STUDY ON THE EFFECT OF LOCAL COOLING ON PEOPLE WITH DIFFERENT TYPES OF SLEEPING POSTURE

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DECLARATION

I declare that this thesis entitled "Study on the effect of local cooling on people with different types of sleeping posture" is a result of my own research except as cited in the reference. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this project report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (with Honours).

Signature : ………………………………

Name : Dr. Abd Rahman bin Dullah

Date : ………………………………

DEDICATION

To my beloved family, friends and lecturers

ABSTRACT

Thermal comfort is a sense of mind that appear to be the well-being of human body in the surrounding environment. To ensure human body achieves thermal comfort at all times, it is essential that the heat produced because of human activities in daily life is depleted at a rate to provide equilibrium inside the body. However, the heat intake in a human body cannot be controlled at times which means there can be a sudden temperature rise and excessive sweating in the body. This phenomenon is known as thermal discomfort in the human body. Due to the globalization the world is frequently affected in terms of thermal comfort in the surroundings. There are more possibilities for extreme heat events to occur. In many ways, this heat events cause human body to lose thermal comfort. Hence, the purpose of this report is to study the effect of local cooling people based on the sleeping posture factor in a cold and hot environment. The scope of this research is to obtain major parameters affecting thermal comfort such as temperature and relative humidity at different position of a human body in regards of three sleeping postures namely back, front and side. A test rig section is developed by preparing a data logger which collects the data by using micro-sensors and transmits it to a software. The micro-sensors measure both temperature and relative humidity data at six positions across a human body (head, neck, back/chest, lower back/abdomen, thigh and feet). Five subjects are tested in hot and cold environments for each type of sleeping posture and the microclimatic condition in a confined space between the micro-sensors and human body are studied. A human perception data is collected based on level of hotness and humidity that is felt by subjects. A detailed analysis is done based on the relationship of the data obtained and the variation of environment and subject's BMI value. Results show the interaction of temperature and relative humidity based on the different sleeping postures. The BMI values are compared to the findings of the study. A general manipulation of environment of the subjects being tested are also taken in count. Relationships involving the sleeping postures and BMI with the human comfort in terms of temperature and relative humidity is compared. Relationships between the temperature and relative humidity measured are correlated in the final part of this thesis respectively with the perception data of hotness and humidity obtained. The temperature measured coincides with the level of hotness, whereas the relative humidity recorded coincides with the level of humidity rated by subjects.

ABSTRAK

Keselesaan termal adalah keadaan minda yang mewakili kesejahteraan tubuh manusia di persekitarannya. Untuk memastikan tubuh manusia mencapai keselesaan termal pada setiap masa, haba yang dihasilkan pada tubuh manusia kerana aktiviti yang dijalankan dalam kehidupan seharian haruslah disingkirkan pada kadar yang mampu memberikan keseimbangan di dalam tubuh badan seorang manusia. Walau bagaimanapun, penyerapan haba dalam tubuh manusia tidak dapat dikawal dan mungkin terdapat kenaikan suhu secara tiba-tiba dan berpeluh berlebihan di dalam tubuh badan. Fenomena ini dikenali sebagai ketidakselesaan terma pada tubuh badan manusia. Oleh kerana globalisasi, dunia sering terjejas dari segi keselesaan termal di persekitaran. Terdapat pelbagai potensi untuk peristiwa panas yang melampau berlaku yang mampu menyebabkan tubuh manusia kehilangan keselesaan termal. Oleh itu, tujuan laporan ini adalah untuk mengkaji kesan pendinginan tempatan berdasarkan factor posisi tidur dalam persekitaran dingin dan panas. Skop penyelidikan ini adalah untuk mendapatkan parameter utama yang mempengaruhi keselesaan termal seperti suhu dan kelembapan relatif pada kedudukan tubuh manusia yang berbeza berkenaan dengan tiga posisi tidur iaitu belakang, depan dan sisi. Bahagian rig ujian dikembangkan dengan menyiapkan "data logger" yang mengumpulkan data dengan menggunakan sensor mikro dan menghantarkannya kepada perisian komputer riba. Sensor mikro mengukur data suhu dan kelembapan relatif pada enam kedudukan di seluruh tubuh manusia (kepala, leher, punggung / dada, punggung bawah / perut, paha dan kaki). Lima subjek diuji dalam persekitaran panas dan dingin untuk setiap jenis posisi tidur dan keadaan mikroklimatik dalam ruang terkurung antara sensor mikro dan tubuh manusia. Data persepsi akan dikumpulkan berdasarkan tahap kepanasan dan kelembapan yang dirasai oleh subjek. Analisis terperinci dilakukan berdasarkan hubungan data yang diperoleh dan variasi lingkungan dan nilai BMI subjek. Hasil menunjukkan interaksi suhu dan kelembapan relatif berdasarkan posisi tidur yang berbeza. Nilai BMI dibandingkan dengan dapatan kajian. Manipulasi umum persekitaran subjek yang diuji juga diambil kira. Hubungan yang melibatkan posisi tidur dan BMI dengan keselesaan manusia dari segi suhu dan kelembapan relatif dibandingkan pada bahagian akhir kajian ini. Hubungan antara suhu dan kelembapan relatif yang diukur berkorelasi dengan data persepsi panas dan kelembapan yang diperolehi. Suhu yang diukur mengaitkan tahap kepanasan, manakala kelembapan relatif yang dicatat mengaitkan tahap kelembapan yang dinilai oleh subjek dalam process pengumpulan persepsi.

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Firstly, I would like to whole heartedly thank my supervisor, Dr, Abd Rahman bin Dullah from the Faculty of Mechanical Engineering UTeM for his wilful guidance, beneficial support and advantageous supervision towards the completion of this research.

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CHAPTER 1

INTRODUCTION

1.1 Background of the project

Human thermal comfort is a state of mind that reacts to the physical ease and relaxation of the body. Changes in climate and global warming phenomenon has brought imbalance in thermal environment around the world. Due to the exposure and the trending technologies, people have learnt to maintain their indoor thermal environment in order to keep up a good health and progress further in their lives. Solutions such as instalment of air conditioning system and creating a good indoor air circulation systems are brought up. However, people have started researching about new systematic solutions due to the emergence of energy saving problems and inflated economic positions. Research based on the study of local cooling has been trending. Local cooling can be accepted as one of the methods used to gain thermal comfort. Local cooling is a method to study the thermal condition of different parts of a human body since they are exposed to different thermal environment.

Sleep is a basic need for humans to move on with daily tasks and activities. In general, humans spend almost one third of their live by sleeping. Sleeping requirements for a certain individual may differ depending on age groups and their work done in a day. A person above 10 years old spends an average of 7-10 hours of sleep in a day. Hence they look forward to the betterment of comfort sleeping. While sleeping, the blood flow throughout the body and the corresponding contact area between human body and the surrounding varies depending on sleeping postures. Sleeping postures do affect the thermal comfort of a person. Initially, local cooling test has been conducted on humans with different sitting posture. In this study, the local cooling effect is tested on various parts of body while differing the sleeping postures. The local cooling test is tested in microclimate conditions where it is an atmospheric condition that vary from those in the surrounding.

1.2 Problem Statement

Sleep is a critical need for humans to have an optimal health condition and to carry out daily chores in a normal manner. In order to maintain a good sleep throughout, there is a need of thermal comfort. Without thermal comfort, human body undergoes an internal stress which results in health conditions. Due to the globalisation this world is undergoing, frequent extreme heat events occur. This causes human body to lose thermal comfort and end up not getting enough sleep on a regular basis. Sleep is being gradually recognized as a general health complication and also found that improper and irregular sleep strongly relates to vehicle accidents, industrial downfalls, as well as random errors. Death tolls and nonfatal accident events tend to rise linearly due to drowsy driving accounts. Long term chronic diseases such as hypertension, depression and obesity are more likely to be suffered by persons undergoing sleep deficiency. In this modern evolving society, shortage of sleep is often a result due to the ever busy work schedules.

However, there are many possible external factors resulting in the enhancement of a good night's sleep. Few of those factors are, maintaining a proper sleeping posture throughout the sleep, refurbishing the bedroom infrastructure and following a disciplined sleeping habits. Maintaining a proper sleeping posture based on human body's adjustment of thermal comfort may result in an improved sleeping time. Meanwhile, this can be tested using the local cooling test and the understanding of microclimate conditions.

1.3 Objectives

The objective of this project are as follows:

1. To study the effect of local cooling in microclimate conditions based on sleeping postures.
2. To investigate the effect of BMI on thermal comfort.

1.4 Scope of Project

The scopes of this project are:

1. Five subjects will be experimented by letting them lie in 3 different sleeping postures.
2. Experiment will be carried out using 6 sensors on different parts of the body such as head, chest, abdomen, back, thighs and legs. Relative humidity and thermal conditions will be measured accordingly.
3. Perceptions such as moisture and heat changes occurring throughout the experiment will be manipulated and set based on configurations being tested.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter will analyse researches and studies carried out related to local cooling effect on people with different sleeping postures. Section 2.1 describes the definition of thermal comfort and its effect on human body. Section 2.2 explains the idea of microclimate. Several methods used to analyse the microclimatic condition such as analytical method and simulation method is discussed in this section. Consequently, section 2.3 briefs about the development of thermoregulation and the human thermoregulatory behaviour. Meanwhile, the relationship between relative humidity and temperature and human thermal comfort is portrayed in section 2.4. Finally in section 2.5, studies focusing on the sleeping postures and the location of sensors on human body are discussed.

2.2 Thermal Comfort

The lead to a good life and to be effective in enduring the fast moving life, human being needs a comfortable environment in order to focus and take part in it. Conditions such as thermal sensation and thermal comfort plays an important role in achieving such desires. Thermal comfort is defined as the most comfortable condition where a person would like to be in, in relation with the persons' surrounding environment. However, environmental change and the earnestness of decarbonizing the current environmental condition are driving technological development in order to provide thermal comfort to people (Cde Dear et al. 2013). This in turn, results in ecological harm and undesirable practices that makes terrible impacts to surrounding. Therefore, the focus now is to study and implement an effective cooling method that does zero damage to the nature and serve the purpose of achieving a satisfactory level of human comfort.

Since thermal comfort is certifiably not a physical quantity but instead a state of mind, it is not possible to resemble specifically. Comfort models must be utilized to connect (simulate) physical attributes to these psychological factors. The improvement and refinement of comfort models is a generally new logical research field. MacPherson proposed six fundamental parameters which influence thermal comfort such as temperature, mean radiant temperature, relative humidity, air velocity, clothing and metabolism (Macpherson, 1962). A controllable thermal condition exposed individuals to this condition and requested to rate their comfort on a 7-point scale. From these tests, a model was created to foresee the thermal condition rating of a group of individuals dependent on the six MacPherson factors. This model is known as the Predicted Mean Vote (PMV) – model (Fanger, 1972).

The most remarkable process to take in count the level of thermal comfort of a human body is to get the perception straight away from the person. The survey questions inquired the sample's thermal sensation vote (TSV), also known as temperature, on the ASHRAE seven-point thermal sensation scale which are Cold (-3), Cool (−2), Slightly cool (−1), Neutral (0), Slightly warm (1), Warm (2), Hot (3). Whereas, sample's comfort level was questioned on a six point thermal comfort scale which are Very comfortable (1), Comfortable (2), Just comfortable (3), Just uncomfortable (4), Uncomfortable (5), Very uncomfortable (6) (Loomans et al. 2018). Thermal sensation vote (TSV) relies upon the experienced thermal condition of the surrounding. At points where the thermal condition contrasted significantly over the occurrences being compared with, the comfort temperature (Tc) is determined using the Griffiths' equation. This equation was also utilized for comparisons, to give a more unprejudiced viewpoint, since it depends both on TSV and the thermal condition. In the equation, the slope 'm' was taken as 0.5 (Humphreys et al. 2013).

2.3 Microclimate

Erell et al. (2011) stated that climate is a persisting condition of the environment in a proposed region. It is influenced by specific factors such as temperature, relative humidity, pressure, wind, precipitation and cloud cowl. Whereas, a microclimate is a local set of atmospheric condition where the climate varies from the surrounding area. The subject may refer to areas as small as a few square meters or as large as many square kilometers. Microclimates exist, as an example, close bodies of water which may cool the local atmosphere (Ragheb et al. 2016). A source of a temperature difference or humidity difference would influence the microclimate accordingly.

2.3.1 Analytical Method

In this analysis, the discomfort index (DI) which is an index fitting for urban spaces, was used to estimate the level of thermal comfort of human body. It is computed as a combination of air temperature and humidity and expresses the degree of thermal comfort under various microclimate conditions.

$$DI = T - 0.55\ (1\ - 0.01RH\ )(Tair\ - 14.5)$$

Equation 2.1 Relation of air temperature and humidity

Where Tair is the air temperature (°C), RH is the relative humidity (%). The purpose of the DI serves the feeling of discomfort that certain people express when they locate themselves in a certain area. To evaluate the feeling of discomfort, few limits were fixed, which are shown in the Table 2.1 (Yan et al. 2012).

Table 2.1 Values of DI and scale of discomfort

Scale	DI	Feeling of discomfort
1	< 21.0	None
2	21.0 ~ 23.9	< 50% of the population
3	24.0 ~ 26.9	> 50% of the population
4	27.0 ~ 28.9	Most of the population
5	29.0 ~ 31.9	Everyone
6	> 32.0	Phases of medical alarm

The thermal comfort computed as the Thom's discomfort index (DI), was determined based on calibrated values of air temperature and relative humidity. In a hot environment, and specifically, in a hot-humid summer environment, the greater the DI values are, the more uncomfortable it will be. Table 2.2 represents the measurements of discomfort index of different time frames in different microclimates.

Table 2.2 Discomfort Index of different time and different microclimate conditions

Community	Observation time							
	8：00	10：00	12：00	14：00	16：00	18：00	20：00	Mean
CK	29.6	30.4	31.3	31.3	30.4	29.2	28.5	30.1
Com.1	27.8	29.8	30.3	30.4	29.8	29.0	28.2	29.3
Com.2	27.5	29.2	29.3	30.0	29.4	28.7	28.3	28.9
Com.3	27.2	29.3	30.4	30.5	30.0	29.0	28.2	29.2
Com.4	27.2	29.3	29.8	29.9	29.6	28.6	28.2	28.9
Com.5	27.7	29.1	29.6	29.6	28.9	28.6	28.1	28.8
Com.6	28.2	29.3	30.5	30.1	29.4	28.5	28.0	29.1
Com.7	27.6	28.9	29.5	29.6	29.3	28.6	28.1	28.8
Com.8	28.4	29.7	30.1	30.3	29.7	28.4	28.1	29.2

2.3.2 Simulation Method

2.3.2.1 Analysis of microclimatic thermal comfort of human by Finite Element Analysis

Kaynakli and Kilic exhibited two researches, where the first one introduced a theoretical and experimental analysis of the in-cabin thermal comfort amid the heating time frame by isolating the human body into 16 portions, with the difference in temperature estimated and determined in both experimental and theoretical premise. The air temperature, air speed and relative moistness inside the automobile were obtained experimentally through numerous sensors circulated over the compartment (Humphreys et al. 2013).

While, Kaynakli's second research confronted a model for thermal connections between the human body and the interior environmental condition inside the vehicle. Additionally the impacts of both warming and cooling forms were analyzed. The model utilized relies upon the heat balance condition for human body (portioned into 16 sections), with experimental conditions characterizing the perspiration rate and mean skin temperature (Macpherson, 1962).

The National Renewable Laboratory (NREL) enhanced the current models by expanding the quantity of body sections and the model was improved using a finite element analysis surrounding condition. Their physiological model comprised of 126 portions, the skin temperature, the perspiration rates, and the breathing rate. Consequently, these information are transmitted to the manikin to anticipate the body's reaction to the environment. Likewise, this model determined the conduction heat transfer depending on the temperature slope between the tissue nodes (Fanger, 1972).

2.3.2.2 Analysis of microclimate around human body by CFD method

As of late, the subject of indoor air conditions has drawn consideration, concentrating on issues, for example, the requirement for a high level of air tightness to ration energy utilized in the room, and the IAQ (Indoor Air Quality) identified with compound substances, for example, VOCs (Unpredictable Organic Compounds), and so on. Humans play an important role in indoor environmental issues, regardless of whether they are issues identified with air quality or comfort assessment. In analysing any indoor environment issue, the most critical thing is to illuminate the connection between the human body and the surrounding condition.

In recent years, the introduction of CFD (as an alternative method to local cooling method) has advanced and made it conceivable to research in detail about the microclimates that are made around the human body. Accordingly, a wide range of microclimates that surround the human body have been researched, for example, the ratio between the amount of convective heat transfer and radioactive heat transfer released from the body, the attributes of the upward wind stream produced around the body, the wind stream encompassing the mouth while respiration, and similar analyses, none of which could have been made prior to the introduction of CFD. Clarifying these situations has given important details that has prompted to the design of more agreeable and energy saving indoor conditions, to the design of conditions with a lower air contamination load.

2.3.2.3 Analysis of Radiation-Convection Couple

Murakami et al. (1998) states that the discharge of heat to the environment by human body can be categorized to three methods. Heat loss by radiation, heat loss by convection and heat loss by convection. Same amount of heat is loss by the methods mentioned. Therefore, in order to fully understand the microclimates created around the human body, it is vital to analyze precisely the radiative heat transfer coupled with the convective one. Figure 2.2 shows a flow chart for the coupled analysis of radiation, convection and moisture movement.

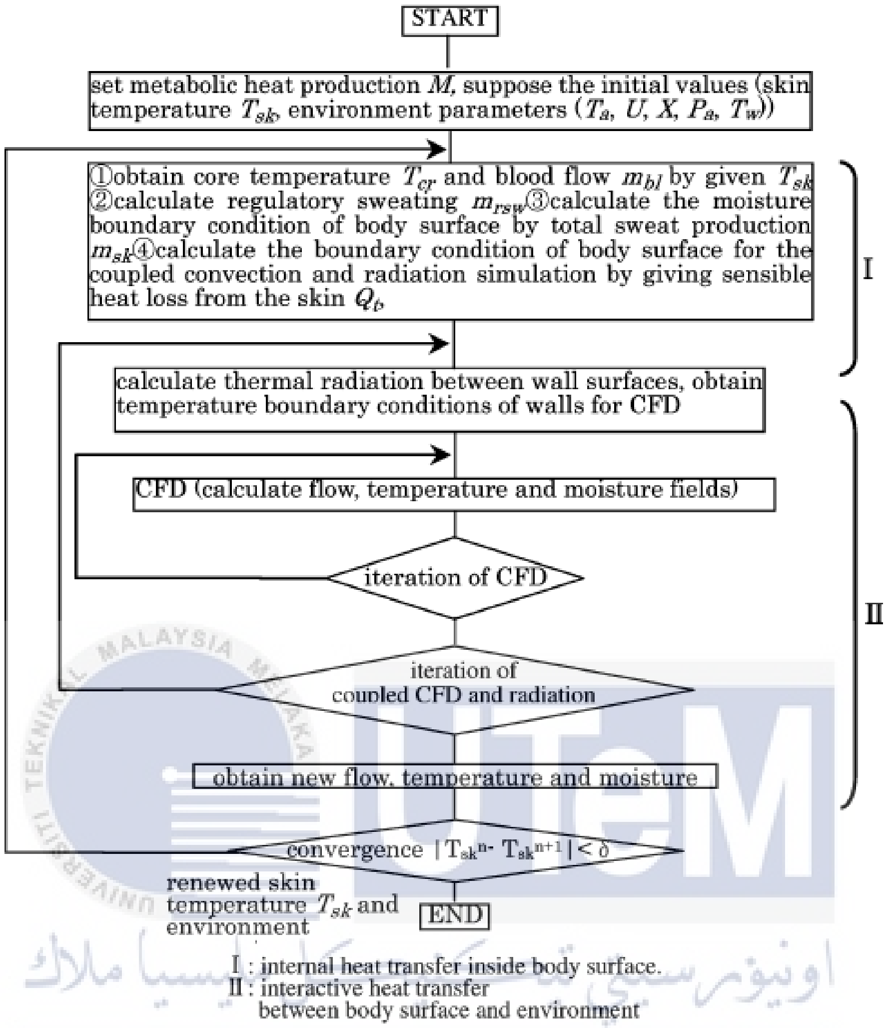

Figure 2.1 **Flow chart of combined simulation of airflow, radiation and moisture movement (Murakami, 2004)**

Reference of part I is heat transfer simulation inside human body, whereas Part II refers to heat transfer between human body and surrounding condition. Both parts correlates by the surface temperature of the body.

2.3.2.4 Microclimate around human body in sleeping position

In Figure 2.4, Kasahara et al. (2002) explains the upward airflow surrounding the human body during sleep. It also presents the upward flow and a circulating flow filled in the room were produced around the upper part of the human body. The room model used in this research as shown in Figure 2.3, was predicted to be in a naturally ventilated condition with heating. The upward airflow was set at an extremely low velocity. Figure 2.5 shows the result of the CFD assumption.

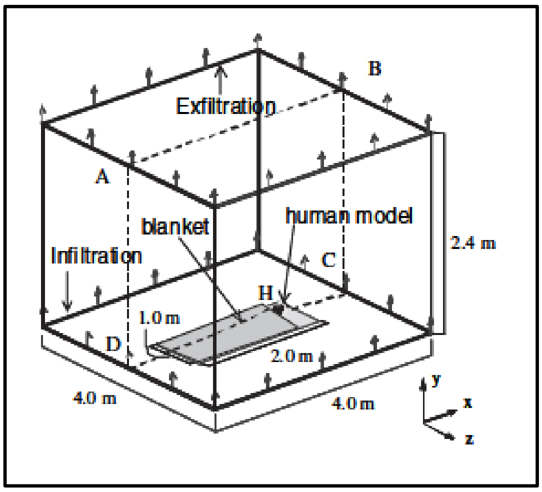

Figure 2.2 Room model tested (Murakami, 2004)

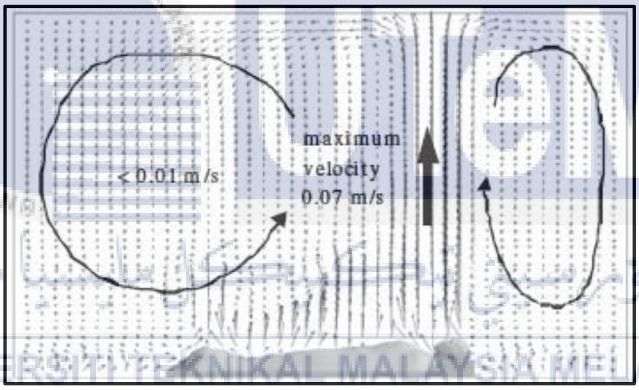

Figure 2.3 Velocity-vector field in terms of CFD (Murakami, 2004)

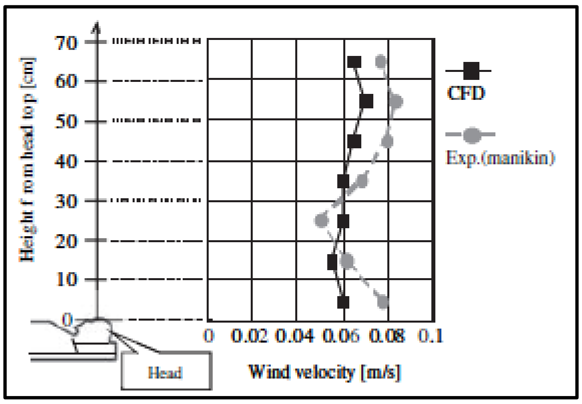

Figure 2.4 Correlation of CFD and experiment method (Murakami, 2004)

2.4 Thermoregulation

2.4.1 Introduction

Thermoregulation is an internal process that grants human body to retain its core internal temperature. All thermoregulation systems are designed to recover human body to a state of equilibrium which is also known as homeostasis.

A normal internal body temperature falls within a narrow window. The baseline temperature of an average human body is between 37°C and 37.8°C. Human body has some resilience with temperature. However, if temperature gets to an extreme level, it can affect the body's ability to operate normally.

When the internal temperature of a human body fluctuates, sensors in the central nervous system (CNS) send pulses to the hypothalamus. In return, it sends signals to various organs and systems in the body. They respond as a feedback through a variety of mechanisms.

There a few processes that takes place in the human body when the body needs to cool down. These mechanisms that takes action are stated below.

Sweating process takes places when the sweat glands discharge sweat, which cools the skin as it evaporates. This helps regulate the internal body temperature to a normal level.

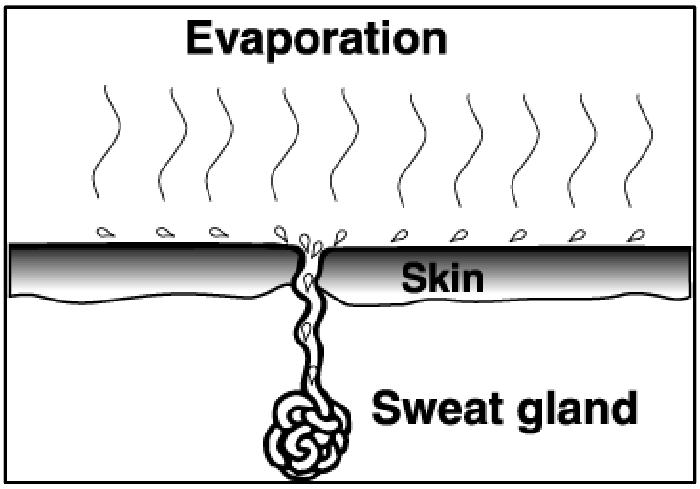

Figure 2.5 Sweating process (Romanovsky, 2007)

Vasodilatation process happens when blood vessels under the skin get expanded. This significantly increases blood flow to the skin where it is cooler, practically away from the warm inner body. This lets the body exchange heat through heat radiation.

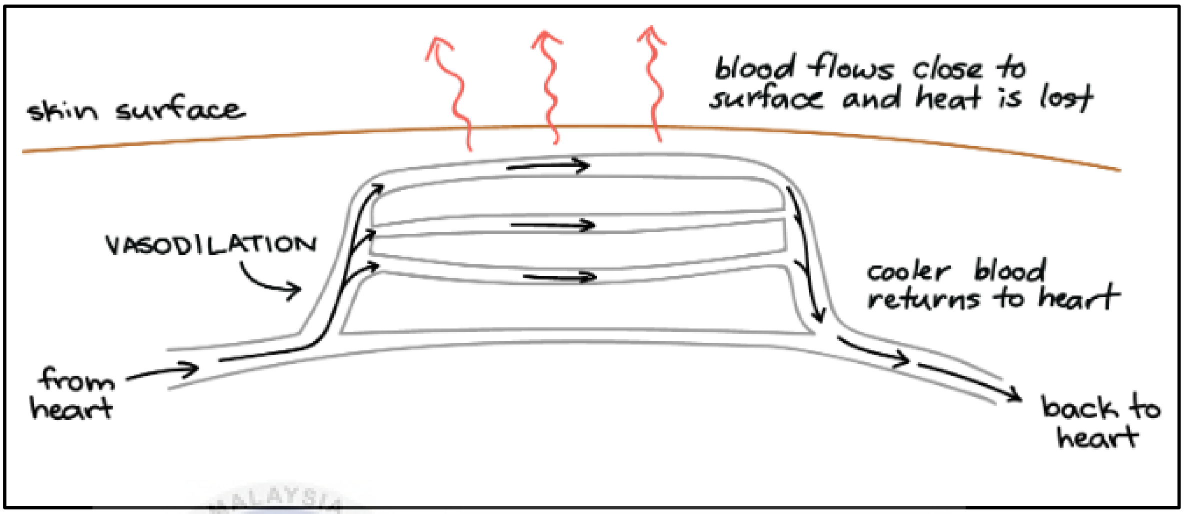

Figure 2.6 Vasodilation Process (Romanovsky, 2007)

There a several other processes that takes place in the human body when the body needs to warm up. These processes that takes action are explained below.

Vasoconstriction process undergoes a process where blood vessels under the skin become cramped. This declines blood flow to the skin, preserving heat near the warm inner body.

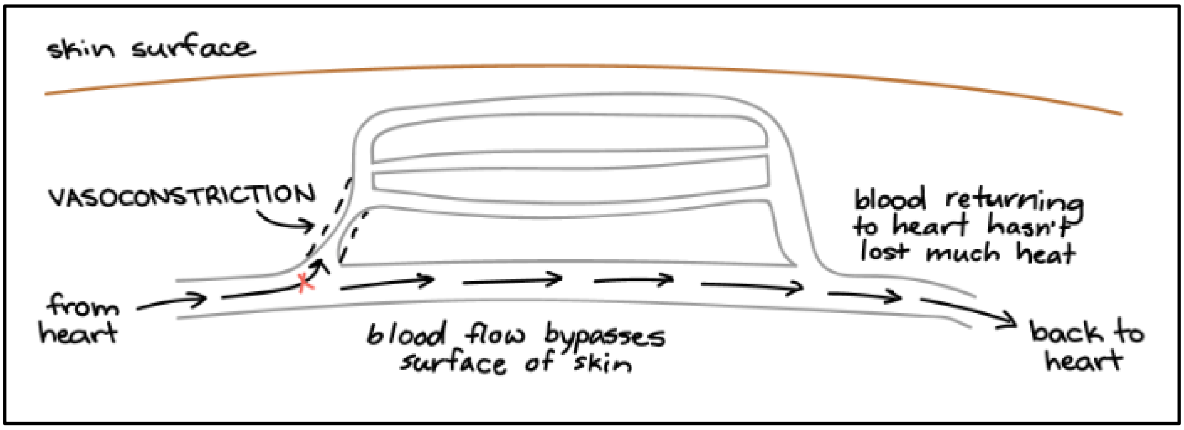

Figure 2.7 Vasoconstriction Process (Romanovsky, 2007)

Thermogenesis happens when the production of heat in a variety of ways through the human body’s muscles, organs, and brain. For instance, muscles can produce heat by shivering.

Hormonal thermogenesis, in contrast takes place when the thyroid gland releases hormones in order to increase the metabolism of the body. This eventually increases the energy that the body forms and the amount of heat it dissipates.

In conclusion, when the internal body temperature fluctuates to an abnormal level, the body will take steps to regulate it back to a decent range. This process is known as thermoregulation. It helps to ward off or retrieve the body from potentially dangerous conditions, such as hypothermia.

2.4.2 Characteristics of the human thermoregulatory behaviour

Behavior is often neglected as a physiological parameter in the regulation of body temperature, but it is a vital system by which people and other homeothermic endotherms thermoregulate. While the autonomic systems in charge of temperature control have a restricted limit, the abilities of behavioral temperature regulation are boundless and surpass those of changes, for instance, in metabolism (Benzinger, 1969) or perspiring better known as sweating. It has been proposed that the role of thermoregulatory behavior is in prevention of an imminent thermal insult, acting to avoid stimulation of energy as well as water-absorbing autonomic reactions (Romanovsky, 2007).

Difference in both skin and core temperatures have been involved in intervening the thermoregulatory behavior in numerous species (Almeida et al. 2006). In humans, it has been demonstrated that, when given thermo-behavioral flexibility, behavior is a suitable endeavor to avoid an adjustment in the core temperature, and consequently, skin temperature is recommended to be the thermal input probably activating the thermoregulatory behavior (Cabanac et al. 1971).

An improved behavioral reactivity to heat has been exhibited in non-human homeotherms such that behavioral responses to heat emerge in a more exact regulation of the thermal inputs such as skin as well as core temperatures, when contrasted with cold

(Chatonnet, 1965, Frank, 1999). Nonetheless, the main observational understanding relating to this 'asymmetrical (Romanovsky, 2007) behavioral regulation of temperature in humans is the perception that the thermal sensation results to be more definite when the skin is being heated instead of being cooled (Chatonnet, 1965).

2.4.3 Experiment Protocol (Shuttle-box as a thermoregulatory model)

Two different climatic chambers utilized in the experimental duration where one was hot and the other one was cold. The inception of exit from the hot chamber plays the role of the thermoregulatory behavior point. The rectal temperature, mean skin temperature, thermal comfort and time are the vital points in both chambers prior to the initiation of release.

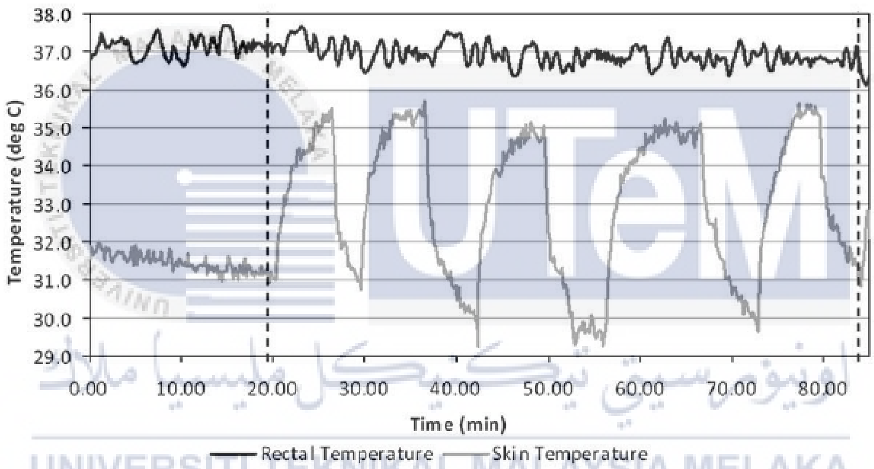

Figure 2.8 Skin and rectal temperature as a function of thermoregulatory behavior in one subject. Dashed lines indicate the commencement (left) and completion (right) of the shuttle box procedure (Frank et al. 1999)

2.5 Relative Humidity and Temperature

Relative humidity can be defined as the level of water vapour in the air in proportion to the equilibrium level of water vapour in the air at a given temperature. It plays a combined role of the real moisture content of the atmosphere, the temperature, and the barometric pressure. Human being are sensitive to humidity, as the skin depends on surrounding air to avoid moisture. While recording moisture conditions in indoor environment, it is important to take in count human comfort, human health and effectiveness as well as the energy consumed to regulate the air in the building. At present, the factors by which humidity influences comfort are not completely known. Air humidity influences evaporation of moisture from human skin and consequently has an effect on human body heat loss and thermal sensation. High air humidity may cause uneasiness regardless of thermal neutrality. This might be caused by a high level of skin humidity.

2.5.1 Influence of temperature and relative humidity on general activity in warm environment

The relative humidity and the rate of air changes have been perceived as vital parameters, and multiple researches on the impacts of environmental conditions on thermal sensation and work yield in industrial settings were completed (Rugh et al. 2004). Analysis have revealed a slowing of focused race performance (Ely et al. 2007; McCann and Adams 1997) as wet-bulb globe temperature (WBGT) inflates. Despite the fact that the significance of humidity for effective thermoregulation amid exercise, particularly in warm conditions, has been perceived in these analysis, there has been no precise analysis to affirm and evaluate this impact. While Armstrong (2000) detailed that steady state core temperature during exercise would expand in proportion to the relative humidity at ambient temperatures above 16 degrees Celcius. The significant increase in body center temperature creates a straightforward impact on the central nervous system instead of to any metabolic, cardiovascular or respiratory restriction (Nielsen et al. 1993). As the temperature slope between the skin and the air is small under these conditions, the ability to dissipate heat through radiation and convection is restricted to a certain level only. Eventually, the body turns out to be over dependent on evaporation to balance the body temperature, with heat lost because of the latent heat of vaporization of water from the respiratory tract and the skin surface. At the point when relative humidity is low and the skin temperature is high, sweat discharged onto bare uncovered skin is promptly vanished and heat can be exchanged at high rates from the body to the surrounding. Contrarily, when the relative humidity of surrounding is high, the rate at which sweat vanishes from the skin is lower than it would be under dry conditions. This would probably result in a marked increment in core temperature although the loss of sweat takes place (Maughan et al. 2011).

2.6 Sleeping Postures

Sleeping postures play an important role in achieving the thermal comfort of human body. Sleeping postures may vary for different people based on their comfort of body posture and body temperature. Sleeping on the back is by far the healthiest option of sleeping postures for most people. This posture allows the head, neck and spine to be in a neutral position. Besides, sleeping on the side keeps the spine elongated and avoids back and neck pain. This position enhances blood circulation especially when you sleep on the left side. Thirdly, sleeping on the stomach is another common option, even though it leads to back and neck pain due to the difficulty to maintain a neutral position of the spine. All these postures never disturbs the circulatory of blood in human body. Nonetheless, sleeping on the back regulates the blood circulation efficiently.

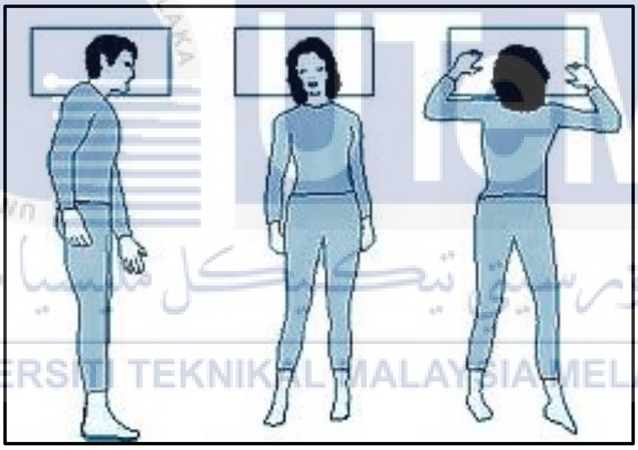

Figure 2.9 Types of Sleeping Postures

2.6.1 Sensor Location on Human Body

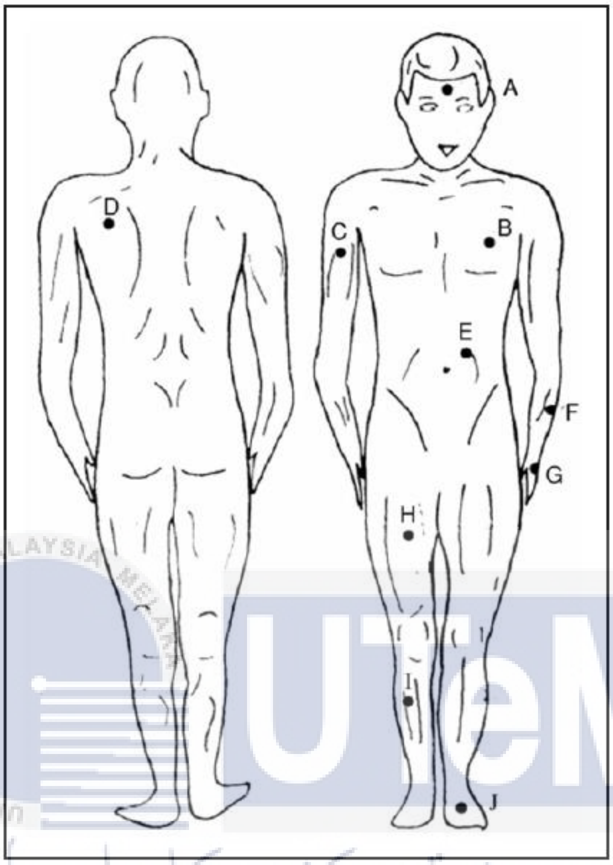

Figure 2.10 Sensor location on human body. A- forehead, B- chest, C- upper arm, D- back, E- abdomen, F- elbow, G- hand, H- anterior thigh, I- anterior calf, J- foot (Liu et al. 2014)

CHAPTER 3

METHODOLOGY

3.1 Introduction

In the process towards achieving the objectives mentioned, there will be a set of approaches which will thoroughly be observed throughout this chapter. In order to describe the sequence of the project, this chapter will begin with an overall project flowchart as shown in Figure 3.4. Steps needed to be taken towards the progress of this analysis will briefly be stated in the flowchart as a synopsis of how the development of thermal comfort on people in sleeping posture using the local cooling approach will take place. The three sleeping postures and the location of sensors at the body parts will be explained in the diagram below.

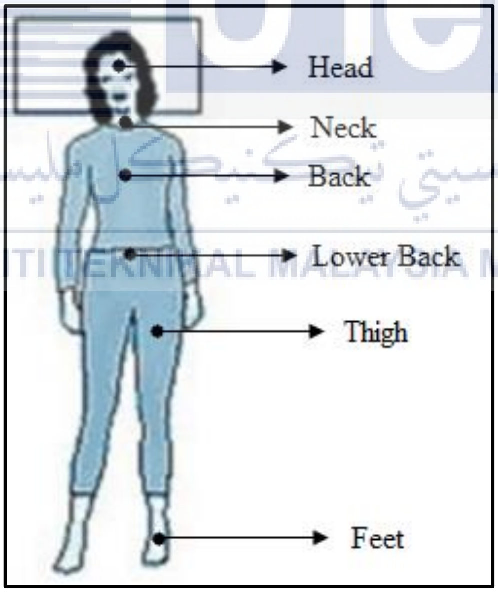

Figure 3.1 Sleeping Posture 1 (Back)

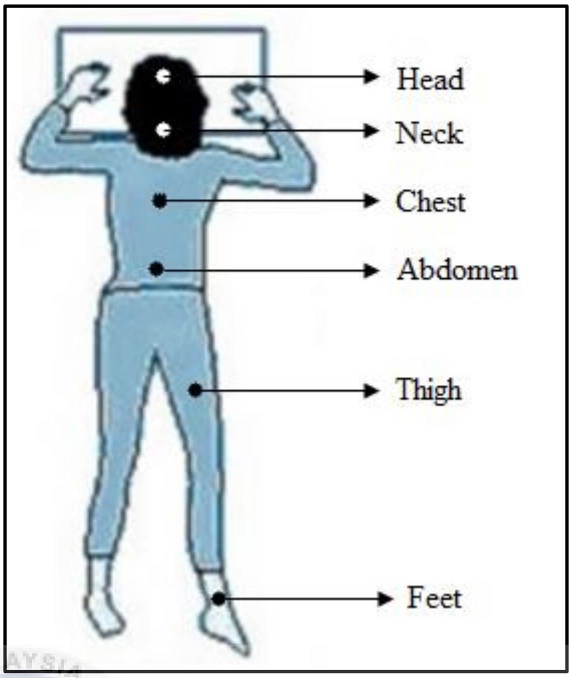

Figure 3.2 Sleeping Posture 2 (Front)

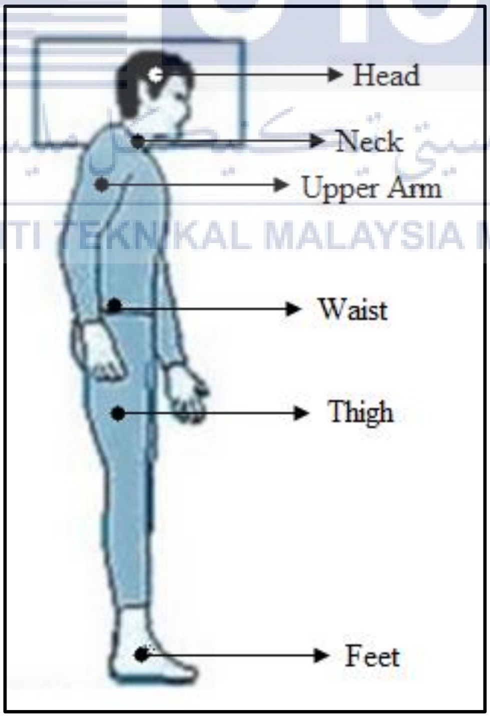

Figure 3.3 Sleeping Posture 3 (Side)

3.2 Overall Flowchart

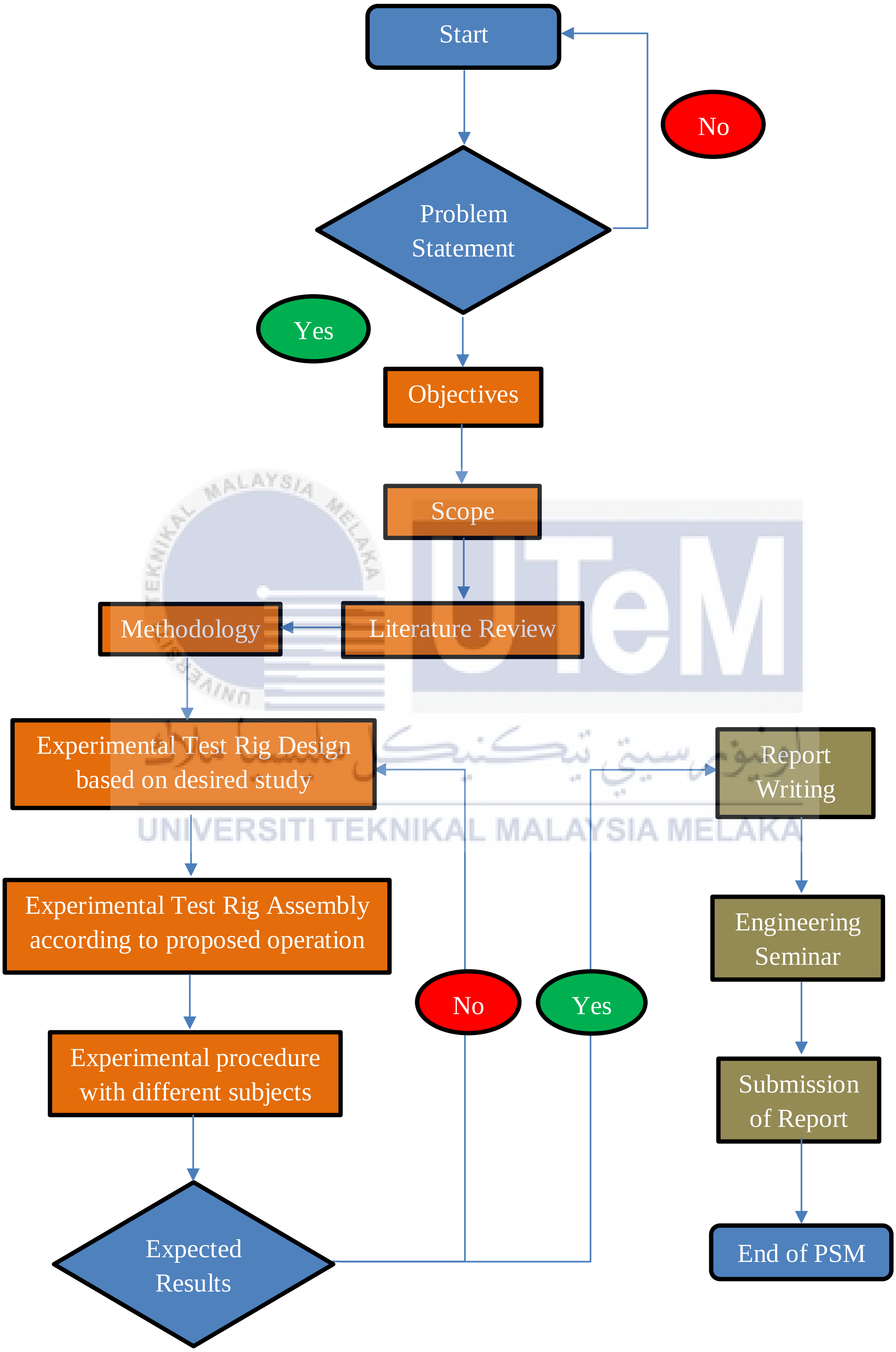

Figure 3.4 Flowchart Diagram

3.3 Chronology of Project

The fulfilment of this project depends on every vital procedure that will be done throughout the analysis. Important parameters such as objectives, scope and problem statement is well-established in order to ensure a smooth flow of the project. Objectives set for this project is to be able to study the effect of local cooling in microclimate conditions based on sleeping postures and to investigate the effect BMI on thermal comfort. However, before the initiation of the project, it is important to find out the key points and brief description on the research done previously which creates a path to the review of literature such as journal and research papers. They resemble a general idea and informative understanding on the analysis done before and upcoming study that should be done for better knowledge.

It is important to determine the experimental setup so that the study can be conducted. Hence, a test rig is prepared as per requirement of the study. Required parts making up the whole system is listed and assembled. The project is further be followed by the fabrication process. Consequently, the test rig section which differentiates the type of postures which are to be tested is developed. Once the room model and the necessary equipment are prepared and tested, the experiment is conducted with first type of sleeping posture. Simultaneously, data collection using sensors and also perception takes place. Once completed, the same experiment is conducted with a different sleeping posture. Necessary parameters such as the ambient temperature, relative humidity and microclimate temperature are observed and readings are recorded at a prefixed interval. Based on data collected, analysis is made by comparing the manipulating factor in the test.

3.4 Parts and Components

Parts and components used to build the local cooling system will be described in following sub sections. The function and method of use will also follow suit.

3.4.1 Test Rig Section

The test rig section is made up of a bed, a plywood sheet and a mattress. Different postures are tested as mentioned in the objectives. A plywood sheet with a dimension of 2 metres by 0.8 metre is placed on a simple bed made of steel. There are 22 holes being punched on the plywood sheet and the mattress in order for the sensor and cable wires to go through.

Figure 3.5 Test Rig Section

Figure 3.6 Sensor fitted through the plywood hole

3.4.2 Data Logger and Sensors

Data used in this testing are temperature and relative humidity of body parts. It is logged by a Senserion temperature and humidity kit. Sensors used are of model EK-H4. It is connected to a personal computer via USB for data analysing and tabulation purposes. It has an easy plug-and-play system. Data is collected at a predefined interval time relevant to the experiment to determine major changes.

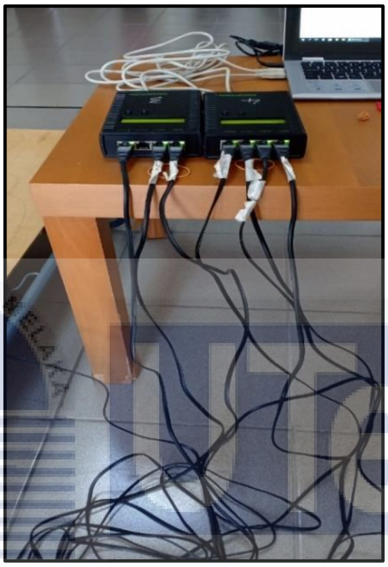

Figure 3.7 Sensirion Data Logger

Figure 3.8 Sensor EK-H4 model

3.4.3 Sensor cables

Sensor cables are used to connect the EK-H4 sensors to the multiplexer box device. The cables are of length three metres and are attached to a RJ45 plug. These are high performance cables and enables an in-depth evaluation.

3.5 Data Measurement

For experiment purposes, certain data is required to be measured prior and during the testing. These data displays the system's performance based on the parameters observed. Measured data include temperature, relative humidity and time. The table below display tools used for measurement of the following parameters.

Table 3.1 Data measurement details

Parameter	**Instrument**	**Unit**
Height of subject	Measuring Tape	Centimetres (cm)
Weight of subject	Weighing Scale	Kilogram (kg)
Time	Stopwatch	Second (s)
Temperature	Sensirion Evaluation Kit	Degree Celcius (°C)
Dew Point Temperature	Sensirion Evaluation Kit	Degree Celcius (°C)
Relative Humidity	Sensirion Evaluation Kit	Percentage (%)
Absolute Humidity	Sensirion Evaluation Kit	Grams per Cubic metre (g/m3)

3.6 Experimental Procedure

A test rig section is prepared before testing the first subject, where the plywood sheet is placed on the bed and the mattress is placed on the plywood sheet. Sensors are fixed to the mattress and connected to the data logger. Five subjects are asked to arrive 20 minutes prior to the experiment time at different times, in order to regulate the temperature and humidity of their body parts. The subject’s height and weight will be taken to obtain the BMI.

Next, out of the seven sensors, one is placed somewhere in the surrounding in order to observe and record the ambient temperature. The other six sensors are prefixed on the mattress based on the height of subjects. The subject is asked to lie on the bed according to the first posture. Data of temperature and relative humidity are observed and recorded in an interval of 5 seconds for a total of 30 minutes. A perception form is filled by the examiner by asking the rate of temperature and humidity in a scale of hot to very cold (temperature), very dry to very humid (relative humidity). This form is filled in every 5 minutes interval. Upon completion, the data recorded is analysed in the results and discussion section. This procedure is repeated for a total of 3 times for one subject, manipulating the sleeping posture thrice. 2 of the total 5 subjects are tested in a hot environment, where a blanket is used to cover the subject from head to toe. The other 3 subjects are tested without the use of a blanket which means a cold environment. Hence, a total of 15 experiment will be tested. The readings and graph plots will be obtained from the software in the personal computer.

Table 3.2 Body location tested

Sensor Count	Body Location Tested
1	Head
2	Neck
3	Back/Chest
4	Abdomen
5	Thigh
6	Feet
7	Ambient

Table 3.3 BMI details of subjects

Subject	Height (m)	Weight (kg)	BMI
1	1.83	70.2	21.0
2	1.90	68.6	19.0
3	1.70	65.5	22.7
4	1.88	115.3	32.6
5	1.67	95.5	34.2

CHAPTER 4

RESULT AND DISCUSSION

4.1 Experimental Setup

An experimental setup is developed as shown in Figure 4.1. This setup includes mainly a test rig section for posture variation (posture 1-back, posture 2-front and posture3-side). Six micro-sensors will be slotted to a mattress which will be placed on the plywood sheet and one micro-sensor will be left aside to measure ambient air data. Position of the six micro-sensors will be in place at the subject’s head, neck, back/chest, lower back/abdomen, thigh, feet respectively. These micro-sensors will be connected to the Sensirion data logger which will interpret the data into table. The data will then be analysed and plotted into graphs for each position in regards of each posture.

The human subjects will undergo a 30 minutes testing period in each sleeping posture. Once human subjects arrive at the test rig room, their weight and height will be recorded at first before resting for 10 minutes. Resting purpose is to regulate their body temperature beforehand. Between the testing of each postures, another 10 minutes rest will be given for the same reason stated above. There will be a perception data collected verbally from the subjects during the test. Two of the subjects will be tested with a blanket over them. This means these two subject’s testing environment is considered to be the warn environment compared to the other subject who are tested in a cold environment.

Figure 4.1 Test rig section

4.2 Data and Results

4.2.1 Subject 1

Temperature-time graph

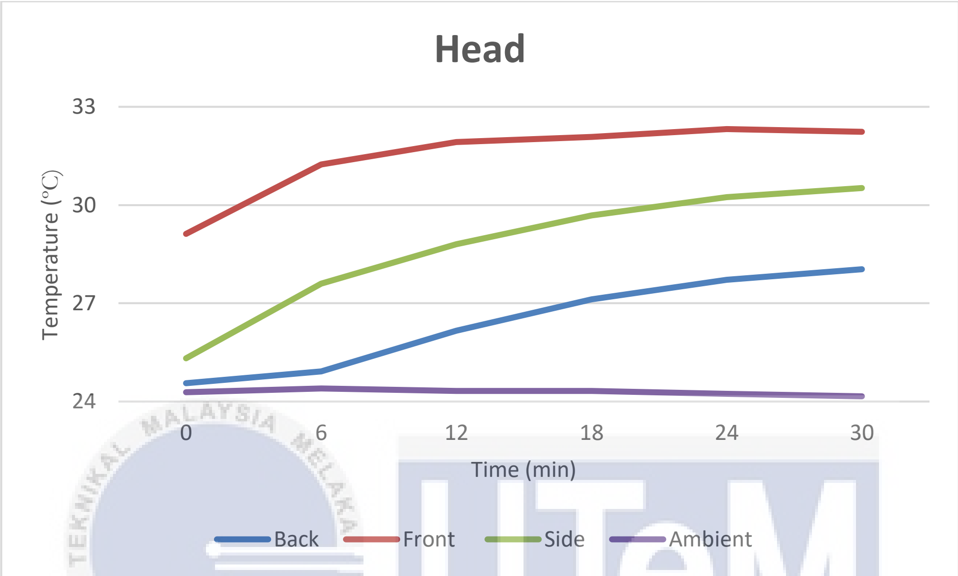

Figure 4.2 Head sensor for temperature graph

Relative humidity-time graph

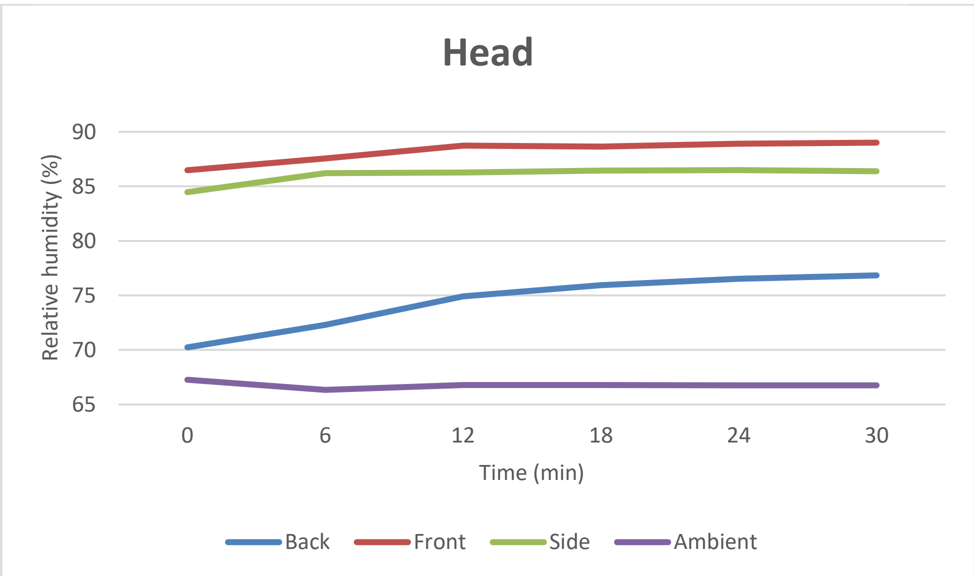

Figure 4.3 Head sensor for relative humidity graph

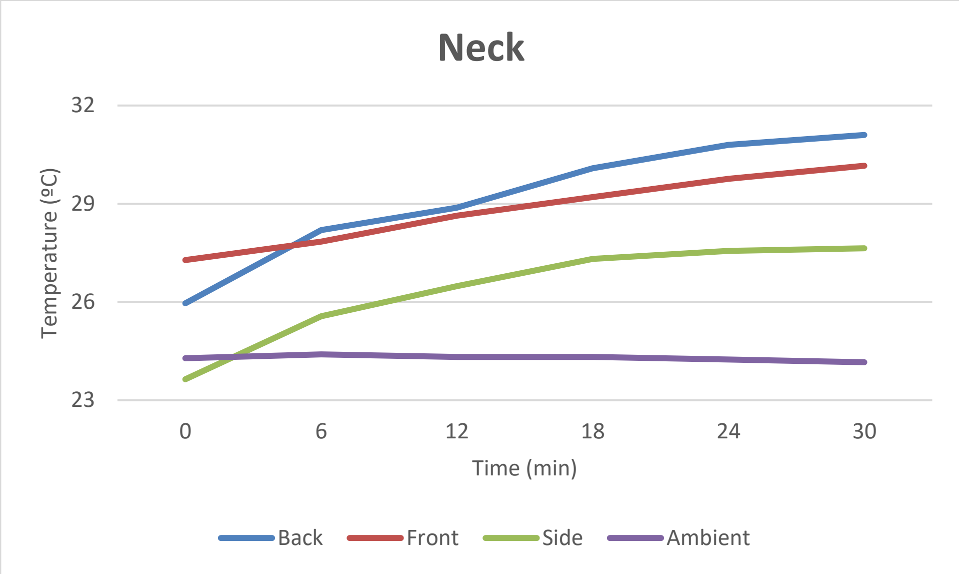

Figure 4.4 Neck sensor for temperature graph

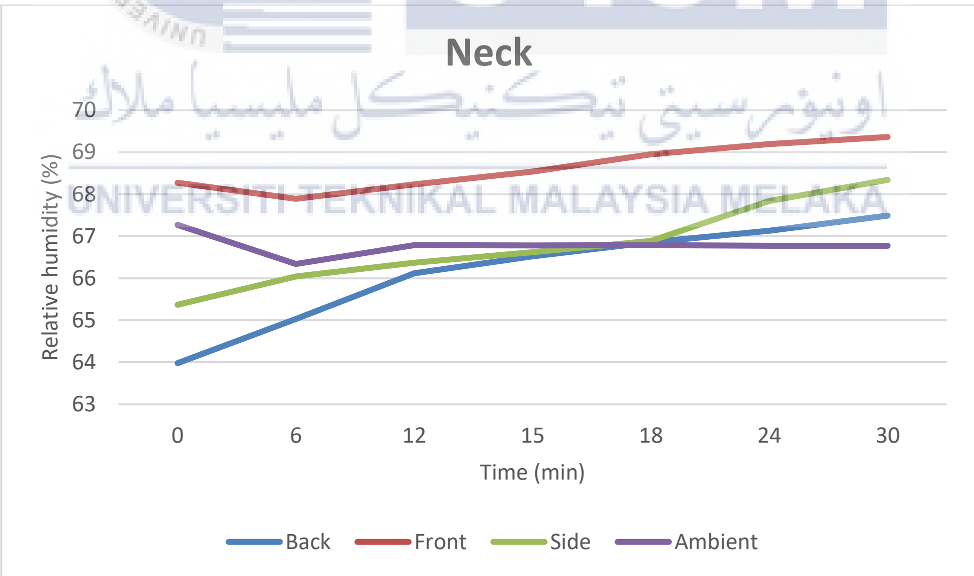

Figure 4.5 Neck sensor for relative humidity graph

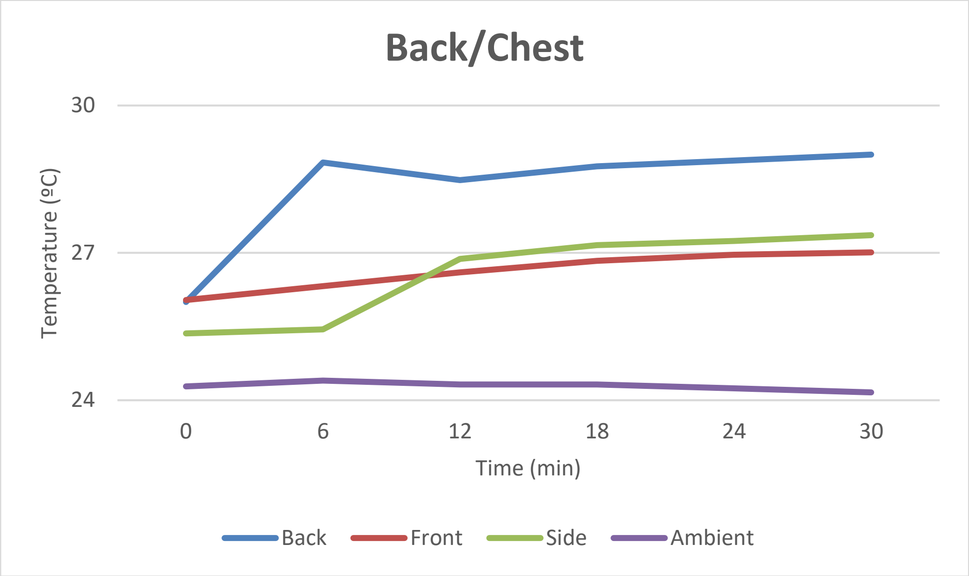

Figure 4.6 Back/Chest sensor for temperature graph

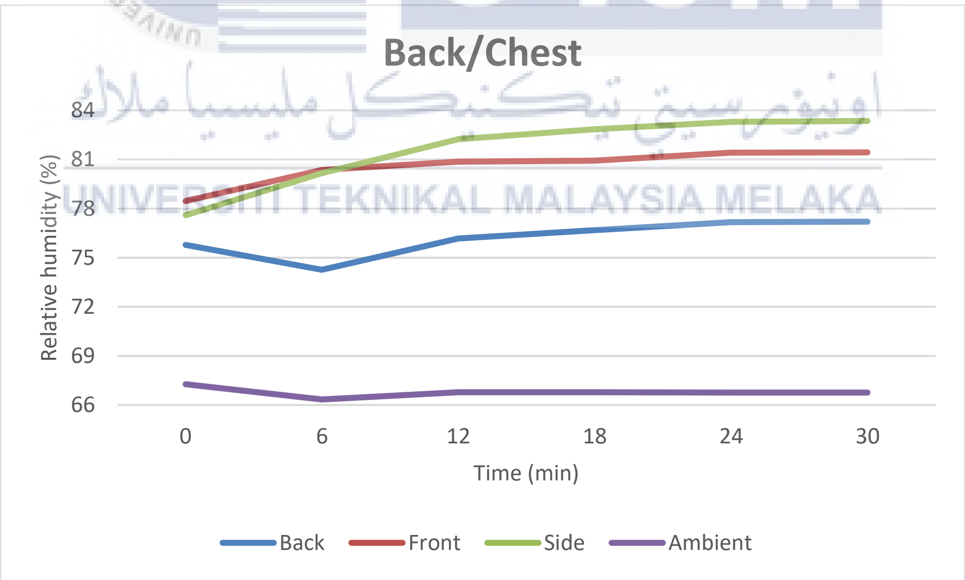

Figure 4.7 Back/Chest sensor for relative humidity graph

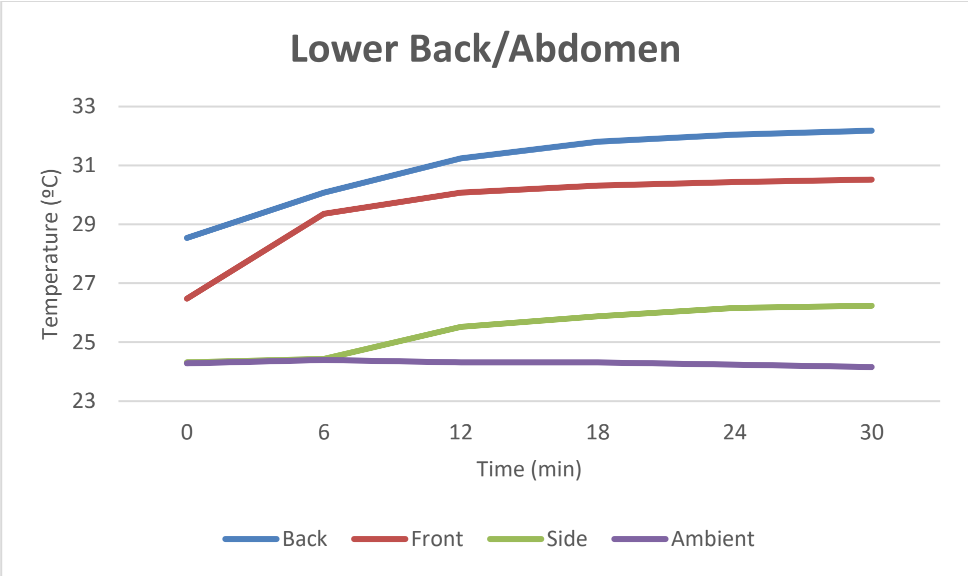

Figure 4.8 Lower back/Abdomen sensor for temperature graph

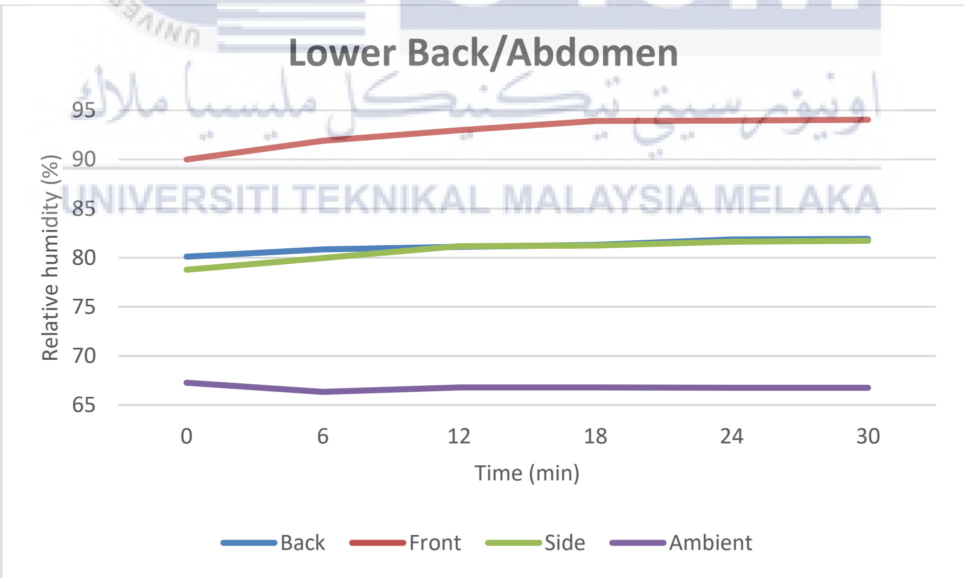

Figure 4.9 Lower back/Abdomen sensor for relative humidity graph

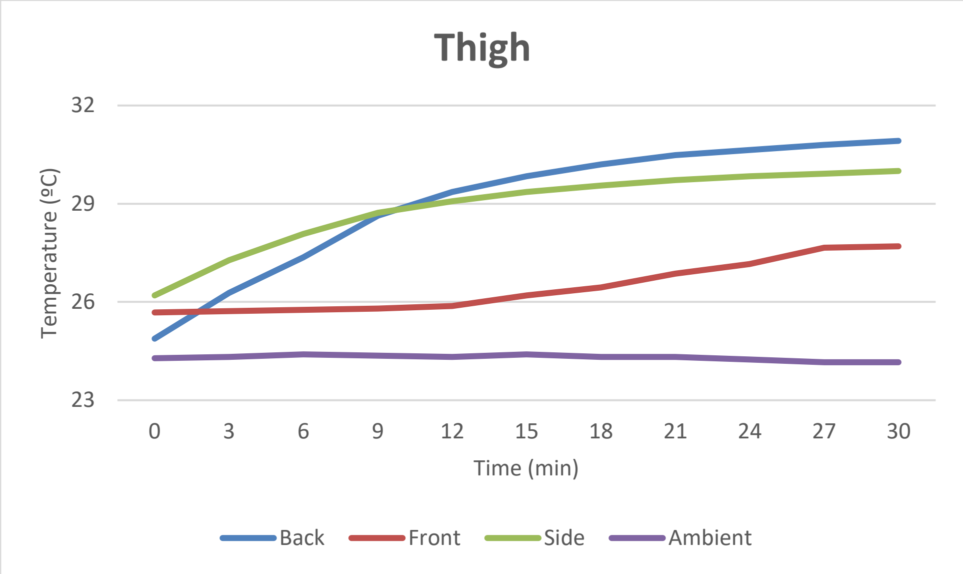

Figure 4.10 Thigh sensor for temperature graph

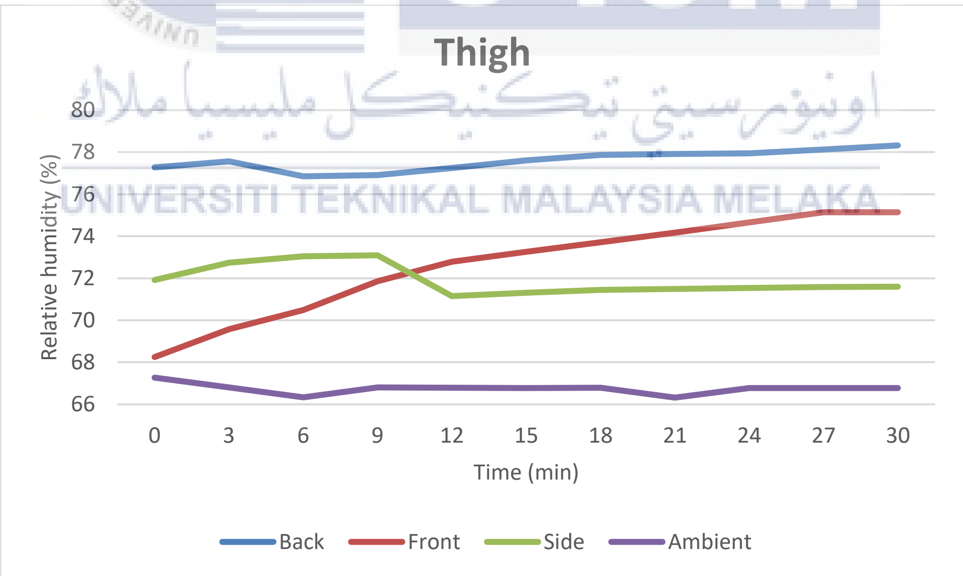

Figure 4.11 Thigh sensor for relative humidity graph

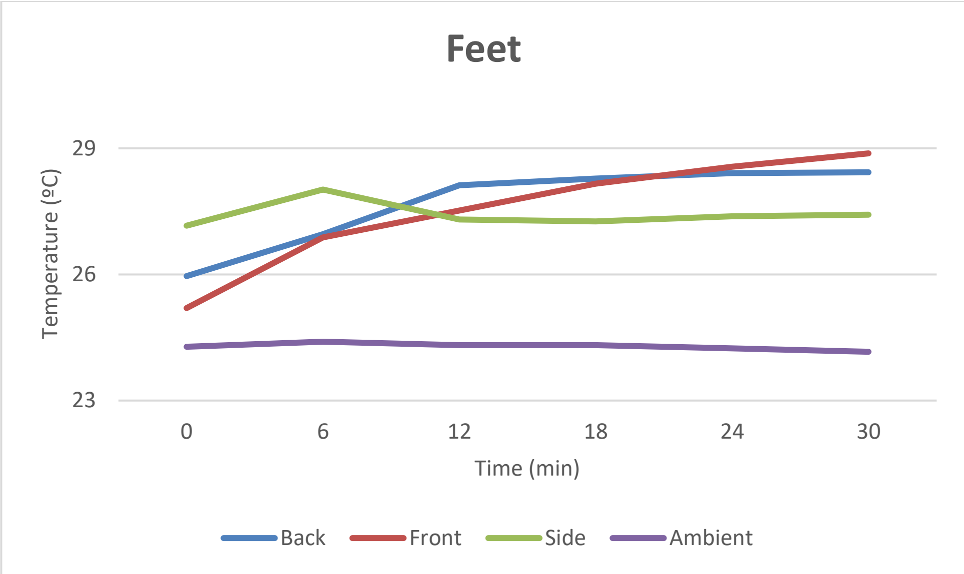

Figure 4.12 Feet sensor for temperature graph

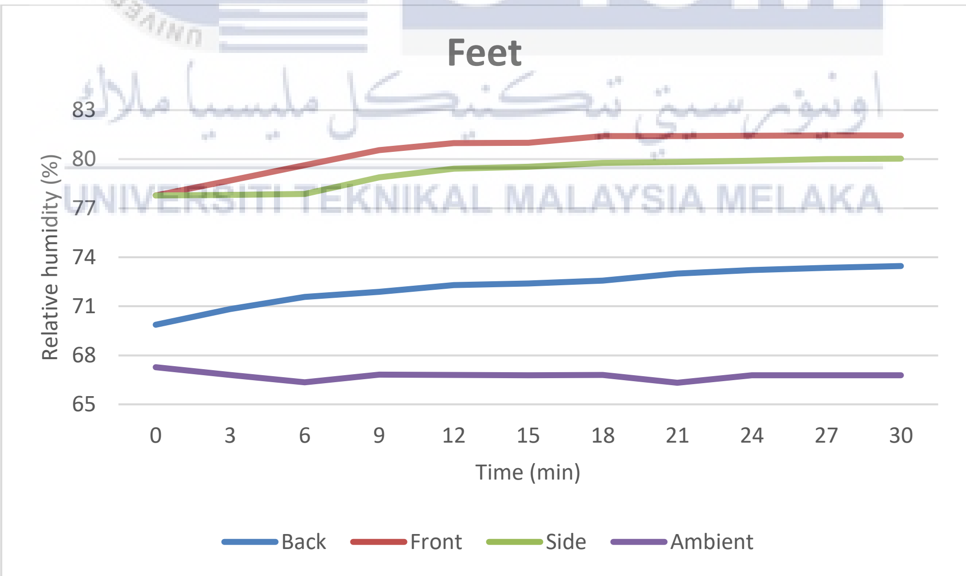

Figure 4.13 Feet sensor for relative humidity graph

Human Perception

Factor/ Rating	1	2	3	4	5
Temperature	Very Cold	Little cold	Moderate	Little warm	Very warm
Humidity	Very dry	Little dry	Moderate	Little humid	Very humid

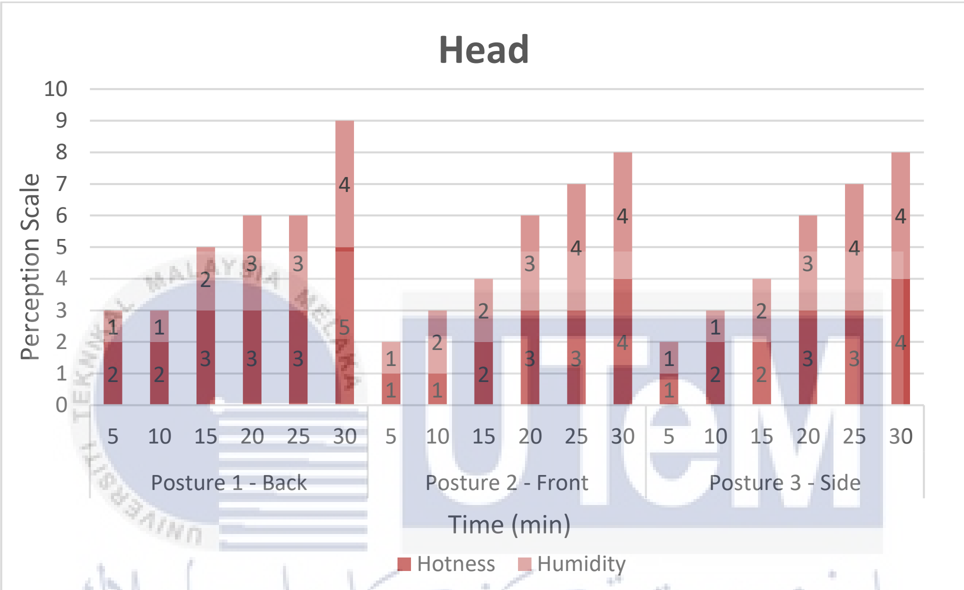

Figure 4.14 Human perception scale for head sensor

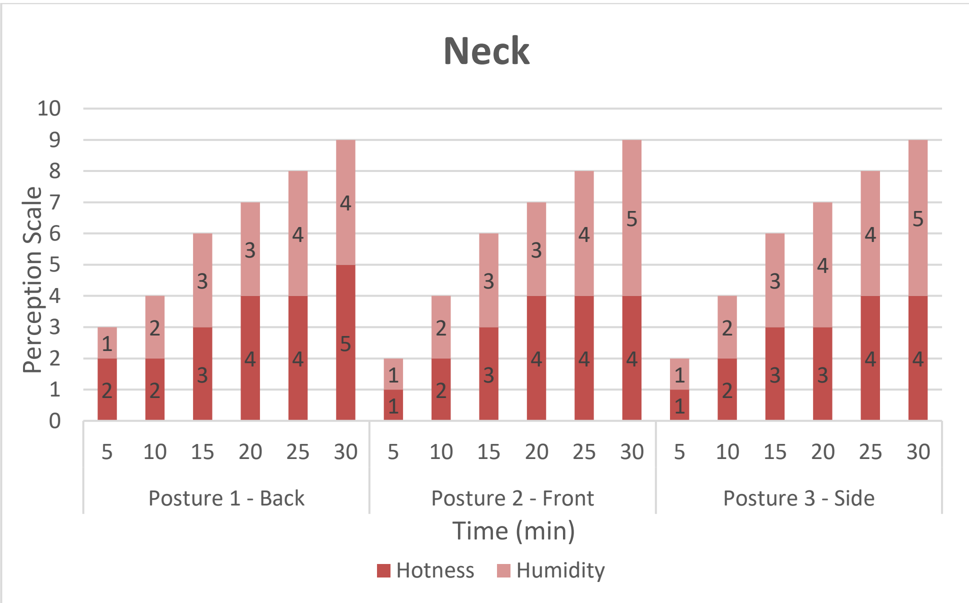

Figure 4.15 Human perception scale for neck sensor

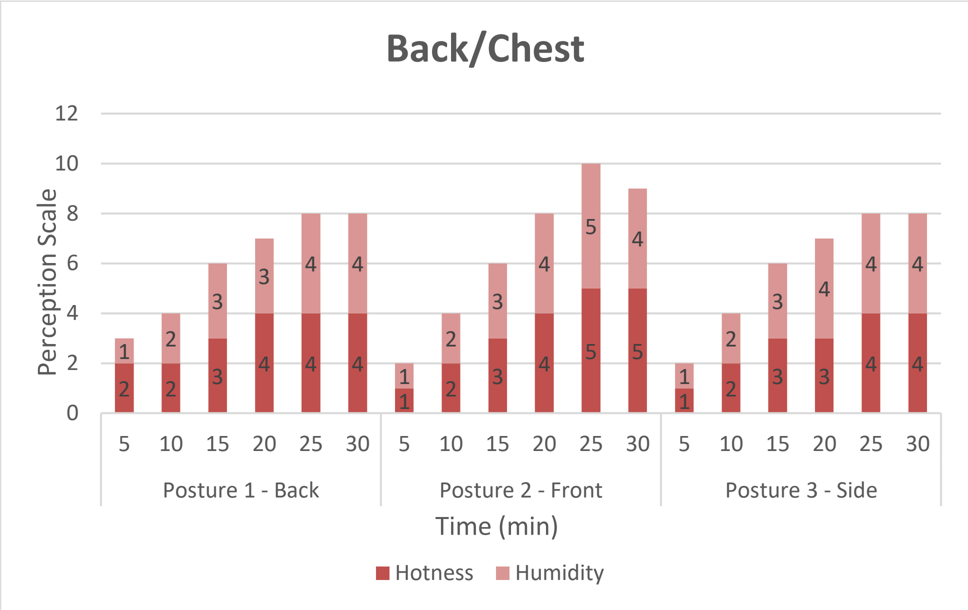

Figure 4.16 Human perception scale for back/chest sensor

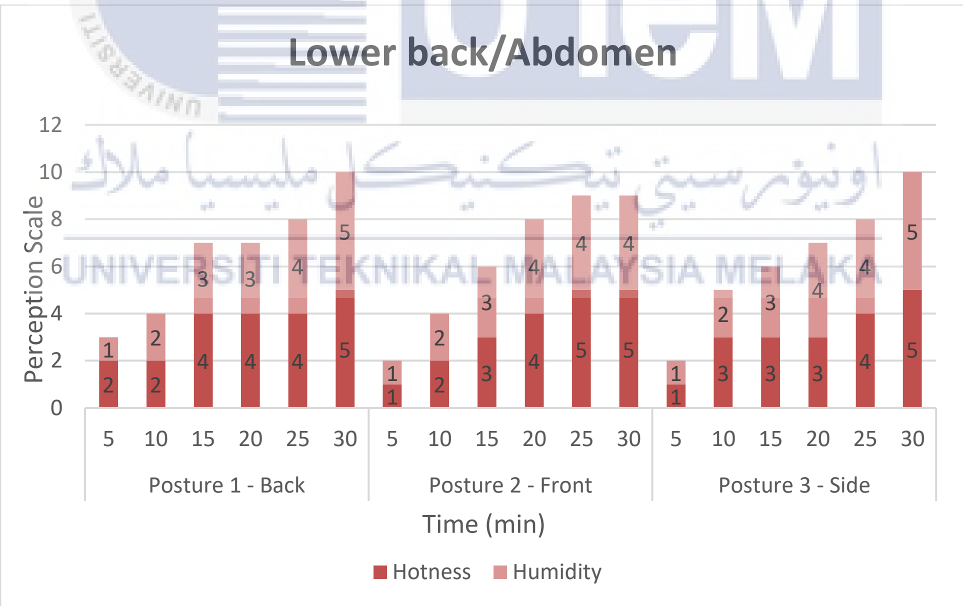

Figure 4.17 Human perception scale for lower back/abdomen sensor

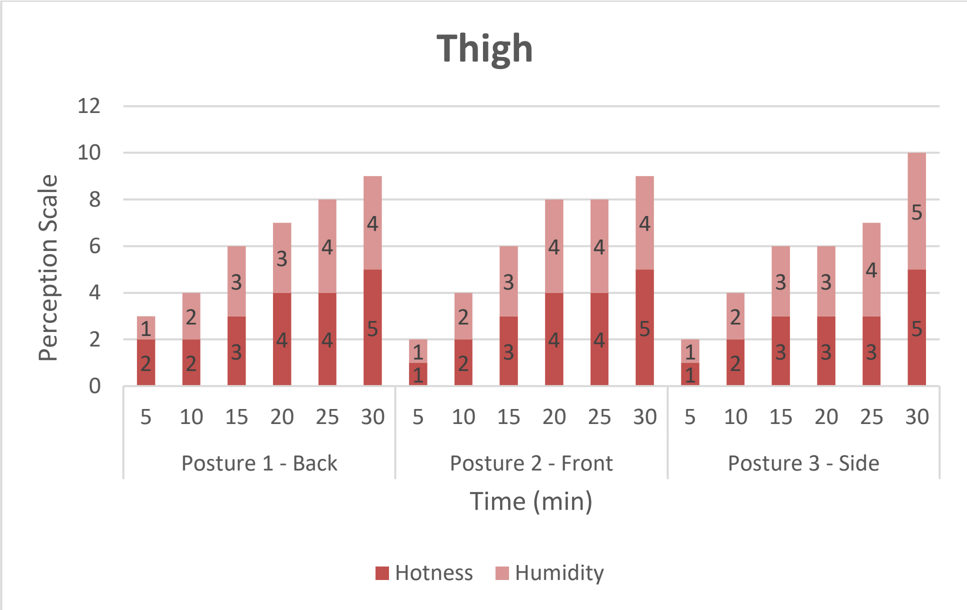

Figure 4.18 Human perception scale for thigh sensor

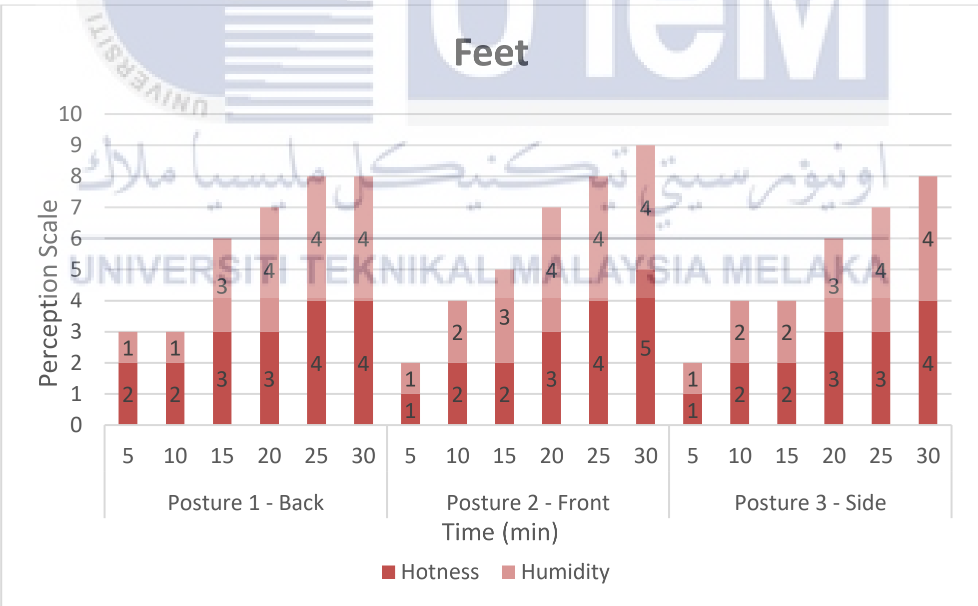

Figure 4.19 Human perception scale for feet sensor

4.3 Discussion

4.3.1 Overall average graphs of temperature and relative humidity for each posture

4.3.1.1 Posture 1 – Back

Temperature-time graph

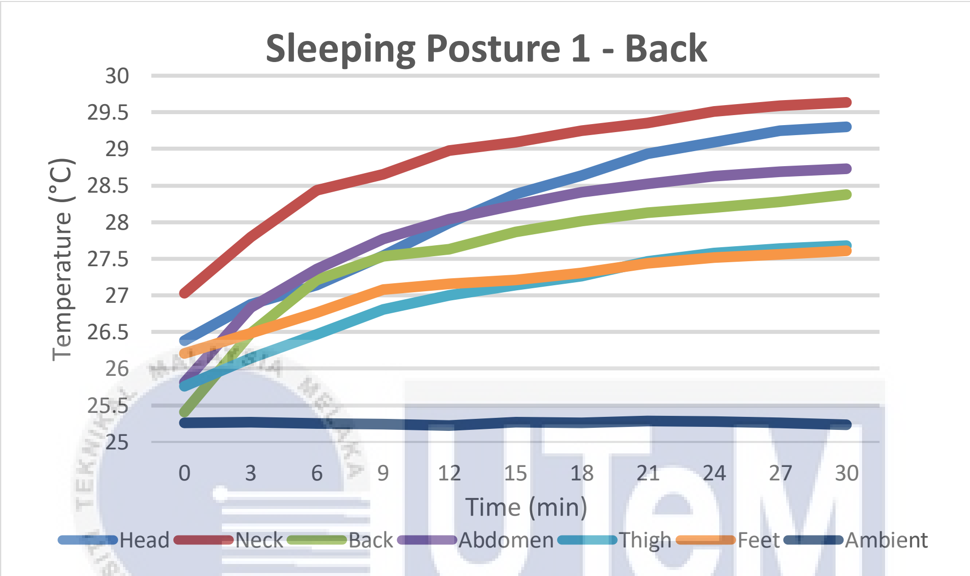

Figure 4.20 Overall average graph for Posture 1 (Temperature)

Relative humidity-time graph

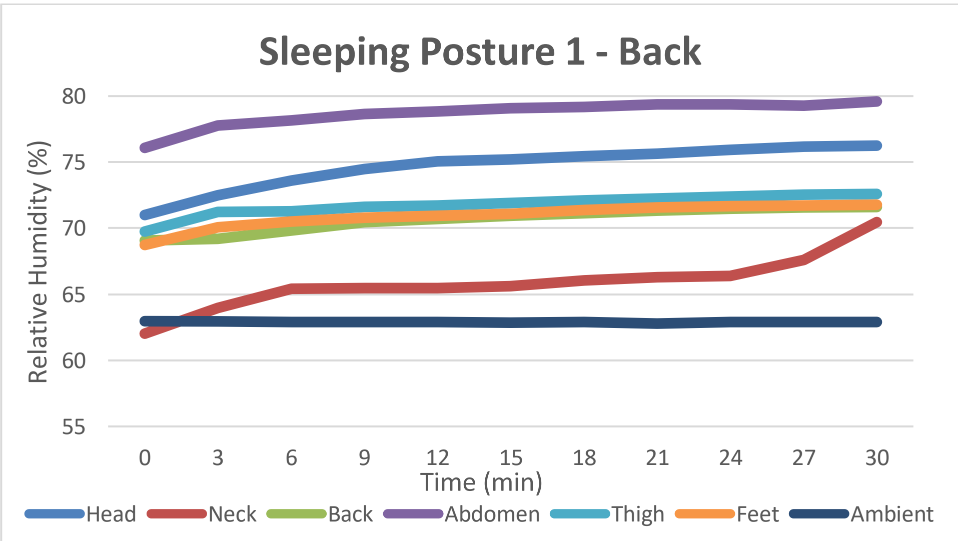

Figure 4.21 Overall average graph for Posture 1 (Relative humidity)

Sleeping posture 1 in the experiment means lying on back facing up. Figure 4.20 above shows the overall average relationship between temperature and time for each position of micro-sensor for all the subjects for sleeping posture 1. Likewise, Figure 4.21 shows the overall average graph relationship between time and relative humidity for each position of micro-sensors for all the subjects for sleeping posture 1. Each testing period took 30 minutes and the data were observed and collected.

Based on the graph findings in Figure 4.20, the neck sensor has measured a high value of temperature in average compared to the other sensors. At the end of the 30 minutes testing period, the readings reaches almost a constant value. As for the head sensor, it started at a temperature point same as the other sensors but the end of the test period, it has reached almost the temperature value of the neck sensor. All the other sensors seemed to have started at a same point of temperature and increased simultaneously until the reading have reached a point at range of 1°C difference. The ambient sensor measures a constant temperature value throughout the test period.

As shown in Figure 4.21, the lower back/abdomen sensor has recorded the highest value of relative humidity since the start to the end of the testing period. Whereas, the head sensor has recorded the second highest value of relative humidity in a similar manner with the abdomen sensor. The back, thigh and feet sensors have recorded a constant value of humidity from the beginning until the end of the testing period. Finally, the neck sensor has a relatively low value of humidity at the beginning stage before hiking up to reach the value of the humidity of the other sensors. The ambient sensor obtains a constant value of relative humidity throughout the test period.

4.3.1.2 Posture 2 – Front

<u>Temperature-time graph</u>

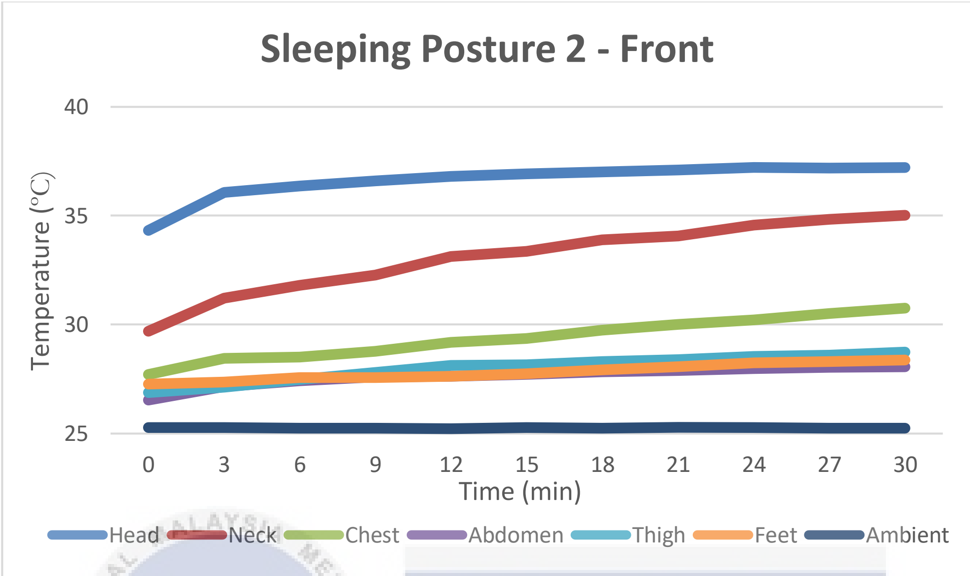

Figure 4.22 Overall average graph for Posture 2 (Temperature)

<u>Relative humidity-time graph</u>

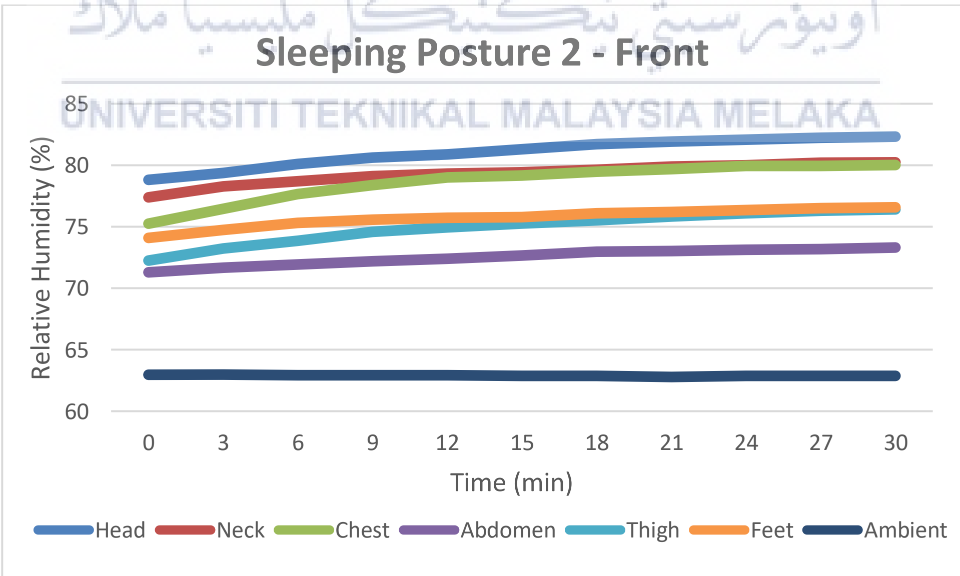

Figure 4.23 Overall average graph for Posture 2 (Relative humidity)

Sleeping posture 2 in the experiment means lying on the front facing down. Figure 4.22 above shows the overall average relationship between temperature and time for each position of micro-sensor for all the subjects for sleeping posture 2. Furthermore, Figure 4.23 shows the overall average graph relationship between time and relative humidity for each position of micro-sensors for all the subjects for sleeping posture 2. Each testing period took 30 minutes and the data were observed and obtained.

From the graph shown in Figure 4.22, the head and neck sensors stand out from the other sensors with head sensor having a higher value of temperature value throughout compared to the neck sensor. The chest sensor has a higher value of temperature compared to the abdomen, thigh and feet sensors, but it records a lower value than the heads and neck sensors. The sensors fixed at the abdomen, thigh and feet have recorded a same value of temperature from beginning to the ending of test period, with no much temperature difference. As per normal, the ambient sensor has a constant value throughout the testing period.

Based on graph 4.23, to justify the high temperature value of head sensor, the highest value of relative humidity also is taken by the head sensor. The neck sensor is next to the head sensor in terms of higher value of relative humidity while chest sensor also joins neck sensor and has the same relative humidity at the end of the testing period. The value of relative humidity for the abdomen, thigh and feet sensors is relatively low in regards of the low temperature value. The ambient sensor holds a constant value of relative humidity throughout the testing period.

4.3.1.3 Posture 3 – Side

Temperature-time graph

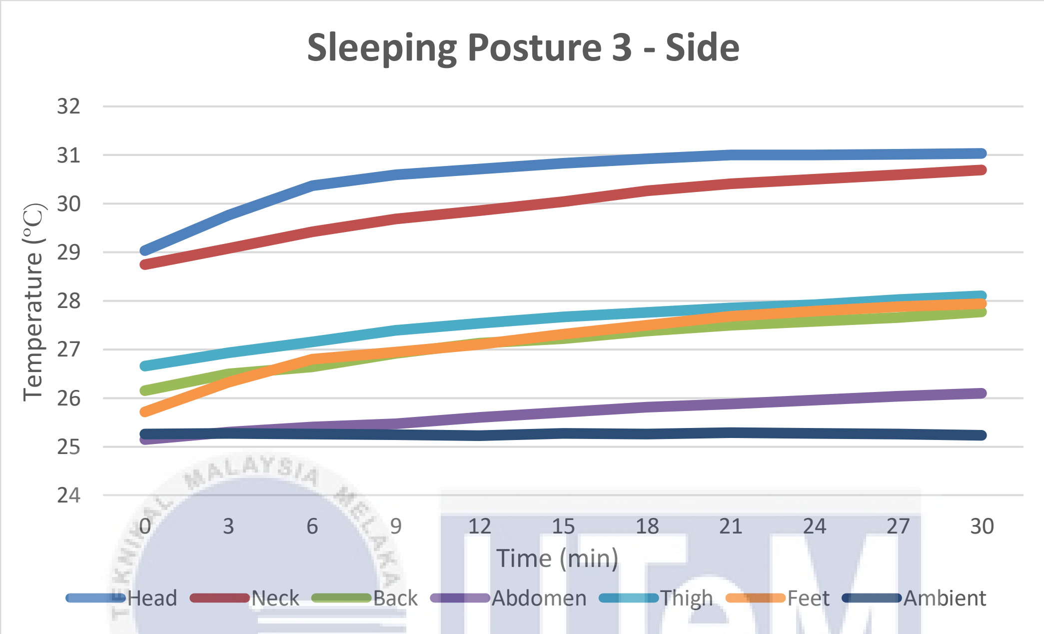

Figure 4.24 Overall average graph for Posture 3 (Temperature)

Relative humidity-time graph

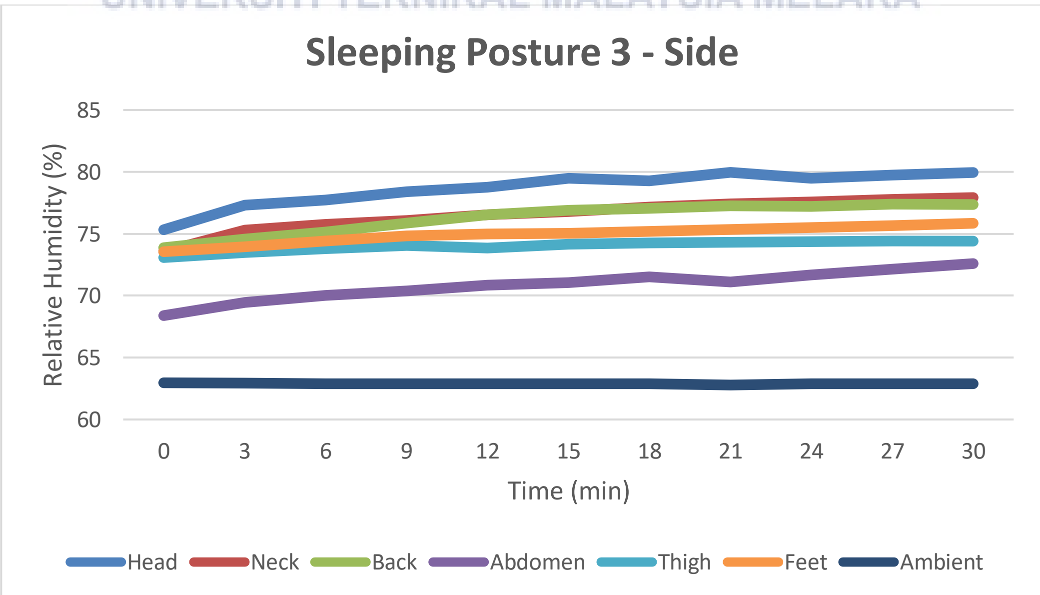

Figure 4.25 Overall average graph for Posture 3 (Relative humidity)

Sleeping posture 3 in the experiment means lying sideways. Figure 4.24 above shows the overall average relationship between temperature and time for each position of micro-sensor for all the subjects for sleeping posture 3. Besides, Figure 4.25 shows the overall average graph relationship between time and relative humidity for each position of micro-sensors for all the subjects for sleeping posture 3. Each testing period took 30 minutes and the data were observed and recorded.

Referring to the Figure 4.24, the head sensor recorded the highest value of temperature while neck sensor being just below the temperature value of head sensor. The back, thigh and feet sensors have recorded slightly different values of temperature at the beginning of the testing period but all the three sensors have obtained almost the same temperature value at the end of the testing period. Meanwhile, the abdomen sensor has recorded a lower value of temperature at the beginning of the testing period in this sleeping posture. This is because in this position, the confined space from the sensor and the body surface has a larger area due to the curve of the body. However, at the final stage of testing period, the sensor has recorded a hike in the temperature value. The ambient sensor holds a constant temperature value throughout the testing period as usual.

In the graph shown in Figure 4.25, it can be seen that the highest value of relative humidity is held by the head sensor. The relative humidity value of the neck, back, thigh and feet sensors begin at a constant point, however, the neck sensor records a slightly higher value compared to the other sensors. But there is not much of a difference in the value of relative humidity at the end of the testing period. The range of difference in temperature values is about 4°C. Besides, the abdomen sensor has a lower value of relative humidity compared to all the other sensors in general. Whatsoever, there is an increase in the value of relative humidity as time passes by for the abdomen sensor. The ambient sensor obtained a constant value of relative humidity throughout the testing period.

4.3.2 Overall comparison graphs for each sleeping postures at head sensor

4.3.2.1 Posture 1 – Back

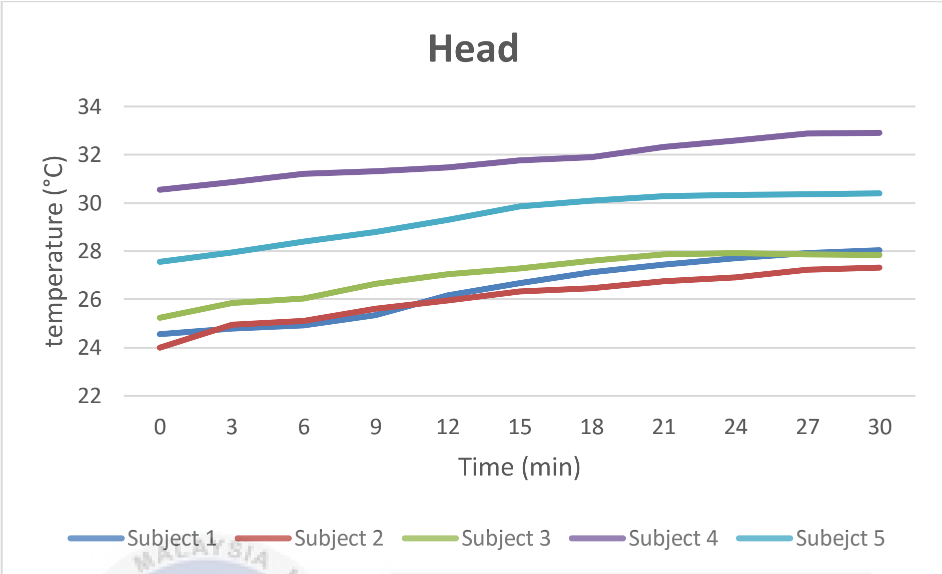

Figure 4.26 Overall graph of temperature for Posture 1 (Head sensor)

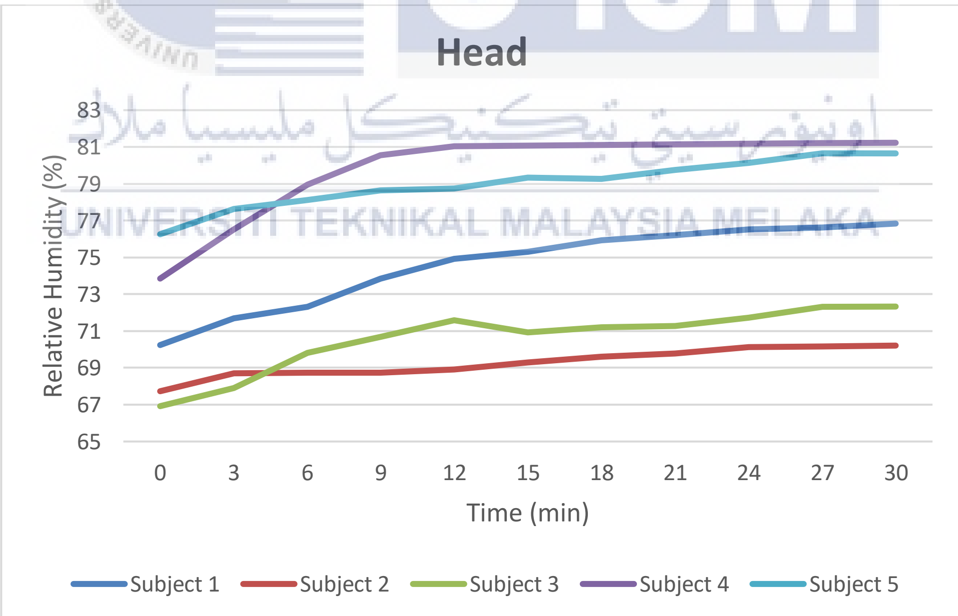

Figure 4.27 Overall graph of relative humidity for Posture 1 (Head sensor)

4.3.2.2 Posture 2 – Front

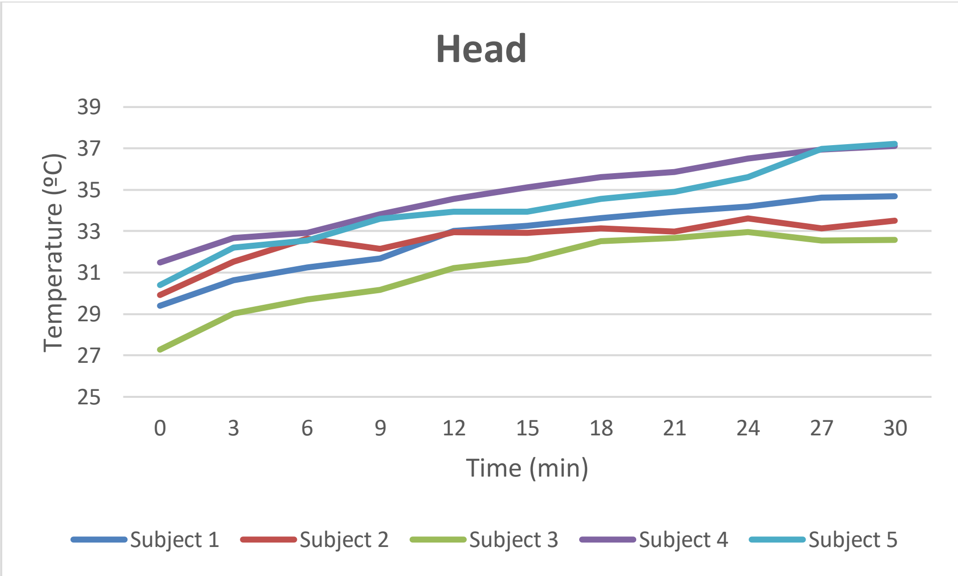

Figure 4.28 Overall graph of temperature for Posture 2 (Head sensor)

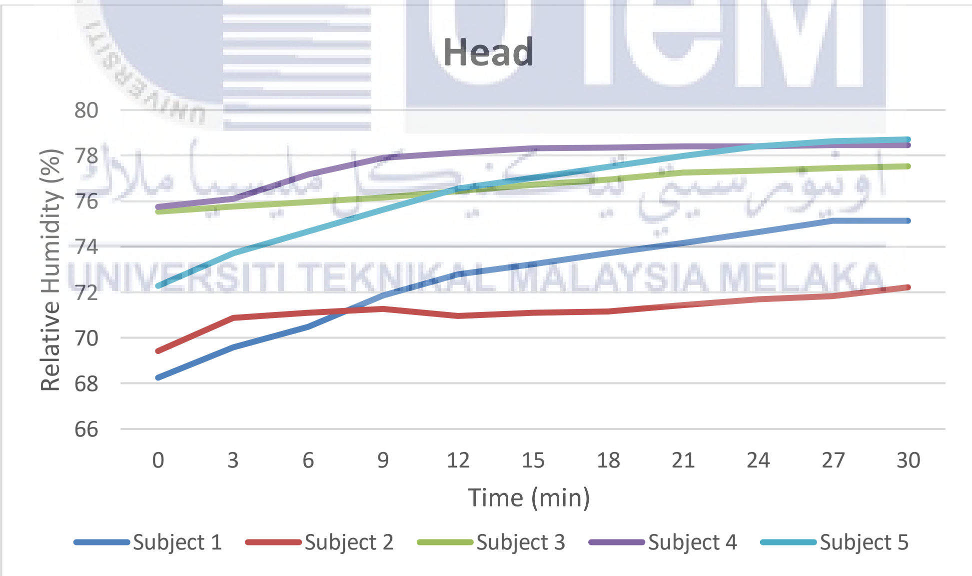

Figure 4.29 Overall graph of relative humidity for Posture 2 (Head sensor)

4.3.2.3 Posture 3 – Side

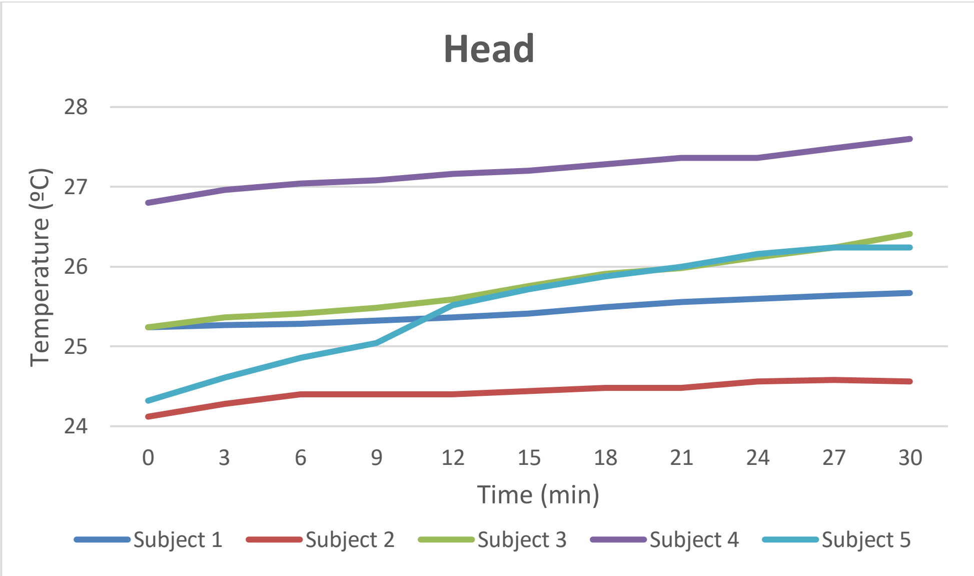

Figure 4.30 Overall graph of temperature for Posture 3 (Head sensor)

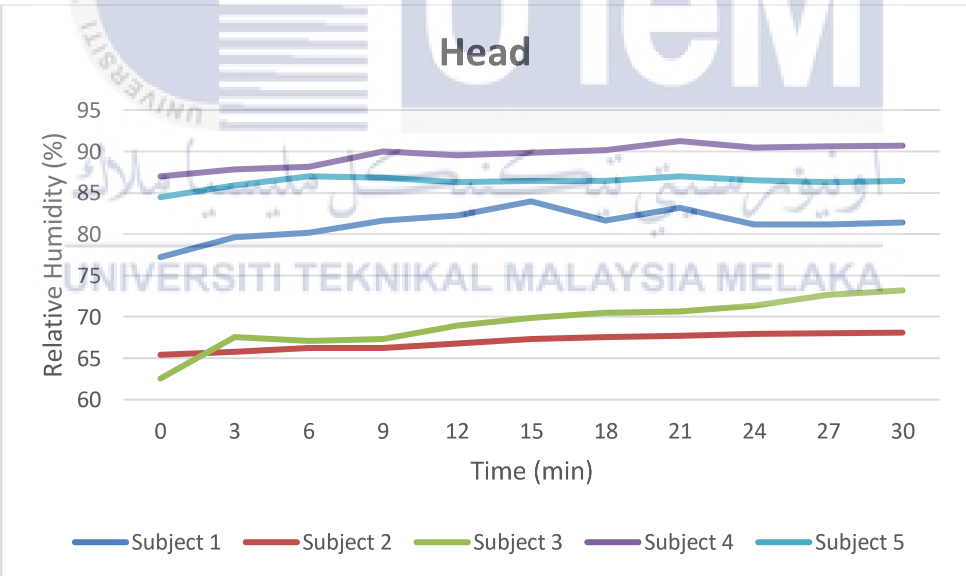

Figure 4.31 Overall graph of relative humidity for Posture 3 (Head sensor)

Figures 4.26-4.31 shows the graphs of overall comparisons for all the subjects specifically at the head sensor. There are two factors need to be noticed which are the environment that the testing took place in and the BMI of the subjects. In regards of the environment, subject 4 and 5 had undergone the test in a hot environment which is as explained in the experimental procedure, that a blanket is used to cover the subjects from head to toe. This gives a warmer environment in the microclimatic conditions compared to the environment without the blanket where it is colder.

The most evident detail that can be noticed from the graphs is that the two topmost values of temperature and relative humidity in all the graphs of the three types of sleeping postures are recorded by the head sensor of subject 4 and subject 5. It is justified as such because the testing was done in the hot environment compared to the other 3 subjects where the graph plot are shown to be comparatively lower than subject 4 and 5.

Besides, considering the next factor which is BMI, the highest value of BMI among the subjects belongs to subject 4 (BMI stated in table 3.3). As a result, this factor also gives an extra reason for the plotting of subject 4's graph to be higher above the other subject's plotting. Subject 5 has a slightly lesser BMI compared to subject 4, but a higher BMI than the other 3 subjects, hence, the tabulation of data for subject 5's head sensor is in the second highest position in the graph. The lowest value of BMI is owned by subject 2. This explains why the tabulation of data in the graph for subject 2 is comparatively lower than all the other subjects. Supporting this analysis, it is evident that subject 1 and subject 3's findings are averagely plotted in between subject 5 and subject 2's data.

Sensors in position of neck, back/chest, lower back/abdomen, thigh and feet are found to have the same pattern of graphs compared to the head sensor due to the differing factors such as testing environment and BMI.

4.3.3 Overall human perception data for each sleeping posture

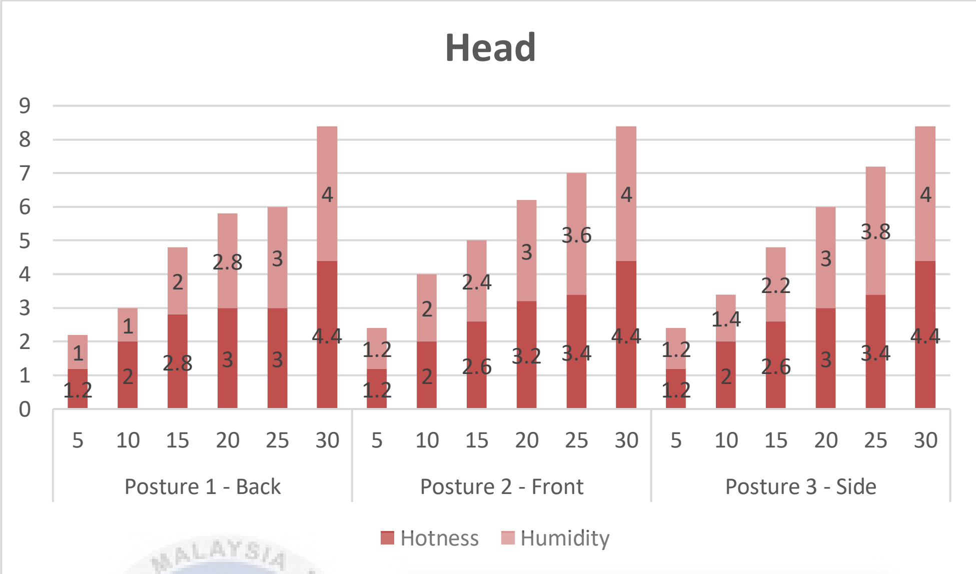

Figure 4.32 Overall human perception scale for head sensor

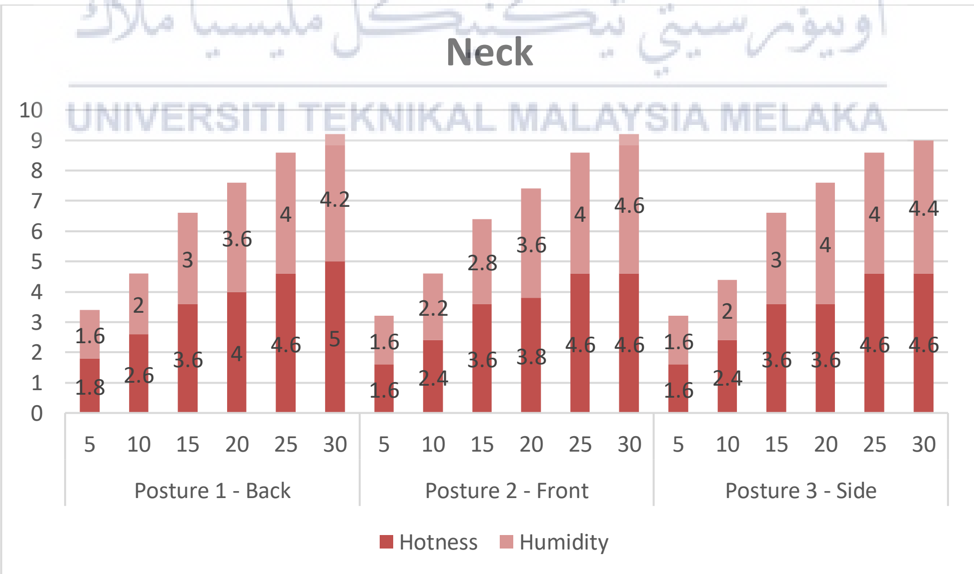

Figure 4.33 Overall human perception scale for neck sensor

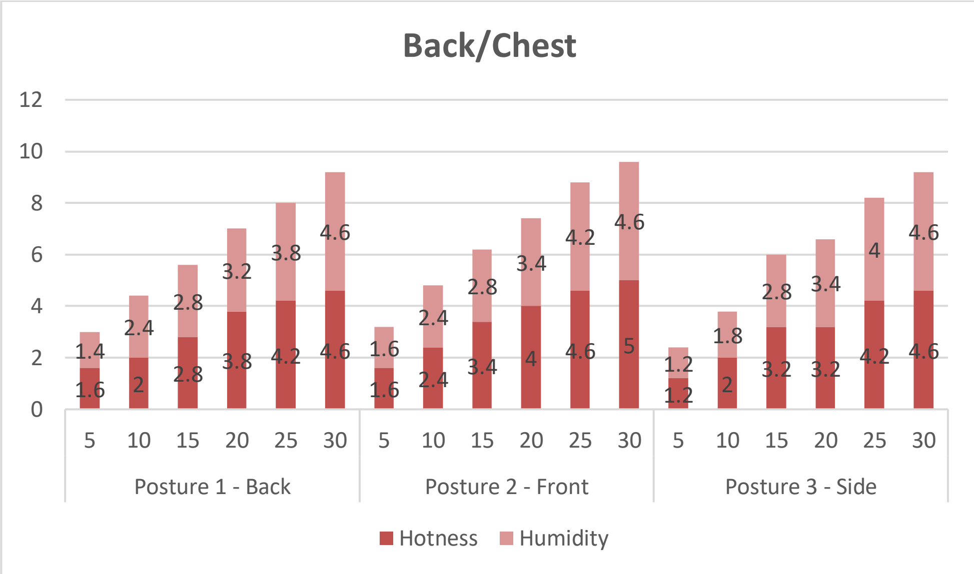

Figure 4.34 Overall human perception scale for back/chest sensor

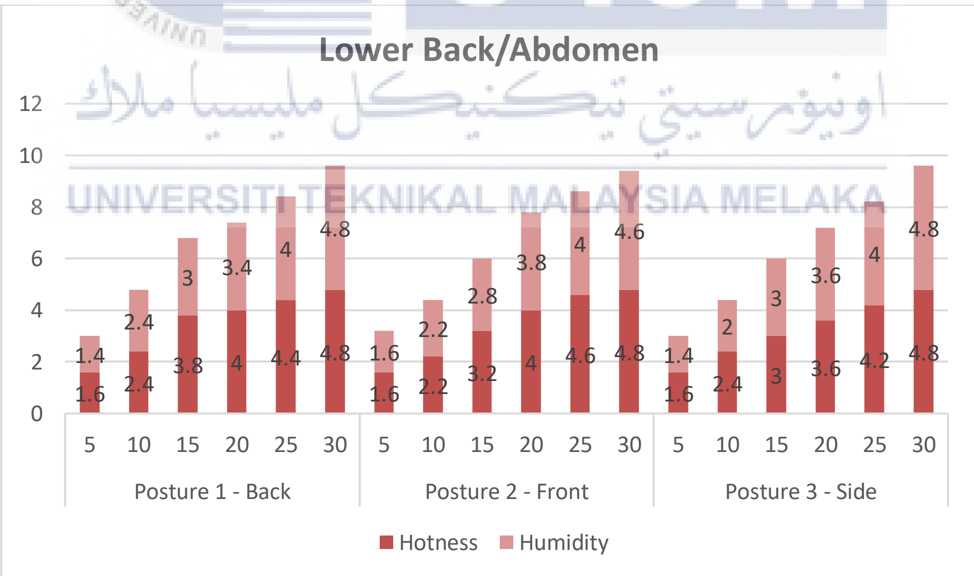

Figure 4.35 Overall human perception scale for lowerback/abdomen sensor

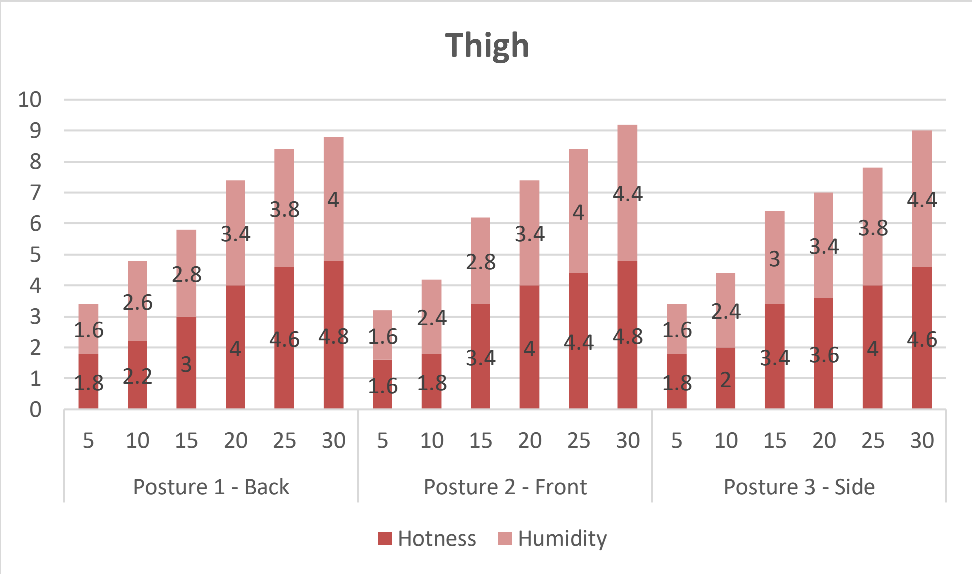

Figure 4.36 Overall human perception scale for thigh sensor

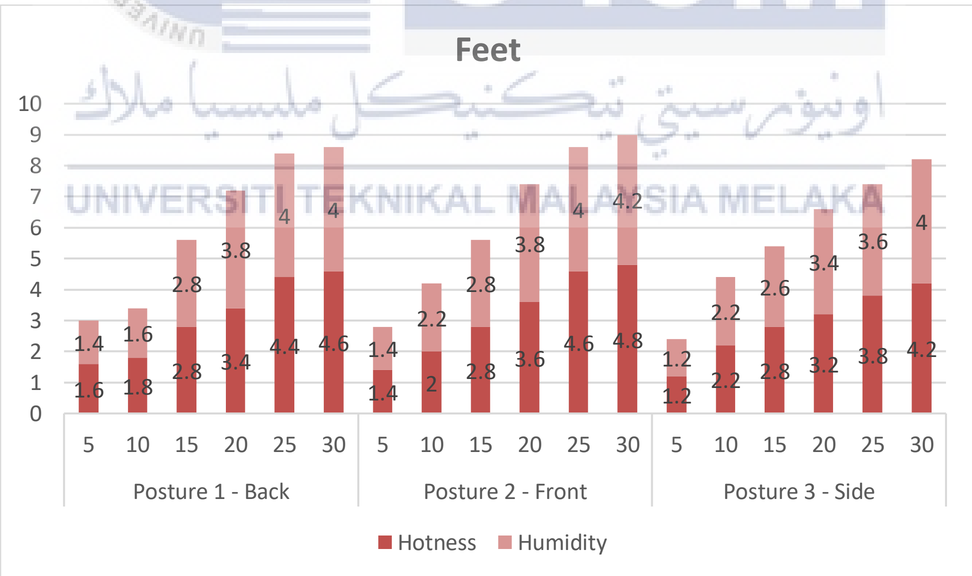

Figure 4.37 Overall human perception scale for feet sensor

The human perception also known as survey is done during the testing of the subjects. Subjects had to rate the condition at specific location where the sensors are placed based on a scale provided. The very hot/very humid being at scale 5 while very cold/very dry being at scale 1. The filling up is done verbally, which means they just have to speak up and tell the rating and the rating will be recorded. The total period of testing is 30 minutes and this perception data is taken once in every 5 minutes. The collection of data is done during the test of all the three sleeping postures which are 1-back, 2-front and 3-side. The very hot-very cold rating in the human perception form evaluates the level of temperature in a human body. Likewise, the very humid-very dry scale in the form defines the level of relative humidity level in the human body. Hence, the human perception data correlates with the data of temperature and relative humidity obtained from the testing.

Referring to the figures 4.32-4.37, at the first 5 minutes of testing, all the subjects feel somewhere between very cold-little cold (temperature) and very dry-little dry (relative humidity) in average. Within the next 10 to 15 minutes, there is a hike in all the data towards a warmer and more humid condition. For instance, almost all the data plotted shows a significant increase of hotness and humidity conditions.

In the first sleeping posture (back), at the end of the testing, the subjects have felt very warm at neck and very humid at the lower back. The condition at the other positions are also considered to be highly humid and warm in average. Besides, in sleeping posture 2 (front), at the final minute of the testing, subjects have felt very warm and very humid at the chest. Whereas, in the sleeping posture 3 (side), the highest rating of hotness and humidity are found to be in the thigh position.

In comparison of all the perception data, it is noted that at head sensor, there is a significant increase between each 5 minutes intervals compared to the other sensor positions. At the other positions, the perception is said to be gradually increasing between intervals, whereas only in head sensor, it can be noticed that there is a sudden increase within intervals.

4.3.3.1 Overall comparison of human perception data for each sleeping posture

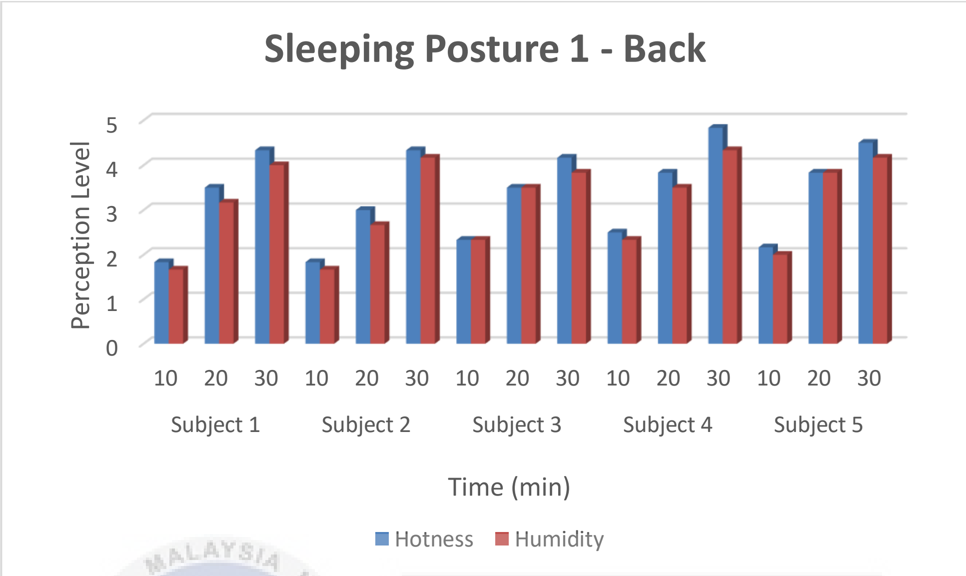

Figure 4.38 Overall human perception scale for sleeping posture 1

Factor/ Rating	1	2	3	4	5
Temperature	Very Cold	Little cold	Moderate	Little warm	Very warm
Humidity	Very dry	Little dry	Moderate	Little humid	Very humid

The overall human perception data tabulation shown in Figure 4.38 is classified for sleeping posture 1 in regards of all the five subjects involved in the testing. In general, it can be seen that both hotness and humidity keep increasing for all the subjects. However, there is a noticeable difference in subject 4's data where the perception data at 30 minutes is higher compared to the other subjects. The next subject trailing that manner would be subject 5. It can be concluded that this is due to the variation of environment and the BMI of subjects. Subjects 4 and 5 being in a warmer environment and having higher BMI compared to others would be the reason for a slight different at the tip. Meanwhile, considering the variation of sleeping postures, this sleeping posture, which is posture 1 can be concluded to be the optimal sleeping posture because in comparison with the other two sleeping postures, the data is considerably low in average.

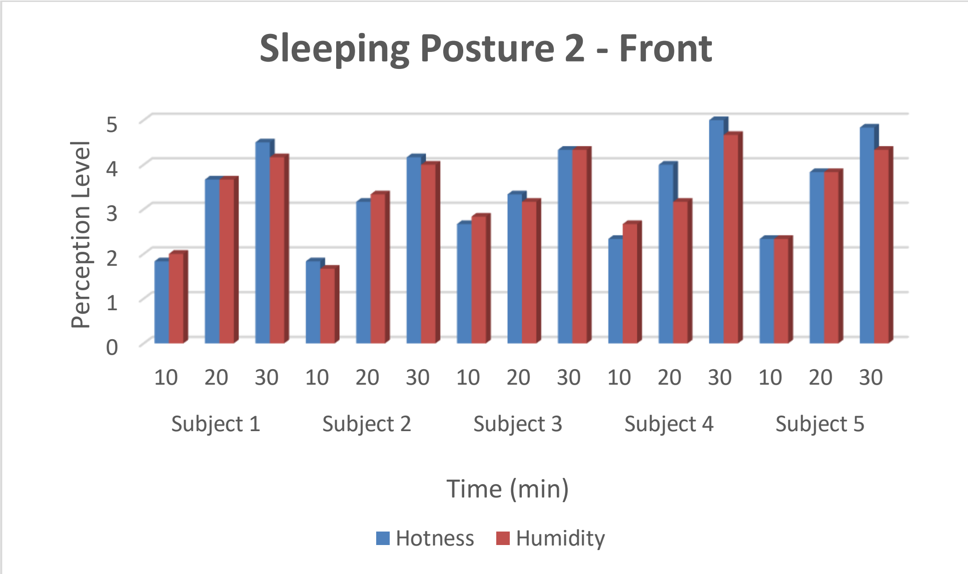

Figure 4.39 Overall human perception scale for sleeping posture 2

The overall human perception data tabulation shown in Figure 4.38 is classified for sleeping posture 2 in regards of all the five subjects involved in the testing. Similar to posture 1, we can see that the graph is increasing linearly for all the subjects. Subjects 4 and 5 have the higher data in terms of hotness and humidity compared to the other subjects. Subject 2 has the lowest data tabulation values among the other subject's values. As per the discussion in the previous part, this can be analysed in terms of variation of temperature and BMI of subjects. In the hot environment, with the blanket on the subjects, there would not be much air circulation or ventilation in that confined space resulting in the hike of hotness and humidity or sweating.

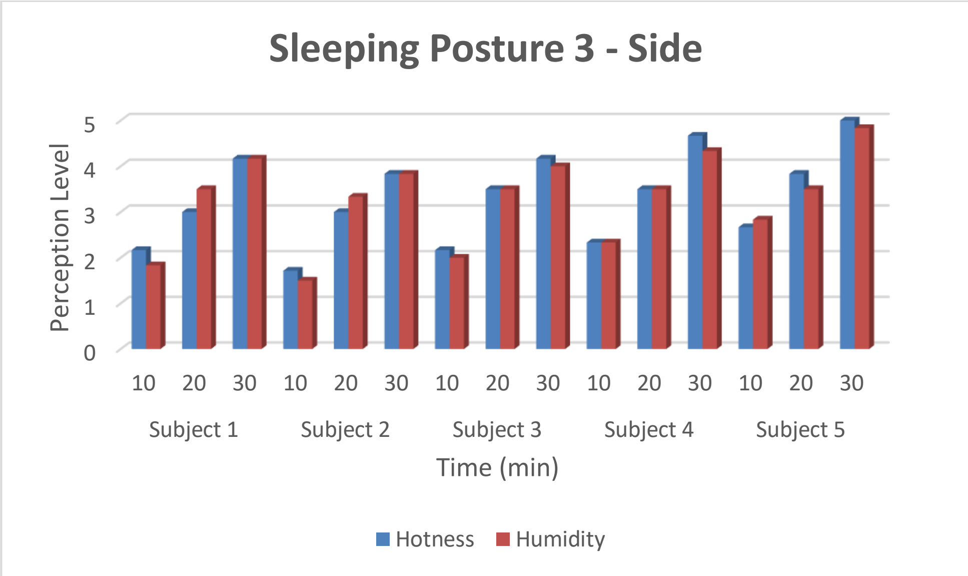

Figure 4.40 Overall human perception scale for sleeping posture 3

The overall human perception data tabulation shown in Figure 4.40 is classified for sleeping posture 3 in regards of all the five subjects involved in the testing. Again, the subjects 4 and 5 experienced a higher feeling of hotness and humidity which is why the graphs are higher than the other subjects' data. The data tabulation of perception for subjects 1, 2 and 3 are averagely same due to the almost similar BMI count. However, the hike in the hotness and humidity is evident because even when the subjects are tested in a cold environment, the microclimatic condition between subject's body and the sensor is sensitive. There will be temperature and relative humidity rise is that confined space which results in the feeling of hotness and humidity.

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

As an outcome, human thermal comfort is characterized as a state of mind and feeling, which indicates well-being in regards of the surrounding environment. High temperatures and relative humidity give unpleasant sensations which could lead to serious health issues. Thermal comfort varies depending on each person, condition of the person and the surrounding environment of the person. Dependence on a person and the corresponding condition means the difference of BMI of a person, clothing insulation, the metabolic rate of body and the activities involved play a big role in thermal comfort. Whereas, the surrounding environment factor means the climatic conditions, air temperature, relative humidity, air speed and the warmth of the environment. The scope of the study is narrowed down to the sleeping postures of human in terms of studying the level of thermal comfort. Three sleeping postures have been tested in regards with five subjects with different BMI samples and varying environment. The problem statement initiated at the beginning is the possible external factors causing lack of sleep including the failure to maintain a proper sleeping posture. Hence, the objectives of this study was discovered as the study of local cooling effect in microclimatic conditions based on sleeping postures and investigating the effect of BMI on thermal comfort. In order to conduct the testing, five random subjects were chosen and tested under two types of environment which are hot and cold. The BMI of subjects were recorded and tested with the data obtained from the testing process.

Based on sleeping posture 1 (back) overall temperature graph (Figure 4.20), the neck sensor has recorded the highest value of temperature and the head and abdomen sensors come in line. This is because in the back posture, the confined space between the neck and sensor attached to the mattress is very small and has a low level of air circulation or ventilation. This causes the skin to experience a higher temperature and sweat. Likewise, in the overall relative humidity graph in Figure 4.21, it is noted that the humidity at the head and abdomen are high, while the relative humidity at neck seemed to be low at beginning but kept rising as times passed by. Referring to sleeping posture 2 (front) and 3 (side), it is justified that the graph plotting in Figure 4.22 to 4.25, where the head and neck sensors remain at higher values of temperature and relative humidity throughout the testing period.

Besides, taking in count the BMI factor of subjects, referring to Figure 4.26 to Figure 4.31, it is observed that higher BMI values of subjects reacts more sensitively towards temperature and relative humidity compared to other subjects. The average comfort temperature among the overweight and obese groups are found to have a higher average comfort temperature. This drastically higher comfort temperature seen in overweight and obese subjects is noticeably due to the higher fat content in the body resulting in higher thermal comfort. Similarly, referring to the same plots above, we can observe that in a hot environment, the values of temperature and relative humidity tend to be higher in contrast with the colder environment.

5.2 Recommendations

In the process of the fulfilment of this study, various possible ways for improvement have been gained. Since this is a study related to thermal comfort, the improvement has to be made personally by the subjects in order to achieve the results in terms of thermal comfort. One of the main ways to improve thermal comfort would be to follow a proper sleeping posture. Based on this study, it is concluded that the first sleeping posture is the best posture in order to achieve a proper sleeping habit. Besides, adjusting the clothing insulation according to the surrounding environment is another way to achieve thermal comfort. In a hot environment, it is advised to wear thin and loose clothing during sleep so that the air circulation in minor and confined space can regulate the temperature and relative humidity at that particular space.

Moreover, sleeping in a room which has a good the ventilation and speed of air are more ways to improve the thermal comfort. A good ventilation means the thermal equilibrium could be reached and the hot air keeps circulating in change with the colder air. This also could reduce the relative humidity which in result reduces the possibilities of sweating. Furthermore, another improvement method is to set the room temperature to a colder environment so that the body does not lose the thermal equilibrium faster.

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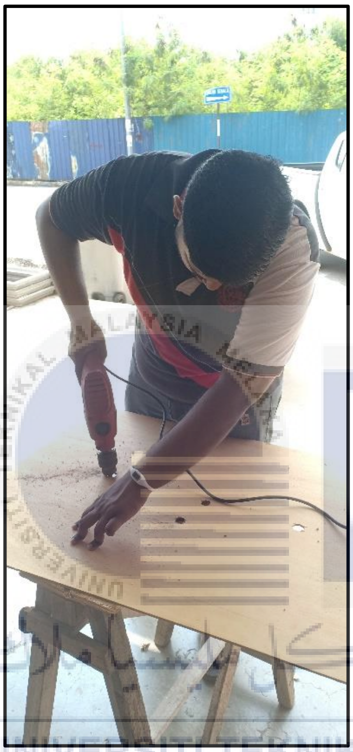
APPENDICES

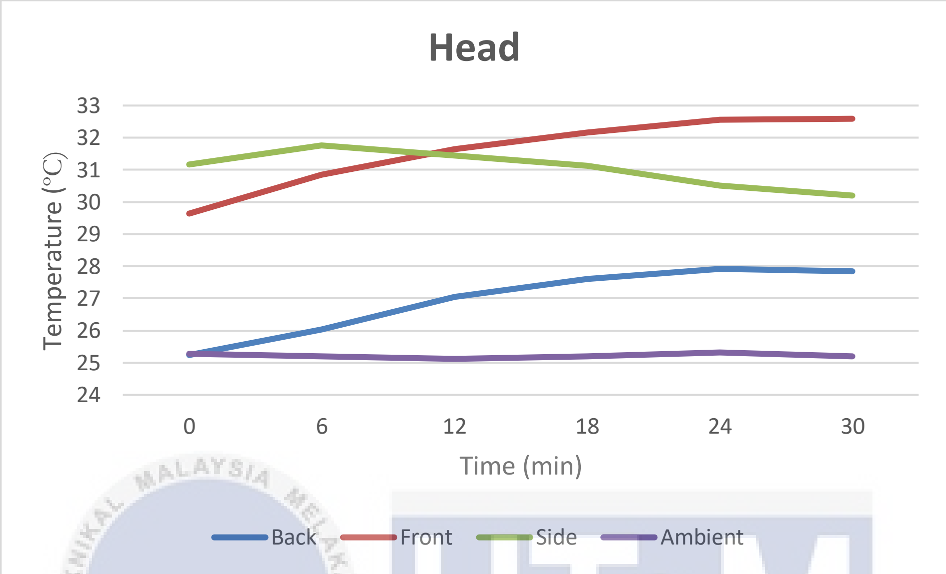
Preparation of test rig



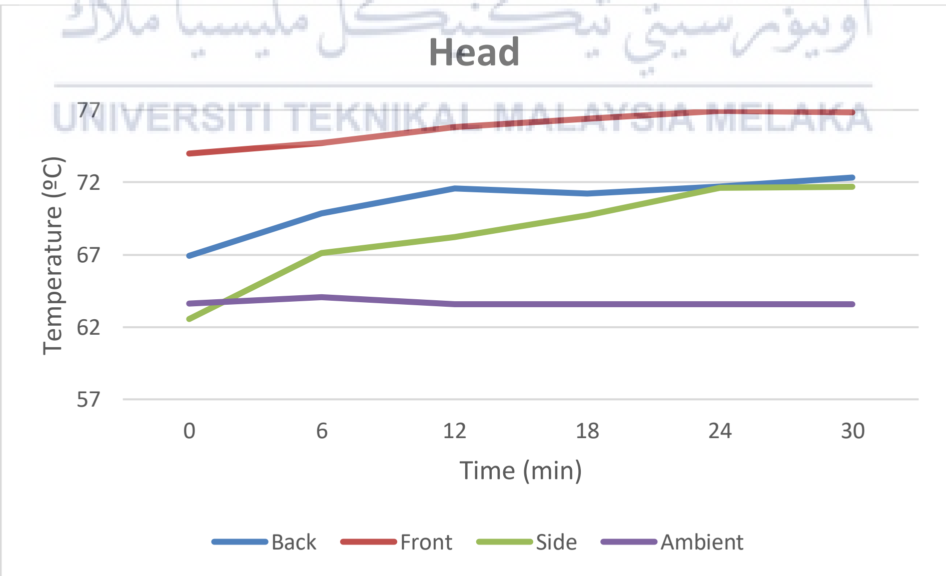
Testing of subjects

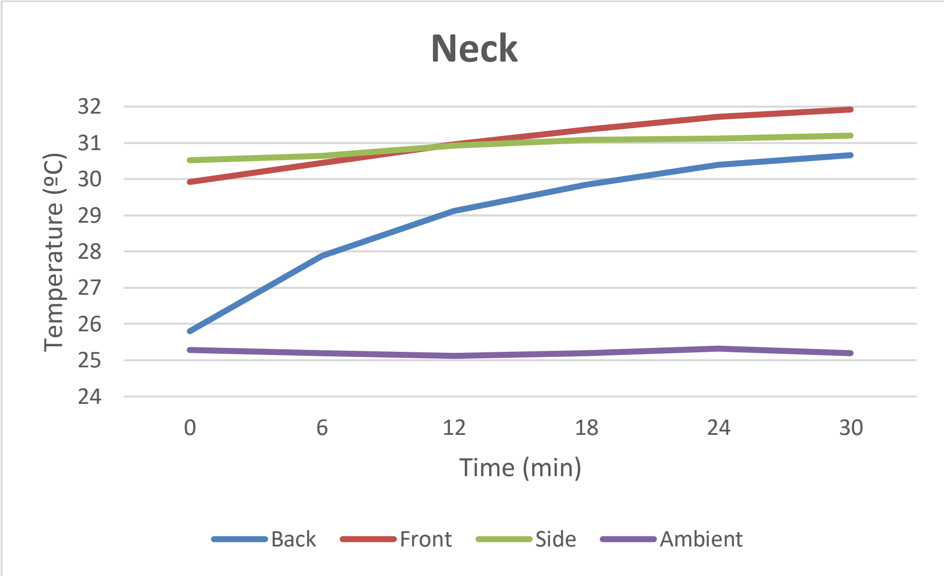
Results for subject 2

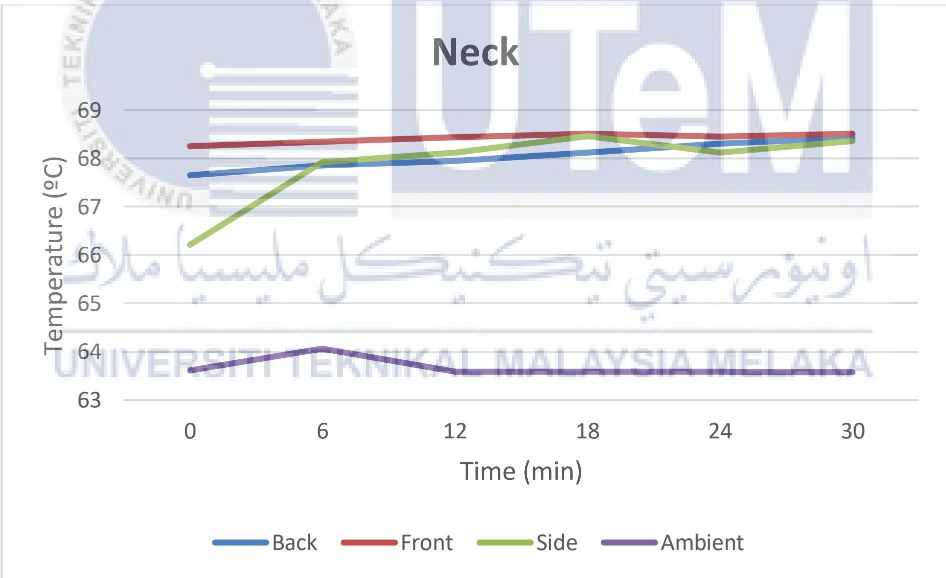
Temperature-time graph



Relative humidity-time graph




Neck
Temperature (ºC)
32
31
30
29
28
27
26
25
24
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Neck
Temperature (ºC)
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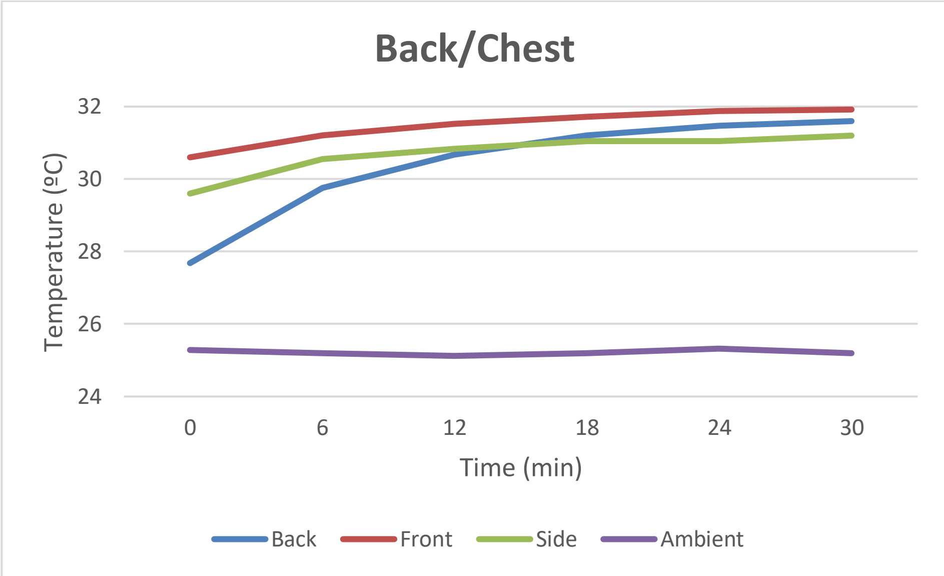
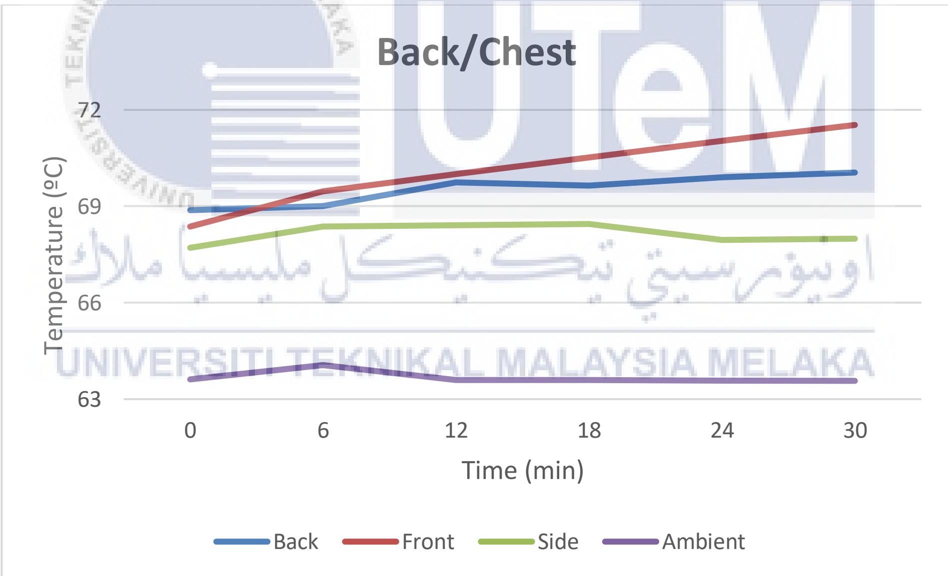
68
67
66
65
64
63
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Back/Chest
Temperature (ºC)
32
30
28
26
24
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Back/Chest
Temperature (ºC)
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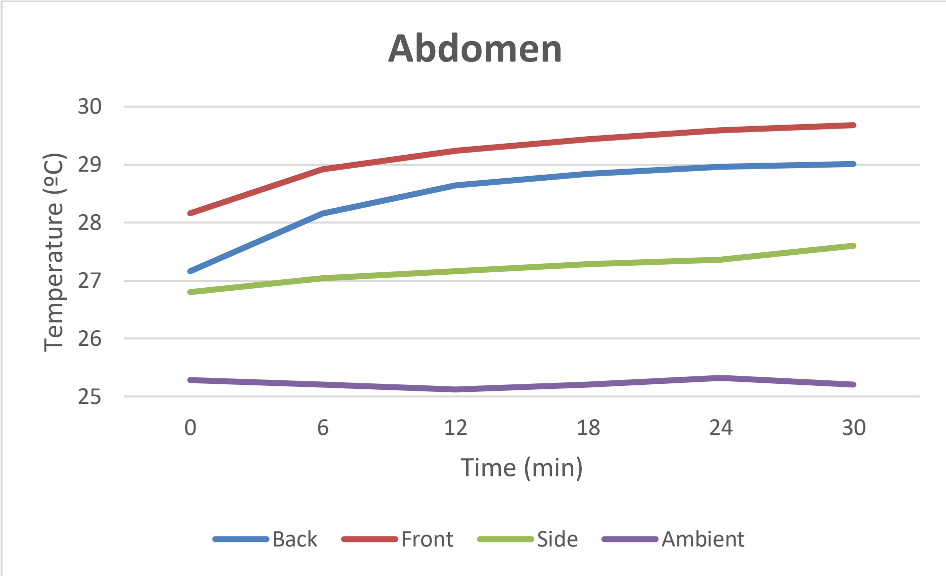
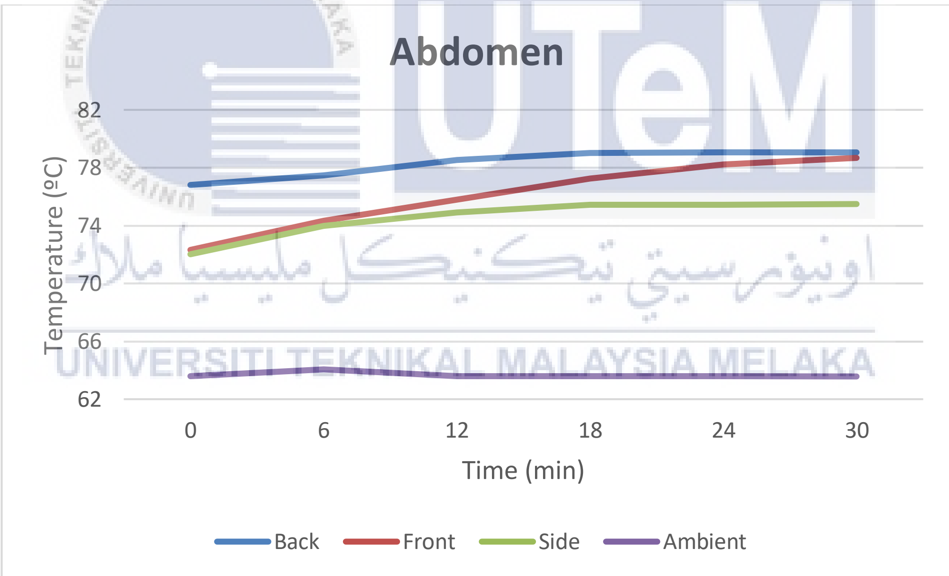
69
66
63
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Abdomen
Temperature (ºC)
30
29
28
27
26
25
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Abdomen
Temperature (ºC)
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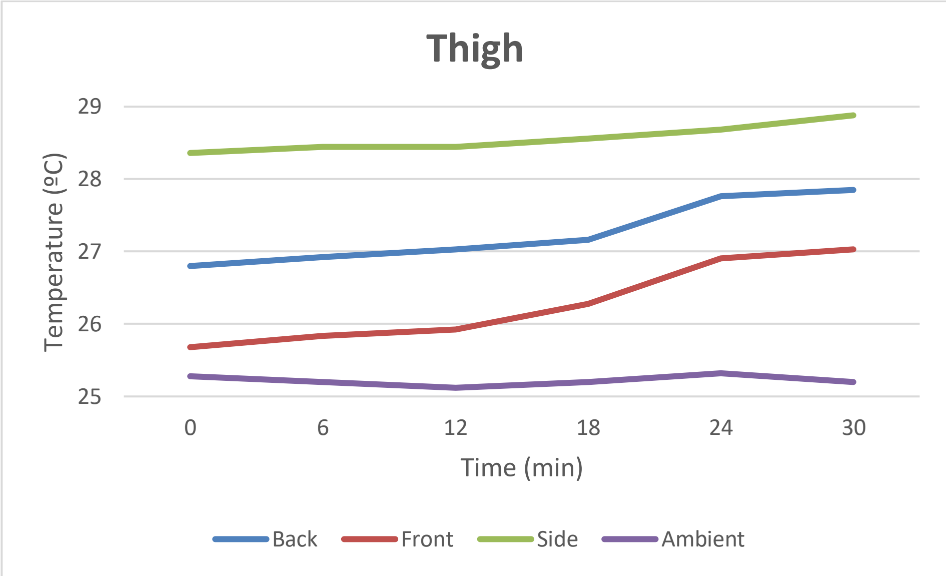
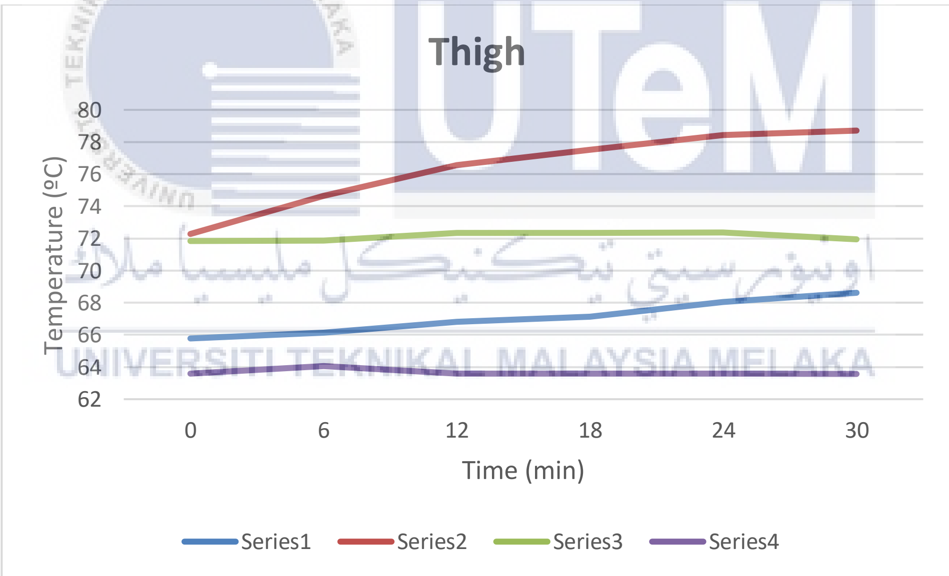
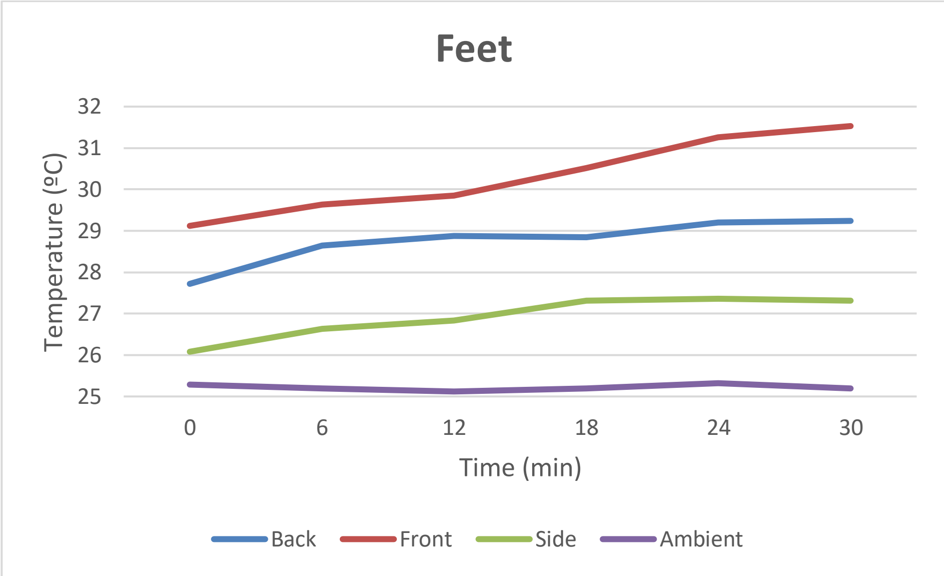
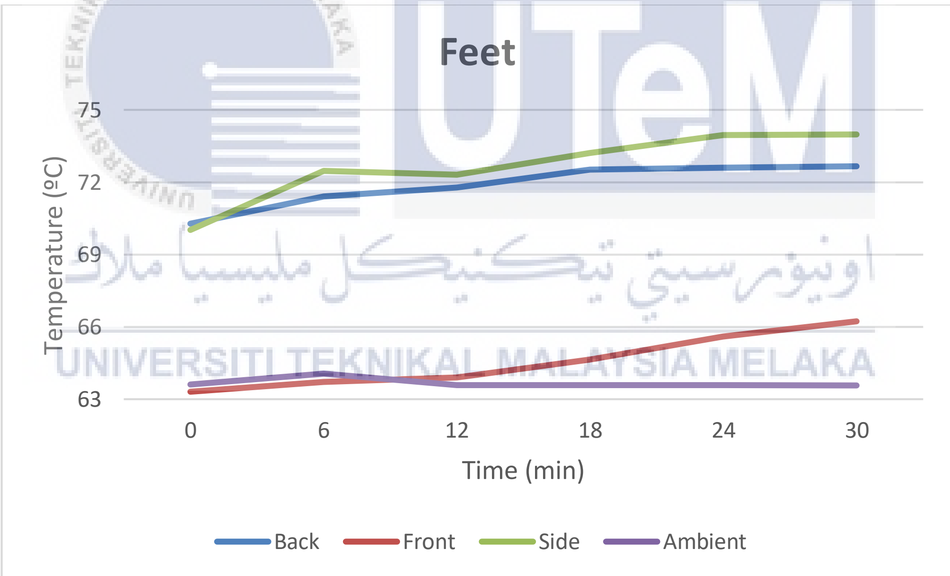
78
74
70
66
62
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

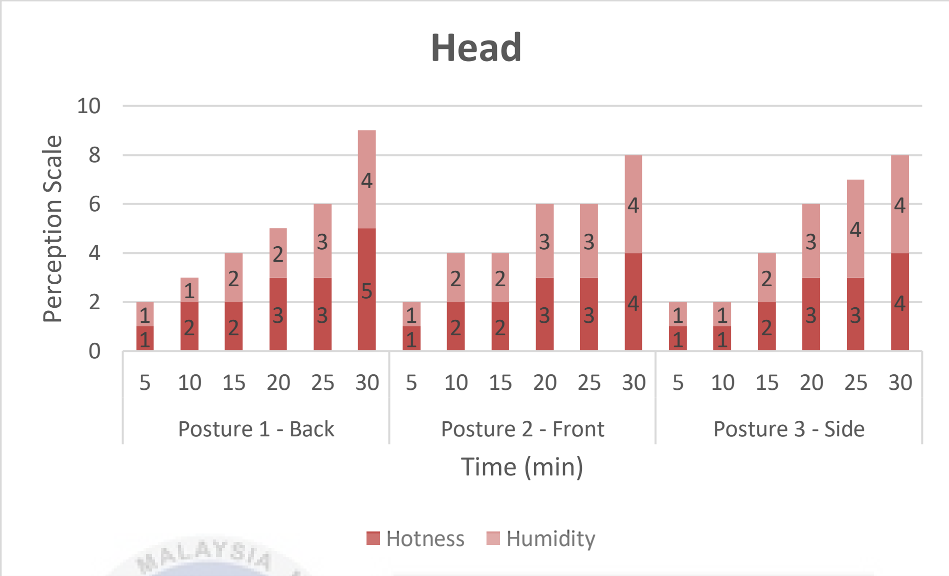

Thigh
29
28
27
26
25
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

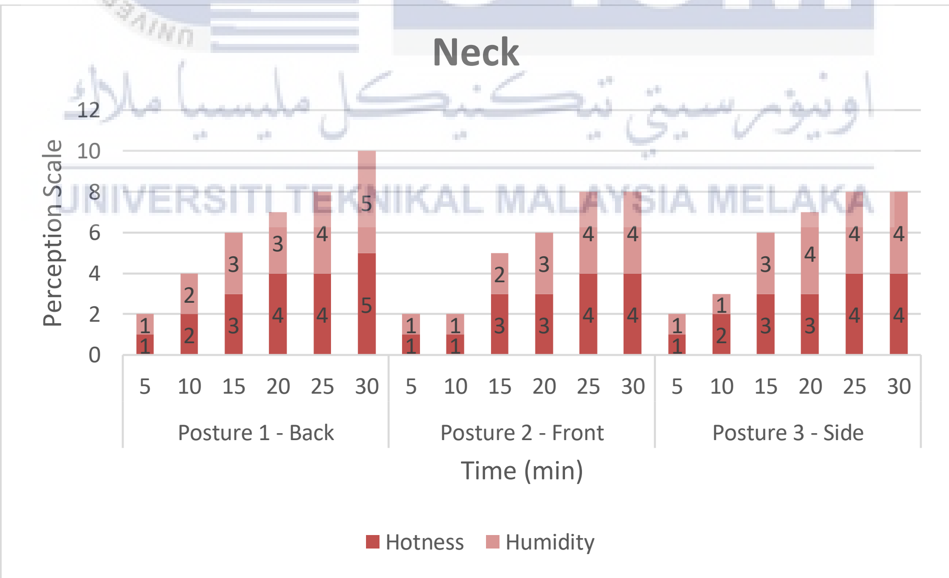

Thigh
80
78
76
74
72
70
68
66
64
62
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Series1
Series2
Series3
Series4

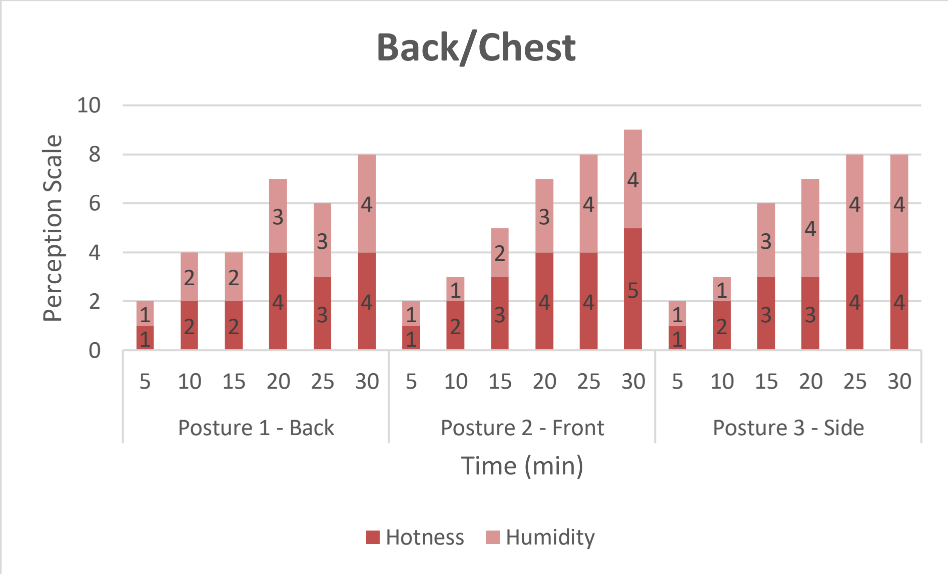

Feet
Temperature (ºC)
32
31
30
29
28
27
26
25
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

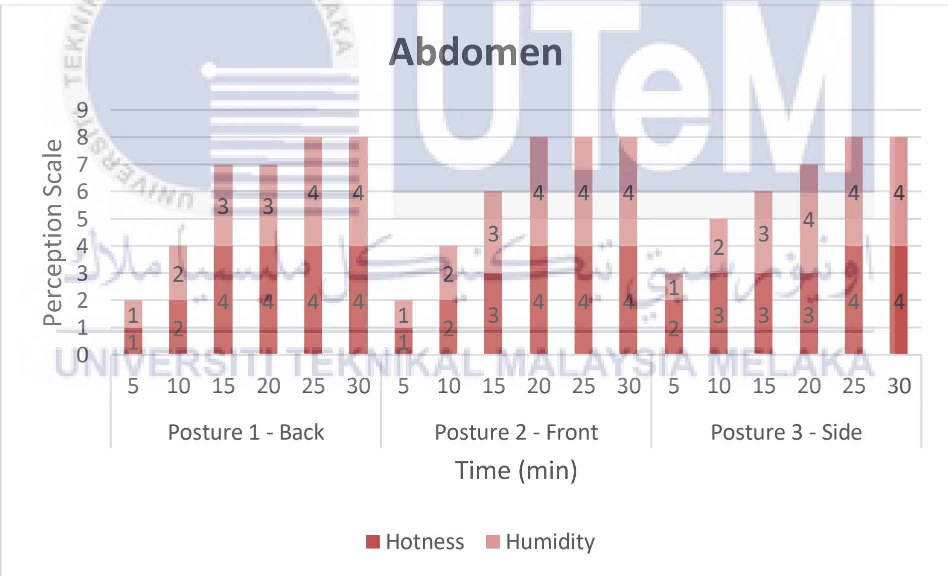

Feet
Temperature (ºC)
75
72
69
66
63
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

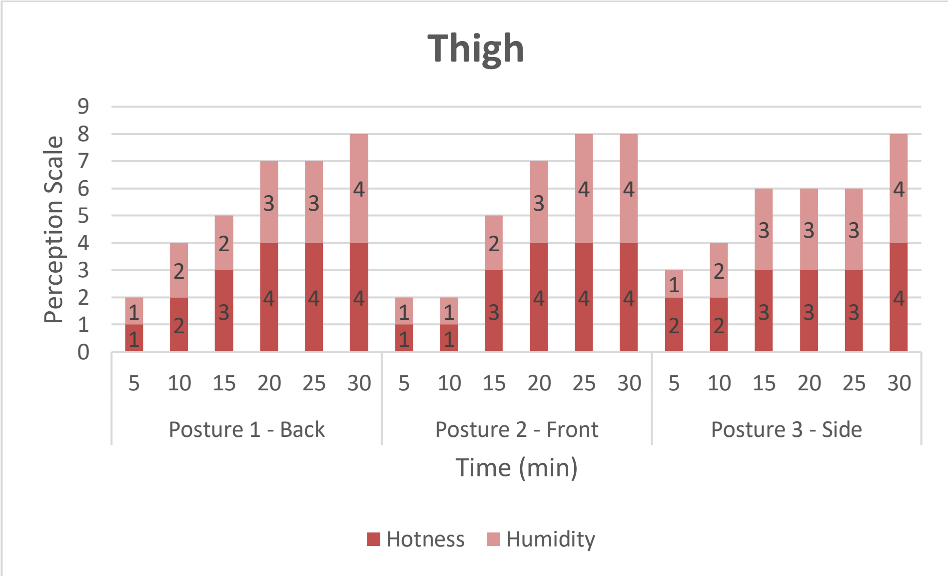
Human perception data for subject 2

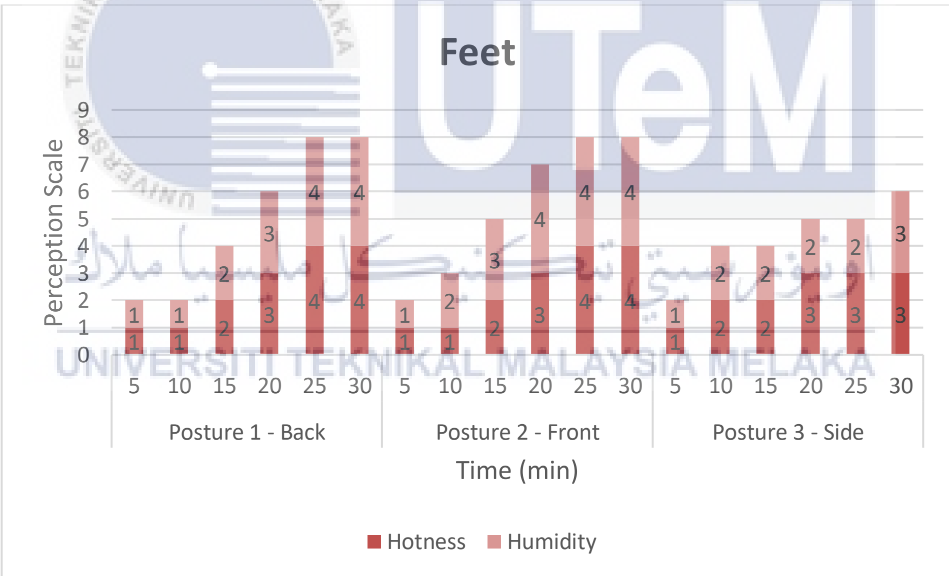





Back/Chest
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity

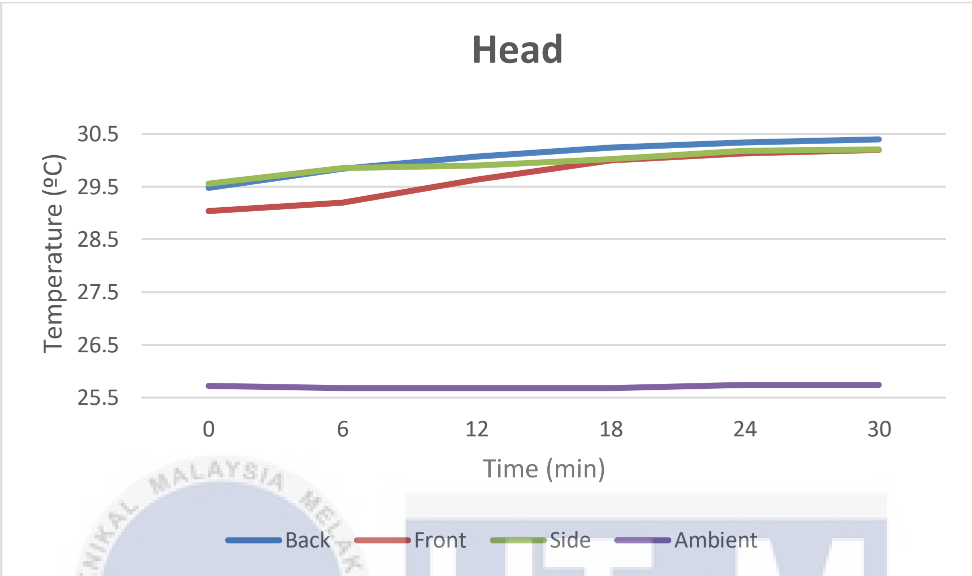

Abdomen
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity


Thigh
Perception Scale
0 1 2 3 4 5 6 7 8 9
5 10 15 20 25 30
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Time (min)
Hotness
Humidity

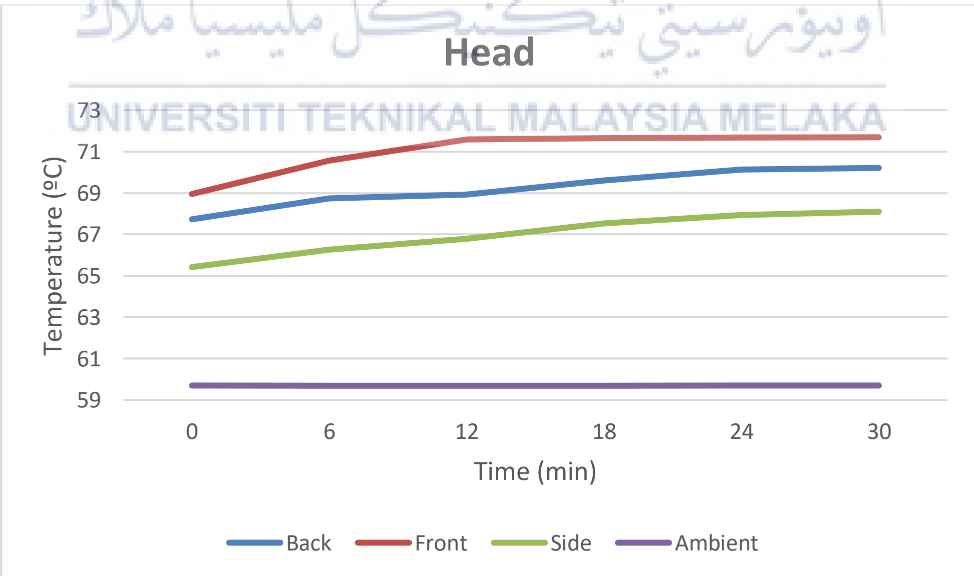

Feet
Perception Scale
0 1 2 3 4 5 6 7 8 9
5 10 15 20 25 30
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Time (min)
Hotness
Humidity

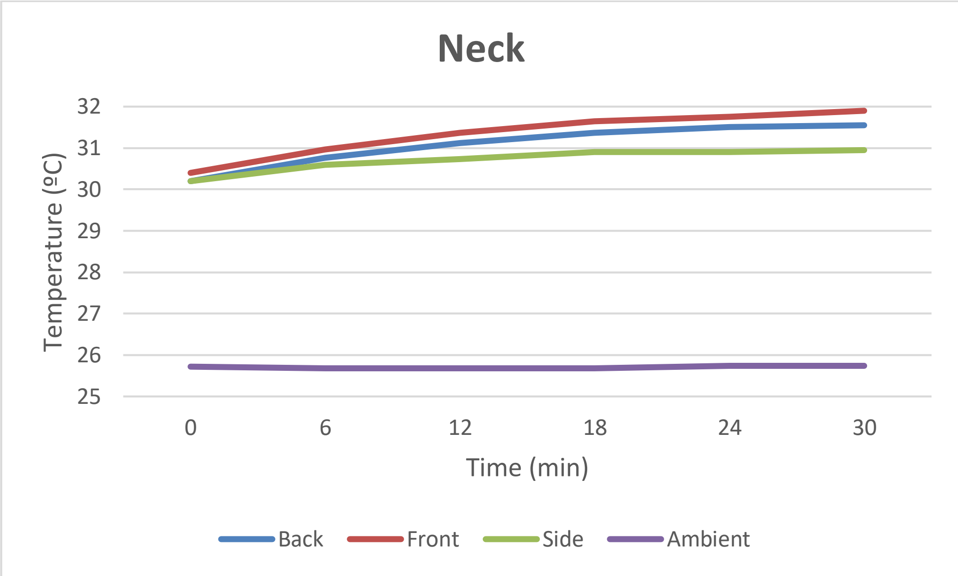
Results for subject 3

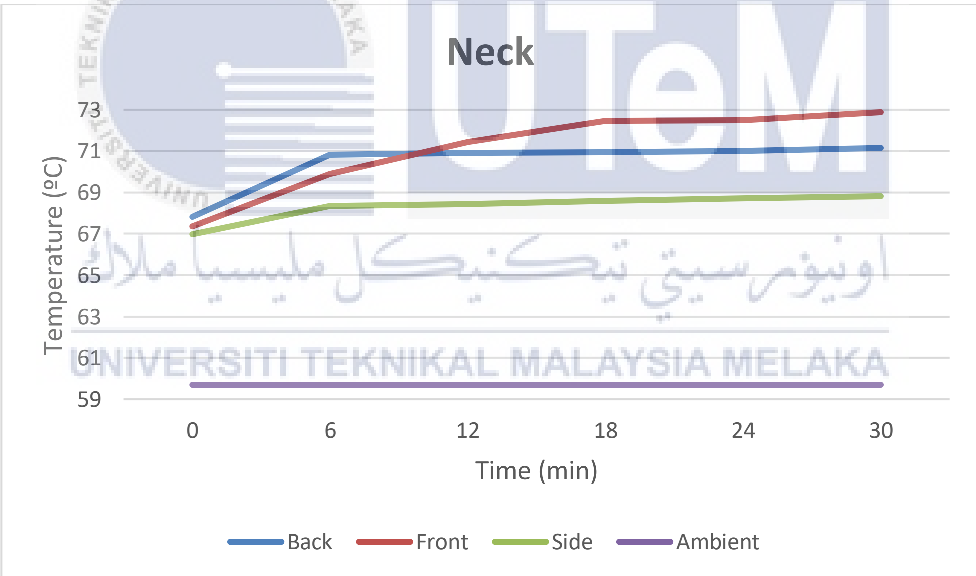
Temperature-time graph



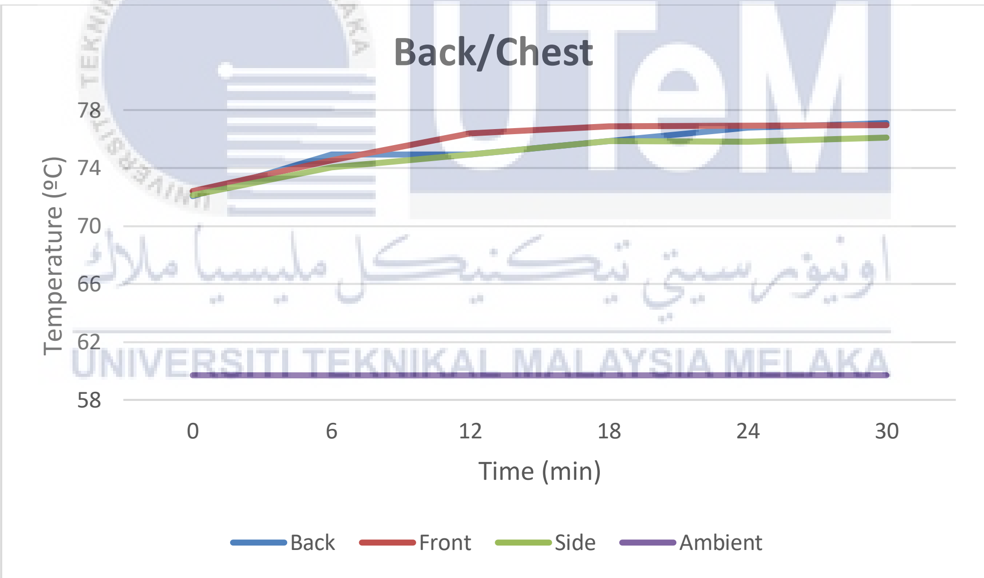
Relative humidity-time graph

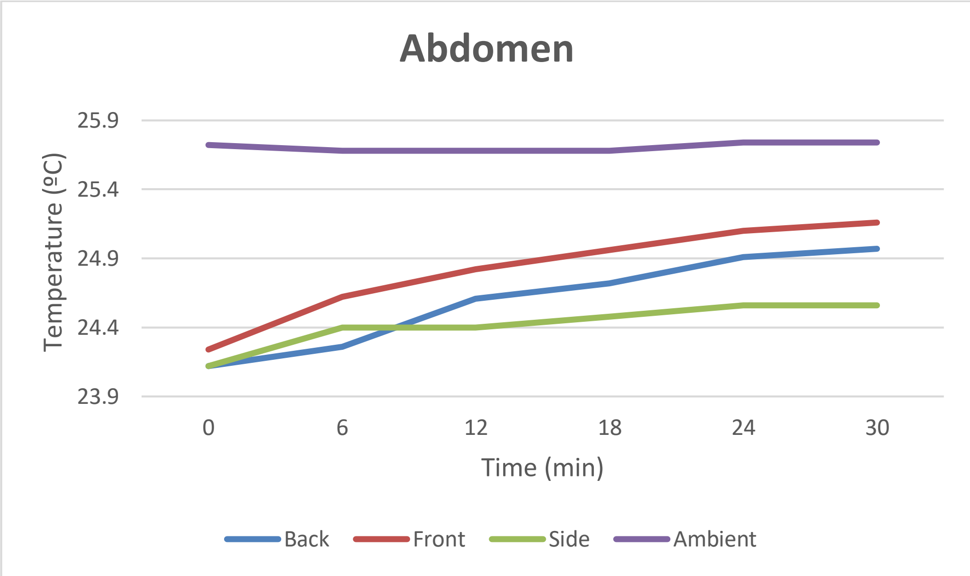



Neck
32
31
30
29
28
27
26
25
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

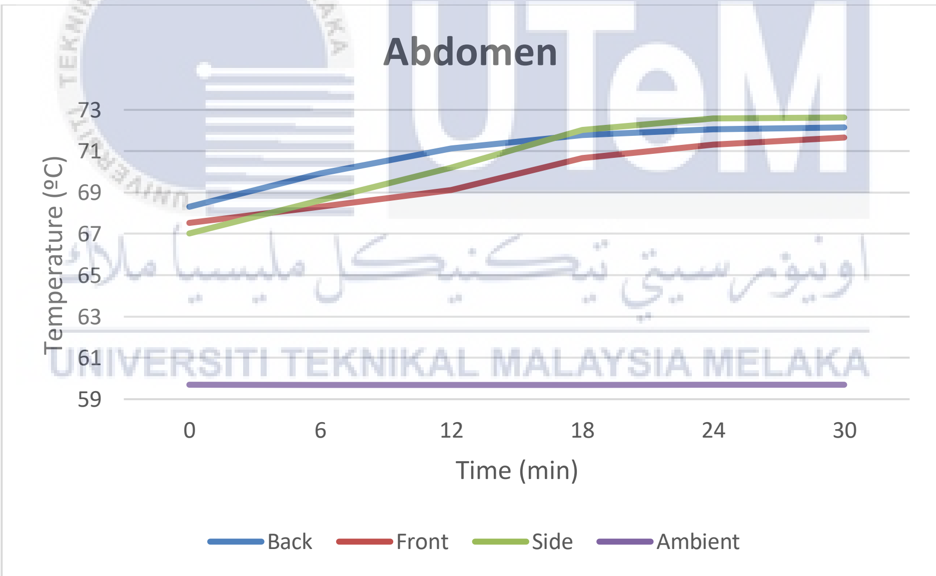

Neck
73
71
69
67
65
63
61
59
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Back/Chest
27
26
25
24
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

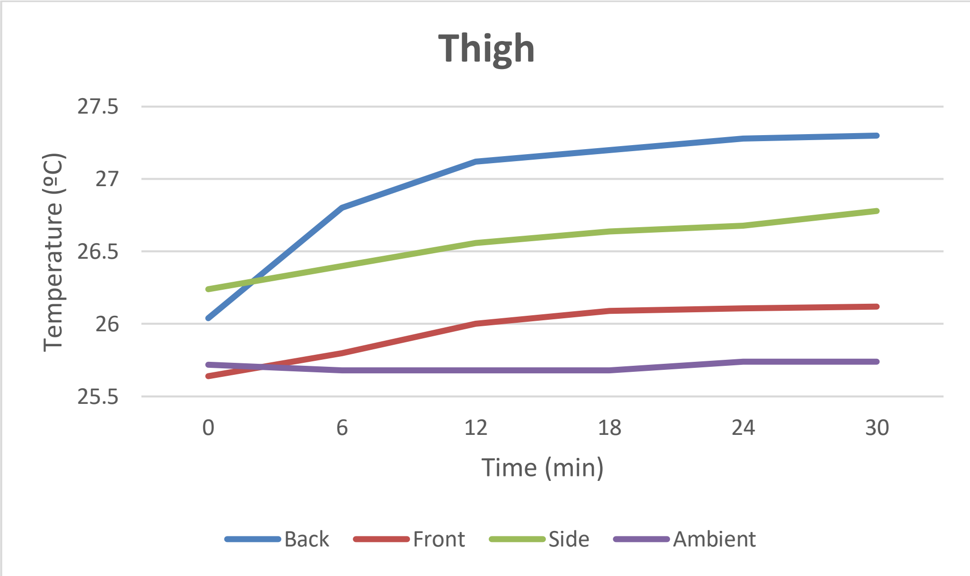

Back/Chest
78
74
70
66
62
58
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

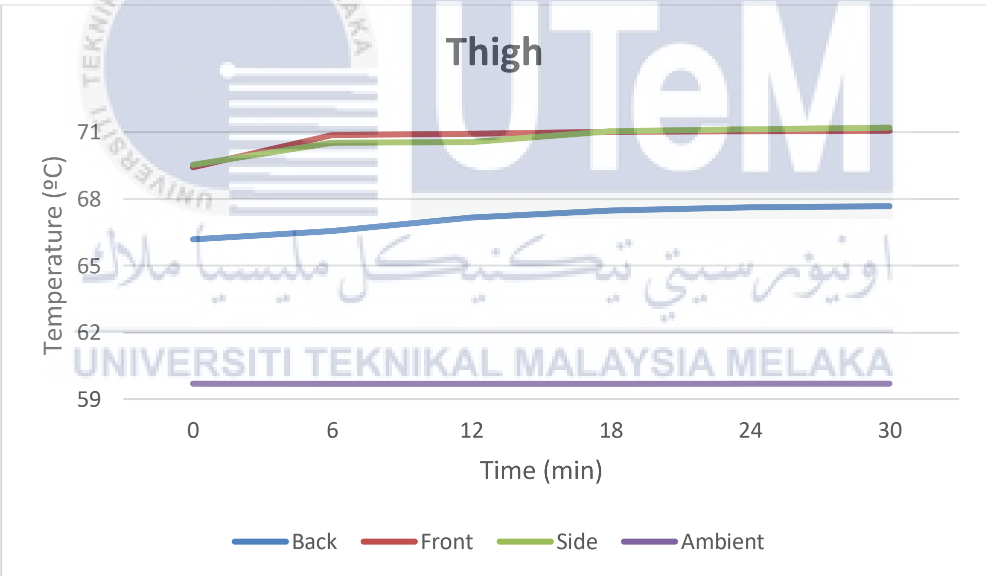


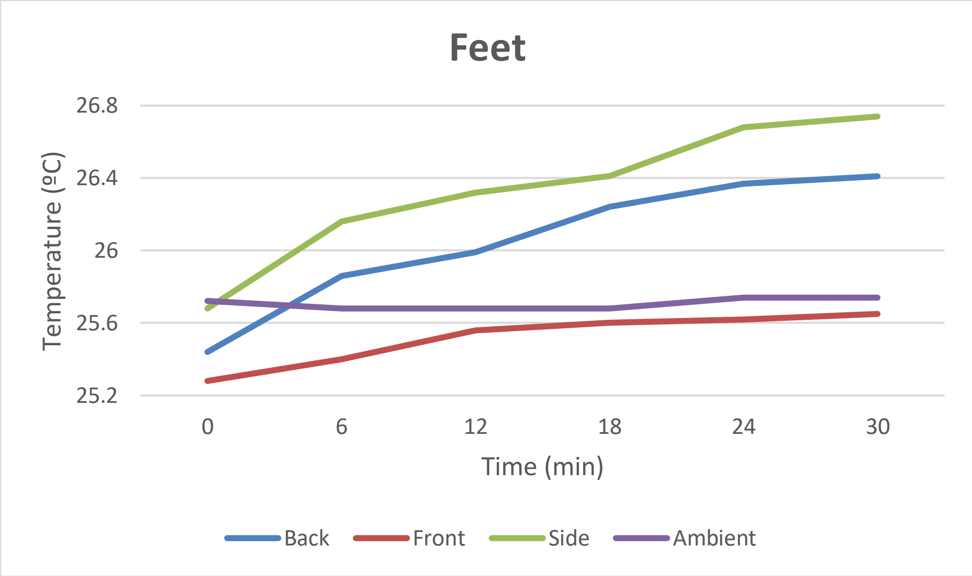
Abdomen
25.9
25.4
24.9
24.4
23.9
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

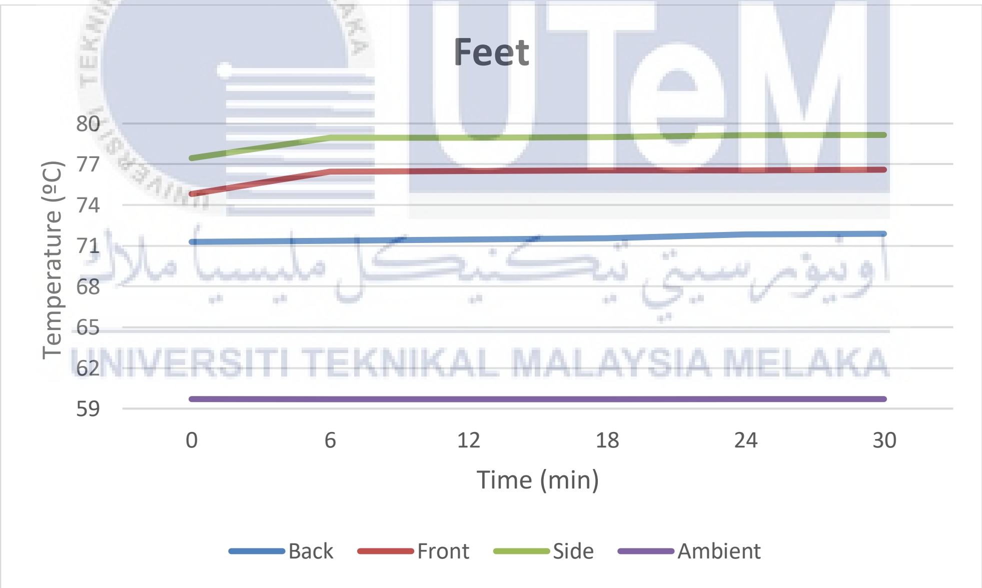


Abdomen
73
71
69
67
65
63
61
59
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

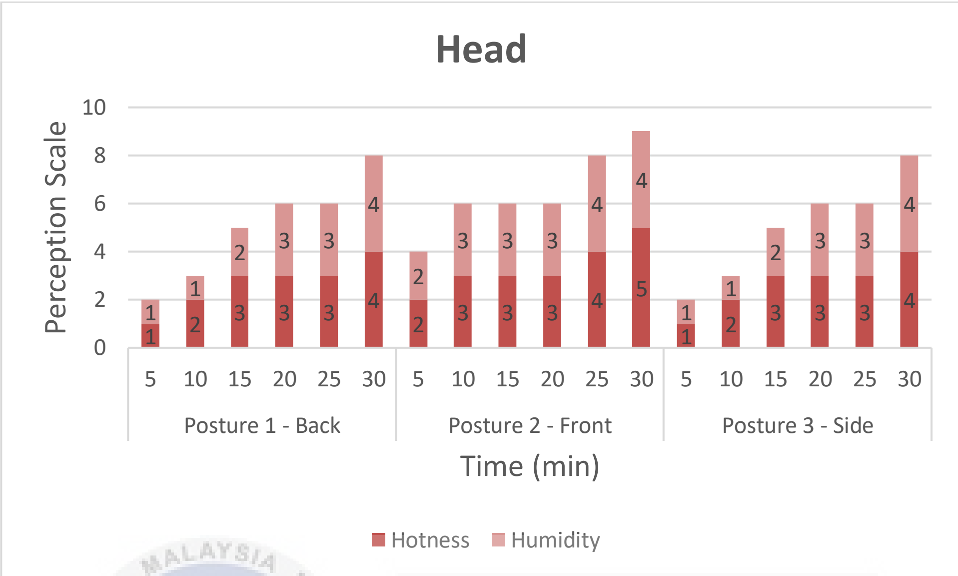

Thigh
27.5
27
26.5
26
25.5
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

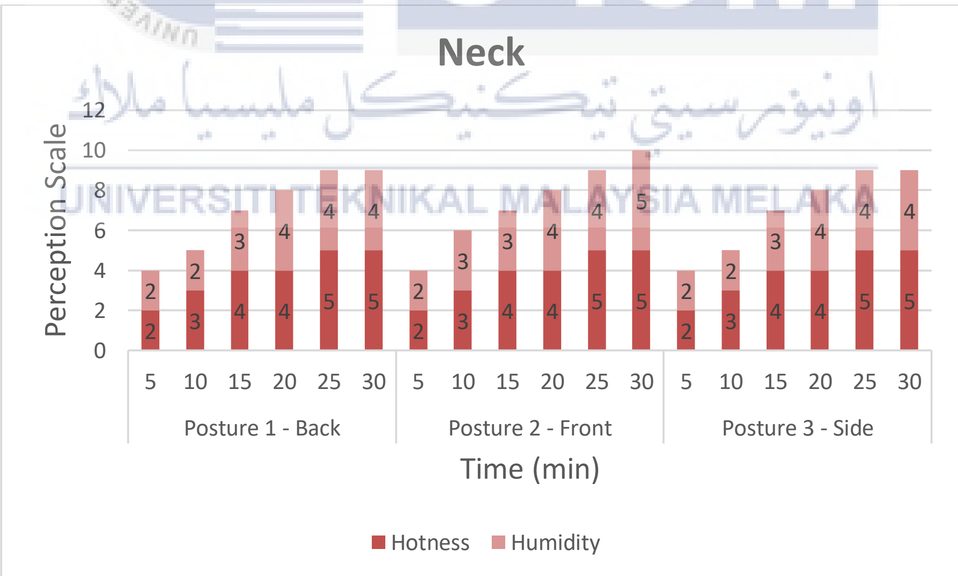

Thigh
71
68
65
62
59
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

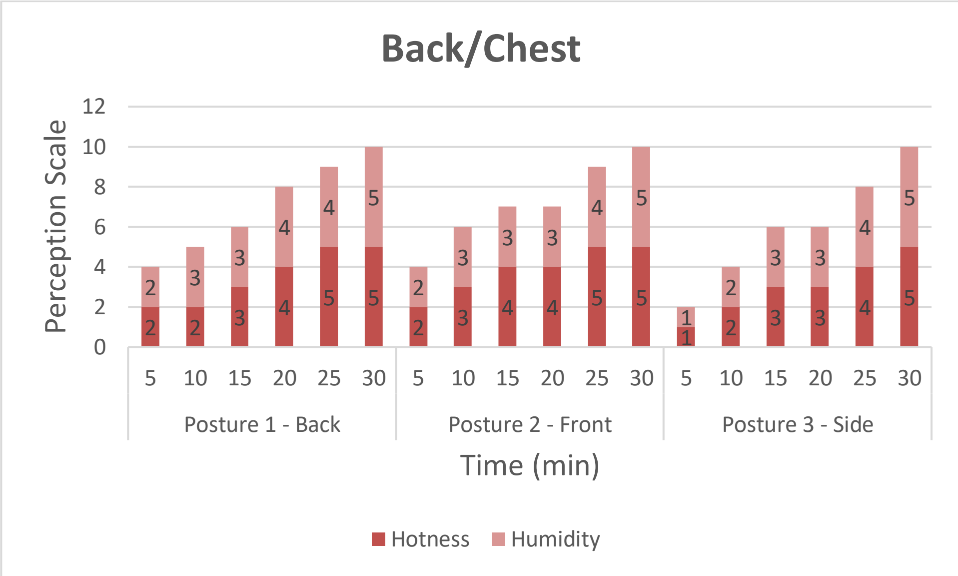

Feet
26.8
26.4
26
25.6
25.2
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

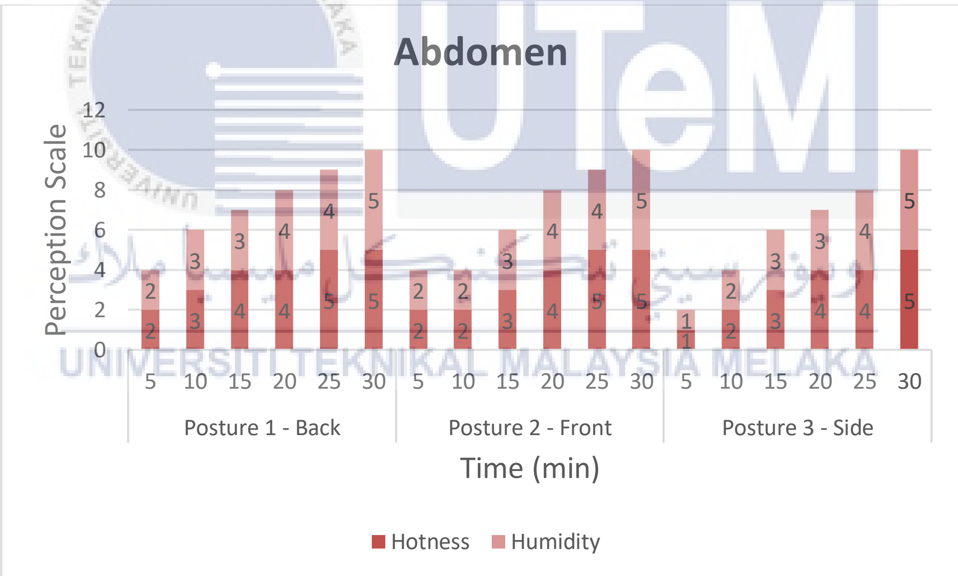

Feet
80
77
74
71
68
65
62
59
Temperature (ºC)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

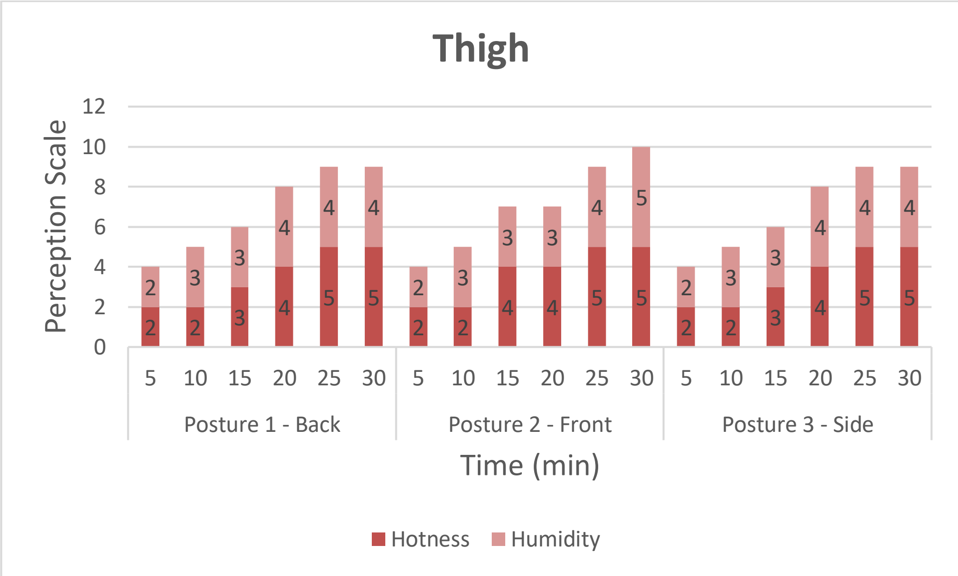
Human perception data for subject 3

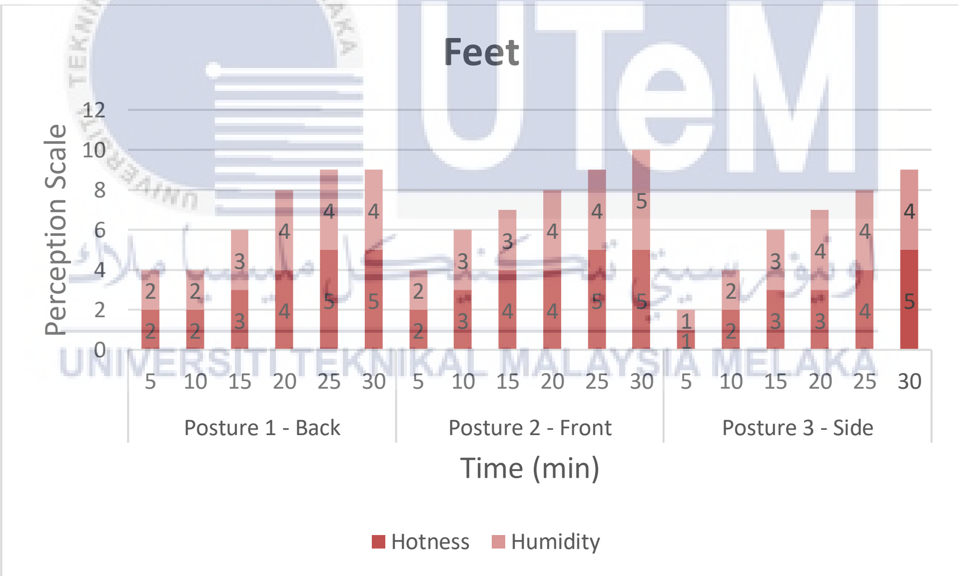





Back/Chest
Perception Scale
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Time (min)
Hotness
Humidity

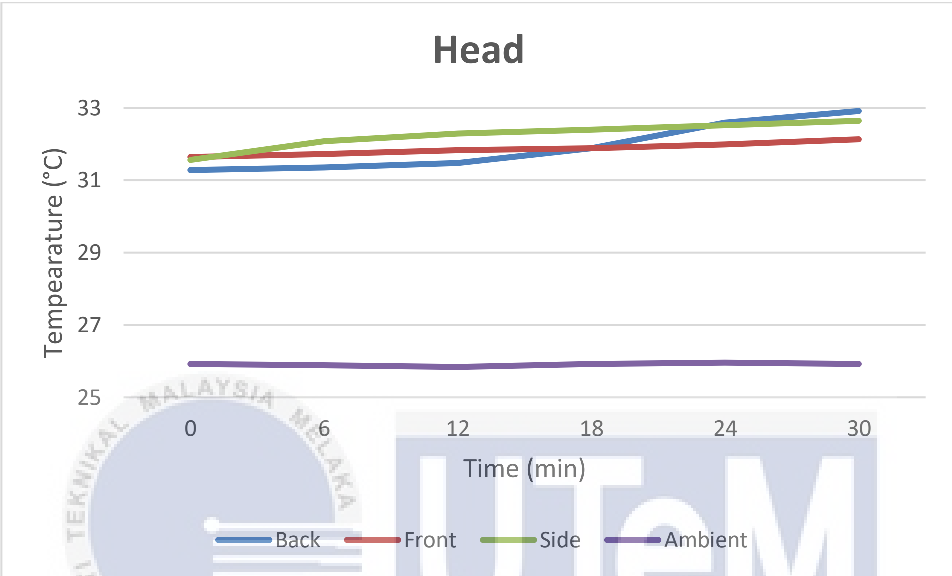

Abdomen
Perception Scale
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Time (min)
Hotness
Humidity


Thigh
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity

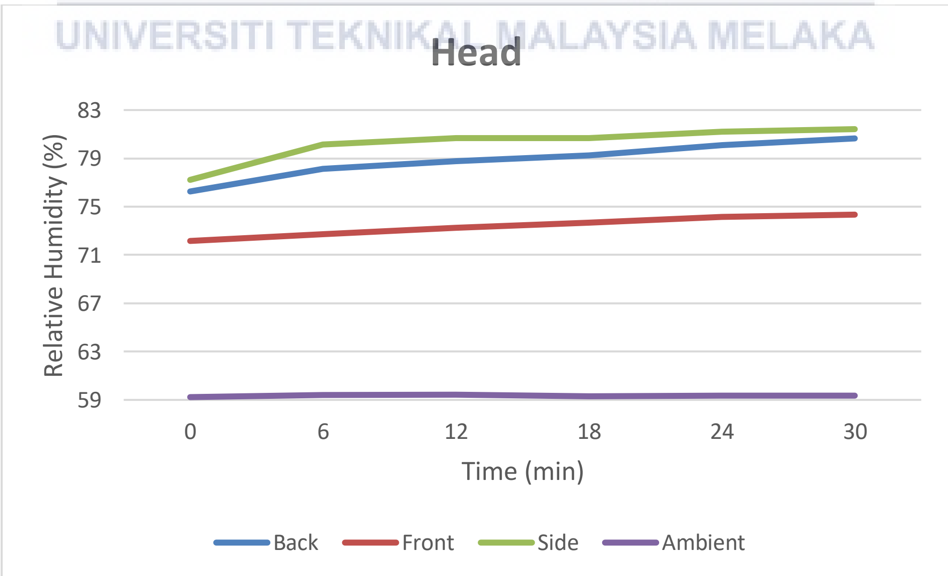

Feet
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity

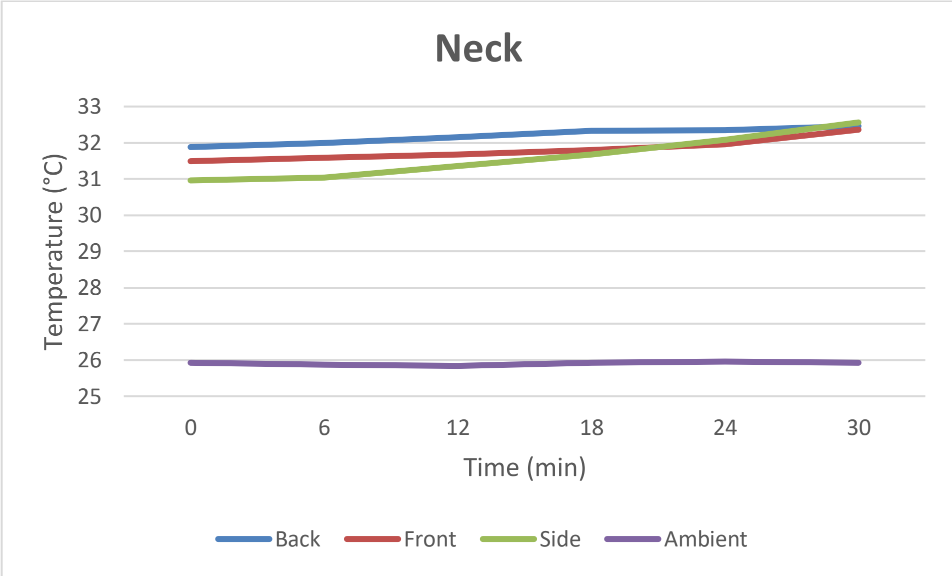
Results for subject 4

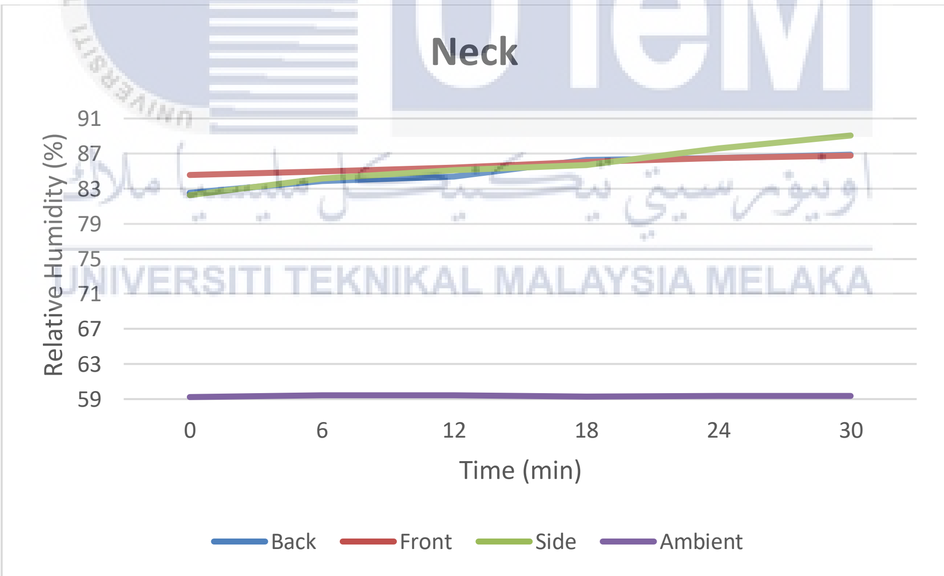
Temperature-time graph

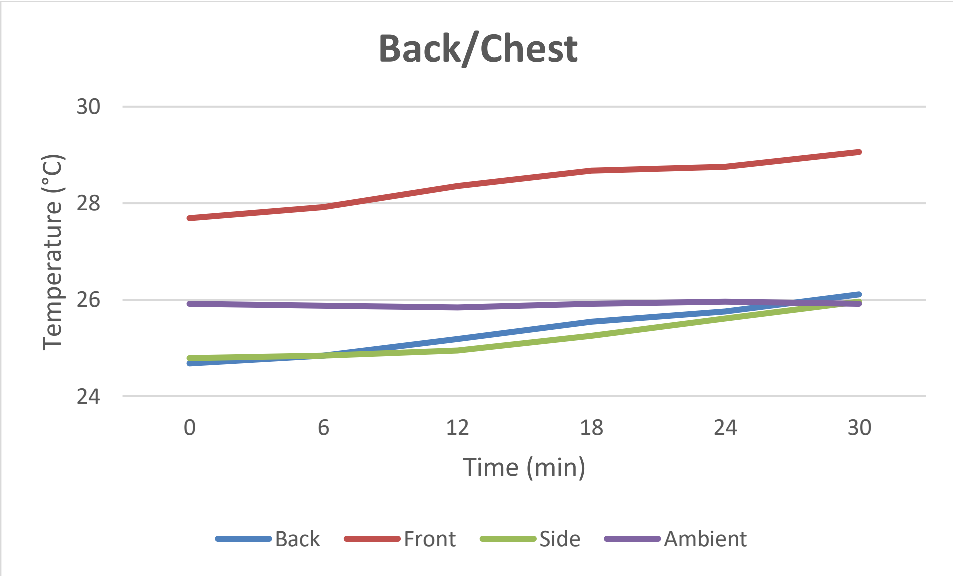


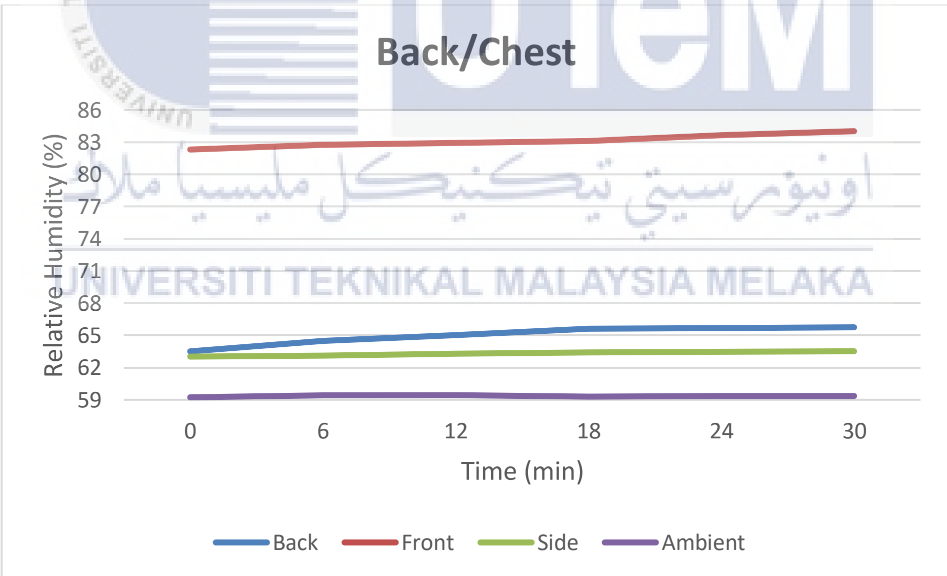
Relative humidity-time graph

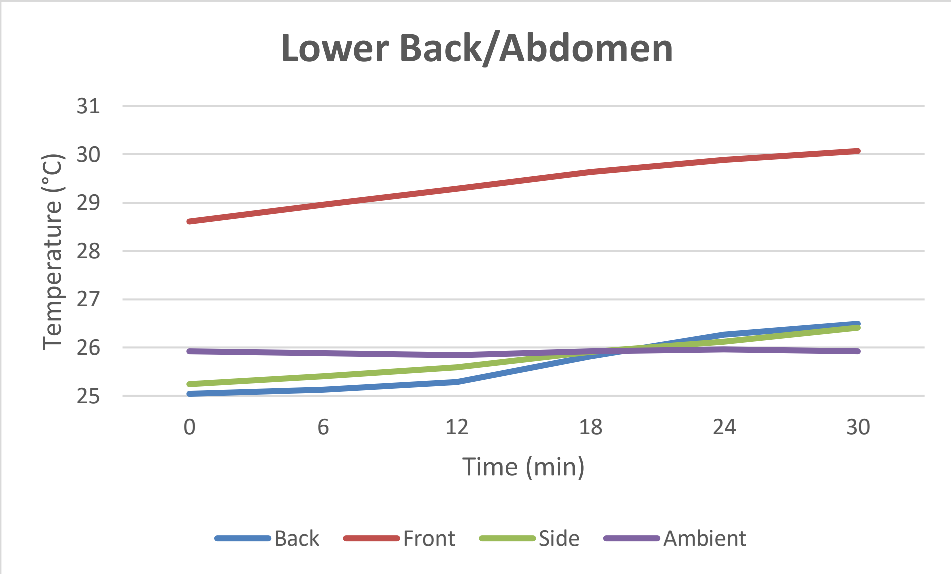


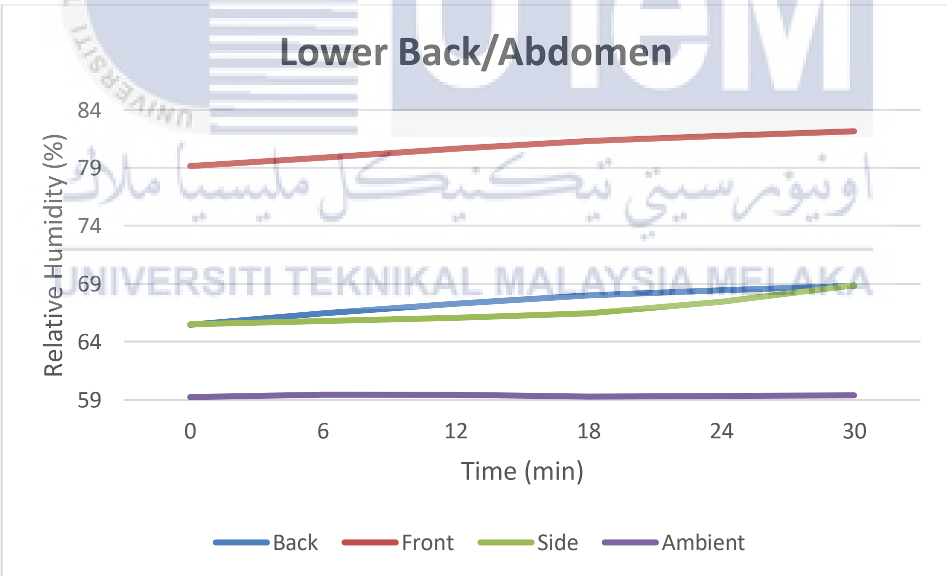

Neck
33
32
31
30
29
28
27
26
25
Temperature (°C)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

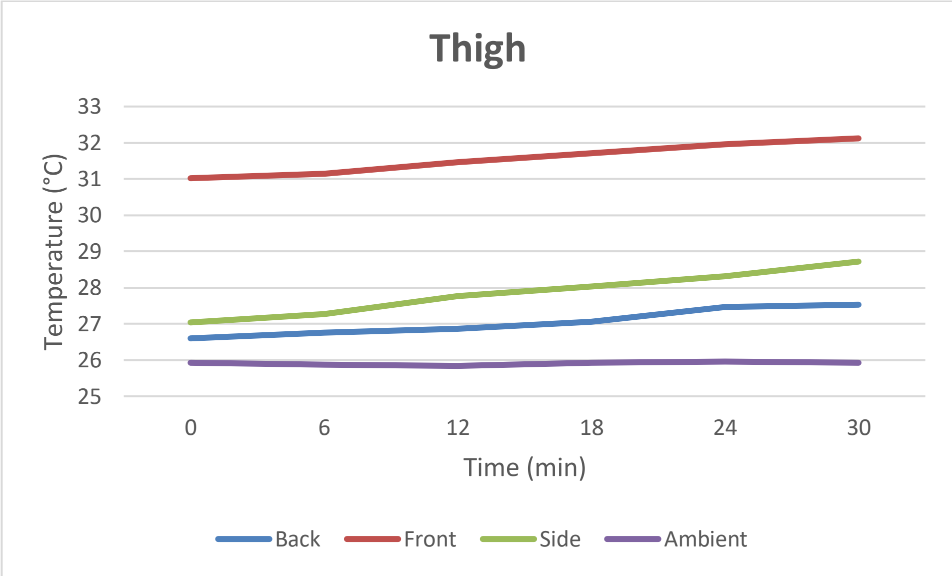

Neck
91
87
83
79
75
71
67
63
59
Relative Humidity (%)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

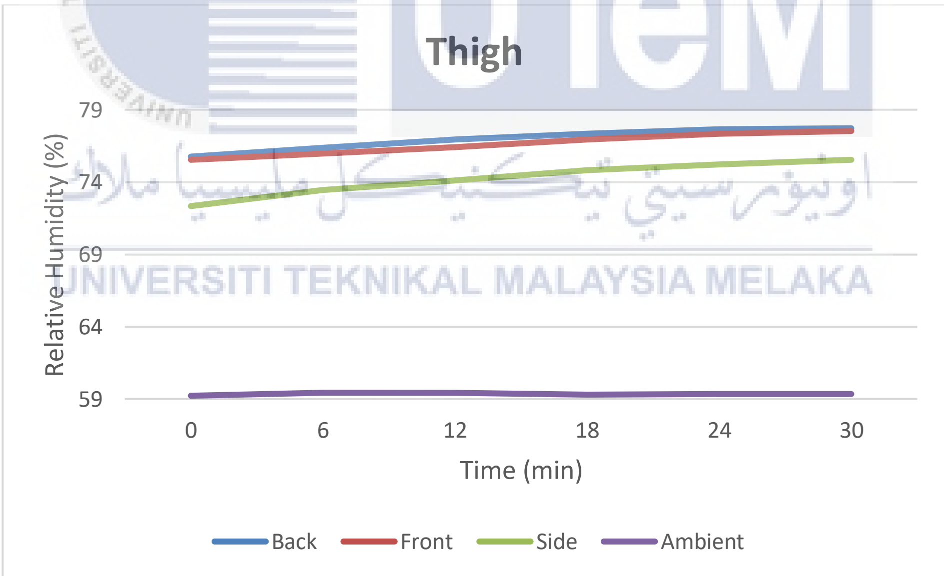

Back/Chest
Temperature (°C)
30
28
26
24
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

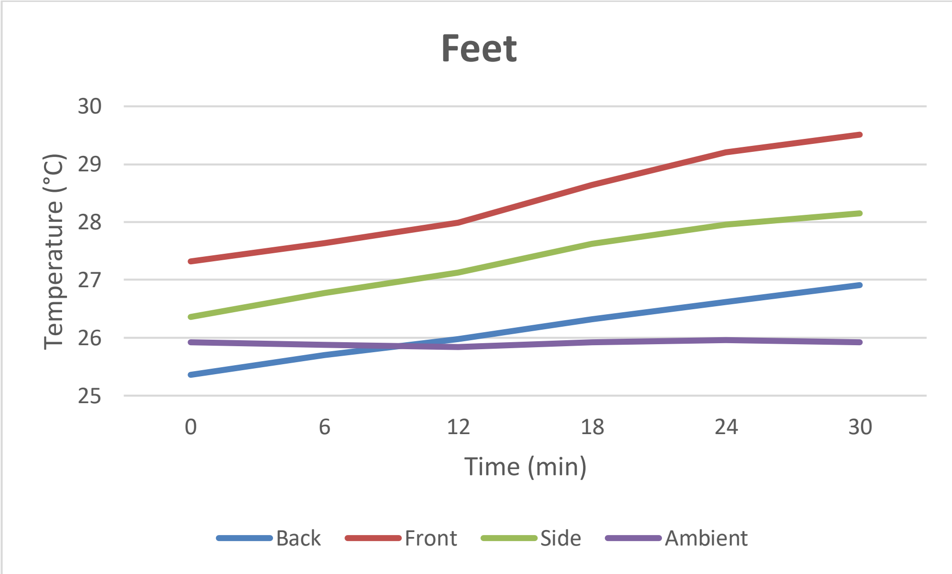

Back/Chest
Relative Humidity (%)
86
83
80
77
74
71
68
65
62
59
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

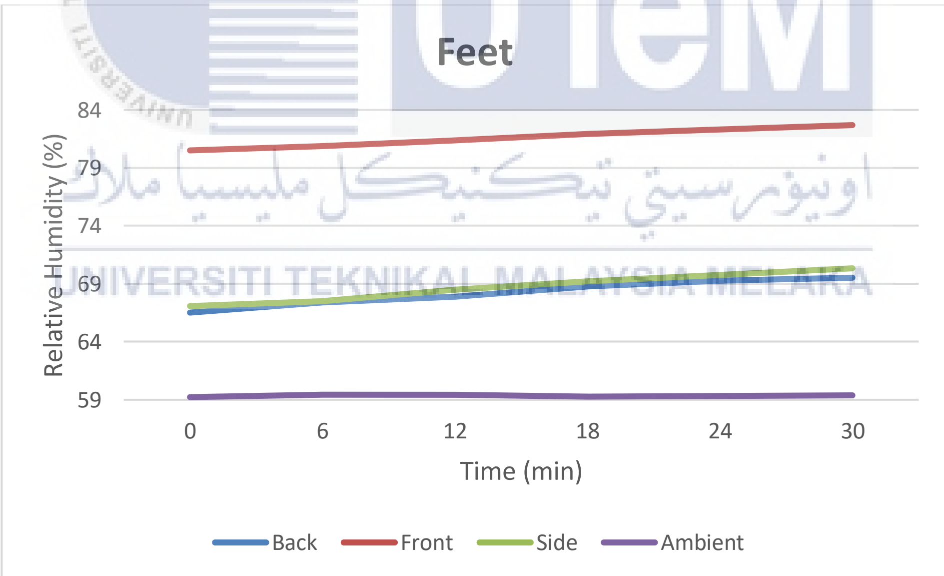

Lower Back/Abdomen
Temperature (°C)
31
30
29
28
27
26
25
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Lower Back/Abdomen
Relative Humidity (%)
84
79
74
69
64
59
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

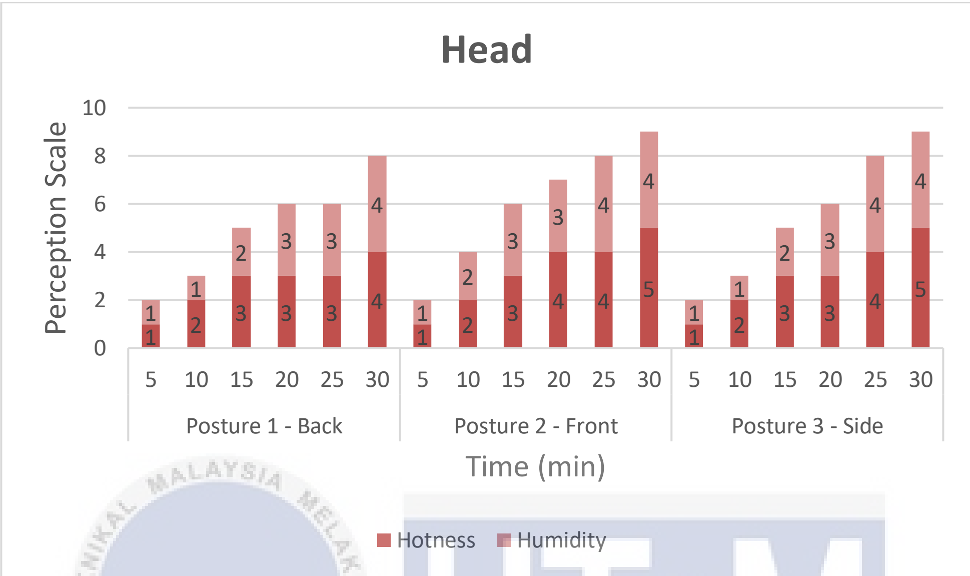

Thigh
Temperature (°C)
33
32
31
30
29
28
27
26
25
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

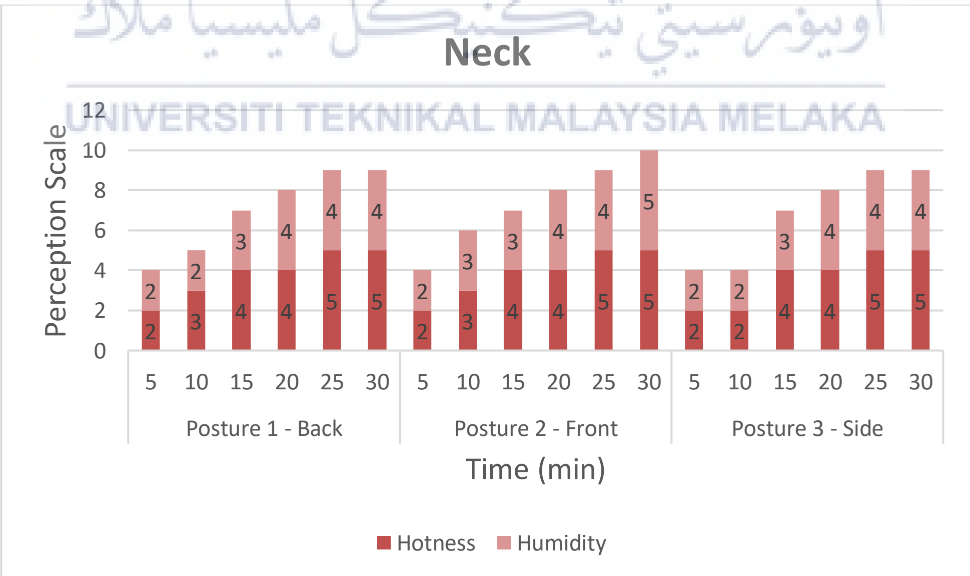

Thigh
Relative Humidity (%)
79
74
69
64
59
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

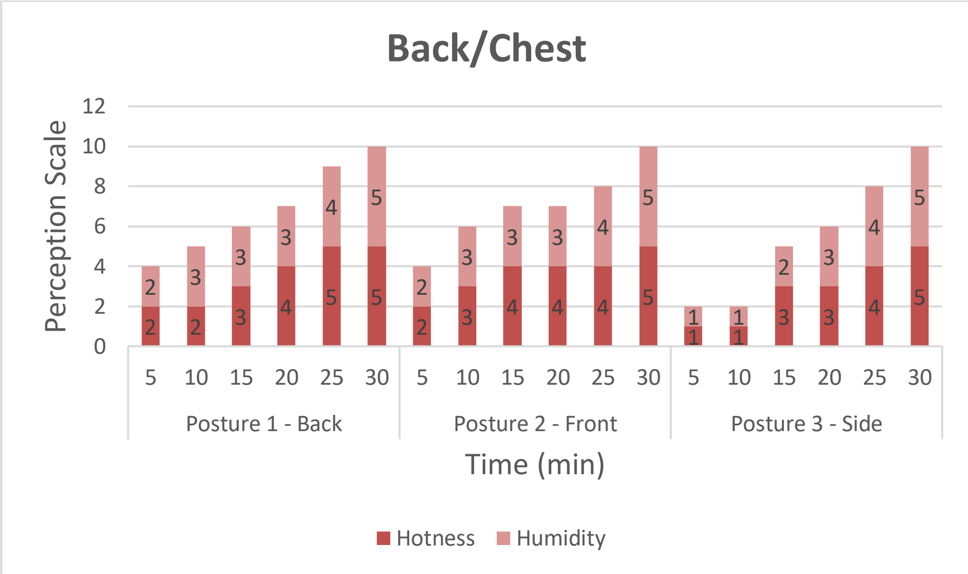

Feet
Temperature (°C)
30
29
28
27
26
25
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

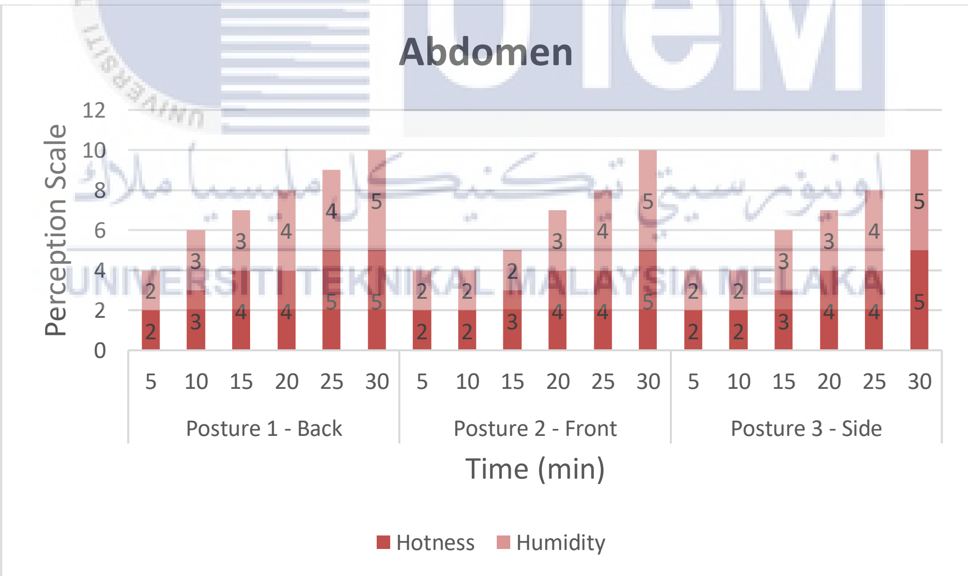

Feet
Relative Humidity (%)
84
79
74
69
64
59
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

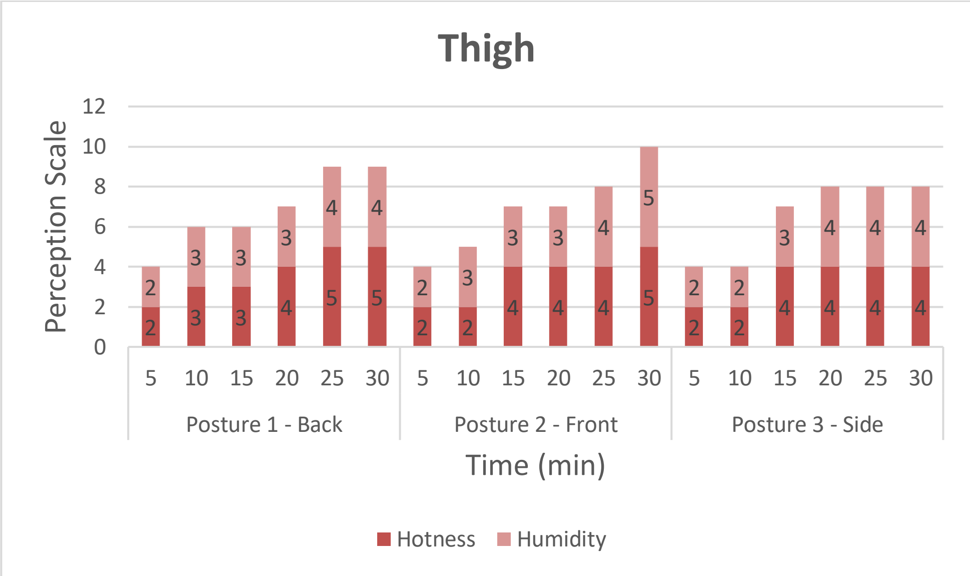
Human perception data for subject 4

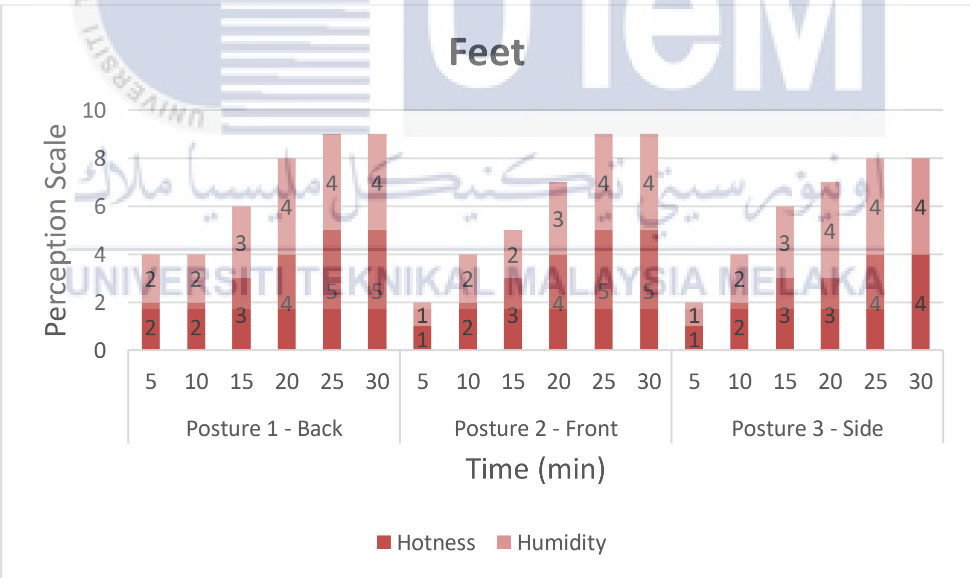





Back/Chest
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity

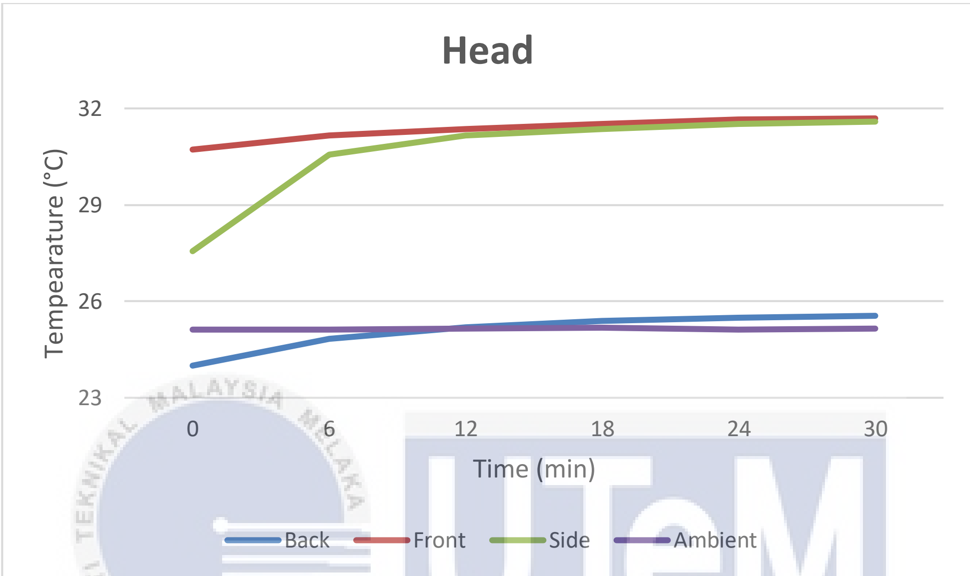

Abdomen
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity


Thigh
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity

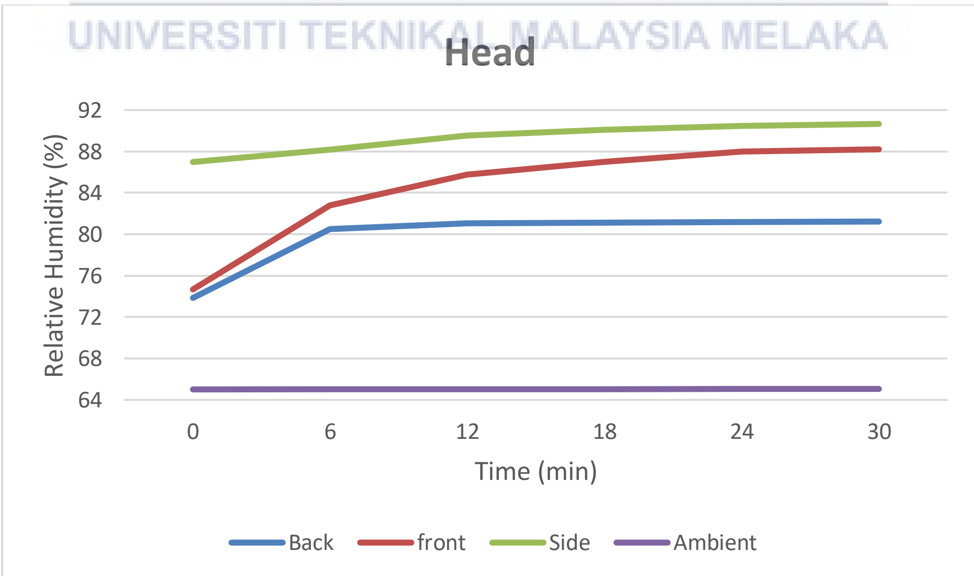

Feet
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity

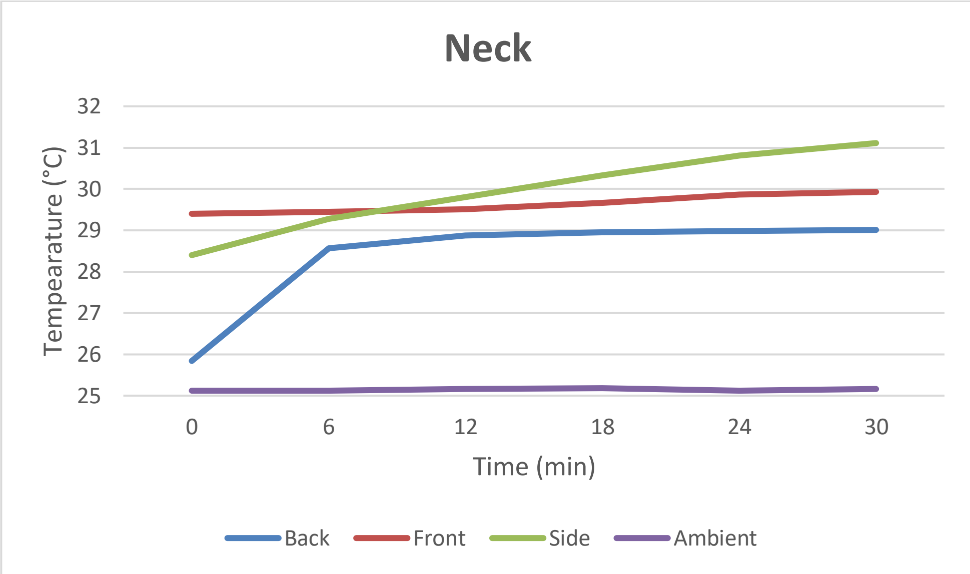
Results for subject 5

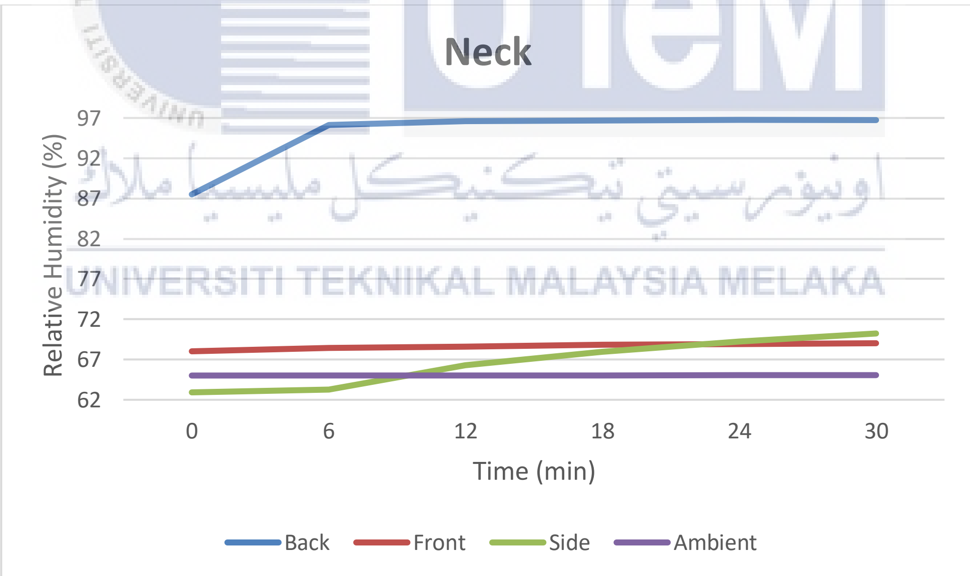
Temperature-time graph

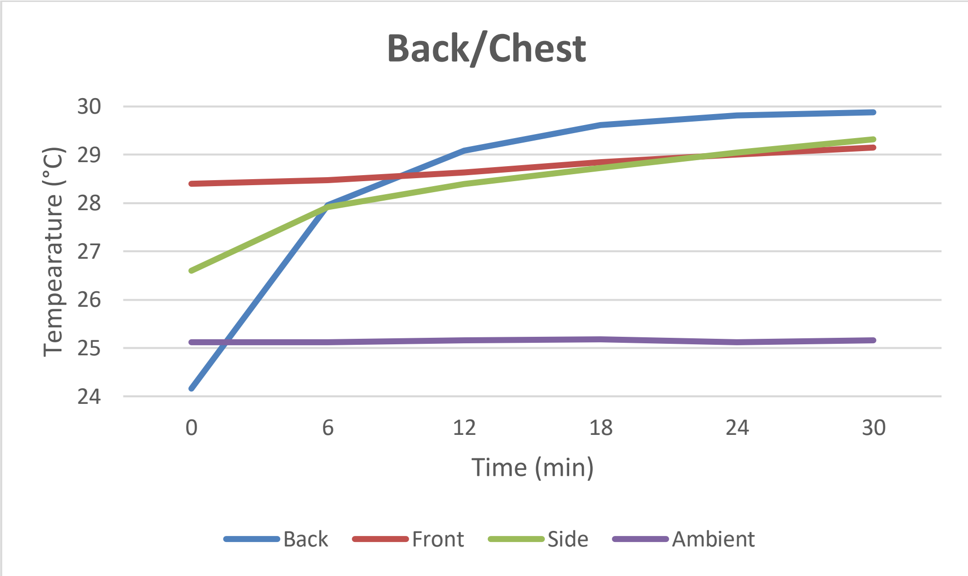


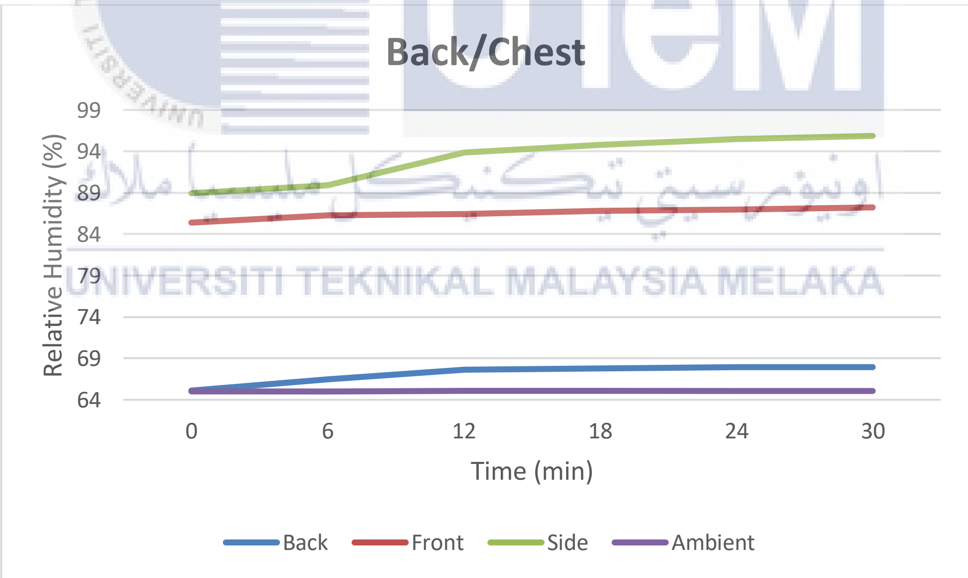
Relative humidity-time graph

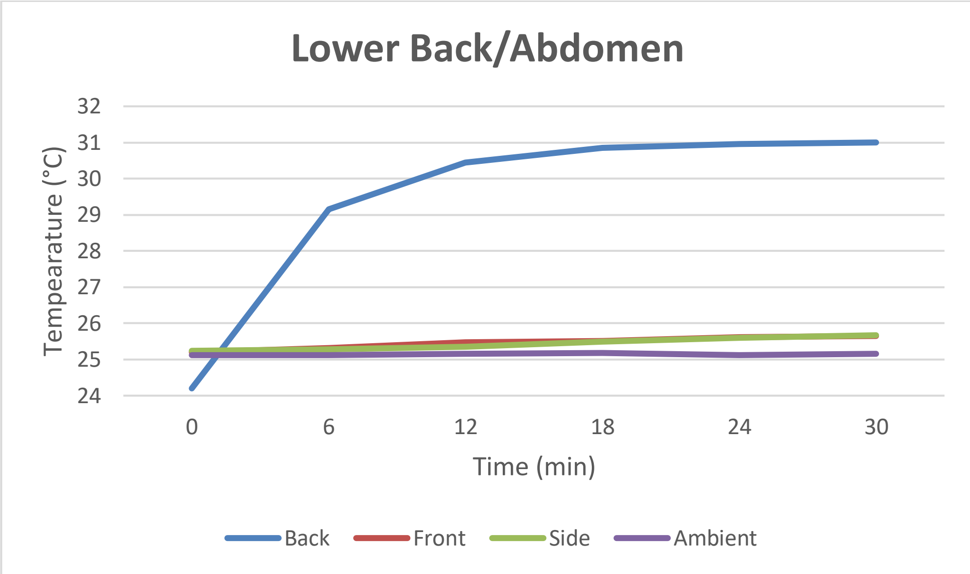


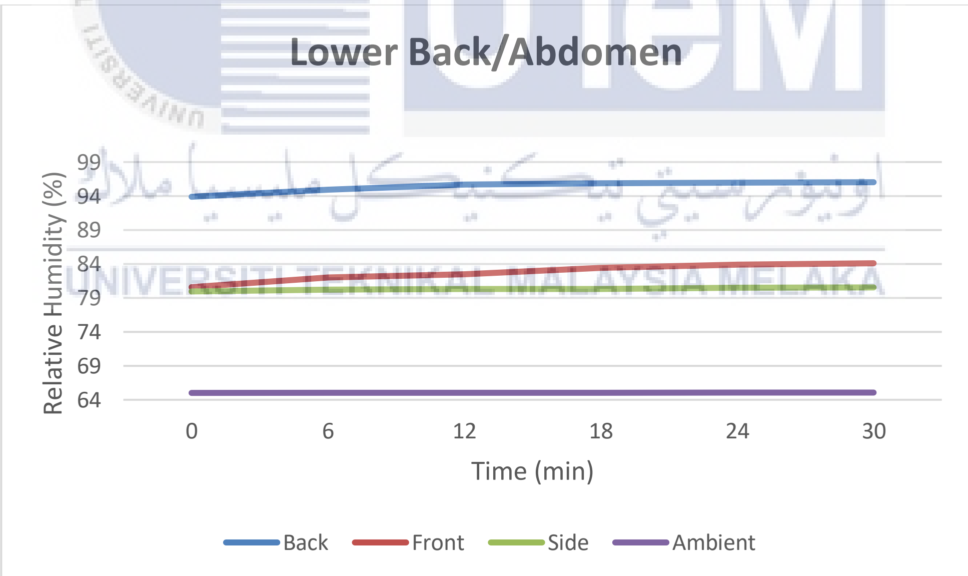

Neck
Tempearature (°C)
32
31
30
29
28
27
26
25
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

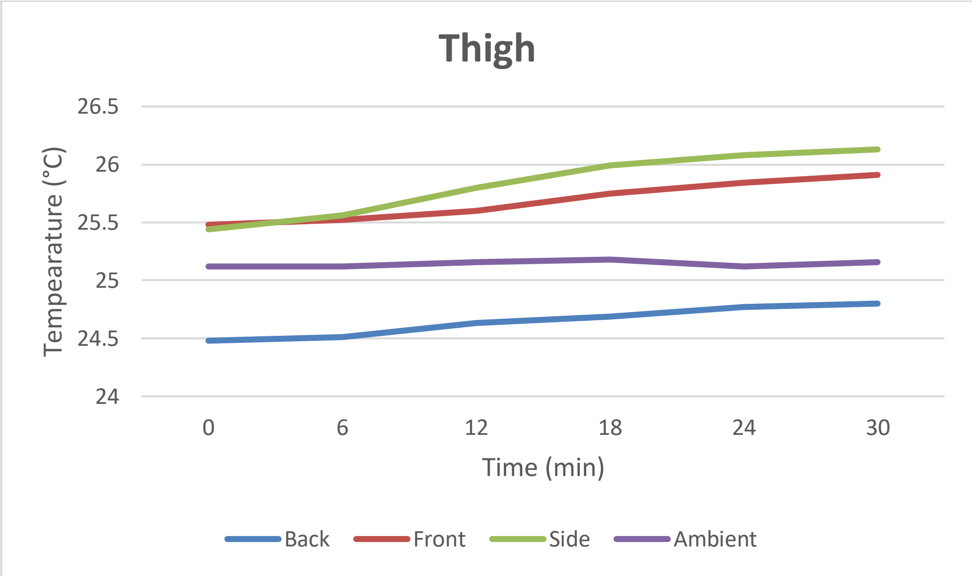

Neck
Relative Humidity (%)
97
92
87
82
77
72
67
62
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

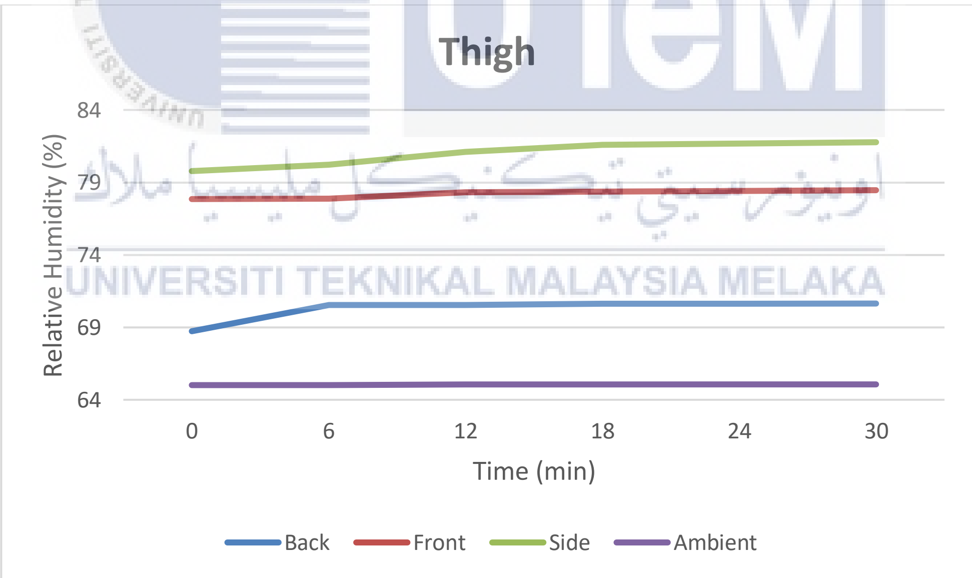

Back/Chest
Tempearature (°C)
30
29
28
27
26
25
24
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

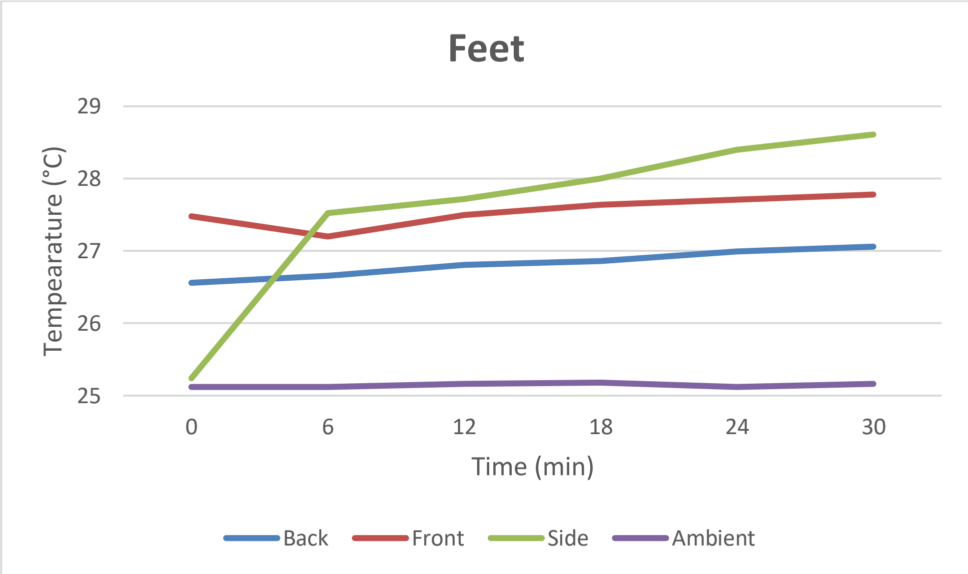

Back/Chest
Relative Humidity (%)
99
94
89
84
79
74
69
64
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

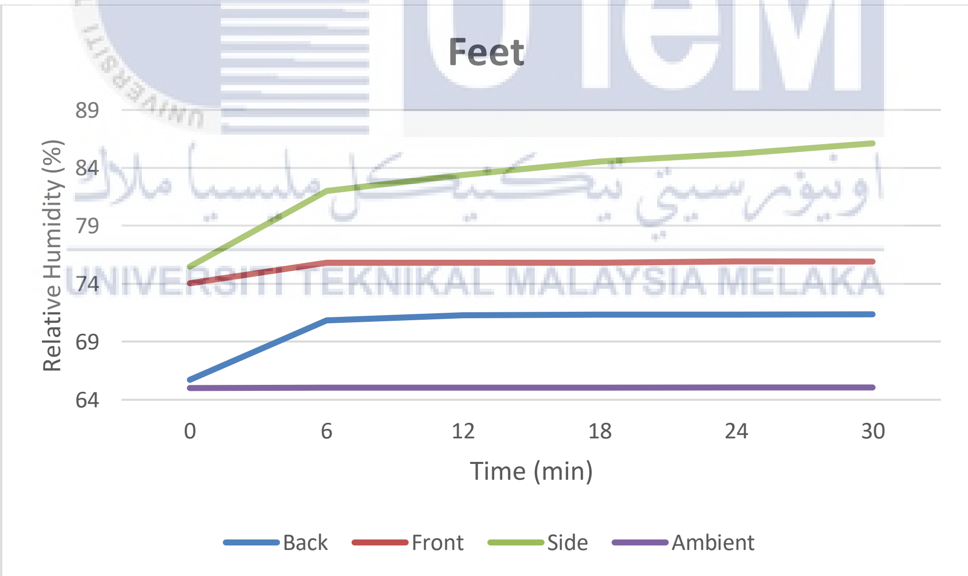

Lower Back/Abdomen
Tempearature (°C)
32
31
30
29
28
27
26
25
24
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient


Lower Back/Abdomen
Relative Humidity (%)
99
94
89
84
79
74
69
64
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

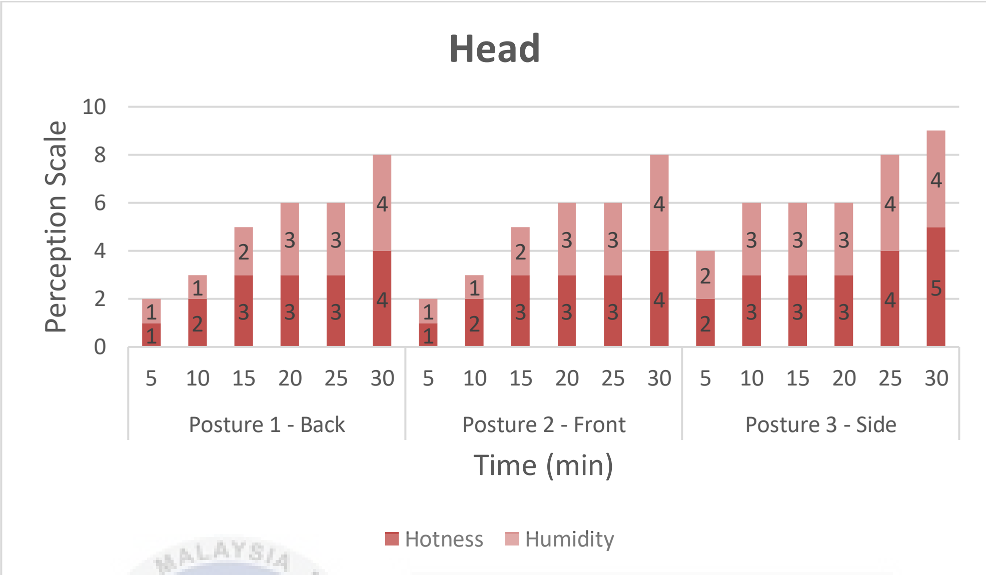

Thigh
26.5
26
25.5
25
24.5
24
Tempearature (°C)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

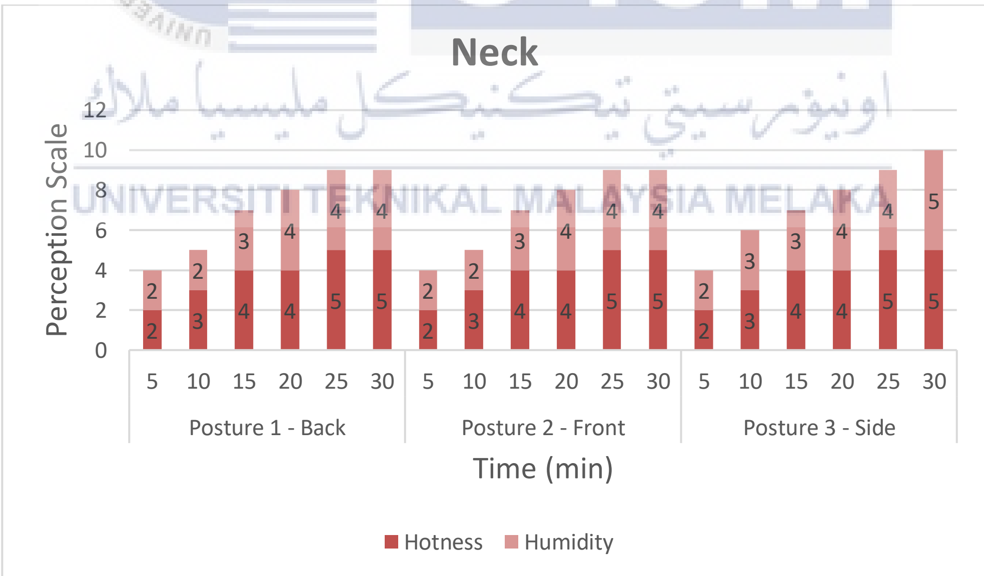

Thigh
84
79
74
69
64
Relative Humidity (%)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

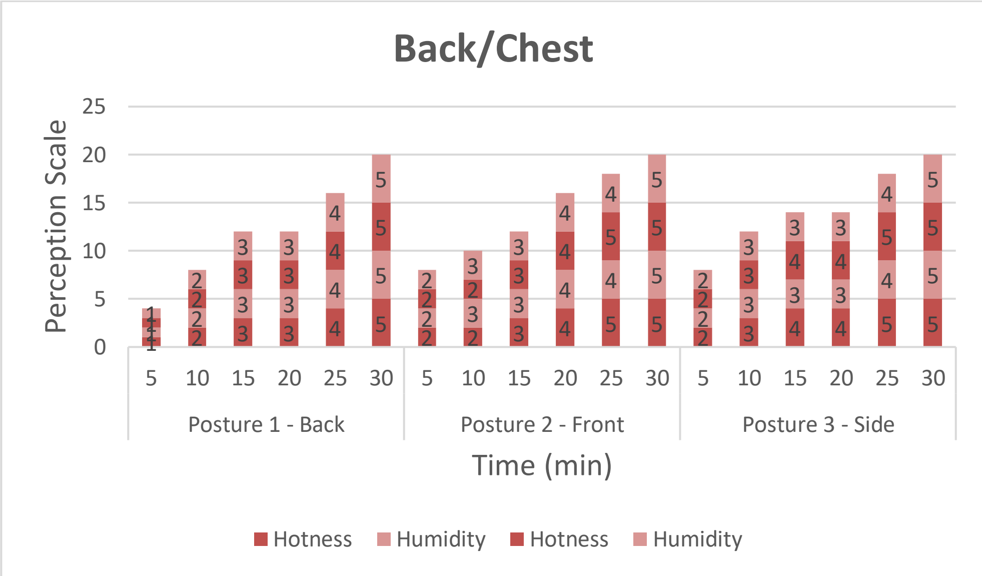

Feet
29
28
27
26
25
Tempearature (°C)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

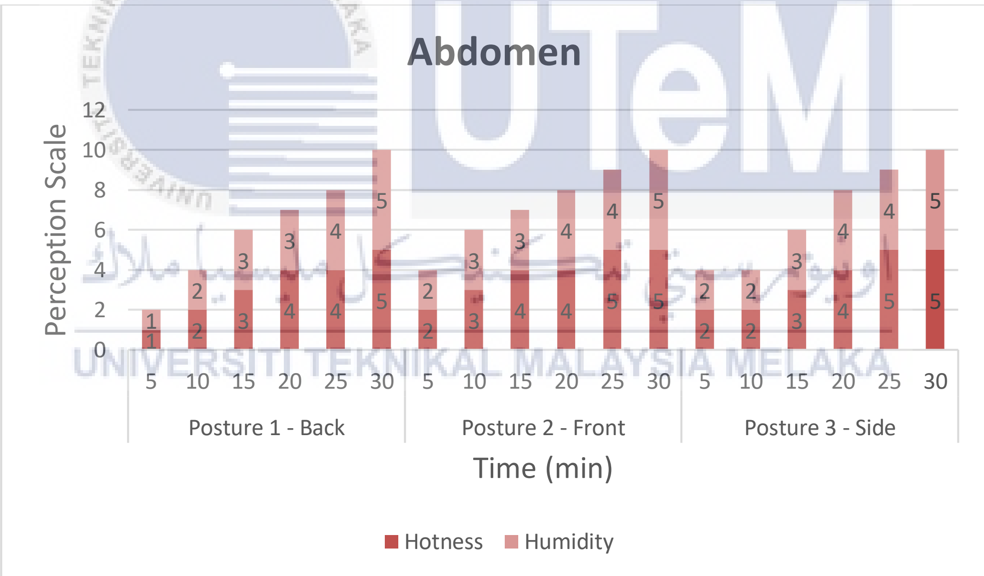

Feet
89
84
79
74
69
64
Relative Humidity (%)
0
6
12
18
24
30
Time (min)
Back
Front
Side
Ambient

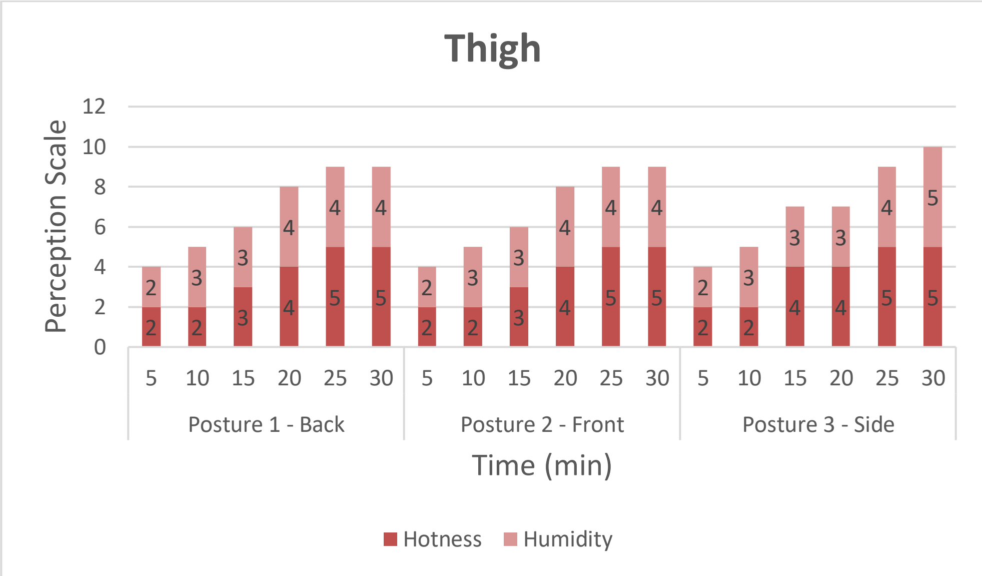
Human perception data for subject 5

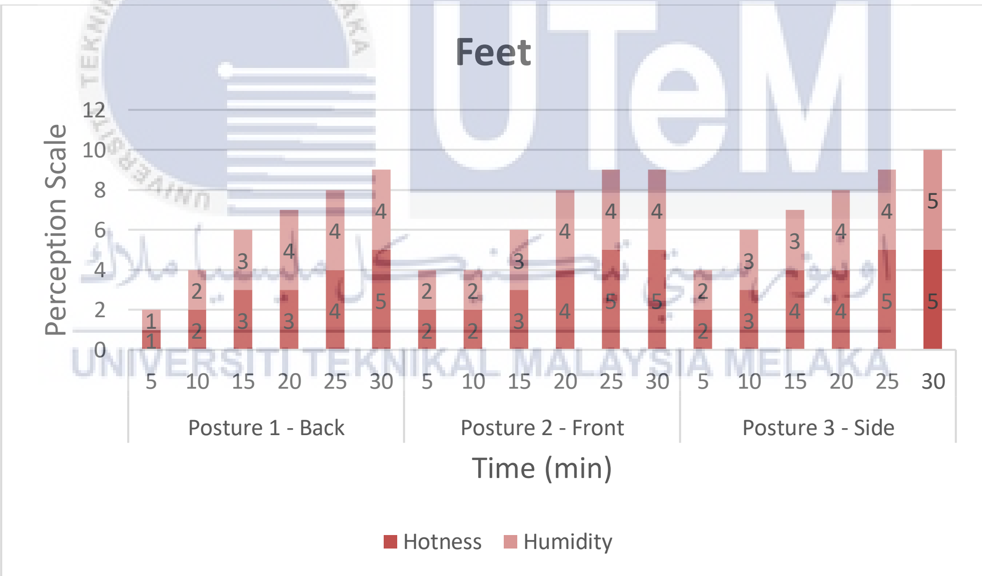





Back/Chest
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity
Hotness
Humidity


Abdomen
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity


Thigh
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity


Feet
Perception Scale
Time (min)
Posture 1 - Back
Posture 2 - Front
Posture 3 - Side
Hotness
Humidity

Sample of data list

Timestamp	Runtime [ms]	Device id	serial	Relative humidity [%RH]	T [°C]
2019-05-14T16:15:56.982	0	COM4.1	8.14394E+11	77.28	24.88
2019-05-14T16:15:56.982	0	COM4.2	8.14274E+12	79.15	24.96
2019-05-14T16:15:56.982	0	COM4.3	4.84645E+13	66.41	24.92
2019-05-14T16:15:57.498	516	COM3.1	8.24494E+12	72.54	24.56
2019-05-14T16:15:57.498	516	COM3.2	6.34494E+12	66.59	25.96
2019-05-14T16:15:57.498	516	COM3.3	4.94705E+13	83.49	26
2019-05-14T16:15:57.498	516	COM3.4	9.74524E+12	87.3	26.88
2019-05-14T16:16:26.876	29894	COM4.1	8.14394E+11	77.32	25.08
2019-05-14T16:16:26.876	29894	COM4.2	8.14274E+12	79.21	25.28
2019-05-14T16:16:26.876	29894	COM4.3	4.84645E+13	65.93	24.92
2019-05-14T16:16:27.407	30425	COM3.1	8.24494E+12	72.08	24.6
2019-05-14T16:16:27.407	30425	COM3.2	6.34494E+12	66.15	26.24
2019-05-14T16:16:27.407	30425	COM3.3	4.94705E+13	83.12	26.4
2019-05-14T16:16:27.407	30425	COM3.4	9.74524E+12	86.97	27.4