Experimental Investigation of Workers Physiology under Tropical Climate in Construction Industries

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ARTICLE INFO	ABSTRACT
	Construction workers are particularly susceptible to heat-related illnesses, for the weather is very hot and humid. The objective of this study is to investigate the interaction between the temperature and relative humidity to the physiological parameters such as heart rate (HR) and volume oxygen uptake (VO_2 max) of the workers in the construction industry. The experiment was conducted in an environmental chamber which simulates the environment of the construction industry with three conditions combining air temperature and relative humidity (34 °C/74 %, 34 °C/92 %, 38 °C/83 %). The HR and the VO_2 max of three subjects were monitored, and all the data were continuously recorded every 15 minutes. For each condition, the activity levels such as lifting the heavy sand (10 kg) were conducted for subjects. In the VO_2 case, a significant correlation was observed between air temperature (p=0.043) and the relative humidity (p=0.000). Meanwhile, in HR case, a significant correlation was also observed between air temperature (p=0.004) and the relative humidity (p=0.028). The high-risk thermal environment (38 °C/83 %) and subject were identified. In conclusion, it can be empirically proved that environmental factor such as temperature and relative humidity have a significant impact on workers' performance.

1. Introduction

Malaysia is one of the countries situated in the tropical zone, also affected by the increase of global temperature. As Malaysia is targeting to be a developed nation, this issue should be addressed properly to ensure sustained growth in the economy. The construction sector, which is among the biggest industries in Malaysia, must be optimized to avoid any undesirable effects of heat exposure [1]. Also, construction is among the most hazardous industries [2,3]. It has been shown that human

errors, mentally unstable workers, insufficient safety training, and policy all affect the incidence of construction accidents. Construction accidents are also affected by weather factors such as temperature and humidity, due to the outdoor nature of most construction work [4]. Thus, the performance of the workers in these sectors can augment, and this will lead to higher production output and increase the industries competitiveness in the global market.

The study on the impacts of the working environment on the workers is dominated by most Western scholars [5]. But there is still a lack of awareness of this issue in Malaysia even though there is already an enactment which aims to promote an excellent occupational environment for persons at work [6].

Global warming will unquestionably increase the impact of heat on individuals who work in already hot workplaces in hot climate areas [7-9]. The increasing prevalence of this environmental health risk will become a threat to the public and occupational health in some areas of the world and is likely to reduce productivity [8-11].

Construction work involves manual lifting and carrying and may lead to musculoskeletal injuries. Working at heights, with heavy overhead loads, operating heavy machinery and power tools or working under temperature extremes contribute to risk of accidents and injuries. Physical work in a hot and humid environment imposes a considerable physical strain on workers, with significant associated health risks, reduced productivity and certain safety problems [14]. Many countries located in the subtropical climatic zone suffer from high temperature, high humidity, and occasionally coupled with low wind speed in summer. Heat stress can cause more health problems and deaths to humans as compared with extreme cold [15]. The risk of subjecting workers to heat stress when working outdoors has been increased. In view of this, the American College of Sports Medicine has published position stand papers for recommendations preventing heat illness in hot weather [16]. Besides, some countries and regions such as Malaysia announce very hot weather warnings to the public so that appropriate preventive measures against heat stroke can be taken accordingly.

The workers at the construction site had low to high workloads. The workers' metabolic rates varied from 84 Wm2 to 257 Wm². The metabolic rate of lifting heavy sand was 2.2 Met. The majority of workers perceived their workload as 'moderate', thought the environment was too hot for work and experienced thorough wet skin. The subjects felt little fatigue, excessive thirst, and only approximately 22 % of workers felt too weak to work in such a hot environment.

Occupational heat exposure threatens the health of workers not only when heat illness occurs but impairs the productivity and worker's performance as well. It consists of hot and humid climatic conditions, heavy physical workloads or protective clothing that creates a potentially dangerous thermal load for a worker [18].

The combined effects of all indoor and outdoor environmental factors can affect performance in the short-term [19]. This is supported by the finding of Ismail *et al.,* [20] and Ismail *et al.,* [21] that the environmental factors, such as temperature, illuminance and humidity levels, have a significant effect on workers' performance at the production line.

Many factors influence the level of heat exposure depends on whether the individual is indoors with or without air-cooling, outdoor in the shade or full sun. The duration of exposure, acclimatization, the level and type of activity and clothing also determine the effect of heat exposure. Individual health, age, obesity, and sex also need to be considered for estimating impacts [22]. The result from studies on thermal comfort shows that there are two types of factors that play a role in adjusting the comfort level, which are individual factors and environmental factors. Individual factors such as metabolic rate, clothing and human perception while environmental factors such as air temperature, radiant temperature, airspeed and humidity [23-25]. Research work by Ismail *et al.,* [26] stated that different heart rate readings have been recorded for different types of tasks at

different temperature ranges. This study was conducted in the climate chamber with five conditions air temperature. The results show the most comfortable zone for an office room bears an air temperature of 23 °C. At this temperature, the heart rate level shown by subjects are at medium level, indicating that subjects are comfortable to do their office tasks and it leads to an increasing of performance and productivity.

Physiological parameters are known as "metabolic heat", referring to the heat produced by the body if the man would carry out physical activities. Therefore, the objective of this study is to investigate the interaction between the temperature and humidity to the physiological parameters (heart rate and VO_2 max) of the workers in the construction industry.

2. Methodology
2.1 Subject

This study uses three healthy subjects that consist of all males. The statistics from the Department of Statistics Malaysia mentioned that for the year 2018, there are 1.3 million of workers in the construction industry and 2.2 million of workers in the manufacturing industry [27]. It can be concluded that majority of the workers in the construction industry work at the construction site rather than in an indoor office and there are many workers in manufacturing industry who work in a hot environment. The number of this study samples might be insufficient compared to this total number of workers. But, most of the studies in the literature on human experiment in the field of ergonomics and human performance use samples not more than 10 subjects. Yusof *et al.,* [28] use six subjects to identify the effect of temperature, humidity and illumination on the productivity at the automotive industry. Nguyen *et al.,* [29] study the performance of walking, standing, sitting and lying of three subjects. While, Nazari *et al.,* [30] only use two subjects to study the effect of the temperature and relative humidity on the skier. So, a number between two and six which is three subjects is chosen.

Figure 1 shows the three healthy subjects (black shirt) is in an interview by the researcher. The subject's task is lifting heavy sandbag with a maximum acceptable weight. All the subjects must be physically active, but none were specifically trained. The subjects will be fully informed of the risks and discomfort associated with the experiment before providing written consent. The study gets approval from the Ethical Committee of NIOSH Malaysia.
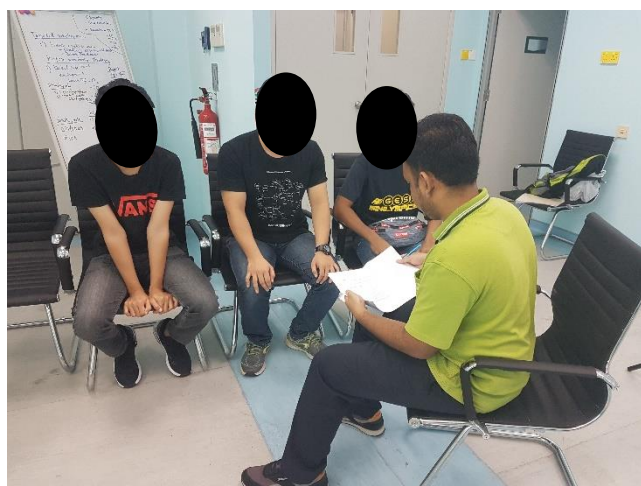

Fig. 1. Three subjects participated in this study

Physical characteristics such as age, height and body mass are recorded for further analysis and are presented in Table 1. Details of demographic subjects and a survey form are prepared to get this information from the subjects. Their average age, height, and body mass were 23 years, 169.8 cm, and 61.7 kg.

Table 1
Demographic subjects

Subjects	Sex	Age (years)	Body mass (kg)	Height (cm)	A_{DU} (cm^2)	BMI
A	Male	24	76.3	168.5	1.87	26.9
B	Male	24	53.4	165.3	1.58	19.5
C	Male	20	55.4	175.5	1.68	18.2
Mean		23	61.7	169.8	1.71	21.5
Std. Dev.		2.31	12.68	5.22	0.15	4.70

2.2 Experiment

This study is conducted in a climatic chamber (Espec) or known as an environmental chamber at NIOSH, Johor Bahru, with the dimensions of 407 cm (L) × 407 cm (W) × 250 cm (H). The chamber was enclosed with 65 mm thick double colour steel plate with polyurethane filling in the middle. This ensured that the indoor thermal environment was less affected by external environments and solar radiation. The air supply was from a perforated ceiling plate, designed to provide a uniform air distribution during the experiments. The controlled range of temperatures in the environmental chamber was from 10 °C to 40 °C within an accuracy of ± 0.3 °C and from −5 °C to + 10 °C within an accuracy of ± 0.5 °C.

Figure 2(a) shows the image of the environmental chamber. In this chamber, the temperature and the humidity can be adjusted based on the parameters decided for the design of experiment as presented in Figure 2(b). Other parameters environment could not be controlled directly. Still, it can be measured by an external Quest-Thermal Environment monitor as shown in Figure 3, which combines the effects of ambient temperature, relative humidity and air velocity to get a measure that can be used to monitor environmental conditions during a task. The controlled range of temperatures in the Quest-Thermal Environment was from ± 0.5 °C between 0 °C and 120 °C and relative humidity was of ± 5 % between 20 to 95 %. This environmental chamber is configured to simulate a lifting task in the construction environment.
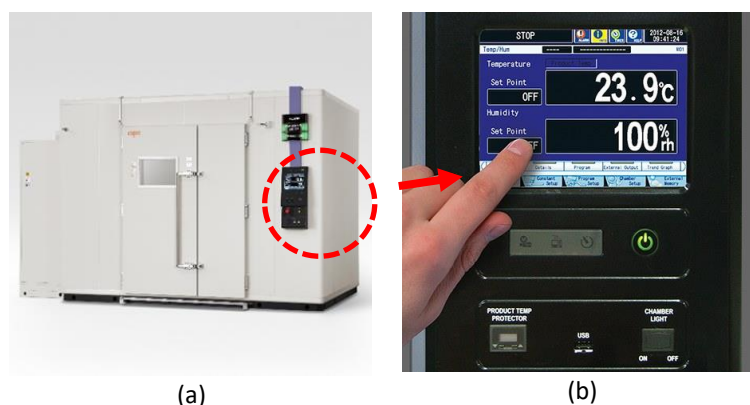

(a)   (b)

Fig. 2. (a) Environmental chamber, (b) controller panel in the environment chamber

Fig. 3. Quest-Thermal Environment monitor

For the study of heat stress factors on the subject performance, the experiment in the environmental chamber is arranged, as shown in Figure 4. The Quest-Thermal Environment monitor tool that records the WBGT index is placed on the left side of the subject (marked with 'x'). the subjects will do lifting task with maximum acceptable weight which is 10 kg from Table A to Table B. The distance from Table A and B is 287 cm. Table 2 shows 4 steps of the task done by the subject. This operation is repeated continuously for 15 minutes in three conditions of air levels (34 °C, 34 °C, 38 °C). Considering a combination of elevated relative humidity and air temperatures would create significant stress on the human body under hot conditions, three different relative humidity levels (74 %, 92 %, 83 %) were selected to make comparisons [23,31].

Table 2
The workflow of lifting heavy sand

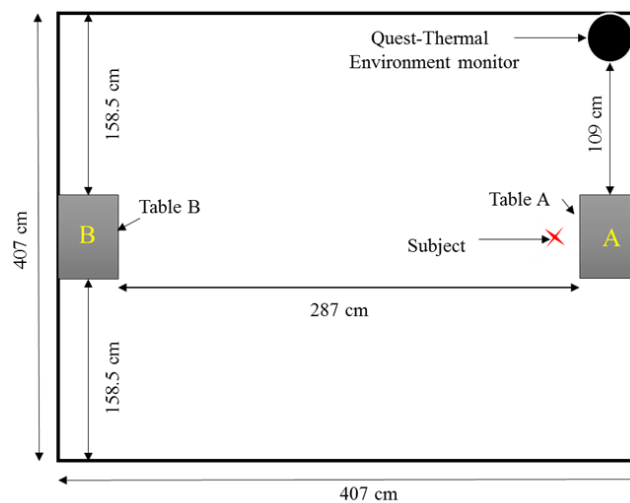| Step	Details
1	Lifting the sand from Table A
2	Walk to Table B
3	Drop the sand to Table B
4	Return to the Table A

Fig. 4. The layout of the experiment in the environmental chamber

A spiroergometry is used to measure the volume of oxygen uptake during the task. It is a portable device which can analyze the volume inhale and exhale during an exercise. The equipment name is Cortex MetaMax 3B from Cortex Medical are presented in Figure 5. The system was calibrated on gas sensors, flow rate, and pressure before each testing. It uses a face mask that covered both mouth and nose to collect gas from the subjects, and the captured gas was analysed in a micro-dynamic mixing chamber provided oxygen consumption rate (VO_2). This equipment is a valid and reliable system for measuring ventilation parameters during exercise [29].
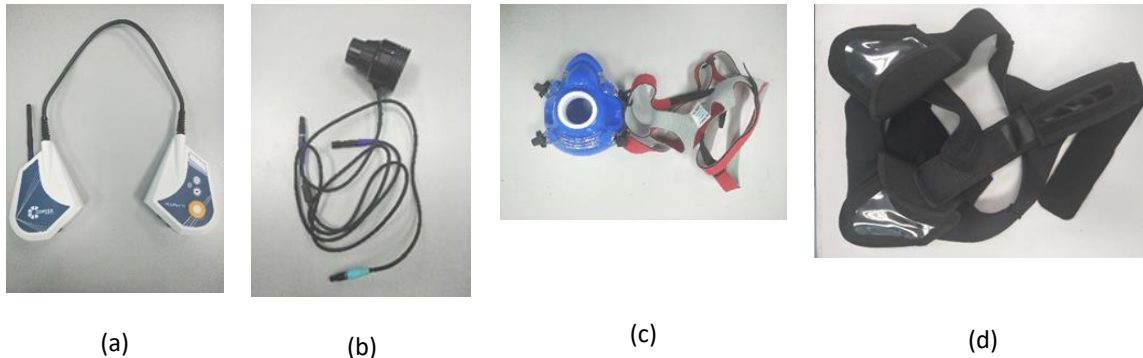

(a)　　　　　(b)　　　　　(c)　　　　　(d)

Fig. 5. Device for VO_2 measurement; (a) MetaMax 3B Main Unit, (b) flow sensor, (c) CORTEX breathing mask set with fastening net and (d) MaxSport belt set, including two belts

The heart rate can be measured by the Polar as shown in Figure 6. The previous study mentioned that this equipment could provide reliable and valid measurements of heart rate for multiple purposes [30].

This equipment can be connected through Bluetooth connection which is essential during the measurement to avoid any constraint while completing the task by the subject. It can be used with OmniSense™ 5.1, which is software that can manage and analyse the data in real-time.
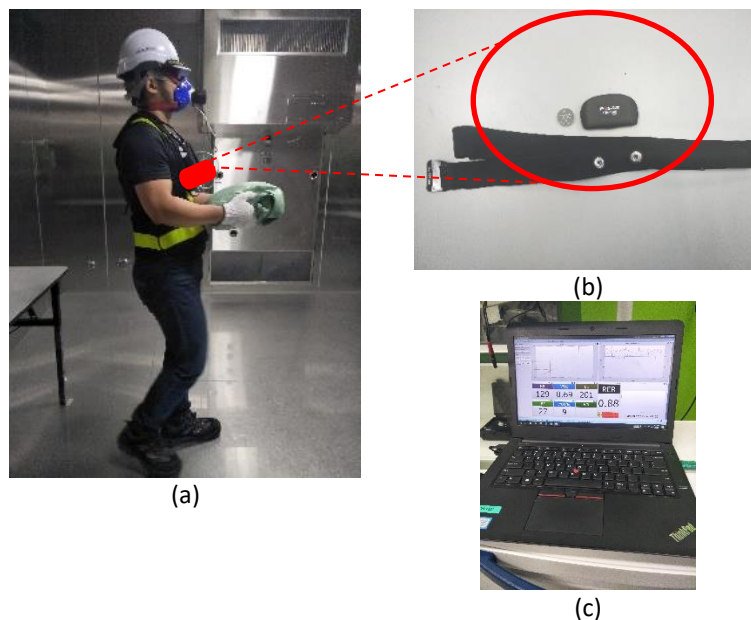

(a)

(b)

(c)

Fig. 6. HR measurement process, (a) the participant lifting the task, (b) Polar and (c) HR data display while lifting the task

3. Results and Discussion

The three subjects completed finishing the task without complications. All statistical analysis was done using by MINITAB.

3.1 Volume Oxygen Uptake

VO_2 max depends on gender, age, lactic acid tolerance, exposure to chemical pollutants, levels of physical activities, genetics, diet and also on natural environmental factors like altitude and climate.

Table 3 shows the coded coefficients to analyse the variability. The coefficient describes the size and direction of the relationship between volume oxygen uptake and the response variable (temperature and RH). Table 4 shows the results of analysis of variance. It shows that the P-value obtained for the two environmental factors of ANOVA is below the value of 0.05. The p-value is a probability that measures the evidence against the null hypothesis. Lower probabilities provide stronger evidence against the null hypothesis. Usually, a significance level (denoted as α or alpha) of 0.05 works well. A significance level of 0.05 indicates a 5% risk of concluding that the coefficient is not 0 when it is. If the p-value is less than or equal to the significance level, so with this situation, it can conclude that there is a statistically significant association between the response variable and the term. In this study, it was found that the coefficient of temperature is (p=0.043) and the coefficient of relative humidity is (RH) (p=0.000). With this result, it showed that there has a significant effect on the worker's performance for volume oxygen uptake. The observed increase in oxygen consumption is primarily due to the rise in intensity and heat stress.

Table 3
Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.982	0.003	290.22	0.000	
Temperature	-0.009	0.004	-2.46	0.043	1.00
RH	-0.043	0.004	-11.22	0.000	1.00
Temperature*Temperature	-0.182	0.006	-31.29	0.000	1.02
RH*RH	-0.034	0.006	-5.92	0.001	1.02
Temperature*RH	0.014	0.008	1.83	0.009	1.00

Table 4
Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.064	0.013	223.19	0.000
Linear	2	0.0076	0.0038	65.99	0.000
Temperature	1	0.0000	0.0003	6.07	0.043
RH	1	0.0072	0.0072	125.90	0.000
Square	2	0.0562	0.0281	490.30	0.000
Temperature*Temperature	1	0.0562	0.056	979.10	0.000
RH*RH	1	0.0020	0.0020	35.04	0.001
2-way Interaction	1	0.0001	0.0001	3.36	0.109
Temperature*RH	1	0.0001	0.0001	3.36	0.109
Error	7	0.0004	0.0000		
Lack-of-fit	3	0.0004	0.0001	34.33	0.003
Pure error	4	0.0000	0.0000		
Total	12	0.0394			

Similar can identify from HR performance. It can conclude that there is a statistically significant association between the response variable and the term. In Table 5 and Table 6 below shows that the coefficient of temperature is (p=0.004), and the coefficient of relative humidity is (RH) (p=0.028). With this result, it showed that there has a significant effect on the worker's performance for HR.

This indicates that any changes in Temperature value, RH will cause significant changes in the workers' performance. HR is a general indicator of stress on the body, which is been found to be associated with work intensities [37]. The workload is one of the significant factors influencing the time course of HR at the onset of dynamic exercise; the higher the work intensity, the faster and greater the increase in HR [38]. It was reported that at the heat exposure limits the HR of subjects performing heavy work were in the range of 120-160 bpm.

Table 5
Coded Coefficients

Term	Coef	SE Coef	T-Value	P-Value	VIF
Constant	0.991	0.004	236.31	0.000	
Temperature	-0.020	0.005	-4.30	0.004	1.00
RH	-0.013	0.005	-2.77	0.028	1.00
Temperature*Temperature	-0.061	0.007	-8.49	0.000	1.02
RH*RH	-0.011	0.007	-1.55	0.166	1.02
Temperature*RH	0.033	0.010	-3.35	0.012	1.00

Table 6
Analysis of Variance

| Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	5	0.0097	0.0019	21.93	0.000
Linear	2	0.0023	0.0012	13.10	0.004
Temperature	1	0.0016	0.0016	18.51	0.004
RH	1	0.0007	0.0007	7.69	0.028
Square	2	0.0064	0.0031	36.11	0.000
Temperature*Temperature	1	0.0064	0.0064	72.15	0.000
RH*RH	1	0.0002	0.0002	2.40	0.166
2-way Interaction	1	0.0010	0.0010	11.21	0.012
Temperature*RH	1	0.0010	0.0010	11.21	0.012
Error	7	0.0006	0.0000		
Lack-of-fit	3	0.0006	0.0001	12.91	0.016
Pure error	4	0.0000	0.0000		
Total	12	0.0102			

3.2 Heart Rate

Figure 7 presents the patterns of HR from three subjects A, B, and C in three condition climates. Table 7 describes the average HR of collected in three condition climates. According to Table 7, average HR subject C is lower than A and B. Humans can be comfortable within a wide range of RH depending on the temperature from 30–70 % but ideally between 50 % and 60 % [31-33]. Very low humidity can create discomfort, respiratory problems, and aggravate allergies in some individuals. When the subjects are lifting the sand in condition 3 (38 °C/83 %), the average heart rate of participant A is rise faster than other subjects, as shown in Figure 7. When temperatures and RH soar, the heart pumps a little more blood, so your pulse rate may increase, but usually no more than five to 10 beats a minute. Normal heart rate varies from person to person, but a normal range for adults is 60 to 100 bpm. However, a normal heart rate depends on the individual, age, body size, heart conditions, whether the person is sitting or moving, medication use and even air temperature. The

lower value HR for subject C at condition 3 is 49 bpm. According to the American Heart Association, heart rate lower than 60 bpm doesn't necessarily have a medical problem. Active people often have lower heart rates because their heart muscles don't need to work as hard to maintain a steady beat. Athletes and people who are very fit can have a resting heart rate of 40 bpm.

In Figure 7 also shows the changes in real-time heart rates of three subjects under three conditions. The subject's heart rates differed in different conditions. The higher the air temperature and relative humidity were, the higher the heart rates of subjects were, especially when subjects walked under hot environments. Choi *et al.,* [34] reported that at an equal activity level of 2.5 Met, the HR was significantly higher in subjects in the warm environment than in a cool environment. Habibi *et al.,* [35] stated that overweight subjects showed a higher thermal perception and recommended that they should avoid hot and dry weather condition to avoid strain. Yazdanirad *et al.,* [35] reported that the mean HR was significantly higher in the subject having a BMI of over 25. This research has in line with this study. This study shows that BMI subject A is over than 25, which is 26.9 and his HR is 151 bpm which is the highest than other subjects in temperature 38 °C.

Table 7
The designed and measured HR (mean ± SD)

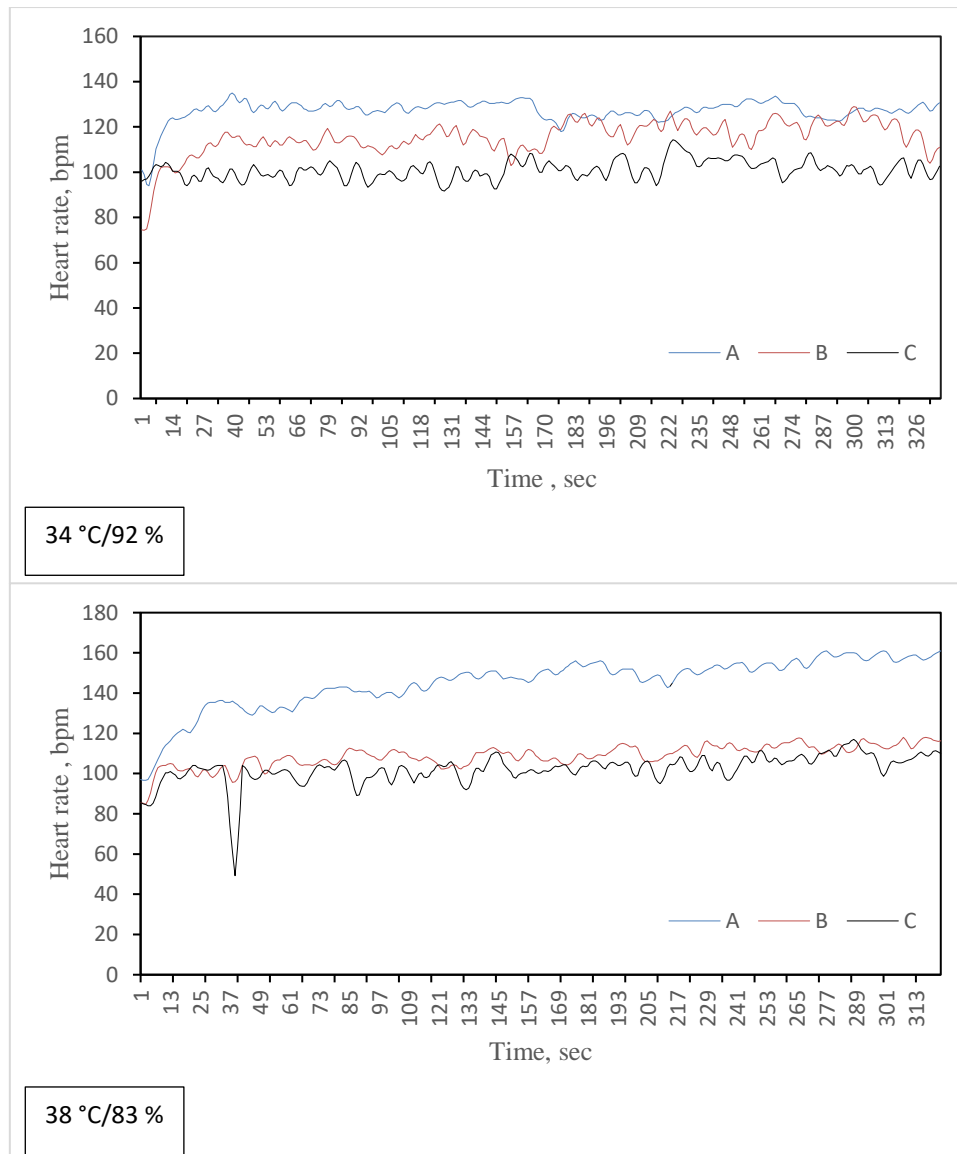| Condition	Designed conditions		Average HR, bpm		
	Temperature, °C (T_a)	Relative Humidity, % (RH)	A	B	C
1	34	74	124±5.8	114±4.9	91±3.5
2	34	92	129±5.1	116±7.7	101±4.1
3	38	83	151±12.6	118±5.5	103±7.2
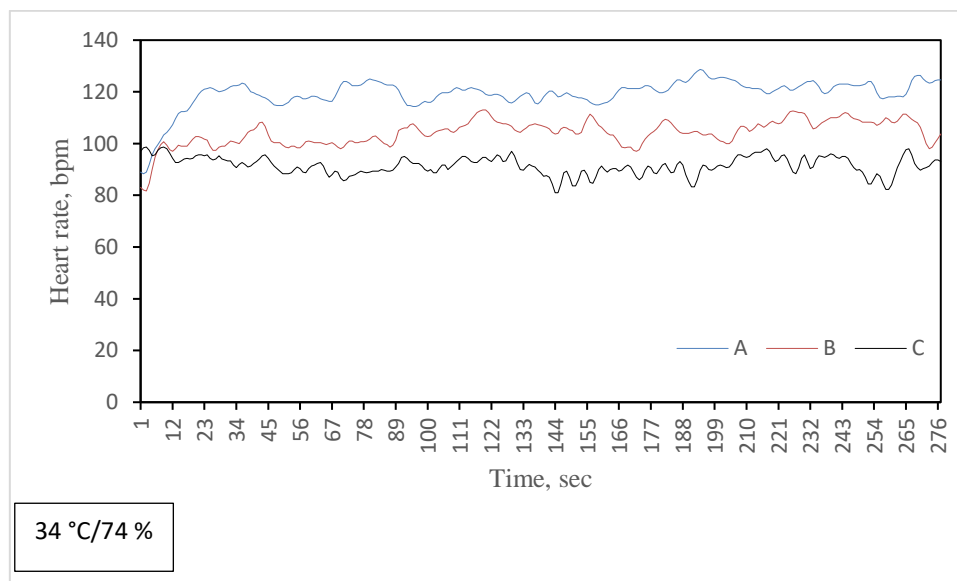
Fig. 7. The heart rate changes of subjects in the three conditions

4. Conclusions

In conclusion, the interaction of human physiology (oxygen uptake and heart rate) with increasing temperature during worker in Malaysia construction was studied. It can be empirically proved that environmental factor such as temperature and relative humidity have a significant impact on workers' performance. This study examined physiology factors affecting the environment factor in the construction industry. The limitation of this study is the limited sample size. In this study, participants were mainly university students. Their physical abilities may be different from construction workers. Further research work should be done to increase the sample size and to replicate the experimentation on site to detect the real effect on construction workers.

Acknowledgement

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