A PILOT STUDY OF HEAT STRESS RISK EVALUATION WHILE WEARING PERSONAL PROTECTIVE EQUIPMENT SUIT IN A TROPICAL CLIMATE

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DECLARATION

This work has not previously been accepted in substance for any degree and is not being concurrently submitted in candidature for any degree.

Signed... (AINI SYAZWINA BINTI AHMAD KHAIZI)

Date ..23/07/2022...............................

STATEMENT 1

This thesis is the result of my own investigation, except where otherwise stated. Other sources are acknowledged by giving explicit references. Bibliography/references are appended.

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LIST OF ABBREVIATIONS

bpm	Beat per minute
HR_0	Initial Heart Rate
HR_t	Heart rate at time = t
MET	Metabolic Equivalent of Tasks
NIOSH	National Institute for Occupational Safety and Health
PPE	Personal Protective Equipment
PSI	Physiological Strain Index
$T_{re,0}$	Core body temperature at time = t
$T_{re,t}$	Initial core body temperature
USM	Universiti Sains Malaysia
WHO	World Health Organizations

ABSTRAK

PPE diperbuat daripada bahan tidak telap yang dipakai oleh pekerja dalam bidang perubatan untuk melindungi diri mereka daripada penularan virus, terutamanya semasa wabak seperti SARS-CoV-2 atau COVID-19. Pakaian ini boleh menjadi penyumbang utama kepada berlakunya tekanan haba kerana sifat penebat yang terdapat pada pakaian ini adalah penting untuk mengekalkan keselesaan terma. Iklim di Malaysia adalah panas dan lembab, dan mempunyai purata suhu tahunan yang boleh mencapai sehingga 25.4°C. Justeru, suhu ini boleh menyebabkan tekanan haba berlaku dengan lebih cepat. Matlamat kajian ini adalah untuk menilai tahap tekanan haba apabila memakai PPE dalam iklim tropika menggunakan Indeks Ketegangan Fisiologi (PSI). Dua orang lelaki sihat tubuh badan telah mengambil bahagian dalam kajian ini, di mana suhu badan teras dan kadar denyutan jantung mereka diukur semasa mereka melakukan aktiviti sambal memakai PPE. Aktiviti-aktiviti tersebut termasuklah berdiri, berjalan di atas pengisar injakan pada kelajuan 0.5 m/s dan menulis menggunakan komputer, berjalan di atas pengisar injakan pada kelajuan 1.5 m/s, dan berjalan perlahan di sekitar gelanggang. Aktiviti-aktiviti ini dilakukan dalam tiga ujian berbeza (kawalan, intervensi; dalam dan luar). Suhu badan teras maksimum peserta telah diukur pada 37.8°C, kadar degupan jantung antara 150 hingga 160 denyutan per minit, dan mereka mengalami tekanan haba sederhana semasa menjalankan aktiviti intensiti sederhana. Penyelidikan yang akan dilakukan mesti menganalisis tindak balas fisiologi apabila pakaian pelindung diri dipakai dalam keadaan iklim tropika menggunakan ruang iklim dan peralatan yang tepat.

ABSTRACT

PPE is made of an impermeable material that healthcare workers put on to protect themselves from the transmission of viruses, particularly during pandemics such as SARS-CoV-2 or COVID-19. It can be a significant contributor to heat stress since the insulating effect of the clothing is essential for maintaining thermal comfort. The climate in Malaysia is hot and humid, and the average annual temperature can reach up to 25.4°C. As a result, it will cause heat stress to occur more quickly. The objective was to assess the level of heat stress when wearing PPE in a tropical climate using PSI. Two males participated in this pilot study, in which their body temperature and heart rate were measured while they engaged in activities while wearing PPE. The activities comprised standing, walking on a treadmill at a speed of 0.5 m/s and writing on a computer, walking on a treadmill at a speed of 1.5 m/s, and walking slowly around the court. These activities were included in three different studies; control and intervention in indoor and outdoor working conditions. The participants' maximum body temperature was measured at 37.8°C, their heart rates ranged from 150 to 160 beats per minute, and they experienced moderate level of heat stress while carrying out work of moderate intensity exercises. Future research must analyse the physiological responses when PPE is worn in a tropical climate using a climatic chamber and precise equipment.

CHAPTER 1

INTRODUCTION

1.1 Project Overview

The world is currently dealing with an infectious disease caused by the SARS-CoV-2 virus known as Coronavirus disease (COVID-19). Although the virus can spread in small liquid particles from an infected person's mouth or nose, the healthcare personnel required to wear PPE when providing treatment with confirmed or suspected COVID-19. The occupational exposure risks groups including healthcare workers, day-care and schools and other essential infrastructure need to maintain awareness of the thriving community epidemiology.

Protective clothing can be a leading factor of heat stress because heat comfort is heavily reliant on the insulating reaction of clothing. It is made from thermally insulated and impermeable material that traps body heat and causes physiological stress to the human body. PPE can be classified as hot and it can be extra hot when wearing it in a tropical climate (Hartl et al., 2014). Heat is produced within the body due to the work rate, and the healthcare worker may be at risk of heat stress if the heat lose is insufficient as well as when the core body temperature increases. In Malaysia, the hot and humid weather condition might contribute to a higher degree of heat discomfort when wearing the PPE while working. Additionally, Malaysia is predicted to has increase in average temperature between 1.7 to 4.2°C by 2100 (Zander & Mathew, 2019).

The study proposed is to evaluate levels of heat stress and thermal discomfort when working in PPE in a tropical climate. Heat stress is the amount of heat that the body can encounter. Working in a lack of air movement such as inadequate air circulation and high temperature as well as humidity can lead to heat stress and cause serious health problem to the healthcare workers. The exchange of heat between the human body and the environment occurs in response to environmental conditions and activity. Heat stress occurs when the core body temperature is more than 37.5°C and the body's mean starts to fail. Heat stress can manifest itself in a variety of ways, including cramping in the muscles, an inability to concentrate, intense thirst, fainting, and heat rash. Some people are more likely to exhibit some symptoms than others, and not everyone is equally sensitive to the condition (Yon et al., 2016).

The impermeable nature of protective clothing combined with physical activity, dehydration and exhaustion can induce changes in the body’s normal functions which are heat illnesses; heat stroke; confusion, convulsions and loss of consciousness, heat exhaustion; giddiness and nausea, heat cramps and heat rash. Other factors other than clothing that contribute to heat stress is relative humidity. Humidity is when the heated water evaporates to the environment and generates amount of water in the air. A large amount of vapor is present in high-humidity environments, which prevents sweat from evaporating from the skin's surface. Humidity becomes critical in a hot climate since less sweat evaporates when the humidity is above 80% (Yon et al., 2016). The primary resources of reducing body heat is through sweat evaporation.

Messeri et al., (2021) conducted a web survey to examine the thermal stress among healthcare workers while wearing PPE during COVID-19 pandemic. 191 questionnaires including hospital doctor, nurses and other healthcare professionals were collected. As a result, about 60% of healthcare worker declare feeling heat discomfort working with PPE. 99% of the participants feeling “hot” heat stress perception throughout working and more than 50% claim a “very hot” thermal sensation. The most perceived symptoms felt by the healthcare workers are excessive sweating, thirst, general discomfort, fatigue and headache. There are 155 persons working in healthcare who have admitted that heat stress causes them to lose productivity. Therefore, the aim of the study is to evaluate the human physiological response when wearing the PPE and assess the level of heat stress and thermal discomfort when walking while wearing PPE.

1.2 Aim of the Study

The aim of this pilot study is to evaluate levels of heat stress and thermal discomfort when working in PPE in a tropical climate. PPE can be a challenging for people who needs to work in a hot and humid environment as the material is impermeable. The fabric itself may be a significant contributor to heat discomfort and may even be the cause of heat stress in some cases.

1.3 Problem Statements

PPE suit is essential for frontline health care workers involved in handling COVID-19 cases. PPE suit prevents microbiological contamination such as viruses and bacteria from spreading through the skin, mouth, nose, or eyes. PPE suit itself traps excess heat and moisture inside, causing the body to become even hotter and resulting in heat stress.

PPE is made from an impermeable material that generates heat by sweating cannot escape to the surroundings. The risk of heat stress becomes higher since Malaysia is known for its hot and humid weather. Therefore, understanding the human physiological response which is heart rate and body temperature when wearing PPE is vital for reducing heat stress and thermal discomfort. Furthermore, the study about level of heat stress cannot be found in Malaysia. Hence, this pilot study is conducted to evaluate the level of heat stress when wearing PPE in a tropical climate especially in Malaysia.

1.4 Scope of Work

The pilot study is limited to evaluate the level of heat stress using the data of heart rate and body temperature. This pilot study will familiarize the experimental design and equipment set-up in general. This stage allows for detecting any flaws in the experimental design, which can then be corrected before proceeding with the full-scale test study. Before beginning the experiment, the subject's body temperature and heart rate must be measured simultaneously. Following that, the treadmill speed must be adjusted by the specifications for light and moderate-level activity for control study and intervention study in indoor working condition. As soon as the termination criteria have been met, the recording data is turned off.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This chapter will specify the review from previous researchers that are related to this final year project. It begins with heat stress and its aftereffects, PPE, thermal discomfort and the circumstances of thermal discomfort. Then, an evaluation of core body temperature through non-invasive measurements, metabolic equivalent of tasks (MET) and PSI, are discussed. At the end of this chapter, a research gap which is the summary of the literature review is conversed.

2.2 Introduction to Heat Stress

Heat stress is defined by Department of Occupational Safety and Health as “the overall heat load to which an employee may be exposed from the combined contributions of metabolic heat, environmental factors and clothing requirements” (Yon et al., 2016). Heat stress may risk an individual who is performing strenuous work in hot weather as the material of PPE constrained the sweat evaporation.

Heat stress can occur when the internal core body temperature does not recover to the normal body temperature. Heat can induce the body to sweat and increase blood flow to the skin's surface. Sweating cools the body's surface, and heat is transferred to the surface as blood flow increases (Yon et al., 2016). A decrease of the metabolic heat is required, while the cooling by sweating is not adequate for the body to hinder heat stroke (Kjellstrom et al., 2009). The core body temperature must be in the range of 36°C to 38°C to avoid failure in thermoregulatory mechanisms of the body (Dr et al., 2016).

‘Six fundamental factors’ adds to the heat stress which are air temperature, radiant temperature, humidity, air movement, clothing and the metabolic heat. The worker can be in danger if the person works in a hot climate while dealing with a high proactive task and can experienced heat stroke (Kjellstrom et al., 2009). Insufficient of thermoregulatory responses can cause heat stroke to befall and lead to other heat challenges and complications including acute respiratory distress syndrome (Dr et al., 2016).

2.2.1 Consequences of Heat Stress

Heat stress might raise the percentage of workers losing output from 16 percent to 27 percent by 2080, especially in hotter locations. Exposure to hot environment working conditions and uncomfortable clothing might reduce the labour productivity and thus, gives impact to the economy. A study stated that 15 to 20% of yearly work hours are wasted in heat-exposed occupations in Southeast Asia, and this number is expected to double by 2050 (Zander & Mathew, 2019).

Heat stress can affect a worker's mental functioning, causing them to be unable to solve issues, forget information, and find it difficult to learn and make decisions. An online survey is conducted by Davey et al., (2021) to evaluate the effect of wearing PPE on health care workers. As a result, 59.8% of the respondents acknowledged lost focus during working, 41.4% which includes 60 respondents declared cannot solve complex problems such as numerical calculations, and 34.5% of the respondents felt difficult to make decisions when working while wearing PPE for a long time.

Heat stress will lead the workers to experience heat-related sickness symptoms in addition to poor physical performance at work. Rapid heartbeat, headache, weariness, and excessive perspiration are some of the symptoms. There is evidence that shows the effect of heat stress symptoms among workers, and the study by Carter et al., (2020) has found that the workers who work in the hot and humid environments experienced daily mild to moderate heat stress symptoms by means of heavy sweating (54%), feeling hot (58.3%), and thirst (60.9%). The study by Stephens et al., (2022) confirmed that most of the workers experienced excessive sweating while working in PPE and they have to bear unbearable level of heat at works.

Excessive sweating can cause dehydration and put a burden on the body's thermal and cardiovascular systems. According to the National Institute for Occupational Safety and Health (NIOSH), sufficient rehydration is critical as excessive heat stress can result in increased water loss into the environment and hyperthermia. As seen in Greenleaf Harrison's research, if dehydration surpasses 1.5 percent to 2 percent of body weight, heart rate and body temperature would rise, considering sweating may produce up to 8 litres in a workday under heat stress circumstances (Jacklitsch et al., 2016).

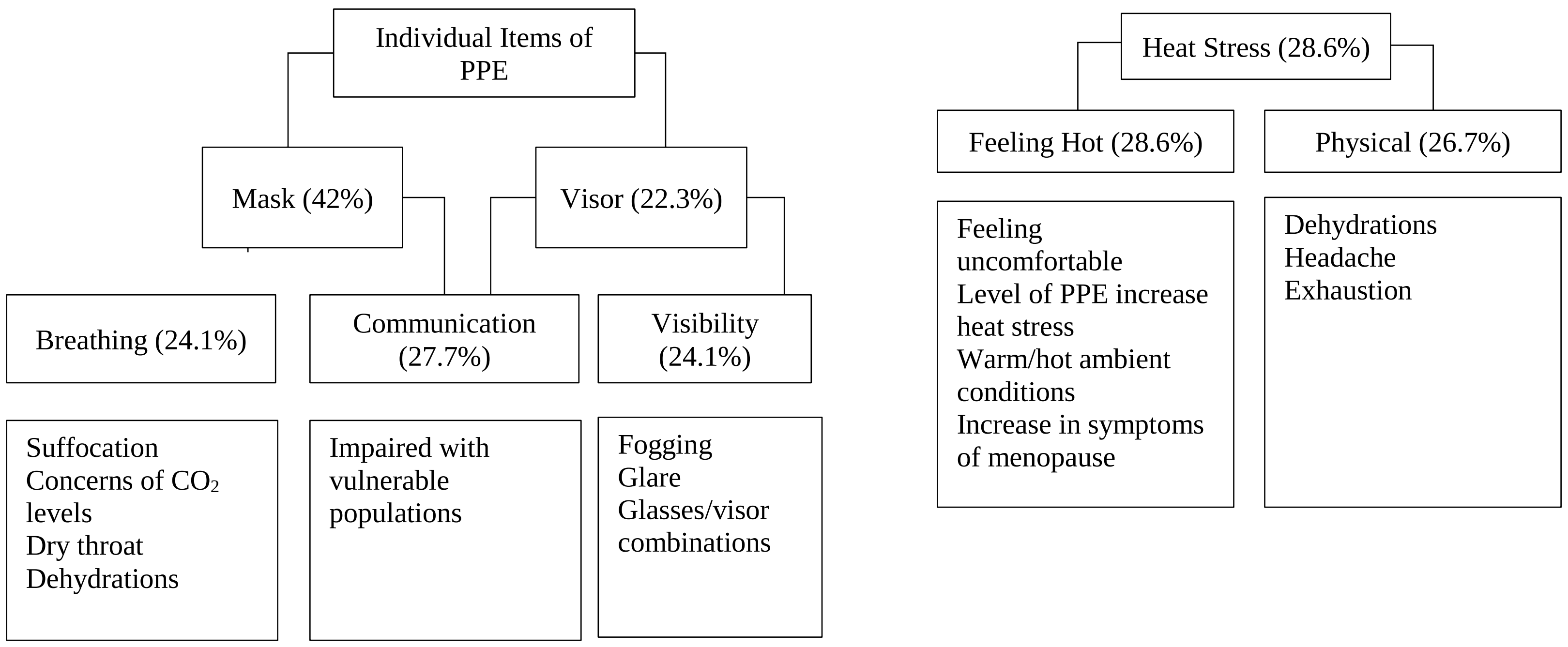

Figure 2.1 Main themes generated from the additional information provided regarding respondent's experiences of wearing PPE and how these experiences may have impacted their working life (n = 112) (Davey et al., 2021).

2.3 Personal Protective Equipment (PPE)

PPE which is a set of clothes worn to lessen one's exposure to potentially harmful chemicals and microbes that might lead to serious diseases. The World Health Organization (WHO) recommends that all healthcare workers who come into contact with COVID-19 patients should wear the appropriate PPE in order to protect themselves and prevent the spread of the virus within the healthcare system. In addition to this, WHO recommends that healthcare workers refrain from entering the rooms of COVID-19 patients.

There are a few types of PPE recommended by WHO depending on the work activities and risk of exposure. A medical mask identified as Type II or higher, gown, gloves, and aprons, should be worn by a health care professional who must provide direct treatment and assist COVID-19 patients for transportation. Additionally, the health care worker's face should be covered with a face shield or goggles (World Health Organization (WHO), 2020).

2.4 Thermal Discomfort and Factors That Contribute to Thermal Discomfort

Thermal discomfort can be felt when the temperature drops below 18°C or starts to rise above 24°C for an extended period of time, which can indicate healthcare health is at risk (Ormandy & Ezratty, 2016). A study on thermal comfort examines three constraints: the body is in heat balance, perspiration rate is within comfort limits, and mean skin temperature is within comfort limits (Epstein & Moran, 2006).

Uncomfortable temperatures can make workers more likely to engage in unsafe behaviour because their ability to make decisions and carry out manual tasks diminishes, making them more vulnerable to mistakes; not wearing protective clothing in a right way and drop of workers' concentration. Wearing protective clothing for a long day can affect thermal discomfort since the healthcare workers can no longer adapt with the situations. When a worker's perspiration is stopped from evaporation while wearing PPE, it might raise the chance of physical discomfort and prevent the cooling process from occurring (Byrne & Ludington-Hoe, 2021).

The factors that contribute thermal discomforts is environmental and individual objective, and subjective factors. The air temperature and radiant temperature are some of the environmental factors that affect thermal comfort. Radiant temperature, which comes from the sun, hot surfaces, and kiln walls, contributes more to the environment's heat loss or gain than air temperature. Other factors that influence thermal discomfort is the clothing insulation and metabolic heat. Metabolic heat gives a big impact on thermal comfort as doing more physical work can cause more heat needs to be lost. Physical characteristics such as size and weight as well as age, fitness level, and gender can all have an impact on how comfortable a person is even if other variables such as air temperature, humidity, and velocity remain constant (Ormandy & Ezratty, 2012).

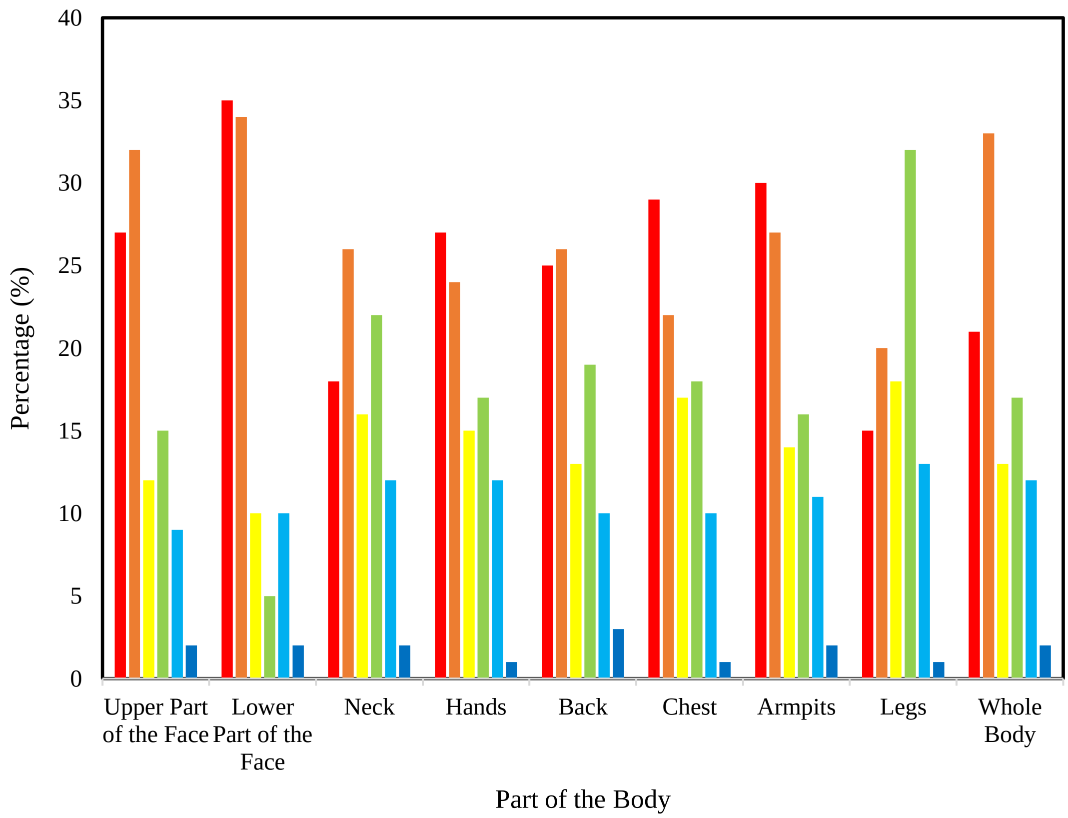

Figure 2.2 Thermal sensation of the worker when working while wearing PPE (Messeri et al., 2021).

Figure above shows the effect of wearing PPE from 191 interviewees on a web survey conducted by Messeri et al., (2021). The results showed that 35.6% of the workers declared very hot at the lower face part. 78% of the respondents felt very hot on the body areas when wearing PPE. From figure above, it is concluded that almost all the body parts that is covered with PPE were declared high thermal sensation by the respondents especially on chest, face, hands and back of the body.

2.5 An Evaluation of Core Body Temperature Through Non-Invasive Measurements

Heat strain have to be monitored through core body temperature, heart rate and subjective evaluation to reduce the percentage of heat stroke occurs (Lee et al., 2011). Core body temperature can be evaluated using two methods which are invasive (rectal and gastrointestinal thermometer) and non-invasive (ear and skin) measurements. Many studies have been conducted to investigate the validity of non-invasive measurements to assess heat strain, and a few researchers have concluded that tympanic temperature is the one that has stronger relationship between heart rate and core body temperature (Chaglla et al., 2018; Herstein et al., 2021; Lee et al., 2011). The ear canal is chosen to record the core body temperature as the tympanic membrane in the ear canal directly imitates the core body temperature (Chaglla et al., 2018).

Lee et al., (2011) evaluated eight male workers' heat strain in hot environments based on infrared tympanic temperature and rectal temperature measurements at various depths. The core body temperature is taken using infrared tympanic thermometry and from the left ear canal because it does not hurt the subjects, responds quickly to changes, and is easy to use outside operations. As a result, the infrared tympanic temperature has equal or higher values compared to rectal temperature for the conditions with most heat strain. When the subjects exercise, the infrared tympanic temperature proves to have a more substantial relationship between temperature and heart and total sweat rate compared to the rectal temperature at 16 cm from the anal sphincter. It is also stated that rectal temperature has a lag response during exercise when the environment changes, unlike infrared tympanic temperature, which response quickly to transient thermal situations.

Chaglla et al., (2018) evaluated the core body temperature in the tympanic membrane using graphene-inked infrared thermopile sensor. Ten subjects are involved in the 25 minutes of test under resting and exercising and using four different devices. The infrared thermometer ThermoScan 7 Age Precision was used as a reference. As a result, the graphene-inked sensor is able to detect the changes in core body temperature but no as accurate as the infrared thermometer as shown in figure below.

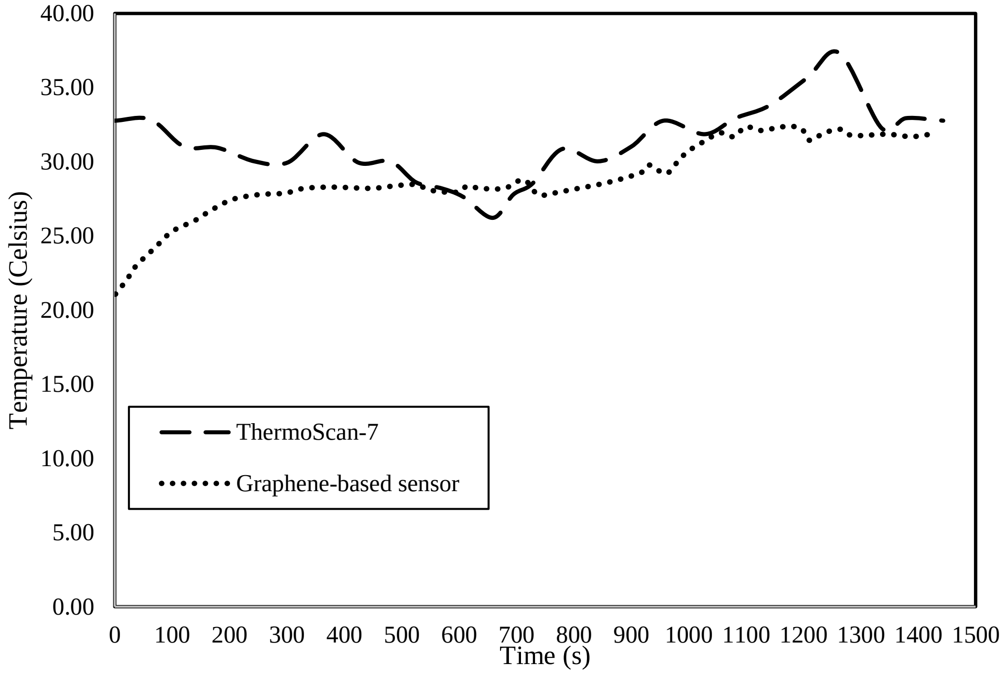

Figure 2.3 Temperature data during physical activities (Chaglla et al., 2018).

Herstein et al., (2021) investigated the core body temperature of the healthcare workers in the Nebraska Biocontainment Unit (NBU), Omaha, wearing personal protective equipment (PPE) using a wireless-transmission thermometer. Five to six hours before the experiment is conducted, the participants are asked to swallow the ingestible thermometer device. The ingestible thermometer generates the actual core body temperature data to an iPhone running the HQ Inc. application. The differences between the oral and core temperature at baseline prove that the oral temperature might delay diagnosis for heat-related illness. The data, however, is said to be inaccurate because interference from hospital monitors may have caused artificial peaks in temperature recordings. Moreover, the ingestible thermometer device is expensive and according to Wilkinson et al., (2008), the pill is not accurate to measure core body temperature in physical activity after the cool fluids swallowed.

2.6 Metabolic Equivalent of Tasks (MET)

MET is used as a reference for the level of activities according to its intensity. MET is a measurement that compares the amount of energy that is burned by the body during exercises in comparison to its metabolism while at rest. According to Sanghvi, (2013), MET referred to the rate of oxygen intake by the body during a certain exercise, expressed as a multiple of its oxygen intake while at rest (VO_2). One metabolic equivalent task (MET) requires an average individual to use 3.5 milliliters of oxygen per kilograms of body weight multiplied by minutes of exercise (Sanghvi, 2013).

The MET level is divided into three different levels which are (Ainsworth'•^ et al., 2011):

i. Light intensity activity where the MET is in the range of below 3.0;
ii. Moderate intensity activity where the MET is in the range of 3.0 to 6.0; and
iii. Vigorous intensity activity where the MET is more than 6.0.

Light intensity physical activity does not demand a lot of energy and the activities that are categorized as light physical activities include strolling slowly, sitting while performing work on a computer and preparing food. Moderate intensity physical activity usually consumes more oxygen compared to light activities such as walking at 3 mph on a flat surface, sweeping floors and cycling. Meanwhile, for a vigorous activity, the completion of activity consumes the highest amount of oxygen, as an example, jogging, hiking and jumping rope (Haskell et al., 2007a). The other physical activities that are categorized as light, moderate and vigorous intensity is shown in table below:

Table 2.1 MET equivalents of common physical activities classified as light, moderate or vigorous intensity (Haskell et al., 2007a).

Light (MET < 3.0)	**Moderate (3.0 ≤ MET < 6.0)**	**Vigorous (MET ≥ 6.0)**
Walking slowly = 2.0	Walking 3.0 mph = 3.3	Walking at very brisk pace (4.5 mph) = 6.3
Sitting – using computer work at desk using light hand tools = 1.5	Walking at very brisk pace (4 mph) = 5.0	Jogging at 5 mph = 8.0
Standing performing light work such as making bed, = 2.0 – 2.5	Cleaning – heavy: washing windows, car, clean garage = 3.0	Jogging at 6 mph = 10.0
Arts and crafts, playing cards = 1.5	Sweeping floors or carpet, vacuuming, mopping = 3.0 – 3.5	Jogging at 7 mph = 11.5
Billiards = 2.5	Carpentry – general = 3.6	Shoveling sand, coal = 7.0
Boating – power = 2.5	Carrying and stacking wood = 5.5	Heavy farming = 8.0
Croquet = 2.5	Badminton = 4.5	Soccer – casual = 7.0
Darts = 2.5	Basketball = 4.5	Basketball game = 8.0
Fishing – sitting = 2.5	Table tennis = 4.0	Tennis singles = 8.0
Playing most musical instruments = 2.0 – 2.5	Tennis doubles = 5.0	Volleyball competition = 8.0

2.7 Physiological Strain Index (PSI)

PSI is used to evaluate the level of heat stress using a formula. It can evaluate heat discomfort based on heart rate and core body temperature (Moran et al., 1998). A universal scale of PSI is between 0 to 10 and can be used to categorized the individuals according to the risk of physiological strain (Davey et al., 2021).

Moran et al., (1998) classified the level of heat stress as in the table below, with 0 until 2 as no or little physiological strain, 3 to 4 as low heat stress, 5 to 6 as the individual having a moderate of heat stress, 7 to 8 as high level of heat stress and 9 to 10 as the individual experiences very high level of heat stress.

Table 2.2 PSI Index

PSI	**Heat Stress**
0-2	No/Little
3-4	Low
5-6	Moderate
7-8	High
9-10	Very high

The level of heat stress is evaluated using a Physiological Strain Index (PSI) as follows (Moran et al., 1998):

$$PSI = 5\frac{(T_{re,t} - T_{re,0})}{(39.5 - T_{re,0})} + 5\frac{(HR_t - HR_0)}{(180 - HR_0)} \quad \text{[Eq. 1]}$$

Where,

$$T_{re,t}: Core\ body\ temperature\ at\ time = t$$

$$T_{re,0}: Initial\ core\ body\ temperature$$

$$HR_t: Heart\ rate\ at\ time = t$$

$$HR_0: Initial\ heart\ rate$$

There are two variations of PSI were evaluated from the past researches. Moran et al., (1998) used equation 1 where the initial body temperature and initial heart rate are the body temperature and heart rate at the starting experiment (0 minute). However, Buller et al., (2008) assessed the level of heat stress using fixed value for the initial core body temperature and heart rate; 37.0 °C and 70 beats min^{-1}. The second version is impossible as generating resting temperature in a thermoneutral environment is not easy to achieve (Davey et al., 2021).

2.8 Comparison of Temperature and Humidity Used in The Previous Study

A few researchers have done the similar methodology about this study with different temperature and humidity (Bach et al., 2019; Herstein et al., 2021; Lee et al., 2011; Loibner et al., 2019; McQuerry et al., 2018; Potter et al., 2021). The temperature and humidity used in their studies are different and based on these studies, the highest temperature and humidity recorded is 35°C with 49%, respectively.

The comparison is to ensure the temperature and humidity used is resemble to the tropical climate. Although their studies are not conducted in the tropical climate country, however, they use other methods such as using a climatic chamber to set the temperature and humidity at tropical climate. Table 2.3 shows the comparison of temperature and humidity for previous study.

Table 2.3 Temperature and humidity set in the experiments for previous study.

Study	Temperature (°C)	Humidity (%)
Lee et al., (2011) examined the validity of using infrared tympanic temperature as a thermal indicator to measure the heat stresses experienced by employees in hot workplaces, in comparison with rectal temperatures taken at varying depths	25 and 32	50
McQuerry et al., (2018) developed changes to the protective clothing worn by Australian firefighters for heat stress relief.	35	35
Bach et al., (2019) studied the use of personal cooling systems to reduce heat strain wearing chemical and biological protective clothing.	35	49
Loibner et al., (2019) evaluated the benefits and drawbacks of two different protective clothing systems and determined the most limiting factors while wearing protective clothing under tested conditions.	22 and 28	-
Herstein et al., (2021) investigated the core body temperature of the healthcare workers in the Nebraska Biocontainment Unit (NBU), Omaha, wearing personal protective equipment (PPE) using a wireless-transmission thermometer.	20	30 and 40
Potter et al., (2021) tested explosive ordnance disposal (EOD) suit to determine the safe work and biophysical properties of the EOD9 ensemble in Ottawa, Canada.	Ambient: 32 Hot-dry: 48 Temperate: 24	Ambient: 60 Hot-dry: 20 Temperate: 50

2.9 Tropical Climate in Malaysia

Malaysia is known as one of the countries that has a tropical climate. There are two different monsoon seasons: The Southwest Monsoon (which takes place from April to September), and the Northeast Monsoon (October-March). On average, Malaysia is exposed to approximately six hours of direct sunlight each day, with cloud cover most commonly occurring in the afternoon or evening. The average temperature for the entire year in Malaysia is 26.37 °C. Based on figure 2.4, there is just a one-degree Celsius difference between the lowest temperature recorded in January (24.9℃) and the highest temperature recorded in May (25.9℃), indicating that the average monthly temperature experiences only a moderate degree of seasonal variation. The months of April, May, and June consistently have the highest average temperatures throughout the year.

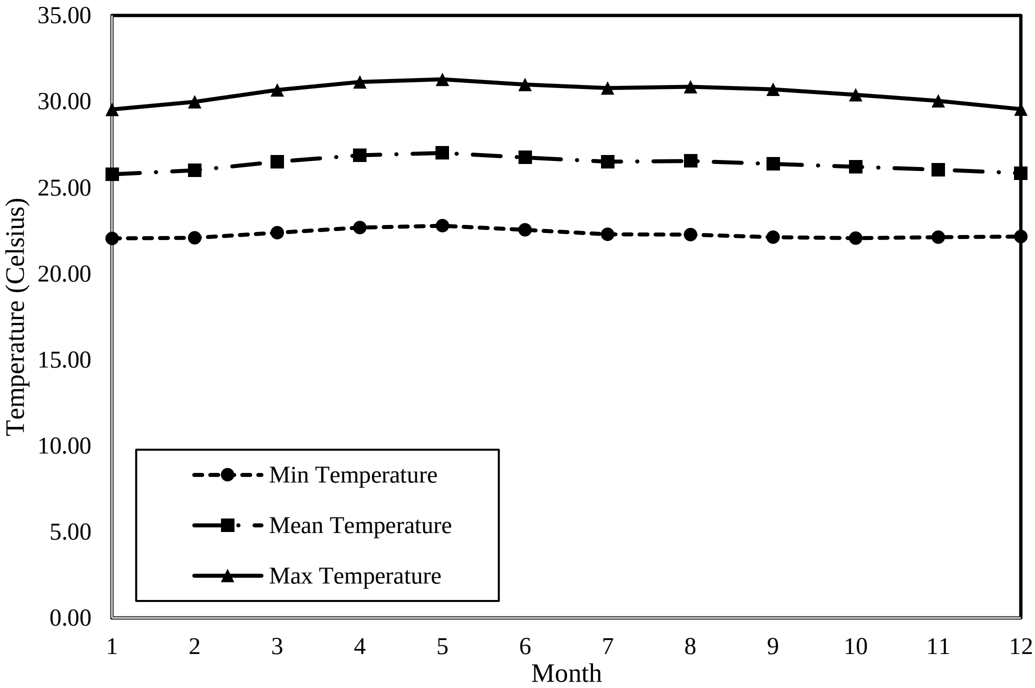

Figure 2.4 Monthly Climatology of Minimum-Temperature, Mean-Temperature, Maximum-Temperature and Precipitation 1991-2020 Malaysia (World Bank Group, 2021)

Temperatures in Malaysia are relatively stable throughout the year, with the mean temperature in the lowlands ranging between 26℃ and 28℃. While the daily mean temperature may only fluctuate by about 2℃ to 3℃ over the course of an entire year, the diurnal variation may be as much as 12℃ higher or lower. Temperatures in Malaysia are expected to rise by up to 1.5℃ by 2050, according to projections made for the country's future (Rahman, 2018).

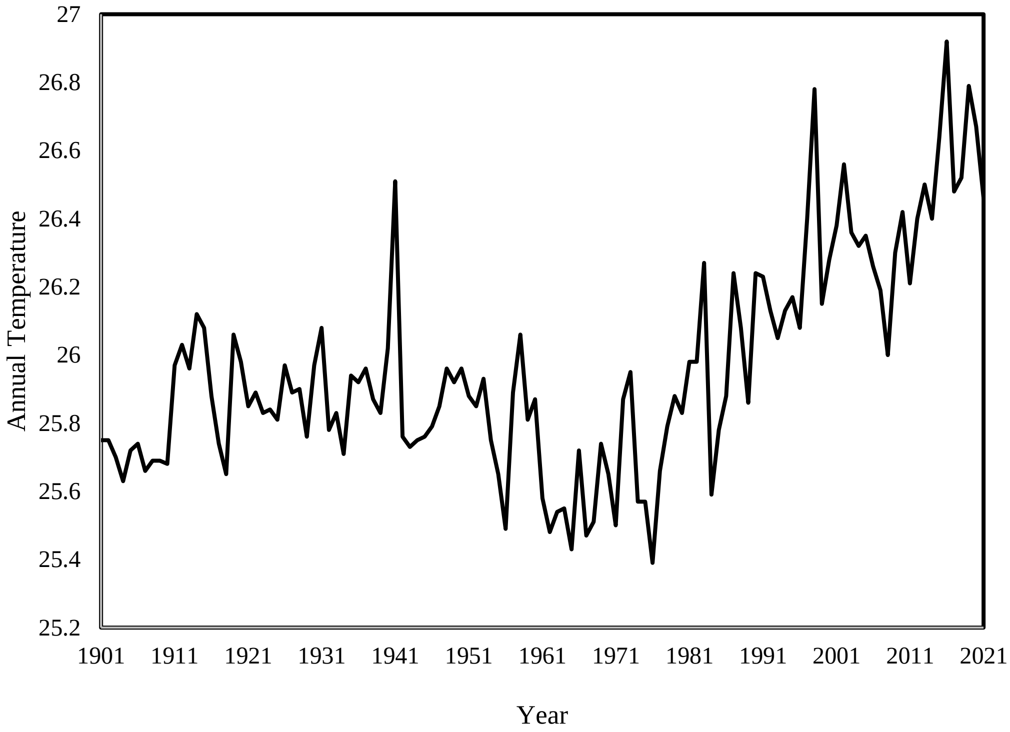

Figure 2.5 Annual Temperature from 1901 until 2021(World Bank Group, 2021).

Figure 2.5 above shows the annual temperature for year 1901 until 2021. The highest annual temperature recorded in Malaysia is on 2016 which is 26.92℃. COVID-19 occurs in Malaysia around 2020 and at that time, the annual temperature achieved 26.67℃ which can be considered as hot and uncomfortable for people who needs to work on the site and wearing PPE. On 2021, the annual temperature reduced to 26.46℃. The reduction annual temperature from 2020 to 2021 is only 0.21℃, which not even 1℃. The mean annual precipitation is around 3001.98 mm, which can be considered high. However, during June and July, the mean precipitation are only 194.58 mm and 185.04 mm, respectively. During these two months, the maximum temperature can even achieve 30.99℃ according to the data observed from 1991 to 2020.

The projection of the possible effects of climate change on health burdens has not received a lot of attention or investigation in Malaysia. Therefore, deaths caused by heat stress or respiratory ailments owing to air pollution could be considered a direct consequence, whereas indirect effects could include an increase in food and water-borne diseases as a result of changes in the pattern of rainfall.

2.10 Research Gaps

According to the literature review discussed, PPE will lead to heat stress and thermal discomfort when wearing it for a long time and while doing moderate to vigorous physical activity. It is due to its impermeable material that traps the sweat from evaporates to the environment. The researches also identified using tympanic temperature is one of the best methods to measure body temperature as its response quickly to the transient thermal situations. From research that have been carried out about MET, there are several activities that can be used in the experiment. The walking at slow pace and different speeds, and sitting while doing work using a computer are the most effective approach for acquiring the heart rate and body temperature's data.

From the literature review conducted, it can be understood the current studies on measuring level of heat stress while wearing PPE mostly evaluated in different temperatures that is not in tropical climate conditions. Although there are a few researchers that have done the experiment in a tropical climate, the experiment on this study cannot be found in Malaysia. Thus, this project will focus on evaluating the level of heat stress and thermal discomfort when wearing PPE in a tropical climate especially in Malaysia.

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter will present the experimental setup and design approaches used in this project. The experimental design is divided into two studies control study, where the subjects are not required to wear PPE while exercising, and an intervention study, where the subjects are required to wear PPE. The intervention study is categorized into two conditions which are indoor and outdoor. All exercise assessment was completed in a gymnasium and Universiti Sains Malaysia (USM) engineering campus sports complex.

3.2 Research Design

The pilot study uses a few instruments to collect the heart rate, body temperature, air temperature, and relative humidity data. A treadmill with different speeds is used to complete the experiment for the control study and indoor working conditions for the intervention study. The details of the test instruments are described as follows:

1. Treadmill

   The treadmill is used for the walking exercise at different speeds to simulate various workloads according to MET.

2. Magene Heart Rate Monitor

   Heart rate data is gained from the wearable heart rate sensor which is Magene Heart Rate Monitor. The subjects are required to wear this heart rate sensor throughout the experiment to monitor their heart rate using a strap. Data is logged into a Strava and myWorkouts applications via Bluetooth.

   Figure below shows the placement illustration of the heart rate sensor for men and women. The subjects are required to wear to heart rate sensor underneath their cloth and ensure the heart rate sensor touched their skin for a better reading and accurate data.

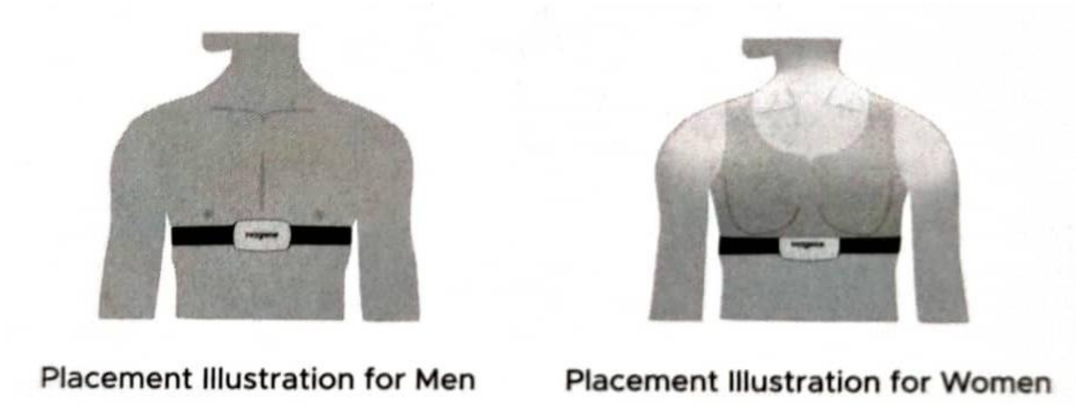

Figure 3.1 Placement illustration for the heart rate sensor.

Figure 3.2 Magene Heart Rate Sensor

3. Infrared Thermometer KF-HW-003

The body temperature data is taken using Infrared Thermometer KF-HW-003 because it does not hurt the subjects, responds quickly to changes and is easy to use outside the operations. The data is taken at left ear canal of the subjects. However, this instrument is a representative for core body temperature based on (Chaglla et al., 2018; Herstein et al., 2021; Lee et al., 2011).

Figure 3.3 Infrared Thermometer KF-HW-003

4. SensorBlue Hygrometer WS07

    The air temperature and relative humidity data is taken using SensorBlue Hygrometer WS07. The device is connected to the Sensor Blue application via Bluetooth.

Figure 3.4 SensorBlue Hygrometer WS07

3.3 Experimental Design

Two subjects are recruited based on their body health, age, physical limitation which is they are able to walk continuously, and medical history such as heart or respiratory problems. The study subjects have read and signed the consent form and their consent forms. In addition, the subject's body weight and body temperature are recorded before each study. The mean age of the subjects was 23.5 which is range from 23 to 24, and has median of 23.5, and the mean body mass was 81.5 kg; range between 65 to 98 kg, and median of 81.5 kg.

Before participating in the experiment, the subjects were asked to consume food and drinks one hour before the start of the session. This pilot study is proposed to identify the approximate levels of heat stress through the PSI, which will pave the way for a larger-scale study to be conducted as part of a future investigation. The study flowchart for the experiments is shown below:

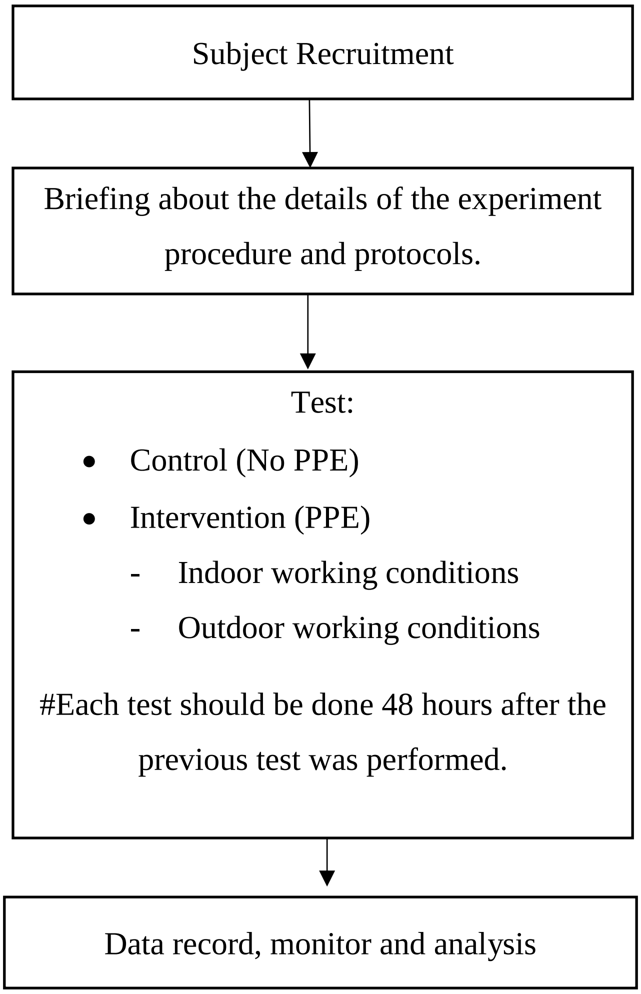

Figure 3.5 Study flow chart of the experimental design.

A minimum of forty-eight hours must pass between each testing session to provide the subjects with the opportunity for proper resting. There are three levels of test that are assigned to the subjects for each study. The levels of test based on Metabolic Equivalent of Task (MET), as described as follows:

1. Resting position

   At this level, the subjects are requested to stand still without doing anything for a minimum of 10 minutes.

2. Light Exercise (MET: 1.5 - 2.0) (Haskell et al., 2007b)

   For MET 1.5, the subjects are required to writing or doing a desk work using computer while sitting. On the other hand, the subjects are asked to walk slowly on a treadmill at a speed of 0.5 m/s at 0° elevation to achieve MET 2.0.

3. Moderate Exercise (MET: 3.0 – 5.0) (Haskell et al., 2007b)

   At this level, to reach MET 3.0, the subjects are asked to walk slowly around the badminton court for a minimum of 10 minutes. Next, the subjects have to walk on a treadmill at a speed on 1.5 m/s at 0° elevation to achieve MET 5.0.

3.3.1 Control Study

In this test, the subjects were not required to PPE except the N95 facemask. Throughout each study's activities, the temperature of the air and its relative humidity were measured. The subjects were allowed to consume food and drink water one hour before the test started. The subjects' body weight and body temperature were recorded before the test. The subjects were asked to wear a heart rate sensor to monitor their heart rate and ensured the sensor touched their skin correctly to avoid disruptions.

The subjects are asked to do three test levels with different intensity based on MET. The first level is the resting position, where the subjects were asked to stand still for 10 minutes. In the next level, the subjects were required to walk on a treadmill at a speed of 0.5 m/s to simulate low-intensity activity. The third level is a moderate exercise where the subjects were required to walk on a treadmill with increasing speeds of 1.5 m/s. Each level of activity takes a minimum of 10 minutes, and the subjects' heart rate is monitored throughout the test. After 10 minutes, the subjects' body temperature is taken, and the subjects are permitted to rest for five minutes in the interval between each level of the test. The level of heat stress is then evaluated using PSI, which is stated in equation 1.

Figure 3.6 shows the subject is in a resting position while not wearing PPE. It is done for a control study with indoor working conditions while wearing N95 mask. Figure 3.7 shows subject 2 did low intensity level of activity which is walking on a treadmill at 0.5 m/s.

Figure 3.6 Subject experienced the first level of test which is resting position.