Design and Study of Domestic Cooling System through Roof Ventilation assisted by Evaporative Cooling

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May 2018

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

Universiti Sains Malaysia

Declaration

I hereby declare that this thesis entitled "Design and Study of Domestic Cooling System through Roof Ventilation assisted by Evaporative Cooling", which I now submit for assessment as the final year project on the programme of study leading to the award of Bachelor of Mechanical Engineering (Hons), is a record of an original work done by me 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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17/5/2018

Acknowledgement

First of all, I am using this opportunity to express my gratitude and special thanks to my supervisor Dr Chan Keng Wai who took time out to hear, guide and keep me on the correct path throughout the period of project. With advice and support from my supervisor, I able to learnt a lot and manage to work on my project successfully on time. Without his guidance and help, this dissertation would not have been possible.

Besides that, I wish to thank Dr Khaled Ali Mohammad Al-Attab for the excellent advice about the knowledge of heat transfer. The advice is importance during the early stage of the final year project which is known as the cooling system designing stage. Next, I also like to thank Dr. Mohd Sharizal Abdul Aziz for the advice about the knowledge of simulation. His comments help me to improve my work and making my project presentable.

I would like to thank my friends especially Peh Ching Guan who help me a lot to move the test house around indoor and outdoor during the experiment stage. Without their help, I would not able to set up the apparatus for experiment purpose. Last but not least, I dedicate this thesis to my parents who unconditional support me physically and mentally throughout the project.

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List of Symbol and Abbreviations

A_s	Heat Transfer Area of Cooling Duct
C_p	Specific Heat Capacity of Air
D_h	Hydraulic Diameter
D	Hydraulic Diameter
f	Friction Factor
h	Convection Heat Transfer Coefficient
k	Thermal Conductivity of Air
$\dot{m}$	Mass Flow Rate of Air
Nu	Nusselt Number
Pr	Prandtl Number
Re	Reynold Number
$\dot{Q}$	Heat Transfer Rate
T_e	Air Outlet Temperature
T_i	Air Inlet Temperature
T_s	Temperature of Surface of Cooling Duct
ΔT_{lm}	Mean Temperature Difference
V_m	Mean Velocity of Air Flow inside Cooling Duct
v	Kinematic Viscosity of Air
CP	Cooling Performance
CS	Cooling System

DC	Direct Current
DCS	Domestic Cooling System
EC	Evaporative Cooling

Abstrak (BM)

Pada masa depan, permintaan penghawa dingin semakin tinggi untuk mencapai keselesaan terma manusia akibatnya urbanisasi dunia. Sesuatu cara telah diperkenalkan untuk mencapai keselesaan termal melalui pengurangan fluks haba dari bumbung rumah. Oleh itu, system penyejukan direkabentukan dengan gabungan pengudaraan semula jadi, pengudaraan berkuat kuasa dan penyejukan melalui penyejatan air dengan penggunaan air yang rendah dan penggunaan elektrik yang rendah. Prototaip yang berskala rendah dan rumah ujian telah dibina untuk menguji prestasi sistem penyejukan. 4 termokopel dipasang ke dua bahagian rumah ujian untuk mengukur suhu. Rumah ujian diletakkan di bawah matahari dari 10 pagi hingga 3 petang sehari untuk eksperimen. Prestasi peranti penyejuk diukur dengan membandingkan perbezaan suhu antara dua bahagian rumah ujian yang hanya satu daripada bahagian dipasang dengan sistem penyejukan. Model prototaip yang berskala - rendah dan model yang saiz sebenar sistem penyejukan telah dibina untuk simulasi untuk menyiasat prestasi sistem penyejukan domestik dan bandingkan keputusan eksperimen. Keputusan eksperimen menunjukkan bahawa bahagian dengan sistem ujian rumah ujian lebih sejuk daripada bahagian tanpa sistem penyejukan sehingga 5.97 ℃. Keputusan menunjukkan bahawa prestasi penyejukan meningkat apabila peningkatan suhu rujukan. Hasilnya juga menunjukkan bahawa saluran penyejukan dengan kelajuan udara perbezaan dilakukan dengan baik dalam pelbagai suhu rujukan. Hasil simulasi menunjukkan bahawa prestasi penyejukan tertinggi ditunjukkan semasa keadaan kelajuan udara rendah (1m / s) untuk semua keadaan sumber haba. Perbezaan di antara pengiraan teori, keputusan eksperimen dan keputusan simulasi adalah disebabkan oleh perbezaan prestasi muncung semburan kabus. Boleh disimpulkan bahawa sistem penyejukan domestik yang baik direka bentuk. Ia dapat berfungsi dengan baik (sehingga 5.97 ℃) dengan penggunaan air yang rendah dan penggunaan elektrik yang rendah.

Abstract (BI)

There is an increasing trend of demand of air conditioning increase to achieve thermal comfort of human due to urbanization of the world in the future. An alternative way is introduced to achieve the thermal comfort which is reducing the amount of heat flux from house's roof. Hence, a CS with combination of natural ventilation, force ventilation and water evaporation is designed to achieve cooling process with low water consumption and low electricity consumption. A scale – down prototype and test house is built to test the performance of the CS. 4 thermocouples are installed to two section of test house to measure temperature. The test house is placed in the sun from 10am to 3pm of a day for experiments. The performance of the cooling device was measured by comparing the temperature difference between two sections of the test house which only one of the sections is installed with CS. Model of scale – down prototype and actual size of CS is built for the simulation to investigate the performance of the DCS and compare the result of the experiment. The experiment results show that the section with CS of test house is cooler than the section without CS up to 5.97℃. Result shows that CP is increase as the reference temperature increase. The Result also shows that cooling duct with difference air speed is performed well in difference range of reference temperature. The result of the simulation shows that the highest CP is shown as the air speed condition is low (1m/s) for all heat source conditions. The difference among the theoretical calculation, experimental result and simulation results are due to the difference of performance of mist spray nozzle. It can be concluded that a good DCS is designed. It can performance well (up to 5.97℃) with low water consumption and low electricity consumption.

Chapter 1: Introduction

1.1 Overview of Project:

DCS is a system that employed to house to enables a cooling process for an enclosed-space area of house to achieve thermal comfort for human. According to the Standard 55-2010 by ANSI/ASHRAE, thermal comfort is the condition of mind which expresses satisfaction with the thermal environment. It is assessed by subjective evaluation [1]. Although it is a subjective evaluation, the thermal comfort is strongly related to temperature. Therefore, demand of CS will be higher especially for the country like Malaysia with hot weather. This can be support by the report of Tetsu Kubota et al, the report mentions that the air conditioning is the biggest contributor of domestic energy consumption in Malaysia in 2009 which has average value about 1167kWh as shown as figure 1.1 [2]. Based on the infobook of the NEED project, there is 47% of domestic energy usage are used for the cooling and heating process to maintain the desired temperature of the home in the world [3]. The world energy statistic 2017 states that the electricity consumption of world is about 470 Mtoe in year 2015 (27.1% of total electricity consumption) which is increase from 101Mtoe (23% of total electricity consumption) in year 1973 as shown in figure 1.2 [4]. It also shows an increase trend of domestic electricity consumption in figure 1.3. On the other words, it also can be say that the electricity consumption of air conditioning is increases years by years. Hence, it is important to introduce an alternative way to reduce the room temperature rather than employ an air conditioning that consumes a lot of electricity. Reducing the amount of heat flux from house’s roof is acted as the alternative way to reduce indoor temperature. This is because roof receives the highest heat flux compare to other parts of a building. As the heat flux from the roof is reduced, the indoor temperature is reduced. Hence, a proper design of DCS is needed to reduce the heat flux from the roof is important to achieve the thermal comfort and reduce the load of the CS such as air conditioning system.

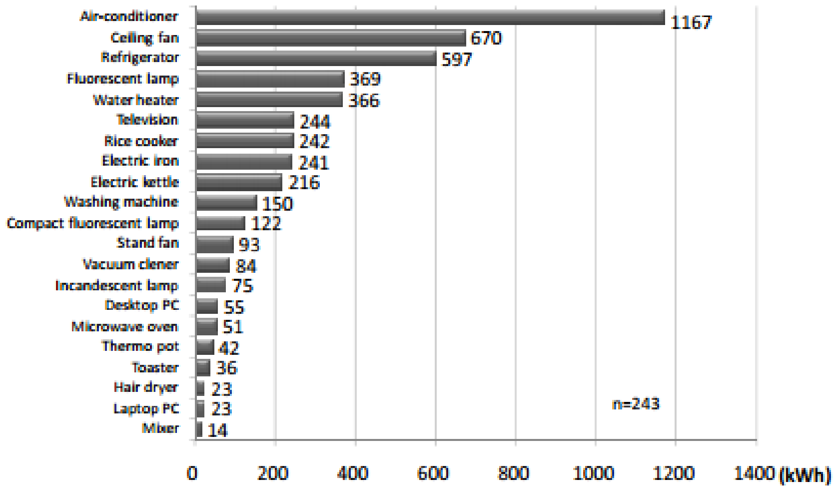


Figure 1.1: Yearly Electricity Consumption of Household in Malaysia[2]

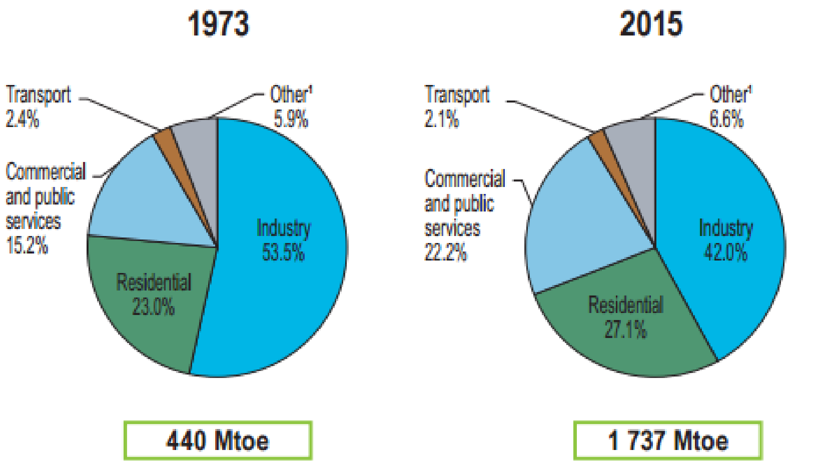


Figure 1.2: World Electricity Consumption [4]

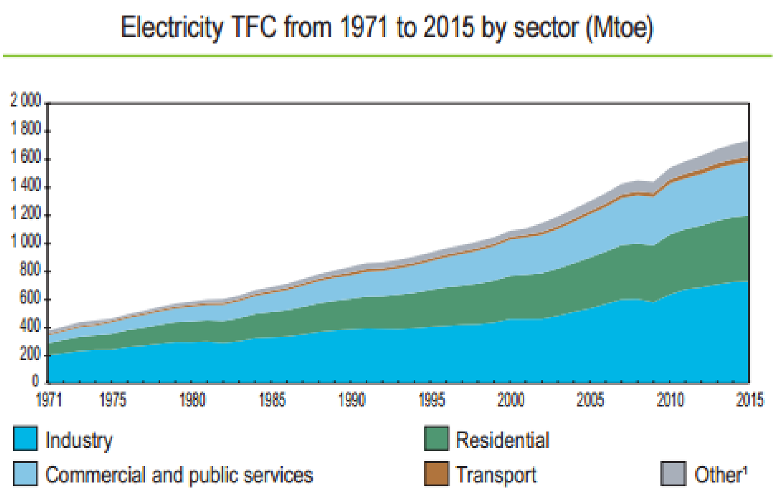


Figure 1.3: Total Electricity Consumption [4]

1.2 Problem Statement:

Large amount of heat flux is transferred from the roof into house due to its location. Hence, reduce the heat flux transfer from roof become a good selection to reduce indoor temperature. There are many existing methods but those methods have its disadvantages.

There ways that is able to reduce the heat flux from the roof are roof ventilation, insulation, EC, and reflection of roof tiles. In country with hot climate, a proper thermal insulation of roof can reduce the indoor temperature and reduce air conditioning load. This sustainable method shows an increasing trend of insulation usage in the future to achieve thermal comfort due to urbanization of the world [5]. There are many type of insulation used for attic insulation. Difference types of the insulation material have their advantages but they also limitation related to cost, moisture trapping, insulating performance.

The natural ventilation shows that it has low effectiveness to reduce the indoor temperature through heat convection due to the flow of air. As compare with vented attic, unvented attics in hot-dry climates have a small effect on cooling energy use when duct leakage is small [6]. It means that the vented roof only shows small effect for saving of cooling energy. Soffit vent does not help in reducing room air temperature during daytime as most designers expect [7].

The forced ventilation increases the rate of flow of the air below the roof and removes the heat through heat convection. It is able to reduce the indoor temperature and reduce the work load of the air conditioning. Although it can reduce the usage of the electricity of air conditioning, it shows high electricity consumption. The powered attic ventilator (forced ventilation) has shows that the electricity consumption of the ventilation fans used is higher than the electricity saved by air conditioning [8]. The roof surface EC shows a significant reduce of temperature of roof and indoor temperature. It is able to reduce the usage of electricity of air conditioning.

The effectiveness of the direct evaporating cooling is high but it also has high water consumption. The quantity of water need is approximate 10kg/day/m2 during peak summer [9]. The cool roof shows a good impact to reduce the surface temperature of the roof up to 20 ℃ and the indoor temperature shows an average reduction about 2.3℃ [10]. As the insulation of the building is increases, the cool roof might show poor performance compare to building with normal insulation [10].

The ways of reducing heat flux from roof shown above have its advantages but they also have its disadvantages. Hence, there is a demand of system with great efficiency of heat flux reduces, acceptable electricity consumption, and low consumption of water. Hence, the DCS through roof ventilation assisted by EC is studied and designed. This system can be known as a design that has a balance of cooling effectiveness, water consumption and electricity consumption.

1.3 Objective:

1) To design a DCS through roof ventilation assisted by water evaporation.

2) To investigate the performance of designed DCS through experiment and simulation.

1.4 Scope of Project:

The project is including design, fabrication, simulation, experiment. The DCS is first designed and makes improvement. As the design stage was finished, the fabrication stage was started. The Fabrication is included building of a scale – down prototype and a small house which is acted as a test house in the experiment. The Prototype was placed into one of two chamber of test house and enclosed the test house by roof. The experiment is carried by placing the test house in the sun. Thermocouples were used to measure the temperature inside two chambers of test house. Performance of cooling effect of prototype is measured by comparing two chamber temperature of test house. Simulation was done to measure the performance of DCS of the prototype and the actual size design.

1.5 Thesis Outline

This thesis is separated into five chapters which are introduction, literature review, methodology, result and discussion, and conclusion respectively. The first chapter is discussed about the introduction of the project and the problem statement that exist for this project.

This chapter also included the objective and the scope of the project. In chapter two, different sources of the literature that related to the methods that reduce heat flux from roof such as ventilation, EC, and cool roof are reviewed. This chapter describes about the working mechanism of reducing heat flux, valuate and summaries the information of the literature to find out a proper solution of DCS design.

The third chapter of this thesis is methodology. In this chapter, the solution of the design of DCS is proposed and shown in 3D CAD drawing. The detail of the designed component is discussed based on the figure. This chapter also comprises the setup and procedure of the experiments and the setup of simulation which are conducted for measuring the CP of the DCS that has been designed.

In the fourth chapter, the result of the experiment and simulation is shown in graphs, figures and tables. The finding of the experiment and simulation is discussed and explained about the reason behind it.

The last chapter concluded the finding of the project and summarized the reason behind the finding of the project. Future work also discussed in this chapter based on the finding of this project.

Chapter 2: Literature Review

2.1 Background of Reducing Heat Flux from Roof

The ways of reducing the heat flux from the roof are roof ventilation, EC, and reflection of roof tiles. The detail of those methods is discussed below. In this project, the combination of the roof ventilation and EC is the main idea of the project.

2.2 Roof Ventilation

There are two types of ventilations which are natural ventilation and mechanical ventilation (force ventilation)[11].

2.2.1 Natural Ventilation

The natural ventilation is used to reduce the temperature underside of the roof through heat convection of the air. As there is natural flow of the air, the heat underside of the roof is absorbed by the air and heat is removed as the air is leaving the building. The natural flow of the air is due to the stack effect of underside of roof and it is not required any mechanical system to force the air.

Stack effect is known as natural vertical movement of the air within a building due to pressure differentials, which are caused by temperature difference [12]. The higher temperature of air underside the roof causes its density is reduced. Hence, its density is less than the outdoor air and a positive buoyancy force is existed due to difference of air density. The buoyancy force forces the air underside of roof with less density to rise vertically and leave the building from the vent. The pressure underside the roof is reduced and the pressure difference of air force the outdoor air to flow into the building through the vent. Therefore, passive flow of the air underside of roof is done and the heat of the building is transferred to the air by natural convection as the air is circulated.

The study of Beal and Chandra, 1995 show that the natural ventilation of roof is low in some condition [13]. The experiments were conducted at a flexible roof testing facility (FRF) as shown in figure 2.1. The roof and attic of the building are partitioned and sectioned into six individual test bays. Those sections are separated by insulated partition walls and R-19 ceiling insulator was installed between the trusses in all attic test sections. For the testing the effectiveness of existence of soffit vent and ridge vent, the result shows that the existing of soffit vent only for the roof shows a low reduction of heat flux from insulated surface to interior of the building which is only 3% of reduction. The effectiveness of the natural ventilation show a significant effectiveness as the roof has both soffit vent and ridge vent. The result shows that the reduction of the heat flux is 32%.

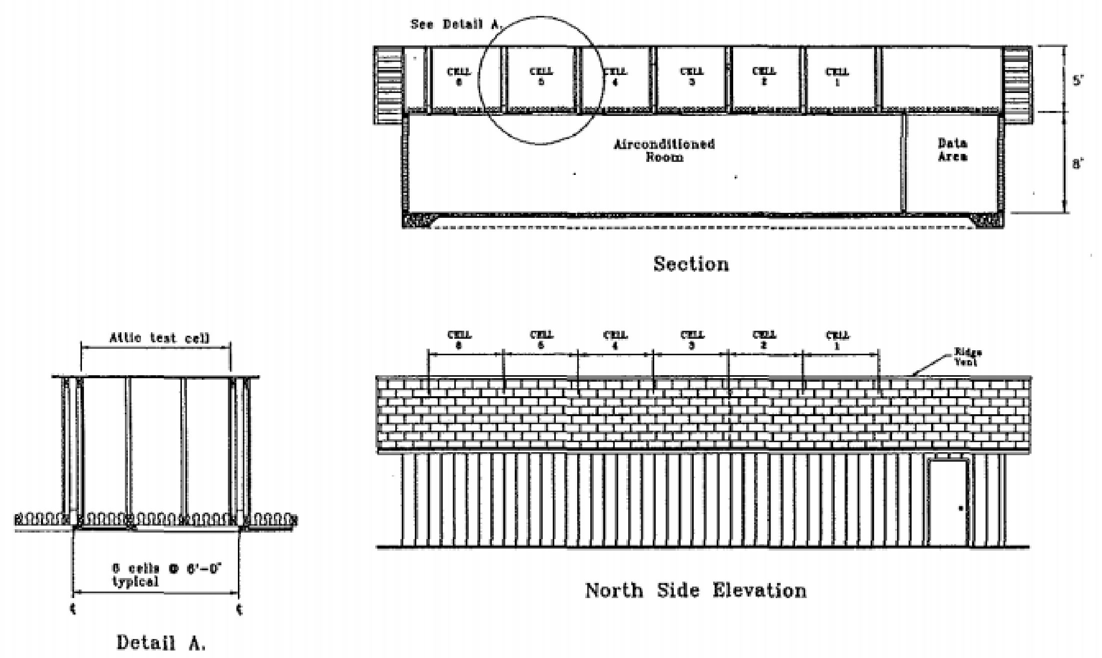
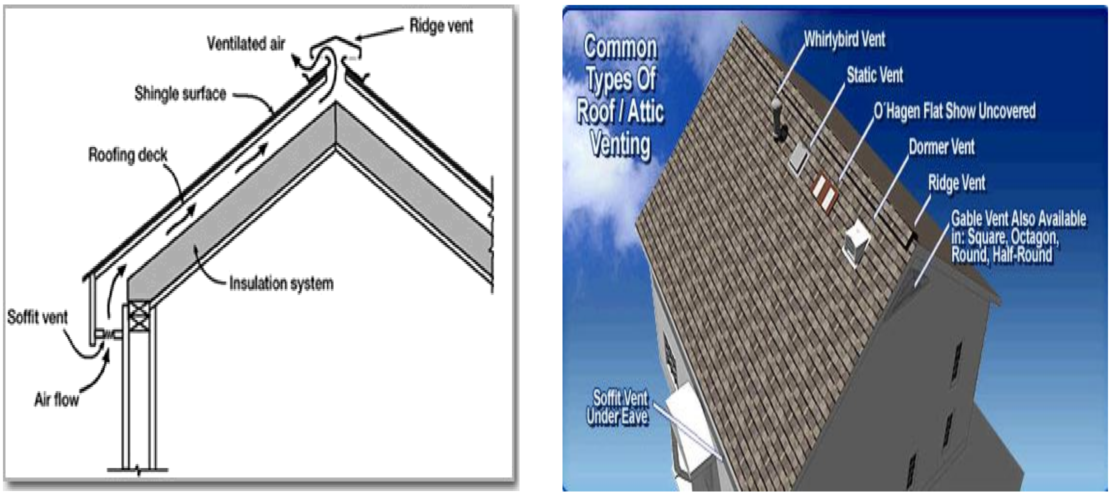


Figure 2.1: The flexible Roof Facility[13]

According to study of Pantuda Puthipiroj (2007), the result shows that soffit vent does not help in reducing room air temperature during daytime as most designers expect [7]. In this study, the comparison between the efficiency of the soffit vent and thermal insulator is done. Experiment is conducted in Bangkok and two three-storey row houses selected. The room on top floor with 4x5 m is selected as a test room for each house to record the electricity consumption. One house having wooden soffit vent while another house with sealed attic. Five experiments are conducted to compare the sealed attic with different condition to the vented attic in day and night. These conditions are existing of insulations, existing of air conditioning control, existing of fiberglass. Efficiency in reducing heat gain of the attic ventilation is lower than using fiberglass insulation in the sealed attic as compare the electricity consumption of the test room. The hourly average electricity consumption was 0.75 kWh for vented attic and 0.29 kWh for sealed attic during day time from 9 A.M. to 6 P.M while hourly average electricity consumption was 0.32 kWh for vented attic and the 0.17 kWh for sealed attic during night time from 9 P.M to 6 A.M. This result shows that the efficiency of reducing heat flux for using soffit vent only. The other type of vented is not used in these experiments.

Hendron et al. (2003) conducted the test to find out the cooling energy savings for unvented attics in several hot and mixed climates [6]. The energy saving is based on the comparison of energy usage between sealed attic and vented attic. Direct measurements of the performance of attics are done under realistic field conditions and estimate annual energy savings for unvented attics with the help of a calibrated model. Two test houses which nearly identical are used. The only difference between two test houses are R 30 insulator is used at ceiling, vented and tile roof for vented attic while R-22 insulator is used at roof plane, unvented and tile roof for sealed attic. The result shows that vented and unvented attics are strongly influenced by the amount of duct leakage regardless of climate. In hot-dry climates, vented attics have a small effect on cooling energy usage as duct leakage is small. This study shows that the effect of using the vented attic is small while the control of the leakage has significant cooling energy loss no matter the climate of the house is hot or not.



(a) (b)

Figure 2.2: Types of Vents with (a) Cross – Sectional View of Building [14], (b) Isometric View of Building [15]

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Natural ventilation is a cooling method that does not consume any water and electricity. This method can be achieved by a proper design of the roof of the house such as adding the structure like ridge vents, soffit vent, gable or dormer vents as shown in figure 2.2 the roof ventilation can be achieved. The cost of installing the vents to the building is relatively low compared to other methods. The cost of installing the ridge vents is higher than other vents as it is required to install along the roof. Although natural ventilation has these advantages, its disadvantage is also significant. The natural ventilation shows a low effectiveness from the study above. The natural ventilation only works better as the attic has both continuous ridge vent and soffit vent is installed. Ridge vent with small lengths is not necessary for good air circulation of the attic but the long ridge which has lots open space may possible affected by the wind- blown rains. It may cause wetting of the attic sections.

Due to the reasons above, the conventional natural ventilation system is not considered for the design of the cooling domestic system in this project. But the idea of the natural ventilation is introduced for the system due to the natural ventilation is able to reduce the electricity usage. As a cooling source is added below the roof, the natural ventilation can be achieved underside the roof without installing those types of vents.

2.2.2 Forced Ventilation

The mechanical ventilation or force ventilation is a system of ventilation in which air is forced through ventilation ducts under pressure [16]. The forced ventilation also removes the heat energy through the convection of heat. As the air is flow underside the roof, it absorbs the heat energy and remove the heat energy as it flow out from the building. Although the forced ventilation is worked based on the convection of heat, it required devices that can circulate the air through the roof such as fans and blowers as shown in figure 2.3. The fans and blower create a pressure difference and force outdoor air to flow through the roof and the heat of roof is transfer to the air by convection. Due to the flow of the air is affected by the power of device, force ventilation has a higher rate of air flow compare to natural ventilation. According to the principle of the convection heat transfer, convection heat transfer is a heat transfer process that effected by the flow of fluid (air) [17]. The rate of heat transfer is increase as the rate of air flow is increase.

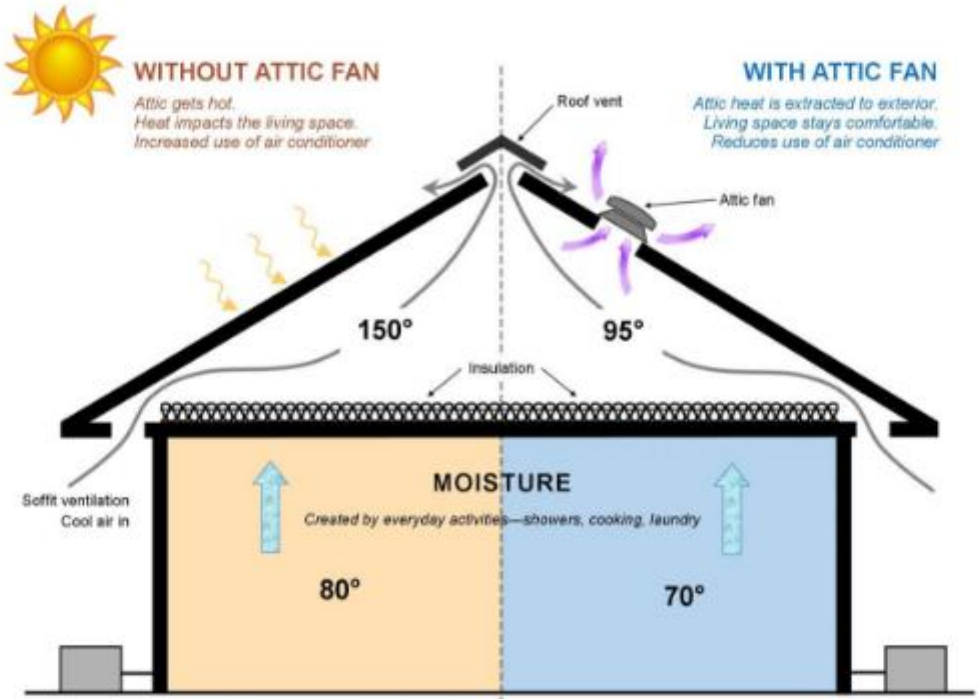


Figure 2.3: Force Ventilation by Attic Fan [18]

The cooling effect of the forced ventilation is higher than the natural ventilation but it consume electricity while natural ventilation do not require any mechanical device that consume electricity. According to the study of Burch & Treado in 1979, the result shows that the daily consumption of the power unit of power vent fans used is higher than the daily reduction of the usage of energy to operate the air conditioning equipment [19]. This result is done by computed thermal performance prediction. It employ weather data, attic data, coefficient of performance of air conditioning, energy to operate the power vent fans, daily energy consumption of the fans, and the daily reduction of energy to operate the air conditioning. The study of Dutt & Harrje in 1979, the research investigate that the difference of usage of energy of air conditioning with and without attic fans is discernible [20]. It means that the reduction of heat flux into living space is only a very small amount of load although it is substantially cooler.

Due to the unattractive economic use of forced ventilation, a solution of using photovoltaic to power ventilation fans is given. In the study of Parker and Sherwin in 2000, photovoltaic attic ventilation fans conducted on a single family home in central Florida. Although this family already installed an attic radiant barrier, the attic air temperature is still excess 130℉. The result of the test shows that the photovoltaic attic ventilation fans are able to reduce peak summer attic temperature by 20℉ [21]. The study of Tzyy-hwang Shieh et al (2010) shows the potential of hybrid ventilator for building ventilation. A prototype of the rooftop turbine ventilator is developed. It is powered by a hybrid of renewable energy which are wind and photovoltaic energy. The result of test indicates that the hybrid ventilator provides approximately 4-times the exhaust capacity of a conventional ventilator [22]. Although the attic forced ventilation power by wind and photovoltaic energy indicate its potential, the cost of installation of this renewable energy device is high. This may cause the low interesting of the user as they make the selection.

The advantage of using the forced ventilation system of roof is this method has relatively higher performance to reduce the heat flux from the roof. Although it has higher performance, it still can be acted as a good method to reduce the heat flux from the roof. This is due to the daily consumption of electricity of the ventilation fan of the forced ventilation system is higher than the daily reduction of the usage of energy to operate the air conditioning equipment. This causes the user will considers the air condition equipment to achieve the cooling demand rather than using the forced ventilation system. Besides that, the installing of the forced ventilation system also needed to install the vents and purchase the ventilation fans that cost a lot.

In this project, the forced ventilation is introduced to the DCS. This is due to the effectiveness of the cooling of the forced ventilation system. As long as the forced ventilation has many problem that discuss above, limiting the volume that required to be ventilate through forced ventilation become the main idea of this project. The forced ventilation is only take part inside the cooling duct of the DCS. Hence, the volume of the air required to ventilate is minimize. This is able to reduce the power required of the ventilate fan and reducing the electricity consumption. The disadvantages of the forced ventilation system are able to minimize by method above.

2.3 Roof surface evaporative

Roof surface EC is a cooling method that applies to the surface of roof assisted with water evaporating. This method is known as direct EC since it will adding moisture to air. The principle of direct EC is the conversion of sensible heat to latent heat of water [23]. As heat energy from hot roof, hot air and sun radiation is absorbed by water, the water is evaporates. The heat energy of roof surface and surrounding air is absorbed by the water. Hence, cooling effect is occurred to the air and the roof simultaneously. This is known as adiabatic process as dry bulb temperature of air decrease but its humidity is increase.

Figure 2.4: Water sprinker and absorptive material [24]

Normally, roof surface EC system is including absorptive and retentive material. The roof is cover with water absorptive and retentive material such as brick ballast which is porosity. It can behave like free water surface for evaporating [24]. According to the study of R.B. Lokapure, J.D.Joshi in 2012, they conduct a test to find out the energy conservation for air conditioning system as using roof surface EC system. In this test, the roof is covered by absorptive and retentive material as shown in figure 2.4. The roof and the material are kept wet by spraying water from water spray. A automatic- sensing device is used to measure the moisture of the absorptive and retentive material and sprayer can operated automatically as the moisture is drop down to certain limit. The result shows that there is 7 ℃ of reduction of temperature of room ceiling and 1 ℃ of room temperature reduction. The energy consumed of the DCS room (tested room) is saved 346 kWh for every 8 Hours.

Rosdi Ab Rahman et al (2014) conducted a CS for zinc roofed house by using circulated water. This CS also can be act as roof surface EC system. The zinc roof is cooled by principle of direct EC. The conversion of sensible heat to latent heat of water is absorbing the heat energy of the zinc roof and the air to reduce their temperature. In this study, absorptive and retentive material is not used. The working mechanism is shown in figure 2.5. The water is pumped from tank to the roof surface for evaporative. Part of the water is not totally evaporating but it is absorbing the heat energy and increases its temperature to achieve cooling effect. Before the water flow back to the tank, the water is passed through cooling box fans to reduce its temperature. The circulation of water is kept operated over the time. The result shows that the room temperature is reduce about 5 ℃. It is effective [25].

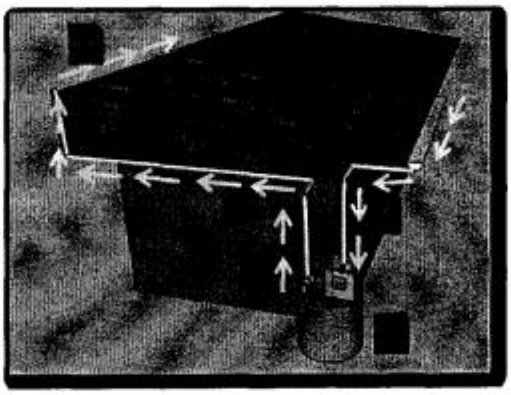


Figure 2.5: Physical System [25]

From the study above, the result shows that the effectiveness of cooling effect of roof surface EC system is high. Through the principle of direct EC, large amount of heat energy can be absorbed by the water. The minimum temperature that can be achieved is the wet bulb temperature of the air [26]. It is effective but it also show it disadvantage as the usage of water is high. The quantity of water need is approximate 10kg/day/m2 during peak summer [9]. This usage of water is based on the roof surface EC system with absorptive and retentive material. The usage of water for second study which is not including absorptive and retentive material is not shows out but its consumption of water also to be high. The high consumption of water is not sustainable for the future. These methods also limited to some countries that have limited water supply.

The EC is introduced to this project due to the effectiveness of cooling of the system. To minimize the water usage of the system, the water EC is not take part at the surface of the roof in this system. The EC is only take part inside the cooling duct of the DCS. As the cooling duct is located below the roof, amount of heat removal is further reduced compare to the traditional method of water EC. Hence, this method is able to further reduce the amount water consumption of the DCS.

2.4 Reflection of Roof Tiles

The type of roof tile that have high reflective to reflect more sunlight to reduce the heat flux that absorb by the roof as shown in figure 2.6 is called as cool roof. It can be the roof cover by high reflectivity, a sheet covering on roof, or highly reflective tile. High solar reflectance value of the roof tile reduces solar radiation absorbed by roof. Hence, it reduces heat flux from roof to the building and reduces its cooling load. The effect of its reflectance has been seen as additional thermal insulation. It is benefit for CP [27].

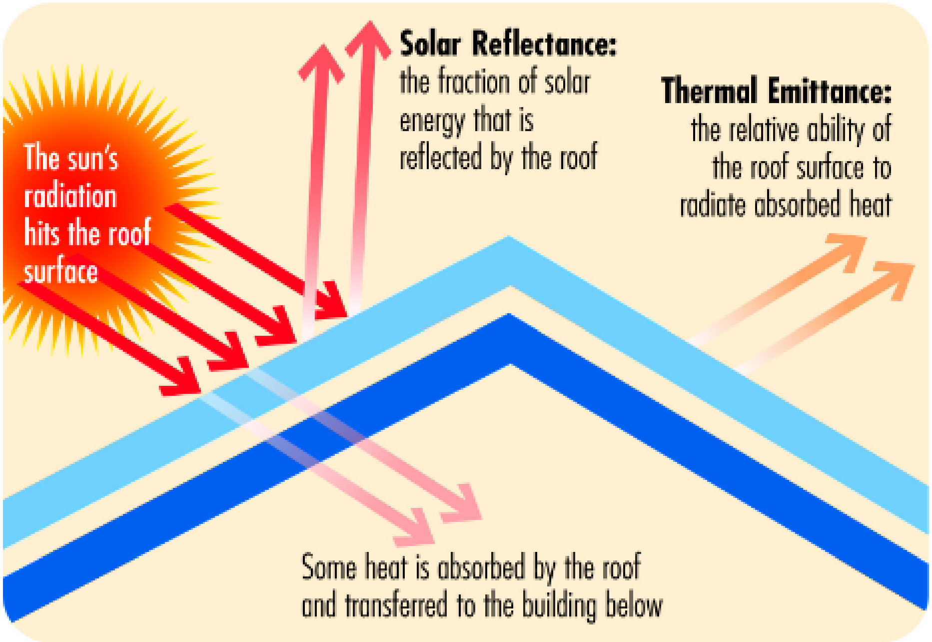


Figure 2.6: Working Principle of Cool Roof [28]

The study of C. Romeo, M. Zinzi in 2013 indicate that the cool roof has a good impact to reduce the surface temperature of the roof up to 20 ℃ and the indoor temperature shows an average reduction about 2.3℃ [10]. Study of Sergio Boixo et al (2012) states that highly implementation of cool roof can lower the contamination and reduce peak power demand. The cool roof can improve the comfort level of house in mild and hot climate. Besides that, the cost of implementation of cool roof also acts as an inexpensive method [29]. David Borge-Diez et al (2013) indicate that the increase of cost to install cool roof is less than $50/m2. The cool roof makes their use affordable and extremely low cost in comparison to other building systems [30].

The cool roof shows its high performance for reducing heat flux but its performance is strongly based on reflectance of cool roof used, climatic condition and insulation level of the building. As the insulation of the building is increases, the cool roof might show poor performance compare to building with normal insulation [10]. In the future, the effectiveness of the cool roof to reduce heat flux may reduce. The trend of insulation demand is increases as the demand of air conditioning increase due to urbanization of the world [5]. The increasing of the insulation of the building was reduces the effectiveness of cool roof that reduce the heat flux from the roof.

2.5 Internal Heat Convection

The internal heat convection is known as heat transfer between the inner wall of pipe (included circular and non-circular pipe) and the fluid which is caused by the movement of the fluid. The flow in the pipe is separated into laminar flow and turbulence flow. Difference type of flow in the pipe shows difference heat transfer mechanism. Hence, the prediction (calculation) of two type of heat transfer is difference. In this study, it is focused on internal turbulence flow heat convection. For the calculation of heat convection in a pipe, it is importance to find out the value of heat transfer coefficient since the result of calculation is strongly depends to it. To find out the heat transfer coefficient, Nusselt Number is act as an importance value as shown as the equation below [31].

$$\text{Heat transfer coefficient, h} \quad = \frac{k}{D}\,\text{Nu} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2.1)$$

The Dittus – Boelter equation is known as the earliest and the widespread heat transfer correlation that used to predict the Nusselt Number of turbulence flow. The equation of Dittus – Boelter for cooling effect is given as below [32].

$$\text{Dittus – Boelter equation, Nu} \quad = 0.023\ \text{Re}^{0.8}\ \text{Pr}^{0.4} \ldots\ldots\ldots\ldots\ldots\ldots (2.2)$$

Although the Dittus – Boelter equation is simple and easy to calculate, the power type correlation of Dittus – Boelter equation is not able to make predict for a large range of Prandtl Number. Large deviation is shown between the experimental result and the prediction done by using Dittus – Boelter equation [33]. After that, a new correlation equation is published. It is known as Gnielinsky Equation and it is given as below [34]. This equation is also widely used for approximate the experimental result [33]. It has higher accuracy.

$$\text{Gnielinsky Equation, } Nu = \frac{\left(\frac{f}{8}\right)(Re-1000)Pr}{1+12.7\left(\frac{f}{8}\right)^{0.5}\left(Pr^{\frac{2}{3}}-1\right)} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.3)$$

$$\text{Where } f = (0.790 \ln Re - 1.64)^{-2}$$

By using the formulas given below, the heat transfer can be calculated [35].

$$\text{Log mean temperature difference, } T_e = T_s - (T_s - T_i)\exp(-hA_s/\dot{m}C_p) \ldots (2.4)$$

$$\Delta T_{lm} = \frac{T_i - T_e}{\ln\left[\frac{T_s - T_e}{T_s - T_i}\right]} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.5)$$

$$\dot{Q} = hA_s\Delta T_{lm} \quad \ldots\ldots\ldots\ldots\ldots\ldots (2.6)$$

2.6 Summary of Literature Review

The performance of cool roof is reduced as the trend of insulation is increased. It has good performance in reflecting the light and heat but this method does not able to remove the heat inside the roof. Hence, it is not considered in the design of CS. The natural ventilation shows a low performance of cooling effect to the house but it does not consume any electricity. Although force ventilation shows good performance to reduce heat from roof, it consumes a lot of energy. Hence, both of them are introduced to the design of DCS. The CS combines the idea of natural ventilation and force ventilation to balance the CP and electricity consumptions. The convention EC of roof shows a high performance of cooling but it consume large amount of water. Hence, the idea of EC of water is not introduced to the roof directly. The EC is introduced as a cooling source to increase the CP of ventilation underside the roof. For the idea of internal heat convection, it is introduced for the calculation of the heat transfer of the CS since the design of the CS is related to the heat transfer in non – circular pipe.

Chapter 3: Research Methodology

3.1 Proposed Solution

In this study, DCS through roof ventilation assisted by EC is studied and designed to full fill the demand of system with great efficiency of heat flux reduces, acceptable electricity consumption, and low consumption of water. This system can be known as a design that has a balance of cooling effectiveness, water consumption and electricity consumption. This system is introduced with forced ventilation, natural ventilation and direct EC to achieve those targets.

The system is designed to have three parts. There are cooling device, air blower and the mist spray system. The cooling device of the system can be known as a rectangular aluminium duct. It is the main body of the CS and installed below the roof. To achieve the cooling ability of the cooling device, the air blower and mist spray system take an important role of the cooling process. The air blower provides the air flow inside the cooling device. This process can be known as force ventilation and it is difference with the traditional method. For conventional force ventilation of traditional method, there is large amount of electricity consumption by using the attic fans and blower. This is due to large air flow rate is required as it needed to ventilate large space underside of roof. Hence, reducing the rate of air flow required is the main idea of design.

The CS is designed to have force ventilation inside the cooling duct only. Therefore, the attic fans or blower used do not ventilate large space underside of roof. The space that needed to ventilate is further less than the traditional forced ventilation and this may reduce the power required of the mechanical ventilation device. The power consumption is reduced as the mechanical ventilation device required smaller power. The force ventilation of inside the cooling duct is able to cool down the cooling duct. The heat energy absorb by the cooling duct from surrounding is removed by the air through internal force convection of cooling duct. Hence, the dimension of the cooling duct is fixed based on the calculation of heat transfer through internal forced convection of cooling duct.

To increase the performance of cooling, EC is introduced to the system. The cooling reagent used for EC is water due to it has high heat capacity and low cost. Although water is low cost in our country, the DCS also been designed to minimize the usage of water. For conventional roof EC system, large amount of water had been used. This is because the water is used to cool down the temperature of roof as well as reduce the temperature of air underside of roof. Large amount of water is evaporated to cool down the temperature of roof. Hence, the DCS is designed to cool down the temperature of air underside the roof rather that reduces the temperature of the surface of roof. Removal of heat energy of air which is underside of roof is further less than removal of heat energy at the roof surface to achieve temperature decrease inside a house. Therefore, the amount of water used to absorb the heat energy from roof is less than the conventional roof EC system. Large amount of water can be saved and less amount of water is required to pump to the cooling device also reduces the power required of the water pump and less electricity is consumed for less water pumping rate. Hence, this system can be known as a design that has a balance of cooling effectiveness, water consumption and electricity consumption.

To achieve the CP, mist spray is installed inside the cooling duct. Therefore, the direct EC of water is take place inside the cooling duct and enhance by the force ventilation by the blower. Small molecule of water is sprayed through mist nozzle inside the duct. With the theory of direct evaporating cooling, the ambient air which forced by ventilation fans from outdoor will decrease its temperature to reach its wet bulb temperature. The flowing of cooling air reduces the temperature of the aluminium duct. Besides that, the evaporating of small water molecule that attach to the aluminium wall also absorbs the heat of the aluminium duct. Due to the internal force convection and direct EC of water inside the cooling duct, the temperature of cooling is less than the air underside the roof.

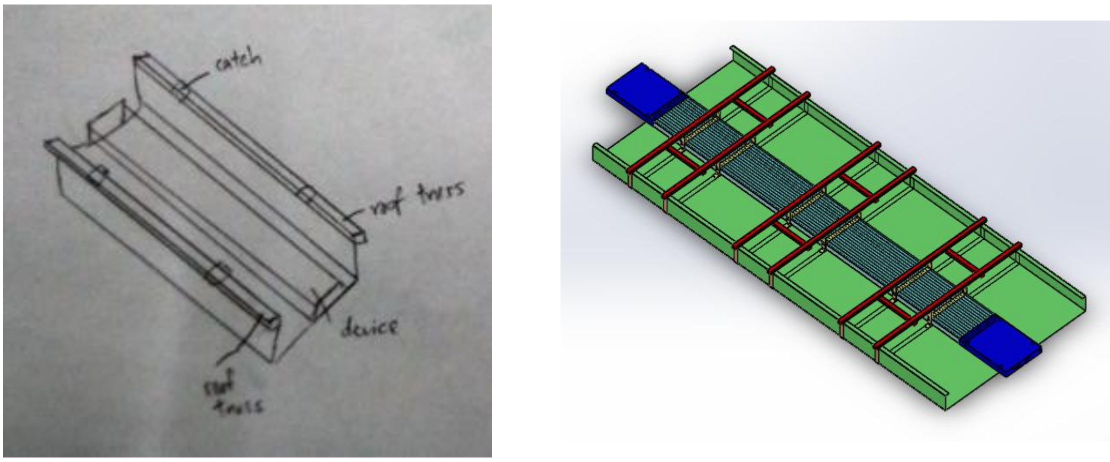
As the system is designed to have forced ventilation inside the cooling duct, the air underside the roof is cooled by the cooling duct by natural ventilation. As the cooling duct is designed to be located below the roof tile, it can create a large temperature difference between cooling duct and the air underside the roof to maximize the performance of the DCS. As the roof tile received the heat flux from the sun, its temperature is increased depending to the solar intensity. The high temperature of the roof tile becomes the heat source to the air underside the roof. The closer the air to the roof tiles, the higher the temperature of the air underside the roof. Hence, the cooling duct of the CS is designed to locate below the roof tile.

The mechanism that cools the air underside of the roof is natural ventilation. It is difference with the force ventilation inside the cooling duct. Since there is not any external force that can force the air underside the roof to flow, the air underside the roof will be cool based on the natural ventilation mechanism. Base on the working principle of natural ventilation, the hot air have low density and the cold air have higher density. The difference of the density of cold air and density of hot air cause the hot air has upward flow and the cold air will flow downward due to the gravity. The hot air that closes to the roof tile will be cool down by the cooling duct. Decreasing of temperature increase the air density and cause the air to pull down due to the gravity. Hence, the cooling effect is achieved.

3.2 Design (DCS)

The project is including design, simulation, fabrication, experiment. The design stage is including the designing of the prototype of the system and the design of the test house for experimental usage of the prototype. The initial stage of the design is to propose various idea of the design. That may included the geometry of the cooling device, design of the support structure of the system, design of supplying water to the cooling device, internal geometry of the cooling device.

From the various idea of the design, the first proper design of the system is designed as shown as figure 3.1.

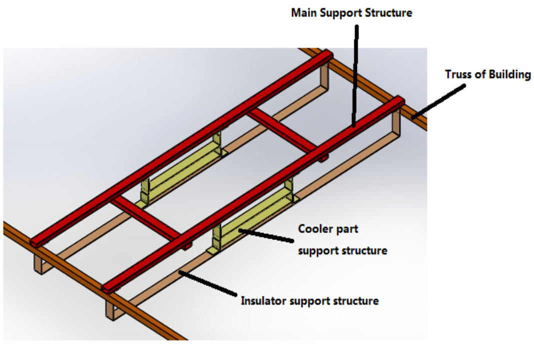
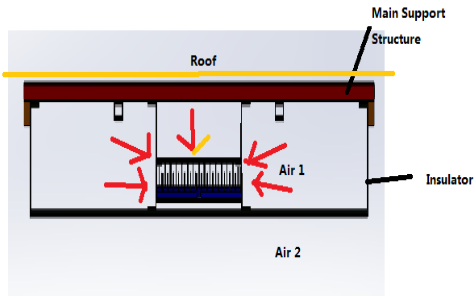


(a) (b)

Figure 3.1: Overview of the First Design by (a) Hand Sketch, (b) 3D Drawing

The first design is including three parts which are support structure (red color), cooling device (blue color) and the insulation layer (green color).

Table 3.1: Descriptions of first design of the DCS

Parts	**Functions**
 Figure 3.2: Support Structure of First Design	The support structure can be separate into three parts. The main support structure is used to support the whole weight of the system but not include the water tank and water pump. The yellow color part is the support structure of the cooling device. It is used to fixed the cooling device in position and support its weight. The pink color support structure is used to support the weight of the insulation layer of the system. It also used to maintain the curve shape of the cooling device.
 Figure 3.3: Insulation Layer of First Design	The insulation layer is used to separate the air below the roof into two sections. Therefore, the heat energy of the air below the roof cannot transfer to the inner air (air 2) through convection easily. The higher temperature of the air 1 can create a higher temperature difference between air and the cooling device. Hence, the rate of heat energy absorbed by the cooling device will be increase.