baru Bangi, Selangor, Malaysia
[4] Department of Mechanical and Manufacturing Engineering, Universiti Kebangsaan Malaysia, Bandar Baru Bangi, Selangor, Malaysia
[5] Faculty of Creative Technology and Heritage, Universiti Malaysia Kelantan, 16300 Bachok, Kelantan, Malaysia

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ABSTRACT

Heat stress normally known as a hidden cause of accidents in construction sectors. To ensure the productivity and health of workers in the construction site, it is necessary to evaluate the effects of temperature and relative humidity on the workers' physiology under hot conditions. Hence, the aims of this paper are: (i) to investigate the knowledge of heat stress and workers perceptions on workers performance in construction site, (ii) to identify the environment factor of heat stress in the construction site and (iii) explore the measurement physiology parameters for heat stress. Heat stress questionnaires and experiment test were combined to extract useful information. An online survey was undertaken with a representative sample (N=292) from Malaysia construction sector. While, the experiment was carried out in a well-controlled climate chamber to obtain datasets with four conditions combining air temperature and relative humidity (32 °C/70 %, 34 °C/92, 34 °C/74% and 38 °C/83%). At a climate chamber, the subjects doing a job such as lifting and carry the 10 kg workload were exposed to different combinations of air temperatures and relative humidity. The subject's physiological responses to the environment were then investigated. The survey's finding showed 71.9% of the workers understand about heat stress. 22.6% of the workers perceive that the temperature is hot and quite hot and relative humidity result showed that 50.9 % of the workers perceived that part of their mouth and throat are dry while working. Besides, the experiment study showed that workers physical demands varies according to their work task with a combination of the influences from individual and environmental factors.

1. Introduction

The global climate change leads to the increase of heat exposure on human, whether in an outdoor environment or indoor environment. Malaysia, which has a hot and humid tropical weather would be influenced by this issue more than other countries at North and South of the earth's

[*] *Corresponding author.*
E-mail address: ahmadrasdan.ismail@utp.edu.my

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hemisphere. Up to this date, majority studies related to impacts of the working environment on the workers is dominated by most Western scholars. There is still a lack of awareness of this issue in Malaysia even though there is already an enactment which aims to promote a good occupational environment for persons at work.

The combined effects of all indoor environmental factors can affect performance in the short-term [1]. This is supported by the finding of Ismail *et al.,* [2] and Ismail *et al.,* [3] that the environmental factors, such as temperature, illuminance and humidity levels have a significant effect on workers performance at the production line. In term of heat stress, multiple environmental factors influence thermal condition. These factors include air temperature, humidity, air speed, radiant temperature and individually dependent factors such as metabolic rate and clothing insulation [4].

Another study shows that the elevated air temperature in a climate chamber reduced the subjects' performance of addition and subtraction [5]. In contrast, one more investigation shows that the heat is related to a thermoregulatory burden which reduces the performance during an exercise [6].

Working in a hot workplace for a long time may lead to poor health and welfare among workers. This may reduce the level of employee's performance, increase the risk of heat illnesses, discomfort, and rate of accidents among the workers [7]. Construction workers are indeed vulnerable to this occupational heat risk. Therefore, primary focus should be given as this group is among the major contributors in the development of key sectors.

Construction industry around the globe is distressed with unsatisfactory occupational health and safety records. One of the primary reasons behind the health and safety issues is the highly physical and demanding nature of the construction tasks. Construction-related work has to be done for a prolonged duration of work-time without a short break to recover from overexertion, in harsh climatic conditions and confined work-spaces. Such circumstances may expose construction workers to the risk of fatigue development. Workers supposed to continue work under fatigued. In that case, they are prone to the development of work-related musculoskeletal disorders (MSDs), make more errors during work, degradation of the workmanship, reduction in productivity, accidents on the construction sites and fall incidents. Based on Department of Occupational Safety and Health Malaysia (DOSH), the death due to accidental cases in construction site is among the highest recorded in 2020 [8]. In fact, according to the Bureau of Labor Statistics [9], 33% of all occupational injuries and illnesses on the US construction sites were related to fatigue and overexertion. Besides, hot and humid conditions may further accelerate fatigue development, which may cause the construction workers to suffer from heatstroke and might even cause death. During 2010, heat strokes arising from hot and humid environments claimed 47 casualties in the Japanese industrial sector [10].

Construction workers are vulnerable to heat stress because the majority (e.g., 73% in the U.S.) engages in heavy work outdoors. Construction workers in the southern United States, the Middle East, Asia, Latin America, and Africa are regularly exposed to too high temperatures with long working hours, yet may have limited or no access to shade or water [11]. Recently, the issues of heat stress management attention have been paid to identify and control of risk factors of heat stress. Thus, the assessment of thermal stress in the workplace is very important [12]. Previous studies have shown that construction workers in the U.S. are 13 times more likely to die from a heat-related illness (HRI) compared to workers in other industries. Within the industry, roofers and road construction workers face an exceptionally high risk of HRIs.

Hence, this paper aims to: (i) to investigate the knowledge of heat stress and workers' perceptions on worker's performance at the construction sites, (ii) to identify the environment factor of heat stress in the construction site and (iii) explore the measurement physiology parameters for heat stress. Following sections will describes the methodology and findings of the survey and experimental test in detail.

2. Methodology

This section discusses methodology related to the perception surveys, and the experimental test on environmental factors measurement and also the physiological measurement.

2.1 Perception Survey

For the perception survey, the quantitative methods by using descriptive statistics (frequency, mean, standard deviation) and analytical tests causal-effect method were used. Al-Bouwarthan *et al.,* [13] and Venugopal *et al.,* [14] stated that quantitative effect in heat stress studies monopolize the workers' performance. Therefore, this study is in line with the methods used by previous researchers [15-18]. Figure 1 shows the conceptual framework of the workers' perceptions study.

The perception survey was conducted to assess the effects of temperature and relative humidity factors of heat stress among the construction workers in Malaysia towards their performance. A questionnaire is developed based on adaptation and adaptation from previous studies [17,19]. This questionnaire has three parts: general information, the performance and the factors of heat stress. Two hundred and ninety-two workers were participated in this survey.

The questionnaire was distributed to the workers who volunteered to join this study which is from various place in the construction sector. A trained interviewer clarified any vague questions. The questionnaire was sent randomly to the construction worker all over Malaysia. Google Form application was used for the purpose of survey distribution.

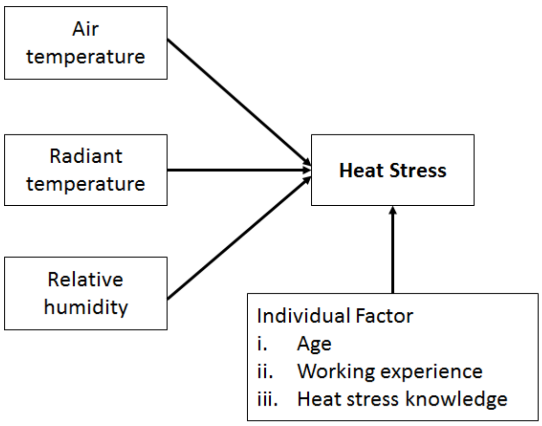

Fig. 1. Conceptual framework of the study

2.2 Experimental Study

The experiment was conducted in a special climate chamber. This chamber simulates similar working environment and task arrangement in the construction site. The environmental parameters such as the temperature, relative humidity and also the physiological parameters such as the volume oxygen uptake level and the heart rate were recorded.

Three healthy participants were participated in this experiment. Table 1 shows particular information related to age, body weight, height and body mass index of the participants. The physical characteristics of the participants were as follows (mean ± SE): age 23.0 ± 8.3 years old; height 169.8

± 5.2 cm and body weight 61.7 ± 12.7 kg. Exclusion criteria of the participant selection are the history of diagnosed major health problem including diabetes, hypertension, cardiovascular disease and regular medication intake. The subjects were clearly informed about the purposes and the procedures of the study prior to experimental tasks. Written consent was obtained from all participants before the experiment test. This study was approved by the Ethical Committee of NIOSH Malaysia.

Table 1
Anthropometric information

Subjects' information	Values
Subjects	Male: 3
Age	23 ± 2.31
Body weight (kg)	61.7 ± 12.68
Body height (cm)	169.8 ± 5.22
Body mass index (BMI)	21.5 ± 4.7

As illustrated in Figure 2, the experiments were conducted in a climate chamber with measurements of 4.1 m (L) × 4.1 m (W) × 2.5 (H). The purpose climate chamber in this study to ensure that the indoor thermal environment was less affected by external environments. The controlled range and accuracy of the air temperature in the climate chamber were -40 to 80 ^oC within ± 0.3 ^oC; the relative humidity (RH) ranged from 10 to 95% within ± 5%. Considering a combination of RH and air temperatures would create significant physiology responses on the human body.

This experiment test was conducted in four conditions combining air temperature and relative humidity (32 ^oC/70 %, 34 ^oC/92%, 34 ^oC/74% and 38 ^oC/83%). It simulates the manual handling work at construction industry. In the construction industry, the workers are demanded to lift a workload manually. Fang *et al.,* [20] suggested that the weight of manual handling is reasonably set at 15 kg for construction workers, and a sandbag would be much less harmful when unexpectedly dropped down. Based on the guideline from DOSH Malaysia [21], for a male worker who lifts an object near to the body from the elbow height, the maximum weight is 20 kg. However, when the tasks are repeated one to twice per minute, the maximum weight must be reduced to 30%, which is 14 kg [29]. Therefore, in this experiment, the weight of the workload used is 10 kg to follow the guideline with much lower weight than the maximum.

In Figure 2, there are four steps of the task must be followed by the subject; (i) lifting the workload, (ii) walk and carry the workload and drop the workload to the other table, (iii) lifting the workload, and (iv) walk and carry the workload and drop the workload to the initial table. This operation is repeated again and again manually for 15 minutes [21]. Total time for completing one single round is 30 s. Additionally, the workload had to be lifted and placed at the height of 1 m to minimize repetitive bending, which could lead to low back discomfort at a rate higher than that of because of whole-body exertion.

Physiological parameters such as heart rate (Polar) and maximum volume oxygen uptake (VO_2 max) were continuously measured every five seconds by a Cortex MetaMax 3B. Prior to the experiment, the calibration of gas and volume were carried out of each subjects and after that the subjects were required to wear a face mask and portable unit.

Fig. 2. Measurement protocol

3. Results and Discussion

3.1 Survey Perception Results

This section discusses the results obtained from a perception survey of workers in the constructions sectors. The demographic background of the respondents taken into account for this study is age, working experience and knowledge on heat stress. The demographic distribution of respondents is as in Table 2.

The majority of respondents in this study (48.3%) are aged between 31 to 40 years old, which is 141 people. Interestingly, there were no respondents involved in this study with the age of 10 to 20 years old. Respondents with 1 to 3 years working experience are the majority in this study with 64 people (21.9%), followed by workers with 4 to 6 years working experience, which are 48 people (16.4%). Regarding the knowledge on heat stress, 71.9% (210 workers) of the workers had knowledge on it while the rest 28.1% (82) did not have any knowledge on heat stress.

Table 2
Demographic distributions of respondents

Demographic		Frequencies (N=292)	Percentage/%
Age	10-20 years old	-	-
	21-30 years old	98	33.6
	31-40 years old	141	48.3
	41-50 years old	32	11.0
	51 years old and above	21	7.1
Working Experience	Less than 1 year	36	12.3
	1-3 years	64	21.9
	4-6 years	62	21.2
	7-9 years	40	13.7
	10-15 years	48	16.4
	More than 15 years	42	14.5
Heat Stress Knowledge	Yes	210	71.9
	No	82	28.1

There were three factors related to heat stress being investigated in this study. The workers' perception due to the factors can be seen as Figure 3, 4 and 5. As for the air temperature, most of the workers perceive that the temperature is hot and quite hot with both of the items give the same value of percentage, which is 22.6%. The rest of the workers' perception can be seen in Figure 3.

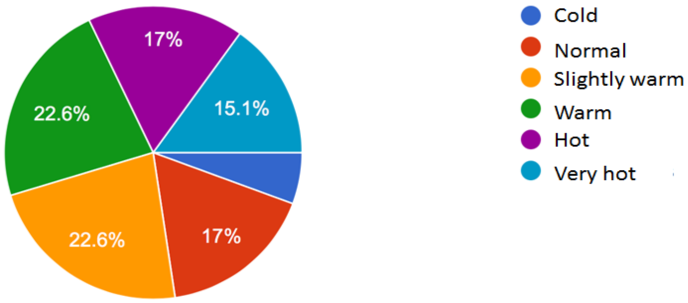

Fig. 3. Perception on air temperature

Figure 4 showed the workers perceptions of radiant temperature in the construction. Most of the workers with the percentage of 39.6% agreed that the surface of their working area is not too cold and not too hot, followed by 26.4% agreed that the surface of their working place is quite warm once being touch by them.

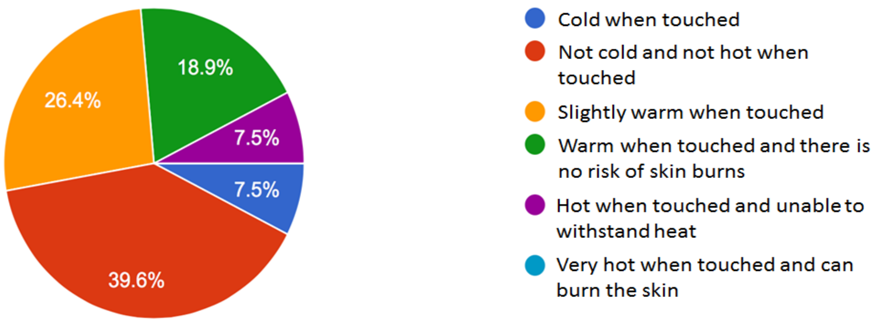

Fig. 4. Perceptions on radiant temperature

Figure 5 showed the relative humidity factor, 50.9 % of the workers perceived that part of their mouth and throat are dry, followed by 15.1% of the workers felt that the humidity of the working surrounding is fit and comfortable. The detail of the worker's perception of relative humidity can be seen in Figure 5.

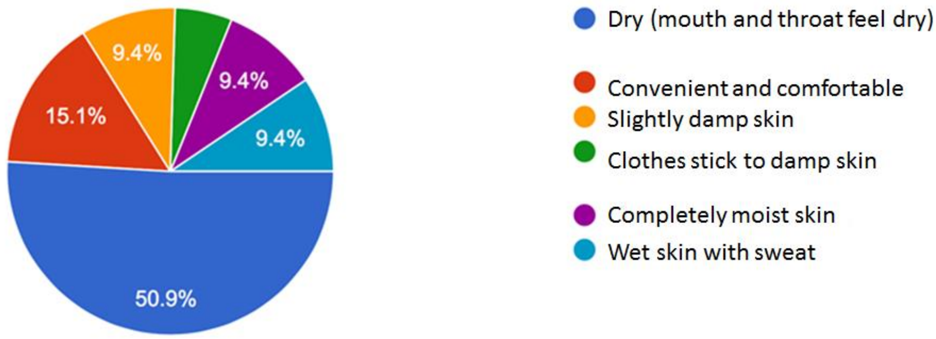

Fig. 5. Perceptions on relative humidity

3.2 Experimental Results

Figure 6 shows the measured heart rate (HR) and maximum volume oxygen uptake (VO_2 max) patterns from three subjects during their task. The trend of HR change in three subjects is similar. The signal in Figure 5 reflects the thermoregulatory changes that occur during lifting, carry and drop the workload. Once the subject starts lifting the workload, a gradual increase in the heart rate signal is observed. The decrease in the heart rate signal is observed when the subject drops the workload and follows by increasing heart rate signal again when the subject lifting and carry the workload to another table (2.9 m distance from table A to table B). Mean HR and VO_2 max for subject A is 133 bpm and 11 ml/min/kg, meanwhile subject B is 106 bpm, and 12 ml/min/kg and subject C is 95 bpm and 8 ml/min/kg. The signal heart rate for subject A is highest than subject B, followed by subject C.

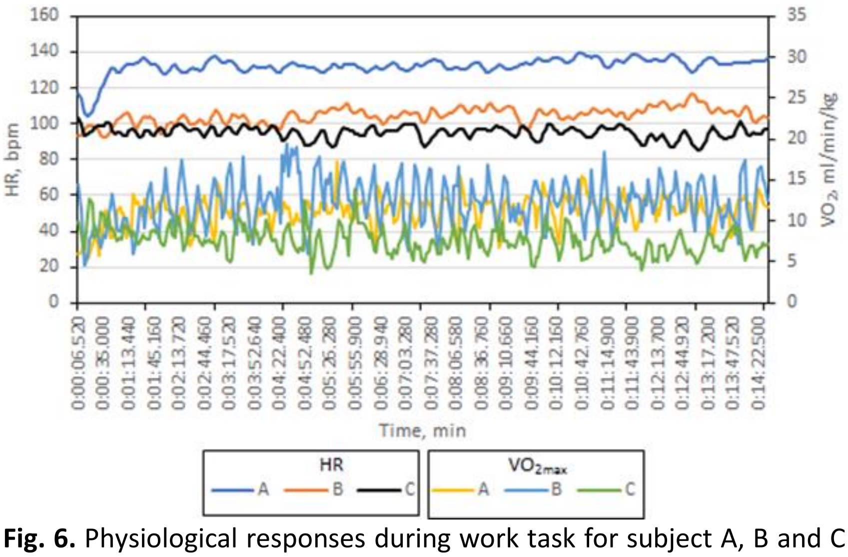

Fig. 6. Physiological responses during work task for subject A, B and C under condition at 32 °C/70%

Figure 7 shows measured HR and VO_2 max patterns from three subjects during their task. Mean HR and VO_2 max for subject A is 128 bpm; 11 ml/min/kg, meanwhile subject B is 115 bpm; 13 ml/min/kg and subject C is 101 bpm; 9 ml/min/kg. Findings also showed that when there is an increment of an initial rapid VO_2, and reached a steady state at minutes of 9 or 10, the subject tends to fatigue. In addition, the value of VO_2 is higher is 28 ml/min/kg at this state. Holmer and Gavhed [22] explained that, if the person tries to maintain the pace frequently at submaximal level, the maximum duration of work is expected about 9 to 12 minutes before reaching exhaustion. The signal heart rate for subject A is highest than subject B, followed by subject C.

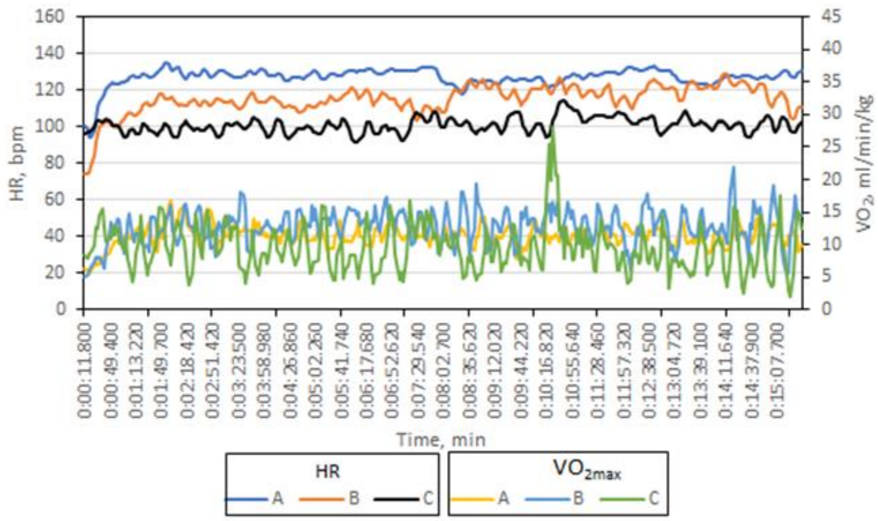

Fig. 7. Physiological responses during work task for subject A, B and C under condition at 34 °C/92%

Figure 8 shows measured HR and VO_2 max patterns from three subjects during their task. The Mean HR and VO_2 for subject A is 123 bpm; 10 ml/min/kg, meanwhile subject B is 113 bpm; 12 ml/min/kg and subject C is 91 bpm; 8 ml/min/kg. The signal heart rate for subject A is highest than subject B, followed by subject C.

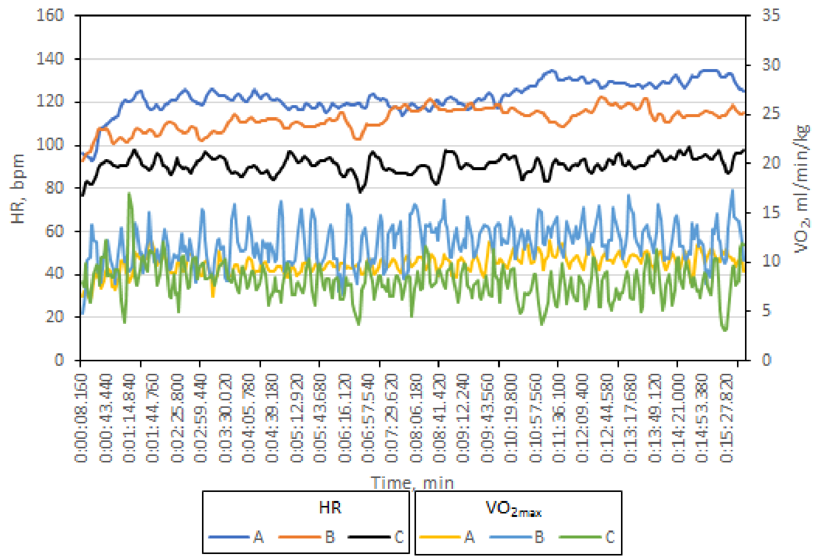

Fig. 8. Physiological responses during work task for subject A, B and C under condition at 34 °C/74%

Figure 9 shows measured HR and VO_2 max patterns from three subjects during their task. Mean HR and VO_2 max for subject A is 149 bpm; 13 ml/min/kg, meanwhile subject B is 110 bpm; 11 ml/min/kg and subject C is 102 bpm; 9 ml/min/kg. The signal heart rate for subject A is highest than subject B, followed by subject C.

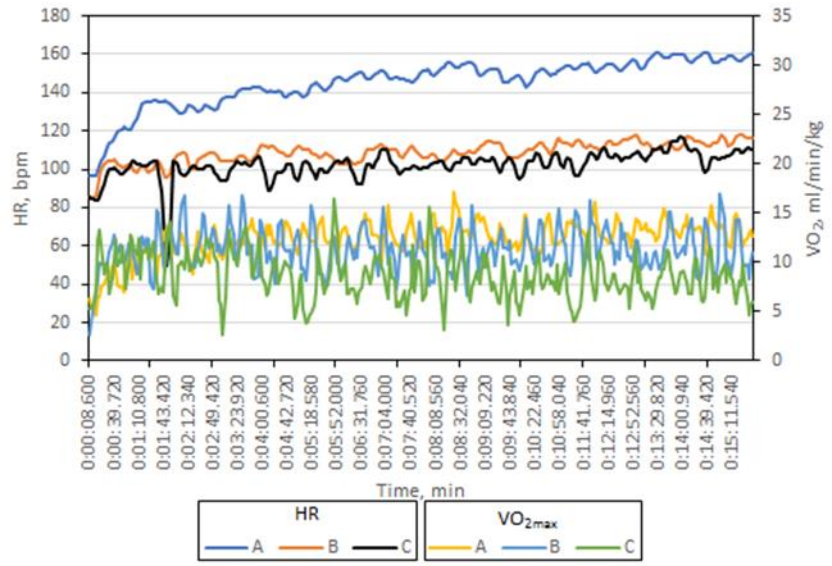

Fig. 9. Physiological responses during work task for subject A, B and C under condition at 38 °C/83%

3.3 Discussions

From the survey, the understanding of how workers perceive and experience heat stress risks based on the workplace heat exposure may be useful in improving heat exposure risks management and occupation health and safety policies in the context of rising temperature and climate change. The workers who experienced heat stress at work were more likely to be associated with well-being, physical, and mental health problems. Previous studies have found that heat stress at work provide negative impacts on work motivation, productivity, and increased injury risk [23][24].

From the experimental test, the heart rate is a general indicator of stress on the body [23]. Heart rate is the safest index because it is the earliest response of physiological strain [24]. Earlier research reported that the standard heart rates for performing heavy work in a hot and humid environment were in the range of 120-160 bpm [23,25]. Our findings of heart rate reinforce the results of the previous studies.

As described in previous research on construction workers' physical demands conducted by Abdelhamid and Everett [26], masons and carpenters experienced higher physical demands than electricians, because masonry and carpentry operations include heavy material handling (e.g., lifting concrete blocks, drywall, or doors: average 3.6 kcal/min of metabolic demands and 105 bpm of HR for concrete block laying; and average 3.88 and 4.17 kcal/min metabolic demands and 109 and 114 bpm of HR for drywall installation and carpentry works, respectively) while electric operations include light arm works or hand works (average 3.09 kcal/min of metabolic demands and 98 bpm of HR for concrete block laying). Physical needs of workers varied with their diverse tasks; however, high physical demands were required during their more physically demanding works.

Individual physical demands can vary with personal and environmental factors even though their workloads and the percentage of working are consistent. Specifically, it has been observed that an age effect on the physical demand is statistically significant. In this study, the higher results of HR is subjects for age 24 years old. According to Table 1, the subject C shows results lowest than other effects. This result is significant with the previous study showed that average 8% higher demands of older individuals [27].

Environmental factors are also known as critical to physical demand variations [28]. Ahmad Rasdan *et al.,* [29] stated that different heart rate readings had been recorded for different types of tasks at different temperature ranges. The HR during work task is not at a stable level but slowly increases when the subjects are exposed to tropical environment overtime, and the HR exceed normal limits in sweltering conditions.

4. Conclusions

The outcome of the survey showed that 71.9% of the workers had knowledge of heat stress. The temperature showed that 22.6% of the workers in the construction perceive that the climate is hot and quite hot and relative humidity result showed that 50.9 % of the workers perceived that part of their mouth and throat are dry while working. The experiment study examined the performance of the physiological responses of Malaysia workers to the heat. In this study, the author observed physiological responses in a simulated heat-exposure experiment in a well-controlled climate chamber. It were compared to different designed conditions by showing the meaningful relations between HR and influence factors that affecting physical demands in construction (e.g., work tasks, individual and environmental factors such as age and temperature). Thus, this study showed that workers' physical needs could be highly variable according to their work task with a combination of the influences of individual and environmental factors.

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