DESIGN AND STUDY OF DOMESTIC COOLING SYSTEM THROUGH ROOF VENTILATION ASSISTED BY EVAPORATIVE COOLING

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May 2019

This dissertation is submitted to
Universiti Sains Malaysia
As partial fulfillment of requirement to graduate with honor degree in

BACHELOR OF ENGINEERING (MECHANICAL ENGINEERING)

School of Mechanical Engineering
Engineering Campus
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DECLARATION

I hereby declare that this thesis entitled “Design and Study of Domestic Cooling System through Roof Ventilation assisted by Evaporative Cooling”, which is submitted now for assessment as the final year project under the programme Bachelor of Mechanical Engineering (Hons), is my original work under guidance of Dr. Chan Keng Wai and this thesis has not been submitted in whole or in part for assessment for any academic purpose other than in partial fulfillment for that stated above.

..........................

Chai Yik Zhien

131136

29/5/2019
ACKNOWLEDGEMENT

First, I want to use this opportunity to thank my supervisor Dr. Chan Keng Wai. He gives me a lot of advices and guidance when I am facing problems in this project. He also gives me some devices when I want to carry out the experiment. Without his guidance, this project will not complete.

Besides that, I want to thank coordinator and lecturers who involve in giving final year project talks. Coordinator of final year project Dr. Mohamad Ikhwan Zaini Ridzwan always arrange the useful activities in helping us to do our final year project. I also get many benefits when involving in the final year project talks.

Apart from that, I want to thank technicians in USM School of Mechanical Engineering. They always give me the useful advices when I want to do my fabrication. They also teach me the way of using the machine that I have never used before.

Last but not least, I want to thank my friends who help me move the prototype in and out from the room when I want to carry out the experiment. Without their help, it will have a lot of trouble for me to carry out the experiment.
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**EQUATIONS**

\[
T_w = T \tan[0.151977(RH\% + 8.313659)^{0.5}] + \tan(T + RH\%) - \\
\tan(RH\% - 1.676331) + 0.00391838(RH\%)^{1.5} \\
\tan(0.023101RH\%) - 4.686035
\]  

(1)

Efficiency = \[
\frac{Ambient \ temperature - Cooling \ duct \ temperature}{Ambient \ temperature - Wet \ bulb \ temperature} \times 100\%
\]  

(2)
ABSTRACT (BM)

Climate of Malaysia is hot. It causes high indoor temperature in the building. Roof is the part which absorbs huge amount of heat flux in a building. To reduce the heat transferred from the roof, roof ventilation is needed. There are many existing roof ventilation methods but they have their disadvantages such as less efficient and much energy loss. In this project, domestic cooling system through roof ventilation assisted by evaporative cooling is designed. The performance of designed domestic cooling system is investigated through experiment and simulation. Domestic cooling system through roof ventilation assisted by evaporative cooling combines the theories of natural ventilation, forced ventilation and direct evaporative cooling. By using this method, the energy used for the cooling system can be reduced. Design, fabrication, experiment and simulation are done in this project. For design part, an actual size model and a prototype model are designed. For fabrication part, the prototype model is fabricated and used for doing experiment. For experiment part, two types of experiment are involved in this project. First type of experiment is carried out to measure the efficiency of the cooling system. Second type of experiment is carried out to measure the performance of the cooling system with different air speed in cooling duct. Simulation is done to compare the performance of cooling system between the prototype design and the actual size design in different conditions. Simulation results is also compared with experimental results. The experimental results show that the cooling system with 4m/s air speed has the highest cooling efficiency, which is 49.3%. The best performance of the roof ventilation assisted by evaporative cooling system can reduce 10.58°C. The temperature difference between the simulation result and experimental result is only 0.26°C, it is still acceptable. Thus, domestic cooling system through roof ventilation assisted by evaporative cooling can be known as an efficient cooling system.
Chapter 1: Introduction

1.1 Research Background

The climate of Malaysia is hot. Extreme hot temperature makes the people feel uncomfortable. Most of the time, people will stay inside the buildings. Based on the research, people spend around 87% of their time in building (Ghisi, 2002). However, heat can be transferred into the building by conduction, convection and radiation. This will make the temperature inside a building become hot.

To remove heat from building, air-conditioning systems are commonly used. In tropical country, the consumption energy of air-conditioning system is huge, it is about 60% of the total energy consumption of a building (Ghisi, 2002). According to the study of Opoku, Edwin, & Agyarko, 2019, electricity consumption of refrigeration and air-conditioning in Ghana in 2017 is between 3260GWh to 3440 GWh and the cost of electricity can reach US$ 648.2 million. Fossil fuel which used to generate such amount of electricity can produce 2.25 million metric tons of CO₂ (Opoku et al., 2019). Using air-conditioner will cause high amount of electricity and pollution of the surrounding. To reduce the usage of air-conditioner, some cooling methods should be proposed.

Due to the roof of the building is exposed fully to the sunlight, huge amount of heat flux is transferred from the roof to indoor area. Reducing heat flux of roof become a good method to reduce the indoor temperature. Roof ventilation can reduce the heat flux of the roof. There are several methods to assist the roof ventilation, such as natural ventilation, forced ventilation and direct evaporative cooling. Although these methods can reduce the indoor temperature, they still have their own shortages. These shortages will cause more energy consumption and low efficiency of cooling.

In this project, a solution is found to combine the characteristics of the methods and compensate the shortages of each method. Domestic cooling system through roof ventilation assisted by evaporative cooling is designed to provide cooling effect. At the same time, it can save the consumption of energy used for the cooling system.
1.2 Problem Statement

Hot climate causes high indoor temperature of the building. To reduce the indoor temperature, heat source of building is needed to be found. Roof is the part which absorbs the huge amount of heat flux in a building because it is exposed fully to the sunlight. To reduce the heat flux from the roof, there are many existing methods can be used. However, there are disadvantages for each method.

Natural ventilation system shows low efficient to reduce the indoor temperature although it does not consume any electricity. Performance of natural ventilation system is also not stable for each different season. For forced ventilation system, it has higher efficiency to reduce indoor temperature than natural ventilation system but it costs much electricity. In conventional forced ventilation system, ventilation fan is used to ventilate large amount volume of attic and this will cost much electricity. Large amount of electricity consumption become the main disadvantage of forced ventilation. Direct evaporating cooling has high efficiency to reduce the indoor temperature. However, it costs much water when water evaporation occurs on the roof surface. In conventional direct evaporative cooling system, much water is evaporated when the roof surface is fully exposed to the sunlight.

To reduce the indoor temperature with low electricity and low water consumption, domestic cooling system through roof ventilation assisted by evaporative cooling is designed.

1.3 Objectives

- To design a domestic cooling system through roof ventilation assisted by water evaporation.

- To investigate the performance of designed domestic cooling system through experiment and simulation.
1.4 Scope of Research

Design, fabrication, experiment and simulation parts are done in this project. Design of scale-down test house and prototype are drawn by using SOLIDWORKS. There are two chambers in the test house. The prototype is acts as cooling system. The prototype of cooling system is put into one of chambers of the test house. After complete designing, the scale-down test house and prototype are fabricated. Experiment is carried out under the sun. Thermocouples are used to measure the temperature of two different chambers in the test house. By comparing the temperature difference between two chambers of the test house, performance of cooling effect can be measured. Simulation is done by using ANSYS FLUENT. Simulation is done to compare the performance of cooling system between the prototype design and the actual size design in different conditions. Simulation results are compared with the experimental results.

Due to not having the suitable device, the electricity and water consumption cannot be measured accurately. Thus, the electricity and water consumption are not considered in this project. The size of water particles sprayed out from the water mist sprayer cannot be measured accurately in this project because absence of the device. Thus, the changing of size of water particles are not considered in this project.

1.5 Thesis Organization

Chapter 1 starts with research background, problem statement, objectives and scope of research. Chapter 2 discusses the literature review of the project. The literature review of the project includes the research of natural ventilation, forced ventilation, direct evaporative cooling and wet bulb temperature. Chapter 3 discusses the methodology of doing the experiment and simulation. Chapter 4 includes the results and discussion. Simulations results are compared with the experimental results. Chapter 5 discusses the conclusion and the future work. Some suggestions are given to improve the project in the future.
Chapter 2: Literature Review

2.1 Roof Ventilation

Roof ventilation can affect the indoor temperature. According to the study of Ran et al. (2017), a warehouse in Shanghai is set as the location of experiment. The warehouse is one storey building. It is divided into four rooms and no window for each room. The results show that the green roof with intermittent ventilation can reduce the indoor temperature by 2.7°C. The cooling effect of the green roof is better than the insulation roof. With air conditioning, roof ventilation can make the energy consumption of the air conditioning reduce by 10%.

2.2 Natural Ventilation

Natural ventilation can be known as Stack ventilation. Stack ventilation works when the thermal buoyancy causes the different in vertical pressure and finally induce movement of air in an area (Al-Obaidi et al., 2014). Due to the density of cold air is heavier than the density of hot air, the hot air will move upwards while the cold air will move downwards and replace the hot air. However, stack effect will only occur when the temperature inside the stack is higher than the ambient temperature (Al-Obaidi et al., 2014). The air flow of indoor house area to the attic increases when the temperature difference between indoor and outdoor increases (Walker et al., 1995).

Figure 1: Example of Stack effect. Image courtesy : Building Science Corporation, www.buildingscience.com

Figure 1 shows the stack effect. The hot air is removed from the top part of the building and the cold air will come in from the bottom side and replace the hot air.
Natural ventilation can improve air quality of indoor area, thermal comfort and finally, reduce the use of electric energy (Sacht et al., 2017). There are two modes of natural ventilation, which are single-sided ventilation and cross ventilation. Based on the study of Omrani et al. (2017), cross ventilation performs better than the single-sized ventilation because the wind speed ratio and indoor air flow distribution of cross ventilation is two or four times higher than the single-sized ventilation.

In indoor area, natural ventilation is influenced by the size of windows and the angle variation of wind incidence. Large opening of window allows greater movement of air in indoor area and thus natural ventilation is more effective. Based on the study of Sacht et al. (2017), wind enters the window at angle between 0° to 45° has the best performances while wind enters the window at angle 90° has the worst performance.

Although natural ventilation can provide cooling effect by not consuming any electricity, it does not always work. Based on the study of Gan et al. (2019), performance of natural ventilation is investigated at different seasons. The results show that natural ventilation cannot always perform well, it can perform most effective during late spring.

According to the study of Al-Obaidi et al. (2014), the environment of Malaysia cannot only depends on natural ventilation. Thus, the conventional natural ventilation is not applied in this project. However, the basic idea of natural ventilation is used in this system so that the electricity consumption can be reduced.

### 2.3 Forced Ventilation

Forced ventilation can be known as mechanical ventilation. Forced ventilation occurs when the air is forced by ventilation fan and the pressure difference will produce cooling effect. Through the theory of convection of heat, the heat energy is removed by the forced ventilation from the building.

According to the study of Zhao et al. (2018), effect of forced ventilation and natural ventilation to the indoor area in winter season is investigated. There are four residences with natural ventilation while other four residences with mechanical ventilation. The results show that mechanical ventilation can reduce temperature of indoor area by 1.6K and humidity by 3% during winter season. The rate of carbon
dioxide in indoor area is also reduced by mechanical ventilation. For natural ventilation, although it has a little better relative humidity but its ventilation is poor.

According to the study of Lai et al. (2018), mechanical ventilation system provides better ventilation than natural ventilation but it consumes more electricity and produces secondary air pollutants and noise. In this research, the usage of mechanical and natural ventilation is investigated based on 46 apartments across five different seasons in China. The results show that natural ventilation system is most frequently used in summer and least frequently used in winter while the trend of mechanical ventilation system is opposite to the natural ventilation system. This is because when the outdoor temperature increases, the stack effect is more effective and thus usage of mechanical ventilation system is less.

According to the study of Kamendere et al. (2015), comparison of heat recovery between mechanical ventilation system and the natural ventilation system is made. Both systems are applied to two similar buildings separately. One is installed with mechanical ventilation system while another one is installed with natural ventilation system. The results show that the maximum heat recovery energy efficient of mechanical ventilation system can reach 86% while the heat recovery energy efficient of natural ventilation system can only reach 75%.

Based on the research above, it shows that forced ventilation system can produce better cooling effect compared to natural ventilation system but it will cost much electricity. In this project, to reduce the electrical consumption, the forced ventilation is not directly applied to the attic because the volume of attic is quite huge. The forced ventilation system is applied into a cooling duct. The volume of cooling duct is much smaller than the volume of attic and thus the electricity used to ventilate the space can be reduced.

2.4 Direct Evaporative Cooling

Evaporative cooling is a cooling method to cool a surface by using evaporation of water. Direct evaporative cooling occurs when the heat is absorbed with the help of evaporation of water supplied. In direct evaporative cooling system, the humidity of the air increases and this causes the decrease of dry-bulb temperature. The minimum
temperature that can be achieved by direct evaporative cooling is wet-bulb temperature (Abbouda et al., 2012).

![Figure 2: Schematic diagram of direct evaporative cooling system. Image courtesy: Abbouda et al., 2012](image)

Figure 2 shows the schematic diagram of direct evaporative cooling system. The temperature can reach the lowest temperature when it reached the wet bulb temperature.

Relative humidity plays an important role in direct evaporative cooling system. Relative humidity is the ratio of mass of water vapour in moist air to the mass of water vapour in saturated air at certain temperature. Normally, relative humidity is acted as percentage. Direct evaporative cooling is less effective in high humidity area because high humidity will reduce the evaporation of water. Occupants will feel discomfort in high humidity and high temperature area (Nayak et al., 2006).

According to the study of Lokapure et al. (2012), roof surface evaporative cooling system is needed in tropical country. By spraying water over the water-retentive materials which mounted on the roof surface, the roof surface can be cooled. When the roof surface is exposed to the sunlight, water evaporation will occur on the roof and it will draw latent heat from the roof surface, thus the temperature of the roof can be reduced. To ensure the roof surface evaporative cooling can run effectively, the roof surface should always be kept wet. In this experiment, the roof is covered with water-retentive material and it is sprayed by sprinkler and drip pipe system. Two conditions are provided in this experiment, one is in normal condition while another one is under steam pressure reducing station. Sprinkler can be used for normal condition but cannot be used under steam pressure reducing station. This is because it will cause steam joint leakage. For steam pressure reducing station condition, drip pipe system is used. After using the roof surface evaporative cooling system, the ceiling temperature is dropped from 31°C to 23°C, which able to reduce 8°C. Room temperature is dropped from 25°C
to 24°C, which able to reduce 1°C. After using roof surface evaporating cooling system, 346kWh energy used for A/C machine can be saved for every 8 hours.

According to the study of Ab Rahman et al. (2014), a direct evaporative cooling experiment is made by splashing water on the zinc roof. The temperature readings are taken from two different rooms, one is installed with direct evaporative cooling system while another one does not. In this experiment, water is recirculated in direct evaporative cooling system to ensure no wastage of water. The water is pumped from a water container to water pipe using water pump. The water is sprayed out from the holes of water pipe and makes the zinc roof become wet. Water evaporation occurs on the zinc roof. The remaining water is flowed back to the water container through a water way. The results show that the room temperature is reduced 5°C by using direct evaporative cooling.

Figure 3: Schematic diagram of water recirculation system. Image courtesy: Ab Rahman et al. (2014)

Conventional direct evaporative cooling system consumes much water. Amount of water needed in peak summer is about 10 kg / day / m² of roof area (Nayak et al., 2006). In this project, water evaporation does not occur on the roof but occurs inside the cooling duct. If water is evaporated on the roof, much water will be consumed. Water recirculation system is also applied in this project so that the water will not be wasted.
2.5 Wet Bulb Temperature

Wet bulb temperature is the lowest temperature that the air is cooled through water evaporation at constant pressure (Turbine, 2007). Wet bulb temperature can be calculated from the dry bulb temperature and relative humidity. Based on the study of STULL (2011), the wet bulb temperature can be calculated from the equation:

\[
T_w = T \arctan[0.151977(RH\% + 8.313659)^{0.5}] + \arctan(T + RH\%) - \arctan(RH\% - 1.676331) + 0.00391838(RH\%)^{1.5} \arctan(0.023101RH\%) \times -4.686035
\]

(1)

Where \(T_w\) is wet bulb temperature, \(T\) is ambient temperature and \(RH\) is relative humidity. Besides that, Gene-expression programming (GEP) can be used to create new regressions based on wet bulb temperature, ambient temperature and relative humidity for any other pressure.

![Psychrometric graph for 101.325kPa. Image courtesy: STULL (2011)](image)

2.6 Air Conditioning System

Air conditioning system is the system that cools the air through refrigeration cycle. Four main components are included in the refrigeration cycle. The components are compressor, expansion valve, condenser and evaporator. According to the study of...
Cheung et al. (2019), effects of air conditioning system to the surrounding is investigated in Hong Kong. Air conditioning is commonly used in Hong Kong, eight houses in Hong Kong are chosen to join this experiment. The experiment is conducted for 72 hours. This research shows that the concentration of carbon monoxide (CO) and carbon dioxide (CO$_2$) will increase when the air conditioning is used. During the use of air conditioning, the mean concentration of CO increases from 220 μg/m$^3$ to 905 μg/m$^3$ while the mean concentration of CO$_2$ increases from 920 μg/m$^3$ to 1711 μg/m$^3$. The use of air conditioning causes the CO increases 312% while CO$_2$ increases 86%. The research shows the sick building syndrome is easier to be happened in air conditioned space compared to naturally ventilated space.

Figure 5: Basic Refrigeration Cycle. Image courtesy: https://www.swtc.edu/Ag_Power/air_conditioning/lecture/basic_cycle.htm
Chapter 3: Methodology

3.1 Proposed solutions

Based on the research, there are pros and cons for each cooling system. Domestic cooling system through roof ventilation assisted by evaporative cooling combines the theories of different cooling systems and creates a design that has a balance of cooling effect, electricity consumption and water consumption.

Domestic cooling system through roof ventilation assisted by evaporative cooling combines the theories of forced ventilation, natural ventilation and direct evaporative cooling. There are three main parts in this domestic cooling system, which are cooling duct, air blower and the mist spray system. Cooling duct is a rectangular galvanised iron duct and it is installed below the roof. Main function of this cooling duct is to create a passage which used in ventilation. Air blower will provide air flow inside the cooling duct, which will create forced ventilation. Mist spray is installed inside the cooling duct. It sprays water inside the cooling duct to undergo direct evaporating process.

Forced ventilation is a ventilation system that uses blower to create pressure difference. It causes the outdoor air to enter the building and replace the warm air. For conventional forced ventilation system, blower is used to ventilate the large space underside of roof. Due to large space is needed to ventilate, large air flow rate is required and thus large amount of electrical consumption of the blower is consumed. In this domestic cooling system through roof ventilation assisted by evaporative cooling system, the forced ventilation is carried out inside the cooling duct. Due to the smaller space of cooling duct compared to the underside of roof, smaller air flow rate is required and thus less amount of electrical consumption of the blower is consumed. Heat energy which is absorbed by the cooling duct from surrounding is removed by the air through internal force convection of cooling duct. Thus, the temperature of the surrounding will be decreased.

Direct evaporative cooling is a cooling method by using the evaporative of water. For conventional direct evaporative cooling, the water is used to cool down the roof surface. Due to the high temperature of roof surface, large amount of water is needed
to cool down the roof surface. In domestic cooling system through roof ventilation assisted by evaporative cooling system, direct evaporative cooling process is carried out in the cooling duct which is installed underside of the roof. The evaporative cooling process will direct cool down the temperature of air underside of the roof instead of reducing the temperature of roof surface. The heat energy from roof surface which is needed to be removed is higher than the heat energy from the underside of roof which is needed to be removed to achieve indoor cooling effect. Thus, when the direct evaporative cooling process occurs underside of the roof, less water is evaporated, the water consumption can be reduced. At the same time, when less amount of water is needed to pump, the electrical consumption for water pumping rate is reduced as well. This shows a balance of cooling effect, electricity consumption and water consumption.

Natural convection is carried out in domestic cooling system through roof ventilation assisted by evaporative cooling system. The basic principle of natural convection is to release the hot air from a building and replace them with cold air. In domestic cooling system through roof ventilation assisted by evaporative cooling system, internal force convection and direct evaporative cooling are carried out inside the cooling duct. Hence, the temperature of the cooling duct is lower than the air underside the roof. Due to the temperature difference between the cooling duct and the air underside the roof, natural ventilation occurs. The lower density of hot air causes the hot air to move upwards while the higher density of cold air causes the cold air to flow down due to gravity. Due to the roof is exposed to the sunlight, the air underside the roof is hotter. At this time, the hot air underside of the roof will be cool down by the cooling duct. When the hot air becomes cold air, it will move downwards and thus the cooling effect is achieved.
3.2 Design

In the early stage of project, research is focused on the study of domestic cooling system. Three domestic cooling systems were studied in this project, which are natural ventilation, forced ventilation, evaporative cooling of roof surface and reflection of roof tile. There are pros and cons in these three domestic cooling systems. By comparing the advantages and disadvantages between them, a solution is proposed which is combining natural ventilation, forced ventilation and evaporative cooling of roof surface. After the solution is proposed, design works are started. The designs are drawn out by using SOLIDWORKS.

3.2.1 Actual size design

The actual size design of domestic cooling system is four times larger than the prototype design. Components of actual size design of domestic cooling system includes ventilation fan, cooling duct, water mist sprayer, water tank and water pump. Cooling duct is installed on the structure of the roof. Water pump is used to pump the water from water tank through the pipe to water mist sprayers. Four water mist sprayers are used to spray the water inside the cooling duct. Ventilation fan is used to suck out the hot air from the cooling duct.

Figure 6: Details of actual size design of domestic cooling system
3.2.2 Prototype design

Prototype of domestic cooling system was fabricated for experiment. The prototype design of domestic cooling system is four times smaller than the actual size design of domestic cooling system. The dimension of the test house is 870mm length x 820mm width x 450mm to 940mm height. There are two chambers in the test house. One chamber is installed with the cooling system while another control chamber without cooling system. A thick layer of insulation wall is put between these two chambers to avoid heat transfer between these two chambers. The body of test house is also covered with insulated wall so that it can avoid the transfer of the heat in and out from the wall. To avoid the heat transferred to the ground, the base of the test house is designed so that it does not touch the ground. There are many components inside the prototype design of domestic cooling system, such as cooling duct, roller fan, water pump and water mist sprayer.

![Diagram of prototype design of domestic cooling system](image)

**Figure 7:** Details of prototype design of domestic cooling system

First, a cooling duct is designed. The cooling duct is designed to have a wide surface area. Due to the wide surface area of the cooling duct, the cooling surface which contacts with the hot air will be larger, and thus there are more hot air that pass through
the roof will become cold. The height of the cooling duct is 2cm, width of the cooling duct is 25cm while the length of the cooling duct is 99cm.

Figure 8: Design of the cooling duct

Besides that, a roller fan is used as blower in this project. There are suction side and pressure side for the roller fan. Suction side of the roller fan is used to suck the air in while the pressure side of roller fan is used to blow the air out. In this project, the suction side of the roller fan is used to suck the air from the cooling duct. Thus, a casing cover is designed to connect the roller fan with the cooling duct.

Figure 9: Roller fan
A water diaphragm pump is used in this project. The purpose of this water pump is to pump the water from a water tank through water tube to the cooling duct and the water will be sprayed out by water mist sprayer inside the cooling duct. There are two holes on the water diaphragm pump, one is suction side while another one is pressure side. Two water tubes are connected to suction side and pressure side separately. The suction side is used to suck the water from the water tank while the pressure side is used to pump the water to the cooling duct.
3.3 Fabrication

After completing the design works, fabrication works were started. The structure of the test house is built by using wood. The wall of the test house is made by using polystyrene foam. The polystyrene foam is acted as insulation wall of the test house. To improve the stability of the test house, plywood sheets were applied to the walls of the test house. To start the fabrication, the plywood sheets were cut down into few pieces by using jigsaw. After that, the plywood sheets were nailed to the test house.

![Plywood sheets which are nailed to the test house](image)

Cooling duct was fabricated based on the design. Cooling duct was fabricated by using the bending process. A barrier was added inside the cooling duct so that the water can flow through the filter funnel and can be transferred back to the water tank. The cooling duct was sealed by using silicone glue. The support part of the cooling duct was fabricated by using bending process. The purpose of support part of the cooling duct is to mount the cooling duct at the top of the test house.
Figure 13: Fabrication process of cooling duct

Casing cover of the roller fan was fabricated based on the design in SOLIDWORKS file. Casing cover of the roller fan was fabricated through the soldering and sealing process. The casing cover of roller fan was connected to the cooling duct.

Figure 14: Casing cover of roller fan and cooling duct

Finally, two pieces of clay tile were acted as roof and were used to cover the top part of the test house. The fabrication of the prototype was completed.
Figure 15: Inner design of the prototype

Figure 16: Complete fabrication of the prototype
3.4 Experiment

Two types of experiment were done in this project. The purpose of first type of experiment is to measure the efficiency of the cooling system. The purpose of second type of experiment is to measure the performance of the cooling system with different air speed in cooling duct.

For first experiment, temperature of four different locations were measured. The locations were chamber with cooling system, chamber without cooling system, surface of cooling duct and the ambient area. The experiments were done with difference air speed in cooling duct which are 0m/s, 3m/s and 4m/s. Humidity of the surrounding area was measured by using a USB DATALOGGER. After knowing the humidity and ambient temperature, wet bulb temperature can be found from an equation (STULL, 2011).

\[ Tw = T \tan[0.151977(RH\% + 8.313659)^{0.5}] + \tan(T + RH\%) - \tan(RH\% - 1.676331) + 0.00391838(RH\%)^{1.5} \tan(0.023101RH\%) - 4.686035 \]  

By using temperature of cooling duct divided by wet bulb temperature, efficiency of the cooling system can be calculated.

\[
\text{Efficiency} = \frac{\text{Ambient temperature - Cooling duct temperature}}{\text{Ambient temperature - Wet bulb temperature}} \times 100\%
\]

For second experiment, four thermocouples were used. Two thermocouples were put inside the chamber with cooling system while other two thermocouples were put inside the chamber without cooling system. The experiments were done with difference air speed in cooling duct. The air speeds are 0m/s, 3m/s and 4m/s. The air speed in the cooling duct was measured by using anemometer. By comparing the temperature difference between the chamber with cooling system and the chamber without cooling system, the performance of the cooling system can be measured. Different air speed in the cooling duct will give the difference performance of cooling system.

Before starting the experiment, some components and apparatus were set up. The components are transformer, roller fan, water circulation system, water mist sprayer, thermocouple and USB TC-08 device. Transformer was used to control the wind speed of the roller fan. Water pump was used to pump the water to the cooling duct. Water mist sprayer was used to spray the water inside the cooling duct. Four
thermocouples were used to detect the temperature within the test house. Two thermocouples were put into the chamber with cooling system while another two thermocouples were put into the chamber without cooling system. The reading of the temperature can be detected by using a USB TC-08 device.

![Transformer and roller fan](image)

Figure 17: Transformer and roller fan

![Water circulation system](image)

Figure 18: Water circulation system
Figure 19: Water mist sprayer

Figure 20: Thermocouple

Figure 21: Pico USB TC-08 device
Procedure of experiment:

1. Roller fan was installed into the casing cover of the roller fan. Transformer was connected to the roller fan so that the wind speed of the roller fan can be controlled.

2. Water circulation system was installed. Power supply was used to supply electricity to the water pump. Water mist sprayer was inserted into the cooling duct so that the water can be sprayed inside the cooling duct. To avoid the leakage of water and air, an insulation cover was used to cover the water mist sprayer.

3. Four pairs of type K thermocouple were located at specific places respectively. For first experiment, the thermocouples were placed at chamber with cooling system, chamber without cooling system, surface of cooling duct and the ambient area. For second experiment, two thermocouples were put inside the chamber with cooling system while other two thermocouples were put inside the chamber without cooling system.

4. Two pieces of clay tile were acted as roof and used to cover the top part of the test house. The clay tile pieces were fixed on the top of the test house by using bolt and nut.

5. The test house was moved outside so that the roof of the test house can be fully exposed to the sunlight.

6. The thermocouples were connected to the Pico USB TC-08 device. Pico USB TC-08 device was used to collect the temperature reading. Pico USB TC-08
device was then connected to the computer. By using Picolog Recorder software in the computer, the temperature reading can be recorded.

7. Roller fan and water circulation system were switched on for 10 minutes before the data were recorded.

8. After the roller fan and water circulation system were switched on for 10 minutes, the temperature readings were started to record. The readings were taken in each minute.

9. This experiment was started at 10am. For first experiment, 100 readings were taken and each reading was taken per minute. For second experiment, 300 readings were taken for 5 hours. Picolog Recorder software will automatically stop when the temperature readings were completely recorded.

10. After the readings were completely taken, the roller fan and water circulation system were switched off. The test house was moved inside.

11. Step 1 to 10 were repeated. For first experiment, the experiments were repeated for the 0m/s, 3m/s and 4m/s air velocity. For second experiment, the experiments were repeated with three different parameters of velocity, which are 0m/s, 3m/s and 4m/s. Each parameter of velocity was repeated for three times.

Figure 23: Set up of experiment
3.5 Simulation

In this project, simulation was done by using ANSYS FLUENT software. Simulation was done to compare the performance of cooling system between the prototype design and the actual size design in different conditions. Simulation results was also compared with experimental results.

3.5.1 Geometry

To do the simulation, simpler models were drawn by using SOLIDWORKS. Two models were drawn, which were simpler prototype model and simpler actual size model. The size of simpler actual size model is four times larger than the size of simpler prototype model. After complete drawing the models by using SOLIDWORKS, the SOLIDWORKS file was saved as STEP file. Then, the STEP file was inserted into ANSYS FLUENT file and the simulation can be started. Four types of surface were selected and named. There were heat source, insulated wall, air inlet and air outlet.

![Figure 24: (a) Simpler prototype model, (b) simpler actual size model](image)

3.5.2 Meshing

In meshing section, surface mesh sizing was used to mesh the model. Surface mesh sizing was used to override the mesh sizing of a surface. By using surface mesh
sizing method, number of mesh elements of the model can be controlled. With the increasing of the mesh elements, the results came out will be more accurate.

![Figure 25: Meshing of the model](image)

### 3.5.3 Setting

To set the boundary conditions, some assumptions were made. Steady state type simulation was applied to the model because the cooling process was assumed steady for whole time. Besides that, pressure based simulation was also selected. Realizable k-epsilon model was chosen because it was normally used for turbulence condition. Enhanced wall treatment method was used to get good wall treatment so that more accurate results can be taken. Thermal effects was chosen for enhanced wall treatment options. Interaction with continuous phase is chosen. Air mixture of the model includes nitrogen, oxygen and water vapour. Iron material was applied to the cooling duct. Styrofoam was applied to the insulated wall of the model. Due to the water was sprayed inside the cooling duct, discrete model phase was selected to create a point of injection. Pressure swirl atomizer was used to act as water mist sprayer. The temperature of air inlet was set as 33°C. Simulation results were obtained by varying the temperature of heat source which were 40°C, 50°C and 60°C. Apart from that, simulation results were also obtained by varying the inlet air speed which were 0.1m/s, 3m/s and 4m/s. 0.1m/s but not 0m/s was chosen because the air flow was still inside the cooling duct although no forced ventilation was applied. Heat flux is set as thermal condition for the insulation wall.
4.1 Experimental Result and Discussion

Two types of experiment are carried out in this project.

4.1.1 First Experiment

The purpose of first experiment is to measure the efficiency of the cooling system. 100 humidity and temperature readings were taken to calculate the average efficiency of the cooling system. Each reading was recorded per minute. Experiments with three different air speed were done.

Figure 26: Graph of Temperature against Time of Experiment with Air Speed 4m/s in the Cooling Duct
Figure 27: Graph of Relative Ambient Humidity against Time of Experiment (Air Speed 4m/s in the Cooling Duct)

Figure 28: Graph of Temperature against Time of Experiment with Air Speed 3m/s in the Cooling Duct
Figure 29: Graph of Relative Ambient Humidity against Time of Experiment (Air Speed 3m/s in the Cooling Duct)

Figure 30: Graph of Temperature against Time of Experiment with Air Speed 0m/s in the Cooling Duct
Based on Figure 26, Figure 28 and Figure 30, temperature of chamber with cooling system, chamber without cooling system, surface of cooling duct and ambient are measured. The ambient temperature is fluctuating all the time. Based on Figure 27, Figure 29 and Figure 31, relative humidity of ambient are measured. The relative humidity is also fluctuating with the time.

To calculate the efficiency of the cooling system, wet bulb temperature is needed to be calculated. Ambient temperature and relative humidity are needed to calculate the wet bulb temperature. By doing the above experiments, the ambient temperature and relative humidity are measured. The wet bulb temperature can be calculated from equation (1).

After wet bulb temperature, ambient temperature and temperature of cooling duct are known, efficiency of the cooling system can be calculated. Efficiency of the cooling system is calculated from the equation (2). The efficiency of the cooling system is calculated for each minutes by using EXCEL. After 100 results of efficiency of the cooling system are calculated, average of the efficiency is calculated.

Table 1: Efficiency of the cooling system with different air speed in the cooling duct

<table>
<thead>
<tr>
<th>Air speed in the cooling duct (m/s)</th>
<th>Efficiency of the cooling system (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>36.7</td>
</tr>
</tbody>
</table>
According to the Figure 32, efficiency of the cooling system increases with the air speed in the cooling duct. Air speed with 4m/s in the cooling duct has the highest cooling effect while the air speed with 0m/s in the cooling duct has the lowest cooling effect. Cooling system with 4m/s air speed has 49.3% efficiency, cooling system with 3m/s air speed has 47.7% efficiency and cooling system with 0m/s air speed has 36.7% efficiency.

The efficiency of the cooling system depends on the efficiency of evaporation in the cooling duct. The water can be evaporated faster when greater power of forced ventilation is supplied in the cooling duct. When greater air speed is supplied, more airborne water particles can be removed from the cooling duct. At this moment, the humidity inside the cooling duct become lower. Low humidity inside the cooling duct causes the water evaporation is easier to be occurred inside the cooling duct. When water evaporation occurs rapidly, the temperature of the cooling duct will become cooler. The low temperature of cooling duct will absorb the heat from its surrounding and the temperature nearby the cooling duct will become cooler. Thus, the cooling efficiency will increase when greater air speed is supplied within the cooling duct.
4.1.2 Second Experiment

The purpose of second type of experiment is to measure the performance of the cooling system with different air speed in cooling duct. Three different types of air speed are used to do the experiment, which are 4m/s, 3m/s and 0m/s. Each air speed parameter of experiment is carried out for three times. Four thermocouples are used in this experiment. Thermocouple 1 and Thermocouple 4 are put in the chamber without cooling system while Thermocouple 2 and Thermocouple 3 are put in the chamber with cooling system.

Figure 33: Location of thermocouples in the prototype

Figure 34: Graph of Temperature against Time of Experiment with Air Speed 4m/s in the Cooling Duct (First time)
Figure 35: Graph of Temperature against Time of Experiment with Air Speed 4m/s in the Cooling Duct (Second time)

Figure 36: Graph of Temperature against Time of Experiment with Air Speed 4m/s in the Cooling Duct (Third time)
Figure 37: Graph of Temperature against Time of Experiment with Air Speed 3m/s in the Cooling Duct (First time)

Figure 38: Graph of Temperature against Time of Experiment with Air Speed 3m/s in the Cooling Duct (Second time)
Figure 39: Graph of Temperature against Time of Experiment with Air Speed 3m/s in the Cooling Duct (Third time)

Figure 40: Graph of Temperature against Time of Experiment with Air Speed 0m/s in the Cooling Duct (First time)
Based on Figure 34, Figure 35 and Figure 36, the temperature against time with air speed 4m/s in the cooling duct is measured. Based on Figure 37, Figure 38 and Figure 39, the temperature against time with air speed 3m/s in the cooling duct is measured. Based on Figure 40, Figure 41 and Figure 42, the temperature against time
with air speed 0m/s in the cooling duct is measured. Based on Figure 34 to Figure 42, the temperature does not constant with the time.

By using EXCEL, mean and maximum temperature difference between chamber with cooling system and chamber without cooling system can be calculated for each range of reference temperature. An analysis is done to analyse the performance of cooling system with difference reference temperature. Due to experiment with 3m/s does not have reference temperature below 35°C and experiment with 4m/s does not have reference temperature above 45°C, the analysis only include the reference temperature from 35°C to 45°C.

Table 2: Mean and maximum temperature difference between chamber with cooling system and chamber without cooling system with difference reference temperature

<table>
<thead>
<tr>
<th>Reference Temperature (Thermocouple 1) (°C)</th>
<th>Temperature difference between Thermocouple 1 and Thermocouple 2</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0m/s</td>
</tr>
<tr>
<td></td>
<td>Mean</td>
</tr>
<tr>
<td>35-37</td>
<td>2.80</td>
</tr>
<tr>
<td>37-39</td>
<td>4.29</td>
</tr>
<tr>
<td>39-41</td>
<td>4.66</td>
</tr>
<tr>
<td>41-43</td>
<td>6.03</td>
</tr>
<tr>
<td>43-45</td>
<td>7.44</td>
</tr>
</tbody>
</table>
Figure 43: Mean temperature difference between chamber with cooling system and chamber without cooling system with difference reference temperature

Figure 44: Maximum temperature difference between chamber with cooling system and chamber without cooling system with difference reference temperature

The graph of mean and maximum temperature difference between chamber with cooling system and chamber without cooling system are plotted to show the performance of the cooling system changes with the temperature. Based on Figure 43 and Figure 44, the higher the reference temperature, the greater the mean and maximum
temperature difference between chamber with cooling system and chamber without cooling duct. This shows that higher heat source temperature can increase the efficiency of the cooling system. When much heat is transferred through the roof, the cooling duct will absorb more heat. The heat absorbed by the cooling duct will increase the water evaporation rate inside the cooling duct. When the water evaporation rate increases, much heat will be absorbed by the water, evaporate and move out from the cooling duct. At this moment, the temperature of the cooling duct will become lower. The adjacent air around the cooling duct will also cooled by the cooling duct. Thus, the temperature of the chamber with cooling system will become low. For the chamber without cooling system, greater heat transferred from the roof will increase its temperature. This is because the chamber does not have any cooling system to absorb the heat. The heat will directly transfer to the chamber and thus the temperature of the chamber without cooling duct will higher. High heat source temperature will cause the cooling system functions better and the temperature of the chamber without cooling duct increases. This causes the mean temperature difference and maximum temperature difference between chamber with cooling duct and chamber without cooling duct become greater.

Mean temperature difference and maximum temperature difference between chamber with cooling system and chamber without cooling system increases when the air speed in the cooling duct increases. Greater air speed in the cooling duct will speed up the water evaporation rate in cooling duct. The greater the water evaporation rate in cooling duct, the lower the temperature of the cooling duct. Thus, more heat will be transferred into the cooling duct and the temperature inside the chamber will become lower. However, some experimental results are different from the theory. This is because the experiment sometimes will be affected by the environmental factors, such as different ambient humidity and weather. Generally, the experimental results follow to the theory that the cooling system will perform better when the air speed in the cooling duct and the temperature of heat source increase.
4.2 Simulation Result and Discussion

A prototype design model and an actual size design model were simulated for different conditions. Comparison of the results between prototype design model and actual size design model were done.

4.2.1 Prototype Design Model

After complete running the simulation, temperature of prototype design model was measured. To measure the temperature of the parts of prototype design model, two specific points were selected. Based on Figure 45, point 1 was located at the bottom part of the prototype design model while point 2 was located at the surface of the cooling duct.

Table 3: Temperature of specific points in the prototype design model with difference air speed and heat source temperature

<table>
<thead>
<tr>
<th>Heat Source Temperature (K)</th>
<th>Air Speed (m/s)</th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1m/s</td>
<td>3m/s</td>
<td>4m/s</td>
<td></td>
</tr>
<tr>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
<td></td>
</tr>
<tr>
<td>Point 1</td>
<td>Point 2</td>
<td>Point 1</td>
<td>Point 2</td>
<td>Point 1</td>
</tr>
<tr>
<td>313</td>
<td>310.0</td>
<td>308.9</td>
<td>307.8</td>
<td>307.2</td>
</tr>
<tr>
<td>323</td>
<td>315.7</td>
<td>313.3</td>
<td>310.0</td>
<td>308.9</td>
</tr>
</tbody>
</table>
Temperature of point 1 and point 2 in the prototype design model were simulated to show the performance of the cooling system in prototype design model with different heat source temperature and air speed. Based on Figure 46, temperature of point 1 increases with the increasing of the heat source temperature. This is because when the heat source temperature is higher, there are more heat entering and staying...
inside the prototype design model, thus the temperature of that specific point will be higher. There are three heat source temperature set in this simulation, which were 313K, 323K and 333K. For 0.1m/s air speed in cooling duct, temperature of specific point increases 5.7K when the heat source temperature increases from 313K to 323K while temperature of specific point increases 5.5K when the heat source temperature increases from 323K to 333K. It shows that the temperature of specific point has an almost linear increasing trend when the heat source temperature increases.

Based on Figure 46 and Figure 47, three different air speed will produce three different types of results. The higher the air speed inside the cooling duct, the lower the temperature of point 1 and point 2. Point with air speed 4m/s has the lowest temperature while point with air speed 0.1m/s has the highest temperature. By comparing Figure 46 and Figure 47, point 2 always has lower temperature than point 1. This is because cooling duct is the cooling source. According to the Figure 47, it has similar trend as Figure 46, the temperature of point 2 reduces when the air speed inside the cooling duct increases. This is because when larger air speed inside the cooling duct, the easier of the water evaporation occurs. When the forced ventilation is supplied within the cooling duct, the airborne water particles will be removed from the air and the humidity of air inside the cooling duct will reduce. Due to reducing of the humidity, the water molecules are easier to be evaporated inside the cooling duct. Greater efficiency of water evaporation inside the cooling duct will make the temperature of the cooling duct become lower. When the temperature of the cooling duct become lower, more heat from the roof can be cooled by the cooling duct and thus less heat will transfer into the attic. Hence, the temperature of point 1 and point 2 will reduce when the air speed within the cooling duct increases.
4.2.2 Actual Size Design Model

Figure 48: Temperature of specific positions measured in actual size design model simulation

Based on Figure 48, positions chosen to measure the temperature in actual size design model were same as the prototype design model. Point 1 was located at the bottom part of the prototype design model while point 2 was located at the surface of the cooling duct.

Table 4: Temperature of specific points in the prototype design model with difference air speed and heat source temperature

<table>
<thead>
<tr>
<th>Heat Source Temperature (K)</th>
<th>Air Speed (m/s)</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1m/s</td>
<td>3m/s</td>
<td>4m/s</td>
<td>0.1m/s</td>
<td>3m/s</td>
<td>4m/s</td>
</tr>
<tr>
<td></td>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
<td>Temperature (K)</td>
</tr>
<tr>
<td>Point 1</td>
<td>309.2</td>
<td>307.3</td>
<td>307.3</td>
<td>307.3</td>
<td>306.7</td>
<td>306.7</td>
</tr>
<tr>
<td>Point 2</td>
<td>314.3</td>
<td>310.9</td>
<td>310.9</td>
<td>310.8</td>
<td>308.7</td>
<td>308.6</td>
</tr>
<tr>
<td>Point 1</td>
<td>318.3</td>
<td>313.9</td>
<td>313.9</td>
<td>313.9</td>
<td>310.8</td>
<td>310.8</td>
</tr>
<tr>
<td>Point 2</td>
<td>323</td>
<td>311.3</td>
<td>311.3</td>
<td>311.3</td>
<td>310.6</td>
<td>310.6</td>
</tr>
<tr>
<td>Point 1</td>
<td>333</td>
<td>318.3</td>
<td>318.3</td>
<td>318.3</td>
<td>318.3</td>
<td>318.3</td>
</tr>
<tr>
<td>Point 2</td>
<td>333</td>
<td>313.9</td>
<td>313.9</td>
<td>313.9</td>
<td>313.9</td>
<td>313.9</td>
</tr>
</tbody>
</table>
Based on Table 4, Figure 49 and Figure 50, temperature of point 1 and point 2 in the prototype design model were simulated to show the performance of the cooling system in actual size design model with different heat source temperature and air speed.
The trend of actual size design model is same as the prototype design model. The temperature of point 1 and point 2 increase with the heat source temperature. Cooling duct with 4m/s air speed has the highest cooling effect while cooling duct with 0.1m/s has the lowest cooling effect. This is because the greater the air speed inside the cooling duct, the easier the water evaporation occurs inside the cooling duct. Thus, the temperature of the point 1 and point 2 will reduce.

4.2.3 Compare the Difference between Experiment Results with Simulation Results

Table 5: Difference between experimental results and simulation results

<table>
<thead>
<tr>
<th>Heat Source (°C)</th>
<th>Experiment results after applying cooling system (°C)</th>
<th>Simulation results after applying cooling system (°C)</th>
<th>Percentage of temperature difference between experiment results and simulation results (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>34.56</td>
<td>34.3</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Based on Table 6, for experimental results, the average temperature of bottom of chamber with cooling system with air speed 4m/s under reference temperature 39°C to 41°C can reach 34.56°C. For simulation results, the temperature of bottom of chamber with cooling system with air speed 4m/s under heat source temperature 40°C can reach 34.3°C. The temperature difference between the simulation result and experimental result is 0.26°C, which is only 0.75%.

4.2.4 Comparison of Results between Prototype Design Model and Actual Size Design Model

Table 6: Contours of temperature with difference heat source temperature and air speed

<table>
<thead>
<tr>
<th>Heat Source Temperature / Air speed within the cooling duct</th>
<th>Contours of temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Prototype design model</td>
</tr>
<tr>
<td></td>
<td>Actual size design model</td>
</tr>
<tr>
<td>Temperature / Velocity</td>
<td>Image 1</td>
</tr>
<tr>
<td>------------------------</td>
<td>---------</td>
</tr>
<tr>
<td>323K / 3m/s</td>
<td>![Image]</td>
</tr>
<tr>
<td>323K / 4m/s</td>
<td>![Image]</td>
</tr>
<tr>
<td>313K / 0.1m/s</td>
<td>![Image]</td>
</tr>
<tr>
<td>313K / 3m/s</td>
<td>![Image]</td>
</tr>
</tbody>
</table>
Table 7: Temperature difference of point 1 between prototype design model and actual size design model with difference air speed and heat source temperature

<table>
<thead>
<tr>
<th>Heat Source Temperature (K)</th>
<th>Temperature difference of point 1 between prototype design model and actual size design model (K)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0.1m/s</td>
</tr>
<tr>
<td>313</td>
<td>0.8</td>
</tr>
<tr>
<td>323</td>
<td>1.4</td>
</tr>
<tr>
<td>333</td>
<td>2.9</td>
</tr>
</tbody>
</table>

Based on Table 7, there are slightly temperature difference of point 1 between prototype design model and actual size design model. The largest temperature difference of point 1 between prototype design model and actual size design model is 2.9K while the smallest temperature difference of point 1 between prototype design model and actual size design model can reach 0.2K. The temperature difference exists in prototype design model and actual size design model because they have the different cooling duct size and difference attic size. Cooling duct is the cooling source, by having different size of cooling duct, the cooling effect will have slightly difference. Attic is the place that is needed to be cooled, by having different size of attic, the cooling effect produced will also different.
Chapter 5: Conclusion and Future Work

Domestic cooling system through roof ventilation assisted by evaporative cooling is designed in this project. It combines the theories of forced ventilation, natural ventilation and direct evaporative cooling to provide a balance of cooling effect, electricity consumption and water consumption. This project includes design, fabrication, experiment and simulation. The objectives of the project are achieved.

Two types of experiment are done in this project. First type of experiment is to measure the efficiency of the cooling system while second type of experiment is to measure the performance of the cooling system with different air speed in cooling duct. For first experiment, it found that cooling system with 4m/s air speed has the highest efficiency while the cooling system with 0m/s air speed has the lowest cooling efficiency. Based on the result, cooling system with 4m/s air speed has 49.3% efficiency, cooling system with 3m/s air speed has 47.7% efficiency and cooling system with 0m/s air speed has 36.7% efficiency. It shows that the efficiency of the cooling system increases when the air speed in the cooling duct increases. For second experiment, it found that the cooling system performs better when the air speed in the cooling duct and the temperature of heat source increase. Mean temperature difference and maximum temperature difference between chamber with cooling system and chamber without cooling system are found in second experiment. Cooling system with 4m/s air speed within the range of reference temperature 41°C to 43°C has the highest cooling performance, which can reduce 10.58°C.

For simulation part, prototype design model and actual size design model are simulated. Two points are selected to detect the temperature which the point 1 is located at the bottom part of the prototype design model while point 2 is located at the surface of the cooling duct. The simulation results show that the temperature of the model can achieve lower when the air speed within the cooling duct is larger. This is because the greater air speed in the cooling duct speed up the water evaporation process and makes the cooling duct become cooler. The temperature of the model is lower when lower heat source temperature is supplied because not much heat is needed to be absorbed and removed by the cooling duct. By comparing the performance of prototype design model and actual size design model, the largest temperature difference of point 1 between prototype design model and actual size design model is 2.9°C while the smallest
temperature difference of point 1 between prototype design model and actual size design model can reach 0.2°C. Temperature difference exists in these two design models because they have the different cooling duct size and difference attic size. However, the temperature difference between prototype design model and actual size design model is not large, thus the prototype design can be used to do the experiment.

The simulation results of prototype model design are compared with the experimental results. For experimental results, the average temperature of bottom of chamber with cooling system with air speed 4m/s under reference temperature 39°C to 41°C can reach 34.56°C. For simulation results, the temperature of bottom of chamber with cooling system with air speed 4m/s under heat source temperature 40°C can reach 34.3°C. The percentage of temperature difference between the simulation result and experimental result is only 0.75%, it is still acceptable.

To improve the project, some further works are needed. In this project, the experiment is carried out at outside. The disadvantage of carrying out experiment at outside is the experiment will be affected by the surrounding factors, such as weather and humidity. Thus, a temperature & humidity control room is needed. With the temperature & humidity control room, the temperature and humidity can be controlled to do the experiment, more accurate results can be collected. Besides that, electricity and water consumption detector can be used in the future. By having the electricity and water consumption detector, the electricity and water consumption of the cooling system can be measured. Apart from that, size of water particles can be studied in the future. The optimum size of water particles can be known to ensure the optimum water evaporation process can be carried out.
REFERENCES


**Figure 51: Specification of roller fan**

<table>
<thead>
<tr>
<th>Spec. Code</th>
<th>Voltage, V</th>
<th>Frequency, Hz</th>
<th>Input Power, W</th>
<th>Rated Current, A</th>
<th>Locked Current, A</th>
<th>Speed, RPM</th>
<th>Maximum Air Flow, m³/min</th>
<th>Maximum Air Flow, CFM</th>
<th>Maximum Pressure, mmH₂O</th>
<th>Maximum Pressure, inH₂O</th>
<th>Noise, dB</th>
<th>Weight, kg</th>
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<tbody>
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<td>0.46</td>
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<td></td>
<td></td>
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<td>2600</td>
<td>5.0</td>
<td>177</td>
<td>5.0</td>
<td>0.20</td>
<td>50</td>
</tr>
<tr>
<td>60</td>
<td>37</td>
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