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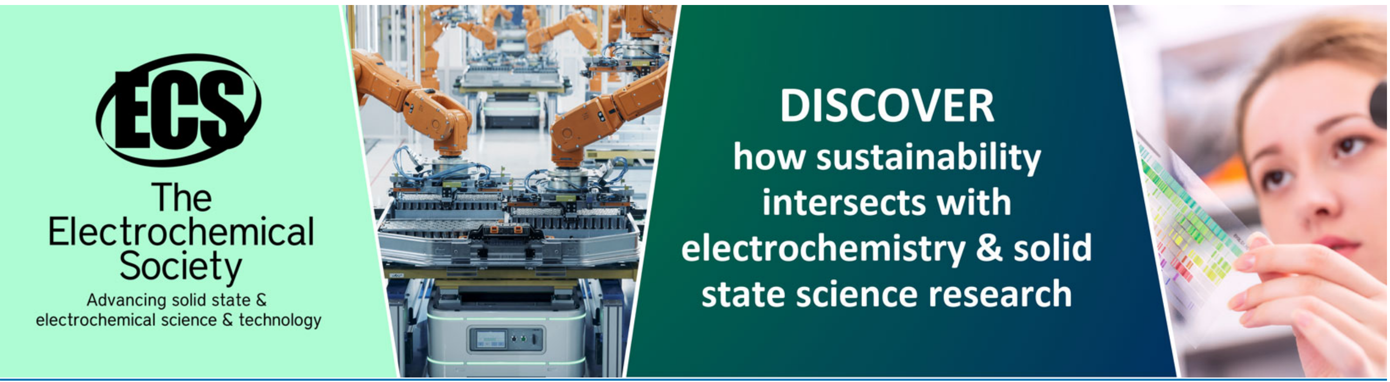

The factor affecting heat stress in industrial workers exposed to extreme heat: A case study of methodology

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Abstract. Excessive heat during work creates occupational health risks; it restricts a worker's physical functions and capabilities, work capacity and productivity. Temperatures above 24–26 °C are associated with reduced labour productivity. Exposure to excessive heat levels can lead to heatstroke, sometimes even with a fatal outcome. The aim of this study is to discuss the methodology in experimental of the factor affecting heat stress in industrial workers exposed to extreme heat. The experiment will be conducted in an environmental chamber which simulates the same environment of the manufacturing industry and another arrangement which simulates the environment of a construction industry. The environmental parameters will be recorded such as the temperature, relative humidity and also the physiological parameters such as the volume oxygen uptake level and the heart rate. The heart rate and the volume of oxygen uptake will be recorded for a 15-minute interval for one shift (2 shift-manufacturing and construction). This study is conducted based on two tasks in two different conditions, outdoor and indoor. It simulates the lifting work at both manufacturing and construction industry. For manufacturing industry, the subjects are demanded to lift boxes (10kg). Meanwhile, for the construction industry, the subjects are demanded to lift a sand bag (10kg). From this study, the optimum values of temperature and humidity can be obtained which can lead to the optimum workers' performance. The increase of performance will ensure the production level at the manufacturing industries at its best and will lead to monetary gain. Besides, this can ensure that a construction project can be delivered at the right time while reducing the cost lost and the accidents at the site.

1. Introduction

Climate change is one of the world major issues that become the focus of many leaders of every nation. Several international meeting was conducted to discuss on this matter [1]. One of the key features of global climate change is the heat exposure during the annual hottest period that continues to increase [2]. Malaysia which is one of the countries situated in the tropical zone, also affected by this increase of heat exposure. As Malaysia is targeting to be a developed nation, this issue should be addressed properly to ensure sustained growth in the economy. Therefore, the manufacturing and construction sector which are the biggest industries in Malaysia and must be optimized to avoid any undesirable effects of heat exposure [3]. 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.

Previous studies have reported that good ergonomics factors at the workplace could reduce the workers' stress [4]. Furthermore, based on experimental and field studies, environmental factors at the workplace have an influence on the health, the performance and the productivity at the workplace [3].

Most recent studies on the ergonomics environment focus on the performance of the workers in the term of the productivity [5]. However, they don't approach the problem in the term of human physiology which is normally used in the study of sport science. Furthermore, some studies used quantitative method to identify the effect of the environmental factors on the physiology factors as a single study without a relation with the human performance at the workplace [6].

Moreover, there are few experimental studies which focus on the heat stress of outdoor environment in Malaysia. Most of the studies, focused on the indoor environment such as industries and building to get the optimum environment factors for the workers [7]. Besides, there are less studies which compare the result of the indoor environment with the outdoor environment.

In Malaysia, there is an enactment to cover the safety and health of all occupations which is the Occupational Safety and Health Act 1994 (OSHA) that includes both private and public sectors. The main goal of this Act is to ensure that a safe working condition to the workers by the employers. It promotes for an occupational environment for persons at work which is adapted to their physiological and psychological needs [8].

Based on a statistic from the Department of Occupational Safety and Health Malaysia, the manufacturing industry is the sector with the highest total number of accidents for 2018 while construction industry is at the third place after agriculture, forestry and fishery. Besides, the number of deaths for the construction industry is the highest followed by manufacturing industry [9][10][11]. This statistic shows that, there is still a lot of improvement need to be made to ensure safe working condition at the workplace.

The main purpose of this study is to discuss the methodology in experimental of the factor affecting heat stress in industrial workers exposed to extreme heat. The concern of this research is to give some awareness to the exposed workers and people outside about the risk of heat stress in industrial environments.

2. Literature review

The increase of temperature would eventually lead to higher heat exposure to human which is hazardous to their health and reduce their performance and work capacity [2]. Consequently, a range of studies are conducted to recognize the real effect of heat exposure or heat stress to human especially the workers in various industries. Figure 1 shows the large potential decrease in work capacity from 1975 to 2050 and the differences between work in the sun and work in the shade. Heavy labor in the sun is most affected and, in 2050, would face a 29% loss of annual work hours. Moderate labor in the sun faces smaller losses (about 15%), and labor in the shade or indoors face even lower levels.

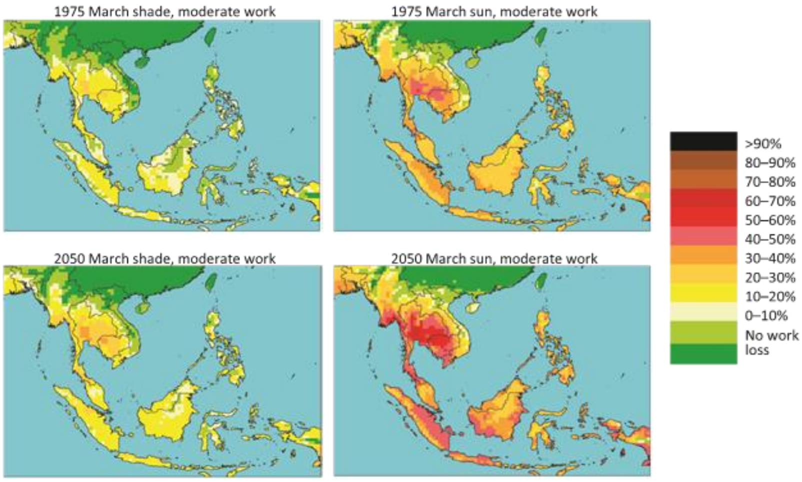


Figure 1. Modeled work capacity loss, in percent of available afternoon working hours in March, in Southeast Asia for moderate (300W) intensity work; comparison of 1975 and 2050 for in-shade and in-sun conditions [2].

2.1. Human performance
'Performance' means "the ability to perform or the manner in which a mechanism performs" [12]. While the verb 'perform' means "to carry out an action or pattern of behaviour" [12].

In the study of human performance, performance exists in three categories; the cognitive domain, the affective domain and the psychomotor domain. Cognitive domain concerns about knowledge-based information and affective domain concern about psychological and emotional-based information [13]. The third domain which is the psychomotor domain related to physical abilities and human movement.

2.2. Heat stress and heat strain
Heat stress is considered a major problem among manufacturing or construction workers not only in Malaysia but also worldwide. Heat stress condition increase in extreme high of temperature and humidity, exposure to high radiant heat, high temperature or humidity occur in combination with heavy protective clothing or higher work rate [14]. The manufacturing or construction has local hot spots which radiate heat. Physical work under this conditions is very stressful and effect the health and efficiency of the workers.

The environmental heat stress and the combination of physical work cause heat strain among industrial workers. Environmental heat stress increases the sweat rate, core body temperature and pulse rate among the employees exposed to heat [15].
Heat Stress is the net heat load to which a worker is exposed from the combination of factors; metabolic heat, environmental factors, and clothing which lead to an increase in bodily heat storage [16]. This will lead to heat strain which is defined as the inability to maintain body core temperature at the level imposed by human thermoregulatory system [17].

Many industries workers related to outdoor occupations are exposed to heat stress, such as construction, agriculture, petrochemical, manufacturing (steel, glass, and textile factories) and work places (laundries, kitchens, military barracks). In such environments, heat stress is eminent [18]. There are several factors that determine the heat stress such as temperature, wind, clothing, humidity, shade, and physical activities. These factors can vary greatly based on the environment, the occupation, and the individual worker [19].

Parsons [20] summarizes the quantitative methods available to evaluate health risks from heat exposure and the specific impact of each variable. The factors are usually measured in combination in order to calculate a heat index that identifies thresholds for heat stress. The Wet-Bulb Globe Temperature (WBGT) is a common type of heat index, and was chosen as the heat index used to evaluate environmental heat stress in this study. It was measured using the instrument shown in Figure 2.

Figure 2. WBGT measurement instrument (QUESTemp) at one of the brick kilns studied.

2.3. Physiological performance

2.3.1. Maximum oxygen uptake (VO_{2max}*).* Maximum oxygen uptake (VO_2max) can be defined as the maximum rate at which body can take up oxygen and utilize during severe exercise. It is used in the field of exercise physiology and can be an indication for cardiorespiratory fitness of an individual. Many scientists put a great interest in identifying the physiological factors that limit VO2max the influence of this variable in endurance performance [21]. The term "maximal oxygen uptake" was first used by Hill et al.

There are several factors that limit the individual maximum oxygen uptake level [21]:
1) The pulmonary diffusing capacity
2) Maximal cardiac output
3) Oxygen carrying capacity of the blood
4) Skeletal muscle characteristics.

The first three factors can be classified as "central" factors; the fourth is termed a "peripheral" factor.

There was a descriptive-analytical study that suggested the maximum oxygen uptake is influenced by age and weight. In the study, they perform oxygen uptake tests to identify the medical students that are suitable for medical emergency jobs that require high ability and physical fitness [22].

Figure 3 shows the study on heat stress model for construction workers in Hong Kong used Cortex MetaMax.

Figure 3. One of construction worker used Cortex MetaMax.

2.3.2. Heart rate (HR). Heart rate or heart pulse can be defined as the number of times a person's heart beats per minute. The value of normal heart rate is different depend on person, but a normal range for adults is 60 to 100 beats per minute.

The combination of environmental heat stress, metabolic rate, and clothing ensembles can lead to an increase in body temperature. An increase of body temperature prompts heat transfers from the human body to the environment in order to maintain a stable body temperature [23]. Heart rate (HR), sweating rate, body core temperature, and skin temperature have been recognized as the main indicators for heat strain. Heat strain is related to the age, weight, physical fitness, medical condition, and degree of acclimatization. As the earliest response of physiological strain. HR has been widely used to evaluate the physiological strain of industrial workers exposed to heat stress. Figure 4 shows the portable heart rate belt (Polar WearLink + chest belt, Polar Electro Oy, Kempele, Finland) to measure the HR of construction workers.

Figure 4. Heart rate belt (Polar).

2.4. Heat stress effects on industry

2.4.1. Construction. The workers in the construction industry are vulnerable to the risk of heat stress due to the intense work nature, exposure to high temperatures, and lack of training. Xiang et al. [24] mentioned that workers in the construction industry are one of the most affected by heat stress which is at the second place after agriculture. Increased heat exposure during summer to female brick workers in India affects heat strain parameters such as peak heart rate and cardiac strain [25].

In the building industry, several contributing factors increase the risk of heat-related illness and injury. These include the constant use of machinery and powered tools, working on elevated surfaces, heavy workload, simple accommodation conditions near work sites, being temporarily employed by a sub-contractor on a daily payment basis, and constant and direct exposure to sunlight.

2.4.2. Manufacturing. Manufacturing workers who spend most of their times in non-air conditioned indoor workplaces have higher risk of heat-related illness even though they are not directly expose by sunlight radiation. This could be higher in some workplaces surrounded by hot machines, furnaces, ovens, and molten metal [24]. This is supported by DOSH Malaysia who found out that employees are exposed to heat stress through high temperature process and machinery.

Ahmad Rasdan Ismail et al. [7] conducted several studies on the effects of environmental factors on the workers in the manufacturing industry especially in the automotive industry. They reported that the temperature, humidity and the illumination can be optimized in to increase the workers' productivity.

2.4.3. Environmental chamber. The climatic chamber studies aim to determine steady-state thermal comfort models which are the production of the desired environment conditions (radiant temperature, air temperature, relative humidity and air velocity) and at the same time, the unwanted variables can be controlled to avoid any influence on the results. This type of study is done in a climate simulation chamber which can fit human subjects for experimental purposes [26]. Figure 5 shows the study was designed to controlled conditions of environmental chamber [27]. The aim of this study is to illustrate how the outcome of thermal comfort changes under different circumstances and how the thermal comfort effects in regards to the changes in different parameters.

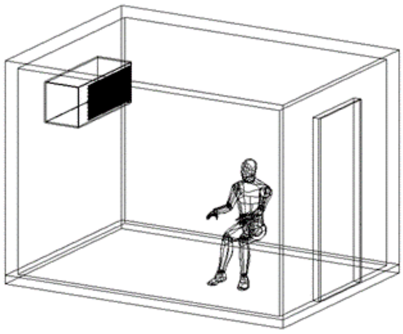


Figure 5. Layout of the environmental chamber [27].

From the findings based on the literature review, the theory of heat stress could be understood and the relationship between heat stress and performance in the manufacturing and construction industry can be identified.

2.5. Research questions
This research is to find out the environment factors related to a working environment that influences workers' performance in manufacturing (indoor environment) and construction (outdoor environment. Below are the research questions:

1. How temperature and humidity affect the performance of workers in both environment (indoor and outdoor environment)?
2. What are the correlation between the temperature and humidity with the performance of indoor and outdoor workers through physiological assessments?
3. How can these factors be improvised in order to enhance the worker's performance in both environment?

3. Methodology

3.1. Flow chart of the research
Figure 6 illustrated the study flow in this research. The environmental data and physiological parameters responses were measured through human subject experiments. These data were analyzed to investigate the relationship between the environment factors and physiological parameter's responses in manufacturing (indoor) and construction (outdoor) industry.

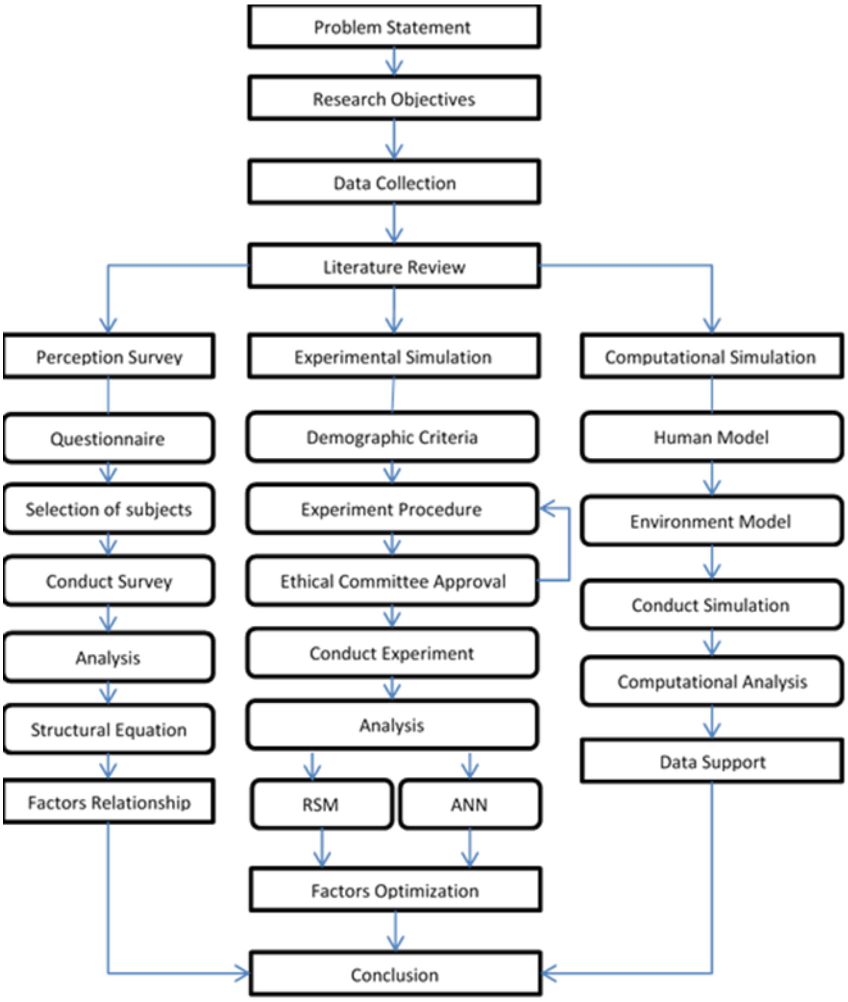


Figure 6. Research flow.

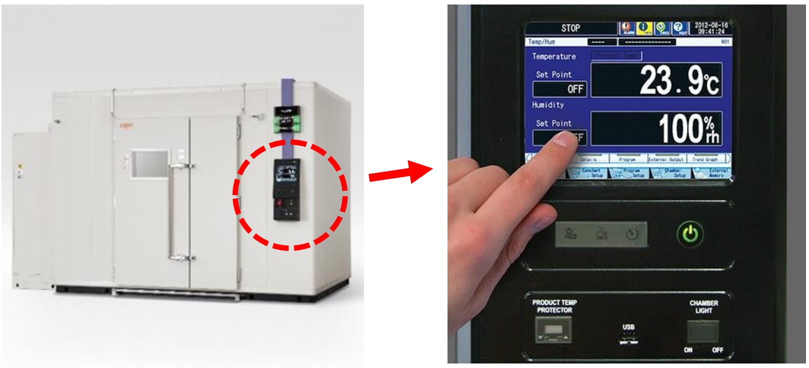
3.2. Research activities

Measurements are taken during this study which includes these parameters:

- Temperature
- Relative Humidity
- Volume Oxygen Uptake
- Heart rate

The environmental chamber as illustrated in Figure 7 is arranged such as Figure 8 for the study of heat stress factors on the subject performance. The Heat Stress Monitor tool (Figure 9) that records WBGT index is placed on the left side of the walking area.

Figure 7 (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). A stainless steel environmental chamber as illustrated in Figure 7 (a) with dimensions of 4.1 m x 4.1 m x 2.5 m (length x width x height) was built in Osaka, Japan. This chamber is a standard modular design. A large LCD microcomputer temperature and humidity controller as shows in Figure 7 (b) are applied to set ambient temperature and relative humidity in advance. The independent conditioning system and humidifier could make the climate temperature and relative humidity reach the pre-set value within 15 min. With the microcomputer controller, the temperature and humidity in the chamber is precise, stable, and reliable.



(a) (b)

Figure 7. The environmental chamber.

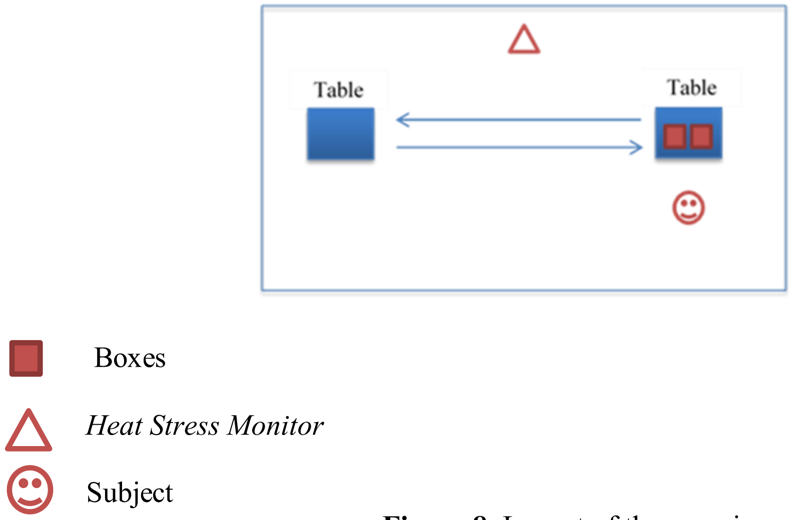


Figure 8. Layout of the experiment.

Figure 9. Quest-Thermal Environment monitor (Heat stress monitor).

3.3. Subjects

The subjects should be healthy and have no medical history of hypertension or heart desease and other desease considering that the experiment was conducted in typical extreme climate. Three male were selected as a subjects. Their average age, height and body mass (Table 1) will be taken during experiment.

Table 1. Subject demographics.

Subject	1	2	3	Average
Age, years				
Body height, cm				
Body weight, kg				
BMI				
BSA, m^2				
Resting heart rate (b/min)				
Resting oxygen uptake (ml/min)				
Maximum heart rate (b/min)				
Maximum oxygen uptake (ml/min)				

Table 2 shows the work flow for lifting task that is conducted by the subject in the environmental chamber. They will be assigned with a task in two conditions; indoor simulated environment and outdoor simulated environment. Box is used for simulation in manufacturing industry (indoor), while Bag is used for simulation in construction industry (outdoor). For both of the environment, the subjects will do lifting task with maximum acceptable weight which is 10 kg. There are 4 steps of the task done by the subject. This operation is repeated again and again manually for 15 minutes.

Table 2. Workflow of the task.

Step	Explanation
1	Lifting the box/bag
2	Walk to the second table
3	Drop the box/bag.
4	Return to the initial table

Table 3 and Table 4 shows the values of temperature and relative humidity that have been set through the design of experiment (DOE). Table 3 presents the design of experiment of indoor environment, while table 4 presents the design of experiment of outdoor environment.

Table 3. Table of design of experiment of indoor environment.

Run no.	Random order	Temperature, °C	Relative humidity, %	Heart rate, b/min	Oxygen uptake 15 min O_2/kg/min	Performance oxygen, %	Performance heart rate, %
1	7	22.0	30				
2	10	32.0	30				
3	11	22.0	70				
4	2	32.0	70				
5	13	34.0	50				
6	12	20.0	50				
7	3	27.0	78				
8	9	27.0	22				
9	8	27.0	50				
10	6	27.0	50				
11	5	27.0	50				
12	1	27.0	50				
13	4	27.0	50				

Table 4. Table of design of experiment outdoor environment.

Run no.	Random order	Temperature, °C	Relative humidity, %	Heart rate, b/min	Oxygen uptake 15 min O_2/kg/min	Performance oxygen, %	Performance heart rate, %
1	7	16.0	74				
2	10	34.0	74				
3	11	16.0	92				
4	2	34.0	92				
5	13	38.0	83				
6	12	12.0	83				
7	3	25.0	96				
8	9	25.0	70				
9	8	25.0	83				
10	6	25.0	83				
11	5	25.0	83				
12	1	25.0	83				
13	4	25.0	83				

3.4. Experimental instruments

The parameters measured in the experiment included body basic parameters and physiological parameters. Body basic parameter contain height, weight, VO_{2max} and heart rate. Table 5 shows the parameter and their corresponding instruments.

Table 5. Experimental instrument.

Parameter	Instrument	Range
Height	Electronic scale	0 – 220 cm
Weight	Electronic scale	0 – 150 kg
VO_{2max}	Cortex MetaMax 3B-R2	Environmental range; Temperature: -20 – 50 ^oC Pressure: 500 – 1050 mbar Humidity: 0 – 99 %
Heart rate	Polar H7	Operating temperature: -10 – 50 ^oC

4. Analysis of the data

The data from the survey will be analyzed through Structural Equation Modelling (SEM) by using SPSS software Version 24 [28]. SEM is a multivariate statistical analysis. By using SEM, structural relationships can be analyzed by combining the factor analysis and multiple regression analysis. It can analyses the structural relationship between measured variables and latent constructs. Data obtained from the experiment on all the subjects are used for the Response Surface Method and Artificial Neural Network Analysis.

5. Conclusions

The results of this study will be contributes significantly to the current body of the literature. The findings from this study will be provides new insights on construction worker safety and health through the non-invasive monitoring of worker stress. Different heart rate readings have been recorded for different types of tasks at different temperature ranges [29]. Furthermore, this study has practical implications as well. For instance, the proposed stress-recognition framework can be integrated with a collective sensing approach for the automatic and early detection of the stressors at construction sites. Also, findings from this study pave new directions for better management of different tasks. For example, by monitoring multiple workers' stress levels in the field, tasks with a high potential for stress can be detected and eventually corrected. Thereby, this research can contribute to enhancing worker health, safety, and productivity.

References

[1] AR5 2014 Climate change 2014 synthesis report summary chapter for policymakers IPCC **31**

[2] Kjellstrom T, Briggs D, Freyberg C, Lemke B, Otto M and Hyatt O 2016 Heat, human performance, and occupational health: a key issue for the assessment of global climate change impacts *Annual Review of Public Health* **37(1)** 97–112

[3] Hancock P A 2012 *Human factors/ergonomics* In Encyclopedia of Human Behavior: Second Edition (2nd ed.)

[4] IEA 2003 Definition and Domains of Ergonomics | IEA Website Retrieved September 15, 2019, from https://www.iea.cc/whats/

[5] Ismail A R, Rani M R A, Makhbul Z K M, Nor M J M and Rahman M N A 2009 A study of relationship betwwen wbgt and relative humidity to worker performance *World Academy of Science, Engineering and Technology* **39** 216–221

[6] Ismail A R, Abu Bakar R and Jusoh N 2013 experimental study of temperature effect on human skin: Discussion of methodology *Advanced Engi. Forum* **10** 71–76

[7] Ismail A R, Jusoh N and Mat Daud K A 2017 Thermal comfort: Scenarios in Malaysia Universiti Malaysia Kelantan

[8] Omar M K, Dahalan N A, Mohammed I H, Shah M M, Nadiah N and Azman M 2016 Supervisor feedback, ergonomics and job performance: A study at one of Malaysia' s frontline government agency **6** 71–75

[9] Fernandez J E 1995 Ergonomics in the workplace *Facilities* **13(4)** 20–27

[10] Mahmud N, Kenny D T, Md Zein R and Hassan S N 2015 The effects of office ergonomic training on musculoskeletal complaints, sickness absence, and psychological well-being *Asia Pacific Journal of Public Health* **27(2)**
[11] Taylor P and Levanon Y 2012 Reducing musculoskeletal disorders among computer operators: Comparison between ergonomics interventions at the workplace 37–41
[12] Merriam-Webster.com 2019 Performance Retrieved September 24, 2019, from https://www.merriam-webster.com/dictionary/performance
[13] Morrow R J, Mood P D, Disch G J and Kang M 2016 *Measurement and evaluation in human performance* 5th Edition
[14] Aziah D, Edimansyah A, Azwan A, Lin N and Rusli N 2012 Assessment of indoor air quality and heat stress exposure in an automotive assembly plant *Air Quality*
[15] Parameswarappa S B and Narayana J 2014 Assessment of heat strain among workers in steel industry- A study *Int J. Curr. Microbiol. App. Sci* **3(9)** 861-870
[16] NIOSH 2016 *NIOSH: Occupational Exposure to Heat and Hot Environments* In US Department of Health and Human Services. https://doi.org/Publication 2016-106
[17] Haldane J S 1905 The influence of high air temperatures *Epidemiology and Infection* **5(4)** 494–513
[18] Hajizadeh R, Farhang Dehghan S, Mehri A, Golbabaei F, Beheshti M H and Haghighatjou H 2015 Heat stress assessment in outdoor workplaces of a hot arid climate based on meteorological data: A case study in Qom, Iran *Journal Mil Med* **17(2)** 89–95
[19] Acharya P, Boggess B and Zhang K 2018 Assessing heat stress and health among construction workers in a changing climate: A review *International Journal of Environmental Research and Public Health* **15(2)** 247
[20] Parsons K C 2000 Environmental ergonomics: A review of principles, methods and models *Applied Ergonomics* **31(6)** 581–594
[21] Bassett D R and Howley E T 1999 Limiting factors for maximum oxygen uptake and determinants of endurance performance *Med. Sci. Sports Exerc* **32(1)** 1–7
[22] Heydari P, Varmazyar S, Nikpey A, Variani A S and Jafarvand M 2017 Step test: A method for evaluating maximum oxygen consumption to determine the ability kind of work among students of medical emergencies *Electronic Physician* **9(3)** 4020
[23] Parsons K C 2003 *Human thermal environments* 2nd ed. CRC Press: London UK
[24] Xiang J, Bi P, Pisaniello D and Hansen A 2014 Health impacts of workplace heat exposure: An epidemiological review *Industrial Health* **52(2)** 91–101
[25] Sett M and Sahu S 2014 Effects of occupational heat exposure on female brick workers in West Bengal, India *Global Health Action* **7** 1-12
[26] Taleghani M, Tenpierik M, Kurvers S and Van Den Dobbelsteen A 2013 A review into thermal comfort in buildings *Renewable and Sustainable Energy Reviews* **26** 201–215
[27] Norfadzilah J 2016 *Analysis of the effect and responsiveness of physiology factors on thermal comfort in an air-conditioned environment* Ph.D thesis UMP Pahang
[28] Dehghan H, Mortzavi S B, Jafari M J and Maracy M R 2015 The reliability and validity of questionnaire for preliminary assessment of heat stress at workplace *Iranian South Medical Journal* **15(4)** 810-826
[29] Ahmad Rasdan I, Norfadzilah J, Rosli A B, Nor Kamilah M and Suriatini I 2015 An analysis in the implication of thermal energy distribution towards human comfort in an office space *International Journal of Creative Future and Heritage (TENIAT)* **4(1)** 15-30