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

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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.

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Chai Yik Zhien

131136

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EQUATIONS

$Tw = T \, atan[0.151977(RH\% + 8:313659)^{0.5}] + atan(T + RH\%) - atan(RH\% - 1.676331) + 0.003\,91838(RH\%)^{1.5} \, atan(0.023101RH\%) - 4.686035$	(1)
$Efficiency = \frac{Ambient\ temperature - Cooling\ duct\ temperature}{Ambient\ temperature - Wet\ bulb\ temperature}\ x\ 100\%$	(2)

ABSTRACT (BM)

Cuaca Malaysia agak panas. Cuaca yang panas mengakibatkan suhu dalam bangunan panas. Bumbung adalah tempat yang menyerap fluks haba. Pengudaraan bumbung diperlukan untuk mengurang haba dari bumbung. Terdapat banyak cara pengudaraan bumbung yang wujud sekarang tetapi mereka ada keburukan, contohnya kurang kecekapan dan banyak kehilangan tenaga. Dalam projek ini, sistem penyejukan domestik melalui pengudaraan bumbung dengan bantuan penyejukan penyejatan telah direka. Prestasi sistem penyejukan domestic ini dikaji melalui eksperimen dan simulasi. Sistem penyejukan domestik melalui pengudaraan bumbung dengan bantuan penyejukan penyejatan ini mengabung teori pengudaraan semula jadi, pengudaraan paksa dan penyejukan penyejatan langsung. Melalui sistem ini, tenaga yang guna untuk sistem penyejukan ini boleh dijimatkan. Reka bentuk, fabrikasi, eksperimen dan simulasi telah dibuat dalam projek ini. Bagi bahagian reka bentuk, satu model yang saiz benar dan satu model prototaip telah direka. Bagi bahagian fabrikasi, model prototaip telah dibina untuk eksperimen. Bagi bahagian eksperimen, dua eksperimen telah dibuat dalam projek ini. Tujuan eksperimen pertama adalah untuk mengaji kecekapan sistem penyejukan ini. Tujuan eksperimen kedua adalah untuk mengaji prestasi sistem penyejukan dengan kelajuan udara yang berbeza dalam saluran penyejukan. Simulasi dibuat untuk membanding prestasi model prototaip and prestasi model saiz sebenar dalam keadaan yang berbeza. Hasil simulasi juga dibanding dengan hasil eksperimen. Hasil eksperimen menunjukkan sistem penyejukan dengan kelajuan udara 4m/s ada kecekapan penyejukan yang tertinggi, iaitu 49.3%. Prestasi sistem pengudaraan bumbung dengan bantuan penyejukan penyejatan yang tertinggi telah berjaya mengurangkan suhu sebanyak 10.58^{o}C. Perbezaan suhu antara hasil simulasi dengan hasil eksperimen ialah 0.26^{o}C. Keputusan ini boleh diterima. Oleh itu, sistem penyejukan domestik melalui pengudaraan bumbung dengan bantuan penyejukan penyejatan adalah cekap.

ABSTRACT (BI)

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^{o}C. The temperature difference between the simulation result and experimental result is only 0.26^{o}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 CO_2 (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^{o}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).

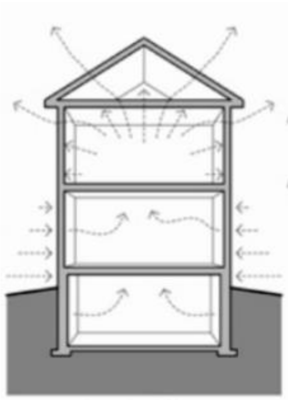

Figure 1: Example of Stack effect. Image courtesy : Building Science Corporation,www.buildingscience.com

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^o to 45^o has the best performances while wind enters the window at angle 90^o 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).

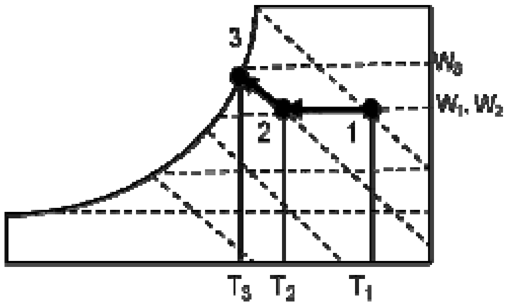

Figure 2: Schematic diagram of direct evaporative cooling system. Image courtesy : Abbouda et al., 2012

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^{o}C, which able to reduce 1^{o}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 form 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^{o}C by using direct evaporative cooling.

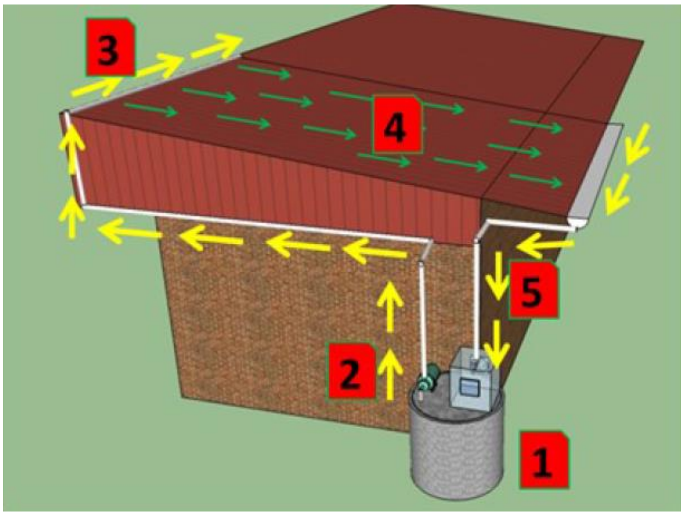

Figure 3: Schematic diagram of water recirculation system. Image courtesy : Ab Rahman et al. (2014)

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:

$$Tw = T\ atan[0.151977(RH\% + 8:313659)^{0.5}] + atan(T + RH\%) - atan(RH\% - 1.676331) + 0.003\ 91838(RH\%)^{1.5}\ atan(0.023101RH\%) - 4.686035 \quad (1)$$

T_w = wet bulb temperature, T = ambient temperature and RH = 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.

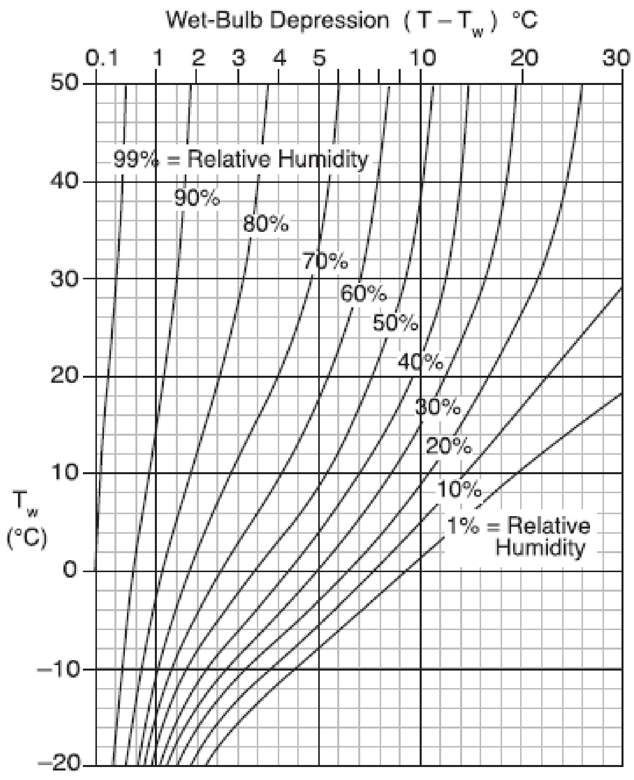

Figure 4: Psychrometric graph for 101.325kPa. Image courtesy: STULL (2011)

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 increases when the air conditioning is used. During the use of air conditioning, the mean concentration of CO increases from 220μg/m^3 to 905μg/m^3 while the mean concentration of CO_2 increases from 920μg/m^3 to 1711μg/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.

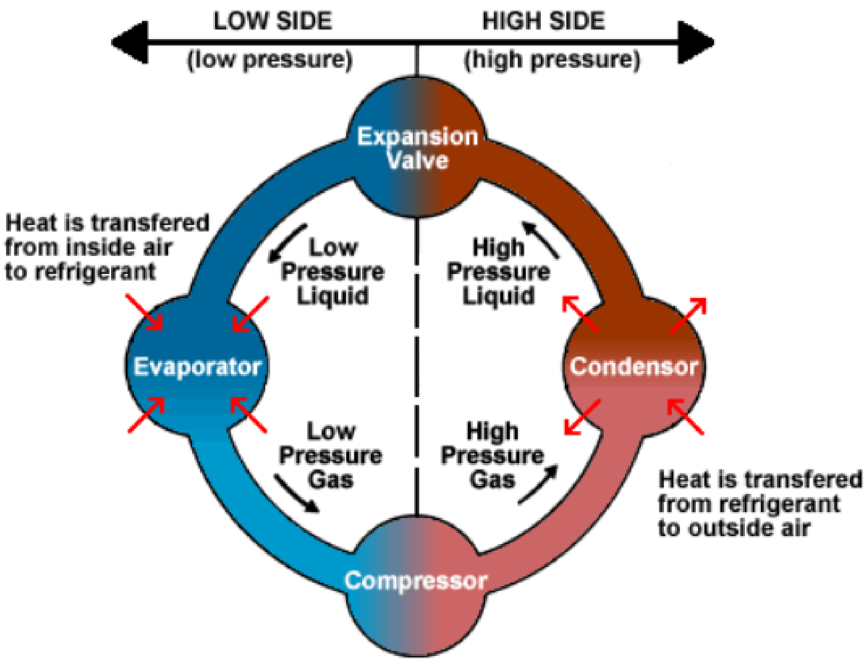

Figure 5: Basic Refrigeration Cycle. Image courtesy: https://www.swtc.edu/Ag_Power/air_conditioning/lecture/basic_cycle.htm

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.

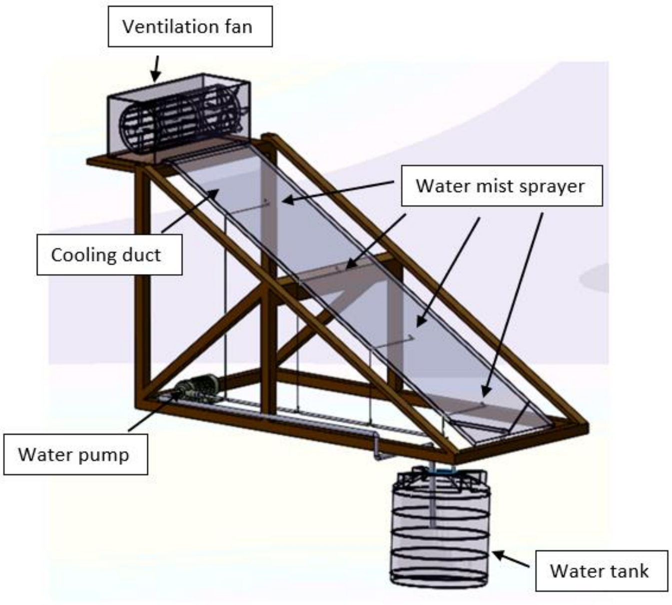

Figure 6: Details of actual size design of domestic cooling system

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.

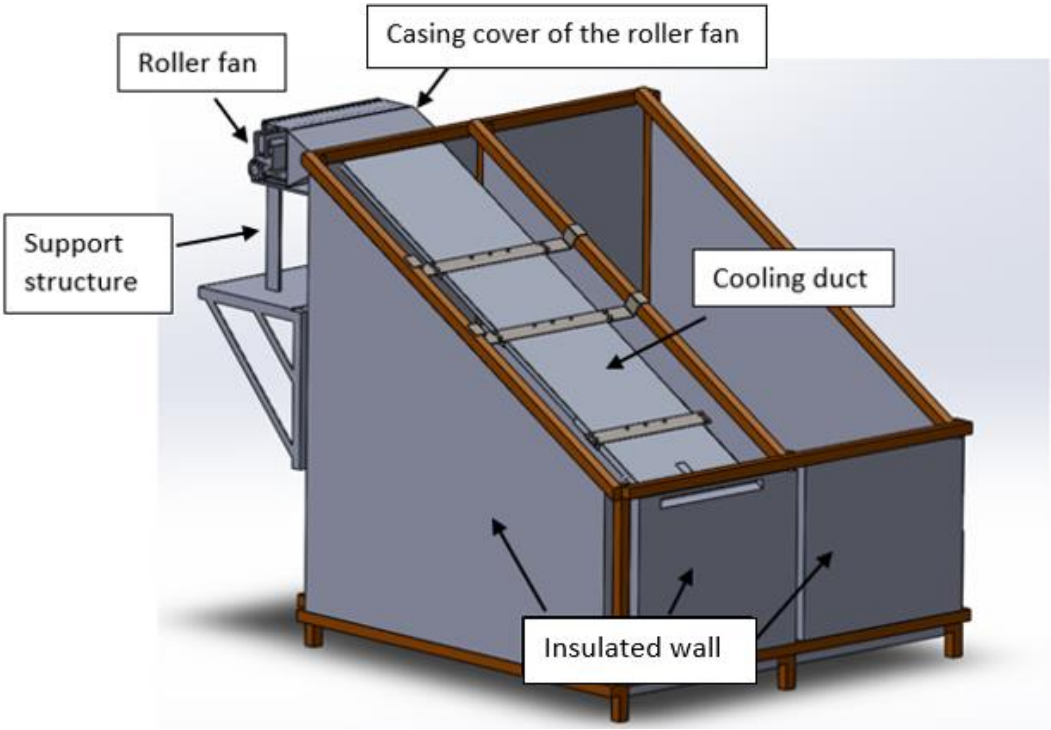

Figure 7: Details of prototype design of domestic cooling system

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.

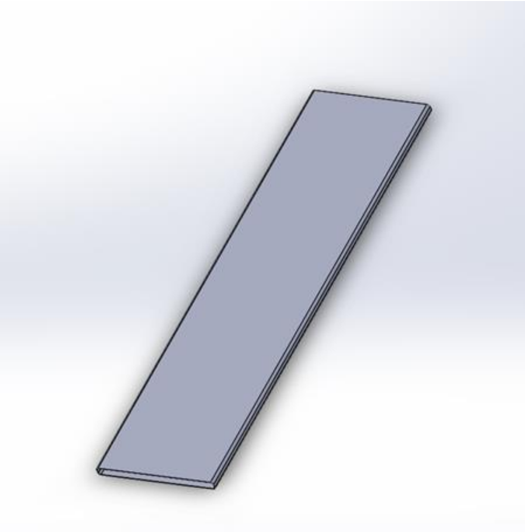

Figure 8: Design of the cooling duct

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.

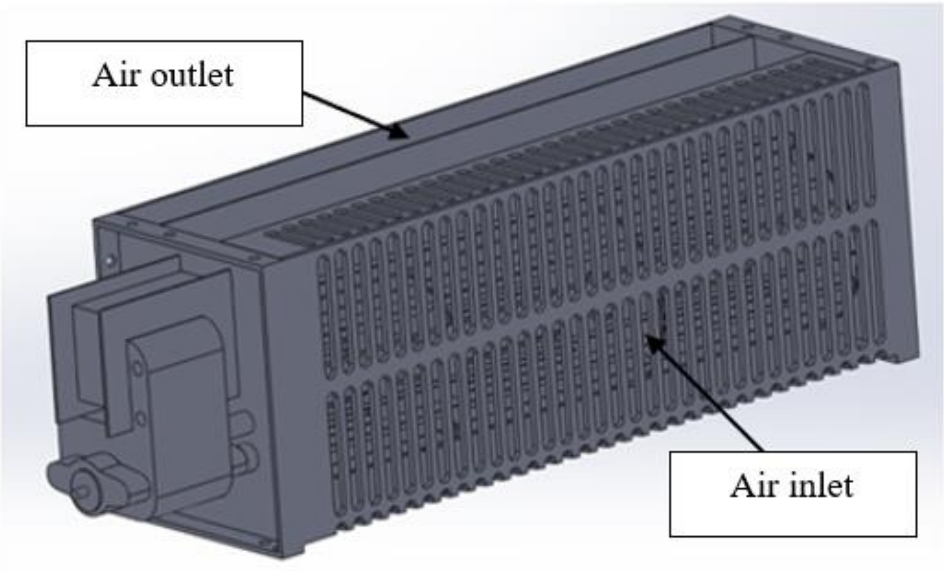

Figure 9: Roller fan

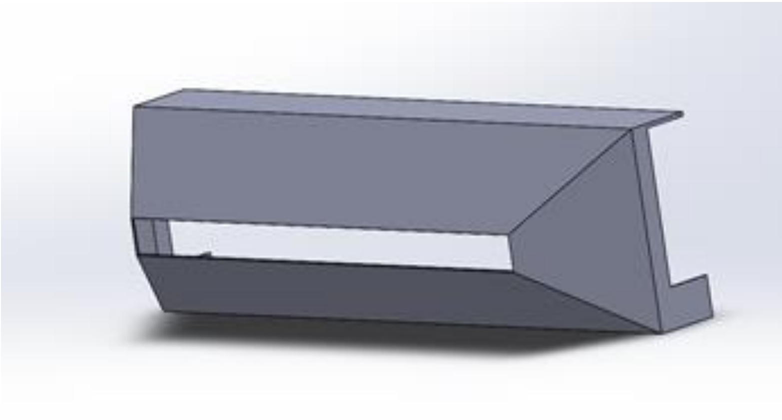

Figure 10: Casing cover of the roller fan

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.

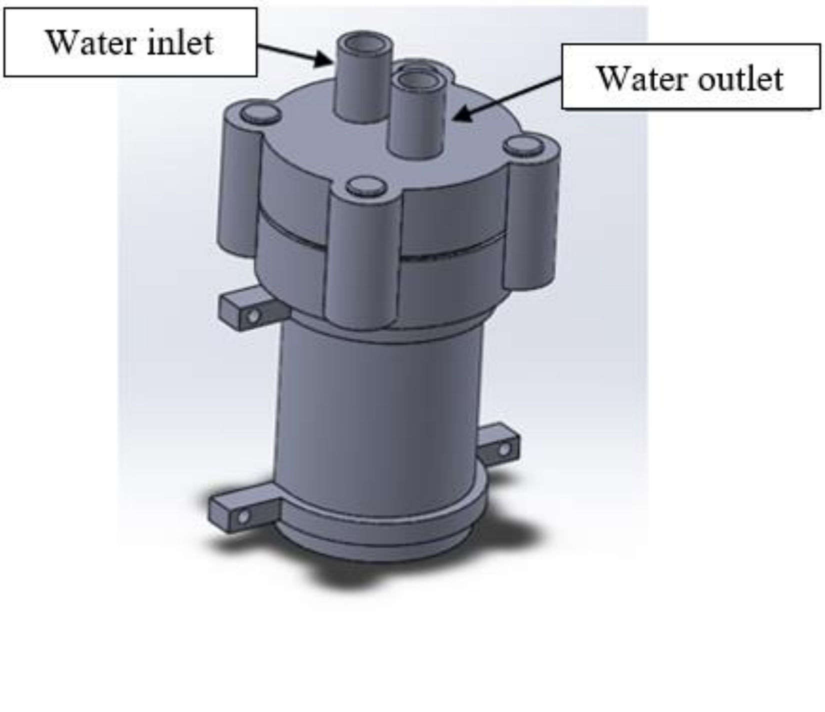

Figure 11: Water diaphragm pump

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.

Figure 12: Plywood sheets which are nailed to the test house

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.

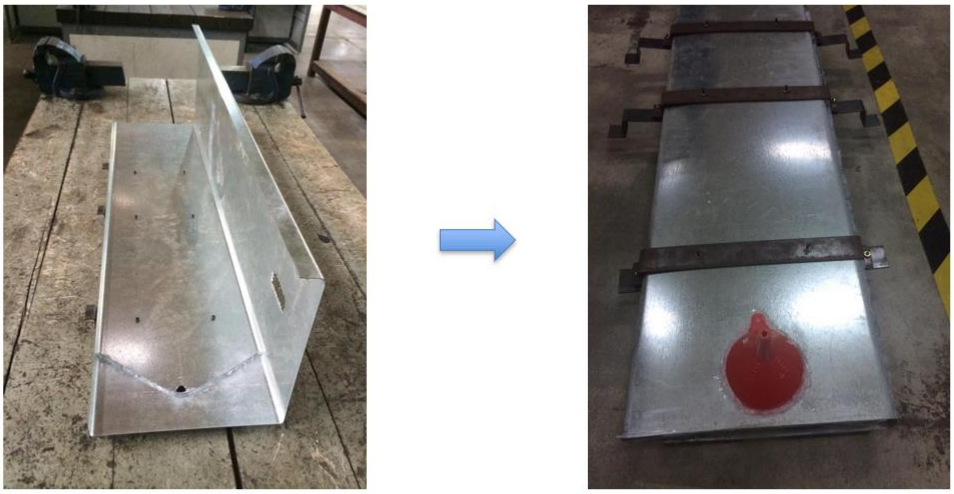

Figure 13: Fabrication process of cooling duct

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.

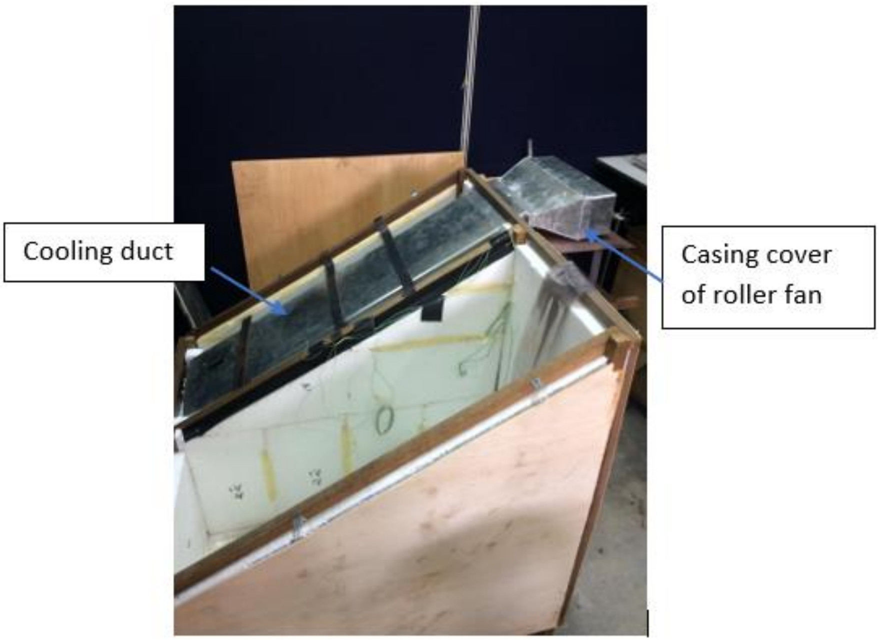

Figure 14: Casing cover of roller fan and cooling duct

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.

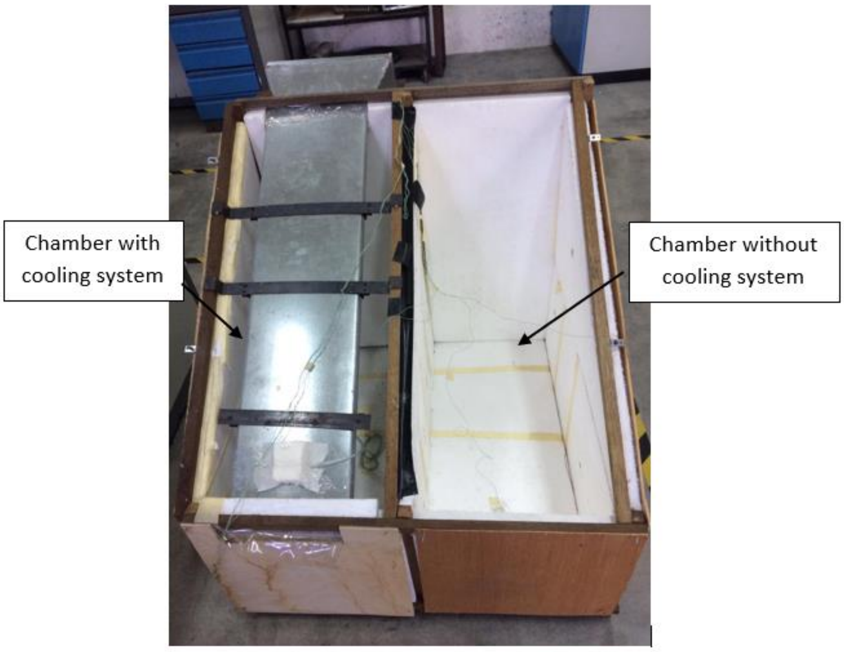

Figure 15: Inner design of the prototype

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).

$$Tw = T\ atan[0.151977(RH\% + 8:313659)^{0.5}] + atan(T + RH\%) - atan(RH\% - 1.676331) + 0.003\ 91838(RH\%)^{1.5}\ atan(0.023101RH\%) - 4.686035 \quad (1)$$

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

$$\text{Efficiency} = \frac{Ambient\ temperature - Cooling\ duct\ temperature}{Ambient\ temperature - Wet\ bulb\ temperature}\ x\ 100\% \quad (2)$$

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.

Figure 17: Transformer and roller fan

Figure 18: Water circulation system

Figure 19: Water mist sprayer

Figure 20: Thermocouple

Figure 21: Pico USB TC-08 device

Figure 22: USB DATALOGGER

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 Recoder 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.

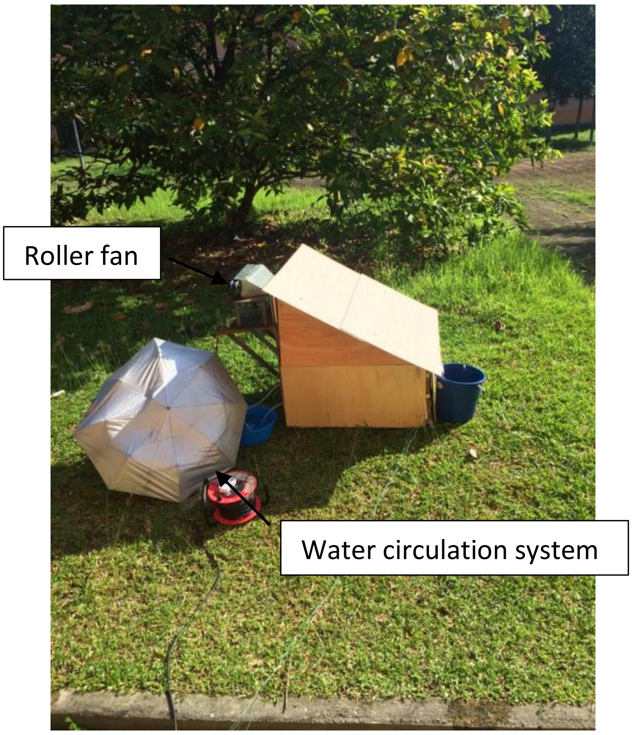

Figure 23: Set up of experiment