DEVELOPMENT OF A HEAT STRESS-RELATED SYMPTOMS PREDICTION MODEL AMONG STEEL MILL WORKERS IN EAST JAVA INDONESIA

By

IMAM MUNAJAT NURHARTONOSURO

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

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

Due to a tropical region and hot workplace environment, workers at steel mills in East Java, Indonesia has high susceptibility to heat stress exposure. The study aims to determine heat stress affecting factors and heat stress-related symptoms that workers can experience due to the exposure to workload and hot environment at steel mill. The total respondents involved in data collection were 119 operators exposed to hot workplace in three different mill locations, i.e., Surabaya, Sidoarjo, and Gresik, East Java, Indonesia. The study consists of two phases, in which Phase 1 was the cross-sectional study and data collection via observation and questionnaires distribution to estimate variables of heart stress, of individual risk factors, acute health score symptoms, environmental factors (WBGTin, relative humidity, clothing and metabolic workload) and physiological changes (body core temperature, heart rate, and blood pressure), and workers' thermal perception. All the data were analyzed to establish the correlation between heat stress factors and heat stress-related symptoms. In Phase 2 as qualitative research, it compared the output of heat stress related symptoms with the in-depth interview with some expert and informants selected from the sample mills. The study results found that the heat stress related symptoms the workers most experienced during working were profuse sweating; fatigue; fainting; dizziness; seizures; heat rash and heat stroke. The results show that respondents from Steel Mill B experienced more symptoms of health problems than the other two mills. Most workers in three mills experienced severe thirst and excessive sweating due to hot environment. In three mills, lowest humidex value of 41, while the highest of 52.1, and the average humidity of 58.03%, and the lowest temperature was at Steel Mill C (28.54ºC). On the other hand, the highest temperature was at Steel Mill B (47.92 ºC). The physiological changes, such as body core temperature, heart rate, and blood pressure were the highest during working and the lowest after working. The variables WBGT, relative humidity, blood pressure diastolic, body core temperature and heart rate are predictors or determinants of heat related symptoms with a coefficient of determination of 61.4%., while 38.6% is explained by other variables that are not used in the model. WBGT positively affects the heat stress related symptoms, humidity, positively, affects the heat stress related symptoms but non-significant effect on heat stress related symptoms. Systolic, positively affects but non-significant effect on heat stress related symptoms, while diastolic, negatively, affects the heat stress-related symptoms but non-significant effect, body core temperature positively and significantly affects heat stress-related symptoms. Heat rate positively and significantly affects the heat stress related symptoms. Based on the principal component analysis (PCA) result, there are three variables that have a strong correlation (> 0.5) with factor 1, namely WBGT, relative humidity and body core temperature. The three variables are then grouped into factor 1; Factor 2. Two variables have a strong correlation with factor 2, namely blood pressure systolic and diastolic. The two variables are then grouped into factor 2. The qualitative data was gathered from 15 informants (5 informants per company) through in-depth interview, where blood pressure was perceived in association with heart rate. There were 15 informants who familiar with the terminology of blood pressure in association with heart rate. This finding is in line with the quantitative results, that heat related symptoms predictive index have positive relationship to heat stress symptoms. This finding is in line with the quantitative results, that room temperature (WBGT and body core temperature) positively affect heat related symptoms predictive index, blood pressure (heart rate), room temperature (WBGT – body rate) have relationship to heat stress- related symptoms. There were significant differences (significance value 0.00 < 0.05) in the WBGT index of the three mills. Based on the Tukey test results, there was a significant difference in the Humidex index only between Steel Mill B and Steel Mill C (Sig 0.035 <0.05). There are significant differences in the AHS index between the three mills, except between Steel Mill B and Steel Mill C (Sig 0.857 > 0.05). There were significant differences in the thermal comfort perception between the three mills, except between Steel Mill A and Steel Mill C (Sig 0.753 > 0.05). There were significant physiological changes (significance value 0.000 < 0.05) from the three mills were only found in the variable of body core temperature. The comparison test results revealed that there were significant differences in workload (significance value 0.048 <0.05) from the three mills. The physiological factor (body core temperature and heart rate) and environmental factor (Wet Bulb Global Temperature – Room Temperature) positively and significantly proven as predictor of heat stress-related symptoms prediction model. It was confirmed by qualitative data as being perceived by the respondents.

Keywords: tropical climate, steel mill workplace, heat stress-related symptoms

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

PEMBANGUNAN MODEL RAMALAN GEJALA BERKAITAN TEKANAN HABA DALAM KALANGAN PEKERJA KILANG KELULI DI JAWA TIMUR INDONESIA

Oleh

IMAM MUNAJAT NURHARTONOSURO

Ogos 2022

Pengerusi : Professor Shamsul Bahri, PhD
Fakulti : Perubatan dan Sains Kesihatan

Disebabkan kawasan tropika dan persekitaran tempat kerja yang panas, pekerja di kilang keluli di Jawa Timur, Indonesia mempunyai kerentanan yang tinggi terhadap pendedahan tekanan haba. Kajian ini bertujuan untuk menentukan faktor yang mempengaruhi tekanan haba dan gejala berkaitan tekanan haba yang boleh dialami pekerja akibat pendedahan kepada beban kerja dan persekitaran panas di kilang keluli. Jumlah responden ialah 119 operator yang terdedah kepada tempat kerja panas di tiga lokasi kilang berbeza, iaitu, Surabaya, Sidoarjo, dan Gresik, Jawa Timur, Indonesia. Kajian ini terdiri daripada dua fasa, Fasa 1 kajian keratan rentas dan pengumpulan data melalui pemerhatian dan pengedaran soal selidik untuk menganggar pembolehubah tekanan jantung, faktor risiko individu, gejala skor kesihatan akut, faktor persekitaran (WBGTin, kelembapan relatif, pakaian dan beban kerja metabolik) dan perubahan fisiologi (suhu teras badan, kadar denyutan jantung, dan tekanan darah), dan persepsi haba pekerja. Semua data dianalisis untuk mencari korelasi antara faktor tekanan haba dan gejala berkaitan tekanan haba. Fasa 2 merupakan penyelidikan kualitatif yang membandingkan keluaran simptom berkaitan tekanan haba dengan temu bual mendalam dengan beberapa pakar dan informan yang dipilih daripada kilang sampel. Keputusan kajian mendapati bahawa gejala berkaitan tekanan haba yang paling dialami oleh pekerja semasa bekerja ialah peluh berlebih; keletihan; pengsan; pening; sawan; ruam haba dan strok haba. Keputusan menunjukkan bahawa responden dari Kilang Keluli B mengalami lebih banyak gejala masalah kesihatan berbanding dua kilang yang lain. Kebanyakan pekerja di tiga kilang mengalami dahaga yang teruk dan berpeluh berlebihan akibat persekitaran yang panas. Dalam tiga kilang, nilai humidex terendah 41, manakala tertinggi 52.1, dan purata kelembapan 58.03%, dan suhu terendah adalah pada Kilang Keluli C (28.54^{o}C). Sebaliknya, suhu tertinggi ialah di Kilang Keluli B (47.92 ^{o}C). Perubahan fisiologi, seperti suhu teras badan, kadar denyutan jantung, dan tekanan darah adalah yang paling tinggi semasa bekerja dan yang paling rendah selepas bekerja. Pembolehubah WBGT, kelembapan relatif, tekanan darah diastolik, suhu teras badan dan kadar denyutan jantung adalah peramal atau penentu simptom berkaitan haba dengan pekali penentuan 61.4%., manakala 38.6% dijelaskan oleh pembolehubah lain yang tidak digunakan dalam model. WBGT memberi kesan positif kepada simptom berkaitan tekanan haba, kelembapan, secara positif, memberi kesan kepada simptom berkaitan tekanan haba tetapi kesan tidak ketara terhadap simptom berkaitan tekanan haba. Sistolik, memberi kesan positif tetapi kesan tidak ketara terhadap gejala berkaitan tekanan haba, manakala diastolik, secara negatif, memberi kesan kepada gejala berkaitan tekanan haba tetapi kesan tidak ketara, suhu teras badan secara positif dan ketara memberi kesan kepada gejala berkaitan tekanan haba. Kadar haba secara positif dan ketara mempengaruhi gejala berkaitan tekanan haba. Berdasarkan keputusan analisis komponen utama (PCA), terdapat tiga pembolehubah yang mempunyai korelasi kuat (> 0.5) dengan faktor 1 iaitu WBGT, kelembapan relatif dan suhu teras badan. Ketiga-tiga pembolehubah tersebut kemudiannya dikumpulkan ke dalam faktor 1; Faktor 2. Dua pembolehubah mempunyai perkaitan yang kuat dengan faktor 2 iaitu tekanan darah sistolik dan diastolik. Kedua-dua pembolehubah tersebut kemudiannya dikelompokkan ke dalam faktor 2. Data kualitatif dikumpulkan daripada 15 informan (5 informan setiap syarikat) melalui temu bual mendalam, di mana tekanan darah dilihat berkait dengan kadar denyutan jantung. Terdapat 15 orang informan yang biasa dengan istilah tekanan darah berkaitan dengan kadar denyutan jantung. Dapatan ini adalah selaras dengan keputusan kuantitatif, bahawa indeks ramalan gejala berkaitan haba mempunyai hubungan positif dengan gejala tekanan haba. Dapatan ini selaras dengan keputusan kuantitatif, bahawa suhu bilik (WBGT dan suhu teras badan) memberi kesan positif terhadap simptom berkaitan haba indeks ramalan, tekanan darah (denyut jantung), suhu bilik (WBGT – kadar badan) mempunyai hubungan dengan tekanan haba. gejala. Terdapat perbezaan yang signifikan (nilai keertian 0.00 < 0.05) dalam indeks WBGT bagi tiga kilang. Berdasarkan keputusan ujian Tukey, terdapat perbezaan yang signifikan dalam indeks Humidex sahaja antara Kilang Keluli B dan Kilang Keluli C (Sig 0.035<0.05). Terdapat perbezaan yang ketara dalam indeks AHS antara ketiga-tiga kilang, kecuali antara Kilang Keluli B dan Kilang Keluli C (Sig 0.857>0.05). Terdapat perbezaan yang ketara dalam persepsi keselesaan terma antara ketiga-tiga kilang, kecuali antara Kilang Keluli A dan Kilang Keluli C (Sig 0.753>0.05). Terdapat perubahan fisiologi yang ketara (nilai keertian 0.000 < 0.05) daripada ketiga-tiga kilang tersebut hanya terdapat dalam pembolehubah suhu teras badan. Hasil ujian perbandingan menunjukkan terdapat perbezaan yang signifikan dalam beban kerja (nilai keertian 0.048<0.05) daripada ketiga-tiga kilang. Faktor fisiologi (suhu teras badan dan kadar denyutan jantung) dan faktor persekitaran (Suhu Global Mentol Basah – Suhu Bilik) terbukti secara positif dan ketara sebagai peramal model ramalan simptom berkaitan tekanan haba. Ia disahkan oleh data kualitatif seperti yang dirasakan oleh responden.

Kata kunci: iklim tropika, tempat kerja kilang keluli, gejala berkaitan tekanan haba.

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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 Doctoral of Philosophy. The members of the Supervisory Committee were as follows:

Shamsul Bahri bin Hj. Md Tamrin, PhD
Professor
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Chairman)

Ng Yee Guan, PhD
Associate Professor
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Member)

Karmegam a/l Karuppiah, PhD
Associate Professor
Faculty of Medicine and Health Sciences
Universiti Putra Malaysia
(Member)

ZALILAH MOHD SHARIFF, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date: 9 March 2023

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Signature: ________________________

Name of Member of Supervisory Committee: Associate Professor Dr. Ng Yee Guan

Signature: ________________________

Name of Member of Supervisory Committee: Associate Professor Dr. Karmegam a/l Karuppiah

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LIST OF ABBREVIATIONS

ACGIH	American Conference of Governmental Industrial Hygienists
AHS	Acute Health Score
AIHA	The American Industrial Hygiene Association
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMI	Body Mass Index
CIBSE	The Chartered Institute of Building Service Engineers
DB	Dry Temperature
DOSH	Department of Occupational Safety and Health
ET	Effective Temperature
FMA	Factories and Machinery Act
GB	Globe temperature
HRD	Human Resources Department
ILO	International Labour Organization
ISO	International Organizational 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 Safety and Health Act
PT	Perseroan Terbatas (private company)
PSI	Physiological Strain Index (PSI)

RH	Relative Humidity
SACHS	The Standards Advisory Committee on Heat Stress
SOCSO	Social Security Organisation
TWA	Time Weighted Average
TLV	Threshold Limit Values
WBGT	Wet Bulb Globe Temperature
WHO	World Health Organization
VBA	Visual Basic Application

CHAPTER 1

INTRODUCTION

Chapter 1 briefly presents the research background and the problems that arise from the current background. Afterward, the chapter also discusses the objectives that this study aims, hypothesis development, conceptual framework of the study, as well as scope and the study limitation.

1.1 Research Background

Industrialization in economic development in low-income and middle-income tropical countries where heat stress is a concern may lead people to perform heavy labor for long periods of time in hot and humid circumstances, especially those in low socioeconomic position (Lemke & Kjellstrom, 2012). As a result, workers are subjected to extreme heat, increasing their risk of heat-related disease and occupational harm (Tawatsupa et al., 2010). In addition, the effect of global warming indicated with the increase in average global temperature aggravate the condition, particularly in tropical regions where the climate is constantly hot and humid. Given the situation, most of the population in these regions are susceptible to the risk of heat stress.

In addition, there are some types of industries that involve extremely hot/high temperature in their processes during manufacturing goods or services. Workers and operators working in these types of industries are susceptible to heat stress-related health risks due to prolonged exposure to heat hazard so called heat stress. Heat stress is a health-related hazard which is commonly found in workplace both at outdoor and indoor environment. In the long term, the heat stress that originates from both external and internal factors, might lead to fatigue and stress in the body. Meanwhile, internal factors determining the heat stress level will impose the human, which comprises temperature of core body, natural heat tolerance, acclimatization, and metabolism produced heat of the body. All these aspects depend on the workload of the workers as the external factors that may include the ambient temperature, radiant temperature, velocity of air (air movement) (Kjellstrom et al., 2009a), and air humidity. Extremely hot workplace reduces workers productivity, increases the accident risks to the workers, and the risk of heat-related disorders (Hassan et al., 2017). When humans undergo high heat stress index, they can experience heat stress, leading to a condition where they fail to survive due to being too warm and unable to self-cool properly. Overexposure to high heat stress index can lead to severe dehydration and even death (Lemke & Kjellstrom, 2012) or increase in early mortality (Kovats & Hajat, 2008). Heat hazard constitutes physical hazard, leading to the workplace health problem and one of the vital and common problems in workplace related to occupational health issues, the condition in which human experiences inappropriate thermal state which can impact the worker's health and productivities (Krishnamurthy et al., 2017).

1.1.1 Amplification of heat stress in tropical regions

The adverse effect of heat stress is amplified in tropical countries due to higher temperature, higher humidity than those of their counterparts in subtropical countries. According to climate and weather.com, the average temperature in Indonesia is around 30 ^oC, while the average humidity is about 85% as the most humid that occurs in January and 71% in September and on average annual percentage humidity of 80%. In contrast, subtropical countries, for instance, Germany, has the lowest temperature of 0 ^oC during winter and maximum temperature in July or August of 23 – 26 ^oC, with the humidity value of 75 – 85%. Given the high temperature and high air humidity in tropical environment, the workers working at industries without proper cooling and air movement in these regions are exposed to higher heat-related occupational health related problems, in particular for low and middle income countries in the world (Krishnamurthy et al., 2017). Apart from high temperature, higher humidity leading to higher probability to heat stress is well recognized in previous studies. The study's results proved elevated value of humidity with temperature according to the Clausius-Clapeyron relationship escalate summer heat stress in the tropical region (Zhang et al., 2021). Therefore, workers who deal with heavy physical loads are susceptible to several heat stress-related problems, such as life-threatening 'severe hyperpyrexia, in which the core body temperature exceeds 40.6^oC. To avoid these symptoms, they need to take frequent break to allow their bodies to cool down the body core temperature to prevent heat stress. Yet, it is not possible in industrial perspective since the method could reduce their work productivities.

Furthermore, the risk of heat stress exposure in the region already hot workplace and hot climate, such as in tropical regions is also amplified by the current global warming effect. The global effect becomes the concerns of growing tropical population, with the extreme heat it may cause to tropical climate (Zhang et al., 2021). The prevalence of heat stress will ultimately threat public occupational health and work productivity (Ismail et al., 2020).

The effect of environmental factors, such as no air movement, high indoor and outdoor temperature, high humidity, as well as the elevated average temperature due to global warming simultaneously increase the likelihood of workers with heavy workload to the risk of heat stress. Individual factors, such as metabolic rate, age, gender, acclimatization, clothing, human perception, should be taken into consideration when determining heat stress (Ismail et al., 2020).

In addition, workload must also be taken into account when determining heat stress. Workload linearly correlated to heat stress which results in heat strain an individual can experience. Heavy workload, together with heat environment simultaneously and adversely impacts workers' health and reduces work productivity (Krishnamurthy et al., 2017). Furthermore, there is strong correlation of WBGT value with workers productivity based on the study results conducted using cross sectional method. This study took samples of agricultural workers using linear mixed effects models. It revealed that the increase in value of WBGT would result in a decrease in workers' productivity (Fahed et al., 2018).

During performing heavy physical activities, human's physiological factors change. Muscular exercise can increase metabolism by up to 15 times the basal rate. Through this condition, the body excretes sweat, and experiences fluid loss. The water intake requirement depends on the type of activities, exercise intensity, duration, heat acclimatization, and environmental factors. Also, working in hot environment requires reduction of sodium intake from food or drinking. It is also evidence, due to higher susceptibility people in tropical regions, they are required to increase protein intake by 5 – 10 grams on daily basis compared to those in subtropical area. It is evidenced from some studies that increasing vitamin C consumption can help reduce heat stress during acclimatization. Meanwhile, fat-soluble vitamins, such as A, D, and E, are considered sufficient as long as the intake is according to 1989 RDAs recommendation (Needs et al., 1993).

1.1.2 Heat stress-related risks at steel processing industries

As one of tropical countries with high temperature and humidity, Indonesia' workplaces are riskier to heat stress incidence. Some previous studies have revealed certain workplaces that are more susceptible to heat stress, such as urban and coastal areas (Setiawati et al., 2022), construction projects (Lestari, 2019), furnace as heat source at workplace (Arianto & Dewi, 2019), airport apron (Syafitri, 2021). In addition, workers working at the oil and gas industry, shipyards, wearing protective clothing and works in a hot, high humidity environment and does heavy physical work is the worker most at risk of heat stress, mining industries, glass factories and rubber factories, metal smelting factories, workers in boiler rooms are also susceptible to heat stress (www.safetysignindonesia.id).

Steel processing mill is one of types of industries that deals with extremely high temperature during its operation to manufacture steel, cast steel, etc. These types of industry are characterized with hot environment where the workers are directly exposed since the association of high temperature up to 1700°C. The steel mills consist of several processing types, such as raw material, forming, refining, melting, tapping, and casting. In this operation, the combination of chemical substances, electrical current is used to heat scrap irons to make molten steel. The operating temperature in this process may reach up to 1700 °C. Meanwhile, in this smill, the heat is source from a furnace The molten steel is then poured into the ladle called as a tapping process requiring extreme temperature of around 1800°C (Hasan et al., 2014).

Previous studies reported that steel mills were associated with heat stress during the operation, consisting of hot rolling area, casting platforms and close furnace's area since the processes requires extremely high temperature (Parameswarappa & Narayana, 2017). In steel making factories, the primary source of radiant heat comes from the furnace.

Due to hot environment, workers performing activities at steel making/processing mills or industries are most likely to encounter heat stress exposure. This health hazard at the workplace is well-known since there have been multitude of studies investigating the health risk associated with thermal hazard. For instance, the study conducted by (Chen et al., 2003), investigating workplace at the electric arc melting area and continuous casting area in a steel plant. They evaluated the workers' physiological response to different levels of heat stress. They found that the WBGT value of the workplace for both working areas range from 25.4 – 28.7ºC to 30.0 – 33.2ºC. Based on their study, they revealed that workers exposed to heat workplace environment are inclined to experience heat strains, as indicated by changes in physiological strains, such as subjective fatigue, working heart rate, increase in body core temperature, eye strain, should stiff, feeling thirsty, and waist pain.

Furthermore, heat exposure in steel mills is also evaluated in the study carried out by (Fahed et al., 2018). They studied the effect of extremely hot environment causing discomfort and limit the performance of the workers at iron and steel mills. This study assessed the effect of workload on the workers using the method of wet bulb globe temperature (WBGT), heat stress index (HIS), and the physiological strain (PSI) index in Turkey. In their study, several dependent factors, such as physiological changes, such as heartbeat and core body temperatures, as well as workers productivity were assessed. Based on their finding, they could predict the occurrence of heat stress within the workplace to the workers.

More specifically, study on steel industries in tropical settings was conducted by (Krishnamurthy et al., 2017) in Southern India with high ambient temperature. Their study found that thermally stressful environments could create well-recognized risks of illnesses related to heat stress and at the same time decreased the workers' productivity. They used the method of cross-sectional study using WBGT, dehydration level, urine specific gravity, and its color. Based on their findings, 90% WBGT measurements exceeded than recommended threshold limit values, which is 27.2 – 41.7ºC. In addition, blooming-mill/coke-oven, with the value of 67.6ºC globe temperature, which is very high, was attributed to heavy and moderate workloads and radiational heat. There were prevalent heat-related health problems related to heat environment among the laborers. It included fatigue, excessive sweating, and tiredness, accounting for 50% of the respondents. Moreover, decreased productivity was significantly found in the workers directly exposed to heat workplace compared to those with indirect heat exposures.

Based on several previous studies above, it is important to investigate the characteristics of hot workplace environment at steel processing steel mills in Indonesia.

In Indonesia, steel industries are one of 10 priority industries in the National Industrial Development Master Plan (RIPIN), which classified into three main divisions, i.e., mainstay industries, supporting industries and upstream industry. The National Industrial Development Master Plan (RIPIN) was prepared as an implementation of the mandate of Article 8 paragraph 1, Law no. 3, year 2014, and become a guideline for the government and industry players in planning and industrial development to achieve the objectives of the industrialization implementation. These ten priority industries require basic capital in the form of natural resources, human resources, as well as technology, innovation, and creativity. Specifically, steel and steel-based industries contribute to gross national product (GNP) around 0.207% for overall basis in 2020 (Suherman & Saleh, 2018).

The industrial development in the future is also requires prerequisites in the form of adequate infrastructure and financing, supported by policies and regulations. Even though workers involved in the metal industries account only for 6%, this type of industry is regarded as vital for the country's development. The number of manpower by type of industry can be seen in Figure 1.1 below, depicting the workforce of different industries in Indonesia for the year of 2011.

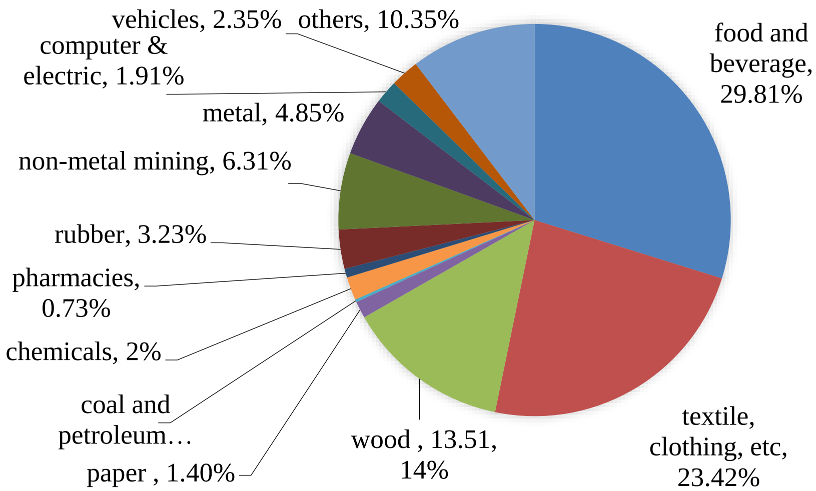

Figure 1.1 : Number of workforces by industries in Indonesia (BPS, 2021)

Previously, the most prominent and well-known steel mill in Indonesia was PT Krakatau Steel, located in the Province of West Java. It is one of state-owned companies processing steel for industrial purposes and construction works established in 1970.

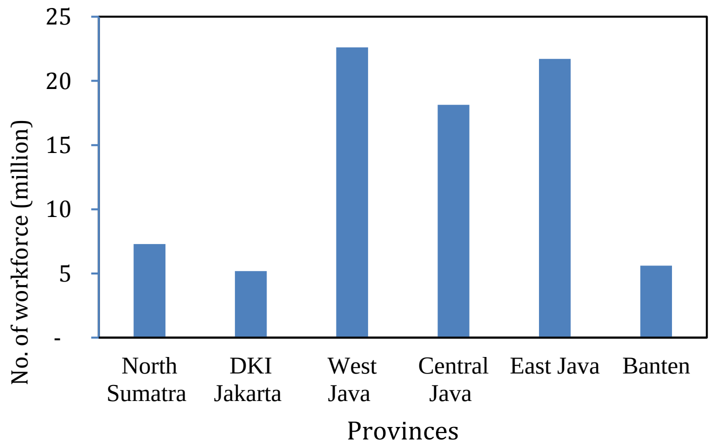

Figure 1.2 : Number of workforces in six largest provinces in Indonesia August 2021 (BPS, 2021)

On the other hand, East Java is one of the industrialized provinces in Indonesia, other than West Java, and DKI Jakarta, where factories, mills are located and based. The province of East Java is potential province as the investment destination as the province is well-established infrastructure, strategic geographical location, and accessible seaport for sea transport. Given such a position, East Java has numerous integrated industrial estates. Currently, there are officially registered industrial estate in this province, such as Surabaya Industrial Estate Rungkut (SIER), Gresik Industrial Estate, Ngoro Industrial Park, Maspion Industrial Estate, and Mojokerto Industrial Park, and others. Thus, the province has vital role and position in national economic development. Based on the data (Ministry of Industries and Trade Affairs, 2022), there are at least 52 steel processing factories and mills companies. Most the steel processing mills are located in three regencies, i.e., Gresik, Surabaya, and Sidoarjo, where the industrial estates/complexes are located.

1.1.3 Risk of heat stress measurement

Heat effects measurement is classified into two categories, i.e., heat strain and heat stress. Whereas the terminology stress refers to external forces, such as environment, the term ‘strain’ is referred to as an object or individual’s responses to the cause of the stresses (Lemke & Kjellstrom, 2012). Due to the significantly adverse effects of heat stress on human health, various endeavors have been made to control, measure, and mitigate the effects. Determining the heat stress index is important whether workers are working outside or inside buildings. When a human is exposed to heat stress, he/she will respond to it by releasing fluid through his skin via evaporation to maintain a cool temperature. The heat stress index is defined as the combination of the amount of evaporation or perspiration an average person or individual requires in relation to his/her maximum ability of perspiration or evaporation.

There are several methods to mitigate, control, and measure, quantify the workplace heat strain and heat stress in workplaces, i.e., the deployment of heat stress and heat strain index. The use of models and heat stress index and models to estimate the quantification of both heat strain and heat stress can help reduce mortality and morbidity in various applications. For instance, broad fields of applications, such as industries, sports, military, and leisure activities, have drastically reduced morbidity and mortality due to heat stress by the utilization of models and heat stress indices. The development of over 160 various climatic stress indices has existed for the past more than 70 years, some of which, more than 100 ones are dealing with heat stress indices (Havenith & Fiala, 2016).

Although several methods in quantifying heat stress and heat strain exist, WBGT or wet-bulb globe temperature is primarily one of the widespread uses in occupational health applications. Among all the direct indices or empirical indices Goldman has reviewed, only WBGT has prevalent use for managing workplace-related heat-stress. Furthermore, the method is then used for formal applications in industries in the European and ISO standard, ISO 7243 related to hot environments, and the method to estimate heat stress on working objects, based on the WBGT-index (wet bulb globe temperature) (Havenith & Fiala, 2016). This method is based on an apparent type of temperature deployed to estimate humidity effect, wind (air velocity), temperature, and the radiation of visible and infrared light, particularly sunlight exposure to humans. The method is widespread and common for athletes, industrial hygienists, and the military for appropriate exposure levels to high temperatures. Owing to its worldwide popularity in use, it becomes the world standard of ISO 7243 given that it is suitable for widespread use. The world standard is globally accepted to control heat-related hazards in the occupational environment based on WBGT-index since it provides a simple assessment and control (Parkes et al., 2019).

1.1.4 Studies on heat stress in Indonesia

As one of the countries lie in tropical regions in Southeast Asia, population in Indonesia are susceptible to hot environment exposure. Therefore, research on the heat stress on its impact is critical to prevent and mitigate its adverse effect. to date, there have been conducted several previous studies investigating heat stress in the country. For instance, a study conducted by (Setiawati et al., 2021) analyzed the effect of climate change that cause great impact on the urban population, such as increased frequency and magnitude of heat waves. In their study, a projection of the current and future heat stress index spatial variability was established for three large cities in Indonesia i.e., Surabaya, Medan, and Denpasar, under the scenario of climate and land-cover change. Furthermore, they quantified the projection using the Universal Thermal Climate Index (UTCI) for two periods.

Furthermore, another study on heat stress was also carried out by (Ramsay et al., 2021). Like the former, they studied the effect of heat stress on urban population in Makassar, one of large cities in Sulawesi, Indonesia. They measured the thermal environment both indoor and outdoor settings employing two metrices, i.e., wet bulb temperature and wet bulb globe temperature to quantify the magnitude and frequency of heat stress.

Previous studies that analyzed specifically the effect of heat stress in workplace setting were conducted by (Fajrianti et al., 2017) and (Puspita et al., 2018). In general, the former study examined one of tin ore smelting located in Pangkal Pinang, Bangka Belitung, and Riau. They found that heat exposure presents in the working area near furnace with the extreme temperature of 1300^{o}C. Meanwhile, the latter study took a metal processing factory located in Bogor, West Java, Indonesia as the study object. The mill processes metal to fabricate ‘gong’ (traditional musical instrument) made of metal alloy. During metal melting process using hot chamber, the mill produces temperature around 500^{o}C while the workers repeatedly swing hammer to form the metal. Both studies revealed that exposure to extremely high temperature and strenuous work in the workplace caused heat stress-related symptoms, such as excessive sweating, dehydration, heat stroke, nausea, and dizziness.

However, to the author best knowledge, there still lacks studies assessing heat stress in the workplace of primary steel mill processing that have been conducted in Indonesia. The study conducted by (Puspita et al., 2018) is related to metal processing factory. Yet, the factory is classified as traditional and home industry that manufacture traditional musical instrument for ‘gamelan’ with the maximum temperature of 500^{o}C. A study that examines a workplace setting in Indonesia with the temperature is extremely high, such as in steel processing foundries with the temperature of 1800ºC is highly required. There are still scarce studies investigating heat stress at steel mills workplace in Indonesia. Therefore, this study has high novelty in the establishment of predictive model for heat stress related symptoms since this aspect is essential for practitioners to mitigate the heat stress adverse effect in Indonesian context.

1.2 Problem statements

Even though more than 35 indices area globally available to evaluate heat stress (Havenith & Fiala, 2016), none of which are regarded as a universal heat stress index. There are many literatures that report the research 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 Indonesia and Malaysia. Theoretically, these indices have adequate quality since it is sufficient to be used by specific applications based on experiences in a particular industry. However, these existing indices are less suitable to measure the thermal comfort experienced from heat stress by the workers 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 research 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 words, frequent exposure to heat within a work environment induced physiological and psychological stress, which led to sensitivity, irritation, and anxiety. The notable industries that had high exposure to heat stress are ceramic plants, steel foundries, rubber product factories, bakeries, and steam tunnels (Azlis et al., 2007).

Furthermore, Threshold Limit Values (TLVs) table as established by the American Conference of Governmental Industrial Hygienists (ACGIH) is the underlying mechanisms supporting Wet Bulb Globe Temperature (WBGT) index that is commonly used to measure heat stress. However, the studies conducted by Goh and Izzah (2007), Azlis et al. (2007), and Ainun et al. (2011) found that heat exposure to operators in Malaysia exceeded the TLVs (Dayana, 2017). Moreover, the WBGT index is characterized that the index considers only the environmental factors without taking into account other factors, such as physiological factors only (Habibollah Dehghan et al., 2015). Thus, it proves the importance of incorporation of other factors than environmental factors.

Furthermore, there still lacks studies on heat stress effect on workers, particularly at steel mill workplaces in East Java, Indonesia. Several studies related to heat stress that incorporated both environmental factors and physiological changes, as well as metabolic rate, workload; clothing factors were conducted at industrial setting and home industrial workplace. However, none of the studies aimed to investigate environmental settings where workers are exposed to extremely high temperature, around 1800ºC.

Previous studies on heat stress are mostly focused on the likelihood of occurrence when the workplace would encounter heat stress. Generally, they investigated the occurrence of heat stress with the presence of heat stress-related symptoms workers might experience empirically. For instance, (Fahed et al., 2018) conducted a study on the effect of extremely hot environment causing discomfort and limit the performance of the workers at iron and steel mills. Another study, conducted by (Krishnamurthy et al., 2017) investigated the risks of illnesses related to heat stress using cross-sectional study and WBGT, dehydration level, urine specific gravity, and its color. Based on their findings, they recommended the threshold limit value of 27.2 – 41.7ºC for the workplace. In addition, (Chen et al., 2003) evaluated the workers' physiological response to different levels of heat stress. Based on their findings, they concluded that workers exposed to heat workplace environment are inclined to experience heat strains, as indicated by the presence of heat stress related symptoms.

In conclusion, the previous studies investigated the effect of heat stress to the physiological changes of workers as indicated with symptoms. They also determined the maximum limit value of environment and workload in order for the workers not to experience heat stress. Several models of prediction of heat stress were established based on their study. However, to date, there is still few research investigating the prediction model for heat stress-related symptoms a worker might experience beside heat stress itself. In addition, among steel mill workplaces in different location, the literatures that compare environmental thermal factors, workers' physiological changes, clothing factors, workload, and thermal perception at the steel mills are still scarce. Thus, it finds difficult to determine the correlation of those factors to establish predictive heat stress index that can estimate heat stress occurrence at workplace. Later, this predictive model is not only used to predict the occurrence of heat stress, but it is also expected to suggest what types of symptoms a worker might experience based on workplace environmental setting. Therefore, based on the elaboration above, the problems that arise from research background can be summarized into the following paragraphs:

1) There still lack data regarding factors related to heat stress (environmental factors, physiological measurement, acute heat symptoms, workload, and human perception) at a steel mill workplace. Meanwhile, these data are important to be available for decision makers to mitigate the adverse effect of heat stress.

2) The relationship between heat stress variables (independent variables: environmental factors, physiological measurement) and heat related symptoms as dependent variable) at a steel mill workplace in East Java, Indonesia has not been established. These data are essential for management for mitigating heat stress and what actions are to be taken in case the heat stress related symptoms are present in their workplace.

3) Determining heat stress using six independent variables of heat stress need to be simplified with reduced three models. In most cases, some data are not available. Thus, with the reduction of data to establish predictive model, it helps to simplify the management to cope with heat stress in their workplace.

4) There lacks data related factors affecting heat stress condition, heat stress-related symptoms at three mills, whether they have significant differences in

these factors. These data are considered important to generalize for predictive model of heat stress related symptoms.

5) There still lacks evident that validates the study results with the qualitative data obtained from actual workplaces. This aspect is vital to support quantitative study.

6) There still lack evident whether there is difference between predicted model of heat stress-related symptoms workers perceived and physiological and predictive model. This aspect is significantly important to prove whether the predictive model can accurately predict heat stress related symptoms and workers' perception.

1.3 Research questions

Based on background and problem statements, the research questions are stated as follows:

1) What are the factors related to heat stress among steel mill workers at three mills located in East Java, Indonesia?
2) Can heat stress-related symptoms be predicted by physiological changes and environmental factors among steel mill workers?
3) If heat stress-related symptoms can be predicted by physiological and environmental factors, can the predictive model variables be reduced?
4) Are there any significant differences on heat stress-related symptoms, physiological factors, and environmental factors among steel mill workers in three mills?
5) What is the model of heat stress-related symptoms based on steel mill workers perceive that physiological and environmental factors affected their health?
6) Is there any difference between predicted model of heat stress-related symptoms workers perceived and physiological and predictive model?

1.4 Objectives of the study

Based on the issue of study in the problem statements above, the objectives of this study are:

1.4.1 General objective

The general objective of this research is to development of a heat stress-related symptoms prediction model among steel mill workers in located in three different regencies in East Java Province, Indonesia.

1.4.2 Specific objectives

The general objectives as mentioned above can be further specified to the specific objectives as follows:

1) To determine the factors affecting heat stress among steel mill workers at three mills in East Java, Indonesia.
2) To predict heat stress-related symptoms among steel mill workers based on physiological and environmental factors.
3) To reduce the number of predictive model variables if heat stress-related symptoms can be predicted by physiological and environmental factors.
4) To determine whether there are significant differences on heat stress-related symptoms, physiological factors, and environmental factors among steel mill workers in three mills.
5) To find out the steel mill workers perception regarding physiological and environmental factors affecting their health.
6) To determine whether there is difference between predicted model of heat stress-related symptoms workers perceived and physiological and predictive model.

1.5 Hypotheses development

Based on some objectives, some hypotheses are developed in this study as follows:

1) H_0: There is no significant relationship between environmental variables, physiological changes, workload, clothing factor, and the occurrence of heat stress at the steel mill workplace.

   H_1: There is a significant relationship between environmental variables (WBGTin, RH, and temperature), physiological changes, workload, clothing factor, and the occurrence of heat stress at the steel mill workplace.
2) H_0: There is no significant relationship between environmental factors, physiological changes with heat stress-related symptoms among steel mill workers.
3) H_2: There is significant relationship between environmental factors, physiological changes with heat stress-related symptoms among steel mill workers.
4) H_3: the number of predictive model variables of heat stress-related symptoms which can be predicted by physiological and environmental factors can be reduced.
5) H_4: there are significant differences on heat stress-related symptoms, physiological factors, and environmental factors among steel mill workers in three mills.

6) H_5: the steel mill workers perception regarding physiological and environmental factors affecting their health can be determined.

7) H_6: there is difference between predicted model of heat stress-related symptoms workers perceived and physiological and predictive model.

1.6 Conceptual framework of the study

This research defines the relationship between dependent and independent variables known to all those operators of steel industries suffer complications from stress in their working environment. Heat stress is a physical hazard found to cause thermal discomfort among the operators. Figure 1.3 shows the conceptual framework of this study. The establishment of heat stress index is based on the dependent variables and thermal comfort. The independent variables of this study are divided into three aspects as follows:

1. Environmental factors of heat stress (Zare et al., 2018), (Zhang et al., 2021).
2. Physiological changes/individual factors (Zhang et al., 2021), (Boonruksa et al., 2020).
3. Acute Heat Symptoms Score (AHSS) (Boonruksa et al., 2020), (Flouris et al., 2018).

The regression of independent variables was established and integrated into single value of predictive heat stress index in this study to predict the thermal comfort and determine the maximum limit workers can withstand without the exposure under heat stress. Consequently, the interaction between the perception of thermal comfort, physiological changes, and environment are the substantiation based on the assessment in terms of environmental, and psychological (Epstein & Moran, 2006); (Simson et al., 2017). The interaction vice-versa between perception thermal comfort and physiological changes was related to mechanism of the physiological thermal adaptation towards heat exposure (Dear & Hwang, 2011).

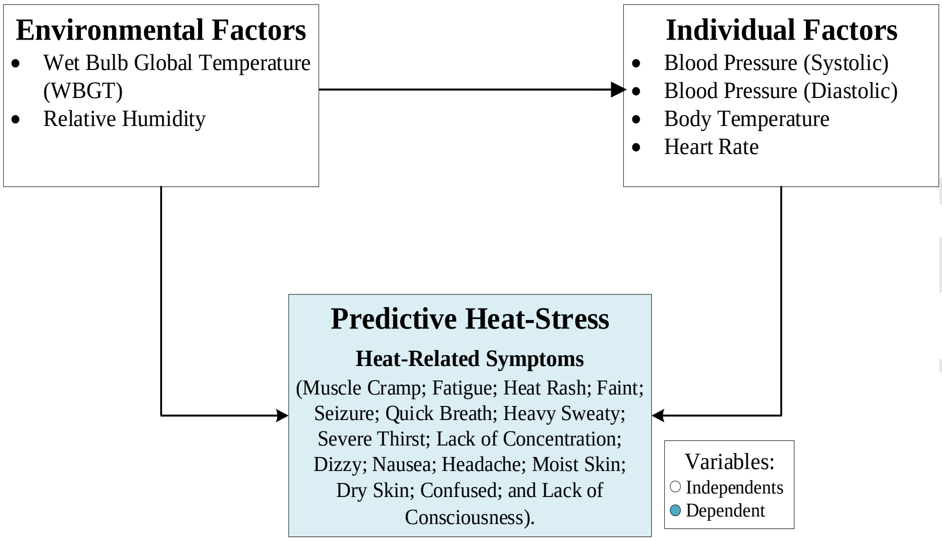

Figure 1.3 : Research conceptual framework

Furthermore, environmental variables, clothing factors, and workload becames the cofounding factors of heat stress-related symptoms since they influence both the symptoms and physiological changes, such as blood pressure (systolic and diastolic), body core temperature, heart rate.

1.7 Study justification

Studies related to heat stress were conducted and published internationally. However, in Indonesia particularly, there still lacks specific research that is conducted on heat stress index in order to improve thermal comfort and determine maximum limit below which workers can withstand. Therefore, research on this field would help reduce the adverse effect and impact of heat stress among industrial operators, particularly in hot workplace environment. Therefore, the present study aims to investigate the establishment of heat stress index in order to determine the maximum limit of thermal environment among the operators in Indonesia. The aim of this study is to development and validation of a heat stress-related symptoms prediction model among steel mill workers in east java Indonesia. In addition, the predictive index obtained in this study will be validated and compared with well-established heat stress indices, such as ACGIH TLV and Humidex index. As such, the mill management and the operators will be well prepared on effective occupational health and safety measures related to heat stress present in their workplace.

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, Indonesian government has issued Law No. 36 year 2009 concerning workers health, specifically, work activities in industries that can cause a hot workplace environment, regulated in the Regulation of the Minister of Manpower and Transmigration No. PER. 13/MEN/X/2011. It stipulates that the maximum limit of

31.0°C for light workload, 28.0°C for medium workload, and 25.9°C for heavy workload with work duration of 8 hours per day and resting duration of 1 hour. This guideline was aimed to educate workers on the recognition, estimation, prevention, and treatment of heat stress at workplace. However, the guidelines still use 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, Indonesia.

1.8 Scope of the study

The study focuses on assessment of heat stress at workplace in steel mills located in East Java Province, Indonesia and determine the heat strain of the workers who are exposed to the environment. Later, the output of the study is compared with other previous study conducted in other tropical countries, such as Malaysia. Finally, the results of the study can be generalized to be reference for heat stress assessment for tropical regions.

1.9 Thesis organization

The thesis consists of five chapters, in which, Chapter 1 contains the background of the study, the problem statements, objective of the study, hypothesis development, and scope of the study. Chapter 2 presents a literature review of the thesis that elaborate relevant previous studies in heat stress. In Chapter 3, the thesis explains the research methodology, by which research, data collection, analysis, etc. is conducted. Meanwhile, Chapter 4 elaborates the results and discussions. Furthermore, Chapter 5 concludes all findings from this study and recommendations for future research/studies.

1.10 Summary

Chapter 1 explains the process involved in this study, in particular, the background, problem statement, research question, objectives, hypotheses development, scope of study and organization of the chapters have been set out in chapter one. The following chapters are provided to elaborate the process outlined in the first chapter. Furthermore, the literature review, concept and theory, methodology, finding and discussions and finally the conclusions and recommendations are discussed in subsequent chapters.

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