Experimental Investigation of Roof Top Solar Chimney for Natural Ventilation

by

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the
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Approved by,

____

(A.P. Dr. Hussain H Al - Kayiem)

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TRONOH, PERAK
January 2006

CERTIFICATION OF ORIGINALITY

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

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(YIT MAN HENG)

ABSTRACT

Roof top solar chimney function to create natural ventilation of buildings. It is a solar driven device which induces buoyancy force through the chimney channel to updraft the air out of the building. The design parameter of the rooftop solar chimney would affect the ventilation performance. This research has been carried out experimentally and by computational simulation and focused on evaluating the system performance at various design configuration and operational condition. There are 3 different designs that are compared; first design is the basic rooftop solar chimney which contain absorber plate, room's air outlet and total air outlet, second design is the basic rooftop solar chimney with additional of ambient air inlet and third design is the basic rooftop solar chimney with extra absorber plate. Experiment is carried out to measure the performance of these three different designs in turn. The parameters that had been measured include the solar radiation, the air velocity of each air apertures, the temperature of the absorber plates, and the temperature of air inlet and outlet of each air apertures. Simulation has also been done to compare the performance for these designs using software name "Energy2d". Experiment and Simulation Results is gathered and analysed.

The results of basic rooftop solar chimney with additional of ambient air inlet show the lowest performance with volume flow rate of 0.230 m^3/s and average heat transfer rate of 242.56W. The additional of ambient air inlet improve the updraft force of the solar chimney channel. However, the updraft force towards the room's air outlet aperture is weakened because an extra suction of air is created towards the ambient air inlet itself which causes the performance of the rooftop solar chimney reduces. The results of basic rooftop solar chimney with additional absorber plate show the highest performance with volume flow rate of 0.249 m^3/s and average heat transfer rate of 288.82W. The additional of absorber plate increases the temperature of air throughout the solar chimney channel which results is better stack affect. Simulation is also done to help in determine the performance of the model and verifying the results obtained from experiment. The simulation results show that the model with additional vertical absorber plate has the highest air velocity at the room's air outlet compare to the others.

ACKNOWLEDGEMENT

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Thank you.

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CHAPTER 1
INTRODUCTION

This chapter will discuss on the background study, problem statement, objectives and scope of study for the on project.

1.1 Background of Study

Air conditioning and mechanical ventilation have been for decades the standard method of environmental control in many building types, especially offices, in developed countries. Pollution and reallocating energy supplies have led to a new environmental approach in building design. Innovative technologies along with bioclimatic principles and traditional design strategies are often combined to create new and potentially successful design solutions. The solar chimney is one of these concepts currently explored by scientists as well as designers, mostly through research and experimentation.

A solar chimney can serve many purposes. Direct gain warms air inside the chimney causing it to rise out the top and drawing air in from the bottom. This drawing of air can be used to ventilate a home or office, to draw air through a geothermal heat exchange, or to ventilate only a specific area such as a composting toilet.

Natural ventilation can be created by providing vents in the upper level of a building to allow warm air to rise by convection and escape to the outside. At the same time cooler air can be drawn in through vents at the lower level. Trees may be planted on that side of the building to provide shade for cooler outside air.

The basic design elements of a solar chimney are the solar collector area, ventilation shaft and inlet and outlet air apertures. Solar collector can be located in the top part of the chimney or can include the entire shaft. The material to be used for solar collector is painted plywood as it performs better in lower radiation flux strength due to it being able to release the stored energy at a period of time.

1.2 Problem Statement

There are a number of solar chimney variations. The basic design of the solar chimney could affect the efficiency of the natural ventilation. There are 3 types of design which are proposed. These different designs are used to test for the performance and the air flow rate passing along the chimney channel through the air aperture. The tested result is then use to determine which type of design has the highest performance.

1.3 Objective

The main objective of this experiment is

- To design and fabricate a new model of roof top solar chimney system for natural ventilation.
- To evaluate the system performance at various design configurations.
- To evaluate the system performance at various operational conditions.

1.4 Scope of Study

The scope of this study is on the performance of different design of solar chimney. Different design are subjected to different performance and hence, different efficiency on natural ventilation. The performance of the solar chimney is measured base on the airflow rate that flow along the chimney channel through the inlet and outlet air aperture.

There are three different solar chimney designs that are tested. The first design is the basic design which consists of absorber plate, room's air outlet and total air outlet. Room's air outlet is the air aperture where connected to the room. The total air outlet is the air aperture where connected to the surrounding outside the building. Absorber plate heated up the air along the chimney channel between the room's air outlet and total air outlet. The second design is the basic design with additional ambient air inlet. Ambient air inlet consists of additional absorber plate that helps to heat up the ambient air and send them to the chimney channel. The third design is the basic design with additional vertical absorber plate. The additional of vertical absorber plate further increase the temperature of air along the chimney channel.

The experiment results give a significant understanding on which type of design of solar chimney that will give the better performance for natural ventilation. Simulation is carried out to study the overall performance and also support the experiment results.

CHAPTER 2
LITERATURE REVIEW

This chapter will review on the current knowledge including substantive findings, as well as theoretical and methodological contributions of solar chimney.

2.1 Review of Previous Work

The climate conditions of the tropical regions are characterized by high air temperature, high relative humidity and very low wind speeds. This makes the environmental conditions in a house uncomfortable. The use of solar roof chimney in building is a way to increase natural ventilation and improve indoor air quality. Nugroho and Ahmad (2005) [1] carried out an investigation on the stack induced ventilation strategies performance on experimental room model in Malaysia condition. The results show that the solar chimney can increase air flow in the room but also increase the heat gain. Solar roof reduced heat gain but result in low air velocity. The use of solar wall increases air velocity. However, it depends on the orientation of the solar wall.

Degree of inclination of absorber in Roof Top Solar Chimney will affect the performance where the airflow rate will vary with different degree of inclination. Mathur et al. (2006) [2] study shows that optimum inclination at any place varies from 40^o to 60^o depending upon latitude. The maximum mass flow rate through an inclined solar chimney at Jaipur (India) 27^oN latitude is 45^o, which has 10% more than the flow rate at 30^o and 60^o inclinations. Other than inclination, ratio between height of absorber and gap between glass and absorber would affect the rate of ventilation. Mathur et al. (2006) [3] study shows that there is a potential of inducing ventilation corresponding to 55-150m^3/h airflow rate for 300-700W/m^2 solar radiation incident on the vertical surface. This rate is corresponding to 2-5.6 air changes per hour for a typical room of 27m^3. Airflow will increase linearly with increase in solar radiation or increase in gap between absorber and glass cover. Other than air gap and solar radiation, ratio between inlet and outlet area would also affect the airflow. However, this ratio could not be obtained with the experiment carried out by them. Another study by done by Jianliu (2013) [4] shows that, the rate of ventilation increases with the increase of the ratio between height of absorber and gap between glass and absorber.

Solar intensity is one of the most influencing parameter on the roof top solar chimney performance. Al-Kayiem et al. (2014) [5] presented a mathematical model and analysis of an inclined type roof top solar chimney. The thermal energy and fluid flow processes was simulated mathematically using MATLAB computer program and solved by iteration method. The analysis was carried out with various collector areas which are 15 m^2, 150 m^2 and 600m^2. The validated steady, one dimensional mathematical model successfully predicted the flow velocity and mass flow rate. From this experiment, it is found that the solar intensity is the most influencing parameter. Even with a large collector area up to 600 m^2, the system is not able to feasibly perform when solar intensity is less than 400W/ m^2. The system performance also improves as the collector area and chimney height increase. The increase in wind speed will also reduce the system performance.

A study had been conducted by AboulNaga and Abdrabboh (2000) [6] on the combined wall-roof solar chimney. Wall-roof solar chimney is possible to create a maximum air flow of 2.3m^3/s when the wall is extended to 3.45 m high with an inlet height of 0.15m. The combined wall-roof solar chimney that has been tested in this experiment has induced an air change per hour up to 26. Wall-roof solar chimney is a highly efficient design where it could absorb more heat. However, wall chimney may affect the efficiency of ventilation because it depends on the orientation. Figure 1 below shows the design of the wall-roof solar chimney.

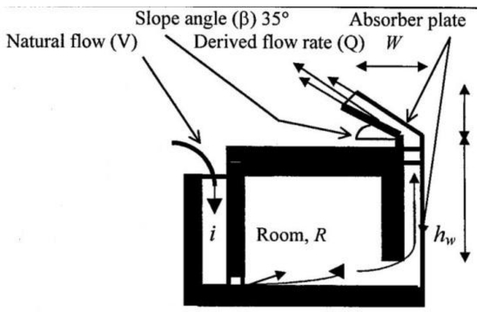

Figure 2.1: A combined wall-roof solar chimney incorporated into a residential building in Al-Ain, UAE [6]

Another study had been carried out by Al-Kayiem et al. (2014) [7] on the effect of Chimney Height on the performance of Root Top Solar Chimney. The experimental measurements were carried out with 2, 4 and 6 m chimney height. The results show that the performance of the chimney is highly dependent on the height. At 6m, a velocity of 1.8 m/s was achieved. These results could generate a small amount of electricity when a wind turbine generator is attached. However, it is not suitable for power generation for domestic usage. The increase in velocity of air could improve the performance of ventilation.

An experimental and numerical model on a solar chimney is carried to predict its performance under varying geometrical features in Iraqi environmental condition by Imran et al. (2015) [8]. The results of numerical model showed that; the optimum chimney inclination angle was 60 ° to obtain the maximum rate of ventilation. At this inclination angle, the rate of ventilation was about 20% higher than 45 °. Highest rate of ventilation induced was found to be 30 air change rate per hour in a room of 12 m^3, at solar radiation of 750 W/m^3, inclined surface angle of 60 °, aspect ratio of 13.3 and chimney length of 2 m. The maximum air velocity was 0.8 m/s for a radiation intensity of 750 W/m^3. A study of influences of ambient air speed and internal heat load on performance of solar chimney in tropics is conduct by Tan et al. (2014) [9].The effect of ambient air speed and internal heat load on the thermal environment of the solar chimney ducts and classroom's interior has been studied. Experimental and computational results show that high ambient air speed greater than 2.00 m/s improves the air speed within the solar chimney ducts; both low and high ambient air speeds are found to improve the classroom's interior air speed. Ambient air speed drops when solar irradiance is greater than 700W/m^2. Other than that, the influences of internal heat lot on the air temperate and speed within solar chimney duct as well as classroom's interior are limited.

DeBlois et al (2013) [10] has carried out research on the design and zonal building energy modelling of a roof integrated solar chimney. The results show that with the proposed rooftop design, the chimney airflow is induced mainly by buoyancy forces whenever the temperature difference from interior to ambient differs by more than a few degrees. A sensitivity analysis evaluates the model's sensitivity to several inputs and assumptions. They confirm that the inlet to ambient temperature difference is the most important predictor of ventilation airflow. Solar insolation levels are less important. The amount of pressure loss in the flow through the vent at the entrance to the chimney is a significant factor for the ventilation flow rate. A numerical and analytical investigation has been done by Khanal and Lei (2012) [11] on flow reversal effect of buoyancy induced air flow in a solar chimney. The reverse flow is quantitatively examined by calculating its penetration depth. Inclined passive wall is proposed as a new design to suppress the reverse flow and enhance ventilation performance. The study shows that the new design improves the ventilation performance significantly in comparison with the vertical passive wall configuration. It is identified that there exists an optimum inclination angle corresponding to an optimum aspect ratio at which the mass flow rate is the maximum for a given Rayleigh number. Improvement is achieved by controlling the reverse flow and minimizing its penetration depth.

An experiment has been carried out by Arce et al. (2006) [12] to study on the natural ventilation of solar chimney. Thermal performance of the solar chimney is investigated. The results show that a maximum irradiance of 604 W/m2, occurring around 13:00 h on September 15th, 2007, a maximum air temperature increment of 7 ℃ was obtained through the solar chimney. Also, a volumetric air flow rate ranging from 50 to 374 m^3/h was measured on that day. Thus, an average air flow rate of 177 m^3/h was achieved from 0:00 h to 24:00 h. It was observed that he airflow rate is influenced by a pressure difference between input and output caused by thermal gradients and wind velocity. Figure 2.2 shows the schematic diagram of the solar chimney ront view (y–z left plane) and lateral view (x–z right plane). The absorber wall is 4.5 m high, 1.0 m wide and 0.15 m thick, air gap is 0.3 m deep, and the glass cover is 0.004 m thick. A lattice panel at the air outlet of the chimney was used to protect it from rodents and from birds. At the same time, air inlet was protected by using a plywood box in order to avoid high turbulences due to wind. Inlet air flow was collimated by employing a laminated array in order to have the velocity component in the x-direction only.

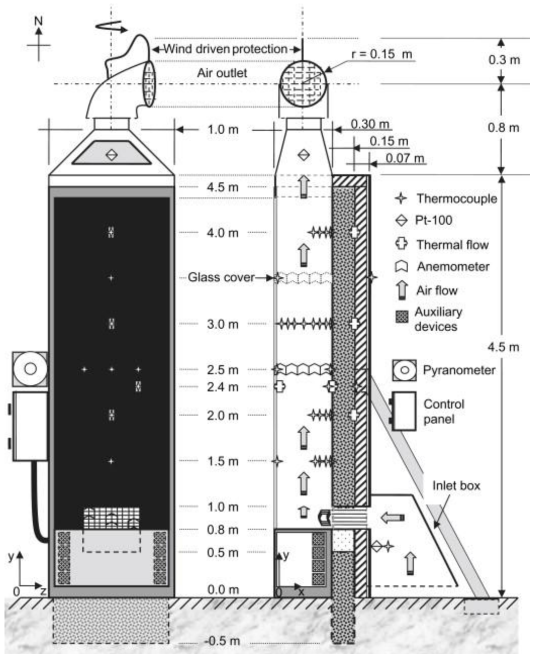

Figure 2.2: Schematic diagram of designed solar chimney [12]

Another study on the effect solar chimney inclination angle on space flow pattern and ventilation rate has been carried out by Bassiouny and Korah (2008) [13]. Figure 2.3 shows the schematic diagram of the inclined solar chimney. Different inclined angle, ɵ has been applied to the solar chimney to study the effect on the flow pattern and ventilation rate. The analytical results showed that an optimum air flow rate value was achieved when the chimney inclination is between 45 ° and 70 ° for latitude of 28.4 °. The numerically predicted flow pattern inside the space supports this finding. Moreover, in the present study a correlation to predict the air change per hour was developed. The correlation was tested within a solar intensity greater than or equal to 500 W/m2, and chimney width from 0.1 m to 0.35 m for different inclination angles with acceptable values.

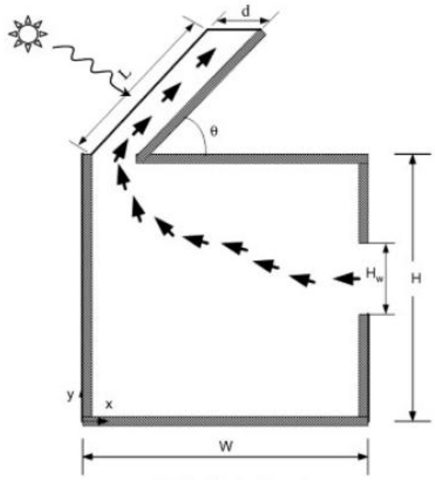

Figure 2.3: Schematic diagram of inclined solar chimney [13]

2.2 Summary of Literature

Performance of solar chimney could be affect by different parameter. Base on the current research and study, the parameter that could affect the performance of solar chimney is the inclination angle of absorber plate, ratio between height of absorber and gap between glass and absorber, area of absorber plate, height of the chimney and ambient air speed. There are still no research has been done on additional absorber plate and additional air inlet. Therefore, the research on this project will be focusing on investigating the performance of the solar chimney after additional of air inlet and additional of absorber plate.

CHAPTER 3

METHODOLOGY

This chapter will be focused on the method to be used throughout the experiment. This will include the designing of the prototype, step for fabrication, measuring tools required and procedure for experiment and simulation

3.1 Designing the Solar Chimney

The solar chimneys need to be designed and fabricated to meet the requirement of the experiment. The solar chimney is design to be a model that can be modified manually into different type of solar chimney design. These modified designs will be tested to determine which of them has the best performance. Decision tree at Figure 3.1 illustrates the design stage of the experimental work from generating concept of the solar chimney design to produce the technical drawing for the prototype.

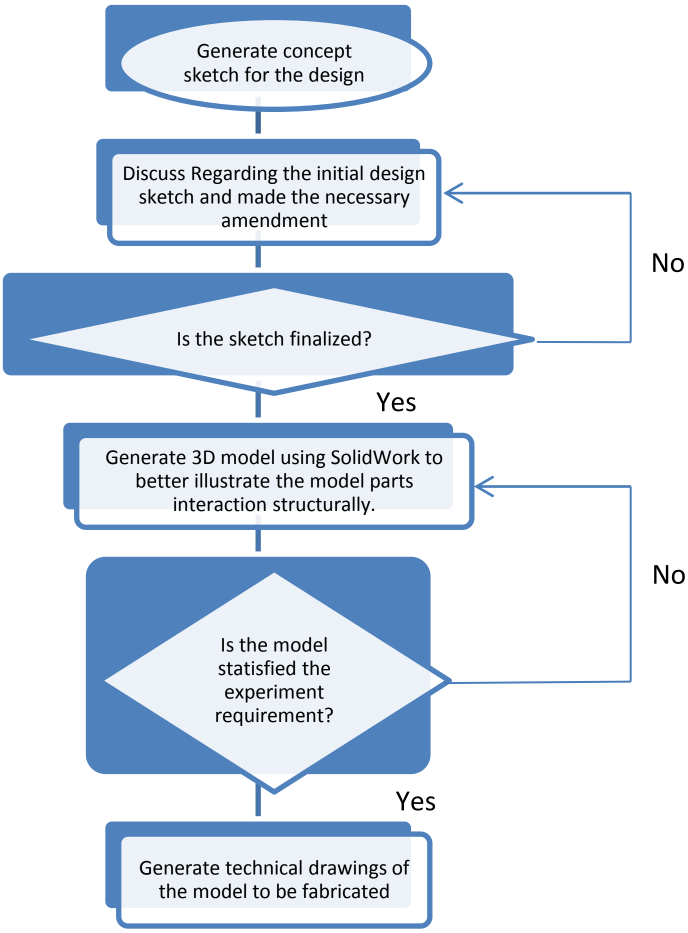

Figure 3.1: Decision tree illustrating the process of concept generation of the design of solar chimney for the experiment

3.1.1 Concept Design

Referring to figure 3.2, it shows the finalized sketch for solar chimney prototype. The finalized sketch included three air apertures which are total air outlet, ambient air inlet and room's air inlet. The design has a slot for extra cover to block the ambient air hole (1) and a slot for extra absorber plate (2). The design included two solar absorber plates, one is located between air inlet for room and total air outlet (3), and another one will be located near the ambient air inlet (4). The absorber plates function to absorb heat from the sunlight and used the absorbed heat to heat up the air. The absorber plates will be cover with transparent Perspex plate (5) so that the sunlight can reach them. The frame of the chimney will be built with aluminum sheet with insulated frame (6). The designed prototype will be placed at the proposed location on the rooftop of the office as shown in the figure 3.3.

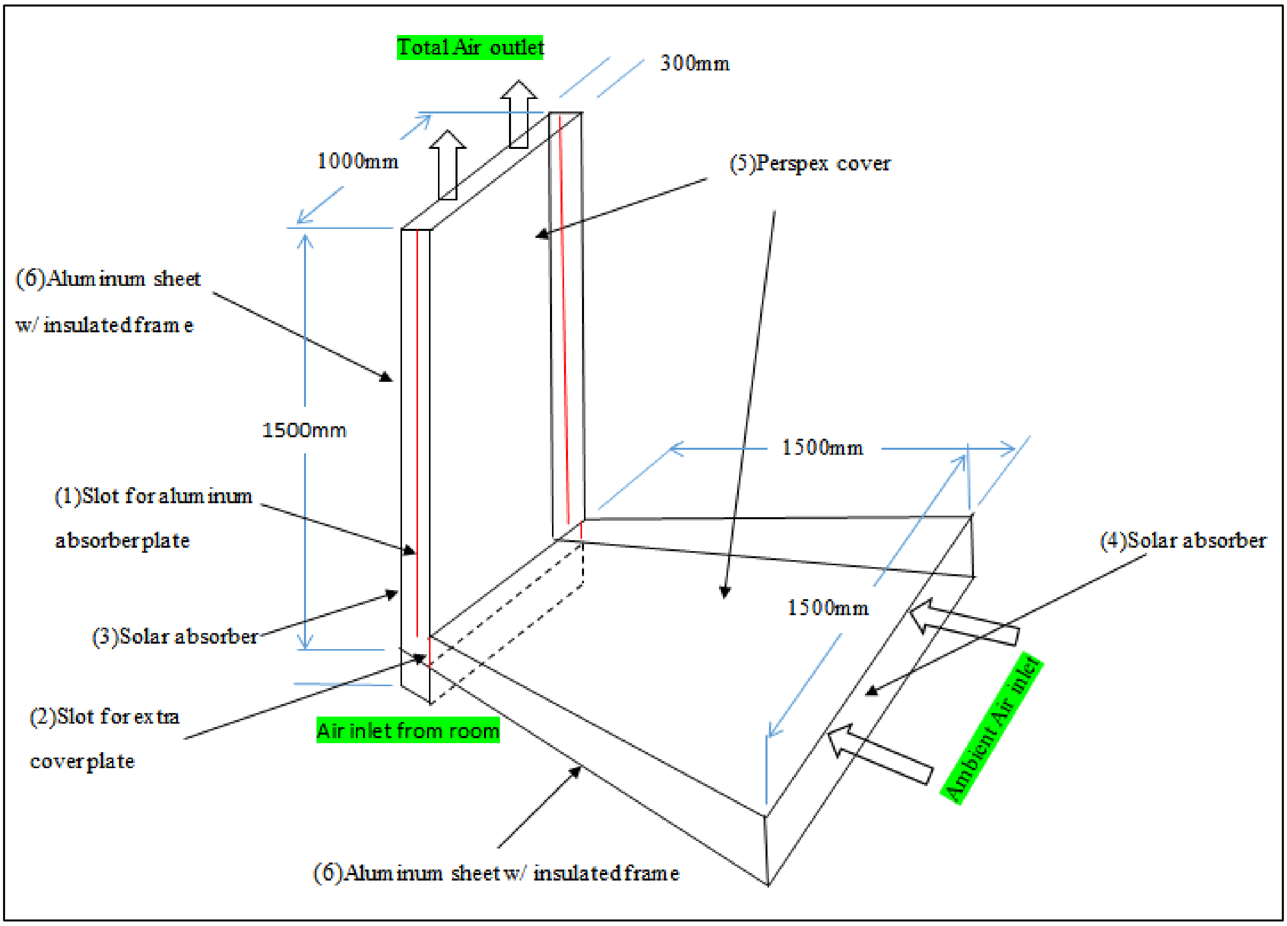

Figure 3.2: Finalized Sketch for Concept Design

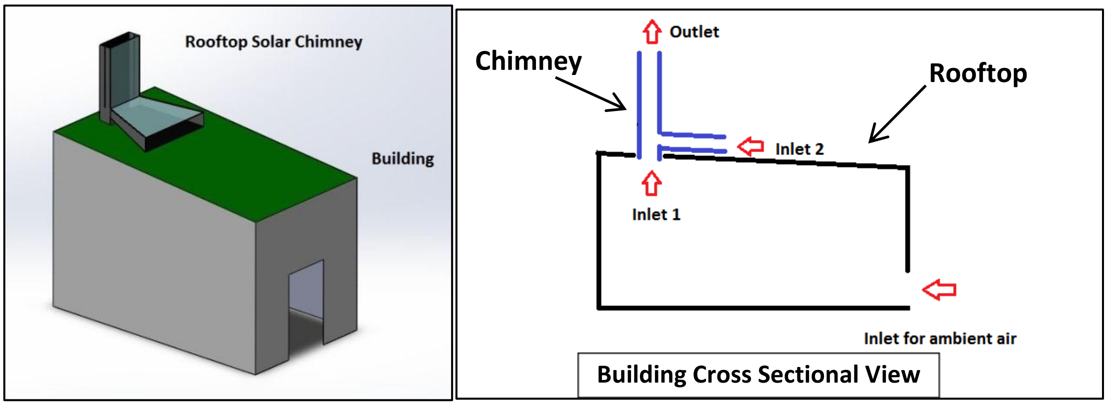

Figure 3.3: Proposed location for solar chimney

The material used for the design:

Absorber Plate: Black Painted Aluminium Plate

Cover Plate : Transparent Perspex Plate

Frame : Aluminium Sheet with insulated frame

Aluminium Plate has high thermal conductivity which is around 150 W/m K which can perform well in absorbing heat from sunlight. Black paint will enhance the performance of the aluminium plate because only a small fraction of light will be reflected off.

Perspex plate is chosen instead of double glazing glass for safety reason when installation. However, for better performance, double glazing glass is recommended. Double Glazing glass provides a better performance by preventing heat loss and reflecting heat back to the chimney duct.

The frame of the chimney will be built with aluminum sheet with insulated frame. Aluminium sheet is wrapped with rock wool to prevent heat loss from the chimney. Rock wool has a low thermal conductivity which is around 0.045 W/m K which can prevent heat loss and trap heat inside the solar chimney.

3.1.2 Finalized Design

Figure 3.4 shows the finalized drawing file with details dimension.

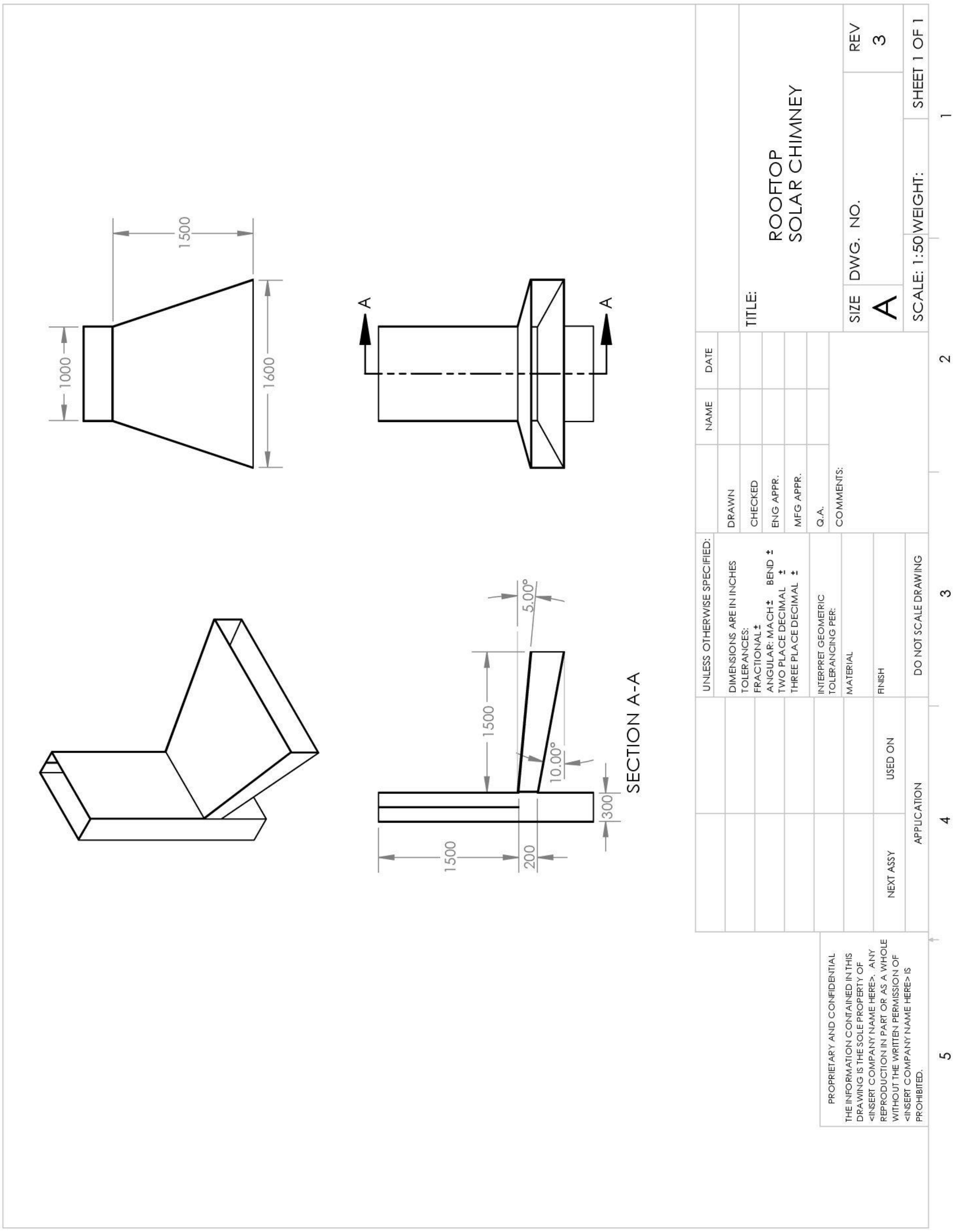

Figure 3.4: Finalized drawing file

Figure 3.5 until figure 3.7 show the finalized drawing file of the design for solar chimney. The designs are drawn using Solid Work 2012. The prototype is allowed to be modified manually in to six different type of model for experiment. Below shows the specification of each model:

Model 1: Vertical Absorber Plate, Total Air Outlet and Room's Air Outlet

Model 2: Vertical Absorber Plate, Total Air Outlet, Room's Air Outlet, Ambient Air Inlet and Ambient Air Inlet's Absorber Plate

Model 3: Vertical Absorber Plate, Total Air Outlet, Room's Air Outlet and Additional Vertical Absorber Plate

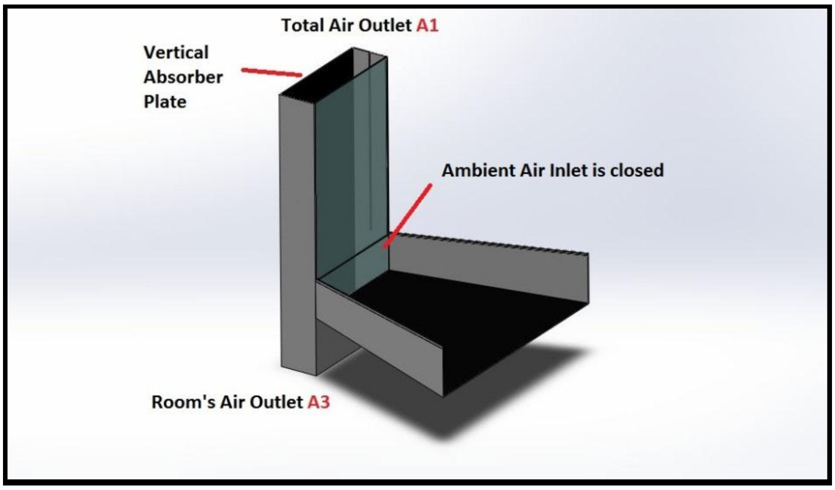

Figure 3.5: Model 1 - Basic design

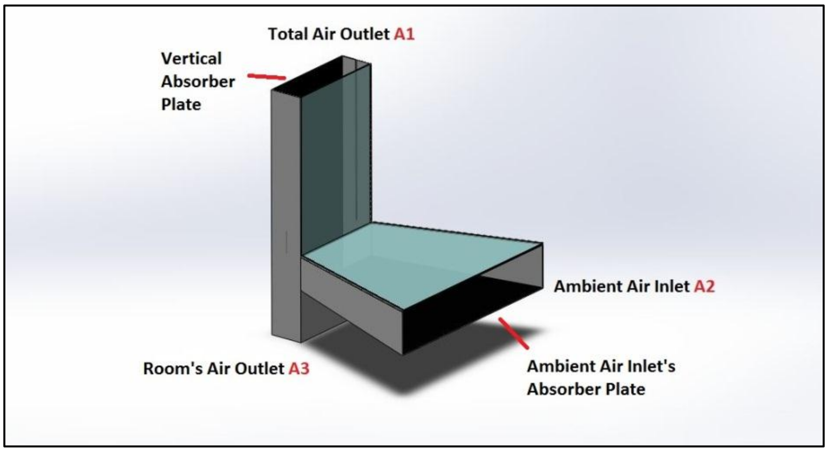

Figure 3.6: Model 2 – Basic design with additional ambient air inlet

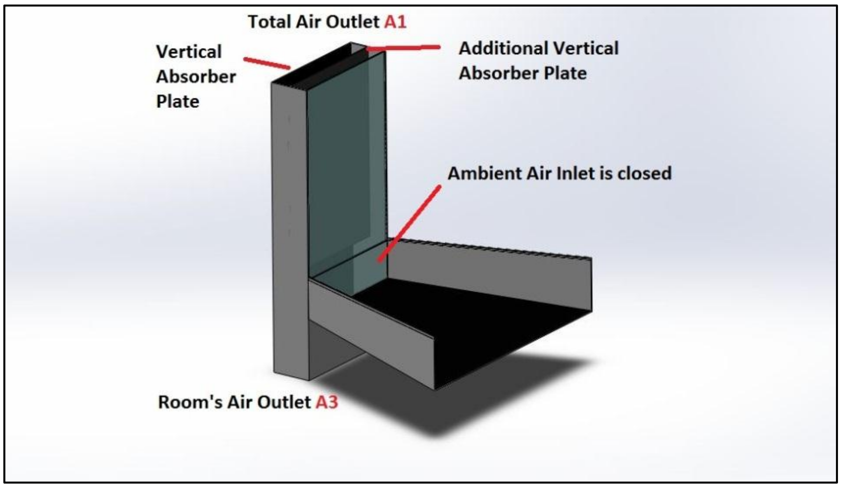

Figure 3.7: Model 3 – Basic design with additional vertical absorber plate

3.2 Fabrication

The fabrication starts when the finalized design is being created. Below is the breakdown of the fabrication process.

1. Undergo fabrication process
2. Follow up on discussion on the physical development of the prototype.
3. Perform protection task to the prototype as it arrived to the site for example painting.
4. Set up the prototype on the dedicated location.
5. Prepare additional setup and housing for safe-keeping of the recording instrument during experiment run.

3.3 Conducting the Experiment

The experiment will be carried out to gather the required data. The data collection is done manually with the help of measuring equipment. Below is the procedure of the experiment:

1. Set up and rearrange the parts to build prototype for model 1.

2. Set up the thermocouple type J at the designated position of the absorber plate.

3. Measure the temperature of the absorber plate by connecting the data logger to thermocouple every two hour from 10am to 4pm.

4. Measure the air velocity and air temperature at the designated position of the solar chimney inlet and outlet by using hot wire anemometer every two hour from 10am to 4pm.

5. Measure the solar intensity by using solarimeter every two hour from 10am to 4pm.

6. Set up and rearrange the part to build prototype for model (2 and 3). Repeat the step 2 to step 5.

7. Analyze the data obtained.

3.4 Measuring Instrumentation

Manual measurement methods are applied for this experiment. Below shows the tools and equipment used for this particular experiment.

1. Thermocouple Thermometer TK102
    - Figure 3.8 shows the thermocouple thermometer TK102
    - Consists of different measuring elements, they are Thermocouple Type K, J, T and S.
    - Temperature Range depends on the type of thermocouple.
    - Main function in this experiment is to record temperature at different point of the absorber plate with the extension kit of thermocouple.

Figure 3.8: Thermocouple thermometer TK102

2. Thermocouple Type J
    - Measurement of Surface Temperature in ℃ or ℉.
    - Measuring Ranges from -100 ℃ to 750 ℃
    - Accuracy of ± 0.8 ℃

3. Kimo Solarimeter SL100
    - Figure 3.9 shows the Kimo solarimeter SL100
    - Measurement of solar intensity in W/m^2,
    - Solar irrigation measuring range from 1 W/m^2 to 1300 W/m^2
    - Main function in this experiment is to record the solar intensity of the day

Figure 3.9: Kimo solarimeter SL100

4. Kimo Multifunction Measuring Tools AMI 300
    - Figure 3.10 shows the Kimo multifunction measuring tools AMI 300
    - Measurement of air flow rate and air temperature with extension unit of Hotwire.
    - Air Velocity measuring range from 0.15 m/s to 3 m/s
    - Air Temperature measuring range from -20 ℃ to 80 ℃
    - Main function in this experiment is to record the air velocity at the inlet and outlet or air aperture.

Figure 3.10: Kimo multifunction measuring tools AMI 300

3.5 Conducting the Simulation

Simulation is carried out to compare between the design Model 1, Model 2 and Model 3. The simulation is carried out in two dimensional using a software name Energy2d [8]. Energy2d is a simulation tools based on solving basic equation in physic, such as the Navier-Stokes equation for modeling fluid dynamics, are routinely used to tackle complex science and engineering problems and to search for optimal solutions in many engineering practices. The results of the simulation will determine which design will create a better air flow rate that enters the office.

3.5.1 Simulation Set up

Modeling is done base on the actual dimension of the experiment site. However due to complexity and the limitation of the software, some complex part has been simplify for the ease of simulation. The simulation result will not be the same with the actual condition. However, the results can be used to compare the performance of the designed models. Figure 3.11, Figure 3.12 and Figure 3.13 show the drawn simulation model for Model 1, 2 and 3. The simulation sensor used to record the simulation results are anemometer and thermometer. Thermometers are placed on each of the absorber plate while anemometers are place on different air inlet and air outlet. The simulation is run until the wind speed and temperature reaches steady state. Data of the air velocity and temperature of the absorber plate is recorded every 50 seconds and last for 7200 seconds.

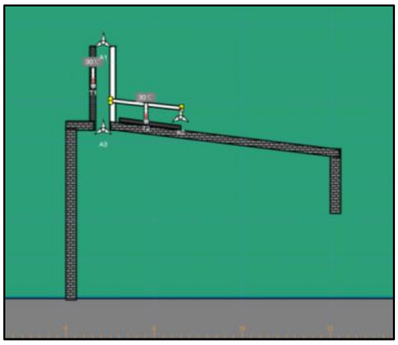

Figure 3.11: Simulation Model 1

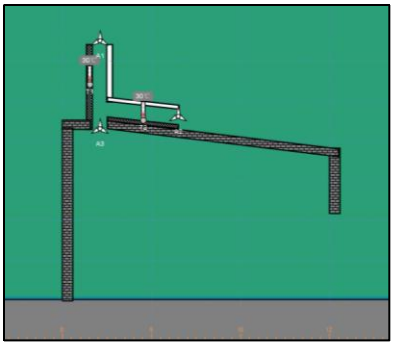

Figure 3.12: Simulation Model 2

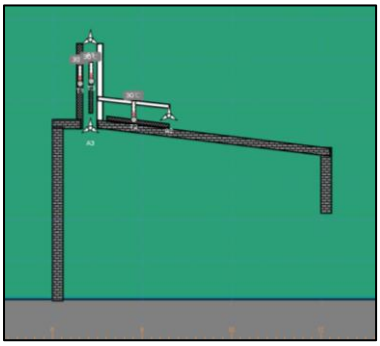

Figure 3.13: Simulation Model 3

3.6 Gantt Chart and Key Milestone

Activity (FYP1)	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Research and Study														
Literature Review														
Survey for tools and equipment														
Designing Prototype for Experiment					X									
Designing the Experimental Setup														
Fabrication									X					
Obtaining Test Materials														
Set up the Test Materials														X

Activity (FYP2)	Week													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Conduct Test			X											
Results Analysis										X				
Report Compilation														

X = Key Milestones

CHAPTER 4

RESULTS AND DISCUSSION

This chapter will mainly focus on the results gather from the experiment and simulation. Further discussion is made to analysis the results.

4.1 Experimental Results and Discussion

Table 4.1 to Table 4.15 show the data collected from the experiment. Due to limitation of the amount of experimental site, the experiment for these three models is carried out in turn. The result collected from the experiment had been tabulated. The tabulated data contain average air velocity at different air aperture, average volume flow rate at different air aperture, average surface temperature of absorber plates, average temperature of air at different air aperture and average solar radiation during experiment period for Model 1, 2 and 3. Table 4.16 to Table 4.19 show the calculated Heat Transfer Rate by absorber plate to air particle. Heat Transfer Rate by absorber plate is calculated using the formula below:

$$Q = \dot{m} c_p \Delta T$$

Where,

Q = Heat Transfer Rate of Absorber Plate to the air (W)

$\dot{m}$ = Mass Flow Rate of air through the chimney channel (m^3/s)

c_p = Specific Heat Capacity of Air (J/kg.K)

ΔT = Temperature difference between air at Room's Air Outlet and Total Air Outlet (°C)

Model 1 - Basic Design

Model 1 is the basic design of solar chimney. Figure 4.1 shows the cross sectional area of the basic design. Referring to Table 4.1, the ambient air inlet is closed by a cover plate; therefore the air volume flow rate at ambient air inlet, A2 shows 0 m^3/s. Referring to Table 4.2, highest average volume flow rate for room's air outlet, A3 occurs at 2pm with volume flow rate of 0.259 m^3/s; while for total air outlets, A1 occurs at 4pm with volume flow rate of 0.258 m^3/s. Air will be drag out from room's air outlet toward total air outlet, therefore the differences in volume flow rate between A1 and A3 doesn't show big gap with only maximum differences of 0.03 m^3/s.

Referring to Table 4.3 and Table 4.5, Vertical Absorber Plate shows the highest average surface temperature, 50.88 ℃ at 2pm with highest average solar radiation of 752.5 W/m^2. Referring to Table 4.4, the air temperature difference between AT3 and AT1 show the highest at 2pm with differences of 1.332 ℃. This is why volume flow rate at A3 show the highest at 2pm. The higher the differences between air temperature of inlet and outlet, the higher the heat transfer rate. High heat transfer rate will increase the buoyancy force throughout the chimney channel which leads to higher volume flow rate.

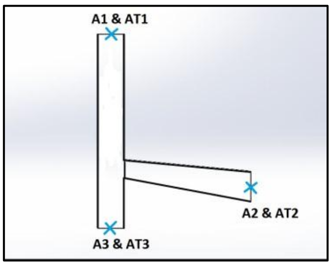

Figure 4.1: Measurement points for Model 1

Table 4.1: Average air velocity at different air aperture for Model 1

	Average Air Velocity at Different Air Aperture (m/s)				
Time	10AM	12PM	2PM	4PM	Average Performance
A2	0	0	0	0	0
A3	0.742	0.819	0.863	0.856	0.820
A1	0.845	0.841	0.813	0.859	0.839

Table 4.2: Average volume flow rate at different air aperture for Model 1

	Average Volume Flow Rate(m^3/s)				
Time	10AM	12PM	2PM	4PM	Average Performance
A2	0.000	0.000	0.000	0.000	0.000
A3	0.223	0.246	0.259	0.257	0.246
A1	0.253	0.252	0.244	0.258	0.252

Table 4.3: Average surface temperature of the absorber plate for Model 1

	Average Surface Temperature of Absorber Plate (°C)			
Time	10AM	12PM	2PM	4PM
Vertical Absorber Plate	43.786	47.956	50.881	47.269
Horizontal Plate	60.033	73.608	72.842	62.188

Table 4.4: Average temperature of air at different air aperture for Model 1

	Average Temperature of Air at Different Air Aperture (°C)			
Time	10AM	12PM	2PM	4PM
AT2	35.822	37.219	42.048	37.038
AT3	33.766	35.711	37.056	37.130
AT1	34.342	36.636	38.388	37.971

Table 4.5: Average Solar Radiation during Experiment Period for Model 1

	Average Solar Radiation (W/m^2)			
Time	10AM	12PM	2PM	4PM
	443.75	680	752.5	652.5

Model 2 - Basic Design with Additional Ambient Air Inlet

Model 2 is the basic design of solar chimney with additional ambient air inlet. Figure 4.2 shows the cross sectional area of the basic design. The ambient air inlet is opened which allowed flow into the chimney channel. Referring to Table 4.7, the highest average volume flow rate for the ambient air inlet, A2 is 0.16 m^3/s happens at 2pm. Highest average volume flow rate for room's air outlet, A3 occurs at 4pm with volume flow rate of 0.251 m3/s; while for total air outlets, A1 occurs at 10am with volume flow rate of 0.309 m3/s. Due to windy condition occur during morning and evening throughout the experimental period, the results are affected by the natural wind which travel through the ambient air inlet towards the total air outlet. Therefore, the volume flow rate during 10 am and 4pm is higher compare to 12 pm and 2pm.

Referring to Table 4.8 and Table 4.10, vertical absorber plate shows the highest average temperature, 53.325 ℃ at 2pm with highest average solar radiation of 977 W/m^2. Referring to Table 4.9, the air temperature difference between AT3 and AT1 show the highest at 2pm with differences of 1.457 ℃. The overall temperature difference between.AT3 and AT1 for Model 2 is higher compare to Model 1 and Model 3 because the ambient air inlet which equipped with ambient air inlet's absorber plate intake ambient air with higher temperature towards the chimney channel. This causes the temperature at the total air outlet higher compare to other model. The intake ambient air have highest average temperature of 41.672 ℃ at 2pm. High temperature ambient air could improve the stack effect along the chimney channel. However, due to the ambient air inlet, the buoyancy force updraft air from room's air outlet and ambient air inlet itself which causes the overall average volume flow rate at room air outlet lower compare to other model. The overall average volume flow rate at room's air outlet, A3has only 0.23 m^3/s.

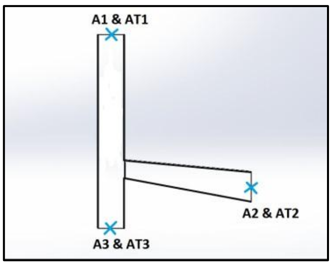

Figure 4.2: Measurement points for Model 2

Table 4.6: Average air velocity at different air aperture for Model 2

	Average Air Velocity at Different Air Aperture (m/s)				
Time	10AM	12PM	2PM	4PM	Average Performance
A2	0.191	0.245	0.355	0.262	0.263
A3	0.798	0.727	0.706	0.838	0.767
A1	1.029	0.895	0.889	0.900	0.928

Table 4.7: Average volume flow rate at different air aperture for Model 2

	Average Volume Flow Rate(m^3/s)				
Time	10AM	12PM	2PM	4PM	Average Performance
A2	0.086	0.110	0.160	0.118	0.118
A3	0.239	0.218	0.212	0.251	0.230
A1	0.309	0.269	0.267	0.270	0.278

Table 4.8: Average surface temperature of the absorber plate for Model 2

	Average Surface Temperature of Absorber Plate (°C)			
Time	10AM	12PM	2PM	4PM
Vertical Absorber Plate	46.603	50.275	53.325	51.169
Horizontal Plate	66.246	93.342	82.096	78.938

Table 4.9: Average temperature of air at different air aperture for Model 2

	Average Temperature of Air at Different Air Aperture (°C)			
Time	10AM	12PM	2PM	4PM
AT2	36.534	39.341	41.672	40.598
AT3	35.099	37.818	39.717	40.701
AT1	36.938	39.133	41.174	40.884

Table 4.10: Average solar radiation during experiment period for Model 2

	Average Solar Radiation (W/m^2)			
Time	10AM	12PM	2PM	4PM
	580	949.25	977	785

Model 3- Basic Design with Additional Vertical Absorber Plate

Model 3 is the basic design of solar chimney with additional vertical absorber plate. Figure 4.3 shows the cross sectional area of the basic design. The ambient air inlet is closed by a cover plate; therefore there is no volume flow rate at ambient air inlet. The additional vertical absorber plate separates the total air outlet into two which is A1 and A2. Referring to Table 4.12, the highest average volume flow rate for room's air outlet, A3 occurs at 12pm with volume flow rate of 0.251 m3/s. For total air outlets, highest volume flow rate at A1 and A2 occurs at 10am with volume flow rate of 0.279 m3/s and 0.252 m3/s. This is due to the windy weather at the morning that causes the increase of volume flow rate at total air outlet increases. However, referring to the Table 4.14 and considering air temperature difference between total air outlet and room's air outlet, highest differences in temperature occur at 12pm with temperature difference of 1.315 ℃; calculated by the average temperature of total air outlet deduct the temperature of room's air outlet. High temperature difference between inlet and outlet lead to highest volume flow rate at room's air outlet at 12pm.

Referring to Table 4.13 and Table 4.15, vertical absorber plate shows the highest average temperature, 45.375 ℃ at 12pm with highest average solar radiation of 968.75 W/m2. For additional vertical absorber plate, it shows the highest temperature of 49.292 ℃ at 2pm. The temperature of vertical absorber plate is always lower compare to additional vertical absorber plate, because the vertical absorber plate blocks some of the sun ray from reaching the vertical absorber plate.

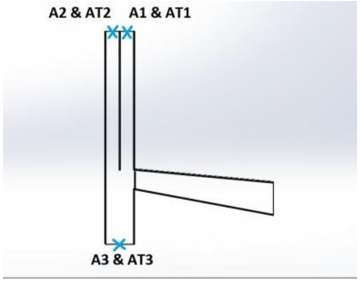

Figure 4.3: Measurement points for Model 3

Table 4.11: Average air velocity at different air aperture for Model 3

	Average Air Velocity at Different Air Aperture (m/s)				
Time	10AM	12PM	2PM	4PM	Average Performance
A2	0.839	0.835	0.837	0.813	0.831
A3	0.831	0.837	0.822	0.829	0.830
A1	0.930	0.843	0.771	0.790	0.834

Table 4.12: Average volume flow rate at different air aperture for Model 3

	Average Volume Flow Rate(m^3/s)				
Time	10AM	12PM	2PM	4PM	Average Performance
A2	0.252	0.250	0.251	0.244	0.249
A3	0.249	0.251	0.247	0.249	0.249
A1	0.279	0.253	0.231	0.237	0.250

Table 4.13: Average surface temperature of the absorber plate for Model 3

	Average Surface Temperature of Absorber Plate (°C)			
Time	10AM	12PM	2PM	4PM
Vertical Absorber Plate	40.850	45.375	44.300	42.725
Additional Vertical Absorber Plate	42.504	47.592	49.292	46.242

Table 4.14: Average temperature of air at different air aperture for Model 3

	Average Temperature of Air at Different Air Aperture (°C)			
Time	10AM	12PM	2PM	4PM
AT2	36.941	38.293	37.827	36.913
AT3	36.076	37.119	37.336	37.372
AT1	36.875	38.576	38.088	36.837

Table 4.15: Average solar radiation during experiment period for Model 3

	Average Solar Radiation (W/m^2)			
Time	10AM	12PM	2PM	4PM
	650	968.75	882.5	582.5

Heat Transfer Rate by Absorber Plate to Air

Table 4.16: Model 1 average heat transfer rate calculation data

Model 1 - Basic Design							
Time	Chimney Channel Average Temperature (°C)	Density of Air (kg/m^3)	Chimney Channel Average Volume Flow Rate (m^3/s)	Temperature Difference (K)	Mass Flow Rate (kg/s)	Specific Heat Capacity (J/kg.K)	Heat Transfer (W)
10am	34.054	1.145	0.238	0.576	0.272	1.005	157.76
12pm	36.173	1.138	0.249	0.925	0.283	1.005	263.33
2pm	37.722	1.274	0.251	1.333	0.320	1.005	429.00
4pm	37.550	1.274	0.257	0.841	0.328	1.005	276.87

Table 4.17: Model 2 average heat transfer rate calculation data

Model 2 - Basic Design with Additional Ambient Air Inlet							
Time	Chimney Channel Average Temperature (°C)	Density of Air (kg/m^3)	Chimney Channel Average Volume Flow Rate (m^3/s)	Temperature Difference (K)	Mass Flow Rate (kg/s)	Specific Heat Capacity (J/kg.K)	Heat Transfer (W)
10am	36.067	1.138	0.236	0.853	0.268	1005	230.12
12pm	38.764	1.127	0.216	1.314	0.244	1005	321.97
2pm	40.854	1.120	0.226	1.457	0.253	1005	371.27
4pm	40.728	1.120	0.227	0.183	0.254	1005	46.89

Table 4.18: Model 3 average heat transfer rate calculation data

Model 3 - Basic Design with Additional Vertical Absorber Plate							
Time	Chimney Channel Average Temperature (°C)	Density of Air (kg/m^3)	Chimney Channel Average Volume Flow Rate (m^3/s)	Temperature Difference (K)	Mass Flow Rate (kg/s)	Specific Heat Capacity (J/kg.K)	Heat Transfer (W)
10am	36.631	1.138	0.260	0.832	0.296	1005	247.50
12pm	38.079	1.130	0.251	1.440	0.284	1005	411.18
2pm	38.368	1.130	0.250	1.548	0.282	1005	438.95
4pm	37.356	1.134	0.243	0.208	0.276	1005	57.63

Average Volume Flow Rate and Heat Transfer Rate

The performance of the Rooftop Solar Chimney is compared by the amount of average volume flow rate through the room’s air outlet because this outlet indicates how much volume of air is being drag out from the room. Table 4.19 shows the comparison of the average volume flow rate at Room’s Air Outlet. Model 3 shows the highest average volume flow rate while Model 2 shows the lowest average volume flow rate.

Table 4.20 shows the comparison of average volume flow rate at Total Air Outlet. The average volume flow rate at Total Air Outlet for Model 2 shows the highest value. This indicates that the additional of ambient air inlet increases the buoyancy force of the chimney channel. However, due to unnecessary suction of air from ambient air inlet itself, the volume flow rate of Room’s Air Outlet reduces.

Figure 4.4 shows the drawn line graph of average heat transfer rate by absorber plate to the air particle over time referring to the tabulated data from Table 4.16, Table 4.17 and Table 4.18. Model 3 shows the highest average heat transfer rate from 10am to 2pm. However, the average heat transfer rate drop below 100W during 4pm which is lower compare to Model 1. Model 2 has higher average heat transfer rate from 10am to 12pm compare to Model 1. However, during 2pm to 4om, Model 1 has higher average heat transfer rate compare to Model 2. Data shows inconsistency is believed to be cause by the inconsistency of weather condition. Regardless data for volume flow rate at Room’s Air Outlet at time 4pm, Model 3 shows the highest average heat transfer rate. With the additional of vertical absorber plate, it helps to increase the buoyancy force along the chimney channel which creates higher volume flow rate at Room's Air Outlet. Therefore, Model 3 has the highest performance compare to Model 1 and Model 2.

Table 4.19: Comparison of average volume flow rate at room's air outlet for different model

	Average Volume Flow Rate of the Room's Air Outlet (m^3/s)
Model 1 - Basic Design	0.246
Model 2 - Basic Design with Additional Ambient Air Inlet	0.230
Model 3 - Basic Design with Additional Vertical Absorber Plate	0.249

Table 4.20: Comparison of average volume flow rate at total air outlet for different model

	Average Volume Flow Rate of the Total Air Outlet (m^3/s)
Model 1 - Basic Design	0.252
Model 2 - Basic Design with Additional Ambient Air Inlet	0.278
Model 3 - Basic Design with Additional Vertical Absorber Plate	0.253

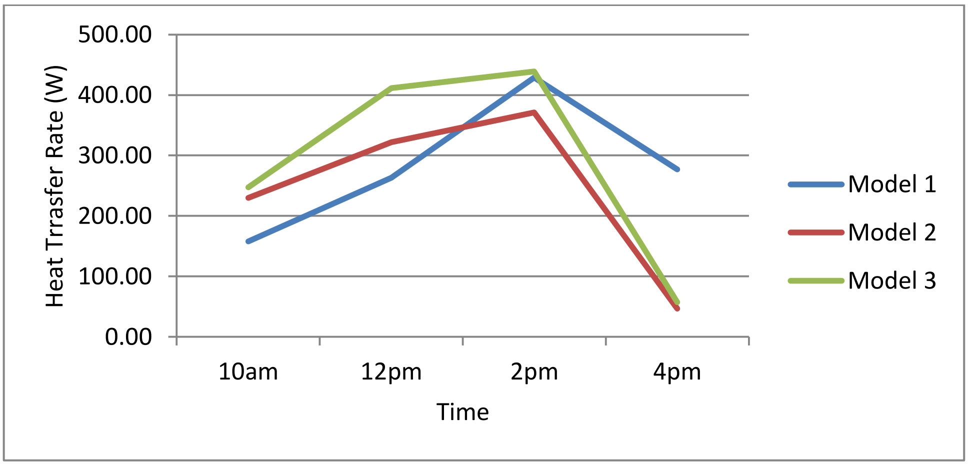

Figure 4.4: Heat transfer rate by absorber plate to air for different model over time

Surface Temperature of Absorber Plate

Figure 4.5 shows the average surface temperature of Absorber Plate for different model over time. Model 2's Ambient Air Inlet's Absorber Plate shows the highest surface temperature. This is because the orientation of the Ambient Air Inlet's Absorber Plate always has the closest angle that orientated nearly perpendicular to the sun. Therefore the solar radiation absorb by Ambient Air Inlet's Absorber Plate is the highest.

The temperature of Model 3's Vertical Absorber Plate shows the lowest value which has an average surface temperature of 44 ℃. This happened because Model 3 is equipped with an additional absorber plate which blocks most of the solar ray from reaching the vertical absorber plate. The vertical absorber plate for Model 3 has an average surface temperature which is lower than the vertical absorber plate for Model 1 and Model 2 too. This happened because the vertical absorber plate for Model 1 and Model 2 is one sided insulated and one sided expose to the air particle. Compare to the additional vertical absorber plate for Model 3, which is two sided expose to the air particle. The air particle carry more heat from both side of the additional vertical absorber plate and causes the surface temperature drop lower compare to other models.

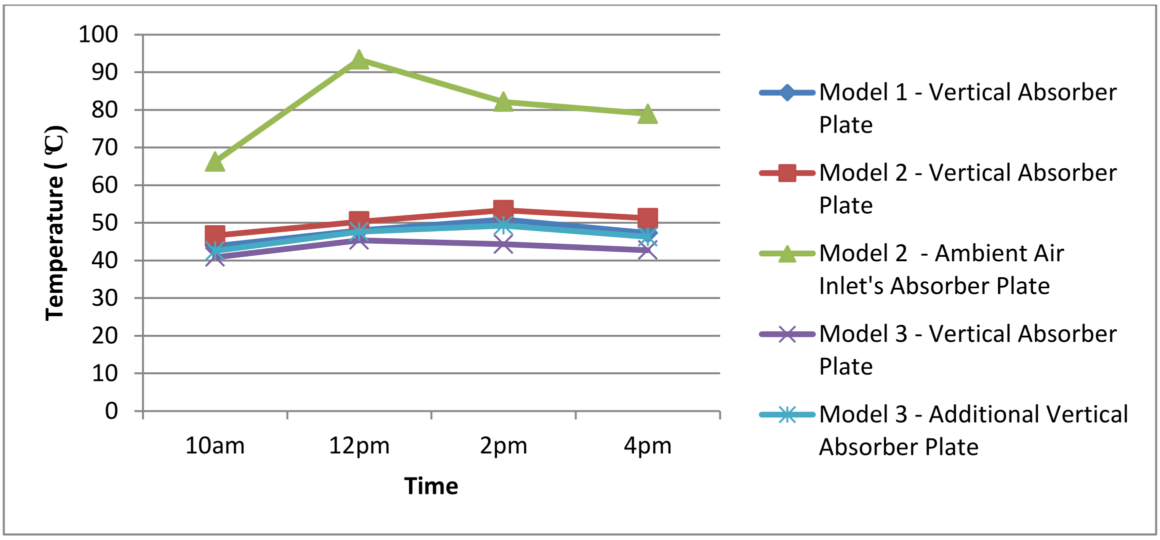

Figure 4.5: Average surface temperature of absorber plate for different model over time

Temperature of air along Chimney Channel

Figure 4.6 shows the average temperature of air along chimney channel for different model over time. Referring to Graph 4.2, Ambient Air Inlet's Absorber Plate of Model 2 has the highest average temperature. This is because the preheated ambient air from ambient air inlet channel is sent towards the vertical chimney channel. Model 3 has higher average temperature compare to Model 1 because Model 3 is equipped with an extra vertical absorber plate which help to increase the heat transfer rate of absorber plate to the air particle.

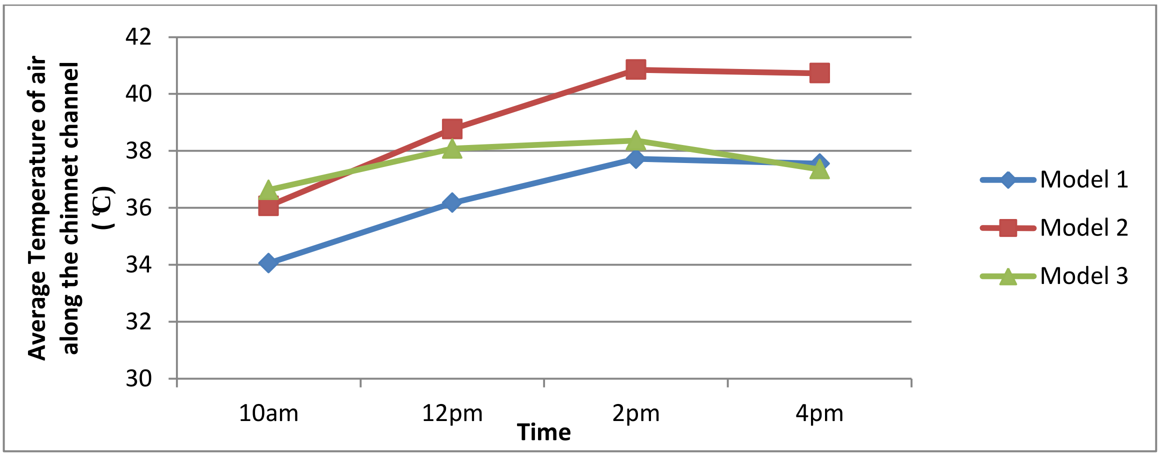

Figure 4.6: Average temperature of air along chimney channel for different model over time

Limitation of the experiment

Different limitation had been met during the experiment. The main limitation is the inconsistency of whether. The inconsistency of whether greatly affects the results recorded. During cloudy day, it reduces the amount of solar radiation direct to the absorber plate. This greatly reduces the heat transfer rate of the absorber plate and performance of the solar chimney. During windy day, it affects the measurement of air velocity. Reading which taken during windy day fluctuated. Some readings need to be retaken due to bad weather condition.

Other than inconsistency of whether, there is only one experimental site available which limits the experiment to be carried out in turns and not simultaneously. Data taken in different whether condition which result in inconsistency of value increases the difficulty in comparing data.

4.3 Simulation Results and Discussion

Air Stream Line

The simulation results are recorded in air velocity and temperature of the absorber plate. Figure 4.7, Figure 4.8 and Figure 4.9 show the streamline of air ventilating the house. The Air Streamline shows air is being updraft by the solar chimney and escaping the house through the solar chimney channel. In the meantime, Ambient Air is being drag into the house which created ventilation. Referring the Figure 4.8 to 4.9, the area along the solar chimney channel shows higher temperature compare to the surrounding air, this is due to the heat from solar absorbed by absorber plate and being transfer to the air particle. The higher temperature air particle have higher density which lead to the occurred of stack effect.

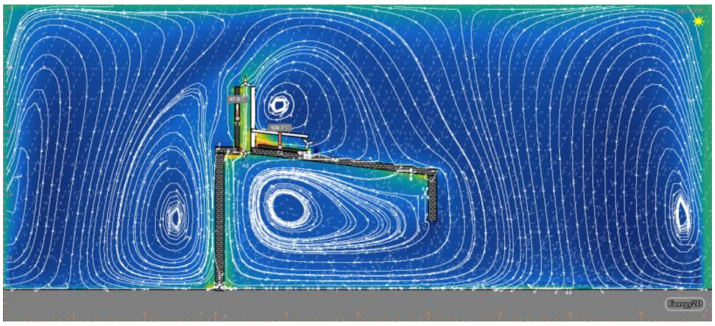

Figure 4.7: Air Streamline for Model 1

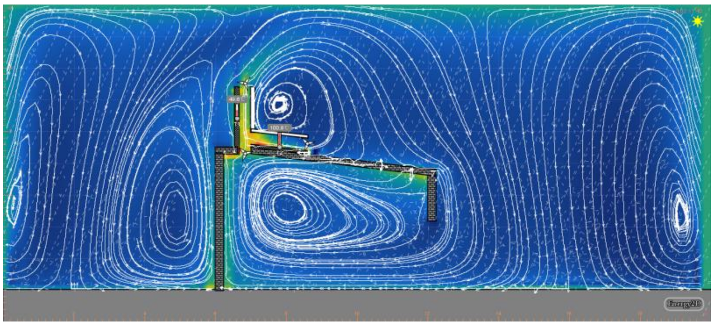

Figure 4.8: Air Streamline for Model 2

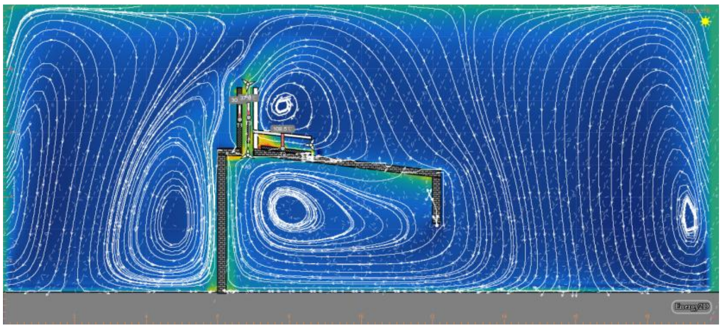

Figure 4.9: Air Streamline for Model 3

<u>Air Velocity at Different Inlet and Outlet</u>

Figure 4.10 and Figure 4.11 show the air velocity at room's air outlet and total air outlet respectively between Model 1, Model 2 and Model 3 over time. The simulation time is 7200 seconds. The trend line of the graph reached steady state after 2100 second for Room's Air Outlet and 1900 seconds for Total Air Outlet.

Figure 4.10 shows that Model 1 and Model 3 have higher air flow rate compare to Model 2. With the same explanation from experiment analysis, Model 2 with Ambient Air Inlet has a lower air flow rate because the buoyancy force created is weakened by ambient air inlet itself. The buoyancy force created at Model 2 updraft the air through room's air outlet and ambient air inlet. However, for Model 1 and 3, the buoyancy force updraft the air only though the room's air outlet.

Figure 4.11 shows that Model 2 has the highest air flow rate at total air outlet. This is because the ambient air inlet with absorber plate creates air flow that helps increase the air flow rate at total air outlet. However, this didn't give a positive effect to help increase the air flow rate at room's air outlet. Comparing Model 1 and Model 3, Model 3 with extra absorber plate has a higher air flow rate at total air outlet. This is due to the help from extra vertical absorber plate. Extra vertical absorber plate absorbs extra heat and increase the buoyancy force. Larger buoyancy force create higher air flow rate which increases the performance of solar chimney.

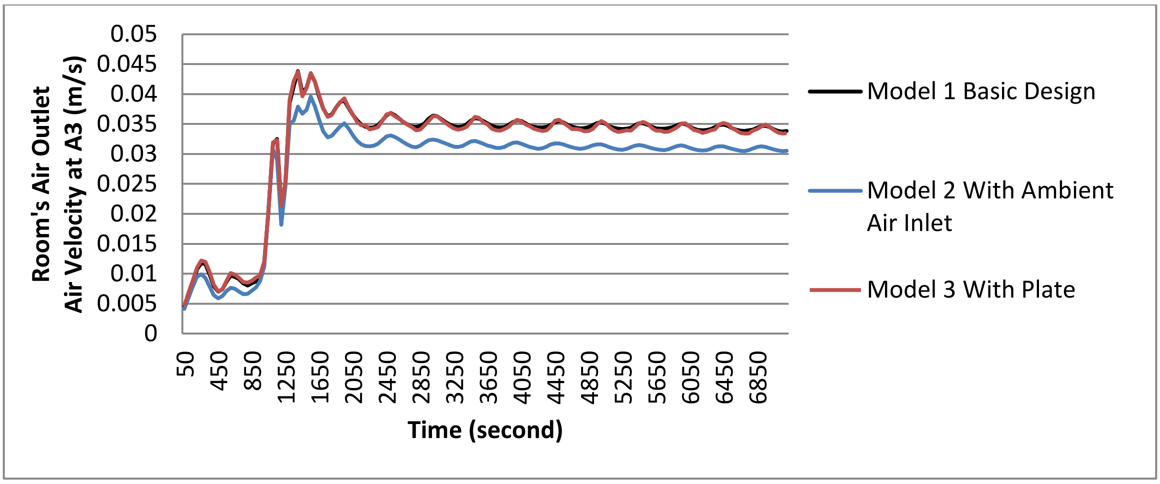

Figure 4.10: Comparison of Air Velocity of Room's Air Outlet over Time

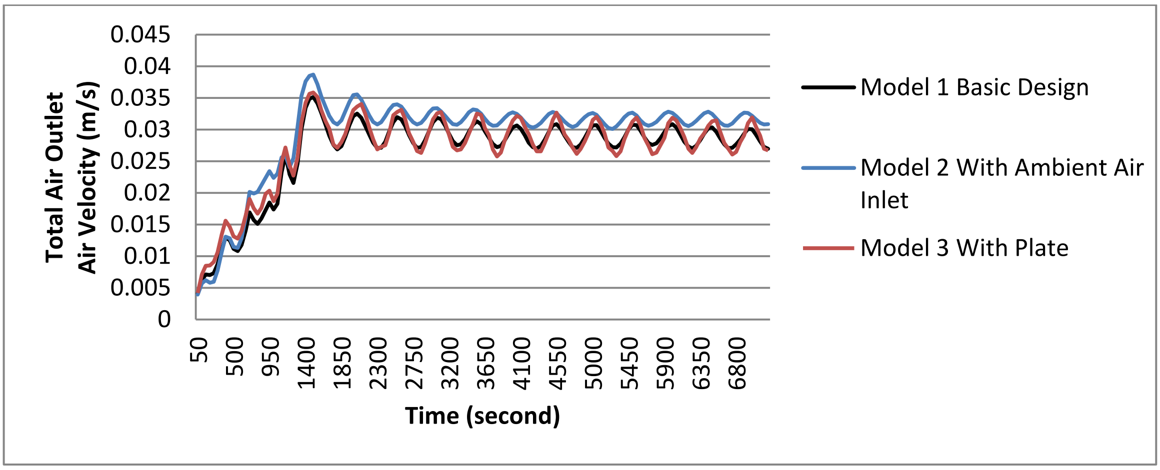

Figure 4.11: Comparison of Air Velocity at Total Air Outlet over Time

<u>Temperature for different Absorber Plate of different model</u>

Graph 4.12, Graph 4.13 and Graph 4.14 show the temperature for the absorber plates of Model 1, Model 2 and Model 3 respectively.

Base on the data collected from Figure 4.15 to Figure 4.17, the ambient air inlet's absorber plate for each model shows an average temperature of 100 ℃. Vertical absorber plate for model 1 and model 2 has an average temperature of 49 ℃. However, Vertical absorber plate for model 3 only shows an average temperature of 32 ℃. This is due to most of the sun ray is blocked by the additional vertical absorber plate, causing the average temperature of the vertical absorber plate decrease. Additional vertical absorber plate has an average temperature of 40 ℃ which is lower compare to the temperature of vertical absorber plate for Model 1 and Model 2. This is because the additional vertical absorber plate transfer heat to the air particle 2 sided which is front side and back side. Comparing to vertical absorber plate for Model 1 and Model 2, the vertical absorber plate is one sided insulated; there is only one side which works to transfer heat to the air particle. Therefore, the temperature of the additional vertical absorber plate is lower for Model 3. Hence, Model 3 performs better compare to Model 1 in terms of higher buoyancy force.

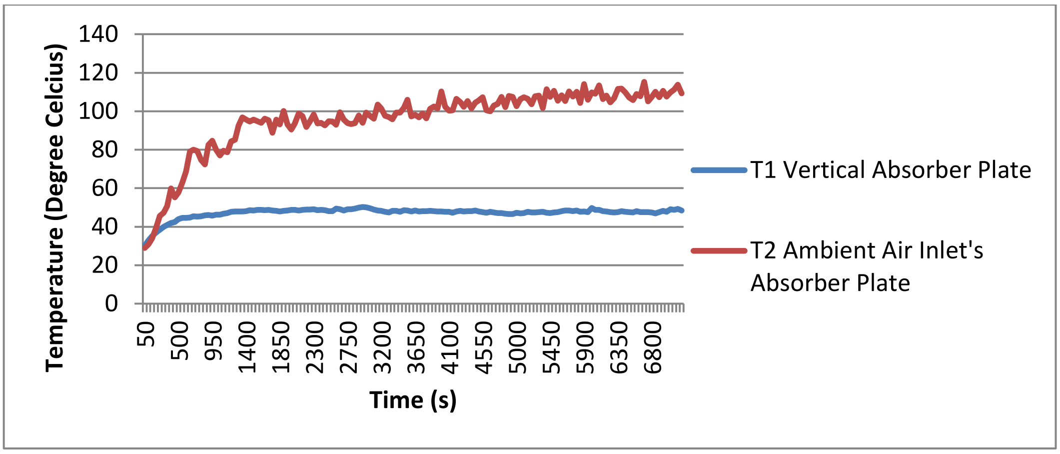

Figure 4.12: Temperature of absorber plate for Model 1 over Time

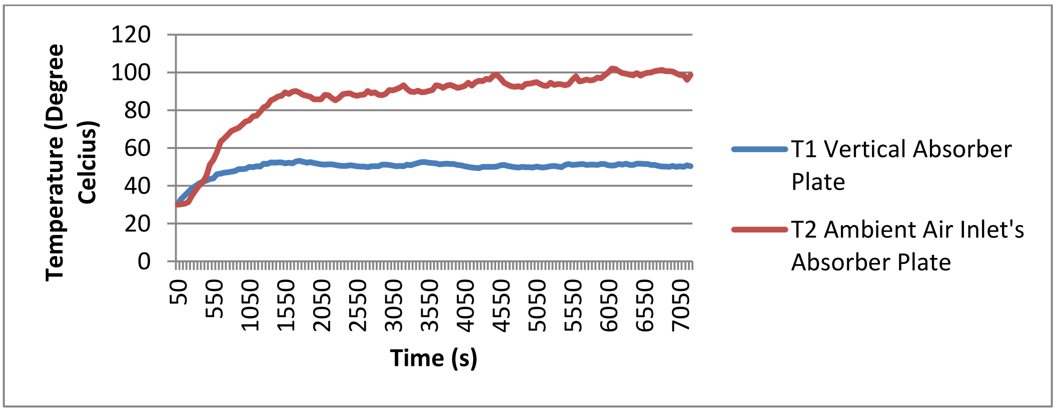

Figure 4.13: Temperature of absorber plate for Model 2 over Time

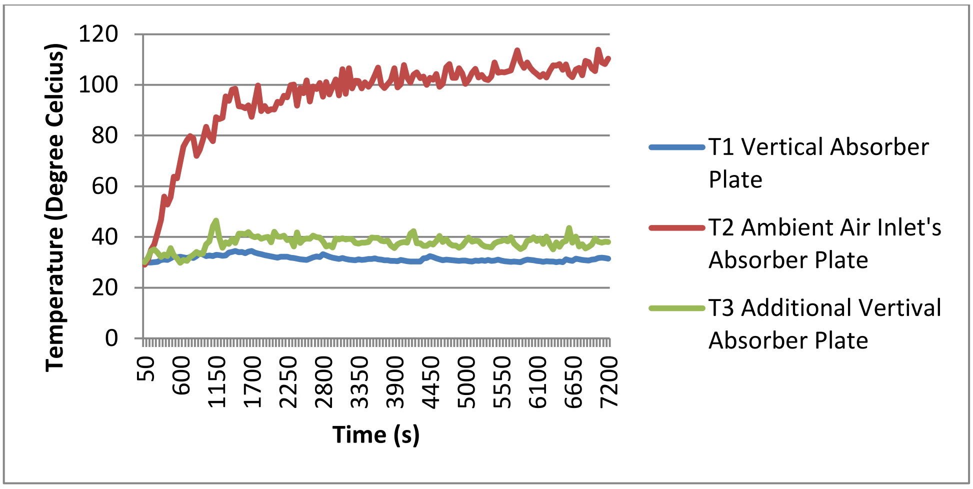

Figure 4.14: Temperature of absorber plate for Model 3 over Time

CHAPTER 5

CONCLUSIONS & RECOMMENDATIONS

This chapter will discuss the conclusion of the project and recommendation for future design improvement.

5.1 Conclusions

Solar Chimney uses solar energy to heat the air creating an updraft of air in the chimney. This is suitable to be use in country that has a sun hour above 6 per day. Solar Rooftop Chimney can provide ventilation with only using renewable source of energy which is solar power. To enhance the performance of the chimney, different design is built to undergo testing. The research has been carried out experimentally and by computational simulation. The results of this experiment would help in future development of Solar Rooftop Chimney. For Final Year Project Phase 1, the design of the chimney is achieved and has been sent for fabrication. For Final Year Project Phase 2, experiment site has been set up. Experiment and Simulation have been carried out to gather the required data. Experiment Results and Simulation Results show that Basic Design with additional vertical absorber increase the performance of the roof top solar chimney. However the Basic Design with additional of Ambient Air Inlet and Ambient Air Inlet's Absorber Plate lower the performance of the roof top solar chimney.

5.2 Recommendations

From the data gathered, it shows that the model with additional ambient air inlets increase the air volume flow rate at total's air outlet by 10.3%. However, the performance of the solar chimney is still low because the air flow rate at room's air outlet is low. To resolve this problem, the design of the solar chimney is advised to be modified. The current and the recommended rooftop solar chimney are shown at Figure 5.1. The proposed design has shifted the ambient air inlet into the building. With the help of transparent rooftop, the sunlight is able to reach the absorber plate of this new inlet. The air change rate of the room is believed will improve with the recommended design because the new inlet 2 function to draw out the air from the building and not from ambient air like what occurred with Model 2. Below is the listed recommendation for future research:

- Redesign the solar chimney base on the recommended concept shown in Figure 5.1 and measure the its performance
- Measure the ambient air speed which could help in further analysis for the performance of solar chimney in various weather condition
- Make optimum holes along the additional vertical absorber plate to reduce the blockage of the sunray which might help increase in chimney performance.

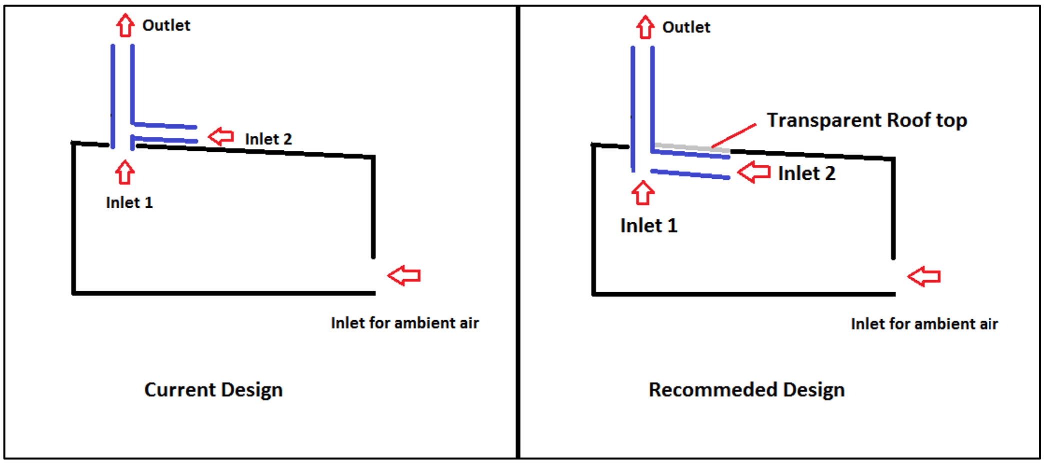

Figure 5.1: Current design and recommended design

CHAPTER 6

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