DESIGN, FABRICATION, AND EXPERIMENTAL STUDY OF THE PERFORMANCE OF THERMOELECTRIC MODULES FOR COOLING OF A SINGLE ROOM TEST HOUSE

By

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Universiti Teknologi PETRONAS

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CERTIFICATION OF APPROVAL

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A report submitted to the
Mechanical Engineering Department
Universiti Teknologi PETRONAS
In partial fulfillment of the requirement for the
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Approved by,

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JANUARY 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 specified sources or persons.

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ABSTRACT

This study highlights on the experimental study of the performance of the thermoelectric (TE) modules, which in this case will be used in a single room test house. With the rise of energy requirements today throughout the world, innovations that would reduce costs of energy and dependence on traditional fossil fuels and reduce environmental impacts are in high demand. Among the biggest consumption of energy in both industrial and residential areas is in space conditioning in the form of cooling and heating in order to meet the requirements of human thermal comfort. Among the latest potential technology being researched in fulfilling the requirements of space conditioning is thermoelectric (TE) devices [1]. As for the thermoelectric modules, recent reviews shows that there are significant advantages of using this TE cooling or heating systems. This includes, they are compact in size, significantly lighter, highly reliable, no-fluid involve in the process, no mechanical moving parts involved, and easy to configure between cooling and heating. It is expected that based on this experimental study, the performance of thermoelectric modules will be examined and to see the impact towards cooling for a single room.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

In this project, there two major aspects that needs to be highlighted. The first one is the performance thermoelectric modules in providing cooling power to lower down the room temperature when subjected to different current input, and the second one is the effect of air velocities on cooling performance for a single room test house. First and foremost, a thermoelectric (TE), commonly referred as thermoelectric module is a semiconductor-based electronic part that operates and works like a small heat pump. When the TE module is subjected to a low-voltage DC power input, heat will be transferred and travel through the module from one side to the next. One side of the module will be cooled resulting in decrease in temperature, while the other side will be heated resulting in increase in temperature. Both process cooling and heating are happen simultaneously. Thus, this is evident showing that a TE module is highly suitable for use for both heating and cooling, which in this case for precise temperature control applications inside an enclosed building.

TE materials are solid-state energy converters that can create a temperature difference when an electric potential is applied to the material (Peltier effect) or generate electric potential by introducing a temperature difference (Seebeck effect) [2]. TE materials arranged in a certain configuration are called thermoelectric modules (TEMs) and theses can be classified into either thermoelectric generators (TEGs), which directly convert heat to electricity, or thermoelectric coolers (TECs), which directly convert electricity into a temperature gradient [3]. Research has revealed that semiconductors exhibit excellent TE properties and commercial TEC modules composed of Bismuth Telluride semiconductor pellets are widely used in cooling computer Central Processing Units (CPUs) and dish warmers [4].

A standard TE module by and large comprises of two or more doped semiconductor materials of n-type and p-type, which are thermally connected in parallel and electrically connected in series. This TE elements are generally mounted between two ceramic substrates, which will support the entire structure together. There are wide range of shapes, mounting choices, substrate materials and metallization configurations available. Figure 1.1 [1] shows the schematic diagram for a commonly used TE module assembly.

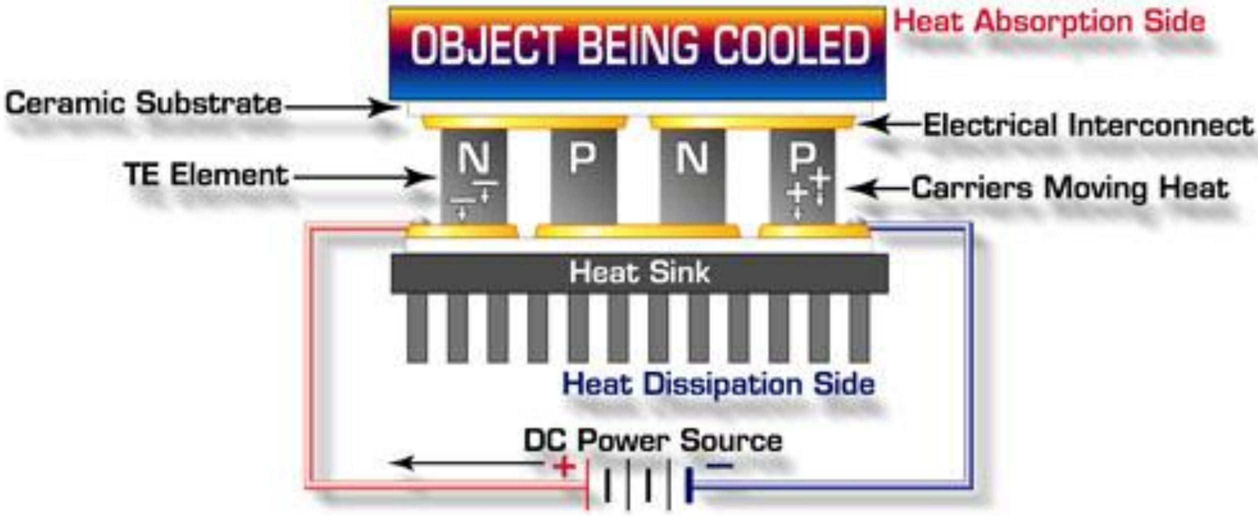


Figure 1.1: A schematic diagram for a typical TE module.
(https://www.ferrotec.com/technology/thermoelectric/)

Recent studies suggested that TE materials have the potential to replace the conventional air conditioning devices for both heating and cooling mode. This is due to the fact that TE modules do not have moving parts, light in weight, reliable and easy to configure. Furthermore, studies also suggested that TE modules ceramic surface can act as dehumidifier, which in this case means TE modules can control humidity of air inside

The primary disadvantage of TEMs is their low energy conversion efficiency which has led to them being limited to niche low powered applications such as CPU coolers as previously stated. This project thus aims to perform an experimental study to investigate the viability of using a novel system composed of TE devices to manage the indoor environment of a building to achieve thermal comfort in a tropical climate, such as in Malaysia, where cooling is a major concern due to the high ambient temperature as well as high humidity.

The proposed system consists of using commercially available thermoelectric (TE) modules attached in an air duct on the northern side of a building. When applied with electricity, the TE modules produce hot and cold surfaces upon which air flows through. The air flowing through the duct is then cooled in the duct's cool side and warmed in the hot side of the duct. The cooled air is used to decrease the indoor temperature of the building while the warmed air is directed toward the outdoor environment.

The project aims perform an experimental study to investigate the performance of TE modules for use in a single room test house. This experiment also aimed to determine the cooling performance when subjected to different current supplied, and different air velocities flow in the duct. The project will involve the design, fabrication and installation of the thermoelectric (TE) air-duct and measurement of data including temperature in Universiti Teknologi PETRONAS, Perak, Malaysia, before and after the TE air-duct is installed. The experiment will primarily be concerned with the effect the TE air-duct on the temperature of the single room test house. The analysis of the data will also include calculating the actual amount of cooling power provided by the TE air-duct when installed.

1.2 Problem Statement

Due to low COP, thermoelectric cooling has been restricted to small applications, such as scientific equipment cooling for laser diode or integrated circuit chip. There are limited information regarding the use of thermoelectric (TE) modules attached to the air duct, for use in cooling in a room. One of the major concern which regard to this topic is whether the proposed system can lower the room temperature up to 3°C or not. Due to the fact that Malaysia has high ambient temperature and high humidity, it is uncertain whether these TE modules can provide enough cooling power to cool down the room temperature. Although this TE air duct system have the advantage of having no moving parts and no refrigerant required to operate, it is known that the coefficient of performance is lower compared to conventional air-conditioning system.

In addition, another concern is regarding the effect of air velocity travels in the air-duct towards cooling performance. It is uncertain about the optimum air velocity that should be directed in the air-duct to provide the best cooling performance to lower down the room temperature. Thus, in this experimental study, it is expected to examine the performance of TE modules for cooling of single room test house.

1.3 Objective and Scope of Study

The objectives of this project are to:

a) Study the performance of thermoelectric (TE) modules for cooling of a single room test house, when subjected to different amount of current supplied to the system.

b) Determine the effect of air velocities inside the thermoelectric (TE) air-duct on cooling performance of a single room test house.

The scope of this project is clarified as follows:

a) This project focusses on the on the use of thermoelectric (TE) air duct, in which thermoelectric (TE) modules are attached on the inside of the air duct and is powered by power supply.

b) This project includes the design and fabrication of thermoelectric (TE) air-duct prototype, which going to be installed on wall of single room test house.

c) Parameters need to be consider in this experiment is the climate and intensity of solar radiation for tropical countries, which in this case the condition as in the campus Universiti Teknologi PETRONAS, Perak, Malaysia.

CHAPTER 2

THEORY AND LITERATURE REVIEW

2.1 Thermoelectric Coolers (TEC)

The conversion of electricity into thermal energy in the form of a temperature gradient in thermoelectric (TE) materials was first observed by Jean Peltier in 1834 [1]. Peltier observed that when an electric current is applied across a junction of conductive materials that are electrically dissimilar, heat is absorbed on one side of the material and dissipated on the other side. Khire et al models a thermoelectric cooler as shown in Figure 2.1 [11]. When a TEC is applied with a current, temperature at one junction decreases while temperature of the other junction increases causing heat to be absorbed at the cold junction and dissipated at the other. In this way, thermoelectric materials can act as heat pumps to cool a space by moving heat from a conditioned space to a heatsink.

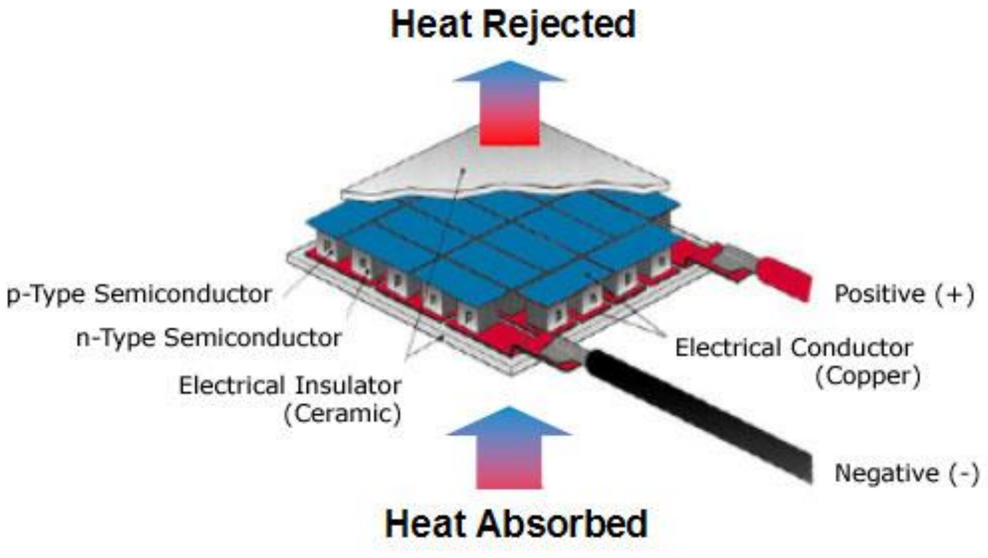


Figure 2.1: A cutaway of thermoelectric module. (*Khire, A. R., Messac, A., & Dessel, S. V. (2005). Design of thermoelectric heat pump unit for active building envelope systems. International Journal of Heat and Mass Transfer , 48, 4028–4040*)

The primary operating characteristics of a thermoelectric module (TEM) based on a 2012 study by Jradi et al include the temperatures of the hot (Th) and cold (Tc) sides of the module, the cooling capacity of heat pumping on the module's cold side (Qc), the amount of heat dissipated on the hot side of the module (Qh), the input of electrical current (I), and the voltage difference across the module (V) [7].

The performance of any TEM is determined by three energy processes: the Joule effect, the Peltier cooling effect, and the thermal conduction between the cold and hot sides of the module. The Joule effect is the amount of heat dissipated caused by a flow of electrical current on the resistive heating of the module. The Peltier effect governs the heat absorption on the cold side and heat dissipation on the hot side of a TEM when it is applied with an electrical current. The third energy process of a TEM is the thermal conduction between the hot and cold sides of the module.

Cosnier et al in their study notes that various sizes of thermoelectric modules are commercially available to suit different applications. The most powerful modules are capable of absorbing hundreds of watts on the cold side per module. Many commercially available TEMs today consist of arrays of thermoelectric materials arranged in series electrically and in parallel thermally [4].

2.2 Effect of using thermoelectric (TE) coolers on cooling power performance

In a hot country such as Malaysia, one of the primary objectives of any air conditioning unit is to decrease the indoor temperature of the conditioned space. Hence, the viability of a TE device in Malaysia depends largely on its potential to reduce indoor temperature

Various studies have been conducted on the effect that TEMs have on the temperature. Cosnier et al in their 2008 numerical study found that by keeping the temperature between the hot side and the cold side as low as possible, about 5-10°C, and applying an electrical intensity of 4 A, a cooling power of 50W per module can be obtained, with a coefficient of performance (COP) of 1.5 to 2 [4]. An increase in temperature difference between the hot side, Th, and the cold side, Tc, can reduce the cooling power provided by a TEM while an increase in input current can increase the cooling power provided, as show in Figure 2.2. Since at a constant voltage and current, thermoelectric modules exhibit a constant temperature difference between the hot and cold sides, it is thus necessary to maintain the hot side temperature to ensure that cold side temperature remains below the cooled object. If hot side temperature is too high, the cold side temperature will also rise and if it is more than the temperature of the cooled object may instead heat it rather than cool it. For this reason thermoelectric modules are commonly installed with heat sinks and cooled by forced convection using fans. They also concluded that TE device have great potential as air-cooling devices especially when coupled with a photovoltaic source to provide power to it.

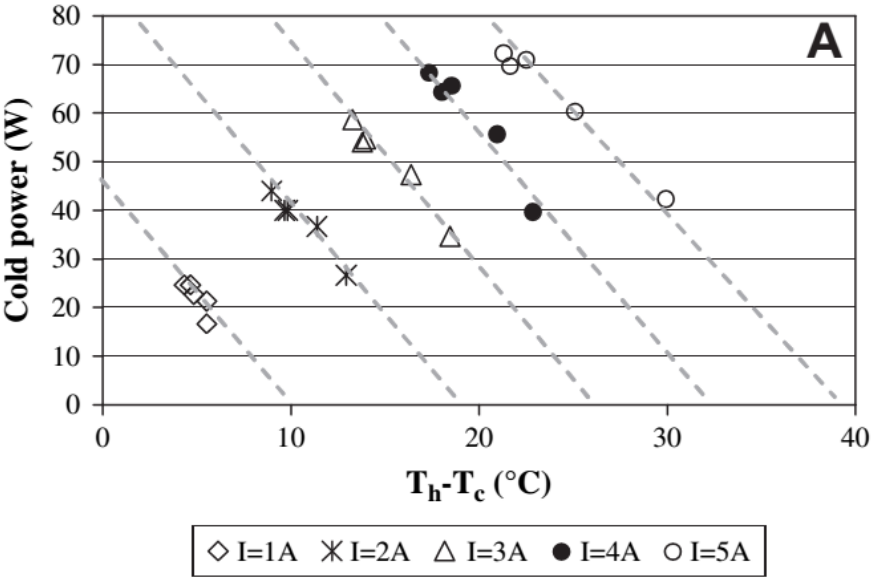


Figure 2.2: Effect of temperature difference between cold and hot sides in a TEM and current input on the cooling power in cooling mode (*Cosnier, M., Fraisse, G., & Luo, L. (2008). An experimental and numerical study of a thermoelectric air-cooling and air-heating system. International Journal of Refrigeration , 31, 1051-1062.*)

Totala et al in their 2014 study has also attempted to study the effect of thermoelectric cooling in a 1 m3 box using a single TEM [9]. Their design was able to cool the ambient air temperature from 32.5°C to 22.1°C using 4 TEMs, each providing 37.7W of cooling power. They note that such a system could be made more compact by using a single high powered (>200W) TEM and that providing a better air flow using a blower fan can improve the rate of heat transfer of the system.

Previous study by Raut and Walke has investigated the viability of thermoelectric air conditioning by designing and testing a prototype for a car [10]. They found that by using six TEC1-12704 modules at 12V and 4A, they were able to reduce car temperatures from 32 to 27.5°C. They note that at higher operating temperatures the system performance decreases and at ambient temperature of 43°C the system was only able to cool the car by 1°C. This indicates that thermoelectric air conditioning has potential, but may not be suitable at high operating temperatures.

Since the heat dissipated in a TEC is typically the summation of the cooling power and power input, it is thus necessary to ensure that TECs maintain their performance, the hot side of the module must be installed with a heat sink to improve heat dissipation in order to maintain the hot side temperature. If the dissipation rate is inadequate and the temperature of the hot side increases, the temperature of the cold side will also be affected as at a constant current the temperature difference is maintained [10].

CHAPTER 3

METHODOLOGY

3.1 Final Year Project (FYP) flow of work.

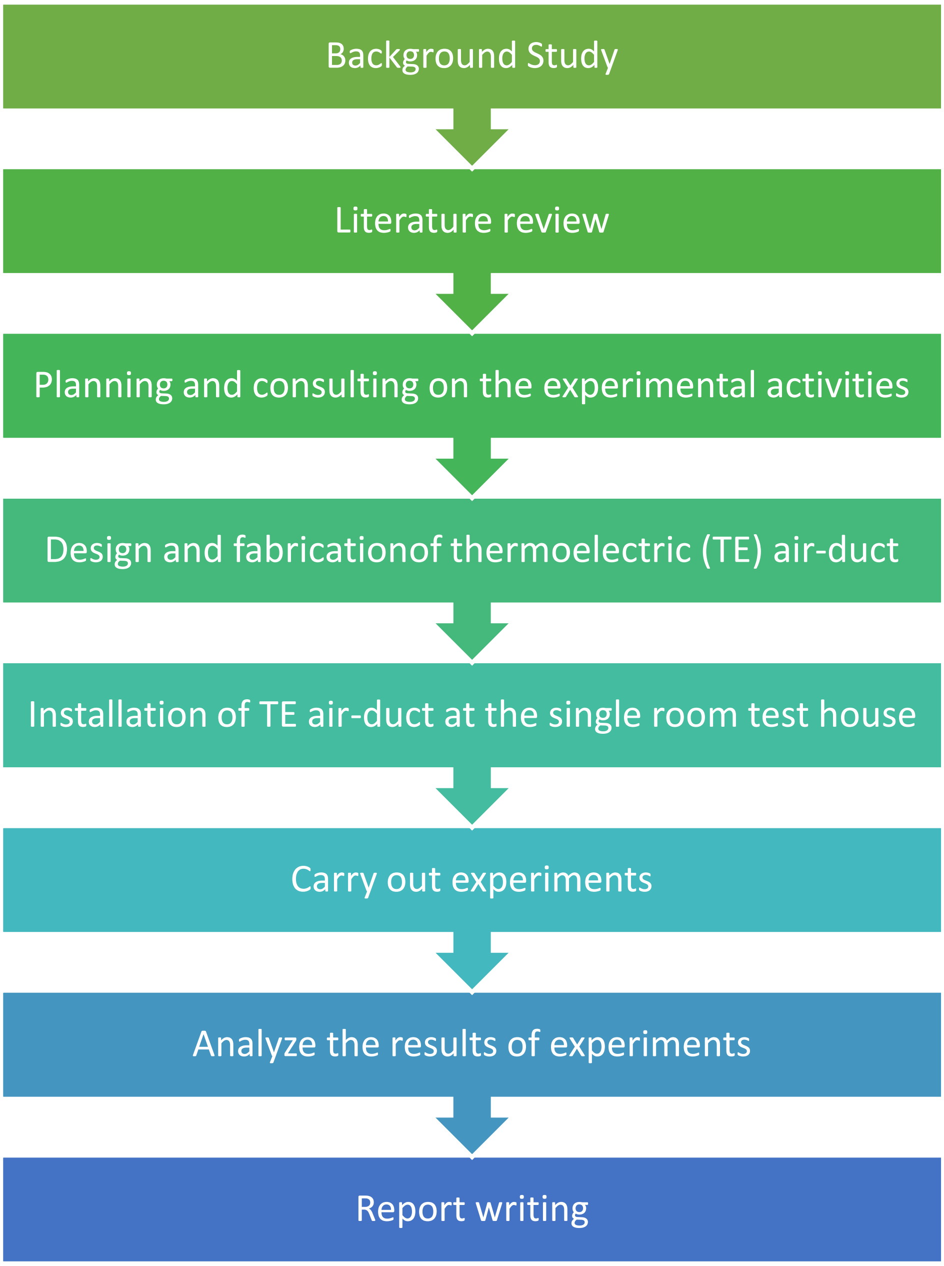


Figure 3.1: Flow chart for the entire project.

3.2 Description of Experimental Work

This experiment study will be conducted inside the campus of Universiti Teknologi PETRONAS (4°23'11"N and 100°58'47"E, Perak, Malaysia). A single room test house, as shown in Figure 3.2 with 3.0m X 3.0m X 2.6m in dimension is chosen. In addition, while the air duct that is attached with 30 thermoelectric (TE) modules on the inside, will be installed at the north side of the house. Information and summary about the test house's materials and thickness, as well as thermo physical properties are provided in Table 3.1 and Table 3.2.

Figure 3.2 – Single room test house inside UTP Campus, before the installation of thermoelectric (TE) air-duct.

Table 3.1 – Information on the material and thicknesses of test house's building layers

Building section	Layer	Material	Thickness (cm)
External walls	Inside	Cement Plaster	1.3
	Middle	Brick Wall	20
	Outer	Cement Plaster	1.8
Roof	Inside	Limestone Tile	16.0
	Middle	Cement Mortar	2.2
	Outer	Cement Plaster	2.3
Floor	First	Cement Mortar	12.0
	Second	Sand Gravel	22.0
	Third	Mud Phuska	35.0

Table 3.2 – Thermo physical properties of test house building materials

Material	**Density (kg/m^3)**	**Specific heat ($kJ\ kg^{-1}\ K^{-1}$)**	**Thermal conductivity ($W\ m^{-1}\ K^{-1}$)**
Brick tile	1892	0.88	0.798
Mud brick	1731	0.88	0.750
Mud phuska	1622	0.88	0.519
Cement plaster	1762	0.84	0.721
Cement mortar	1648	0.92	0.719
Limestone tile	2420	0.84	1.800
Sand grave	2240	0.84	1.740

To explain the flow of this experiment, when air from the environment is directed towards inside of the duct, air that passes through a chamber with cooled TE modules' surface will be cooled. To add on that, the ceramic surface of the TE modules also will dehumidify the air inside the chamber. Then, this cooled and dehumidified air will be directed to the inside of the house to reduce the indoor temperature. The illustration on how the thermoelectric (TE) air duct works is shown in Figure 3.3.

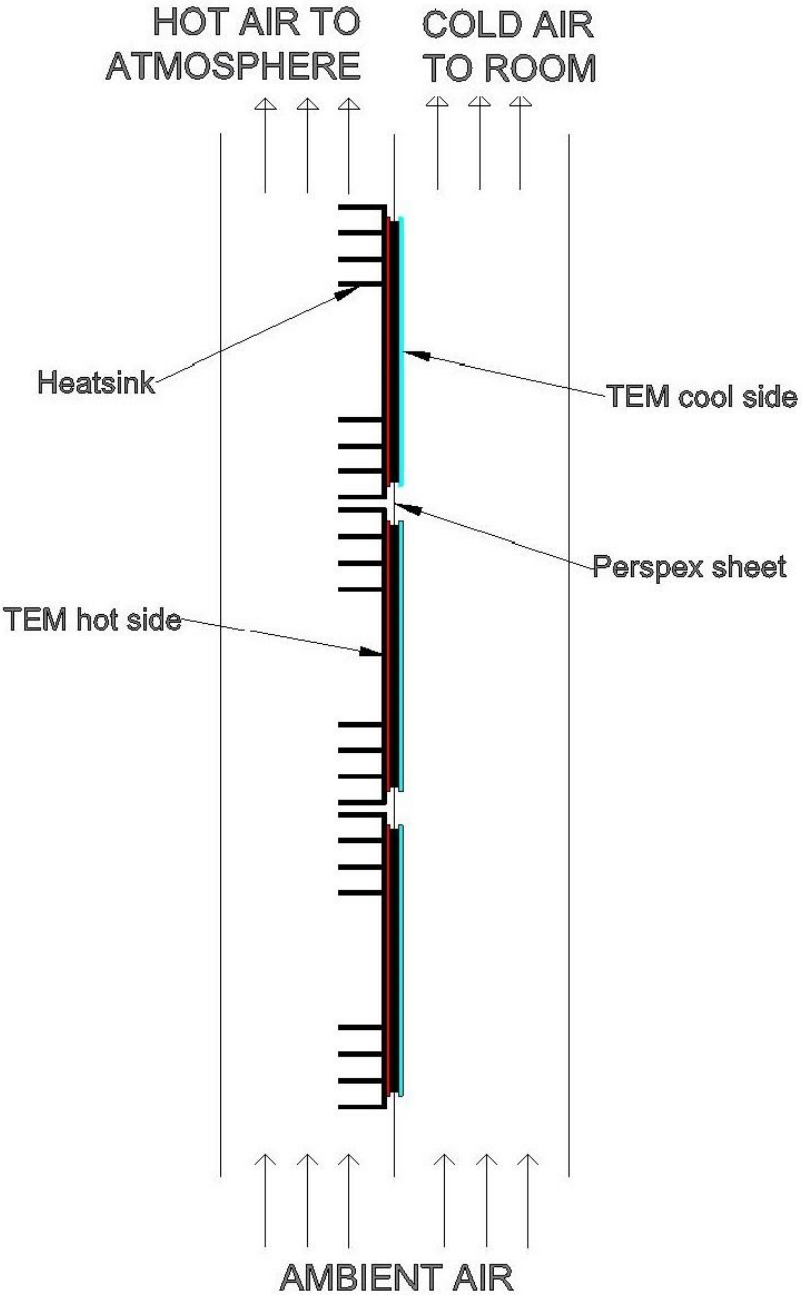


Figure 3.3: Illustration on how the thermoelectric air-duct works

3.3 Cooling load calculation

In order to select a suitable TE module as well as the quantity required, the cooling load required to cool the house to the desired temperature has to be calculated and compared with the cooling power that the TE module can provide. For the project a desired room temperature, Troom, reduction of 3°C - 4°C is initially aimed to be maintained throughout the day.

The cooling load by conduction through the external walls and the roof are given by:

$$Q_{conduction} = \frac{A_s(T_s - T_{room})}{R} \qquad (1)$$

Where As is the surface area of the wall or roof, Ts is the temperature of the external walls or roof, Troom is the desired room temperature, and R is the thermal resistance of the wall or roof, given by:

$$R = \frac{L}{k} \qquad (2)$$

Where L is the thickness of the wall or roof in m, and k is the thermal conductivity of the wall or roof in Wm-1K-1, as listed in Table 3.2 previously.

To calculate the cooling load contributed by conduction, the temperatures of the external wall was recorded on a sunny day from 8.00a.m. to 6.00p.m. and the results are as in Appendix A - ii.

From the dimensions of the test house given previously, the area for each external wall is 7.8m2 while the roof area is 9m2. Using the wall temperatures and taking the average of the wall temperatures as the roof temperature, the peak cooling load was found to occur at 12:40p.m. where Qconduction,total was calculated to be 589W.

Assuming that there are no losses in the TE air-duct, the total cooling power to be provided by the TE modules was assumed to be equal to the cooling load of the test house, provided there is no heat loss along the TE-AD. Thus the cooling power needed to cool the ambient air entering the TE-AD to a desired exhaust temperature is given by:

$$Q_C=\dot{m}c_p\,(T_a-T_{out}) \qquad (3)$$

Where $\dot{m}$ is the mass flow rate of air flowing through the cold side of the TE-AD, Tout is the temperature of the air at the exhaust (outlet) of the cold side of the TE-AD, and cp is the specific heat of air, taken to be 1007 J kg-1 K-1 at 32°C [11].

Assuming that the desired cold side exhaust temperature Tout is 15°C below the desired room temperature and that the average ambient air temperature at the inlet of the TE air-duct is 32.5°C, the required mass flow rate of air entering the cold side-exhaust was found to be 0.04 kg/s. The velocity of the airflow, v, required meanwhile is:

$$v=\dot{m}/\rho A \qquad (4)$$

where ρ is the density of air, taken to be 1.15 kg/m3, while A is the area of the inlet of the cold side of the TE-AD. For a duct of length and width of 12” (0.3048m), the area of the inlet is 0.093m2 and the velocity required is found to be 0.4m/s.

3.4 Thermoelectric Coolers Selection

In this experiment, based on earlier cooling load calculations, suggested of 24 thermoelectric (TE) modules will be used, which to be attached on the inside of the air duct. The thermoelectric (TE) module that will be used is 62mm X 62mm X 62mm in dimension, with model number TEC1-12730 by Hebei I.T (Shanghai) Co. Ltd. [10].When all equipment is installed and tested, experiments will be carried out. Indoor temperature and indoor relative humidity of the test house will be recorded before and after using the thermoelectric (TE) air duct.

From the performance chart in the manufacturer specifications, when the hot side temperature is 50°C and at an applied voltage, V, of 5V, the current draw, I, is 6A while the cooling power per module is 26W. Thus for a cooling load of 589W, the number of units required was 24 units which can provide up to 624W of cooling power at the given configuration, which is greater than the cooling load.

The total power input requirement, P, of the TE air-duct is:

$$P=IV \qquad (5)$$

Where I is the current draw of the TE air-duct and V is the voltage applied. For 24 units of Heibei TEC1-12730 TECs at 5V and 6A, the power input needed is 720W.

The TEMs will be powered by a CPX400DP Dual 420 Watt DC Power Supply obtained from the campus laboratory. It has a maximum voltage of 60V and maximum current of 20A. The power supply has two outputs with each capable of supplying 420W for a total of 840W which is greater than the required and the voltage and current draw can be adjusted.

3.5 Heat sinks to dissipate heat at the hot side of TE modules

To maintain the temperature of the hot side of the TEM, a heat sink is necessary to be installed on the hot side of the TEMs. An ideal heat sink would be one that could absorb unlimited amounts of heat without its temperature rising [7]. In practice however this is not possible and a heat sink temperature rise of 5°C to 15°C above the ambient air is applicable in most situations.

The rate of heat that is required to be dissipated, Qh, is given by:

$$Q\_h = Q\_c + P \qquad (7)$$

Where Qc is the heat to be absorbed on the cold side while P is the power input of the TE modules. The heat sinks attached to the hot side of the TE modules are aluminium sinks with fins that are bought from a local shop. Each heat sink has eight fins, each 1mm thick, 75mm in length and 15mm in height. The heat sinks bought were the cheapest available that could cover all 24 TE modules. In order to improve heat transfer between the TE module and the heat sink thermal paste is applied between the heat sinks and the hot side of the TE modules. The author notes that more efficient heat sinks with more fins and thus greater surface area are available but could not be purchased due to a limited budget and thus it is possible for the system to overheat if the operating ambient temperatures are too high but this can be overcome if the speed of air at the hot side is increased by increasing the fan speed.

3.6 Data collection and Analysis of Data

For collection of data, data will be measured on two separate days. Initial data is taken before the thermoelectric (TE) air-duct is installed and the second measurement of data is taken once the Thermoelectric (TE) air-duct is installed. The data will be recorded for several intervals per day, which are, from 8 a.m. to 12 p.m, 12 p.m to 4 p.m, and from 4 p.m to 6 p.m. Both sets of data will be compared to determine the effect as well as the performance of thermoelectric (TE) air-duct for cooling of a single room test house.

A hygrometer will be used to record the indoor relative humidity, in %, of the single room test house. Meanwhile, the solar radiation value in W/m2 will also be taken using a TES1333r Datalogging Solar Power Meter. The measurement is taken during a sunny day, in a condition where no shading is present to ensure a good and reliable solar intensity reading is recorded.

Figure 3.4 – Thermocouple is connected to midi Logger GL220 data logger in order to take temperature reading

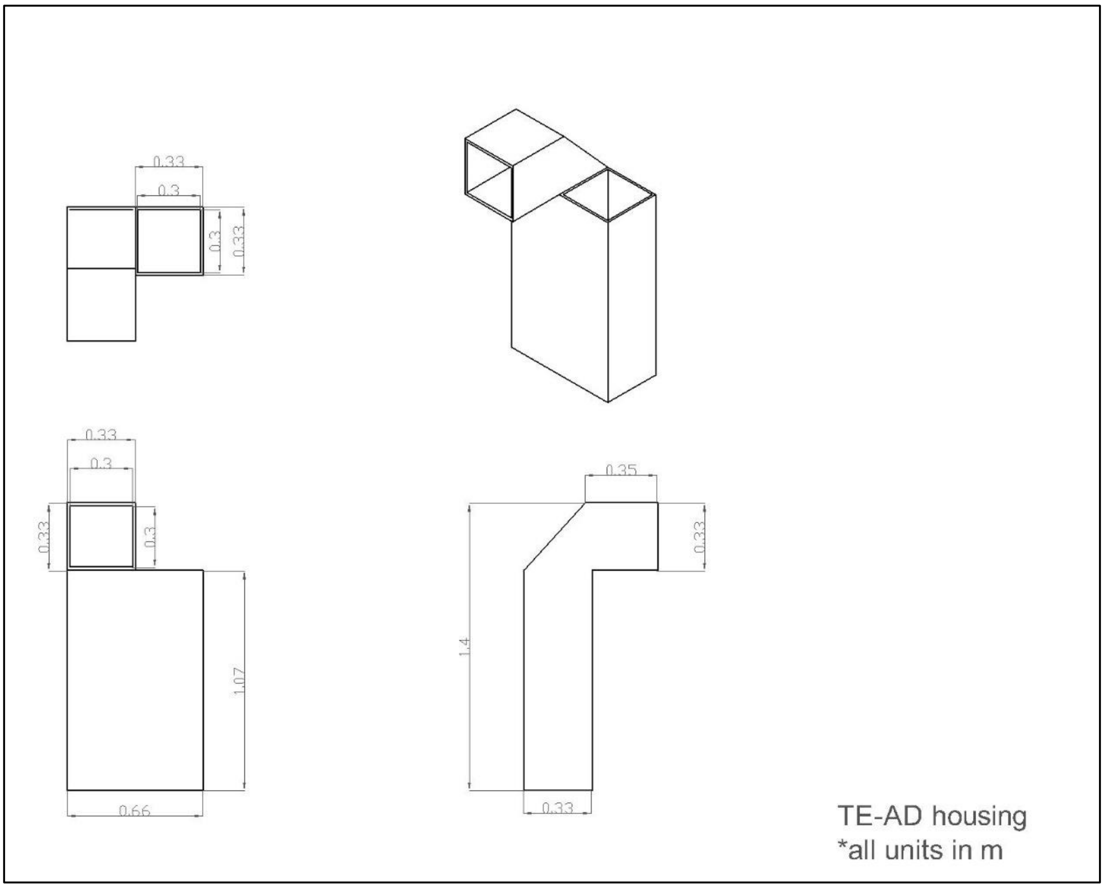
The experiment is then continued with collecting data when the TE modules are subjected to different current supplied, ranging from 2A to 6A. The cooling power is calculated based on the current supplied and the temperature difference between the room temperature and the temperature at the cold chamber of TE air-duct. The Coefficient of Performance is also calculated by using the formula shown in Equation 6 below.

$$\text{COP} = (\text{Cooling power}) / (\text{Power input}) \qquad (6)$$

Another parameter that is considered in this experiment is the air velocity required at the cold chamber of the thermoelectric (TE) air duct. The air velocities tested are 0.5 m/s, 1.0 m/s and 1.5 m/s respectively. Based on the controlled air velocities, temperature drop of the room is recorded and analyzed accordingly.

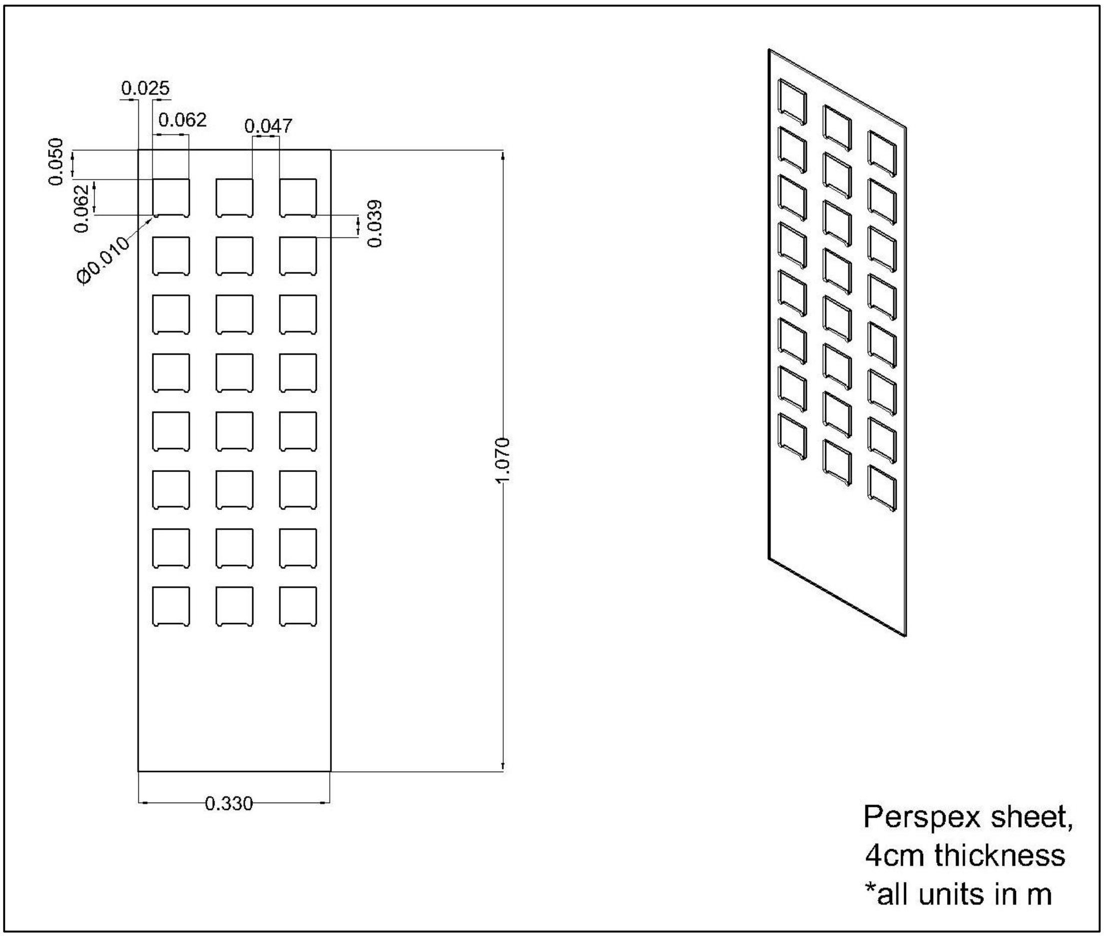
3.7 Design and Fabrication Work of Thermoelectric (TE) Air Duct

Based on the specifications of the test house and early calculations of cooling load, TE air duct is designed accordingly. Based on the approved design, the thermoelectric (TE) air-duct consists of 2 separate chambers supported by a frame, and enclosed with thin aluminum sheet. The aluminium sheet is then covered with an insulation. A Perspex sheet with 30 thermoelectric (TE) modules is installed at the center of the air-duct, in which the hot side of the thermoelectric (TE) modules facing the hot chamber, and cold side of TE facing the cold chamber. One HDEF-12 industrial suction fan is installed at the cold chamber, to suck air from surrounding and cool the air to the room. On the other hand, one HDEF-12 industrial fan is installed at the hot chamber to regulate and dissipate heat at the hot side of the TE. Refer Figure 3.5 and Figure 3.6 for complete and detailed illustration of thermoelectric air-duct.



TE-AD housing
*all units in m

Figure 3.5: Drawings of the air-duct frame and enclosure



Perspex sheet,
4cm thickness
*all units in m

Figure 3.6: Drawings of the thermoelectric (TE) modules arrangement on a Perspex sheet.

The thermoelectric (TE) air duct aluminum housing and frame has been successfully fabricated according to the specifications desired and provided before. After that, two industrial fans, model HDEF-12 Heavy Duty Exhaust Fan were installed at the two chamber of the air duct. At the cold side chamber, the fan will act as a suction fan to suck air from the surroundings. On the other hand, another fan at the hot side chamber will act as an exhaust fan to direct the air to the outside, as well as regulate the temperature, so that heat is effectively dissipated. Figure 3.7 shows the fabricated air duct aluminium housing with fans installed.

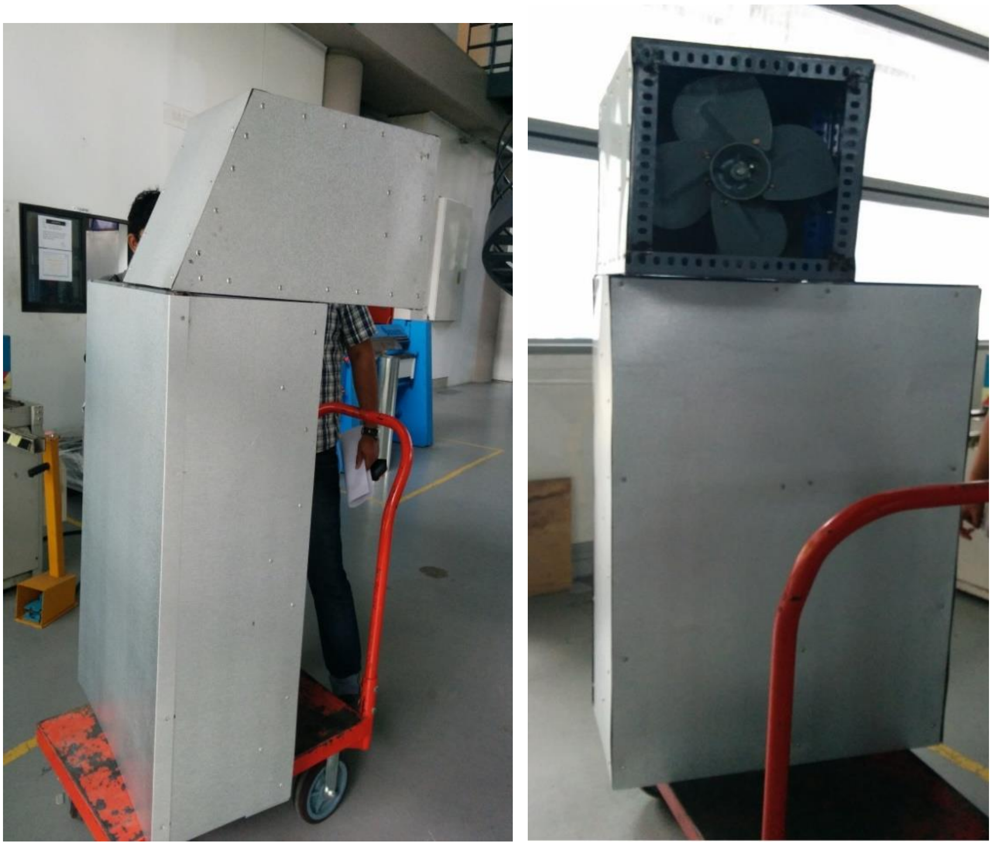


Figure 3.7: Completed fabrication of aluminium air-duct housing

After that, 30 aluminium plates were cut using shear cutting machine as shown in Figure 3.8, at which these aluminium plates will be used for proper mounting of heatsinks and thermoelectric (TE) modules. Then, holes of 4.5mm in diameter are drilled as shown in Figure 3.9, for all 30 heatsinks and 30 aluminium plates to fit in bolt and nuts.

Figure 3.8: Cutting of 30 aluminium plates for thermoelectric mounting with heatsinks.

Figure 3.9: Drilling holes for heatsinks, aluminium and Perspex sheet.

After that, the thermoelectric (TE) modules are arranged in three different series that are in parallel and connected to the DC power source. A layout of the circuit of TE housed on the Perspex sheet is shown in Figure 3.6 in previous chapter. For each series, the positive wires of the TE were connected to the negative wires of the subsequent TE while the positive wires at the end of each series are connected to a busbar (positive bar) while the negative wires at the end were connected to another busbar (negative bar). The positive bar is then connected to the positive terminal of the power supply while the negative but is connected to the negative terminal.

After all thermoelectric modules have been arranged and tested, the Perspex is then placed at the center of the air-duct and tightened with bolts and nuts. Figure 3.10, and Figure 3.11 shows the process of installing the TE in air-duct. After that, the air-duct is then wrapped with insulation and ready to install at the single room test house. For the installation at the test house, the wall is drilled to create a column so that the air-duct can be attached at the wall. Figure 3.12 shows the installation of the air-duct at the test house in Universiti Teknologi PETRONAS.

Figure 3.10: Thermoelectric (TE) modules and heat sinks arranged and placed on a Perspex sheet

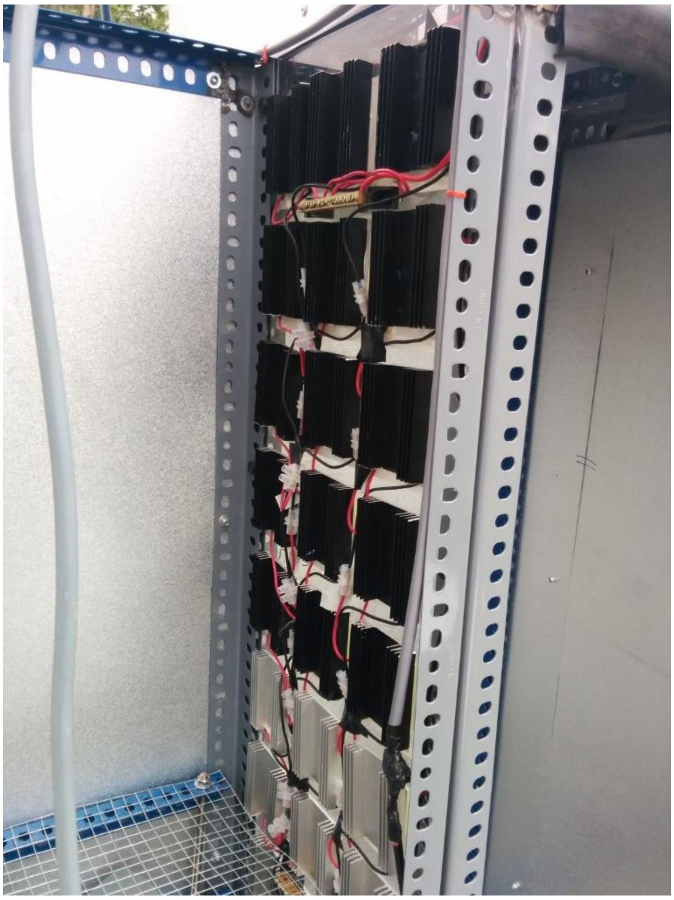
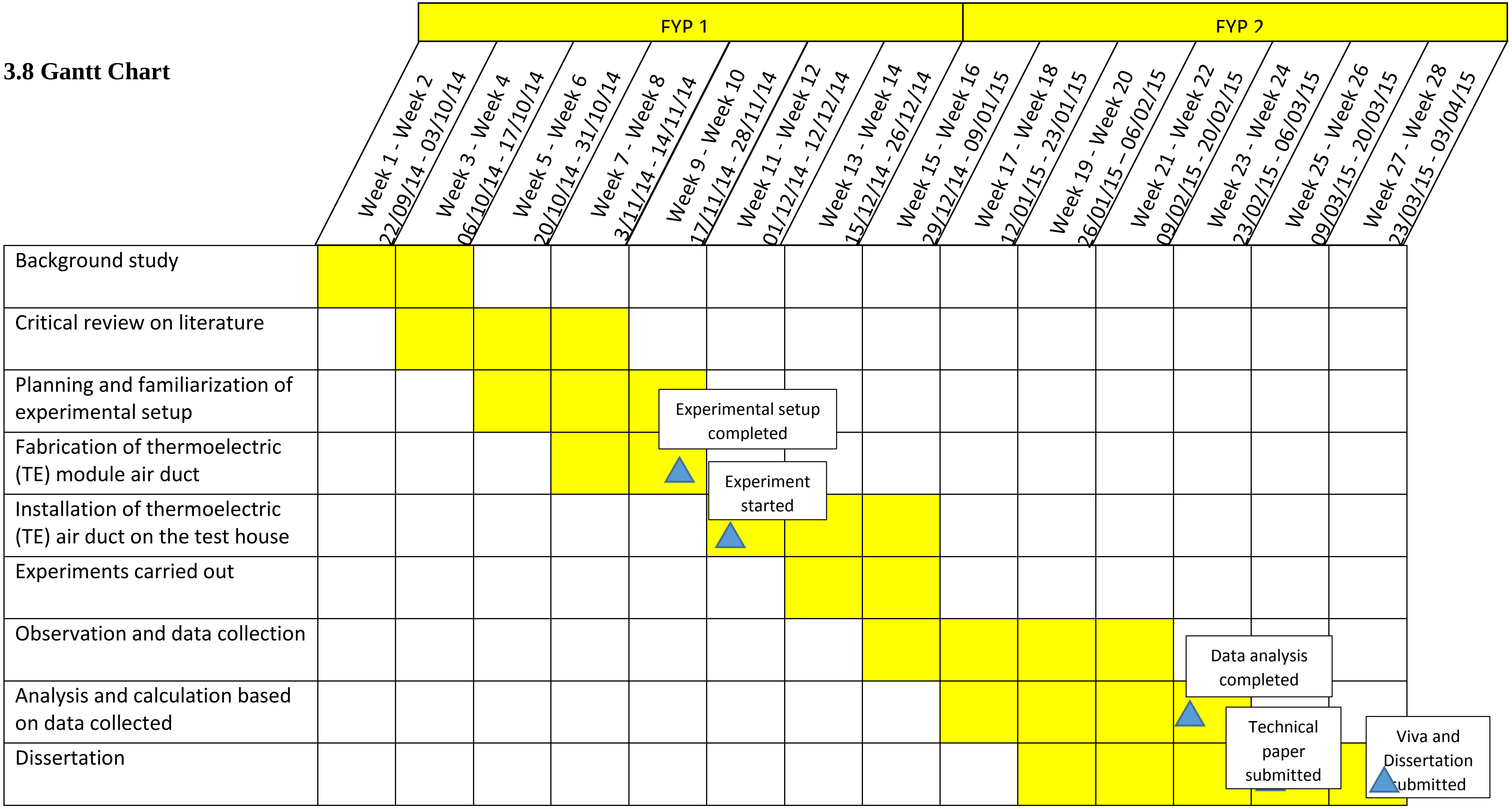


Figure 3.11: Perspex sheet tightened at the centre of TE air-duct

Figure 3.12: Installation of TE air-duct at single test room house

3.8 Gantt Chart



	FYP 1							FYP 2						
	Week 1 - Week 2 22/09/14 - 03/10/14	Week 3 - Week 4 06/10/14 - 17/10/14	Week 5 - Week 6 20/10/14 - 31/10/14	Week 7 - Week 8 3/11/14 - 14/11/14	Week 9 - Week 10 17/11/14 - 28/11/14	Week 11 - Week 12 01/12/14 - 12/12/14	Week 13 - Week 14 15/12/14 - 26/12/14	Week 15 - Week 16 29/12/14 - 09/01/15	Week 17 - Week 18 12/01/15 - 23/01/15	Week 19 - Week 20 26/01/15 – 06/02/15	Week 21 - Week 22 09/02/15 - 20/02/15	Week 23 - Week 24 23/02/15 - 06/03/15	Week 25 - Week 26 09/03/15 - 20/03/15	Week 27 - Week 28 23/03/15 - 03/04/15
Background study	🟨	🟨												
Critical review on literature		🟨	🟨	🟨										
Planning and familiarization of experimental setup			🟨	🟨	🟨									
Fabrication of thermoelectric (TE) module air duct				🟨	🟨									
Installation of thermoelectric (TE) air duct on the test house						🟨	🟨	🟨						
Experiments carried out							🟨	🟨						
Observation and data collection								🟨	🟨	🟨	🟨			
Analysis and calculation based on data collected									🟨	🟨	🟨	🟨		
Dissertation										🟨	🟨	🟨	🟨	🟨

Figure 3.13: Gantt chart

CHAPTER 4

RESULTS & DISCUSSION

4.1 Thermoelectric (TE) Air-Duct Fabrication and Installation

The air-duct has been fully fabricated and assembled according to specifications stated previously. The frame of the duct is shown Appendix D i, with the fans installed in both sides of the duct. The casing of the duct, consisting of aluminium sheet, is also shown. The TEM circuit was assembled on the Perspex sheet in Appendix B ii based on the layout in Figure 5 and is shown in Appendix D ii, before and after the heat sinks were attached.

The 24 TEMs used were tested individually as well as in a circuit divided into three electrically parallel series as previously described. Individual testing showed that there were minute differences in the performance of the TEMs between units with some TEMs requiring slightly higher voltages to achieve the specified temperature gradient.

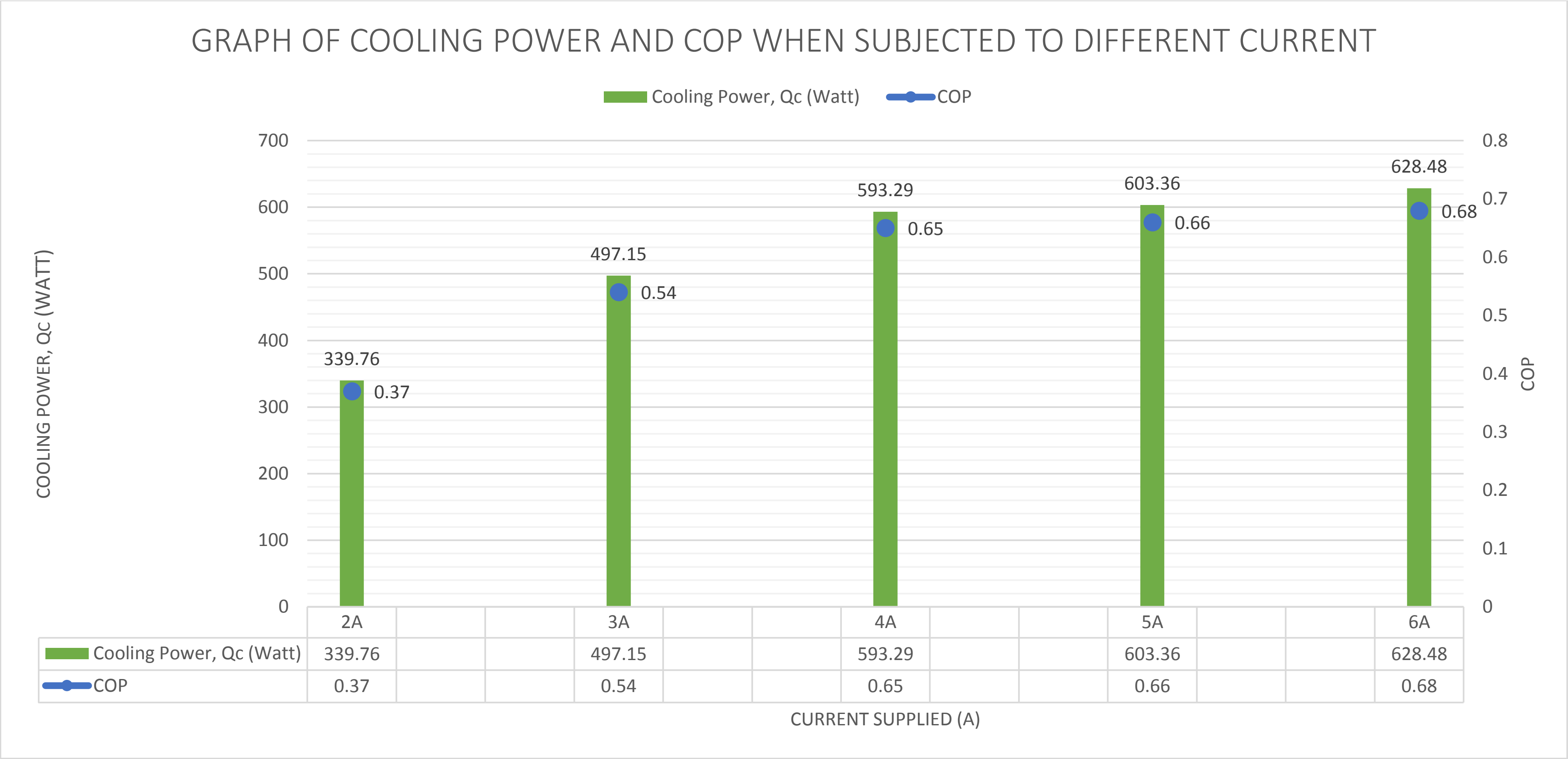
The housing has also been insulated with aluminium sheet for reducing air leakage and installed in the test house as shown in Appendix D iii.

4.2 Air Temperature and Cooling Power Performance

Experiments has been conducted at 5PM, and the values of cooling power, Q_c and air temperature inside the room, T_{in} is obtained, when subjected to different amount of current. Currents supplied are varies starting from 2A until 6A. Based on the cooling power obtained, the Coefficient of Performance is calculated. All results are tabulated in the Table 4.1 and graph of Cooling Power and COP when subjected to different current is shown in Figure 4.1 as follows.

Current Supplied (A)	Air Temperature, T_{in} (°C)	Relative Humidity (%)	Cooling Power, Qc (Watt)	COP
2A	29.6	61	339.76	0.37
	29.1	60		
	29.8	60		
3A	28.9	60	497.15	0.54
	28.7	60		
	29.1	59		
4A	28.7	59	593.29	0.65
	28.2	59		
	28.9	60		
5A	28.2	59	603.36	0.66
	27.6	60		
	28.4	60		
6A	26.9	58	628.48	0.68
	26.5	58		
	27.2	59		

Table 4.1: Tabulated results when currents varies from 2A to 6A



	2A	3A	4A	5A	6A
🟩 Cooling Power, Qc (Watt)	339.76	497.15	593.29	603.36	628.48
● COP	0.37	0.54	0.65	0.66	0.68

Figure 4.1: Plotted graph of Cooling Power and COP when subjected to different current

From the results obtained, it can be observed that when the amount of current supplied to the thermoelectric (TE) modules is increased, the amount of cooling power also increase. The minimum current supplied which is 2A will provide the cooling power of 339.76W, while at 6A of current the amount of cooling power produced is 628.48W, which is more than the cooling load of the single room test house. Basically, with this amount of cooling power, indoor temperature is expected to be drop, below the ambient temperature. On the other hand, from the results obtained also shows that the higher the current supplied, the higher the Coefficient of Performance (COP). At 2A of current, the COP value is 0.37 while at 6A of current the COP is 0.68, which is the highest within the range of current tested. This shows that, when amount of current supplied is increased, the cooling power, Q_c and COP value are increased. To explain the phenomena, this is due to the fact that when higher current is supplied, the greater the temperature difference between the hot-side plate, $T_{Hotside}$ and the cold-side plate, $T_{Coldside}$ of the thermoelectric (TE) modules. The greater the temperature difference between plates, the greater the cooling power at the cold-side of TE modules. In addition, to ensure cooling power generated at the cold-side plate is maintain over time, the amount of heat dissipated and the hot-side of the plate must be maintain as well. Thus, proper heat sinks and large surface areas of heat sinks must be installed.

4.3 Effect of Air Velocity on Cooling Performance and Room Temperature

Experiment is then continued to observe the effect of air velocity on the cooling performance and room temperature. The manipulated variable is the air velocity at the cold chamber of the thermoelectric (TE) air-duct, where it is controlled by using fan controller. The amount of current supplied is maintained at 2A until 6A. The air velocities tested are 0.5m/s, 1.0m/s and 1.5m/s respectively. Results is shown in the Table 4.2 as follows.

Current Supplied (A)	Air Velocity (m/s)	Room Temperature, T_{in} (°C)	Relative Humidity (%)
2A	0.5	29.6	61
	1.0	29.1	60
	1.5	29.8	60
3A	0.5	28.9	60
	1.0	28.7	60
	1.5	29.1	59
4A	0.5	28.7	59
	1.0	28.2	59
	1.5	28.9	60
5A	0.5	28.2	59
	1.0	27.6	60
	1.5	28.4	60
6A	0.5	26.9	58
	1.0	26.5	58
	1.5	27.2	59

Table 4.2: Tabulated results of Room Temperature, T_{in} when subjected to different air velocities.

From the results shown in Table 4.2, at 6A of current supplied, when the air velocity at the cold chamber of the thermoelectric (TE) air-duct is 0.5m/s, the room temperature is 26.9 °C. Meanwhile at 1.0 m/s, the room temperature is dropped to 26.5°C. At 1.5 m/s, the room temperature rise back to 27.2°C. The results of room temperature for other current supplied, i.e 2A, 3A, 4A and 5A show consistency as 6A of current, where the room temperature is at its lowest when air velocity at the cold chamber of thermoelectric (TE) air-duct is at 0.5 m/s respectively.

To explain the situation, the optimum air velocity required at the cold chamber of the thermoelectric (TE) air-duct is 1.0 m/s. The room temperature is not further dropping even though the air velocity is increased to 1.5 m/s. This is because the surrounding air sucked to the cold chamber of the air-duct is not allowed to be cooled further as the air velocity is consider high. Thus, at 1.5 m/s, the room temperature is partially possessed the ambient temperature from outside, resulting in low temperature drop compared to 1.0 m/s of air velocity.

4.4 Temperature Reading in a Day at 6A

The experiment is then continued to observe the temperature drop in the room when using the thermoelectric air-duct in a day. Since the cooling load of the single room test house is 589W, with 6A of current, 24 units of thermoelectric modules can generate approximately 624W of cooling power. Results for temperature reading from 8AM to 6PM is tabulated in Table 4.3 and the graph for temperature reading in a day at 6A is shown in Figure 4.2 as follows.

Time of Day (Hours)	T_ambient (°C)	T_Hotside (°C)	T_Coldside (°C)	T_Indoor (°C)
08:00	27.3	29.6	16.8	25.5
08:20	27.4	29.4	16.5	25.6
08:40	27.6	29.5	17.1	25.7
09:00	27.9	29.6	17.2	26.0
09:20	28.3	29.9	17.2	26.1
09:40	28.6	30.0	17.7	26.2
10:00	29.9	31.2	17.9	26.5
10:20	30.2	31.1	18.1	27.2
10:40	30.5	31.2	18.1	27.7
11:00	30.5	31.1	18.2	27.9
11:20	30.6	31.4	18.4	28.1
11:40	31.0	31.8	18.5	28.4
12:00	31.2	32.1	18.8	29.5
12:20	31.6	32.2	19.1	29.8
12:40	31.7	32.6	19.3	30.0
13:00	32.1	33.0	19.4	30.8
13:20	32.2	33.1	19.7	30.9
13:40	32.2	33.3	20.0	30.8
14:00	32.0	33.2	20.1	30.4
14:20	31.7	33.0	19.8	30.1
14:40	31.4	32.6	19.7	29.8
15:00	31.3	32.5	19.6	29.5
15:20	30.7	32.0	19.3	28.7
15:40	30.3	31.9	18.6	28.2
16:00	29.9	31.7	18.2	27.6
16:20	29.8	31.6	17.7	27.4
16:40	29.3	31.4	17.5	26.7
17:00	28.9	31.1	17.2	26.2
17:20	28.8	31.0	17.1	26.0
17:40	29.2	30.8	16.9	25.8
18:00	28.7	30.6	16.9	26.1

Table 4.3: Temperature reading in a day when current supplied is 6A.

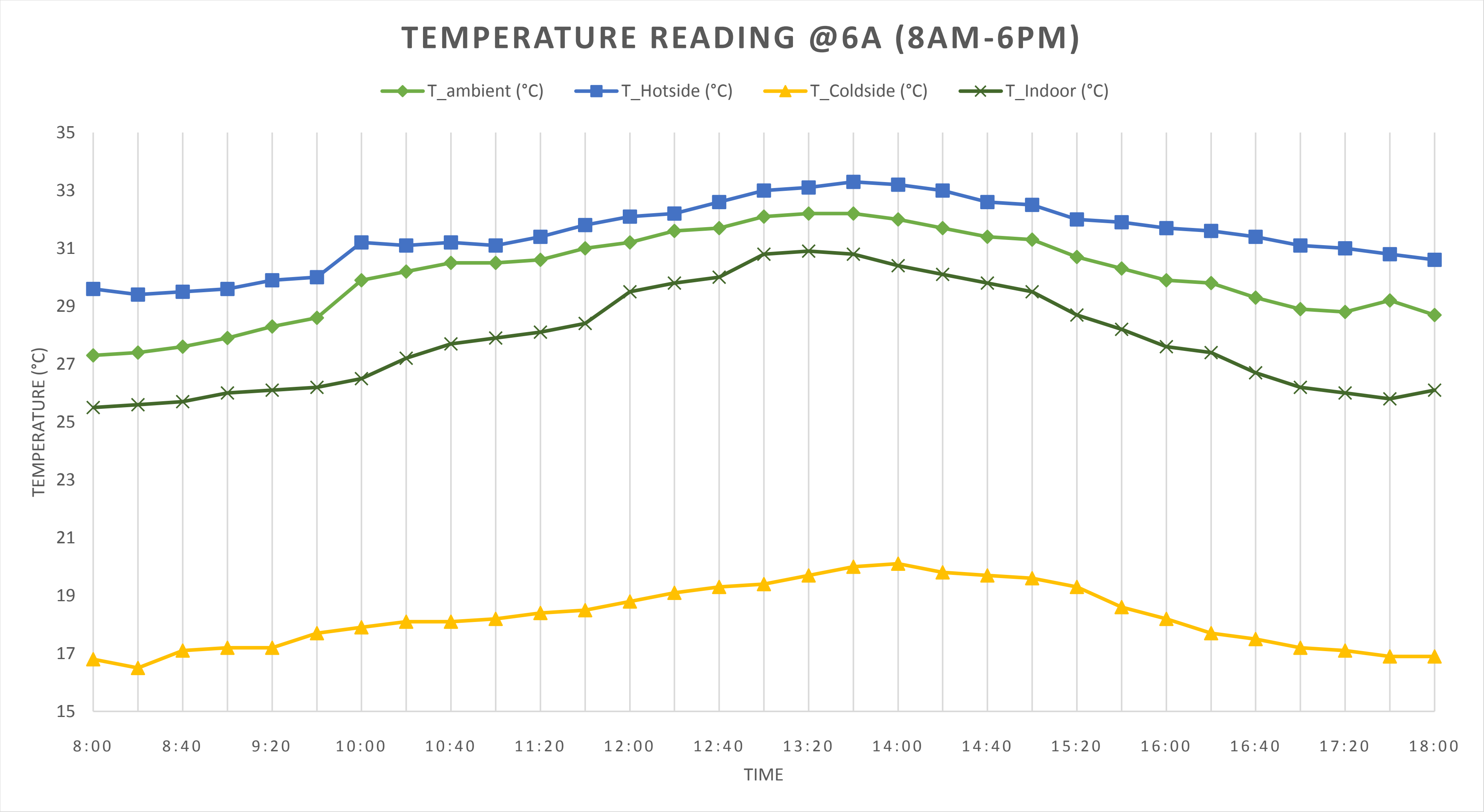


Figure 4.2: Plotted graph of temperature readings in a day at current of 6A.

The graphs of the temperature measurements taken in 4 hour intervals at 8a.m., 12p.m., and 4p.m. in are shown in Figure 4.3, Figure 4.4, and Figure 4.5. T_in is the indoor air temperature, T_a the ambient air temperature, T_H the temperature at the hot side exhaust and T_C the temperature at the outlet of the cold side of the thermoelectric air-duct.

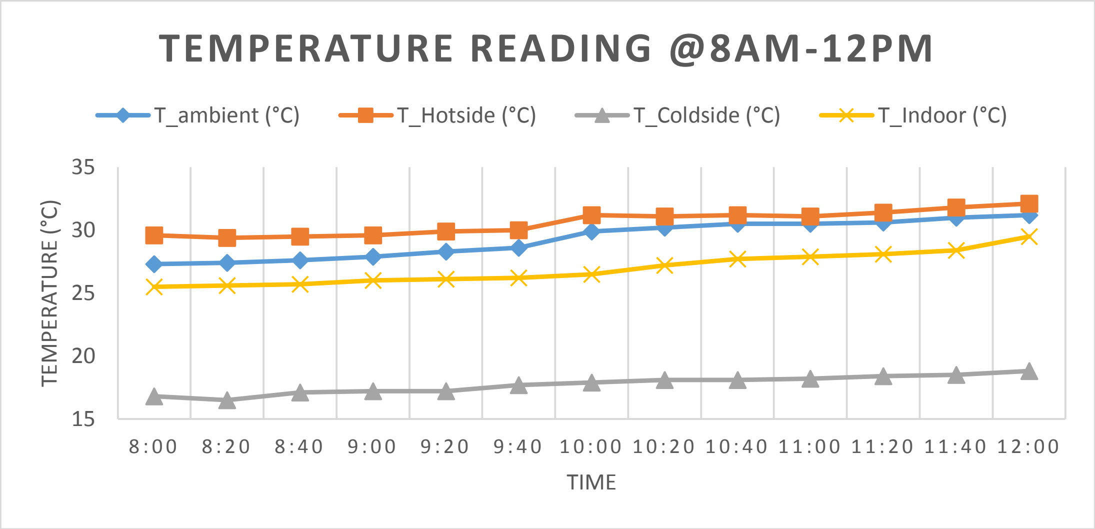


Figure 4.3: Temperature reading from 8AM to 12PM.

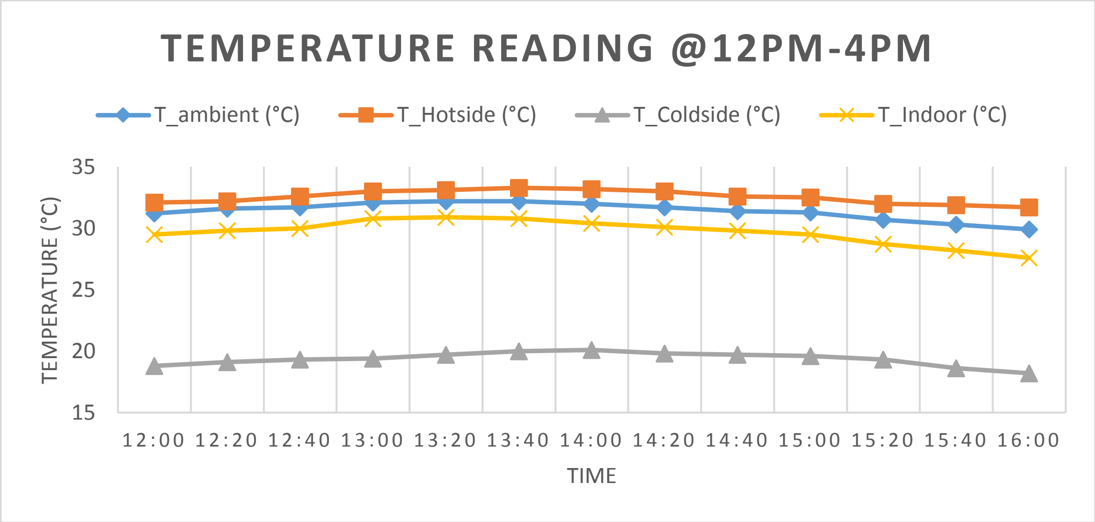


Figure 4.4: Temperature reading from 12PM to 4PM.

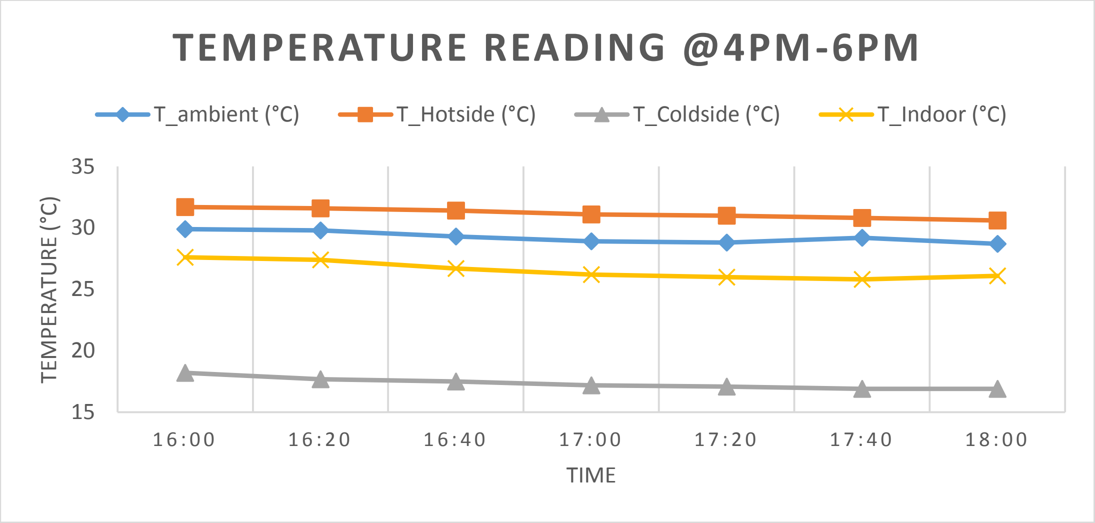


Figure 4.5: Temperature reading from 4PM to 6PM.

From the results obtained it can be observed that when the system is turned on in the morning at 8a.m. where ambient temperature is low, the system was able to cool the ambient air entering the cold chamber of the thermoelectric air-duct by up to 2°C. The indoor temperature of the test house was also able to be maintained at below the ambient air temperature, ranging from a difference of 1 to 2 °C. At 12p.m, when the ambient temperatures were higher, the outlet cold chamber temperature was cooled by up to 11°C. However the indoor temperature is only cooled by less than 1.6°C, and even rising slightly above the ambient air temperature before the system is turned off. At 5.40 p.m when ambient temperature has decreased again, the system was again able to cool indoor temperatures by up to 3.5°C and the air at cold chamber is maintained 15°C.

4.5 Cooling Power and Temperature Difference

The actual cooling power, Qc, of the thermoelectric air-duct prototype is calculated using Equation 3. 3 Graphs of Cooling Power and Temperature Difference for every 4 hours interval in a day are plotted as shown in Figure 4.6, Figure 4.7 and Figure 4.8.

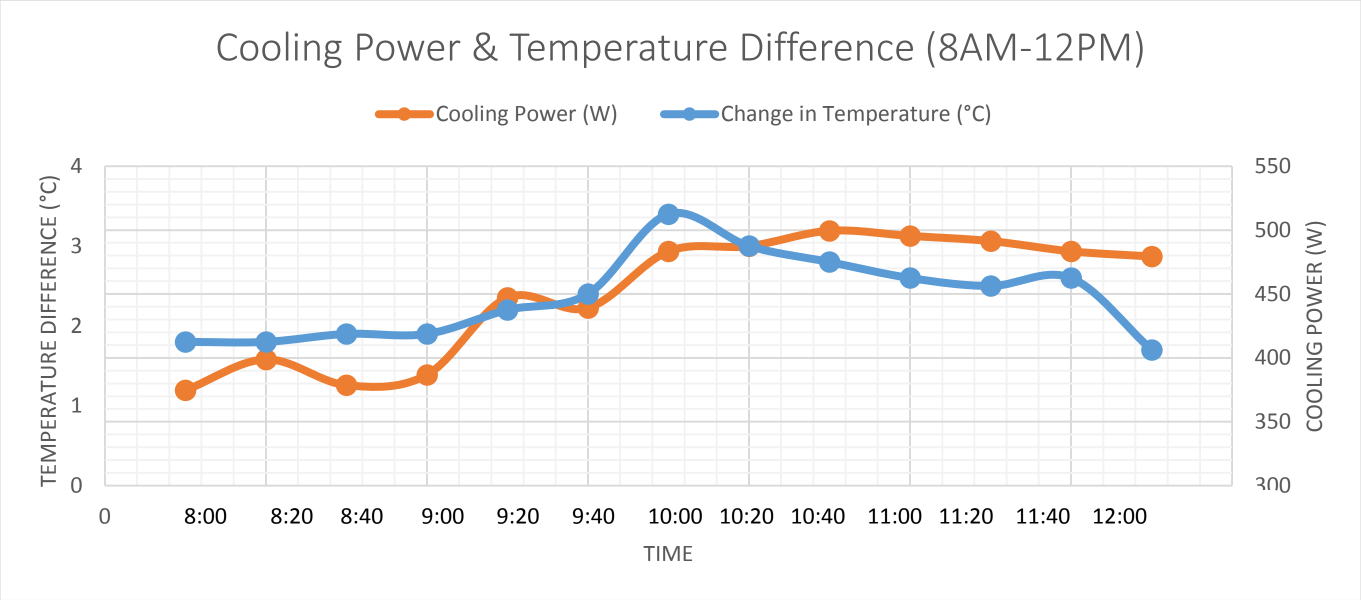


Figure 4.6: Graph of Cooling Power and Temperature Difference at 8AM till 12PM.

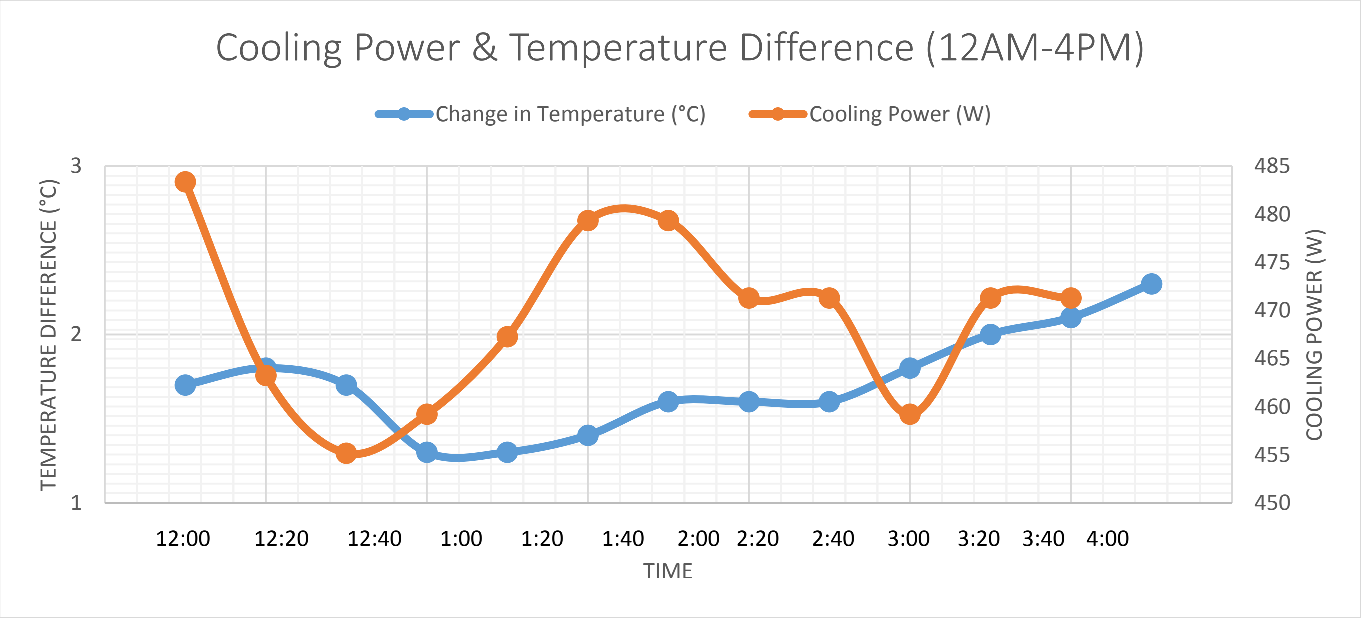


Figure 4.7: Graph of Cooling Power and Temperature Difference at 12PM till 4PM.

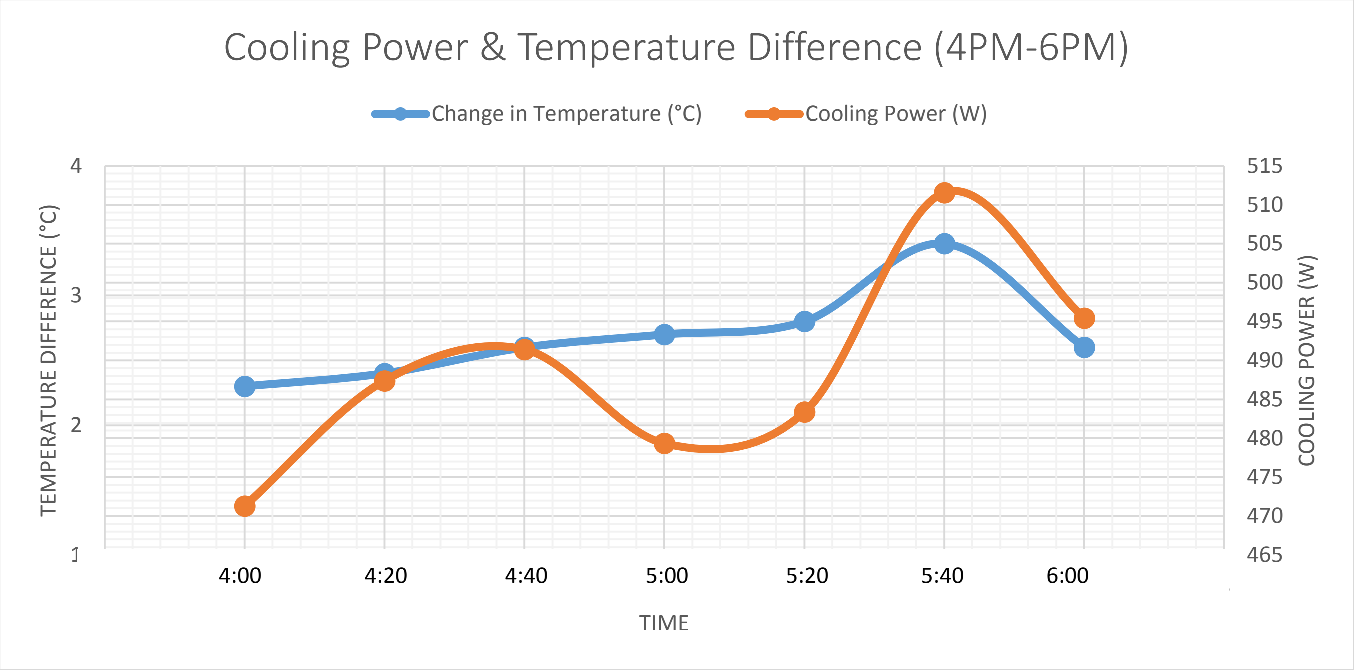


Figure 4.8: Graph of Cooling Power and Temperature Difference at 4PM till 6PM.

From the plotted graphs it can be observed that the peak cooling power of the system was 511W at 5.40 p.m. compared to the expected value of 624W. However the cooling power provided is at other times even less and is inconsistent.

Possible explanations for this include heat loss from leakage of air through the prototype envelope or between the hot and cold ducts as well as heat generated by the fan motor prior to the exhaust. Besides this, it was also observed that condensation occurred on the surface of the cold side of the thermoelectric modules. As the ambient air in Malaysia is high in humidity it is possible that at system startup the air is cooled below the dew point temperature and thus causing condensation.

At periods with higher ambient air temperature especially during mid-day or afternoon, it is found that the system performance decreases, with the system only being able to decrease the indoor temperature ranging from 1.2°C - 1.4°C.

As mentioned previously, the thermoelectric modules are connected in three series in parallel. It is assumed that all TE modules behave the same, and thus produce equal cooling power at the specified voltage and current. However, initial testing indicated that actual performance between units varied thus the cooling power produced will not be the same as that calculated.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

A TE-AD prototype has been succesfully designed, fabricated, and installed at a single room test house. This project, while not fully meeting the intial design cooling load, demonstrates that a thermoelectric air duct system has potential to be a viable alternative to traditional vapor compression air conditioners. The project initially aimed at designing a TE air-duct capable of maintaining the room temperature of a test house at 2°C – 4°C below ambient air temperature which required a cooling power of 589W based on the cooling load calculated using initial temperature measurements. When the system is subjected to different current starting from 2A as the minimum current supplied, and 6A the maximum current supplied tested in this experiment, results show that higher current provides higher cooling power and higher COP value. The number of required units for cooling the room was 24 TE modules, to cool the ambient air entering the TE air-duct and required a voltage of 5V and current draw of 6A resulting in a power input of 720W.

Temperature measurements of the indoor, ambient air, and exhaust of the cold side of the TE air-duct were then taken at different times throughout the day, at 8a.m., 12p.m., and 4p.m. It was found that the cold chamber of the TE air-duct temperature could be cooled up to 11°C and that the room temperature could be cooled by up to 3.5°C. However the prototype performance is not consistent with it only being able to cool by about 1 to 1.5°C for majority of the experiment. At higher ambient temperatures the system performance also decreases and is not able to meet with cooling load of the test house at that particular time.

The actual peak cooling power was found to be 511W, lower than the expected cooling power calculated and may be attributed to heat loss from leakages as well as heat generated by the motor of the fan. Condensation was also observed to occur at the surface of the TE modules cold side, especially in the morning and may affect the cooling power provided. As the performance of the TE modules are highly dependent on current provided any rise or drop in voltage by the power source may also have affected performance.

5.2 Recommendations

The initial design of the TE air-duct prototype was based on maintaining an indoor temperature reduction of 2°C – 4°C, by cooling the ambient air to 10°C temperatures below the desired air temperature. Based on experimentation on a fabricated TE-AD prototype, it was found that the system was only able to cool ambient air by up to 11°C and indoor temperature by an average of 2 to 2.5°C.

To improve performance of the prototype, more efficient heat sinks should be installed at the hot side to improve the rate of heat dissipation to ensure that the system does not overheat at higher ambient temperatures. Heat sinks with twisted channels can also be installed at the cold side of the TE modules to prolong the circulation of air through the cooling side. Better insulation should also be installed between the cold and hot side ducts to prevent heat loss between the ducts.

During the cooling load calculation, assumptions were made such as that the load was only affected by heat transfer through conduction in the walls and roof. Future works should attempt to include other factors such as infiltration and solar gain. Due to the constraint of the power supply available, the TEMs used could only be run at 5V and 6A. If a larger power source was procured it is possible to run the TE-AD at higher current configurations to produce more cooling power and thus produce a greater temperature reduction.

As TE modules use DC current, it is possible to integrate the system with a solar power source or PV and thus has a high potential to produce essentially free cooling power with high reliability.

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Appendices

Appendix A-i: List of Equipments Used in this Project

A list of instruments and equipment to be used, along with their type, quantity, function, and specifications, can be found in Table 3.3 below.

Appendix A-i – Thermo physical properties of test house building materials

Apparatus	Type	Quantity	Function	Specification
Thermoelectric modules (TEMs)	Heibei TEC1-12730	30	To create a temperature gradient from an applied electric current	Maximum Current Input = 30.5A Q_{max}=257W @T_h=25°C Q_{max}=282W @T_h=50°C
VRLA Batteries	MSB MS 12-100 Ultra	6	To store power from grid supply and discharge current into TEMs	12V, 100AH
Charge controller		1	To regulate current from batteries into TEMs	
Hygrometer		1	To measure indoor relative humidity of test house	
Solar power meter	TES 1333R Datalogging Solar Power Meter	1	To measure incoming global solar irradiation	Measured at one hour intervals from a fixed location
Thermocouple	Type-T Copper-constantan	5	To measure temperature	Kept at 0 ˚C, measured accuracy within ±0.2 ˚C
Fan		2	To assist TE-AD by controlling air flow into the duct	12 V, 0.45A
Voltage sensor		1	To measure DC voltage of TEMs	
Current sensor		1	To measure DC current of TEMs	
Data logger	midi Logger GL220	1	To record measured data	Every 10-min intervals record
Computer	Desktop computer	1	To facilitate data logging	

Appendix A-ii: Calculations

At 5:00p.m.,

Building area	Temperature (°C)
West wall, T_{west}	30.5
North wall, T_{north}	33.4
East wall, T_{east}	31.6
South wall, T_{south}	30.4
Roof, T_{roof}	31.5
Indoor, $T_{in,actual}$	29.9

To reduce indoor temperature by 2°C, therefore $T_{in,\ desired} = 27.9°C$

Therefore $Q_c = \frac{(30.5-27.9)}{0.3} + \frac{(33.4-27.9)}{0.3} + \frac{(31.6-27.9)}{0.3} + \frac{(30.4-27.9)}{0.3} + \frac{(31.5-27.9)}{0.15} =$ 589W

Assuming that the cold side exhaust temperature, T_c, is 10°C cooler than the room temperature and that the ambient air temperature, T_a, entering the TE air-duct is 32.5°C, the mass flow rate required is given by:

$$\dot{m} = \frac{Q_c}{c_p(T_a - T_c)} = \frac{589}{1007(32.5 - (27.9 - 10))} = 0.04kg/s$$

And the speed of air required for a duct with an area of $0.093m^2$:

$$v = \frac{\dot{m}}{\rho A} = \frac{0.04}{1.15(0.093)} = 0.4m/s$$

Since the total cooling power provided must be greater than the cooling load, then at 6A and 5V, the cooling power per module is 26W. Assuming cooling power generated per module is 25W:

$$number\ of\ units = \frac{589}{25} = 24\ units$$

For 24 units, the total cooling power provided is: $Q_{c,total} = 24 * 26W = 624W$

And the total power input at 5V and 6A is $P = IV = 5 * 6 * 24 = 720W$

And the heat dissipation is: $Q_h = Q_{c,total} + P = 1344W$

Appendix A-iii: Average Solar Radiation Reading in the month of March 2015