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Final Year Project Report

Mobile Air Conditioning Device

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2014/2015

“ I hereby declare that I have read through this report entitle “Mobile Air Conditioning Device” and found that it has comply the partial fulfilment for awarding the degree of Bachelor of Electrical Engineering (Mechatronic)

Signature : ………………….............................

Supervisor’s Name : ……………………………………..

Date : ……………………………………..

MOBILE AIR CONDITIONING DEVICE

CHIN KAR GHAI

A report submitted in partial fulfilment of the requirements for the degree

of Bachelor of Mechatronic Engineering, BEKM

Faculty of Electrical Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2014/2015

I declare that this report entitle “Mobile Air Conditioning Device” is the result of my own research except as cited in the references. The report has not been accepted for any degree and is not concurrently submitted in candidate of any other degree.

Signature : …………………………….

Name : ……………………………

Date : …………………………….

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ABSTRACT

The motivation behind this project is to design a portable cooling system that able to control temperature in a jacket at a certain degree. In the present extreme heat situation, portable cooling system is a solution to compromise the high temperature especially during daytime. The problem to realize is how to maintain temperature underneath the jacket while minimizing the weight of the equipment and reducing power consumption upon completing this project. It is proposed that water is used as medium to transfer coldness in this project. In order to control the temperature, sensor will be installing on the system as the feedback loop so that the controller can decide an action to overcome the change in temperature. Component is compared so that the smallest size of component will use for this project in order to minimize the weight problem. A 12V thermoelectric cooler is applied as main actuator to produce cooling. Hence, the objectives of this project are to design a system that able to control temperature accurately which is light in weight for portability purpose and is less in power consumption. Two experiments test is carried out in order to achieve the objectives of the project. Experiment 1 is to test the accuracy level of feedback loop in order to maintain temperature. Experiment 2 is separate into two parts which the first part is carried out using Scilab to analyse the efficiency of the system in term of rate of heat transfer. Prototype is needed in order to analyse the efficiency of the system in term of power consumption for second part. Result shows that this cooling system have a temperature difference of 0.7 ◦C in 600s and for experiment 4.3.1 and 2.5◦C in 300s for experiment 4.3.2; while the power consumption is 11.5 watts per unit thermoelectric cooler experiment 4.3.1 and 37.85 watts per unit thermoelectric cooler for experiment 4.3.2.

ABSTRAK

Motivasi di balik projek ini adalah untuk mereka bentuk sistem penyejukan mudah alih yang dapat mengawal suhu dalam jaket pada tahap tertentu. Dalam keadaan panas yang melampau pada masa ini, sistem penyejukan mudah alih adalah satu penyelesaian untuk mengatasi suhu tinggi terutama pada waktu siang hari. Masalah yang wujud adalah bagaimana untuk mengekalkan suhu di bawah jaket dan pada masa yang sama meminimumkan keberatan system serta mengurangkan penggunaan kuasa. Adalah dicadangkan air sebagai medium untuk memindahkan kesejukan untuk projek ini. Dalam usaha untuk mengawal suhu, sensor akan memasang pada sistem sebagai gelung maklum balas supaya pengawal dapat memutuskan suatu tindakan untuk mengatasi perubahan suhu. Komponen dibandingkan sehingga saiz yang paling kecil komponen akan digunakan untuk projek ini untuk mengurangkan masalah berat badan. A 12V sejuk termoelektrik digunakan sebagai penggerak utama untuk menghasilkan penyejukan. Oleh itu, objektif projek ini adalah untuk mereka bentuk satu sistem yang dapat mengawal suhu dengan tepat yang ringan mudah dibawa untuk tujuan dan kurang penggunaan kuasa. Dua eksperimen ujian dilakukan bagi mencapai objektif projek. Eksperimen 1 adalah untuk menguji tahap ketepatan gelung maklum balas bagi mengekalkan suhu. Eksperimen 2 adalah terpisah kepada dua bahagian yang bahagian pertama dilakukan dengan menggunakan Scilab untuk menganalisis kecekapan sistem dari segi kadar pemindahan haba. Prototaip yang diperlukan untuk menganalisis kecekapan sistem dari segi penggunaan tenaga untuk bahagian kedua. Keputusan menunjukkan bahawa sistem penyejukan ini mempunyai perbezaan suhu 0.7 ◦C dalam masa 600s untuk percubaan 4.3.1 dan 2.5◦C dalam masa 300s untuk percubaan 4.3.2; manakala penggunaan kuasa adalah 11.5 watt per unit termoelektrik eksperimen sejuk 4.3.1 dan 37,85 watt per unit lebih sejuk termoelektrik untuk percubaan 4.3.2.

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CHAPTER 1

INTRODUCTION

1.1 Motivation

Climate changed a lot in recent few years' time. This changes has indirectly brings other bad influence to human or World. Extreme weather is one of the influences that give so much of effect to human. As the climate has warmed, some type of extreme weather will become more frequent. Extreme hot, cold, sudden flood, storms and lightning are the examples of extreme weather [14]. Heat-related illness is a public health problem that usually happen when someone expose to extreme heat for too long. Examples of illness are heat stroke, heat cramps and heat syncope.

The issue of extreme weather is not only happen to western country, but it also happen in local, Malaysia. According to the Health Ministry, director-general Datuk Dr Noor Hisham Abdullah, March 2014, a person will also face the signs of muscle pain, spasms, and vomiting, dry and reddish skin before the serious consequence approached-coma or death. There is also a report by The Meteorological Department, announced that the hot weather was worse than previous year [20].

These illnesses will result in death and there is a research about deaths attributed by heat, cold and other wealth events in United States, 2006-2010 [14] with data shown in Figure 1. By focusing to heat-related death, data shown death rate increased from age 45 and above where this can be explain by healthy level is not strong as people at age less than 45 years old. There is actually a way to reduce the death rate which is by controlling body temperature to prevent changes in large scale especially when a person move from surrounding with low temperature into a surrounding that have very high temperature.

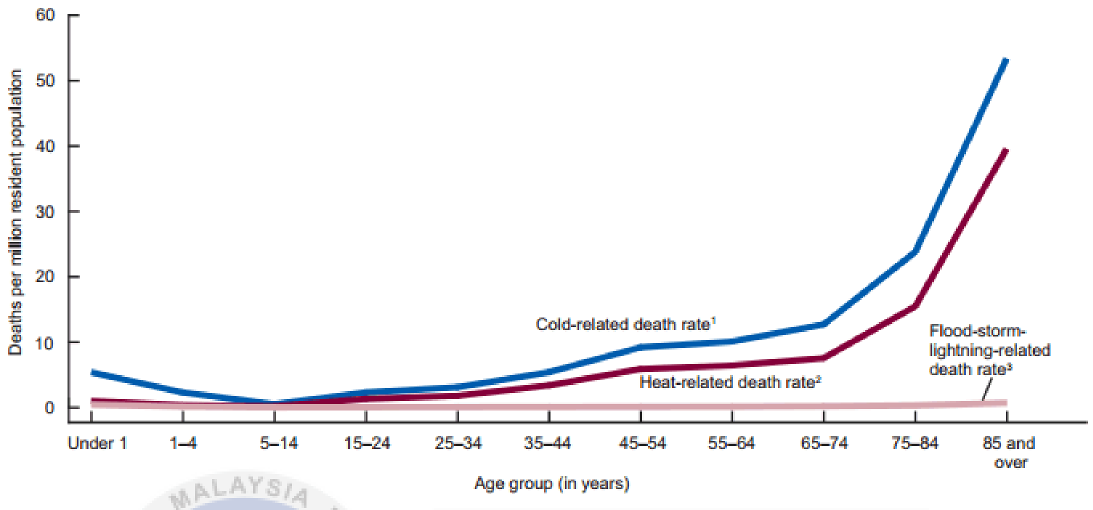


Figure 1: Death rates for extreme weather related to age: United States, 2006-2010

Source: http://www.cdc.gov/nchs/data/nhsr/nhsr076.pdf

Air conditioner is to compromise with the hot weather. Refrigeration cycle is typically used in air conditioner equipment in order to achieve the cooling purpose. Besides that, there are other method used in cooling purpose like evaporation, natural cooling and so on. There was a significant of transformation in air conditioner history where it started with a rotary fan as air conditioning in 2nd century. However, Wills Carrier had successfully invented the first modern air conditioning unit for a plant in 1902 where he applied the knowledge of reversing heating using steam into his invention. The air was send through a cold coil that fills with cold water then produce moisture air. The main purpose of his invention was to control the temperature as well as the humidity of surrounding.

Wills invention was big in size and usually for plant sector. David St. Pierre DuBose has developed a network of ductwork to control the air conditioning in private home in 1933. However, there is still an improvement can be done on current air conditioner status which make it become portable. A portable, in-window air conditioner has designed and invented by Robert Sherman in 1945 which this invention upgraded the previous air conditioner function to another level by combining cooled, heated, humidified, dehumidified and filtered air. The present of air conditioner has indirectly introduced refrigerant development where it contains a complex construction like compressor, filter, blower, evaporator coil, condenser coil and fan.

There is now greater expectation from the public about the portability. There is a need on making the portable become a complete mobile air conditioner device. This requirement is not impossible but actually there is already have inventions on it to solve hot weather during outdoor activity. Invention of cooling jacket will grab attention where it gives the exactly solution to the expectation as a fully portable cooling system which consume less power [4].

1.2 Problem Statement

In developing a mobile cooling jacket, there are few requirements that are needed in order to complete this project. The first requirement in this cooling system is the control system must able to maintain temperature below threshold; second requirement is to make sure the weight of the prototype to be as light as possible while the last requirement is to minimize power consumption.

In this project, the idea in designing the cooling system is by using thermoelectric cooler as the cooling actuator while the medium selected to transfer the coldness is by water or usually called as coolant. However, there are other methods of cooling like ventilation and melting of ice. Ventilation helps the air flow process, how about if the air is hot. In addition, the ice has to supply from time to time if applying the method of ice melting.

In order to solve the first requirement, cold water able to absorb heat from hot object which make it to be chosen as the medium to transfer coldness in this cooling jacket. However, the distribution streamline has to be design well so that the coldness can be transfer equally over the entire jacket. The cooling system should have the ability to stop actuated thermoelectric cooler at temperature threshold and re-actuate it when temperature rise. In addition, consideration of the jacket design to making it seal so that it able to trap coldness for longer time.

The solution for the second requirement is by comparing few components in term of mass, and chooses the component that has less weight for the prototype. Mass distribution is important in order to arrange components equally, so, method of centre of mass can be applied to find out the best position for components arrangement.

Nowadays almost every kind of electric device is implemented to save energy. Hence, components are also being compared in term of power consumption in solving second requirement before finalised.

In addition, basic knowledge of thermodynamic and heat transfer is required in order designing this mobile cooling jacket. It is required to identify which mode is applied within three modes of heat transfer. Basic concept of a cooling system in thermodynamic is important where it helps to design own cooling system and decide what components are needed.

It is proposed that by using thermoelectric cooler with a feedback loop controller, it could optimize the problem of temperature changes which gives a lot of bad influence to human during extreme weather.

1.3 Objective

The objectives of this project are:

1. To design and develop an AC system that able to control temperature accurately while considering light in weight
2. To analyse the efficiency of the cooling system in term of the rate of heat transfer and power consumption while considering the pipe arrangement pattern

1.4 Scope

Several scopes had been outlined in order to achieve the objectives. The scope of this project referring to the two objectives stated in previous section.

- Finding a suitable cooling method
  - i. Two type of cooling methods are being compare
  - ii. Comparing components for cost saving
- Only experimental testing is carry out to test the accuracy of the cooling jacket
  - i. To test the accuracy of feedback loop controller at outdoor
  - ii. Surrounding temperature within range of 25 – 38 ˚C
- Only simulation is carry out to test the efficiency of the system in term of power consumption
  - i. Graph of rate of heat transfer against thickness is tabulated
  - ii. Power consumption will be analyse in watt unit

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

This section describes some of the important aspect in cooling methods characteristic used to cold down a body temperature so that a desired cooling method can be select to fulfil the requirement of a portable cooling jacket. The first part in this chapter is description of the fundamental knowledge that will apply in this project. The second part is the description of cooling methods that exist in nowadays. The third part is to describe the problems and compare the existing cooling jacket invented in other country. The fourth part is to identify the solutions related to the problems. The last part in this chapter is to discuss the selection in terms of performance.

2.2 Fundamental Knowledge

Coefficient of performance (COP) is a type of calculation where we can know the efficiency of the system. COP is usually measure for refrigerator, however, it can also apply for cooling system as well [4]. In addition, COP is also applying on finding the efficiency of thermoelectric cooler. Coefficient calculation for refrigerator or cooling system and heat pump are as below [4]:

$$COP_R = \frac{Q_L}{W_{net,in}} \tag{1}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} \tag{2}$$

Where

Q_L = desired output for refrigerator, watt

Q_H = desired output for heat pump, watt

$W_{net,in}$ = energy needed for the system, watt

A piping streamline that filled with liquid or air is commonly applied in heating and cooling applications. This type of application basically needs external force to complete the works like pump for liquid system and fan for air system. Flow rate is constant regardless diameter of pipe when all pipes are connected in series. For parallel pipes, a junction is joining with two or more piping where flow rate total is the sum of the flow rate in the individual pipes. By limiting the consideration to incompressible flow, an equation can be used to calculate the volume flow rate of a flow as below [15]:

$$\dot{v} = vA_c \tag{3}$$

Where

$\dot{v}$ = volume flow rate, m^3/s

v = flow velocity, m/s

A_c = cross-sectional area of flow, m^2

Depending to the direction of current flow, heat will flow from one side to the other side of thermoelectric cooler, thus making a cool and a hot at both sides. The power used when performing can be calculated using equation as below:

$$W = PIt \tag{4}$$

Where

W = power usage of thermoelectric cooler

P = Peltier coefficient

I = current

t = time

Heat can be transfer in three different modes: conduction, convection and radiation. Heat transfer rate is different in every mode and also depending to the thermal conductivity of the material [9]. Only convection mode is applied in this paper.

Mode 1: Conduction

$$\dot{Q}_{cond} = kA\frac{T_1 - T_2}{\Delta x}$$
$$= kA\frac{\Delta T}{\Delta x} \quad (5)$$

Where

$\dot{Q}_{cond}$ = rate of heat conduction, watt

k = thermal conductivity, W/mK

A = cross-sectional area, m^2

ΔT = temperature different, K

Δx = thickness, m

Mode 2: Convection

$$\dot{Q}_{conv} = hA_s(T_s - T_\infty) \quad (6)$$

Where

$\dot{Q}_{conv}$ = heat transfer rate, watt

A_s = heat transfer area, m^2

h = convective heat transfer coefficient, W/m^2K

T_s = surface temperature, K

T_∞ = fluid temperature away from the surface, K

Mode 3: Radiation

$$\dot{Q}_{rad} = \varepsilon \sigma A_s (T_s^4 - T_{surr}^4) \tag{7}$$

Where

$\dot{Q}_{rad}$ = heat transfer per unit time, W

ε = emissivity

σ = Stefan-Boltzmann constant, $5.67 \times 10^{-8}\ W/m^2K^4$

T_s = absolute temperature of surface, K

T_{surr} = absolute temperature of surrounding, K

2.3 Type of Cooling Methods

Weather of nowadays has change a lot where this lead a serious problem to all living creatures which is hot weather. However, there is also a solution that engineers have comes out to solve this problem and it is what we called it as 'Air Conditioner'. Majority of cooling equipment exist in this world mainly with compression as well. Actually, there is several type of cooling that do have and also being applied by human in daily life in order to lower down the surrounding temperature which are natural cooling, compression cooling [11], evaporative cooling [16], fan and ventilation cooling [12], and thermoelectric cooler [1][10].

2.3.1 Natural Cooling

A cooling method whereby using natural resources from surrounding to cool up a place instead of using passive methods like air conditioner. There are force convection and free convection.

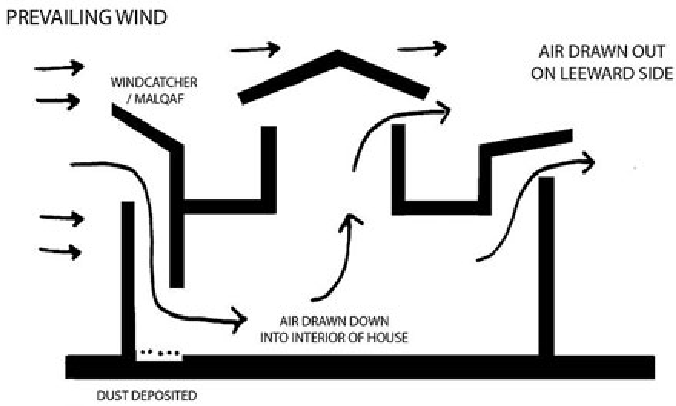


Figure 2: Natural cooling

Source: http://www.alternativebuilder.com/natural-air-conditioning.html

Convection is a mode where energy transfers between a solid surface and adjacent liquid or gas that is in motion. It can be categorised into force convection and free convection. First, force convection or also called as passive convection is where air is blow over a surface by external force like wind, fan and pump. Second, free convection, use of prevailing winds and natural, gravity-induced convection to ventilate an object, a straight forward convective method is cool night air to drive hot air out.

Equation related and used in convection calculation is:

$$Q_{conv} = hA_s(T_s - T_\infty) \tag{8}$$

where,

h= convection heat transfer coefficient, W/m^2, ˚C

$\boldsymbol{A_s}$ = surface area where heat transfer takes place

$\boldsymbol{T_s}$ = surface temperature

T_∞ = temperature of fluid/air sufficiently far from the surface

2.3.2 Compression Cooling

A cooling process which reviewed that liquid absorbs heat when it evaporates. There are five important parts in this method which are compressor, evaporator, condenser, accumulator and flow control device.

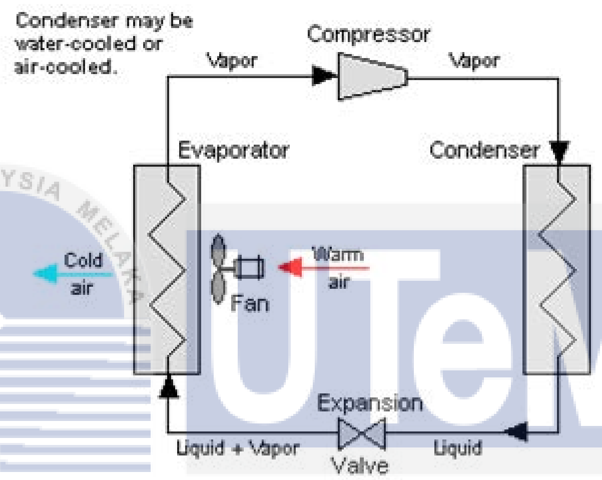


Figure 3: Compression cooling system

Source: http://en.wikipedia.org/wiki/Vapor-compression_refrigeration

There are 5 basic elements contain in a compression cooling system which are compressor, evaporator, condenser, accumulator and flow control device. Each function is as below:

- Compressor: Temperature inside is raise by increasing the pressure in evaporated refrigerant
- Evaporator: Heat is absorb during the change state of liquid to vapour
- Condenser: High pressure refrigerant gas from compressor is transfer into here and being cooled
- Accumulator: A reservoir that keeps liquid refrigerant

- Flow control device: Sometimes called expansion valve is use to control the flow of liquid refrigerant into evaporator

Equation related and used in to calculate the power consumption is:

$$Power(w) = \frac{Energy,\ J}{Time,\ s} \qquad (9)$$

where,

J = energy absorb or dissipate

2.3.3 Evaporative Cooling

Heat absorbing in liquid cause energy change whereby it leads to changing in state. Sufficient energy cause liquid state change to vapour state under evaporation process.

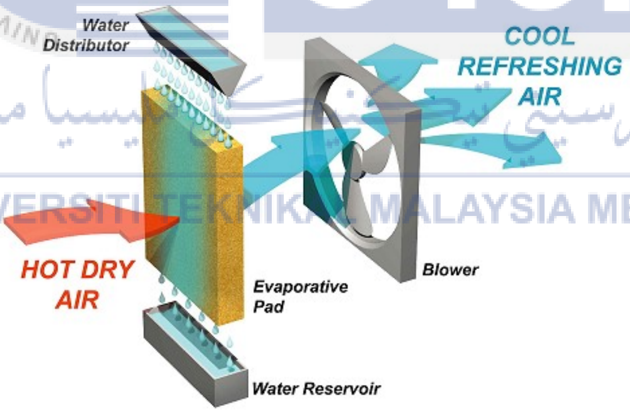


Figure 4: Evaporative cooling

Source: http://muellerdesignlab.wordpress.com/2012/04/20/diy-evaporative-cooler-design/

Method use is evaporation where medium can be applied is only water or cold water (with ice). A pump is installing together with the system to maintain the continuous fluid flow from the reservoir to a pad. The water passes through turns the pad becomes wet. A fan is use to draws air from outside into the system. Outside air is hotter and temperature is higher comparing to the temperature on wet pad. Once hot air pass through wet pad, moisture on the pad is cooled and hence produce cool fresh air

Equation related and use in calculating the flow rate is:

$$Q = uA \qquad (10)$$

where,

Q = volume flow rate, m^3/s

u = fluid velocity, m/s

A = cross sectional area of the pipe, m^2

2.3.4 Fan and Ventilation

Ventilation is a criterion to make surrounding temperature drop when without air conditioner. Fan is an equipment to enhance the ventilation process.

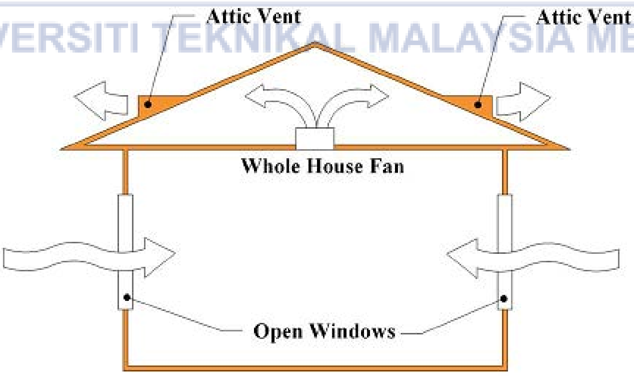


Figure 5: Fan and ventilation cooling

Source: http://arbi.davisenergy.com/?page_id=188

There are 3 ways to cool a body down which are convection, radiation and perspiration. Convection happens when heat is carried away from body to other medium via moving air. During the process of convection, surrounding temperature will rise if the body temperature is higher than the air. This happens because cool air absorbs the heat and becomes warm. Radiation happens when body have contact with other equipment/furniture in home. If your body temperature is lower, heat will transfer toward to you from the object or vice versa. Perspiration or sweat is a powerful natural cooling mechanism in body even though it makes people feel uncomfortable. By using fan, the rate of ventilation can be increase and hence enhance all those 3 process. Since the speed of fan is directly proportional to the voltage supply, hence, there is no any specific equation related in fan and ventilation.

2.3.5 Thermoelectric Cooler

A number of semiconductors joined thermally in parallel and electrical in series to increase the output and hence form up a thermoelectric cooler as shown in Figure 6Figure 6. Thermoelectric cooler (TEC) has been applied in various product and received attention on automobile field as well due to its advantages. There is a question why TEC is chosen and how it works in this project. When we discuss about temperature, it is a variable where it is vary from time to time and also affected by surrounding. TEC is chosen because the heat transfer capacity can be handling easily by controlling the current supply [1][10].

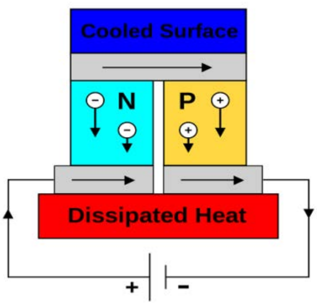


Figure 6: Thermoelectric cooler

Source: http://en.wikipedia.org/wiki/File:ThermoelectricCooler.jpg

A layer of ceramic wafer is chosen to cover the TEC because the characteristic of ceramic material increase electrical insulation. There are a big number of P and N type semiconductors in a piece of TEC. N-type has excess electron, while P-type has lack of electron, therefore P- and N- type is works as a couple to overcome the problem of excess and lack of electron. P- and N- type is joined electrically series but thermally parallel. This is depending on the current direction which means that TEC can be used either to cool or to heat. Heat exchanger is needed to eject heat faster when the design is to obtain significantly different in temperature.

Equation related and use in calculating the temperature different in TEC is:

$$T_h = T_{amb} + (\theta * Q_h) \qquad (11)$$

$$Q_h = Q_c + P_{in} \qquad (12)$$

where,

T_h = temperature at hot side, ˚C

T_{amb} = ambient temperature, ˚C

θ = thermal resistance of heat exchanger, ˚C/W

Q_h = heat release to hot side, watt (W)

Q_c = heat absorb from cold side, W

P_{ih} = electrical input, W

2.4 Problem Related to Mobile Air Conditioning System

The problem that address in this project is to have a mobile AC cooling system that can maintaining body temperature to an acceptable degree while considering constraints including the weight of the final project, the energy consumption in component selected and cost of prototype.

In order to design a mobile AC system that able to cool body temperature, the weight of the prototype is one of the concerns. This cooling jacket is design to produce coldness by using thermodynamic cooler (TEC) where it actually also produce heat when absorbing heat from air. A heat sink is a good way to dissipate all heat around the hot side of TEC. From equation (4), the rate of heat transfer can be enhancing by increasing the cross sectional area of heat sink. However, increasing the area will also increasing the weight of prototype.

In the present energy saving situation, mostly electronic equipment is design to use less power but performing same amount of work. Therefore, selection of electronic device is important where it have to be compatible to system and consume less power. In this case, electrical power delivery, P is equal to the voltage drop V; multiple current across the component, I. Reducing the power consumption can be achieved by choosing components that require less voltage supply.

2.4.1 Comparison of Existing Cooling Jacket

In the existing cooling jacket, Kuchofuku jacket from Japan, ClimaWare jacket from India and Veskimo from Laguna Niguel which actually are three different inventions but with a same purpose. Kuchofuku used fan as the main actuator for cooling where fresh air from outside is draw into the jacket, flow around body and finally hot air will be flow out through sleeves and collar. The weight of Kuchofuku jacket is around 700 grams and it is selling at $167.00 in market. To expand the marketing area, Kuchofuku comes with three different sizes (S, M, and L) by using nylon as the jacket material. Kuchofuku practically used four units of AA rechargeable battery with life time range of 6 to 11 hours.

The advantages of Kuchofuku are save energy, environmental friendly, and effective in low humidity area and are light in weight. However, a disadvantage is user will have a puff look when wearing it.

In the other hands, ClimaWare used thermoelectric cooler (Peltier) as cooling actuator to produce coldness in the jacket. Peltier absorb heat to produce cold at one side and generating heat at other side. Peltier is fragile where it cannot be used if there is cracking on surface of any side, therefore, must handle it carefully. The weight of this jacket is about 1 kilogram and it is selling at $169.00 in market. Basically cooling method using Peltier is in progress to apply to shoe, scarves and even in dinner plates. By using Lithium polymer (LiPo) rechargeable battery, this cooling jacket can be used up to 4 hours. An advantage of ClimaWare are it have two function; to cooling or to warming and is function able in extreme environment. A disadvantage there is many dots on the jacket which might result of uncomfortable.

Besides that, Veskimo cooling vest used the melting process of ice as the cooling method. The cool water is then flow from the backpack to whole vest by using the water pump. The weight of Veskimo cooling vest is about 11 lbs or about 5 kilograms and the price it selling in market is $398. The design of an insulated backpack keeps the melting rate of ice from affecting by outside condition. By using the alkaline AA battery or rechargeable Lithium ion battery (optional), it can perform up to 6 to 8 hours with every full charge. The advantages of Veskimo are adjustable cooling power, environment friendly and two ways function ability. However, there is one disadvantage which is the ice need to fill up from time to time.

Referring to **Table 1**, each of the cooling jackets is portable and able to lower down our body temperature when wearing it. However, the coldness level is depending to the cooling method. The Kuchofuku jacket provide only ventilation process to lower down body temperature; Veskimo provide melting process of ice which pass through whole upper body to lower down the body temperature and the ice supply need to fill up from time to time; lastly the ClimaWare provide cooling by using thermoelectric cooler.

ClimaWare jacket has better characteristic where this method is small in size but still gives the almost same cooling like conventional air conditioning.

Table 1: Comparison of Existing Cooling Jacket

	A Japan Kuchofuku Jacket [19]	B India ClimaWare Jacket [18]	C Laguna Niguel Veskimo [17]
Method of cooling	 Source: http://t17.techbang.com/topics/15445-kuchofuku-air-conditioning-shirt-wearing-heat-is-not-afraid • fan cooling • fresh air flow into jacket and exhaust out through sleeves and collar	 Source: http://timesofindia.indiatimes.com/articleshowpics/msid-8762573,prtpage-1.cms • Peltier light weight plastic plate with thermo electric device • function with 2 metals, when current pass through, one side produce cool another side generate heat	 Source: http://www.cycleworld.com/2012/04/20/cw-evaluation-veskimo-personal-cooling-system/ • process of ice melting • an insulated hydration backpack used to place ice
User friendliness	• suitable to wear under hot and sticky environment • nylon material trap cool air • three size (S, M, L)	• controllable temperature in range 77˚F – 113˚F (25˚C - 45˚C)	• two complete personal cooling system; 4.4 Quart Hydration Backpack System; 9 Quart Hand Carry Cooler System

Cost (1USD : RM3.27)	• $167.00 (ebay) RM546.76	• $169.00 RM553.39	• $398 RM1346.23
Weight	Around 700 g	More or less 1kg	11 lb or 4.98952 kg
Economics	• can be wear under different surrounding environment • suitable for mostly people with flexible 3 sizes	• apply to shoe, scarves and even dinner plates	• mostly selected by motorcyclists and cyclist
Aesthetic	• normal jacket, puff up when switch on	• tight to body	• a normal vest with either a backpack carry or a hand carry cooler
Sustainability	• fan can be replace or reuse for other purpose	• crack Peltier cannot be reuse	• pump can be reuse or replace for other purpose
Practicality	• 4 units of AA rechargeable battery, life time in range of 6 – 11 hours • multiple speed control	• Lithium Polymer (LiPo) rechargeable battery • up to 4 hours	• 8 units of alkaline AA or rechargeable Lithium ion battery • Up to 6 – 8 hours • Ice melting rate is 4 hours for 4.4 Quart and 8 hours for 9 Quart
Advantages	• energy saving (about 5 watts used) • environmental friendly • user can move	• function well in extreme high temperature • 2 function; cooling or warming • jacket can wash by	• adjustable cooling power make system last longer • environment friendly • warm when it cold

	freely • effective in low humidity area	detaching the control unit • enduring quality and robustness that immune to damage in adverse condition	out, cool when it blazing
Disadvantages	• puff outlook	• many dot on the jacket • might decrease comfort ability level	• the ice need to fill up the backpack continuously once it run out

2.5 Identify Available Solution

2.5.1 Comparison of mass and power consumption among five cooling methods

There are actually five cooling methods that are being compared in term of weight and power consumption. Table 2 shown in below is the data of total weight and power consumption for all five type cooling methods in one unit.

Table 2: Comparison of mass and power consumption among five cooling methods

	Natural	Compression	Evaporative	Fan and ventilation (exclude ceiling fan)	Thermoelectric cooler
*Total weight (kilogram)	N/A	Max 30kg	0.3-30kg	2-7.5kg	0.5-1.8kg
*Total power consumption (watt)	N/A	About 2500W	About 1350W	30-70W	50–60W

N/A = Not Available

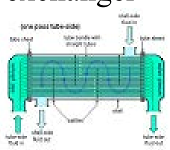
*depend

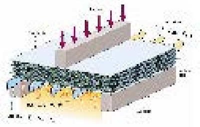
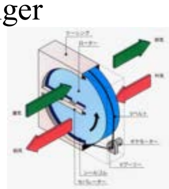
2.5.2 Maintaining temperature

When air passes through the surface of thermoelectric cooler, the temperature will decrease due to the heat is being absorbed by the cold side of TEC. Temperature changing rate is depend on the amount of current supply to the TEC [2]. In the same time one side producing coldness, the other side will generate heat.

In order to maintain the temperature to a certain degree, heat sink is needed to dissipate the heat generated. There are several heat exchanger commonly used in engineering field experiment to promote heat to surrounding. Different type of heat exchangers shown in Table 3 is grouped into different category [5] [6] [7]. Shell and tube heat exchanger and open flow heat exchanger both are usually applied with liquid as the medium to dissipate heat, whereas rotary heat exchanger is used when the medium is hot air and it needs to flow through the aluminium coil. All of these heat exchangers are good in dissipating heat; however, an active heat sink is better in term of the way of using it. It dissipates heat from device to surrounding to lower down temperature on the system. An active heat sink is direct applied on the hot area in a system and the fan speed is controllable.

Table 3: Comparison between heat exchanger in term of type

Type of heat exchanger	Description
Shell and tube heat exchanger  Source: http://en.wikipedia.org/wiki/Heat_exchanger	• one input and one output • flow goes along the inner tube within parallel to tube or cross flow to tube • liquid is used as to dissipate heat
Plate heat exchanger  source: http://www.dhtnet.com/plate_frame_heat_exchangers_as.htm	• plate held in parallel to each other • medium flow separately along the plates • moderate size

Open flow heat exchanger  Source: http://www.virginia.edu/ms/research/wadley/thermal-management.html	• flows is not in confined within the equipment • not specifically piped • mainly used on liquid to ambient air
Rotary heat exchanger  Source: http://commons.wikimedia.org/wiki/Category:Heat_exchangers	• rotor with aluminium foil • heat dissipating and heat absorbing • air flows to heat or to cool the rotating • air supply and extraction must combine and the air have to flow through at the same time
Microchannel heat exchanger  Source: http://www.frostytech.com/articleview.cfm?articleid=2424&page=10	• fins orientation design to perpendicular to the general air flow direction • air flow through fins and pass out in parallel to the board
Active heat exchanger  Source: http://www.techpowerup.com/forums/threads/choosing-a-cpu-amd-phenom-9950.74291/	• a fan is place on top of heat sink to increase the rate of heat dissipation • easy to implemented on a project • low cost for installing • no fix size

2.6 Overall Review

In this project, the important feature is that the cooling system is designed to be portable. To achieve that, the cooling system should be small, light in weight and the power supply should be also one of the considerations. Before deciding which cooling methods to apply, every method should be match with the idea of mobility, obtain the result and analyse it.

The cooling method that will be applied in this project is by using thermoelectric cooler (TEC). By referring to Table 2, natural cooling method is excluded in the selection due to it characteristic where it occurs naturally and is unable to estimate or calculate. However, compression and evaporative cooling methods are excluded as well due to their high power consumption and costly compare to fan and ventilation and thermoelectric cooler cooling methods. There are roughly same in term of power consumption between fan and ventilation and thermoelectric cooler, but the price of thermoelectric cooler cooling is much higher than fan and ventilation method. Thermoelectric cooler will be selected since it can produce coldness while fan and ventilation method is unable to produce coldness.

By designing a feedback loop in the system, control unit in the system can easily control the TEC in order to maintain temperature to a certain degree. A contact type temperature sensor will be applied in the feedback loop to detect the changes of temperature. Heat exchangers are widely used in process engineering at intermediate stage to promote thermal energy flows (by cooling or heating) during a process [8]. However, an active heat sink will be a better option for this project where the desired thickness for heat transfer can be calculated. Heat is transfer from the isothermal base of heat sink to those parallel fins, and will dissipate along with the air flow [13]. To improve heat dissipation rate at the heat sink, a bigger size of fan with a diffuser can be applied [8].

TEC is applied in this project due to its small size and the capability to produce cold by using low power input. As stated in Table 2, a single unit cooling system applying TEC is only about 0.5 to 1.8 kilograms, while the required power to operate is only about 50 to 80 watts.

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Proposed Mobile Cooling System

Figure 7 shows the overview of the proposed mobile cooling system.

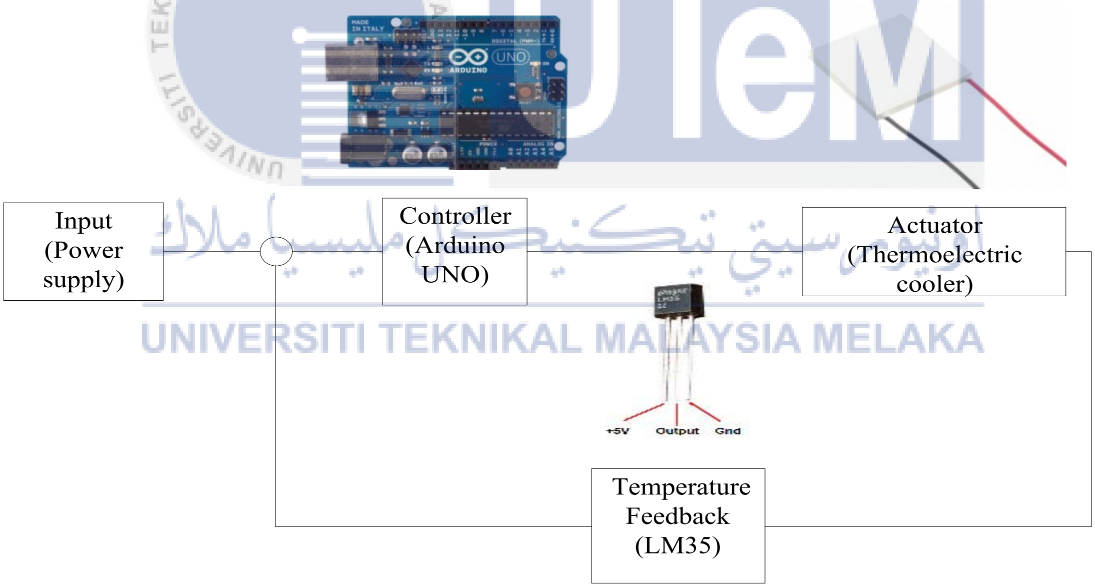


Figure 7: Block diagram of the proposed mobile cooling system

The overall flow for the system can be refer to Figure 7, when the feedback temperature is higher than the desired temperature, microcontroller will then cut off the current supply to the thermoelectric cooler, and hence cooling process is stop. However, when the feedback temperature is lower than the desired temperature, microcontroller will then supply current back to thermoelectric cooler, and the cooling process is back to operation.

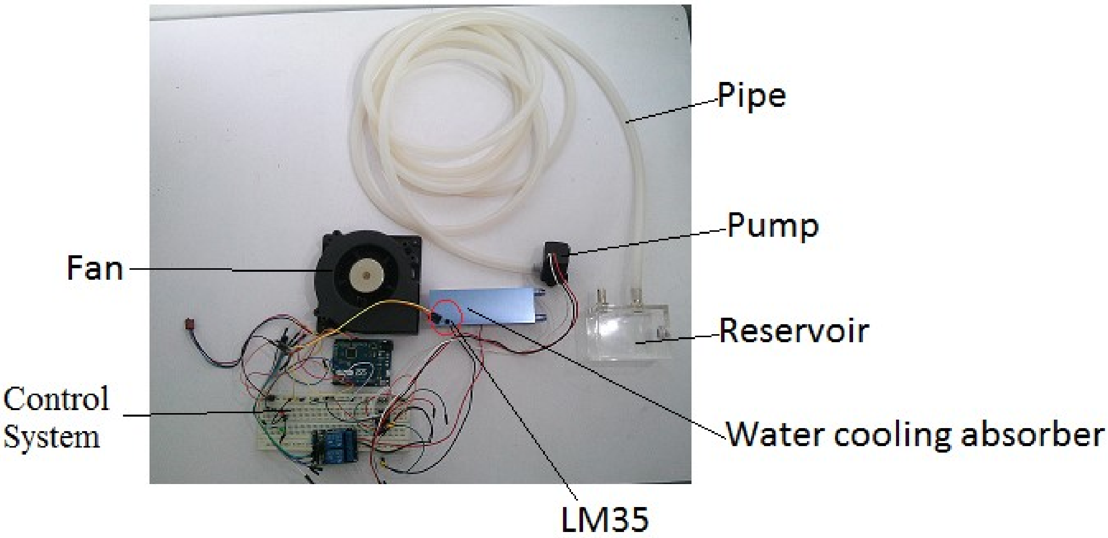


Figure 8: Hardware configuration for mobile cooling system

The system consists of an Arduino microcontroller, thermoelectric cooler as the actuator and a feedback loop handled by a temperature sensor LM35. From the figure 7, Arduino UNO is a microcontroller board with ATmega328 as the processor. The overall features are total of 14 digital input/output (I/O), which 6 of them can be used as PWM outputs and 6 can be used as analogue inputs, oscillator used is a 16 MHz clock speed, a micro USB connection hub, a power jack, an ICSP header, and a reset button. Arduino UNO can be started by supplied the board with an ADC adapter or battery like power bank. The thing that makes UNO different from others Arduino microcontroller is that it does not use FTDI USB to serial driver chip.

TEC1-12706 is the model name for the thermoelectric cooler that used in this project. The serial number in the code name is use to identified it characteristic. 12 in front of the serial number meaning the voltage required for this model is 12 V, while the 06 at the end of the serial number is meaning that this model needs 6 ampere of current. Red colour wire is power input while the black colour wire is for grounded. It can work under environment that has a range from -55 ˚C to 83 ˚C. The refrigeration power, Qcmax is from 50 - 60W.

LM35 is a contact type temperature sensor that will be integrated it with Arduino board to measure temperature and control the feedback loop. LM35 consists of three pins; +5VDC input, analogue output and ground. The analogue output pin (pin 2) gives output of 1 millivolt per 0.1 ˚C (10mV per degree), so, the voltage output obtain have to divided by 10 in order to get the temperature reading in ˚C.

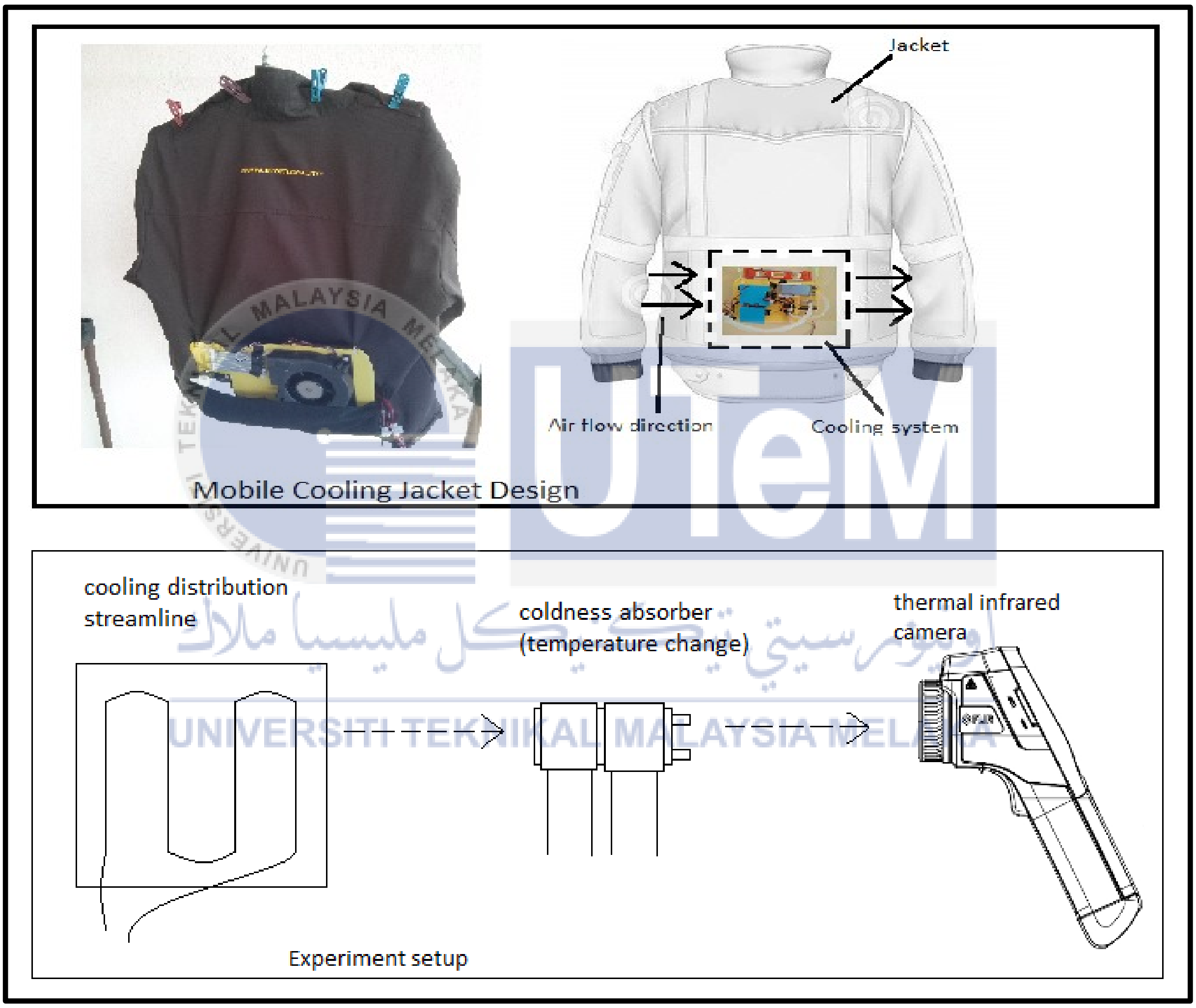


Figure 9: Hardware design and experiment setup

In Figure 9, the upper diagram is the design of this project. The real hardware is shown in the left hand side while the right hand side is the design sketching. The cooling system is put outside the jacket is to make sure the hot air is not flow into the jacket. By ensuring this, only cold air will flow inside the jacket. The diagram at the lower part is the experiment setup. A thermal camera, IRI4010 is used in the experiment in order to capture the changes on the temperature.

The overall operation of the system is shown in Figure 10. There are total of three main modules in this project; water flow module, piping module and control module. Each module represents difference operation in the system. Water flow module basically is control the flow of water/coolant from the reservoir and passes through the whole piping streamline. Piping module helps to connect all the parts by joining them together so that the water is flow continuously in a complete and sealed streamline. Control module is where the electronic device located in the system. Temperature signal feedback to microcontroller where it will then use to control the fan speed and also the voltage supply to thermoelectric cooler.

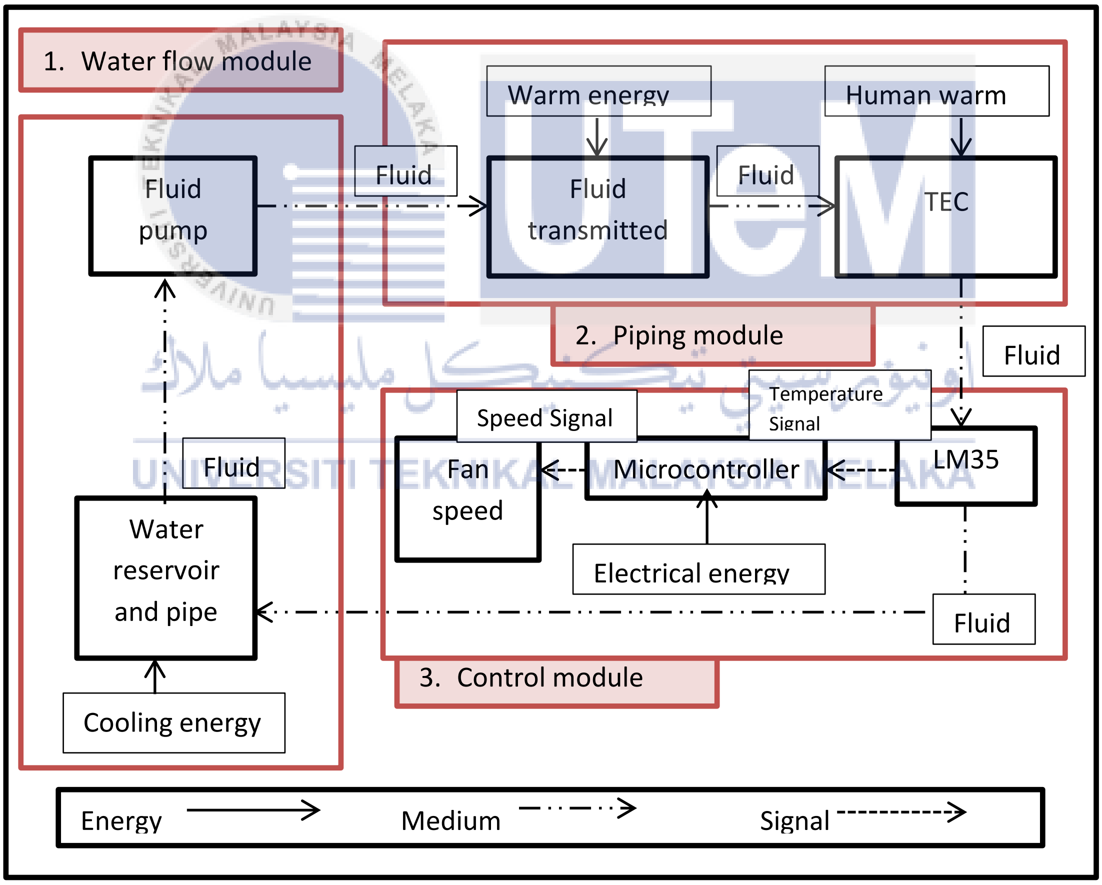


Figure 10: State change during the cooling operation

3.2 Experiments

In order to validate the proposed mobile cooling system, simulation and experiments are designed with the following objectives:

1. To examine the accuracy of the feedback loop
2. To analyse the efficiency of the heat sink in term of the rate of heat transfer
3. To examine the arrangement of the mobile cooling system
4. Experiment Test to Calculate Power Consumption

3.2.1 Experiment Test on the Accuracy of Feedback Loop

In order to verify the contact type temperature sensor LM35 as the feedback sensor to control the temperature of the cooling system, the temperature sensor LM35 is attach on the configuration as shown in Figure 8. This experiment is closed loop systems where the signal detects by LM35 will feedback to the main controller.

For data collection, the range of the temperature is set to 28 – 50 degree and instructions are define as well accordingly to the reading from LM35. As illustrate in Figure 7, the pipe, pump and reservoir are all connected together in series and is joined to water cooling plate absorber. TEC is placed in between the heat sink and water cooling plate absorber while a centrifugal fan is used to control the heat dissipation at the heat sink. 12V dc voltage is supplied to TEC, pump and the fan. Table 4 shows the parameter setting for the experimental test.

Table 4: Feedback loop experiment parameters

Parameters	Value	Unit
HARDWARE PARAMETERS		
Thermoelectric cooler (TEC) voltage	12	[V]
Turbo centrifugal blower fan speed	2800	[RPM]
Brushless pump flow rate	350	[L/H]
LM35	28 - 50	[°]
Silicon tube total length	3	[m]
Silicon tube diameter	9	[mm]
Stainless steel hose clamp diameter	9	[mm]
Heat sink total weight	0.2	[kg]
Reservoir total weight	0.2	[kg]
Liquid cooling plate absorber total weight	0.18	[kg]

The justification of all the parameters from above table is specified in this experiment. The dimension and the weight of all the parts is taken from the real product dimension which considered are suitable for this experiment. For the voltage supply, it is advised to use 12V with at least 6 ampere to drive the thermoelectric cooler.

Figure 8 shows the setup of the cooling system structure for experimental test. When voltage is supply to the system, TEC will start producing coldness and the water flow is circulating by the pump. Simultaneously, TEC will also produce heat on the other side, and the centrifugal fan is activated once the LM35 on heat sink detects the temperature change has reaches to a certain limit. The speed of the fan is controllable by the temperature reading. This means that, the speed of the fan is depending to the temperature. A graph is tabulate for the temperature with fan speed against time.

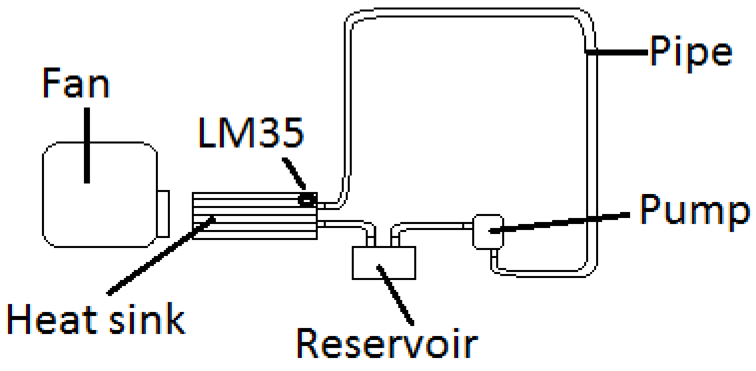


Figure 11: Temperature sensor LM35 is placed at the heat sink in this experiment

The data is analysed by selecting few segments from the graph, and study the performance of the fan accordingly to the temperature. Any changes in the graph will be further discuss and analyse from different view.

3.2.2 Simulation Analysis on the Efficiency of Heat Sink

For the initial verification of the three proposed material for the heat sink as shown in Figure 12, simulation is performed to study each of them. The purpose for the variation of parameters is to investigate the characteristic of each element responses in the cooling system performance.

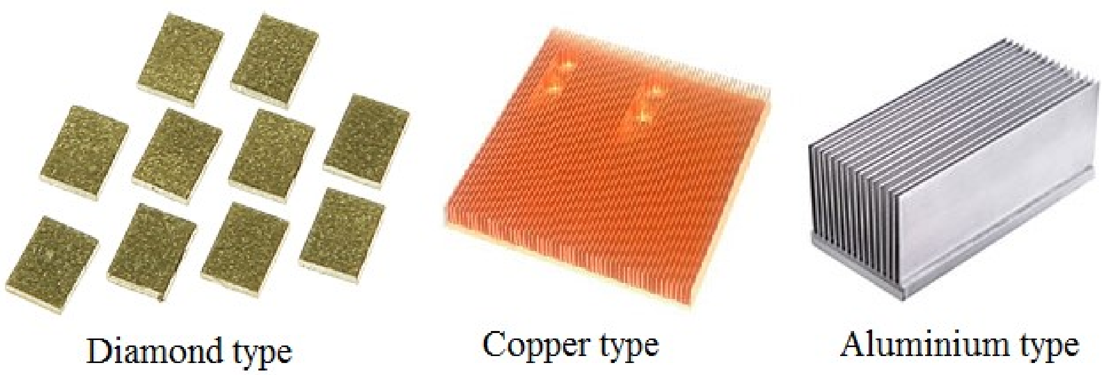


Figure 12: Three different types of materials proposed for heat sink

For data collection, all these three materials are simulating by using Scilab software to determine the performance in term of the rate of heat transfer. The parameter used in the simulation can refer to Table 5. A graph is tabulate for all materials in term of the rate of heat transfer against the thickness.

Table 5: Materials experimental parameters for simulation

Parameters	Value	Unit
Diamond thermal conductivity	2200	[W/mK]
Copper thermal conductivity	401	[W/mK]
Aluminium thermal conductivity	237	[W/mK]
Diamond density	3.53	[g/cm^3]
Copper density	8.96	[g/cm^3]
Aluminium density	2.70	[g/cm^3]
Diamond heat sink thickness	0.01	[m]
Copper heat sink thickness	0.01	[m]
Aluminium heat sink thickness	0.01	[m]

The justification of all the parameters from above table is specified in this simulation. The thickness for all material is the same so that the data obtain can be analyse easily by ignoring the thickness factor. The density and thermal conductivity is fixed value for each material.

The data is analysing accordingly to the performance of each material characteristic. This simulation is mainly to study the rate of heat transfer, while the power consumption of the system is analysed in PSM2. However, the price and weight are also the consideration in order to decide the final material for the heat sink.

3.2.3 Arrangement Trial of Mobile Cooling System Piping

In order to design the mobile cooling jacket is comfortable for user and the weight distributed is equally on the entire jacket, a simple experiment is carry out to find out the most suitable and neat arrangement for the piping streamline. Two examples of the pipe arrangement are shown in Figure 13.

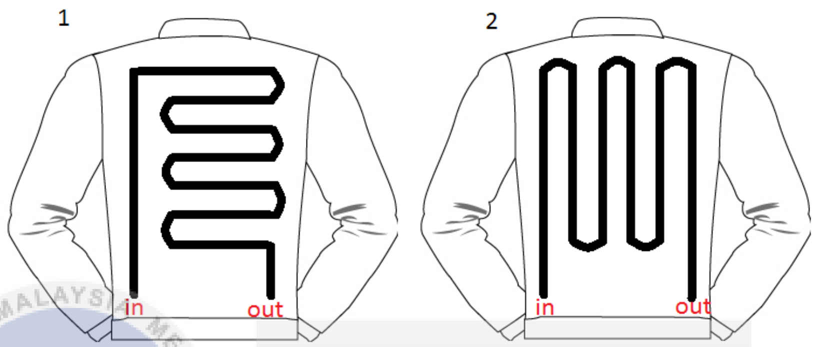


Figure 13: Arrangement test on the piping streamline

By referring to Figure 13, piping streamline is arranged in different pattern with two end parts for water inflow and water outflow. The first pattern is designed to have 'Z' shape while the second pattern is designed to have 'M' shape. Different arrangement have different characteristic, due to pressure in vertical position, amount of flow rate need to estimate correctly so that the water able to pump over the entire streamline.

These two designs will be implementing on a real jacket and test by few volunteers about the level of comfort ability.

3.2.4 Experiment Test to Calculate Power Consumption

Testing the cooling system in a real environment is carrying out in order to calculate the power consumption for cooling system in a period of time. In this section, the testing is carry out on the system where the medium use to carry the coldness is water/coolant as figure shown in Appendix 6. IRI4010, a kind of thermal camera is used to detect the temperature change where the image can be capture and store instantly in a SD card.

The temperature change by time is obtained for the images captured. By initialising mass and specific heat capacity of water, the energy transfer can be calculate by multiplying the temperature with the specific heat capacity and the mass of water use in this experiment.

Table 6: Parameters for calculating power consumption

Parameters	Value	Unit
Energy transfer		[kgm^2/s^2]
Wattages consume by system		[kgm^2/s^3]
Specific heat capacity of water	4180	[Nm/kgK]
Specific heat capacity of aluminium alloy	419	[Nm/kgK]
Mass of water	0.33	kg
Mass of aluminium alloy	0.5	kg
Temperature change		◦C

The justification of all the parameters from above table is specified in this experiment in order to calculate the power consumption. The value for energy transfer, wattages and the temperature change are one of the unknown where the temperature change must be first obtain before continue to calculate the energy transfer and wattages.

3.3 Safety during Experiment Setup

There are few precautions that have to be aware during experiments being carried out. The electric circuit have to be covered up to prevent short circuit happen if water leakage happen during testing. Water leakage might happen at the connection between pump and pipe, so it is recommended to tighten up the connection with hose clamps. Besides that, it is reminded not to touch on any surface of TEC module when experiment is carrying out. Temperature different in between the both side of TEC module is large and it might cause frostbite or scald to your finger. At last, the cooling jacket is not suitable for extreme activity like running or jumping at this stage where the strength of connection might not strong.

3.4 Replicability of Test

There are total of four experiments carried out for this project. In order to carry out every experiment, the steps and setup for each experiment are difference. In the first experiment, accuracy of the feedback loop will be examined. The changing of temperature during this test will directly affect the fan speed. Contact type temperature sensor, LM35 is applied to detect the changes of temperature, and there is no limit on where the sensor should place as long when temperature increase result increase in fan speed and vice versa. In the second experiment, simulation is performed for selected materials in term of rate of heat transfer. Output characteristic of the material can be analysed by changing the material thickness in Scilab software. The constant variable in this experiment is the thermal conductivity for each material. In the third experiment, the arrangement of the pipe is a variable. There is no fix shape to arrange the piping streamline. At last, power consumption is about what to be determined in the last experiment. Duration for carrying out this experiment is not limited; however, temperature is the data can be obtained from the image captured by using the IRI4010 thermal camera. The constant variable applied in this experiment is the specific heat capacity and the quantity of medium applied.

CHAPTER 4

RESULT AND ANALYSIS

4.1 Accuracy of Feedback Loop

Feedback loop is implemented in the system to control the temperature. Temperature sensor will send data to the Arduino controller to increase the fan speed when the temperature is increasing and decrease the fan speed when the temperature is decreasing. According to Figure 16, it is shown that the fan speed (PWM) is changing with temperature. The x-axis in the graph represented the time variable in 100 milliseconds while the y-axis at the right side is representing fan speed (PWM) and at the left side is representing temperature reading.

From Figure 14, it is shown that the relationship between fan speed and temperature is directly proportional to each other and those data is shown in Appendix 5. From the graph, temperature increased result increased in fan speed as well. However, fan speed comes to a constant at 255 PWM even though the temperature is continuing increasing. The reason the graph shows a constant speed for fan is because it has reached to the maximum PWM range. Sparks occurred in the graph is a result of unwanted noise where it actually happen when wires are being touched accidentally during the test.

In Figure 14, the changes are happening from beginning of test until the end. Two segments are highlighted where the Segment A represent the behaviour of the fan speed when temperature remain about constant for some time. It is shows that the fan speed is actually also rotating about a constant speed at 125 PWM. Segment B shows the behaviour of the fan speed when the temperature exceed the limit and continue increasing. The fan speed is at its maximum condition which is 255 PWM and is remain even when the temperature is still increasing. These meaning that, once the temperature reaches the threshold set in command, the fan speed will no longer to increase but is remain at maximum. However, fan speed will decrease when the temperature drop.

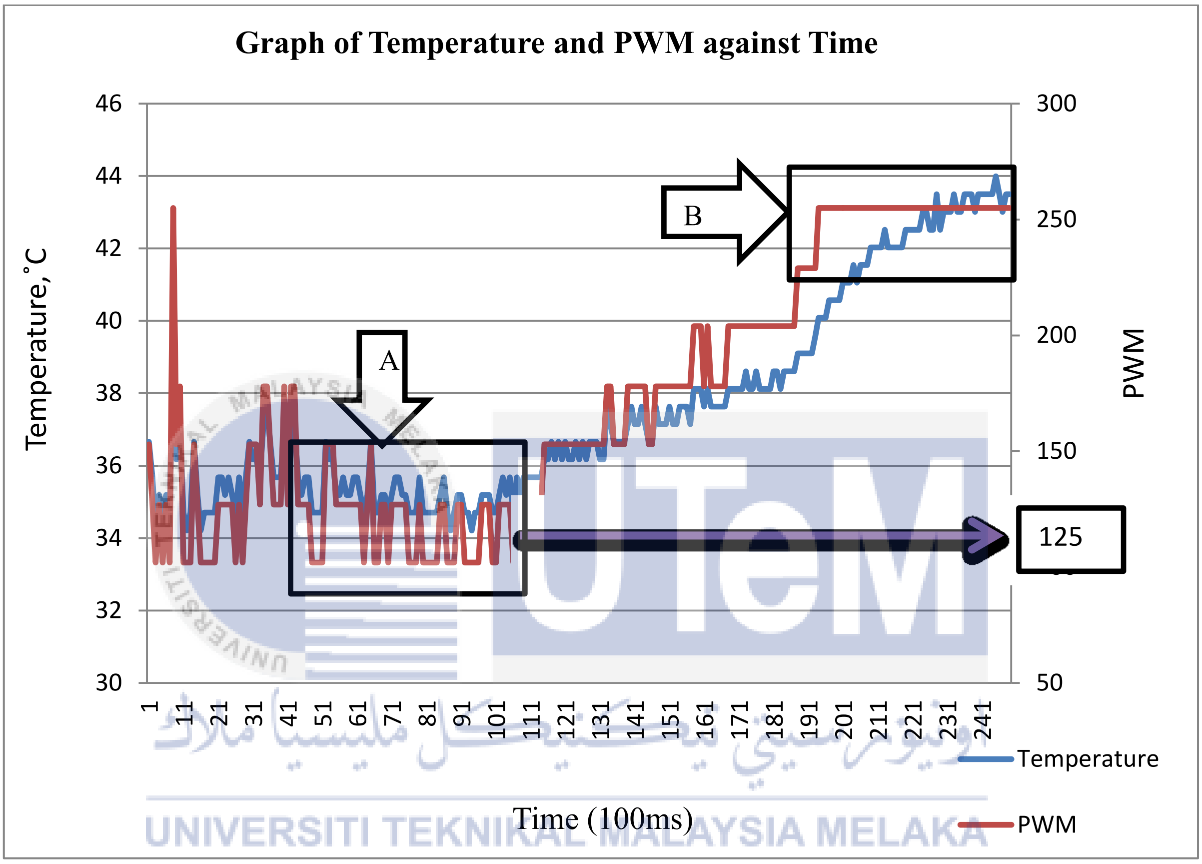


Figure 14: PWM against temperature at instant time

In Figure 14, the information can be obtained is that the value range for PWM is from 0 to 255 and is equivalent to voltage value from 0V to 5V. Every 1˚C changed in temperature results 25.5 changed in PWM which is equal to 0.5V.

Thermoelectric cooler is fast in response where the temperature changes are big and the feedback loop is effective in controlling the temperature. Hence, this cooling method is considered as the best cooling method and is suitable for this project with all the characteristics shown.

4.2 Efficiency of Heat Sink

Thermal conductivity, k for diamond, copper and aluminium are 2200W/mK, 401W/mK and 237 W/mK respectively. Area of heat sink, A is 0.0045m^2, by taking the temperature different between hot surface and cold surface, ΔT is 35˚C or 308.15K, and considering values for thickness of heat sink to be 0.01m, 0.012m, 0.014m, 0.016m, 0.018m and 0.02m. By substituted all variables into equation (4.3a), a graph is simulated by using Scilab software and it shows that the relationship is inversely proportional between the rate of heat transfer against thickness of heat sink.

$$\dot{Q}_{cond} = kA(\frac{\Delta T}{\Delta x}) \tag{4.2a}$$

From Figure 15, the graph shows that the rate of heat transfer, $\dot{Q}_{cond}$ at heat sink is decreasing when thickness, Δx is increasing. The x-axis of the graph represented thickness, Δx, of heat sink while y-axis represented the rate of heat transfer, $\dot{Q}_{cond}$. By referring to the equation (4.3a), the rate of heat transfer is high when the thickness value is small and the rate of heat transfer become low when the thickness value is big. The rate of heat transfer is related to the time needed for heat dissipation from heat sink to surrounding. When the rate of heat transfer is slow, it meaning that the time required dissipating an amount of heat will be longer and this is a disadvantage to the system.

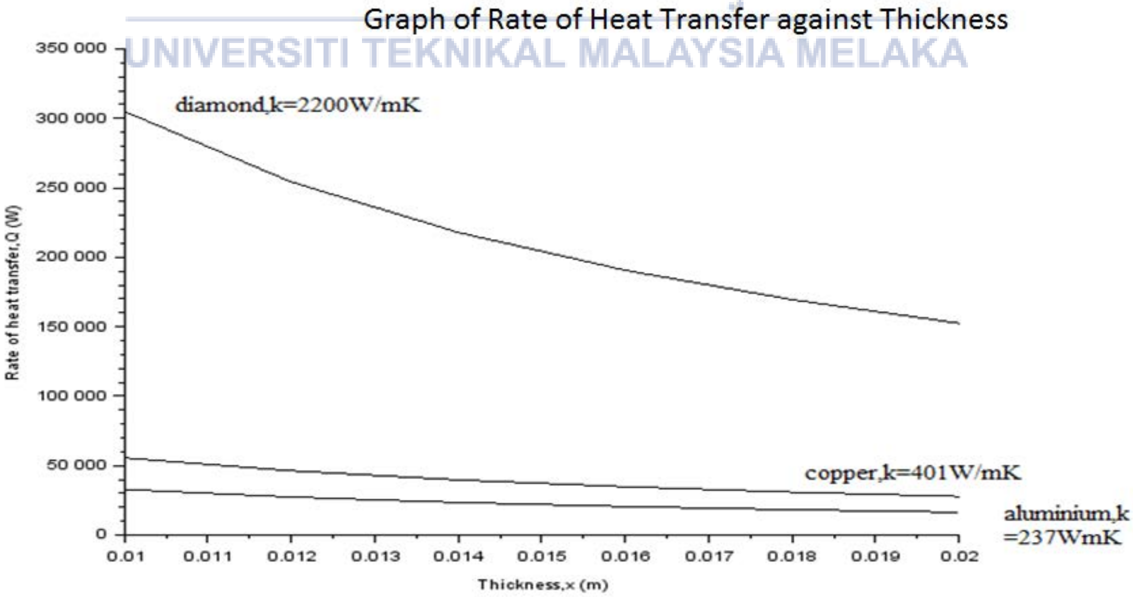


Figure 15: Rate of heat transfer, Q against thickness, x for diamond, copper and aluminium

Different materials of heat sink are also will affected the rate of heat transfer. In Figure 12, three types of materials; diamond, copper and aluminium are compared. The result shows that diamond has the highest rate of heat transfer, continues by copper and lastly is aluminium. However, diamond type heat sink is expensive and usually used for high power integrated circuit and laser diode while copper, which is three times denser ($\rho = \frac{m}{V}$) than aluminium are both excluded from selection.

Slow rate of heat transfer will affect the cooling system. By using heat sinks with thickness of 0.01m, the rates of heat transfer will faster and hence the time required for heat dissipating can be reduce.

4.3 Experiment on two different medium

There are two experiments based on the cooling method but with different medium are carried out in this section. Figure 16 shown below is the result where the medium applied is the water or commonly known as coolant; while Figure 17 shown is the result where aluminium alloys is used as medium. The setup for both experiments can refer to Appendix 6 and 7. The selected location to carry out these both experiments is in a room where the temperature of surrounding inside the room is lower than the outdoor surrounding.

4.3.1 Water as medium

There is a piping streamline constructed for this experiment where it enables coolant to continuous flow through the streamline over the selected body part shown in Figure 16. In Appendix 6, the temperature data is obtained from the image captured by using thermal camera, model IRI4010. There are two different labels that can be seen in the image in Figure 17, which label as cursor 1 and cursor 2, and these two labels are the location representing the data obtained.

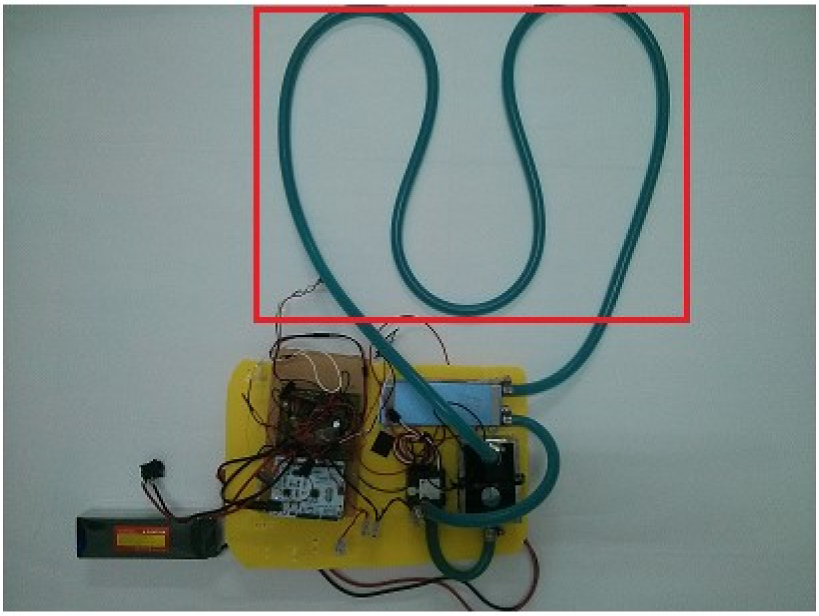


Figure 16: Thermal image captured within the red box

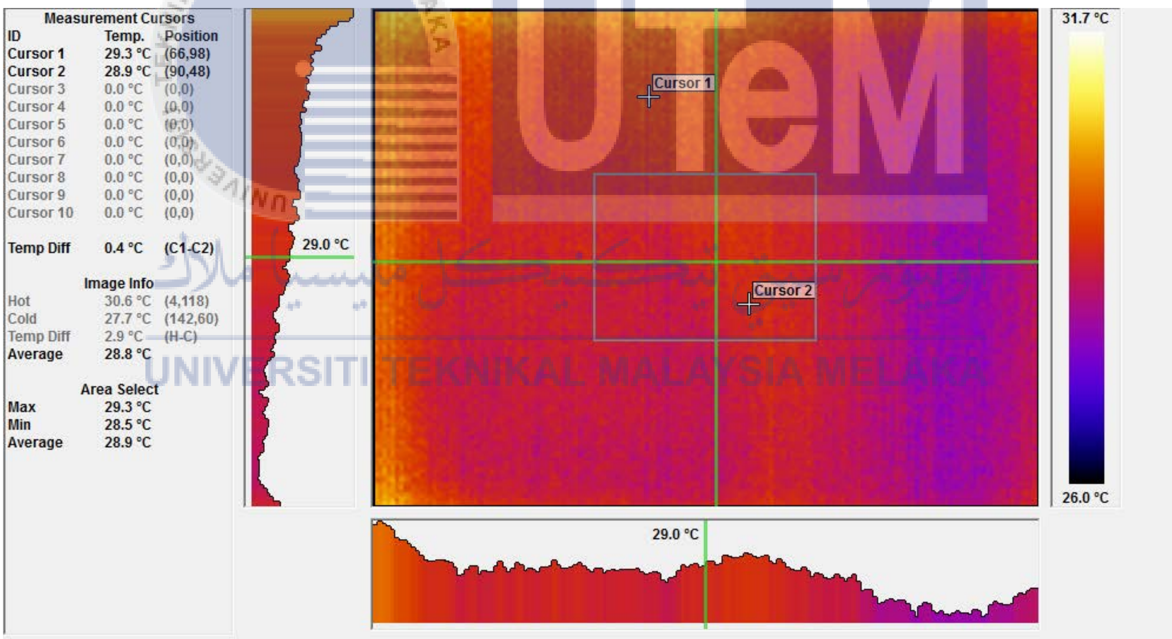


Figure 17: Image captured from the IRI4010

In Figure 18, it is clearly shows that the relation between the average temperature and time is not linear and also independent to each other. The highlighted segment in the graph shows how temperature values change according to time. This cooling system is designed to operate automatically by referring the changes of temperature on the wearer body. The cooling system will actuated to generate coldness when the temperature on the wearer body is higher than the threshold, and the coldness will transfer and carry by the fluid or coolant to the selected area through the piping streamline.

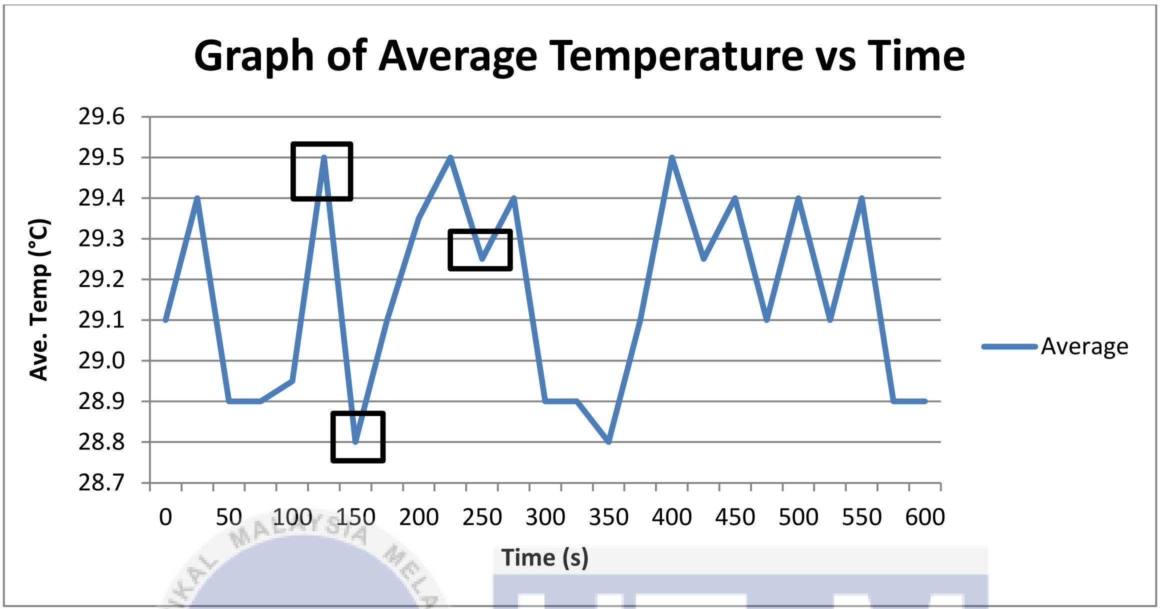


Figure 18: Graph of average temperature versus time

This experiment is carried out to identify the reliability of the cooling system in the real environment. The result shown in Figure 18 is happen in the range of temperature in between 28 to 30 degree Celsius. There are rises and dropped in temperature values where the highest temperature is about 29.5 degree Celsius while the lowest temperature is about 28.8 degree Celsius during the whole test for 600 seconds or 10 minutes with interval of 25 seconds per reading. The different between the highest and the lowest reading is about 0.7 degree Celsius. The rises and dropped phenomena in highlighted segments are expected in this experiment where the cooling system needs some time to generate coldness again when it detects the increasing of temperature.

The changes of temperature are randomly based on the real situation at the instant time. Temperature rise because of the surrounding environment has higher temperature compare to the system.

4.3.2 Aluminium alloy as medium

In this experiment, the construction is more easy and simple compare to the experiment 4.3.1. A material that is made by aluminium alloy is used to indicate the changes of temperature under real environment surrounding. According to Figure 19, the partition inside the red box is the source of the data obtained. Thermoelectric cooler is placed right under the center of the plate while a temperature sensor is placed on the surface of the aluminium alloy plate inside the red box.

Figure 19: Thermal image captured within red box

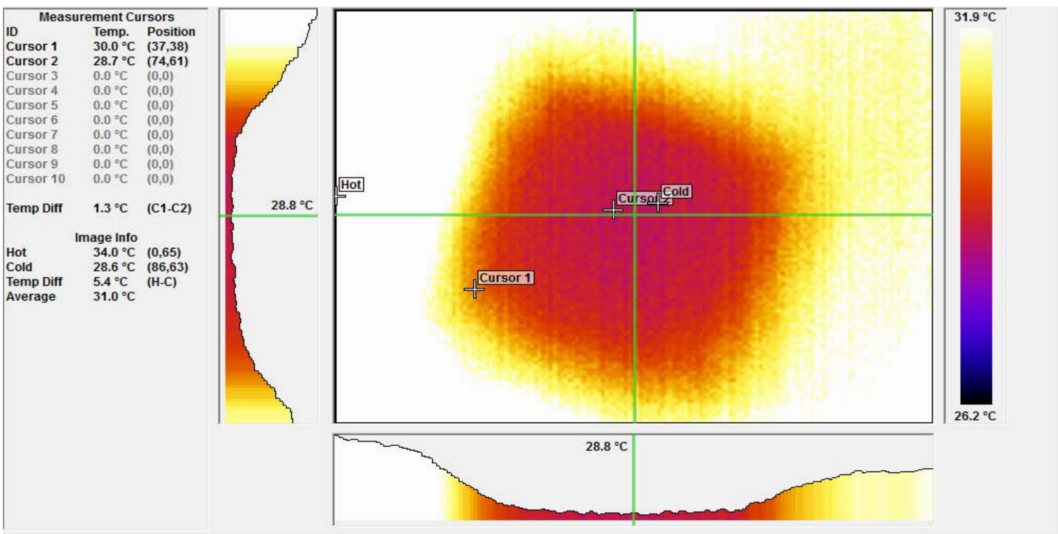


Figure 20: Image captured from IRI4010

In Figure 22, the relation between the temperature different and the time is not directly proportional, but it shows that the temperature rises and dropped against time. The data Appendix 7 is only taken in the area selected by the red box in Figure 19. The coding used for this experiment has the same concept as the previous experiment where it is also able to control the system automatically. The actuator can be stop when the temperature detected by the sensor is lower than a limit.

The coldness will be send to the aluminium alloy directly from the actuator. Coldness is then transfer to the body by placing pieces of aluminium alloy material on several places on a jacket. The relationship between temperatures different against time is shown in Figure 22. There is fluctuating happen in the graph which is highlighted in segment C, D and E. By referring to Figure 20, the temperature different between the cold and hot area is increasing at the beginning, however, a big decrease in the temperature different happen in segment D before it rise back to segment F.

In Figure 21, the diagram is representing the changes of temperature from high to low in a specific duration during the experiment. The cold area (blue) in the diagram 1 is small and this means that the hot area is larger than the cold area at the beginning of the experiment. While the time increasing, the blue area increased and occupied almost all the surface in diagram 8. The explanation for this changes is that the temperature do not reach below the threshold and the cooling actuator is continue to generate coldness.

The result shown in Figure 22 has the temperature different range in between 5.4 to 7.9 degree Celsius. The highest temperature different is about 7.9 degree Celsius while the lowest temperature different is about 5.4 degree Celsius and the different between the highest and the lowest reading is about 2.5 degree Celsius which is represented in the non-linear graph. The reading is recorded for every interval of 20 seconds up to 300 seconds or 5 minutes. There are large changes in temperature different shows in highlighted segment 1, 2 and 3. The changes of temperature happen due to the system stopped the actuator when the temperature is low enough and it actuated back when the temperature is exceed the threshold. This step shall continuously until the whole system is shut down manually or when the power supply is drain off.

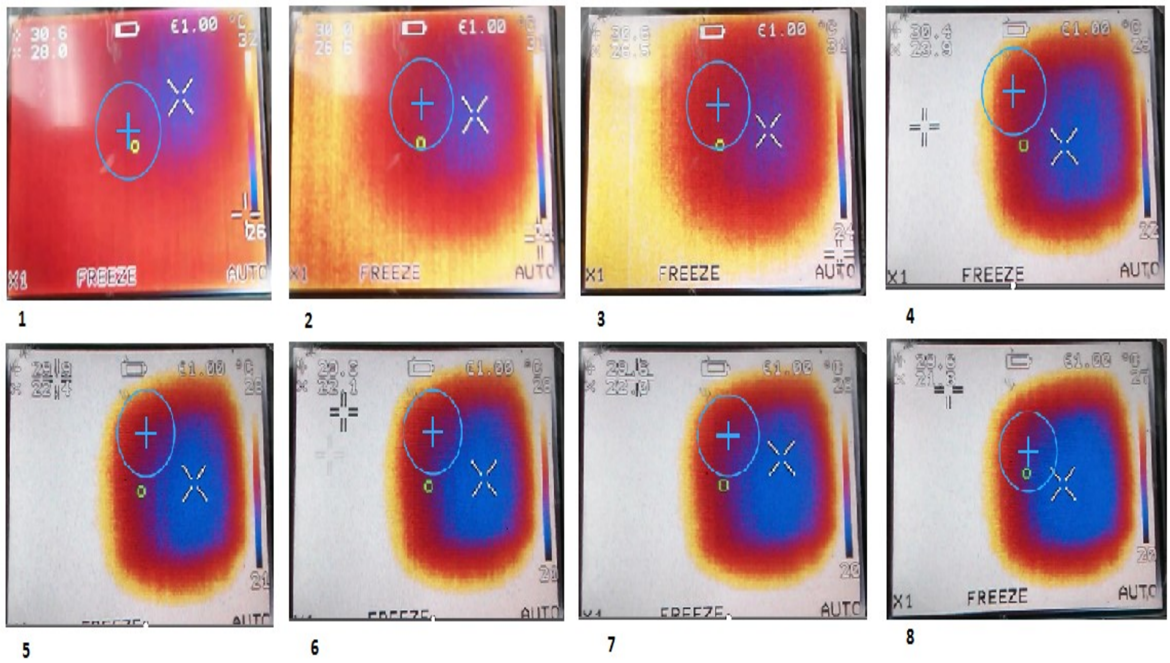


Figure 21: Temperature drops (blue - temperature is low; red - temperature is high)

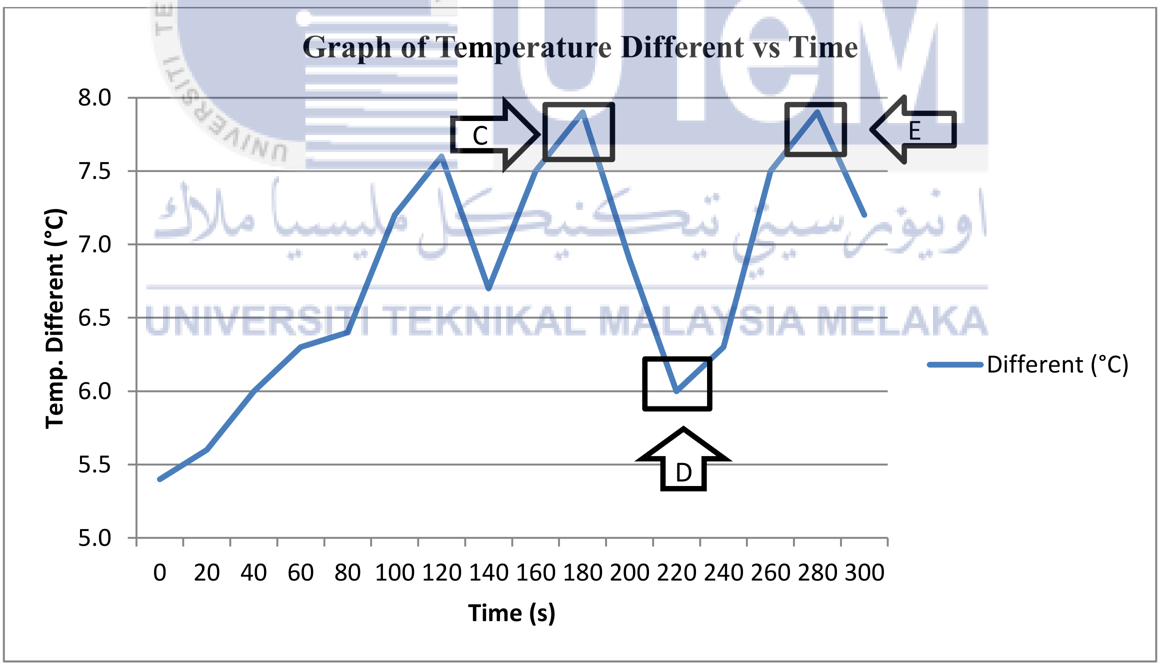


Figure 22: Graph of temperature different versus time

In Figure 23, the graph shown is the temperature drop against time for the same medium which is aluminium alloy. By referring to Appendix 4, the temperature threshold is design not exceed 27 degree Celsius, the temperature at initial of 28.6 degree Celsius dropped to 27.4 degree Celsius after 60 seconds However, the rise in segment F happen is due to the error of the system. The temperature further dropped below the threshold which is highlighted with red colour box in the Figure 23. The graph in segment G should perform a straight line where it represents the cooling system is stopped actuating when it reached lower than the threshold temperature. The fluctuating at time 160 seconds is happening due to the system error. The behaviour of the graph is rise and dropped during the experiment.

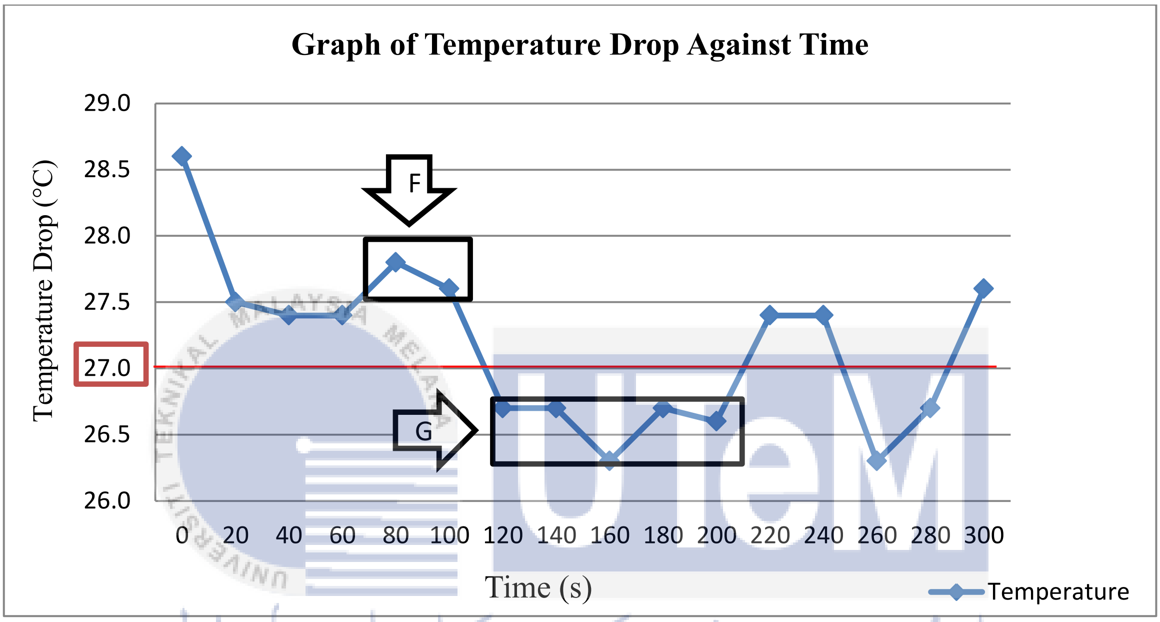


Figure 23: Graph of temperature drop against time

This experiment is carried out as an alternative way of transferring coldness from the actuator to the body. One of the reasons that the changes of temperature in this experiment is more significantly due to the specific heat capacity of aluminium alloy is lower than the water. Hence, the amount of heat energy required to raise the temperature of a body per unit mass is lesser.

4.4 Power Consumption Calculation

The amount of power consumption is one of the finding that needed in this section. Total energy, 13.794k joules is used in the first experiment. Using the fact that 1 Watt equals 1 Joule over 1 second, the wattage of the system to can be calculated as dividing total energy by total time.

$$Power\ (w) = \frac{Energy\ (J)}{Time\ (s)} \tag{4.4a}$$

Model of thermoelectric cooler used in both experiments are TEC-12706. The number defined as it requires 12 volts and 6 Ampere to drive it, and also, we able to find out that the power consume by this type of thermoelectric cooler is 72 watts.

By referring to the Appendix 6 and 7, the total power consumed during this two tests are 22.99 watts for experiment on using water as medium, while 75.70 watts for experiment on using aluminium alloy as medium. However, there are total of two unit of thermoelectric cooler are used in both experiments. So, by dividing 22.99 watts in first experiment, each of the thermoelectric cooler consumed about 11.5 watts. About 37.85 watts is consumed for each of the thermoelectric cooler in second experiment.

4.5 Review of Final Product

Final product is shown in Figure 24. The left side is the front view and the right is the back view for the project. As mention, this project is to design a smart air conditioning device that is portable, the cooling system is placed outside the jacket to make sure the heat generated by the system is directly eject to the outside surrounding.

Figure 24: Diagram for final product (left-front; right-back)

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 Conclusion

From the research and experiment tests that have been carried out, thermoelectric cooler shows it potential in cooling field. With the ability to produce coldness, small size and easy handling, thermoelectric cooler show its advantages as the cooling method for this project. Achievements for the project objectives were fulfilled.

The feedback loop is performing as expected on the practical model and also on a complete prototype. Rate of heat transfer is analysed in the PSM1 and from the result, aluminium is chosen due to the weight and price even though the rate of heat transfer of aluminium is only 10% of diamond.

The cooling system is tested and analysed with two type of different medium as the path to transfer coldness in PSM2. The results had shown that by using aluminium alloy material as the medium was better than using water as medium. The largest temperature different shown by using water as medium is 0.7 degree Celsius but for aluminium alloy is 2.5 degree Celsius.

In addition, power consumption was calculated for both experiments. About 16.0% of power was used from a unit of thermoelectric cooler for the first experiment. However, about 52.6% of power was used from a unit of thermoelectric cooler for second experiment.

In conclusion, thermoelectric cooler was a good actuator in cooling field. However, the medium applied was related and affected the findings. Further improvement and analysis is needed for this project.

5.2 Recommendation

In this project, concept of water circulation is applied to transfer coldness to entity of the jacket. However, there is still some improvement can be done on it in term of performance. Recommendation for improvement is use alternative medium to transfer coldness along with small power of DC fans install at the jacket to increase the ventilation process. Besides that, optimizing the distribution streamline to reduce the weight of the cooling jacket is also one of the improvements.

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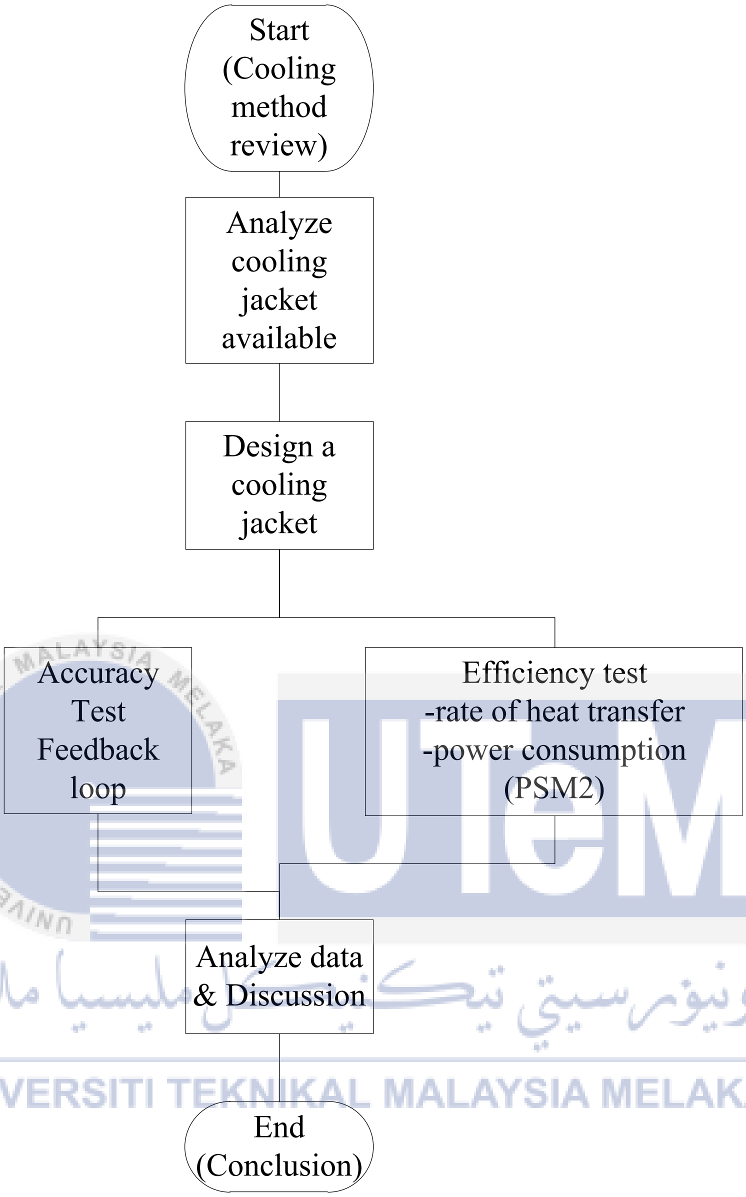
APPENDIX

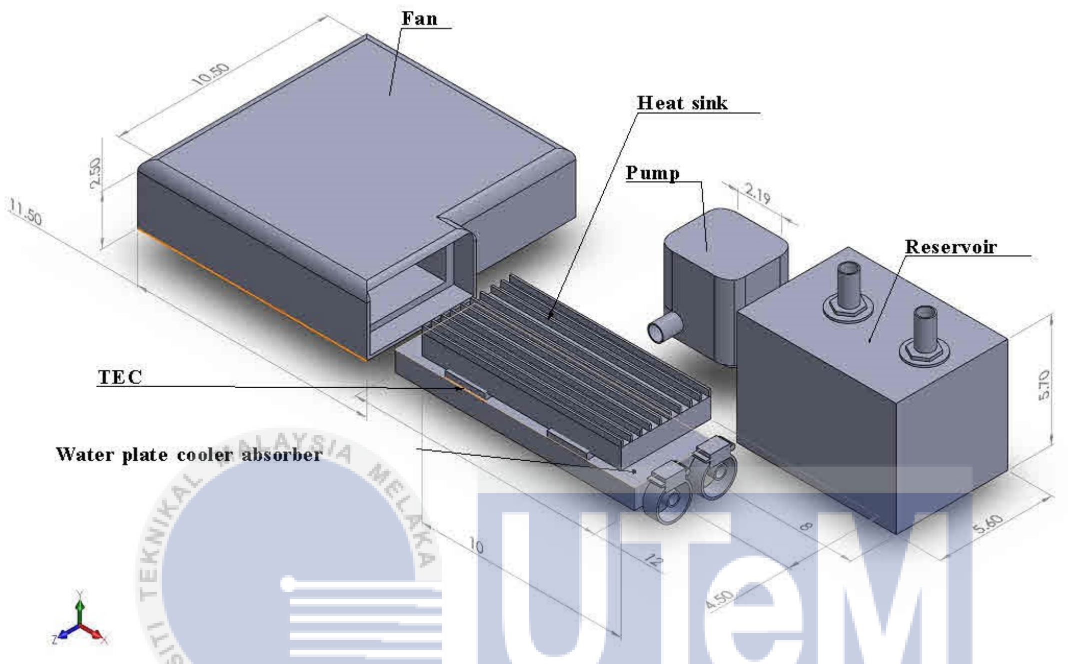
Appendix 1: Gantt chart

FYP1																		
week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
Briefing	■																	
Registration		■																
Gantt chart		■																
Literature review		■	■	■	■	■	■	■	■	■								
Introduction			■	■	■													
Objective			■	■	■													
Scope			■	■	■													
Project Background				■	■													
Methodology				■	■	■	■	■	■	■								
Preliminary Result						■	■	■	■									
Conclusion																		
Submit																		
Presentation											■							
FYP2																		
Research	■	■																
Experiment Planning		■	■															
Carry Out Experiment		■	■	■	■													
Analyse Data		■	■	■	■													
Continue Experiment						■	■	■	■									
Analyse Data						■	■	■	■									
Video Shooting									■									
Discussion		■	■	■	■	■	■	■	■	■	■	■						
Conclusion										■	■	■						
Submit Draft Report													■					
Report Correction														■	■			
Presentation																■		
Submission PSM Thesis																	■	■

Appendix 2: Project Methodology



Appendix 3: Cooling System Prototype



Appendix 4: Cooling System Programing

```
const int tempPin = A0;
int ledPin1 = 13;
int ledPin2 = 12;

int tempMax = 32;
int tempMin = 24;
int pwm = 0;
float volt = 0;
int time = 0;

const int switchPin = 2;
const int motor1Pin = 5;
const int mosfet = 3;



void setup()
{
pinMode(ledPin1, OUTPUT);
pinMode(ledPin2, OUTPUT);
pinMode(switchPin, INPUT);
pinMode(motor1Pin, OUTPUT);
pinMode(mosfet, OUTPUT);
analogWrite(motor1Pin, 0);
analogWrite(mosfet, 0);
Serial.begin(9600);
```

```
  delay(100);

}

void loop()
{

int value;
value = 0;
for (int i = 0; i < 10; i++){
value = value + analogRead(tempPin);
}
value = value / 10.00;
float millivolt = (value * 5.0 / 1023.0);
float tempC = (millivolt * 1000.0 / 10.0);
digitalWrite(ledPin2, HIGH);

if (tempC > 27)
 {

digitalWrite(ledPin2, LOW);
digitalWrite(ledPin1, HIGH);

pwm = (tempC-30);
pwm = pwm*25.5;
if (pwm > 255){
pwm = 255;
```

```
}
analogWrite(motor1Pin, pwm);
analogWrite(mosfet, pwm);

}
else
{
pwm = 0;
digitalWrite(ledPin1, LOW);
digitalWrite(ledPin2, HIGH);
analogWrite(motor1Pin, pwm);
analogWrite(mosfet, pwm);
}

volt = pwm*(5.00/255.00);
time++;
Serial.print(tempC);
Serial.print("\t");
Serial.print(pwm);
Serial.print("\t");
Serial.println(volt);

delay(100);
```

Appendix 5: Data collected for temperature, PWM and voltage

Temperature	PWM	Voltage			
36.66	153	3	37.15	178	3.49
35.68	127	2.49	35.19	127	2.49
34.21	102	2	37.15	178	3.49
35.19	127	2.49	37.15	178	3.49
34.7	102	2	35.68	127	2.49
35.19	127	2.49	35.19	127	2.49
34.21	102	2	35.68	127	2.49
40.57	255	5	35.68	127	2.49
36.17	153	3	34.7	102	2
37.15	178	3.49	34.7	102	2
34.7	102	2	34.7	102	2
34.21	102	2	34.7	102	2
34.7	102	2	36.66	153	3
36.66	153	3	36.17	153	3
35.19	127	2.49	36.17	153	3
34.21	102	2	35.19	127	2.49
34.7	102	2	35.19	127	2.49
34.7	102	2	35.68	127	2.49
34.7	102	2	35.19	127	2.49
34.7	102	2	35.19	127	2.49
35.68	127	2.49	35.68	127	2.49
35.68	127	2.49	35.68	127	2.49
35.19	127	2.49	35.19	127	2.49
35.68	127	2.49	34.7	102	2
35.19	127	2.49	35.19	127	2.49
34.7	102	2	36.66	153	3
35.68	127	2.49	34.7	102	2
34.7	102	2	34.7	102	2
35.68	127	2.49	35.19	127	2.49
36.66	153	3	35.19	127	2.49
36.17	153	3	34.7	102	2
36.17	153	3	35.19	127	2.49
35.68	127	2.49	35.68	127	2.49
37.15	178	3.49	35.68	127	2.49
37.63	178	3.49	35.19	127	2.49
36.66	153	3	35.19	127	2.49
35.68	127	2.49	34.7	102	2
35.68	127	2.49	34.7	102	2
35.68	127	2.49	34.7	102	2

35.68	127	2.49	36.17	153	3
34.7	102	2	36.66	153	3
34.7	102	2	36.17	153	3
34.7	102	2	36.66	153	3
34.7	102	2	36.17	153	3
34.7	102	2	36.17	153	3
35.19	127	2.49	36.66	153	3
35.68	127	2.49	36.17	153	3
34.7	102	2	36.66	153	3
34.21	102	2	36.17	153	3
34.7	102	2	36.66	153	3
35.19	127	2.49	36.66	153	3
35.19	127	2.49	36.66	153	3
34.7	102	2	36.17	153	3
34.7	102	2	36.17	153	3
34.21	102	2	37.63	178	3.49
34.7	102	2	37.15	178	3.49
34.7	102	2	36.66	153	3
35.19	127	2.49	36.66	153	3
35.19	127	2.49	36.66	153	3
35.19	127	2.49	36.66	153	3
34.7	102	2	37.15	178	3.49
34.7	102	2	37.63	178	3.49
35.19	127	2.49	37.15	178	3.49
35.68	127	2.49	37.15	178	3.49
35.19	127	2.49	37.63	178	3.49
35.68	127	2.49	37.15	178	3.49
34.7	102	2	36.66	153	3
35.68	127	2.49	36.66	153	3
35.19	127	2.49	37.63	178	3.49
35.68	127	2.49	37.15	178	3.49
35.68	127	2.49	37.15	178	3.49
35.68	127	2.49	37.15	178	3.49
35.68	127	2.49	37.63	178	3.49
35.68	127	2.49	37.15	178	3.49
35.68	127	2.49	37.15	178	3.49
36.17	153	3	37.63	178	3.49
36.17	153	3	37.63	178	3.49
36.66	153	3	37.63	178	3.49

37.15	178	3.49	40.08	255	5
38.12	204	4	40.57	255	5
38.12	204	4	40.57	255	5
38.12	204	4	40.57	255	5
37.63	178	3.49	40.57	255	5
38.12	204	4	41.06	255	5
37.63	178	3.49	41.06	255	5
37.63	178	3.49	41.06	255	5
37.63	178	3.49	41.54	255	5
37.63	178	3.49	41.06	255	5
37.63	178	3.49	41.54	255	5
38.12	204	4	41.54	255	5
38.12	204	4	41.54	255	5
38.12	204	4	42.03	255	5
38.12	204	4	42.03	255	5
38.12	204	4	42.03	255	5
38.61	204	4	42.03	255	5
38.12	204	4	42.52	255	5
38.12	204	4	42.03	255	5
38.61	204	4	42.03	255	5
38.12	204	4	42.03	255	5
38.12	204	4	42.03	255	5
38.12	204	4	42.03	255	5
38.12	204	4	42.52	255	5
38.61	204	4	42.52	255	5
38.61	204	4	42.52	255	5
38.12	204	4	42.52	255	5
38.61	204	4	42.52	255	5
38.61	204	4	43.01	255	5
38.61	204	4	43.01	255	5
38.61	204	4	42.52	255	5
39.1	229	4.49	42.52	255	5
39.1	229	4.49	43.5	255	5
39.1	229	4.49	42.52	255	5
39.1	229	4.49	43.01	255	5
39.1	229	4.49	43.01	255	5
39.59	229	4.49	43.01	255	5
40.08	255	5	43.5	255	5
40.08	255	5	43.01	255	5

Appendix 6: Data collected based on real environment testing for water as medium

Time (s)	Cursor 1 (°C)	Cursor 2 (°C)	Different (°C)	Average (°C)	Joules (J)	Watts (W)
0	29.3	28.9	0.4	29.1	551.76	
25	29.5	29.3	0.2	29.4	275.88	
50	29.1	28.7	0.4	28.9	551.76	
75	29.2	28.6	0.6	28.9	827.64	
100	29.2	28.7	0.5	29.0	689.70	
125	29.8	29.2	0.6	29.5	827.64	
150	29.0	28.6	0.4	28.8	551.76	
175	29.4	28.8	0.6	29.1	827.64	
200	29.7	29.0	0.7	29.4	965.58	
225	29.7	29.3	0.4	29.5	551.76	
250	29.3	29.2	0.1	29.3	137.94	
275	29.5	29.3	0.2	29.4	275.88	
300	29.1	28.7	0.4	28.9	551.76	
325	29.2	28.6	0.6	28.9	827.64	
350	29.0	28.6	0.4	28.8	551.76	
375	29.4	28.8	0.6	29.1	827.64	
400	29.7	29.3	0.4	29.5	551.76	
425	29.3	29.2	0.1	29.3	137.94	
450	29.5	29.3	0.2	29.4	275.88	
475	29.3	28.9	0.4	29.1	551.76	
500	29.5	29.3	0.2	29.4	275.88	
525	29.3	28.9	0.4	29.1	551.76	
550	29.5	29.3	0.2	29.4	275.88	
575	29.1	28.7	0.4	28.9	551.76	
600	29.2	28.6	0.6	28.9	827.64	
					13794.00	22.99

Appendix 7: Data collected based on real environment testing for aluminium alloy as medium

Time (s)	Hot (°C)	Cold (°C)	Different (°C)	Average (°C)	Joules (J)	Watts (W)
0	34.0	28.6	5.4	31.3	1131.3	
20	33.1	27.5	5.6	30.3	1173.2	
40	33.4	27.4	6.0	30.4	1257.0	
60	33.7	27.4	6.3	30.6	1319.9	
80	34.2	27.8	6.4	31.0	1340.8	
100	34.8	27.6	7.2	31.2	1508.4	
120	34.3	26.7	7.6	30.5	1592.2	
140	33.4	26.7	6.7	30.1	1403.7	
160	33.8	26.3	7.5	30.1	1571.3	
180	34.6	26.7	7.9	30.7	1655.1	
200	33.5	26.6	6.9	30.1	1445.6	
220	33.4	27.4	6.0	30.4	1257.0	
240	33.7	27.4	6.3	30.6	1319.9	
260	33.8	26.3	7.5	30.1	1571.3	
280	34.6	26.7	7.9	30.7	1655.1	
300	34.8	27.6	7.2	31.2	1508.4	
					22709.8	75.70