UNIVERSITI PUTRA MALAYSIA

ESTABLISHMENT OF HEAT STRESS INDEX TO IMPROVE THERMAL COMFORT AMONG INDUSTRIAL OPERATORS IN MALAYSIA

DAYANA HAZWANI MOHD SUADI NATA

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By

DAYANA HAZWANI BINTI MOHD SUADI NATA

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Doctor of Philosophy

December 2017

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Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfillment of the requirement for the degree of Doctor of Philosophy

ESTABLISHMENT OF HEAT STRESS INDEX TO IMPROVE THERMAL COMFORT AMONG INDUSTRIAL OPERATORS IN MALAYSIA

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DAYANA HAZWANI BINTI MOHD SUADI NATA

December 2017

Chairman : Associate Professor Shamsul Bahri Md Tamrin, PhD
Faculty : Medicine and Health Sciences

Malaysia is a tropical climate country with hot and humid condition throughout the year. The hot working environment in the industrial increases the challenges of body homeostasis to induce heat stress and interferes with thermal comfort. For this problem, there is no specific standard or guideline of heat adaptation for the industrial operators in Malaysia to overcome the problems. In addition, no studies have been carried out in Malaysia to model the exposure of heat to workers with thermal comfort. Therefore, the aim of this study is to establish the prediction index of heat stress index in order to improve the thermal comfort among industrial operators in Malaysia. Two phases were conducted, namely (1) Phase 1: Cross-sectional study, and (2) Phase 2: Experimental study. The cross-sectional study was conducted in palm oil mill, steel industry and manufacturing plant in Malaysia to collect the 464 of male industrial workers who were identified exposed to the heat during working. Data collection consisted of the walk-through assessment, questionnaire, environmental monitoring, and personal assessment. The study showed that the mean of WBGTin =30.69±0.99°C, exceeding the ACGIH TLVs which suggested to be 28.2°C for work and rest regime (75% work and 25% rest). In this study, therefore, 100% of operators were identified to suffer heat stress during working y. The perception of comfort checklist showed that 82.1% of operators felt discomfort while working in their workplace. In addition, the variables involved in this study were acute heat symptoms score which recorded as the highest Beta value ($B = 0.480$, $p < 0.001$), followed by, WBGTin ($B = 0.150$, $p<0.001$), metabolic workload ($B= 0.1$, $p=0.11$), body core temperature ($B=0.087$, $p =0.015$), drinking volumes ($B=-0,163$, $p<0.001$) and relative humidity ($B = -0.190$, $p <0.001$). An experimental work was conducted between 60 operators in phase 2 for comparison and validation of the predictive index with the existing procedure to determine thermal comfort value, humidex and perception of thermal comfort checklist. The result showed there was a significant positive correlation between the predictive index and humidex, $r = 0.754$, $p = 0.01$, and there

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was no significant correlation with the perception of thermal comfort checklist (r= 0.032).

In addition, the receiver operating characteristic (ROC) curve showed that rule performed more accurately in predictive index (area under the curve = 0.893) compared to perception of thermal comfort checklist (area under the curve = 0.524). All physiological variables exhibited significant difference with predictive index, namely body core temperature (p<0.001), heart rate (p =0.001), systolic blood pressure (p<0.001) and diastolic blood pressure (p= 0.07). The discriminate function revealed a significant association between groups (comfort and discomfort) with all physiological variables, accounting for 62.41% of between group variability. Moreover, the establishment of heat stress index was integrated into visual basic application (VBA) in Microsoft Excel. The index was found to be able to express comprehensive index which included the individual perception factors, environmental and physiological changes for indoor industries. This index was proved to be more user-friendly and applicable in which the variability of determination of thermal comfort was better than other indexes. In conclusion, the establishment of heat stress index in this study indicated the ability of this index to represent the indoor heat stress condition, as well as applicable and a simple measurement which consisted of all the associated factors (individual, environmental and physiological variables) in heat stress and thermal comfort.

(keywords: thermal comfort, heat stress index, tropical climate, predictive study)

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Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

PENGUKUHAN INDEKS TEGANGAN HABA UNTUK MENINGKATKAN KESELESAAN HABA DALAM KALANGAN OPERATOR INDUSTRI DI MALAYSIA

Oleh

DAYANA HAZWANI BINTI MOHD SUADI NATA

Disember 2017

Pengerusi : Profesor Madya Shamsul Bahri Md Tamrin, PhD
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Malaysia adalah sebuah negara yang beriklim tropika, dengan keadaan panas dan lembap sepanjang tahun. Persekitaran kerja yang panas di perindustrian meningkatkan cabaran homeostasis badan yang mendorong kepada tegangan haba dan mengganggu keselesaan haba. Untuk mengatasi masalah ini, tiada standard tertentu atau garis panduan bagi penyesuaian haba untuk operator industri. Di samping itu, tiada kajian yang telah dijalankan di Malaysia untuk memodelkan pendedahan haba terhadap pekerja dengan keselesaan haba. Tujuan utama kajian ini adalah untuk membangunkan ramalan indeks tegangan haba bagi meningkatkan keselesaan haba dalam kalangan operator industri di Malaysia. Terdapat dua fasa yang telah dijalankan iaitu, (1) Fasa 1: Kajian Keratan Rentas, (2) Fasa 2: Kajian Perbandingan. Kajian keratan rentas telah dijalankan di kilang minyak sawit, industri keluli dan kilang pembuatan di Malaysia dengan mengumpul 464 operator industri lelaki yang telah dikenal pasti terdedah kepada haba panas semasa bekerja. Pengumpulan data adalah terdiri daripada penilaian pemerhatian, soal selidik, pemantauan alam sekitar, dan penilaian peribadi. Kajian ini menunjukkan min WBGTin = 30,69 ± 0,99 ° C, melebihi nilai ACGIH TLV yang mencadangkan suhu 28.2 °C untuk bekerja dan rejim rehat (kerja 75% dan rehat 25%). Oleh itu, dalam kajian ini 100% daripada operator telah dikategorikan mengalami tegangan haba semasa bekerja. Persepsi bagi senarai semak keselesaan menunjukkan bahawa 82.1% daripada operator merasakan ketidakselesaan semasa bekerja di tempat kerja merekaDi samping itu, pembolehubah yang terlibat dalam kajian ini adalah simptom haba akut yang telah merekodkan nilai Beta tertinggi (B = 0.480, p <0.001), diikuti oleh WBGTin (B = 0.480, p <0.001), beban kerja metabolik (B= 0.1, p=0.11), suhu teras badan (B=0.087, p =0.015), isipadu minuman (B=-0,163, p<0.001) dan kelembapan relatif (B = -0.190, p <0.001). . Satu kajian eksperimen telah dijalankan antara 60 operator dalam fasa 2 untuk perbandingan dan pengesahan indeks ramalan dengan prosedur sedia ada untuk menentukan nilai

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keselesaan haba, humidex dan persepsi bagi senarai semakan keselesaan haba. keputusan menunjukkan terdapat korelasi positif yang ketara antara indeks ramalan dan humidex, $r = 0.754$, $p = 0.01$ dan tiada korelasi ketara dengan persepsi bagi senarai semakan keselesaan haba.

Di samping itu, lengkung ciri-ciri penerima operasi (ROC) menunjukkan bahawa peraturan dilakukan dengan lebih tepat dalam indeks ramalan (luas di bawah lengkung = 0.893) berbanding persepsi bagi senarai semakan keselesaan haba (luas di bawah lengkung = 0.524). Semua pembolehubah fisiologi memperlihatkan perbezaan ketara dengan indeks ramalan, iaitu suhu teras badan ($p <0.001$), kadar jantung ($p = 0.001$), tekanan darah sistolik ($p <0.001$) dan tekanan darah diastolik ($p = 0.07$). Fungsi diskriminasi menunjukkan hubungan yang signifikan antara kumpulan (keselesaan dan ketidakselesaan) dengan semua pembolehubah fisiologi, menyumbang 62.41% antara kebolehubahan kumpulan. Selain itu, pengukuhan indeks tekanan haba panas telah diintegrasikan ke dalam aplikasi asas visual (VBA) dalam Microsoft Excel. Indeks ini dapat menunjukkan indeks yang komprehensif termasuklah faktor persepsi individu, perubahan alam sekitar dan fisiologi untuk industri yang tertutup. Indeks ini terbukti lebih mesra pengguna dan boleh diguna pakai yang mana variasi penentuan keselesaan haba panas adalah lebih baik daripada indeks-indeks lain. Kesimpulannya, pengukuhan indeks tekanan haba dalam kajian ini menunjukkan keupayaannya untuk mewakili keadaan tegasan panas tertutup, serta pengukuran mudah dan sederhana yang terdiri daripada semua faktor yang berkaitan (pembolehubah individu, alam sekitar dan fisiologi) dalam tekanan haba dan keselesaan haba.

(Kata kunci: keselesaan haba, indeks tegangan haba, iklim tropika, indeks ramalan)

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This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AHS	Acute Health Score
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
DB	Dry temperature
DOSH	Department of Occupational Safety and Health
FMA	Factories and Machinery Act
GB	Globe temperature
HRD	Human Resources Department
ILO	International Labour Organization
ISO	International Organization for Standardization
MHSI	Malaysian Heat Stress Index
MIDA	Malaysian Investment Development Authority
MLR	Multiple Linear Regression
NIOSH	National Institute of Occupational Safety and Health
NWB	Natural wet bulb temperature
OSH	Occupational Safety and Health
OSHA	Occupational Safety and Health Administration; Occupational Health and Safety Act
RH	Relative Humidity
SOSCO	Social Security Organisation
TWA	Time Weighted Average
TLV	Threshold Limit Values

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WBGT	Wet Bulb Globe Temperature
WHO	World Health Organization
VBA	Visual Basic Application

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CHAPTER 1

INTRODUCTION

Chapter 1 briefly describes the background of this research. It also includes details on the research problem and the justifications. Apart from that, the objectives, hypothesis, conceptual framework and operational definitions were also outlined in this chapter.

1.1 Background

Heat stress is considered as a physical hazard in a working setting. NIOSH, 1986 defined heat stress as a summation of the body's heat production (metabolic load), and environmental temperature minus the heat loss from the body to the environment. Furthermore Barbara (2002) stated that heat stress is the total body's heat load from the combination of the inner and exterior factors. Interior factors include body core temperature, acclimatization, heat tolerance and metabolic load, while the external factors are air temperature, radiant heat, air velocity and relative humidity (Lahey, 1984). Thus, it can be concluded that heat stress is a mixture of the heat capacity of an individual and surrounding environmental factors. This in turn gives negative impacts on operators' performance, safety, and health. (Rasoul et al., 2013). The environmental factors, namely air temperature, radiant temperature, humidity and air movement and personal factors including metabolic load and clothing are the main components that affect the extent of thermal stress imposed on operators. Examples of operations that involved heat stresses are iron and steel foundries, glass mills, rubber factories, boiler places, food industries, and steam tunnels. (OSHA Technical Manual, 1999; Azlis S. J. et al., 2007). Next, heat strain is defined as the response of the human body towards total heat stress. In ideal situation, thermoregulation mechanism of a human body responds well to heat exposures. However, injuries, low productivity and heat related illness takes place when the heat load (environmental and metabolic) is beyond the ability of the body to maintain normal body function. Nevertheless, repeated exposures to heat contributes to physiological adaptation called acclimatization, whereby the body will be able to maintain its performance despite heat denudation.

Figure 1.1 describes the mechanisms of heat exposure. According to Barbara (2002), as the heat storage increases, body temperature will relative rise. In response to this, blood circulation dilates the cutaneous vascular bed which further increases the blood flow to the skin. Thus, sweating mechanism will be activated to sustain the temperature if required. However, this physiological reaction causes an increase in the core body temperature, heat rash and loss of water and salt. The physiological reaction is the increase in skin temperature that results in excess sweating.

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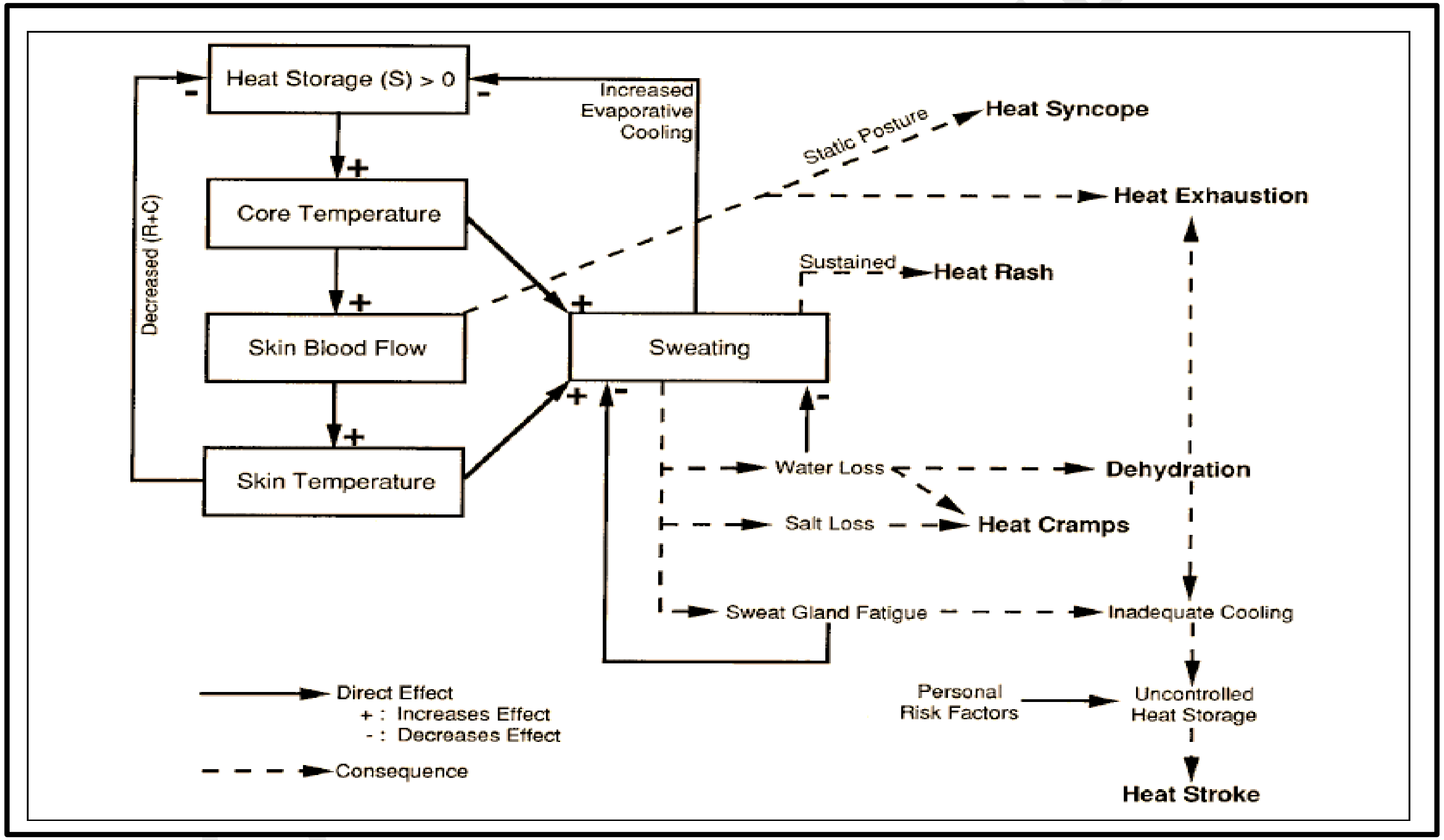

Figure 1.1 : Mechanism due to heat exposure
(Source : Barbara, 2000)

Heat Stress Index is a metric widely applied for heat used as a guideline to measure the six fundamental factors in human heat stress, as a result ensuring safe condition in a working environment. (Parson et al. 2000). The current development of heat stress index was mostly related to the heat disorders and productivity compared to the thermal comfort.

1.2 Problem Statement

Although there are more than 20 indices available to evaluate heat stress at global scale (Moran et al., 2000), however none of those were regarded as a universal heat stress index. There were many literatures that reported on the researches and methods conducted to evaluate array of heat indices for heat stress assessment. Although many indices are proposed, but none of the indices can be utilized by operators within a tropical region, most notably in Malaysia.

Although ample of researches and discussions were carried out to report on the outstanding and universal heat stress indices, however most does not include all the necessary fundamental factors (Goldman, 1988). Theoretically, these indices are of poor quality, but sufficient to be used by specific applications based on experiences in a particular industry. Additionally, the existing index is incapable of measuring the thermal comfort experienced from heat stress by the employees within the tropical region. In addition, no studies were conducted to generate measurable scale of thermal comfort in tropical climate countries (Hassan & Ramli, 2010).

Besides that, enormous researches that were conducted among operators of different workplaces demonstrated significant association between high environmental temperature and negative impact on operators' performance, attitude and satisfaction level (Lee S.Y. et al., 2005). In other word, frequent exposure to heat within a work environment induced physiological and psychological stresses, which led to sensitivity, irritation, and anxiety. These outcomes exerted a direct impact on the performance, health, and safety of the operators (Parson et al. 2000). The notable industries that had high exposure to heat stress are ceramic plants, steel foundries, rubber product factories, bakeries and steam tunnels (Azlis S. J. et al., 2007).

Figure 1.2 depicts the workforce of different industries in Malaysia for the year of 2011. It can be concluded that manufacturing industry holds the highest number of employees. The reports published by the Labour Department, and Social Security Organisation (SOCSO), 2008-2013 exhibited that highest number of accident occurred in the manufacturing industry compared to rest. Most notably, 422 cases of those reported in 2012 were related to exposure or contact with extreme temperatures in the workplace. Along these lines, as the number of operators increased, the possibilities of increment in the number of accidents are also highly viable.

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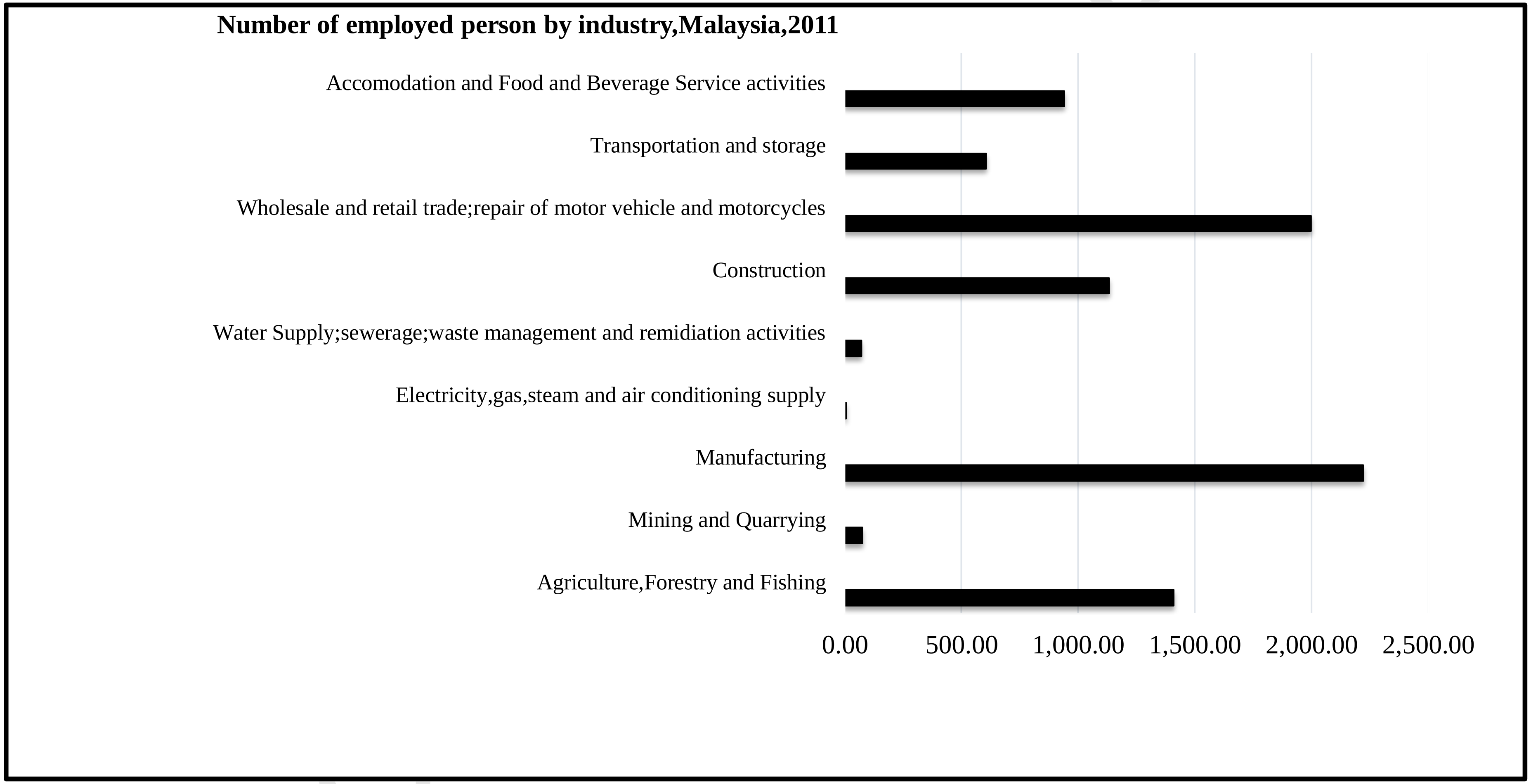

Figure 1.2 : Number of employees relative to industries within Malaysia
(Source : Ministry of Human Resource, 2012)

The American Conference of Governmental Industrial Hygienists (ACGIH) and Table of Threshold Limit Values (TLVs) are the underlying mechanisms that supports Wet Bulb Globe Temperature (WBGT) index, which is commonly used to measure heat stress. Nevertheless, the studies by Siti Fawziah (2000), Goh (2001), Hidayah (2004), and Izzah (2007), Azlis et al. (2007), and Ainun et al. (2011) revealed that heat exposure to operators in Malaysia exceeded the TLVs. In addition, the problem of WBGT index is the index only take account the environmental factors without take consideration others factors such as physiological and psychological factors only (Dehghan, et al., 2011; Mortazavi, Maracy, Dehghan & Jafari, 2012)). A study conducted by Rastoogi, et al. (1992) showed that the exposed workers towards heat would show noticeable physiological strain. Besides, heat stress also leads to increase in the basal body temperature, increased heart rate, and extreme sweating. Therefore, continuous heat exposure will result in heat oedema, fatigue, heat rashes, heat cramps, heat exhaustion and heat stroke (Khogali, 1992). Thus, it showed that the importance of including others factor than environmental factors.

Humidex that is widely used in the measurement of thermal comfort were found to overestimate the actual comfort situation, as being reported by the employees. This situation testified the poor reliability of the tool in determining indoor level of comfort (Rainham, et al., 2003; D’Ambrosio Alfano, et al., 2011).

1.3 Justification of Study

Studies related to heat stress were conducted and published internationally. However, in Malaysia particularly, no specific research was conducted on heat stress index in order to improve thermal comfort. Research into this area would help to reduce the effect and impact of heat stress among operators. Therefore, the present study aims to investigate the establishment of heat stress index to determine the thermal comfort among the operators in Malaysia. The aim of this study is to determine the thermal comfort as well as able to reduce the effect and impact of heat. In addition, the prediction index was designed to increase the efficiency, user friendly, and as a cost saving measure in a workplace. As a result, the management and the operators will be well versed on effective occupational health and safety measures related to heat stress.

Despite the proposal, a major downfall that need to be stressed is the law and regulation. The regulations were supposed to reinforce and increase the awareness among the workers. To date, Department of Occupational Safety and Health Malaysia (DOSH), 2016 had released a guideline entitled “Guidelines on Heat Stress Management at Workplace." This guideline was aimed to educate employees on the recognition, estimation, prevention, and treatment of heat stress at workplace. However, the guideline still uses the existing WBGT index with ACGIH TLVs as underlying references, which led to overestimation of heat stress and thermal comfort values. Therefore, our research functions as a preliminary study, aspiring to provide important information and guideline to DOSH, Malaysia.

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1.4 Objectives

1.4.1 General Objective

The general objective of this study is to establish the prediction index for heat stress index in order to improve the thermal comfort among industrial operators in Malaysia.

1.4.2 Specific Objectives

The specific objectives of this research are:

Phase 1 : Cross-Sectional Study

i. To determine the individual risk factor of operators.
ii. To determine health-related symptoms and the proportion of Acute Heat Symptoms Score (AHS) that are experienced by operators in industries.
iii. To determine the heat stress factors (WBGTin, relative humidity, air velocity, clothing and metabolic workload).
iv. To determine the physiological changes (Body core temperature, Heart Rate, Systolic Blood Pressure and Diastolic Blood Pressure).
v. To determine the perception of thermal comfort among industrial operators.
vi. To determine the relationship between Individual Risk Factors, Acute Health Symptoms Score, Heat Stress Factors (WBGTin, Relative Humidity, Air Velocity, Clothing and Metabolic Workload), Physiological Measurement (Systolic Blood Pressure, Diastolic Blood Pressure, Body Core Temperature, and Heart Rate) with the Perception of Thermal Comfort in order to establish heat stress index among industrial operators.

Phase 2 : Comparative Study

i. To compare the thermal comfort value between the predictive index with selected existing procedure among the operators.
ii. To determine the relationship between the prediction heat stress index of thermal comfort with accessible physiological data of the industrial operators.

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1.5 Research Hypothesis

The hypotheses of this research are:

i) There is a significant association between Individual Risk Factors, Acute Health Symptoms Score, Heat Stress Factors (WBGTin, Relative Humidity, Air Velocity, Clothing and Metabolic Workload), Physiological Measurement (Systolic Blood Pressure, Diastolic Blood Pressure, Body Core Temperature, and Heart Rate) with the Perception of Thermal Comfort, where the goal is to establish the Heat Stress Index.

ii) There is a significant relationship of thermal comfort value between the predictive index with selected existing procedure among the operators among the operators.

iii) There is significant relationship between the prediction index of thermal comfort with accessible physiological data of the industrial operators

1.6 Definition of Terms

1.6.1 Heat Stress

Conceptual Definition

Heat stress is a combination of the heat load from the individual and environmental factors imposed on operators' bodies, which affected the operators' performance, safety, and health. (Rasoul Hemmatjo et al., 2013).

Operational Definition

Heat stress is determined by using Questemp°34 Thermal Environmental Monitor to measure environmental temperature in degree Celsius and relative humidity in percentage, while for the ACGIH index will be used as the reference.

1.6.2 Thermal Comfort

Conceptual Definition

Thermal comfort is a subjective assessment defined as satisfaction of mind with the surrounding thermal environment. (ASHRAE, 1992).

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Operational Definition

Thermal comfort is determined by using ASHRAE Scale to measure the perception among the operators.

1.6.3 Heat Stress Index

Conceptual Definition

Heat stress index is defined as the integration of effects of all basic parameters in any individual thermal environment into a single value (Parson, 2003).

Operational Definition

The heat stress index is established by applying multiple linear regression on individual risk factors, Acute Heat Symptoms Score for heat related symptoms, physiological, and environmental factors in order to improve the thermal comfort by establish heat stress index among industrial operators.

1.6.4 Physiological Changes

Conceptual Definition

Physiological changes are adaptations of the body when being exposed to high temperature, which includes an increase in the basal body temperature, heart rate, and blood pressure. (Barbara, 2002).

Operational Definition

Body core temperature was measured using Omron MC-510 Gentle Temperature Ear Thermometer, while OMRON Blood Pressure Monitor Model T3 was used to measure blood pressure. Apart from that, heart rate was measured by using POLAR Heart Rate Monitor Watch.

1.6.5 Acute Health Symptoms Score

Conceptual Definition

Heat related symptoms occurred after an exposure to high temperature and the resultant symptoms include profuse sweating, headache, nausea and extremely fatigue. Apart from symptoms, the impact of heat can also cause illness, namely heat syncope, heat rashes, heat cramps, heat stroke or heat exhaustion (Barbara, 2000).

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Operational Definition

Heat related symptoms were measured by using self-constructed questionnaire. The questionnaire includes all the symptoms related to heat stress experienced by the operators in their working environment. Acute Health Symptoms score based on the heat related symptoms which cumulated based on seven symptoms, namely profuse sweating, extremely fatigue, heat collapse, dizziness, heat cramp, heat rashes, and heat stroke.

1.6.6 Natural Wet Bulb Temperature

Conceptual Definition

Natural wet bulb temperature measurement allowed air to flow over the sensor naturally rather than by force. When air flow is less than 3 m/s (meter per second), the temperature reduces to absolute humidity. Therefore, natural wet bulb temperature has high sensitivity to both humidity and air movement (Barbara, 2002).

Operational Definition

Wet Bulb temperature is measured using the thermometer that is enclosed by moistened cotton wick and exposed only to the natural air movement (NIOSH, 1986).

1.6.7 Globe Bulb Temperature

Conceptual Definition

Globe temperature originates from the radiant heat of the solid surroundings and convectional heat of the ambient air. The globe temperature is used to estimate the average wall temperature of the surroundings (Barbara, 2002).

Operational Definition

The globe temperature is measured by using a six inch, thin-walled, and sphere black colour on the outside, and the temperature sensor is placed at the centre of the globe (Barbara, 2002).

1.6.8 Dry Bulb Temperature

Conceptual Definition

Dry bulb temperature is the measurement of air temperature, where the sensor is surrounded by free air. (Barbara, 2002).

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Operational definition

Dry Bulb Temperature is measured by using a thermal sensor that is protected from direct radiant energy sources (OSHA, 1999).

1.7 Conceptual Framework

This research defines the relationship between dependent and independent variables. It is known to all that operators of our industries suffered complications from heat stress in their working environment. Heat stress is a physical hazard that were found to cause thermal discomfort among the operators. (Bell, 1981). Figure 1.3 shows the conceptual framework of this study. The establishment of heat stress index is based on the dependent variables, thermal comfort. The independent variables of this study were divided into 4 groups, namely:

1. Risk Factors including individual, job and lifestyle characteristic.
2. Heat stress (Ramphal, 2000; Epstein and Moran, 2006; Kjellstrom et al., 2009)
3. Physiological changes (Moran et al., 1998; Bernard&Cross, 1999; Chen et., 2011)
4. Acute Heat Symptoms Score (AHSS) (Hunt et al., 2005; Harshal et al., 2006; Joseph et al., 2007; Bethel et al., 2014)

The regression of 4 independent variables were established and integrated into single value in order to predict the thermal comfort. Consequently, the interaction between the perception of thermal comfort, physiological changes, and environment are the substantiation based on the assessment in terms of environmental, physiological and psychological. (Epstein and Moran, 2006, (Simson, Kurnitski & Kuusk, 2017). The interaction vice-versa between perception thermal comfort and physiological changes was related to mechanism of the physiological thermal adaptation towards heat exposure (Lin, de Dear & Hwang, 2011).

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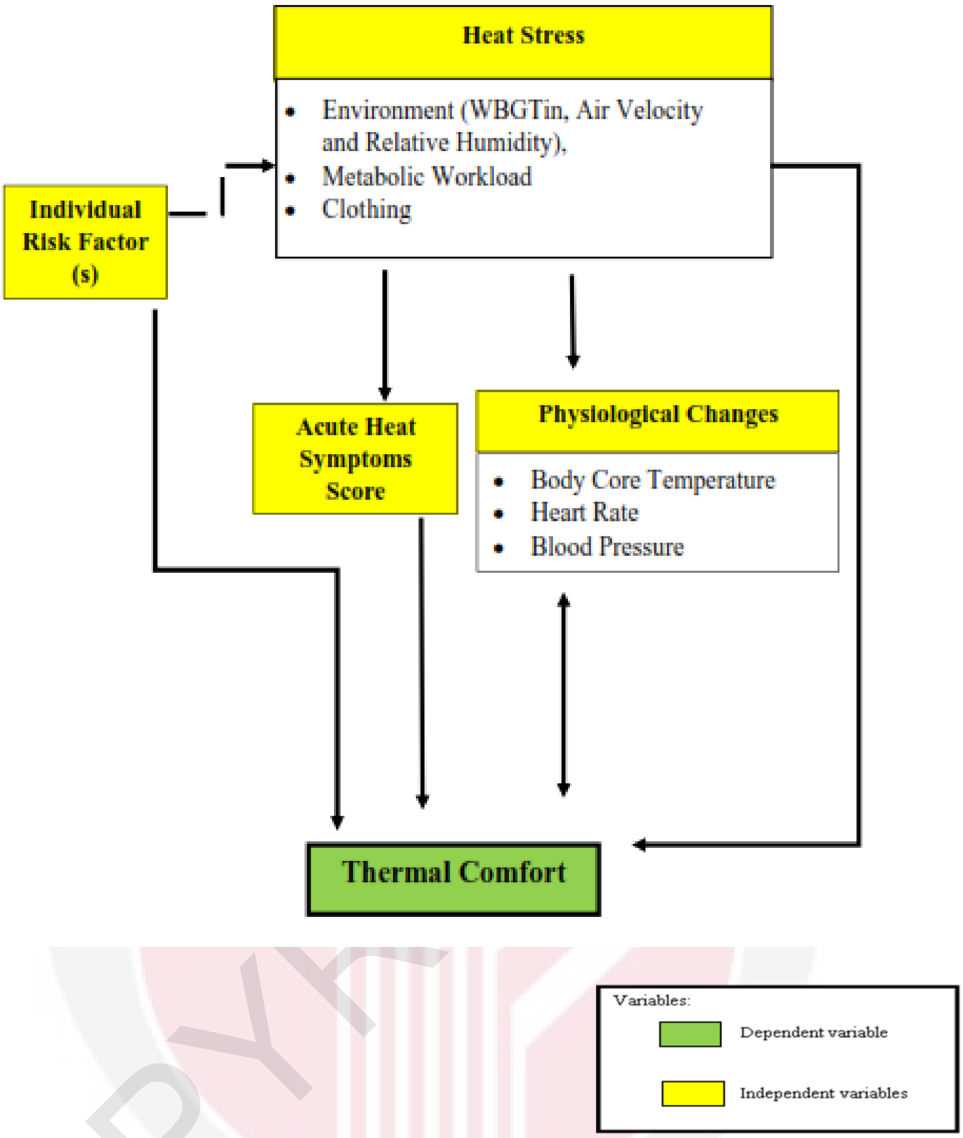

Figure 1.3 : Conceptual framework of research

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