Development of Heat Extraction System for Automobile Application using Peltier Devices

by

KHAIRUNNISA BT HJ KHAIRUDDIN

17093

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Electrical and Electronic Engineering)

SEPTEMBER 2015

Universiti Teknologi PETRONAS

32610 Seri Iskandar

Perak Darul Ridzuan

CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____

(Dr. Nor Zaihar B. Yahaya)

UNIVERSITI TEKNOLOGI PETRONAS
SERI ISKANDAR, PERAK
September 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified source or persons.

KHAIRUNNINSA BT HJ KHAIRUDDIN

ABSTRACT

This paper proposes a development of heat extraction system using Peltier devices to extract the heat trapped inside cars. The heat tremendously increases, when exposed to direct sunlight for extended hours during parking time. A test was conducted and the result showed that at 1.50 pm, the temperature inside the car reached more than 50°C. A heat extraction system uses a solar panel, battery and charge controller as a power supply to the system, Peltier modules and fans as cooling system elements and temperature controller to automatically regulate temperature inside the car. The entire cooling system is assembled and tested on a prototype made from polypropylene and acrylic material. It is found that the heat extraction system is capable of maintaining the temperature inside the prototype effectively in the range of 31.74°C to 35.64°C.

ACKNOWLEDGEMENT

It is a great opportunity for me to research on *"Development of Heat Extraction System for Automobile Application using Peltier Devices"* as part of the curriculum in Final Year Project for Electrical and Electronic Engineering program.

First and foremost, I would like to dedicate my earnest appreciation to my supervisor, Dr. Nor Zaihar B. Yahaya for his patience, consistent support and giving such thoughtful feedback, always aimed at moving me forward. Without his assistance and dedicated involvement in every step throughout the process, this paper would have never been accomplished.

I would like to further express my gratitude to the technicians, who gave the permission to use all required equipment and the necessary material to complete the task and for their valuable advices, guidance and encouragement extended to me.

Last but not least, I take this opportunity to express gratitude to all of the members from the Department of Electrical and Electronic Engineering for their help and continuous support in keeping me motivated.

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CHAPTER 1: INTRODUCTION

1.1 Background of Study

Renewable energy is becoming well-known resource for global in generating electricity. The resource of renewable energy can be categorized into several types such as solar, wind, hydropower and biomass. Renewable energy is important as an alternative to conventional energy generation. Since Malaysia is one of the countries known for its hot weather, therefore the use of solar energy can be a huge benefit.

On the average, Malaysia receives about six hours of sunshine per day. The sunshine duration may affect the solar output power due to seasonal and spatial variations in the amount of sunshine received. On 9th April 1998, at Chuping, Perlis, the Northern part of Malaysia recorded the highest temperature. The temperature recorded was 40.1°C. Besides that, the mean monthly of maximum temperature was also recorded in most part of Malaysia in between 30°C - 34°C [1].

In Malaysia, many parking bays are uncovered. With the high temperature especially in the afternoon, this will allow heat to build up inside the cars. As a result, car occupants will feel very uncomfortable upon entering the cars due to the intense heat. In addition to the problem, the heat build-up would take such a long time to properly ventilate the hot air out of the car. Consequently, a test was conducted at Village 2, Universiti Teknologi Petronas on a Perodua Kancil shown in Figure 1 that the temperature inside the car reached more than 50°C.

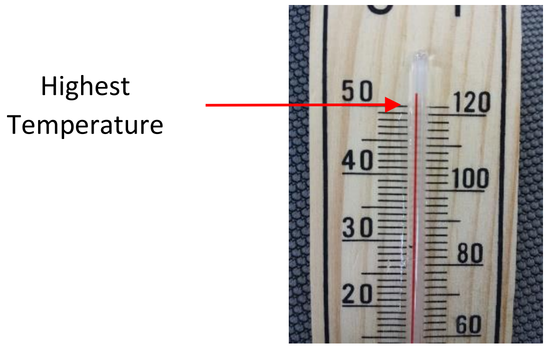

Figure 1: Highest Temperature Recorded inside the Perodua Kancil

A photovoltaic (PV) system is used as a power supply to the system in which the solar panel will absorb the sunlight during daytime and convert it into electricity. A battery can be integrated in this system to store energy during the day and also provide a constant level of power to the loads. A charge controller is also important to protect the battery from overcharging and over-discharging.

The thermoelectric cooling module function based on a phenomenon called Peltier effect. When a voltage is applied between two conductors, a temperature difference is created at both sides of the Peltier plate. One side of Peltier module will become cooler due to heat being absorbed from cooling plate while another side becomes hotter due to heat released to the other side.

As of now, there are no car heat extracting systems available in the market, at least in the Malaysia. Therefore, this work aims to develop heat extraction system using Peltier modules dedicated for compact cars such as Perodua Kancil, Perodua Viva and Proton Savvy that have approximate internal dimensions of 1400 mm x 1100 mm x 1000 mm.

The internal dimensions inside the compact cars mentioned is the main parameter that have a direct influence on the sizing of the cooling system. The car cooling system requires additional thermoelectric cooling modules for the types of car that have a bigger internal dimensions than the compact cars such as sedans, multi-purpose vehicles (MPV) and sport utility vehicles (SUV).

1.2 Problem Statement

Parking in sunny day can get particularly uncomfortable as temperature increases, consequently builds up heat inside car. When a driver is exposed to extreme temperature in an enclosed vehicle, it can cause dehydration, or worse may lead to death especially among infants and elderly [2]. Therefore, this issue can be solved by developing a heat extracting system using Peltier devices to reduce the heat trapped inside cars.

1.3 Objectives

i. To explore an alternative option as an addition to existing cooling system.
ii. To design a ventilation system for car.
iii. To harness renewable energy as a power supply for the system.
iv. To test and analyse the system.

1.4 Scope of Study

i. The study of Peltier effect at the thermoelectric cooling system.
ii. The study in the effect of using four thermoelectric cooling plates.
iii. The concept of photovoltaic cell in supplying an electrical energy.

1.5 Relevancy of Project

This work mainly focuses on giving a solution to car occupants related to trapped heat in cars during day time. This project uses the Peltier as the main element to reduce and ventilate hot air inside the car. The photovoltaic cell is used as a source of power for the overall system.

1.6 Feasibility of the Project

According to the time frame of the final year project, the time given to complete the project is 28 weeks in which the first 14 weeks are allocated to focus on research and experimentation while for the next 14 weeks will be used in assembling and testing the overall project system. Therefore, this makes the work feasible and achievable within the stipulate timeframe.

CHAPTER 2: LITERATURE REVIEW

The global warming phenomena can no longer be viewed lightly as they cause damage and loss of lives. The effects of global warming can be seen among car consumers when extreme heat is trapped inside the car. Thus, car occupant demand for a system that can extract the heat trapped inside the car.

Since there is a high demand in using own transportation, drivers have trouble in acquiring a parking space especially in covered parking bays. Due to the lack of covered parking, the drivers have to park the cars in open areas exposed to the sun, thus causing the temperature inside them gets hotter. It will be much more inconvenient if cars are parked for several hours under sunlight. As a result, there must be a way to find a suitable heat extracting system to reduce this temperature.

2.1 Alternative Cooling System as an Addition to Air Conditioner

In exploring for an alternative cooling system, the requirements of energy efficiency and simplicity of the design must be met. There are several alternative systems that can be considered as an addition to car air-conditioner such as absorption cycle method and thermoelectric cooling method [3]. The methods mentioned are shown in Figure 2 and Figure 3, respectively.

2.1.1 Absorption Cycle Method

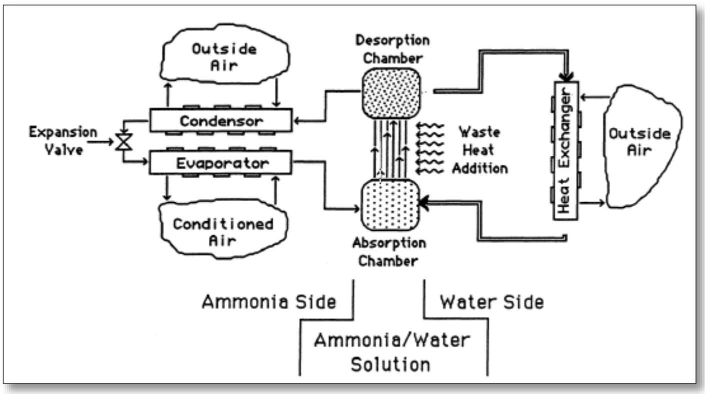

Figure 2: Method of Absorption Cycle System [3]

Absorption cycle method shown in Figure 2 is a cooling technique that reuses the waste heat generated by the engine with the exception of an optional liquid pump. The process cycle is similar to the vapour-compression cycle, but uses ammonia as the functioning fluid which will be compressed and expanded [3]. The output of this system is cool air coming from the evaporator similar to a refrigerator system.

2.1.2 Thermoelectric Cooling Method

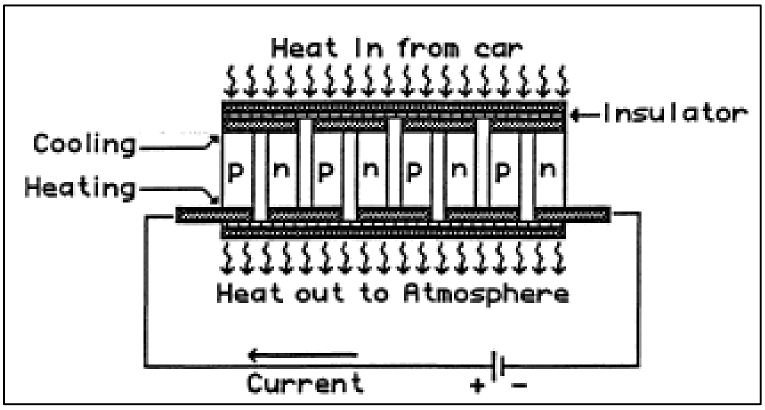

Figure 3: Method of Thermoelectric Cooling System [4]

Thermoelectric cooling method shown in Figure 3 uses electricity to transfer heat. The temperature difference is generated when voltage is applied to the thermoelectric cooling plate terminals. The physics of the thermoelectric cooling requires the thermoelectric plate to produce cold at the cold side and hot at the hot side [4].

2.1.3 Comparison of Alternative Cooling Systems

Since the absorption cycle method had been implemented in refrigeration systems, this system is considered as a good cooling technique. However, considering the use of motor pumps, evaporator, condenser and heat from car exhaust, this setup is too complex to be implemented in an automobile. In addition, the cooling effect may be too great while requiring high input power, hence making it less practical since power supply is very limited. It may also require frequent gas maintenance since ammonia is used as a cooling agent.

The thermoelectric cooling method may not be as effective as absorption cycle method in terms cooling, but it is sufficient to provide a cooling element inside automobile since over cooling is not necessary as long as the temperature inside automobiles is at reasonable level. In contrast, the setup is very easy and does not require frequent maintenance.

Therefore, thermoelectric cooling method is suitable to be used in this heat extracting project since thermoelectric cooling modules have no moving parts, safe for environment, essentially maintenance free and its ability to heat and cool by reversing the current flow.

2.2 Ventilation System Design

2.2.1 Solar Car Ventilator Using Fan

Heat build-up in cars can be extracted in various ways. One research done on heat extraction shown in Figure 4 had implemented the use of fans as the sole tool for ventilating heat. This setup requires the system to be mounted on car window that is slightly open while covering the exposed area with plastic strips. Despite successfully ventilating a considerable amount of heat, the temperature inside the car still remains at an uncomfortable level which is around 50°C based on Figure 5 [5].

Figure 4: Solar Car Ventilator [5]

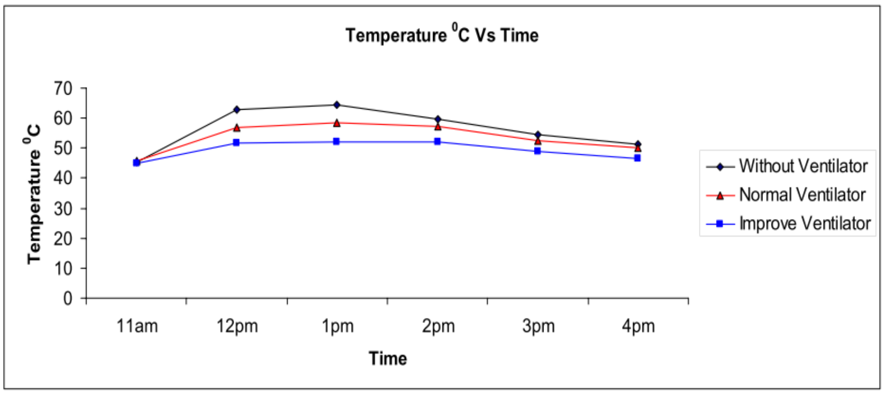

Figure 5: Temperature inside Car [5]

2.2.2 Portable Car Cooling System Using Peltier Module

A similar setup shown in Figure 6 was also done in 2013, implemented a mounting ventilating system as well. However, it had an additional feature by using Peltier plates to reduce the heat inside the car by convection [6]. This method had produced a significantly better result compared to the previously mentioned system which only depends on fan to ventilate heat as shown in Figure 7.

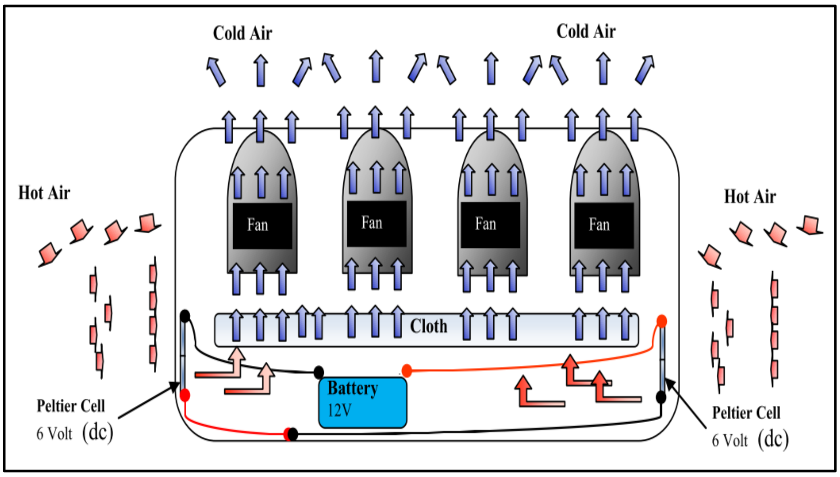

Figure 6: Mechanism for Reducing Car Cabin Temperature [6]

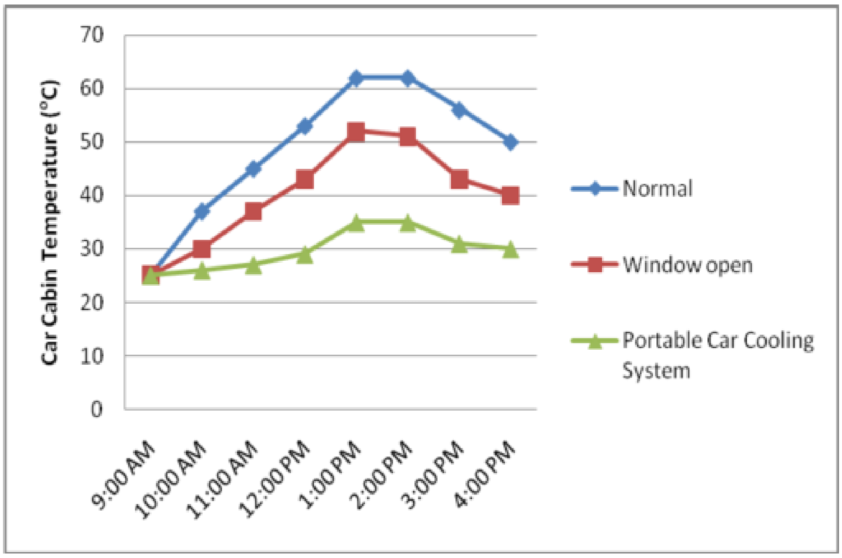

Figure 7: Temperature Difference in the Car Cabin [6]

2.3 Renewable Energy Harness Technique for Solar PV

Development of the solar energy is favourable to Malaysia due to its weather that is mostly sunny all year round. Solar energy is an alternative energy source that produces the electricity through solar radiation emitted. From the photovoltaic system, the direct sunlight will convert into electricity by using solar cell [7]. Although it is complicated to convert sunlight into electricity due to its inconsistent output since it depends on the solar exposure [8], a battery integrated with the system can address this power issue temporarily.

This heat extracting system requires a power supply to operate. Since it is designed to run continuously, it is essential to have a dedicated power supply to prevent from draining the car battery. Besides that, there is no need to interfere with the car's electrical system which will further simplify the installation process of the system.

2.3.1 Solar PV

Fortunately, there are abundant amount of sunlight in Malaysia [9]. This is a good opportunity to harness the sun's energy and convert it into useful electrical energy. This can be done by integrating a photovoltaic (PV) cell with the system. A well-known type of PV cell is the monocrystalline solar panel as shown in Figure 8. Monocrystalline type of solar panel has a higher efficiency compared to the polycrystalline type. This is due to the fact that monocrystalline panels have higher amount of pure silicon, consequently able to convert solar energy into electricity more efficiently [10]. Since space is limited, monocrystalline type is preferred since it has a higher output efficiency.

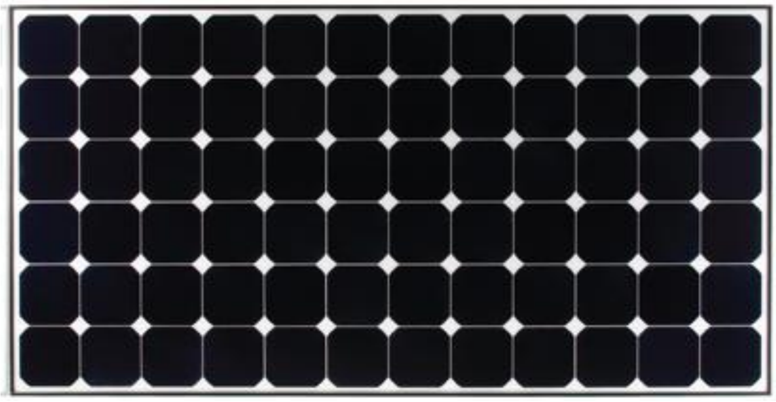

Figure 8: Monocrystalline Solar Panel [11]

2.3.2 Charge Controller

Despite having access to abundant solar energy, power from the sun always fluctuates mainly as a result of the rotation of the earth [12]. Therefore, a power stabilization system is needed. One way to achieve this is by using a charge controller as shown in Figure 9. A charge controller is able to regulate the output voltage from a PV cell. In addition to that, it can also manage the charging process of battery to prevent from overcharging it [13].

Figure 9: Charge Controller [14]

2.3.3 Battery

Another crucial component is a battery which is needed to store the electricity harnessed from the solar panel. A battery can be a backup power to the heat extracting system in conditions where the sunlight is blocked by clouds for a period of time. In this condition, the output of the solar panel may be very minimal, subsequently power supply can be insufficient. In this condition, the role of the battery comes into play by supplying the power it has previously stored. As a result, the heat extracting system can remain operational for a longer period of time.

However, there are various type of battery that can be implemented with this system. Between lead acid and Li-ion batteries, lead acid as shown in Figure 10 is the most suitable type of battery chosen as it possess a good balance between cost and size [15].

Figure 10: Lead Acid Battery [16]

CHAPTER 3: METHODOLOGY

3.1 Design of Ventilation System

A schematic diagram was designed as shown in Figure 11 which can be divided into three parts which are the power supply, controller and the cooling system.

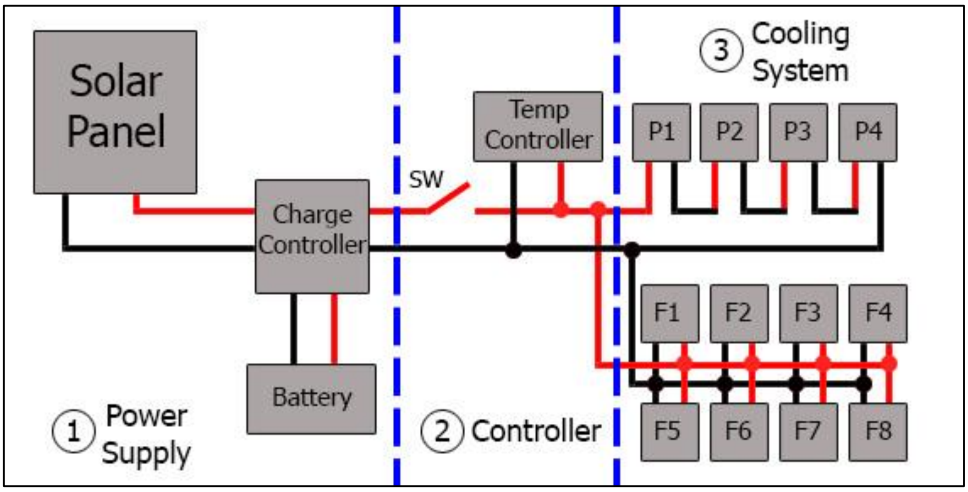

Figure 11: Schematic Diagram of Ventilation System

3.1.1 Power Supply

The power supply module consists of a solar panel, a battery, and a charge controller. The charge controller is an essential tool in administrating the charging and discharging of the battery. The reason for this is the battery might be damaged if overcharging occurs [17]. The charge controller can prevent this from overcharging by regulating the voltage and current coming from the solar panels flowing into the battery.

3.1.2 Controller

This heat extracting system works by first monitoring the temperature inside the car. A pre-specified value of temperature can be set to initiate the heat extracting system. The temperature is monitored by the temperature controller which permits supply to the Peltier plates from the power supply module if the temperature inside the car exceeds the pre-specified value.

3.1.3 Cooling System

At the cooling side, there is a cooling module that comprises of eight fans and four Peltier plates. These components will be installed in between the inner roof and a metal plate. Firstly, heat from sunlight comes mostly from the roof into the car. Since there is a cooling module underneath the roof, the heat will first fill up the space in the module and subsequently vented out by the four side fans. On the other hand, the cold side of all the Peltier plates will start to become cold once the power is supplied and subsequently cools the interior of the car by convection. This way, the heat trapped inside the car can be reduced.

3.1.4 System Configuration

Based on Figure 12, the thermoelectric cooling module has been attached in between two heat sink by using thermal paste to reduce air gap that may exist in between two materials. The use of thermal paste is also vital to the performance of the heat sink. It was used in between heat sink and Peltier to enhance heat conduction. A heat sink is made from metal, used to absorb and diffuse heat from Peltier. Two fans are fixed together with heat sink as one of the fan function is to pull the heat away from the heat sink while another fan pushes in cool air through another heat sink.

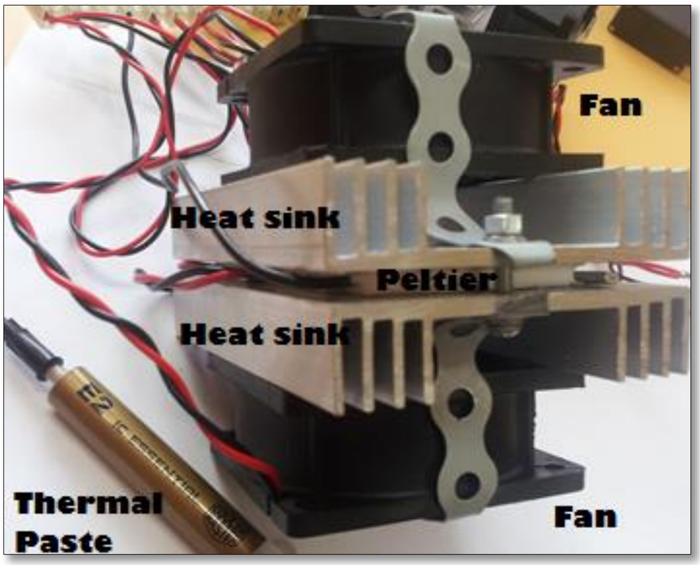

Figure 12: Thermoelectric Cooling Module

The load is then connected to the eight pins of digital temperature controller as shown in Figure 13. The Peltier module is connected to “SEMI” connector (Pin 1 and Pin 2), fans are connected to “FAN” connector (Pin 3 and Pin 4), power supply is connected to “IN” connector (Pin 5 and Pin 6) and temperature sensor is connected to “SENSOR” connector (Pin 7 and Pin 8).

Figure 13: Digital Temperature Controller

Based on Figure 14, the thermoelectric module is installed with digital temperature controller and the system will start to operate through temperature controller once the temperature sensor senses the surrounding temperature equivalent to the setting temperature. When the temperature surrounding is equivalent to the minimum temperature setting, the system will stop operating.

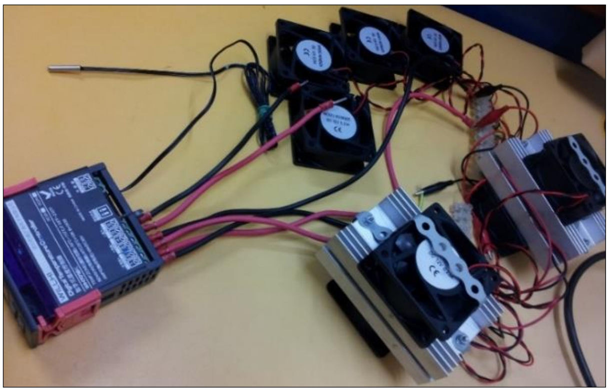

Figure 14: Digital Temperature Controller connection to Cooling System

The battery and digital temperature controller are connected to the solar charge controller as shown in Figure 15. The digital temperature controller will receive the power supply from the battery through the output of the charge controller.

Figure 15: Power Supply System

3.1.5 System Installation

Figure 16 and Figure 17 show the side view and top view of the system's installation on a car respectively. The solar panel will be attached on roof since the roof top receives the sunlight most of the time. The battery and the charge controller will be placed in the car boot. It can be observed in Figure 16, the hot side of the thermoelectric cooling module is placed on the inner base of the roof area, while the cold side is placed on the outer base of the roof area (facing the interior of the car). The fans installed in the roof area will circulate the air inside the roof and push away the heat trapped inside the car to the outside.

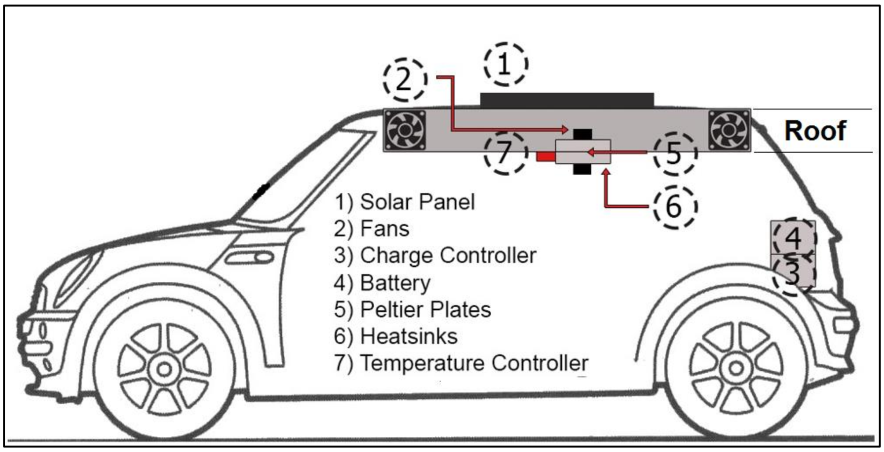

Figure 16: Installed System Side View

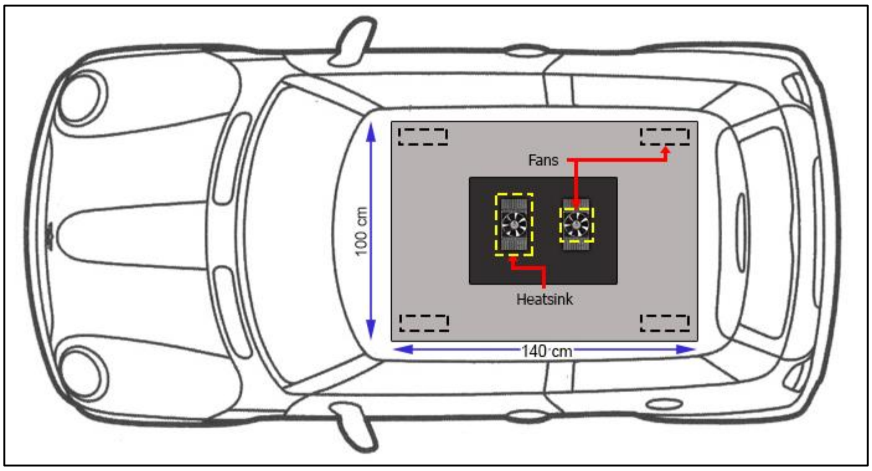

Figure 17: Installed System Top View

3.1.6 Flow of System Operation

Figure 18 show the operation of the heat extraction system. The heat extraction system will operate when the temperature inside the prototype exceeds the triggering point.

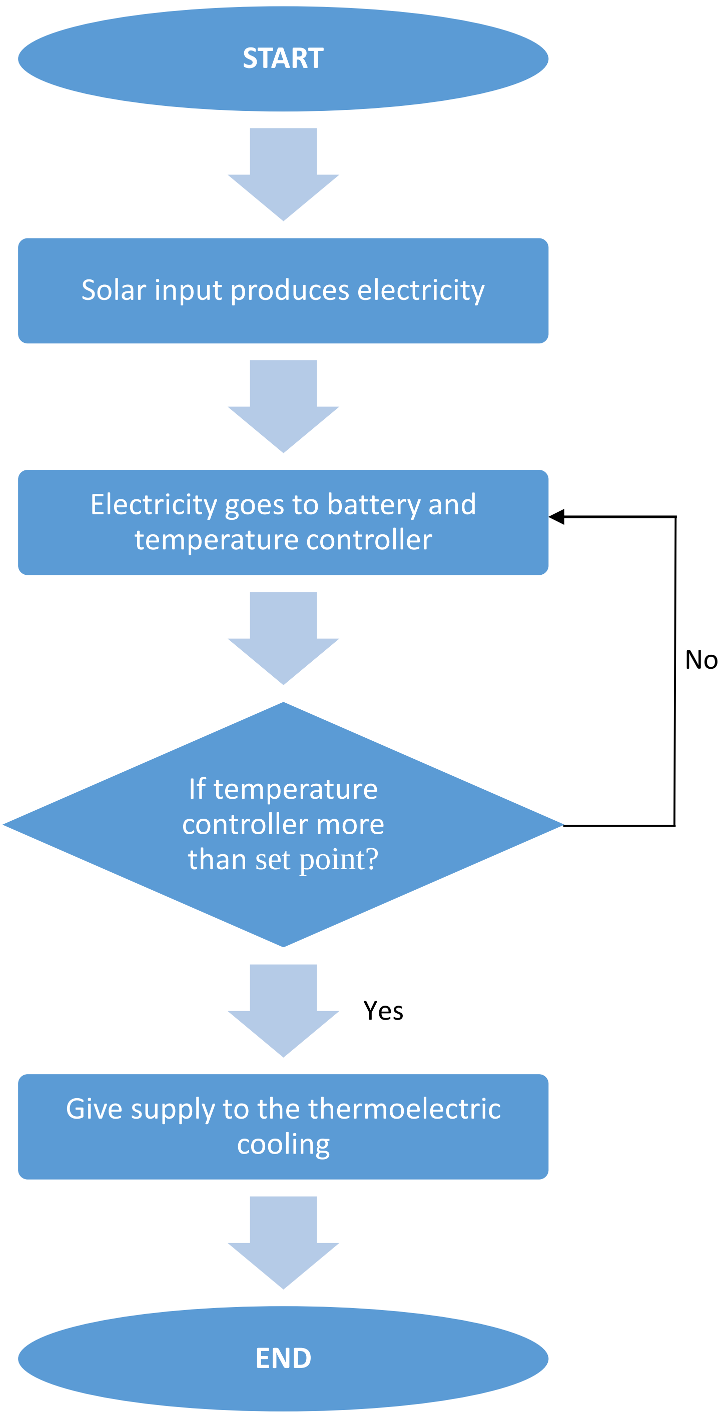

Figure 18: Flow of System Operation

3.1.7 Peltier Selection

In general, Peltier plates are identical in terms of construction and material apart from the specifications. However, there are two types of thermoelectric plates: the thermoelectric generator (TEG) and thermoelectric cooling (TEC). TEG plates are optimized to produce electricity when hot and cold elements are introduced on either side of the plates. For this cooling system, the latter is preferred due to its optimization for cooling purposes when electricity is supplied to its terminals. For this system, the TEC1 12706 with the specifications of 12V and 6A current rating is preferred. A total of four units of this type of Peltier plates will be used for this system.

3.1.8 Calculations

Power at Peltier (in Series);

Voltage = 12V, Current = 6A

Power = 6A x 12V = 72 W

Power at Fan (in Parallel);

Voltage = 12V, Current = 0.23 A

Power = 0.23A x 12V x 8 units = 22.08 W

Power Consumption;

Power at Cooling System = Power at Peltier + Power at Fan

= 72 W + 22.08 W

Total Power = 94.08 W

Current Consumption;

I_o = Current at Peltier + Current at Fan

= 6A + (0.23A x 8 units)

I_o = 7.84A

3.2 Renewable Energy Harness for Power Supply System

Solar energy can be harnessed through solar panel in which the energy from the sun is converted into electrical energy. Solar energy used to charge the solar panel, and the electricity produced will be used to supply power to the system.

3.2.1 Battery Selection

In this system, the battery is the direct supply of power of the cooling system. The worst case scenario is when there is insufficient sunlight and the system is expected to continue to work. To achieve this, the battery capacity needs to be considered. There is a battery available with specifications of 12V, 12Ah.

Therefore,
For I_o = 7.84 A,
Continuous Battery Runtime = Capacity/Current
= 12Ah / 7.84A
= approximately 1 hour

3.2.2 Solar Panel Selection

As discussed earlier, monocrystalline type of solar panel is favoured over the polycrystalline type for having a higher output efficiency. However, there is a need to determine the appropriate specifications in terms of voltage and current.

In this project, the solar panel is used to charge the battery. The higher the current rating, the quicker the charging time will be. Based on the choice of the lead acid battery, the specification is 12V, 12Ah. If the charging time is set to be at 12 hours, then a 12V, 1A solar panel is required.

3.3 Test to Observe Temperature Inside The Car

A test was conducted on 10th June 2015 at Village 2, Universiti Teknologi Petronas for random time to record the temperature inside the Perodua Kancil and its surrounding temperature during the highest sunlight emitted as shown in Table I.

Table I: Inside and Outside Temperature of Perodua Kancil Vs Time

Time (PM)	Inside Temperature (°C)	Outside Temperature (°C)
12.10	44	39.5
12.20	45.7	45.5
1.50	54	38

3.4 Test and Analyse Load System

A setup was developed to observe current consumption at load side. Based on Figure 19, the load was tested using LTspice to compare the result from software and hardware for the load test setup shown in Figure 20.

3.4.1 Load Test using LTspice

The load consists of four Peltier connected in series and eight fans connected in parallel. Since the current will be same when the components are connected in series, therefore 'R_{TP}' from the simulation represent the total resistance of four Peltier. As the fans connected in parallel, thus 'R_{F1} to R_{F8}' represent resistance of each eight fan.

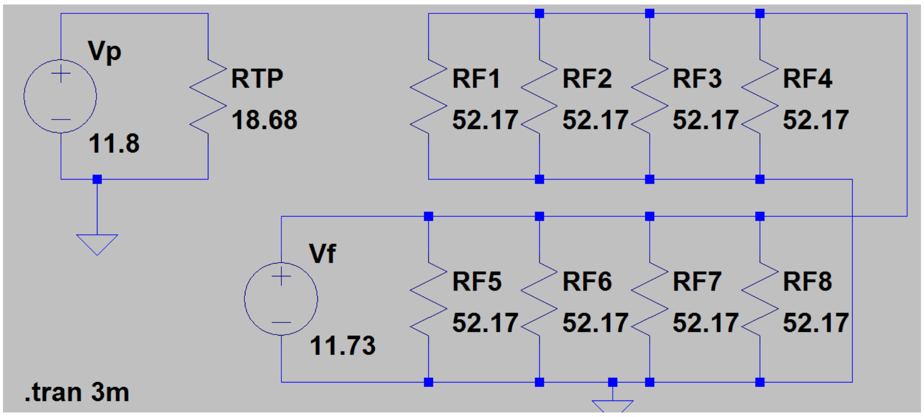

Figure 19: Load Test using LTspice

Where,

V_P = Input Voltage at Peltier

V_F = Input Voltage at Fans

R_{TP} = Resistance of Total Peltier

R_{F1} to R_{F8} = Resistance of Fan 1 to Resistance of Fan 8

3.4.2 Lab Test for Load Components

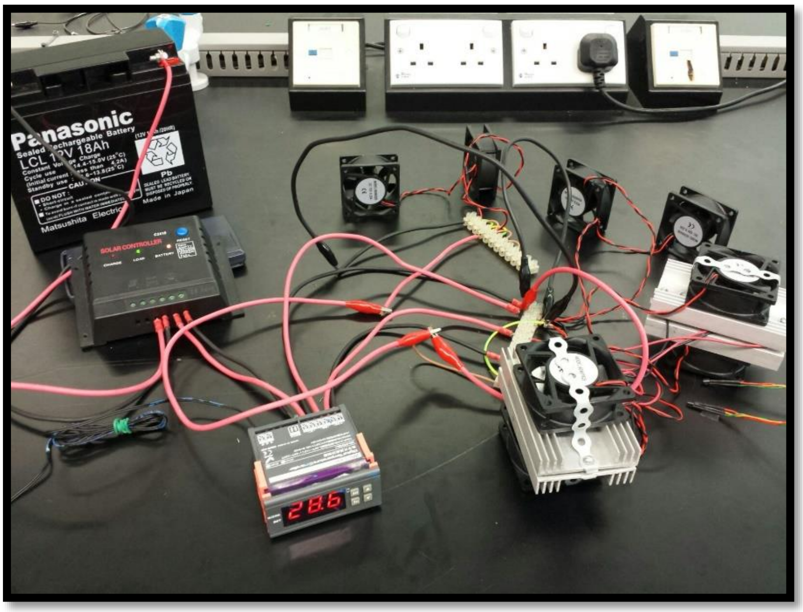

Figure 20: Load Test Setup

A test was conducted at the 27°C of room temperature. In order to operate the system, the temperature sensor was heated until it reaches the setting temperature. The system would start to operate at 35°C and it would stop operating once the temperature reaches its minimum set point at 27°C.

For the load testing, thermoelectric cooling module and fans are connected to the temperature controller. The battery will supply the power to the loads through charge controller and temperature controller. During the test, the battery supplied 12.25V to the load. The components and wires connected from battery to the loads will affect the value of the supplied voltage to the loads. Therefore, loads will receive voltage lower than the input voltage.

3.5 Project Activity

The flow of project activities are shown in Figure 21. The project started with the research to gather the information pertaining the project. Then, the design of the system had been conducted based on the research stage. To ensure the functionality of the components, preliminary testing was done on all of the components . Finally, the system is installed and tested on the prototype to analyze the performance of the system.

The key milestone for Final Year Project 1 and Final Year Project 2 are shown in Table II and Table III. Meanwhile, the Gantt chart for Final Year Project 1 and Final Year Project 2 are shown in Table IV and V. The tables show the activities performed during the 28 weeks of project timeframe.

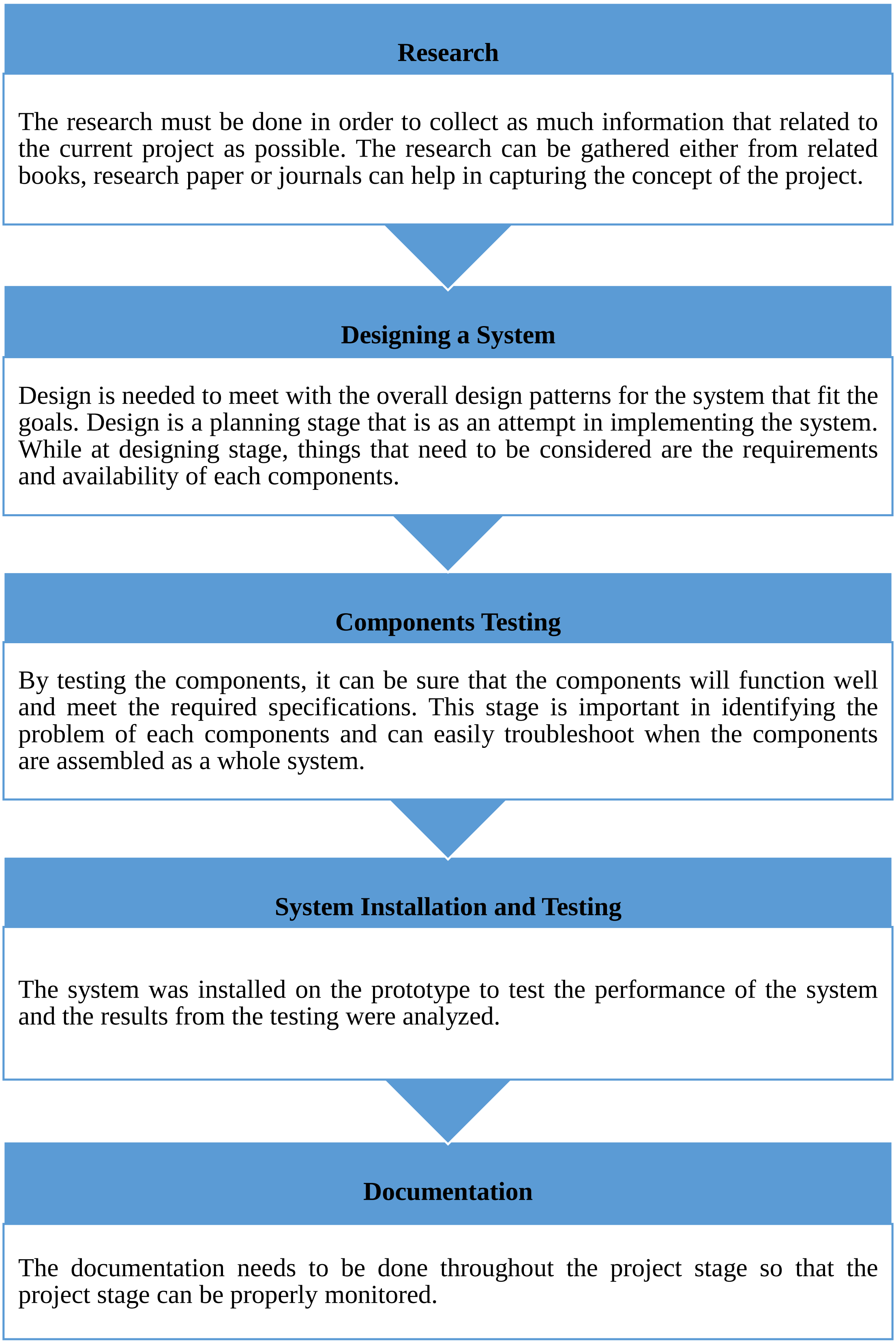

Figure 21: Flow of Project Activity

3.6 Key Milestone

Table II: Key Milestone of Final Year Project 1

Activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of project														
Research on heat extracting concept														
Identify the temperature inside car														
Identify the useful components needed to extract heat														
Designing heat extraction system circuit														
Testing Peltier														
Modification of circuit design														
Conduct a test at the load side														
Stimulate a circuit at the load side														
Final report submission														

Table III: Key Milestone of Final Year Project 2

Activities	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Design a new system with an addition of fans and heat sink														
Drill heat sink														
Assemble cooling system														
Design simulation using LTspice														
Test cooling system at lab														
Assemble cooling system unit with other components														
System installation														
Final report and presentation														

3.7 Gantt Chart

Table IV: Gantt Chart of Final Year Project 1

Activities	**Week**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Selection of project	■	■												
Research on project		■	■	■										
Extended Proposal preparation				■	■	■								
Extended Proposal submission						■								
Proposal Defense preparation							■	■						
Proposal Defense								■						
Finalise the design									■	■	■	■		
Components testing											■	■	■	
Draft of Interim Report													■	
Final Interim Report														■

Table V: Gantt Chart of Final Year Project 2

Activities	**Week**													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Design a new schematic as an addition to the system	■													
Assemble system components		■	■	■	■	■	■	■	■					
Simulation and testing of system				■	■	■	■	■	■	■	■	■		
Progress Report									■					
ELECTREX											■			
Draft Report													■	
Final Report														■

CHAPTER 4: RESULTS AND DISCUSSION

4.1 Hardware and Software Results

4.1.1 Calculation based on Results of Lab Test

From the load test carried out earlier, the results are shown below. The voltage from the Peltier and fan was dropped from 12.25V to 11.8V and 11.73V respectively due to the existence of resistance of the wire connected in between battery, charge controller, temperature controller and load. During testing, it was found that the value of resistance at Peltier increases as the temperature of Peltier plate increases. Since the resistance increases, the value of current will decrease and it may not be able to let the Peltier operate at optimum performance.

Input Voltage, V_{IN} = 12.25V

Input Current, I_{IN} = 1.97A

Input Voltage at Peltier, V_P = 11.8V

Input Voltage at Fan = 11.73V

Resistance of Total Peltier, R_{TP} = 4.67Ω x 4units = 18.68Ω

Total Current at Peltier, I_P = 0.82A

Total Current at Fan, I_F = 1.27A

If the current consumption is 1.97A, thus 11.82Ah battery capacity is required. However, it is essential to be equipped with a higher capacity of around twice the required capacity to ensure uninterrupted power supply and avoid over discharging of battery. Since there is a 12V, 12Ah battery available in the market, therefore this type of battery is suitable for the design.

Therefore,

For I_{IN} = 1.97A,

Continuous Battery Runtime = Capacity / Current

= 12Ah / 1.97

= approximately 6 hours

Without heat sink, it was found that the heat build-up from the hot side started to spread to the cold side after around 20 seconds of operating the load. Over time, both sides of the plates started to overheat and the cold-side may not be able to be utilized. The reason for this predicament is the fact that the heat is restricted to disperse only on the surfaces of the plates. To overcome this problem, a heat-absorbing material might be needed to allow the heat to be dissipated through another body.

After the heat sink was installed, the heat generated by Peltier can spread to the heat sink instead of around the Peltier plates which may affect the performance of the cold side. The fans that was attached at the heat sink will then regulate the temperature of the heat sink, therefore the heat sink will not get overheated.

4.1.2 Simulation for Load Test

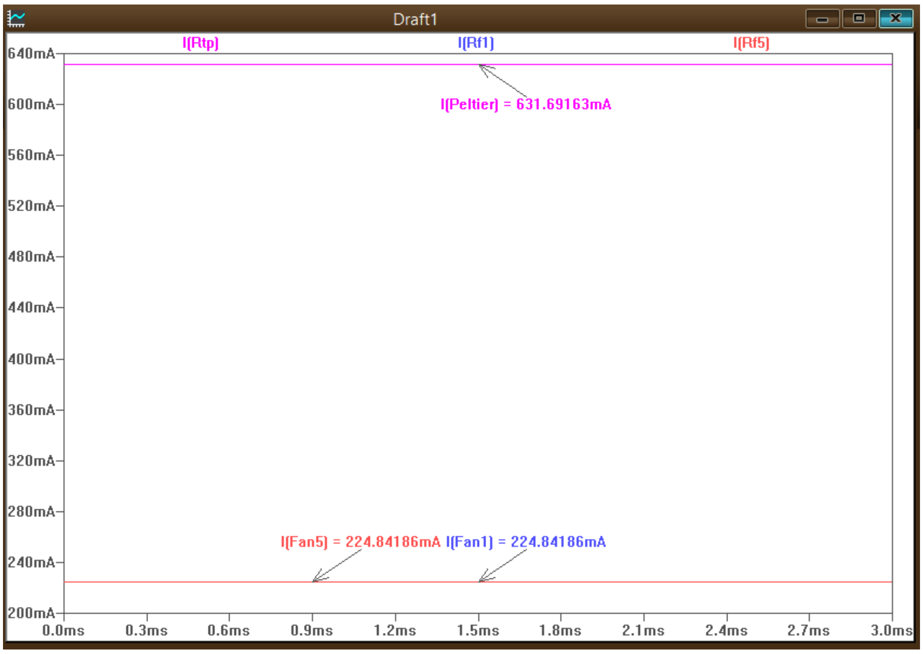

Figure 22: Simulation Result for Load Test

The simulation result is shown in Figure 22 based on the circuit design from Figure 19. This circuit was simulated using LTspice simulation software. In this setup, the testing focuses on the current consumption at the Peltier, fan and power supply.

Based on simulation result, the values are slightly different compared to lab testing but both of the results are consistent. The differences are due to voltage drop across wires used during lab testing. In addition, the resistance of the Peltier increases with temperature during lab test which further affects the consistency of the results.

4.1.3 Comparison of Results from Hardware and Software Testing

Based on Table VI and Figure 23, results from both hardware testing and software simulation at load side show a nearly equal value. The slight difference in value might be due to the possibility of existing resistance in the wire when the experiment is carried out in the lab.

Table VI: Comparison of Load Test Results

Elements	**Hardware Testing (HT)**	**Software Simulation (SS)**	**Percentage Δ = ((HT - SS)/HT) x 100%**
Input Voltage Peltier, VP (V)	11.8	11.8	-
Input Voltage Fan, VF (V)	11.73	11.73	-
Total Current at Peltier, IP (A)	0.82	0.63	23.17%
Total Current at Fan, IF (A)	1.27	1.79	-40.94%

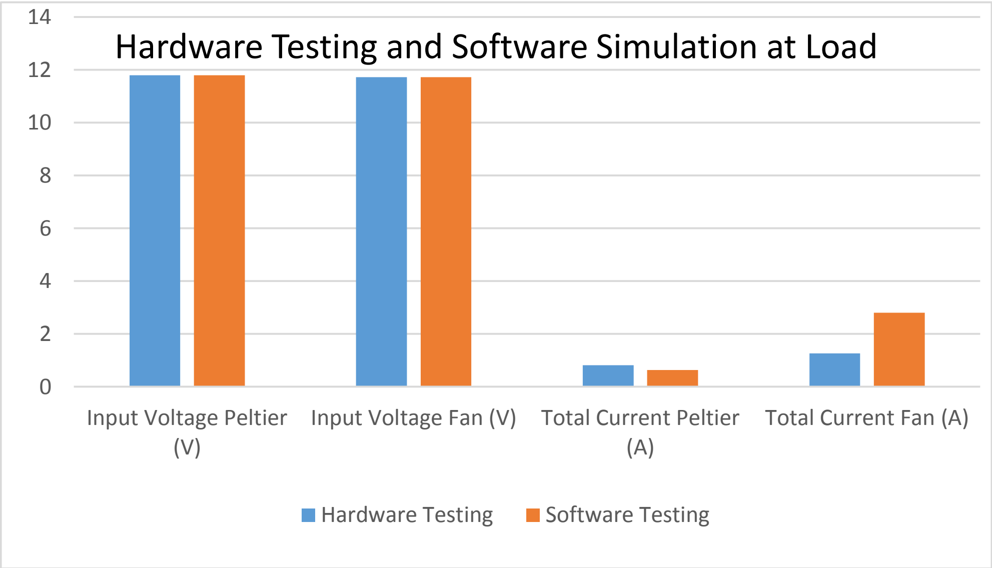

Figure 23: Graph of Hardware Testing and Software Simulation at Load

4.2 Performance of Cooling System

During the operation of the system, the temperature difference at the thermoelectric cooling module was monitored by using Arduino Uno and temperature sensor (LM35) as shown in Figure 24. The temperature sensor was attached to the heat sink at both cold and hot side for the purpose of getting an exact temperature reading. The test was conducted at 27°C room temperature.

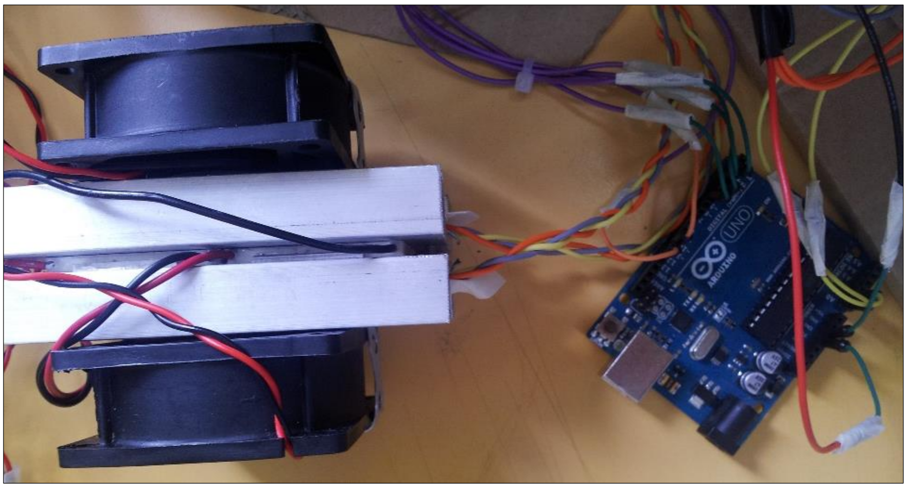

Figure 24: Test on the Performance of Cooling System

The test was conducted to operate the system for 30 minutes. Based on Figure 25 and Table VII, they show that in time, the temperatures at both sides start to decrease and it proves that the heat from the hot side is not spreading to the cold side. Besides that, it also shows that the cooling system is able to maintain its performance in producing cool air to the surrounding while the system is in operation.

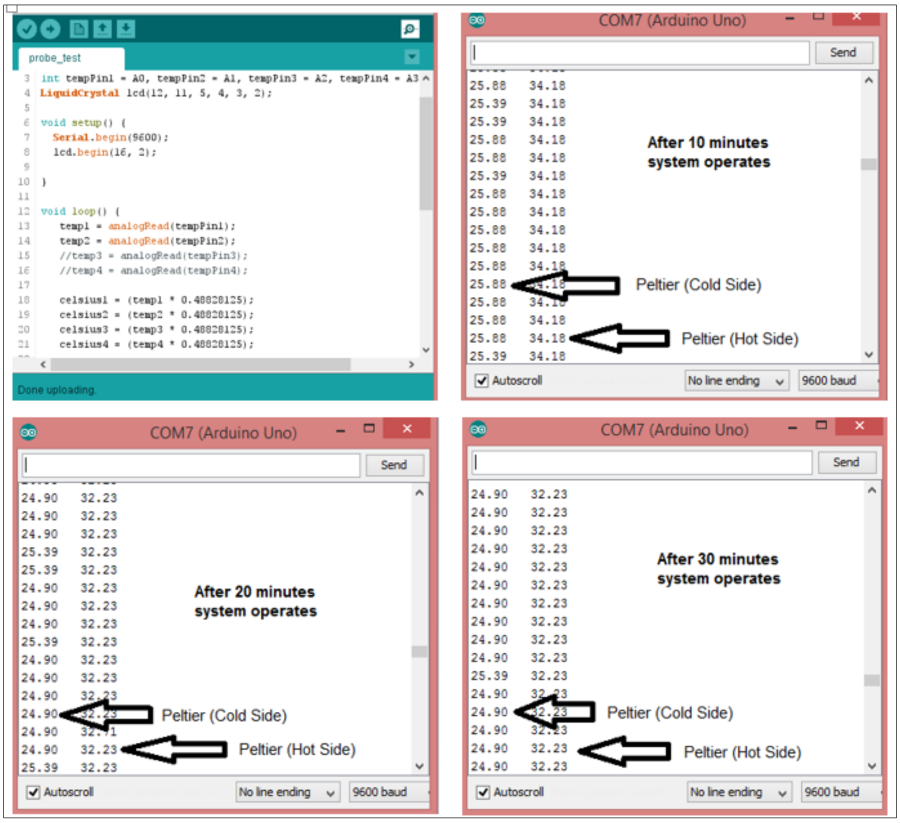

Figure 25: Temperature of Cooling System

Table VII: Temperature of Cooling System Vs Time

Time (minutes)	**Temperature (°C) at Cold Side**	**Temperature (°C) at Hot Side**
10	25.88	34.18
20	24.90	32.23
30	24.90	32.23

When the system operates continuously for 30 minutes, the water droplets can be seen at the heat sink as shown in Figure 26. This is due to the air that comes in contact with heat sink which will make the temperature of the heat sink decrease. The formation of water droplets on the surface of the heat sink indicates that condensation occurred. This show that the performance of the Peltier is good.

Figure 26: Water droplet formed at heat sink

4.3 Performance of Prototype Testing

A test was done on a box without operating the heat extraction system as shown in Figure 27 to observe the highest temperature that can be achieved inside the box. The temperature was measured using two temperature sensors. With this information, it is now possible to know the average temperatures that the drivers usually endure. The results from this test are shown in Table VIII and Figure 28.

Another test was done to observe the performance of the heat extraction system using similar temperature measurement setup. The results from this test are shown in Table IX and Figure 29.

Figure 27: Testing setup

Table VIII: Prototype without System

Time	**Temperature inside Roof (A) (°C)**	**Temperature inside Box (B) (°C)**	**Temperature Difference (A-B) (°C)**
11.30	56.2	42.97	13.23
11.35	58.3	44.43	13.87
11.40	60.9	44.64	**16.26**
11.45	60.4	45.37	15.03
11.50	60.5	45.42	15.08
11.55	58.1	45.91	12.19
12.00	60.8	46.49	14.31
12.05	60.9	48.31	12.59
12.10	60.6	48.16	12.44
12.15	61.6	47.82	13.78
12.20	62.4	47.95	14.45
12.25	62.5	48.34	14.16
12.30	**63.2**	**50.78**	12.42

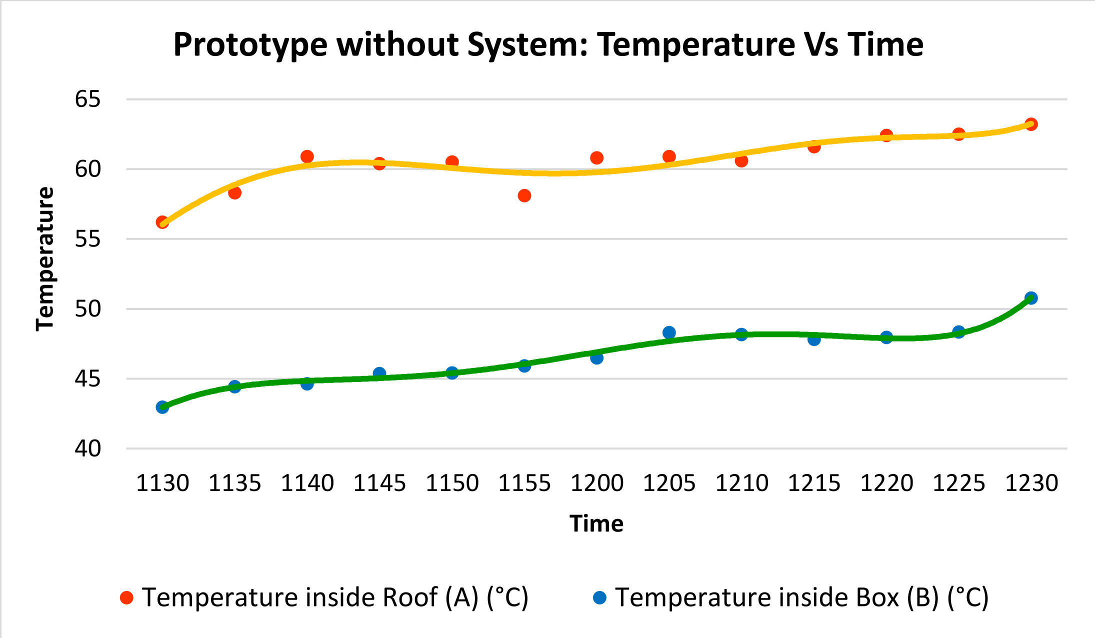

Figure 28: Prototype without System

Table IX: Prototype with System

Time	Temperature inside Roof (A) (°C)	Temperature inside Box (B) (°C)	Temperature Difference (A-B) (°C)
10.00	33.0	31.74	1.26
10.05	32.8	31.74	1.06
10.10	32.3	31.25	1.05
10.15	31.8	31.25	0.55
10.20	32.5	31.74	0.76
10.25	32.9	32.23	0.67
10.30	33.3	32.23	1.07
10.35	33.6	33.20	0.40
10.40	33.7	33.69	0.01
10.45	33.7	32.23	1.47
10.50	34.1	31.74	2.36
10.55	34.9	32.23	2.67
11.00	36.3	34.18	2.12
11.05	36.6	34.18	2.42
11.10	36.8	34.67	2.13
11.15	38.2	34.67	3.53
11.20	38.8	35.16	3.64
11.25	39.2	35.16	4.04
11.30	39.4	**35.64**	3.76
11.35	39.6	**35.64**	3.96
11.40	39.7	**35.64**	4.06
11.45	38.5	34.57	3.93
11.50	38.9	34.18	4.72

11.55	38.7	34.18	4.52
12.00	39.1	34.18	4.92
12.05	39.4	34.18	5.22
12.10	39.7	34.67	5.03
12.15	39.4	34.67	4.73
12.20	40.3	35.16	5.14
12.25	39.9	33.20	6.70
12.30	40.1	33.69	6.41
12.35	38.2	32.71	5.49
12.40	38.4	32.71	5.69
12.45	36.9	31.74	5.16
12.50	37.1	31.74	5.36
12.55	38.0	32.23	5.77
13.00	40.2	33.20	7.00
13.05	39.4	32.71	6.69
13.10	39.9	33.20	6.70
13.15	**40.9**	33.20	**7.70**
13.20	39.1	32.23	6.87
13.25	37.7	31.74	5.96
13.30	38.2	32.23	5.97
13.35	40.1	33.20	6.90
13.40	37.6	32.71	4.89
13.45	39.4	33.20	6.20
13.50	39.9	33.69	6.21
13.55	38.0	32.71	5.29
14.00	36.8	31.74	5.06

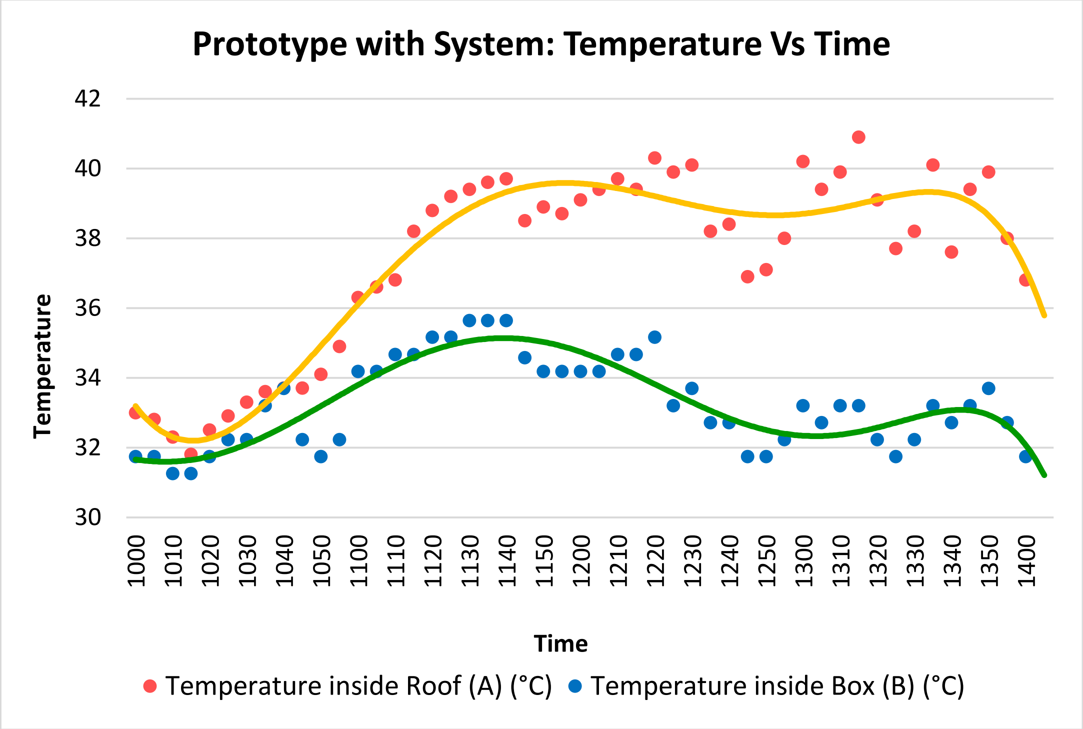

Figure 29: Prototype with System

Based on the results obtained in Table VIII, the highest recorded temperature inside the box without operating the heat extraction system was 50.78°C which occurred at 12.30 pm. At this point, the temperature inside the roof was 63.2°C.

In another test, the heat extraction system was operated to evaluate its performance in maintaining the temperature inside the box at a comfortable level. Upon operating the system, the highest recorded temperature inside the box was 35.64°C which occurred at 11.30 am. However, the maximum temperature recorded inside the roof which is 40.9°C occurred at a different time which was at 1.15 pm.

For the test without system, it was observed that as the temperature inside the roof increased, the temperature inside the box also increased. In contrast, for the test in which the system is operating, the temperature inside the box is maintained in the range of 31.74°C to 35.64°C despite the increase of temperature in the roof.

CHAPTER 5: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

With the present configuration of the system, test results from both laboratory and simulations had shown consistency with minor deviations. This proved that the expected results are achieved.

The system was installed to observe the temperature inside the prototype and to observe the performance of the system in extracting the trapped heat. It was observed that, the temperature inside the box has not exceeded more than 35.64°C despite rising temperature in the roof. This shows that the heat extraction system is reliable in preventing further temperature rises.

However, the heat extraction system cannot be implemented on the roof of existing cars because a revise in roof design is required. Therefore, this system is intended for cars in the future with revised roof designs that will enable it to be incorporated properly and safely.

5.2 Recommendation

It can be seen from the results in Table IX, the temperature inside the box did not go lower than 31.25°C. To strive for a better cooling performance, it is recommended as a future improvement to include a ventilation system to extract heat directly from inside the box as an addition to the current thermoelectric cooling system. So that the internal temperature can be as low as 27°C.

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