Solar Passive Cooling: Solar Chimney for Natural Ventilation

by

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CERTIFICATION OF APPROVAL

Characterizations of Sprays of Modified Starch Solution at Elevated Temperature for Particle Coating Application

by

Uzair Aslam Bin Azlan

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Approved by,

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(Dr Morteza Khalaji Assadi)

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TRONOH, PERAK

SEPTEMBER 2013

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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UZAIR ASLAM BIN AZLAN

Abstract

Passive Solar Cooling is a well establish concept in hot climate such in Malaysia, Thailand, Singapore and Indonesia. This condition causes thermal comfort disturb especially in urban area where there are many Green House Effect Gaseous. Usually society countering this problem by installing air conditioning system but it seems to give negative impact to the environment. As well it will lead to ozone layer depletion due to chlorofluorocarbons emitted. Therefore, more solar radiation will enter and hit the earth surface. Solar radiation is the total frequency spectrum of electromagnetic radiation from the sun. This spectrum contains visible light and near-visible radiation, such as x-rays, ultraviolet radiation, infrared radiation, and radio waves. However, these radiations can harm human and nature life when the intensity becomes high. For example, solar radiation from the sun that contains UV can cause skin cancer to human. While the society is trying to understand more about this phenomenon, they have discovered that solar also can be useful as alternative power. Solar is use to generate electricity by using either photovoltaic cell or solar thermal. Passive cooling is defined as the removal of heat from a building environment by applying the natural processes of elimination to the ambient atmosphere by convection, radiation and evaporation or to the adjacent earth by conduction and convection. While passive solar cooling can be classified as reducing of solar radiation from the Sun by using elimination process without the usage of energy. In this study, one of the applications of Passive Solar which is a solar chimney is examine to cool down building. By using regression method, testing the parameter of solar chimney will lead to better performance of solar passive cooling.

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1.1 Background of Study

Generally, building sector consumes 35.3% of final energy demand. Parts of the major energy consumption in buildings are the heating, ventilating, and air-conditioning systems. They are indoor climate controls that regulate humidity and temperature to provide thermal comfort and indoor air quality. The energy consumption in buildings, whether is the space heating or cooling usually being the dominant in the term of energy consumption. Heating or cooling is closely related to the local climate condition. Cooling systems are to provide cold or protect the building from direct solar radiation and improve air ventilation. That's why this cooling system is in a highly demand for a country with a hot humid climate. The solar chimney also known as a thermal chimney is a way of improving the natural ventilation of buildings byusing convection of air heated by passive solar energy.

A simple description of a solar chimney is that of a vertical shaft utilizing solar energy to enhance the natural stack ventilation through a building.

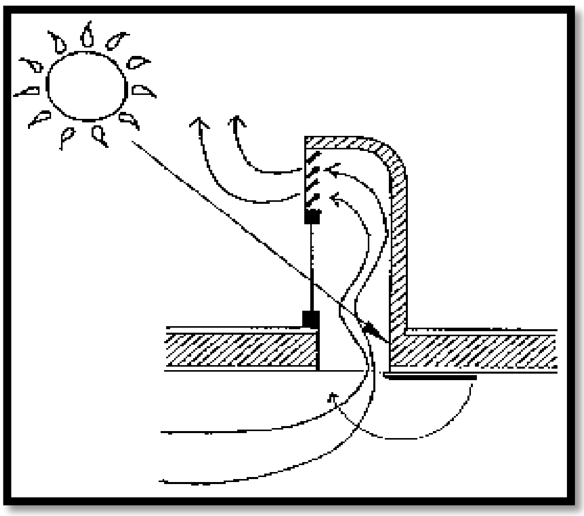

Figure 1: Solar Chimney Roof effect Illustration

The solar chimney has been in use for centuries, particularly in the Middle east and Near East by the Persians, as well as in Europe by the Romans. The principle of the solar chimney effect is a combination of solar stack-assisted and wind-driven ventilation. Air in the chimney expands due to increase in temperature by solar and being relatively lighter, rises out of the chimney outlets, drawing the cooler air into the interior through the fenestrations. This pull effect is further complemented by the push effect from the ambient wind. The stack pressure difference driving the air movement is a combination of the different densities between the interior and ambient environment as well as the stack height where the greater the stack height and temperature difference, the stronger the pressure difference. In solar assisted stack ventilation, the temperature difference is achieved from heat gained due to solar irradiance.

In order to achieve best performance, solar chimney design parameter must be studied based on their effect and function. For instant, the stack height affecting the air flow inside the chimney. However, there is a limitation as the stack cannot be far higher than the building height because it will causing view disturbance. This research is to optimize the parameter design so it can remove more heat from the building.

1.2 Problem Statement

Before regression testing started, solar chimney need to be create from a zone such as a room, it needs to be completely built with precise dimension to allow the software analyses information of the system. However there are some problems in progression of the regression testing. The problem statements of this study are as follow:

- The outdoor temperature is not constant and drastically changes due to time and weather.
- The volume of the interior space, the size of its fenestrations and the inclination angle of the solar affect the on performance is unknown.
- Actual performance measurements of the passive solar may differ from the computational method.

1.3 Significant of the Project

Through this project, parameters that can affect the performance of solar passive chimney will be tested using the same room size. This can result to optimize parameter that solar chimney required to perform better.

1.4 Objective

Research has determined the operability of implementing solar chimneys in the hot, cloudy and humid tropics. This paper aims to discuss the performance of tropical solar chimneys by varying the design parameters and examining their effects on the interior air temperature and speed.The objective of this study is to examine the effect of solar chimney's dimension on the interior performance of a room by using a regression method. This includes as follow:

- Stack height
- Depth
- Inlet position

The study is expected to be relevant and feasible after much deliberation based on the following; Solar Chimney is in need as solar passive cooling method is widely used worldwide, the energy consumption from all over the world keeps on increasing every year and the solar chimney is proven applicable and affordable for the society to install them at their resident.

Chapter 2: Literature Review and Theory

Solar radiation contains other component other than the light and heat that we perceive from the sun [1]. It produces energy in many forms, from perceptible heat, visible and invisible spectrums of light, radiation, and more. The sun must penetrate the atmosphere thus protects us from the more dangerous aspects of solar radiation. As a result of minute changes in our planets distance from the sun during orbit the Earths seasonal climate variation occurs. The elliptical path of the Earth's orbit was creating 100,000-year cycles of warming and cooling that led to the ice ages and tropical periods of the distant past. Sunlight affects different parts of the Earth in different ways, with extremes demonstrating in equatorial regions and the poles. It is important to take consideration both heating and cooling loads in the design devices is to study their impact on energy use or indoor temperatures using a dynamic energy simulation program [2].

The sun rises in the East and sets in the West. The sun travels in an arc, reaching its highest altitude in the South (for the Northern hemisphere) [3]. This in turn can have a positive effect on reducing the heat load and glare, and enhancing the use of natural daylight, thereby reducing the operating costs of the building. The temperature of house is mainly dependent upon the temperature of the roof and walls. A 50% of the heat load in the building is from roof only [4]. From previous study by Nahar (2003), it is found during summer (April–September) for a single storey building having all four sides exposed to the Sun, 36.7% of heat load in the building is from the roof. Commonly, roof is always exposed but some walls may not be exposed to the Sun, in that case, heat load in the building may be 50% or more from the roof [5]. In some cases, the overheating caused by sunshine on a building can completely be stop by a combination of shading and natural ventilation [6].

In this study will be focus on solar passive cooling technique of solar chimney for hot and humid area. Study of solar chimney couple with wind cooled cavity without mechanical intervention in hot humid climates [7]. The solar chimney generates airflow through a building, converting thermal energy from the sun into kinetic energy of air movement [8]. The density difference of air at inlet and outlet of the chimney controls the airflow rate through the solar. It provides ventilation for cooling the building. For hot climate, when the outdoor temperature is higher than the indoor, it operates as thermal insulation to reduce heat gain of the room. The common type used is to have a vertical chimney. Nevertheless, it may not be architectural eye-catching in term of aesthetics aspect as it is very visible and large. A combination of both of cheaper and less visually obtrusive format is to lay the collector along the roof slope while for greater height. From recent studies showed that solar chimneys are able to warm the air or ventilate the room air to create cooling effect even during cloudy days. The ambient air temperatures almost in a range of 42-47°C during the over-heated period in hot-arid regions, direct ventilation is not suggested due to undesirable body heat gain by convection [7].

This study is finding the effect of physical parameters of solar chimney on its performance including the stack height, depth of solar chimney and position of inlet. The measurement of the solar chimney performance is based on of the air velocity at the inlet and outlet of the building, temperature inside solar chimney and room temperature.

2.1 Stack height

The stack effect provides ventilation for a building that is hotter or colder on the inside than [9]. This is because of the temperature difference, the air inside the building is either more or less dense than the air outside. A natural flow will occur when there is opening at top of the building and another low in the building. As the air in the building is warmer than the outside it will float out the top opening, being replaced with cooler air from outside. During night time, migration of building's interior air happen to cool it for the next day.

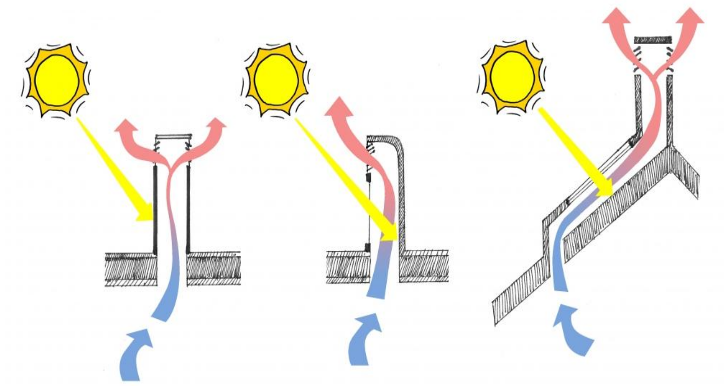

Figure 2: Solar Chimney Stack Difference Configuration. Retrieve from:
<http://sustainabilityworkshop.autodesk.com/buildings/stack-ventilation-and-bernoullis-principle>

Since the solar chimney is incorporated into the roof with a fixed inclination angle of 45° (tropical building codes), the length of its inclined portion will be the :

Cosine of half of the interior's length, $L = w \times cos\,45°$ (1)

However, Aboulnaga [8] carried out theoretical analysis on a common resident building in Al-Ain city, UAE. The solar chimney's depth and inclination angles were varied. Results gave an optimum inclination angle of 35°.The rate at which air flows for the stack depends on several factors which are the inside and outside air temperatures, the area of the openings, and the height difference between the top and bottom openings. The 1997 ASHRAE Fundamentals handbook gives the following relationship:

$Q = 60CdA\sqrt{}[2g(Hn - Hb)](\frac{Ti-To}{Ti})$ (2)

Where,

Q = flow rate in cfm,

Cd = 0.65 (for unobstructed openings),

A = opening area, square feet,

Ti = indoor temp (Rankine),

To = outdoor temp (Rankine),

Hn = height of "neutral pressure point" (for simple systems, assume 1/2 way between top and bottom openings).

Hb = height of bottom opening

g = gravity.

As from the formula of rate of the airflow, (*Hn - Hb*) which is the distance between height of neutral pressure point and height of bottom opening increase along with the height of solar chimney. Thus, increasing the rate of the air flow theoritically.

2.2 Depth of Solar Chimney

The depth of the solar chimney has causing significant amount of research due to the possibility of its effect for optimization. The working principal shows that friction losses are significant and slow down the air speed at small depth[13]. However, the thermal boundary layers may no longer cross each other at large depth, together with the possibility of backflow of air, leading to lower heat transfer. Currently, researchers return mixed reviews about the influence of the solar chimney's depth. The solar chimney's depth is bounded by 0.10 m and 0.90 m with an increment of 0.20 m; depths lower than 0.10 m givefairly low air speed according to published literature while depths higher than 0.90 m will be physically too large relative to the building. In 1998, Aboulnaga says that to obtain best cooling performance separation between the chimney walls should be kept apart at 0.20m and ratio (Ar), *Ai/As*, should also be 2.5 where *Ai* is the area of inlet and *As* is the area of outlet. Moreover, the absorption of an inclined roof solar chimney to a single house in AI-Ain (a hot-arid climate area) has shown an encouraging result. However, mostly the opening of the air inlet is according to the room dimension and depth highly related to the area of outlet. It is also found that the air speed within the solar chimney decreased with increasing depth [20]. According to previous stud, 0.2 m depth will get the best perfomance for cooling effect [8].

2.3 Width of Solar Chimney effects on the air flow movement.

The width of the solar chimney is a parameter that airflow within the solar chimney is generally two-dimensional flow. However, several researchers note that the width will directly affect the volume flowrate and the interior air speed [10]. With respect to the cavity width, it was found that the induced flow rate increases with increasing width. However, the with is also bounded to the width of the building. From recent study by Ong and Chow (2003) it was estimated that a 0.3 m wide channel induced 56% higher flow rate than one of 0.1m. However, Rodrigues et al. (2000) argued that airflow rates grow with cavity width, but the growth ratios decrease as the width increases. In some studies an optimum cavity width (or optimum height-to-width ratio) was reported; for this optimum width the flow rate became maximum, while for wider gaps reverse flow occurred that reduced the mean flow through the solar chimney . This unexpected difference between studies is attributed to the different ranges of height to-width ratios investigated and to the influence of the inlet size. The result is when inlet size increases along with the cavity width, a lower pressure drop in the inlet can counterbalance the reduction in the flow rate caused by reverse flow, so that no optimum width is found (Gan 1998, Chen et al. 2003). To support that the optimum width increases with height, Gan (2006) later reported an optimum width of 0.55m for a 6m high solar chimney. In addition from previous literature, measurement showed that a higher and wider chimney improved volume flow rate although the width is more significant [19].

2.4 The positions of the solar chimney's inlet

When there is an air penetration through a variety of unintentional opening in the building envelope, natural ventilation may occur [11]. From the ground to the ceiling, researchers further examine to find the positions of the solar chimney's inlet. According to Sarachitti et al. (2000) , the interior air temperature profile is not affected but the air speed profile is found to depend significantly. The movement of air inside the room is upwards as warm air rises when it's surrounded by cold air because of its lower density [14]. Therefore it is to put the inlet position high so that the ventilation flow due to stack effect is not against the movement of warm air inside the room. The solar chimney's inlet position was found to influence the interior air speed [18].

Chapter 3: Methodology

The systematic, theoretical analysis of the methods applied to this research begins with defining the tittle problem and scope of studies. After that, find the literature review that is related article such as journal, book and information from the Internet to find information from previous studies. And then, determine the data and parameter to develop a computational by using a program called ANSYS. It is a simulation program primarily used in the fields of renewable energy engineering and building simulation for passive as well as active solar design [12]. From the model developed, regression can perform test on different parameters of solar chimney.

Different parameters affect the performance of the solar chimney. For instance solar irradiance is the most widely research parameter and also the most convincing. Researchers find that air speed and temperature within the solar chimney increase with increasing solar irradiance. Within the time range of this study, solar irradiance is taken in a specific time and location as controlled variable. Inside the building, there is also a temperature drop and temperature lag. As the value of solar irradiance is fairly constant during the hot tropical afternoon and the interior will already be thermally comfortable during low solar irradiance. Hence, solar intensity is given according to its value between 8.00 am till 6.00pm. The value of solar intensity was calculated by using solar calculator provided by the ANSYS FLUENT software by the position of building model in the coordinate system on earth surface as follow [16]:

- Latitude = 4.6
- Longitude = 101.1
- Time Zone =UTC/GMT +8

Table 1: Solar Irradiance with respect to time at the sample location.

Time (hour)	Direct Normal Solar Irradiation (at Earth's surface) [W/m^2]	Diffuse Solar Irradiation - vertical surface: [W/m^2]	Diffuse Solar Irradiation - horizontal surface [W/m^2]	Ground Reflected Solar Irradiation - vertical surface [W/m^2]
8	584.3	46	36	15.2
9	584.3	46	36	15.2
10	584.3	46	36	15.2
11	584.3	46	36	15.2
12	1031.9	54	63.6	95.5
13	1038.8	51.2	64	99.8
14	1033.4	53.5	64	96.4
15	1013.6	58.9	62.4	85.5
16	971.2	64.2	59.8	67.9
17	880.6	64.6	54.2	44.8
18	637.5	50	39.3	18.3

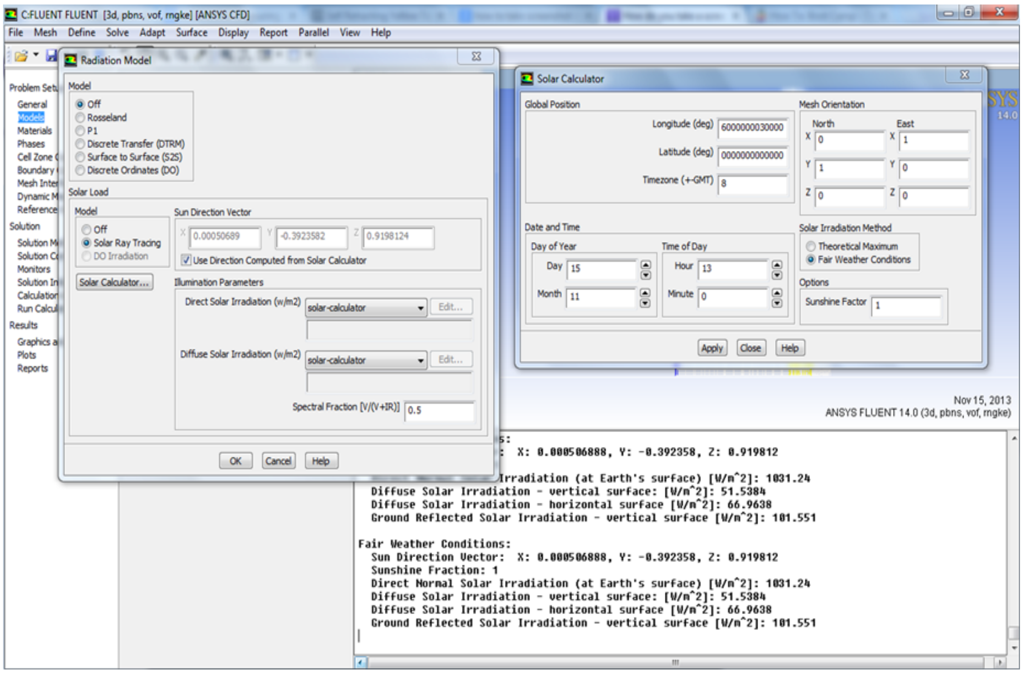

Figure 3: Solar calculator in ANSYS FLUENT.

By adding the direct solar irradiation and diffuse solar irradiation at vertical surface will get the total solar intensity for the specific time. Each hours, will be used to test the performance of solar chimney.

Table 2: Total solar intensity with respect to time at the sample location.

Time (hour)	Direct Normal Solar Irradiation (at Earth's surface) [W/m^2]	Diffuse Solar Irradiation - horizontal surface [W/m^2]	Total solar Intensity [W/m^2]
8	584.3	46.0	630.3
9	584.3	46.0	630.3
10	584.3	46.0	630.3
11	584.3	46.0	630.3
12	1031.9	54.0	1085.9
13	1038.8	51.2	1090.0
14	1033.4	53.5	1086.9
15	1013.6	58.9	1072.5
16	971.2	64.2	1035.4
17	880.6	64.6	945.2
18	637.5	50.0	687.5

After that since the ambient air speed parameter has limited review and in the tropics, solar irradiance is dominance as compared to the ambient air speed due to the relatively high solar irradiance and low ambient air speed. Therefore, tropical solar chimney is recommended to be working under zero ambient air speed. The inclination angle of the solar chimney is another widely research upon parameter, from fully horizontal to fully vertical. The greater the inclination angle, the higher the stack height, the lesser the flow resistance and the better the performance; however, the smaller the angle, the greater the exposure to solar irradiance and also the better the performance. Solar chimney is usually integrated into roof design where designers decide the roof's inclination angle based on building codes. Hence, the roof's and solar chimney's inclination angle is fixed at 45° to the horizon.

Although solar chimney predominately employed glass glazing as its exterior surfaces, there are increasing examples using roof tiles or metal sheets as alternative. Generally, glass glazing amplified the greenhouse effects which increase the thermal stack within the solar chimney but allow heat to be transferred into the interior if insulation fails; non-glass glazing absorbed higher solar irradiance and less heat energy is transferred to the air within but as the exterior surface is of higher temperature than the interior surface, non-glass glazing actually acts as a thermal buffer for the interior. Aluminium solar chimney is employed in the tropics as the material and construction costs are lower with greater construction ease on new buildings or retrofitting on existing buildings. In increasing the absorptivity, a dull and dark colour coating further proposed. Therefore, an assumption is made for the absorptivity value of solar intensity is equal to 1. In the area of interior configuration, the volume of the interior space and the size of its fenestrations are possible input parameters that may affect the performance of the solar chimney. However, limited research are found; this may be because the interior volume and fenestrations size are normally fixed to cater for its function and the configuration of the solar chimney is instead designed based on these pre-determined values. Meaning that changing the building dimension itself will be costly thus is not convincing the solar chimney purpose.

3.1. Physical Model and Parameterization

The interior space on the ground floor of a building with solar chimney is a square area of 14.36 m^2 with a height of 2.85 m, an interior size of residential room in University Teknologi Petronas student's hostel, where the solar chimney is incorporated into the roof. The opening will face north with an area of 0.22 m^2 (0.27 m in height by 0.83 m in width) while the solar chimney will face south at the middle of the wall according to the opening position in order to maximize the amount of solar irradiance. The ambient air outside the interior's fenestration is fixed at 31 °C as it is normally shaded with overhangs. The parameterization of the solar chimney's stack height is bounded by the height of the building (including the height of the roof), ranging from two stories to five stories giving a stack height of 2.85 m to 14.25 m, the number of stories is according to the sample building chosen. The stack height increases with a height of 2.85 m, the height of a typical level. As the solar chimney is incorporated into the roof with a fixed inclination angle of 45°, the length of its inclined portion will be the cosine of half of the interior's length, giving a fixed value of (3.75/2) × cos 45° = 1.33 m. From understanding principle, friction losses are significant and slow down the air speed at small depth. However at large depth, the thermal boundary layers may no longer cross each other, together with the possibility of backflow of air, leading to lower heat transfer. Recently, researchers return diverse reviews about the influence of the solar chimney's depth. The solar chimney’s depth is bounded by 0.10 m and 0.90 m with an increment of 0.20 m; depths lower than 0.10 m give fairly low air speed according to published literature while depths higher than 0.90 m will be physically too large relative to the building.

The width of the solar chimney is a parameter commonly overlooked as most research found that airflow within the solar chimney is generally two-dimensional flow. However, several researchers note that the width will directly affect the volume flow rate and the interior air speed. Similarly, the width of the solar chimney is bounded from 1.00 m to 7.00 m (as the width of the interior is 8 m) with an increment of 2.00 m. If the height of the building is fixed, the position of the solar chimney’s inlet will indirectly affect its stack height. To de-couple this relationship, the inlet position is varied independently from the stack height; when the inlet position is shifted upwards, the entire solar chimney duct is shifted upwards concurrently, assuming that the height of the building will increase to accommodate the stack height. Therefore, the inlet positions located at the bottom, middle and top position with respect to the ground.

Furthermore, as the height of the inlet is 0.25 m and the height of the wall is fixed at 2.85 m, the position of inlet are varies at 0.25m (bottom position), 1.65m(mid position) and 2.6m(top position) from ground level. The following summarize the parameter model of this study that need to be examine in order to understand it effect to the performance.

Table 3: Input parameter range of solar chimney.

Input parameters	Parameterization range				
	Lower bound	Upper bound	variable	Base case	No. of values
Stack Height (m)	2.85	14.25	2.85, 8.55, 14.25	14.25	3
Depth (m)	0.2	0.9	0.2, 0.45, 0.9	0.2	3
Width (m)	0.57	1.7	0.57, 1.14, 1.7	1.7	3
Inlet Position (m)	0.25	2.6	0.25, 2.13, 2.6	1.83	3

Since the are a lot of different combination to test the model, each parameter has been set to have one base case acting as fixed variable. By doing this the parameters can be test more systematically. In this methodology, testing the width of chimney as physical parameter is excluded as the test is in two-dimensional flow.

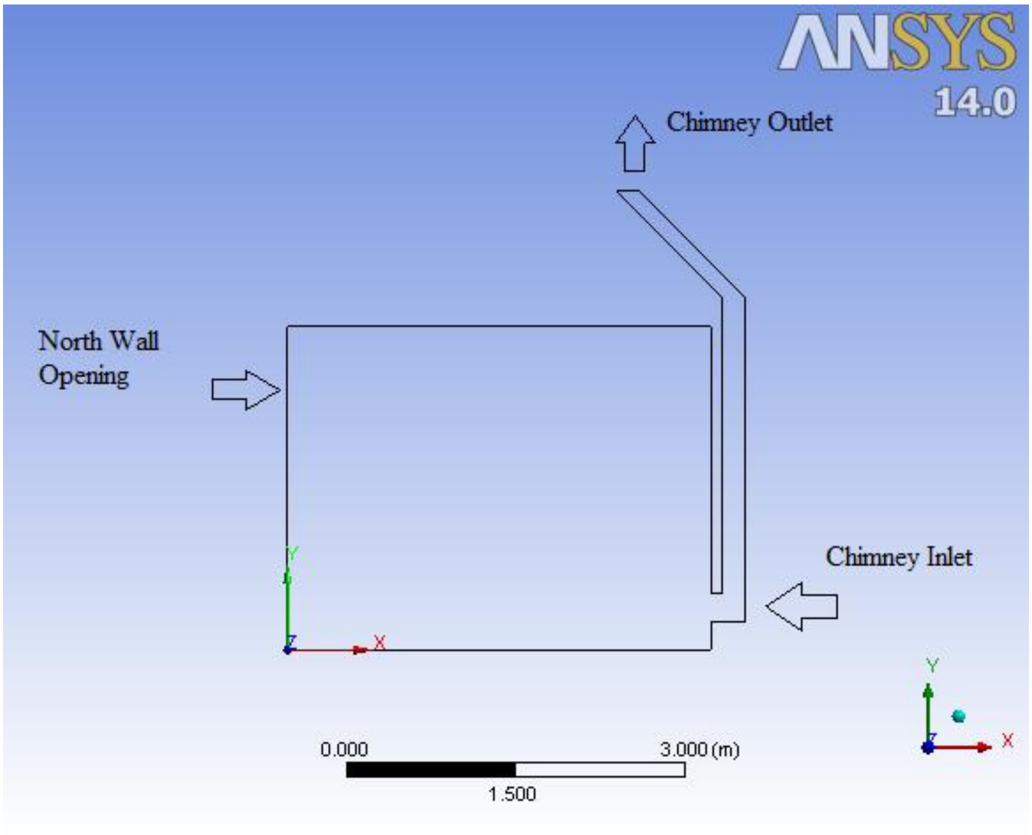

Figure 4: Position of inlet and outlet for computational model.

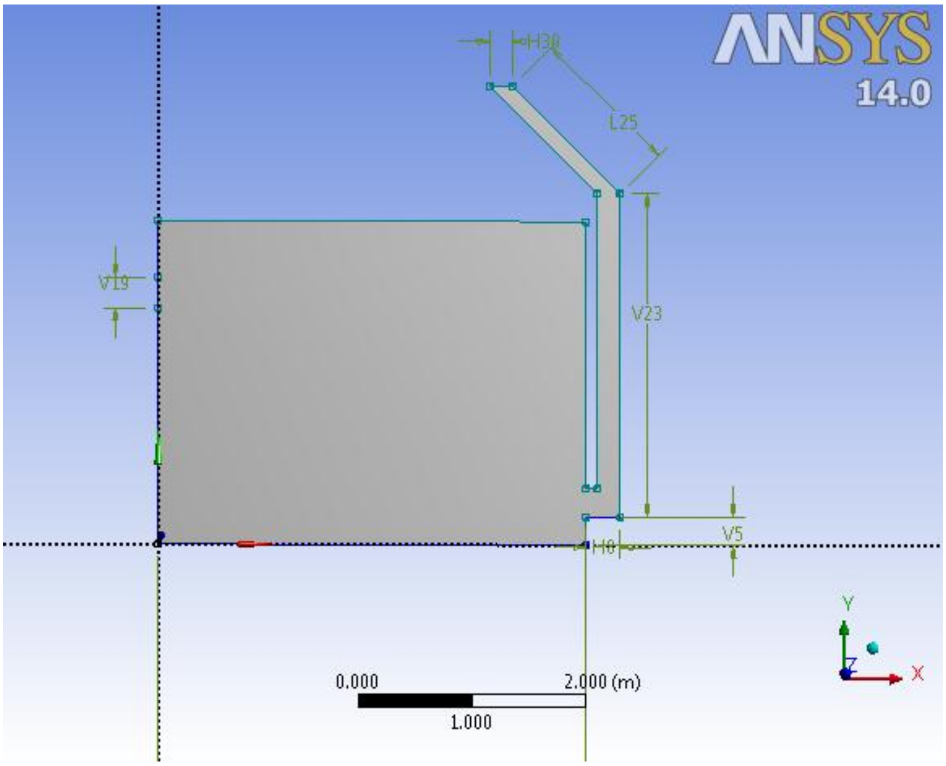

Figure 5: Schematic Diagram of Model; v19 is inlet, L25 is roof length, V23 is stack height, V5 is inlet position, H39 is outlet/ depth.

3.2. Computational Model

In studying the HVAC (heating, ventilation, and air conditioning) system many researcher have chosen FLUENT as the computational software for simulating the physical model as it reliable in the area of solar chimney. The computational model is developed from the physical model by disregarding the stories and roof above the ground floor (Figure 5). Furthermore, only at the mid plane of the model is examine as this study scope is only in two-dimensional flow. The computational model is validated with previous experimental data by researches [21], where the computational and experimental data of the air temperature and speed within the solar chimney as well as the interior are found to be comparable.

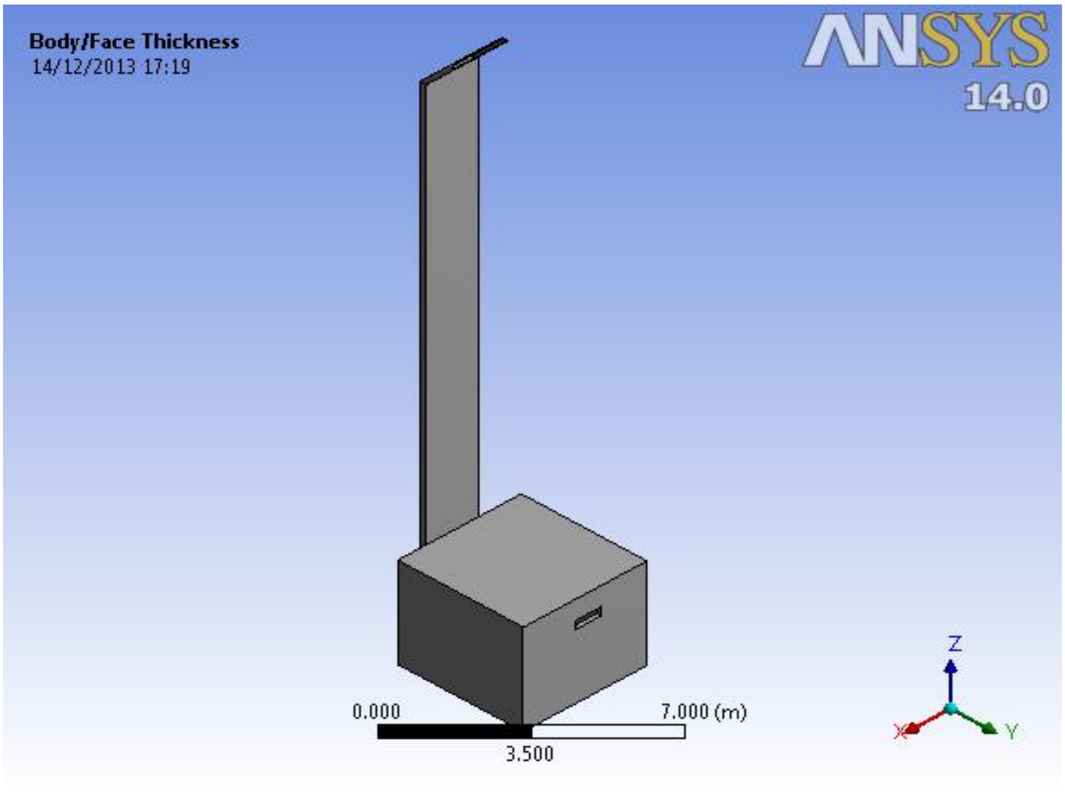

Figure 6: Isometric view of computational model

3.2.1. Boussinesq Approximation and Turbulence Modeling

In determining the setting of FLUENT for the solar chimney model simulations are carried out under steady state as the ambient solar irradiance and is found to be fairly constant during the hot tropical afternoon, the equations for the conservation of mass and momentum are modelled with no external sources [21]. At the inlet and outlet flow of the model, the meshes are further defined by division number of 50 and the mid plane surface is mapped. According to Tan and Wong (2013), the species diffusion and viscous dissipation in the energy equation are ignored as the Brinkman number is much less than unity. Furthermore, as radiation heat transfer is small no radiation model is used within the solar chimney duct as compared to conduction and convection. Strong buoyancy is expected as the ratio of the *Grashof* and *Reynolds* numbers is near unity.

Boussinesq approximation is used for the buoyancy of air as the solar chimney stack effect is natural convection under small change in air temperature [21]. Therefore, the temperature of room 300k is use as the input data. Except for the buoyancy term in the momentum equation, the computational model considers density to be at constant. The *Boussinesq* hypothesis of anisotropy of turbulence flow is insignificant in natural convective flow used for modelling the additional Reynolds stresses in the turbulent momentum equations thus Reynolds stress models are not selected. Due to its better performance under strong pressure gradient among the various turbulent models that employ that *Boussinesq* hypothesis, the realizable k-ε model is used. As the main sources of vorticity and turbulence the near-wall regions need to be modelled. Since the solar chimney stack flow is buoyancy-driven flow, the near-wall model approach is employed over the wall function approach. Both the pressure gradient effects and thermal effects are selected because the flow is natural convective. The *Rosseland* or diffusion approximation for radiation is used as it is valid when the medium is optically thick is greater than 3.

Furthermore, with relatively simple geometry the SIMPLE pressure-velocity coupling method is used as the computational model is under steady state condition. The second order upwind scheme are subjected to the discretization of momentum, turbulent kinetic energy, turbulent dissipation rate and energy as accuracy is preferred over better convergence. In addition, as solar chimney flow is high Rayleigh number natural convection flow PRESTO! is used as the pressure interpolation scheme.

3.2.2. Boundary Conditions and Convergence Criteria

The boundary conditions for the model in ANSYS FLUENT in determining the two-phase flow of natural convection operating at temperature set to 301 K (normal ambient temperature in equator region) with gravity of 9.81 m/s^2 for the flow zero gauge pressure and the ambient pressure of 101325 Pascal (Pa) or 101.325 kilopascal (kPa). The rest of the surface boundaries are stationary walls under no-slip conditions other than the computational inlet and outlet. All interior wall surfaces are under zero heat flux while the solar chimney exterior surfaces are subjected to heat flux of according to solar intensity (absorptivity value of 0.80) with 3 mm thick aluminium plates into the computational model. The result will be according to the coordinate of inlet and outlet in the simulation where x (horizontal) and y (vertical) is the direction of the air flow.

3.2.3. Performance calculation for Solar Chimney

As the ventilation is measure by the air change rate - air changes per hour where the result from regression test is the velocity of air inside the chimney. After calculate the volume flow rate, *q*, air change rate can be expressed in SI-units as:

$n = 3600\, q \,/\, V$ (3)

where,

n = air changes per hour
q = fresh air flow through the room (m^3/s)
V = volume of the room (m^3)

The volume of the sample room is 41 m^3 regardless the volume of solar chimney and the fresh air flow through the room is measure by *q*= velocity of air x solar chimney cross-sectional area. As the air change rate per hour require by a student's hostel room, n_o is $2h^{-1}$ same with typical bedroom [22], the solar chimney performance can be calculated by $n/no \;\; x\; 100\%$ (4).

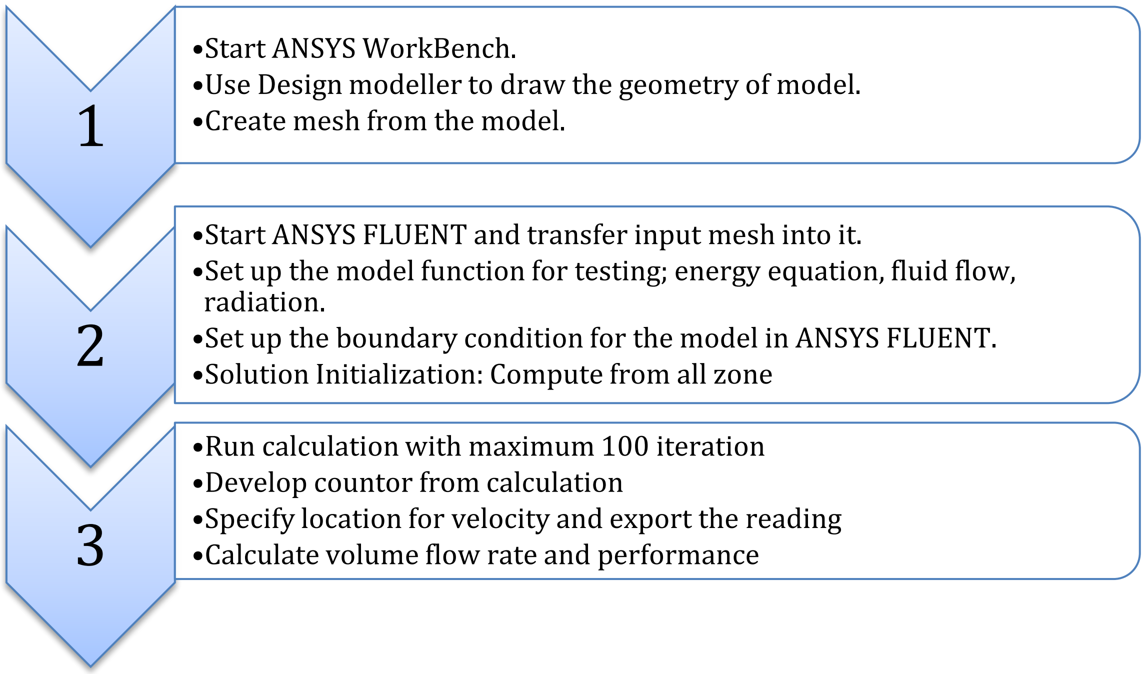

Figure 7: Methodology flow chart for regression test

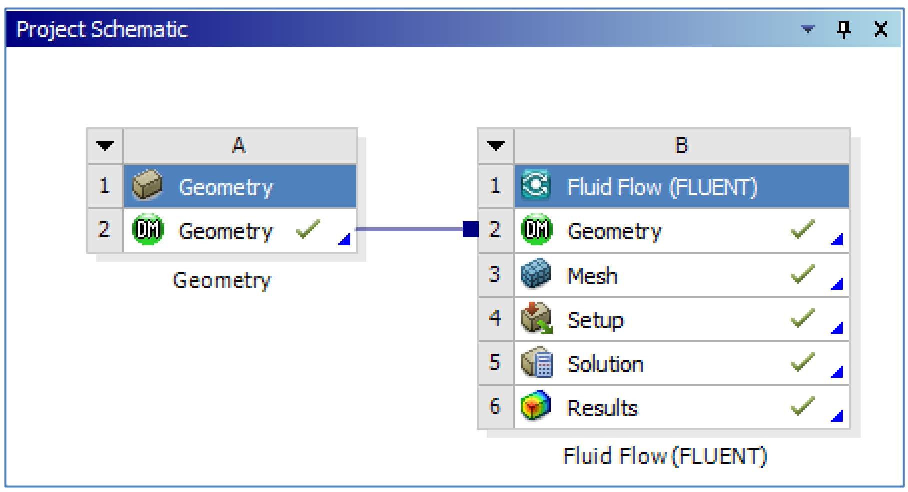

Figure 8: Project Schematic for regression test

3.3 Overall Research Methodology Flow Chart

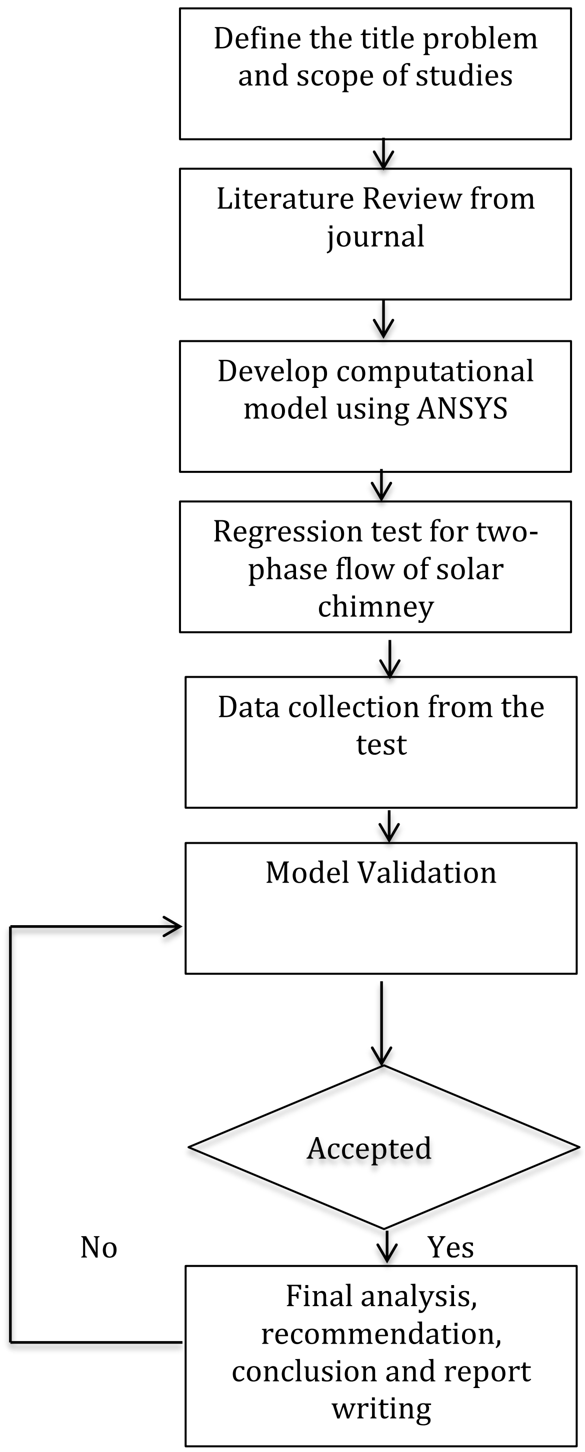

Figure 9: Overall research methodology

3.4 Project Gannt Chart

GNo	Action/Plan	Week													
		1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	Measuring Sample														
2	Collecting Literature review														
3	Analysing Research / Literature review														
4	Data Collection														
5	Model Development														
6	Progress Report														
7	Regression Testing														
8	Analysing Result														
9	Submission of Final Report and technical paper to supervisor, presentation, viva														

LEGEND	
	Project Schedule
	FYP Schedule

Figure 10: Project Gannt Chart

The Gannt Chart represents the progress of the final year project from the beginning until the end of part II. It varies accordingly to the project title and supervisor consult. At the end, the submission of draft will be considered as the end of FYP part II.

Chapter 4: Result and Discussion

With the computational model developed, the effects of the three input parameters: Stack Height , Depth and Inlet Position are simulated to understand their influences on the two primary output parameters which are velocity of air and performance. The parameterization of these three input parameters gives rise topossible different combinations, of which 10 cases are selected and simulated. Grid adaption is carried out based on the gradients of the flow velocity to determine whether the solved flow solution is independent of the mesh grid. The curvature approach is used as the solar chimney flow gives smooth solution. The countour display gives prove that the simulation is valid. This observation gives the confidence that the simulated solution is indeed independent of its grid.

4.1.1 Base case analysis

Table 4: Result for base case analysis.

Time (hour)	Total solar Intensity [W/m^3]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.05	0.02	1.8	100
9	630.3	0.05	0.02	1.8	100
10	630.3	0.05	0.02	1.8	100
11	630.3	0.07	0.02	1.8	100
12	1085.9	0.14	0.05	4.4	220
13	1090	0.15	0.05	4.4	220
14	1086.9	0.14	0.05	4.4	220
15	1072.5	0.14	0.05	4.4	220
16	1035.4	0.13	0.04	3.5	175
17	945.2	0.1	0.03	2.6	131
18	687.5	0.06	0.02	1.8	100

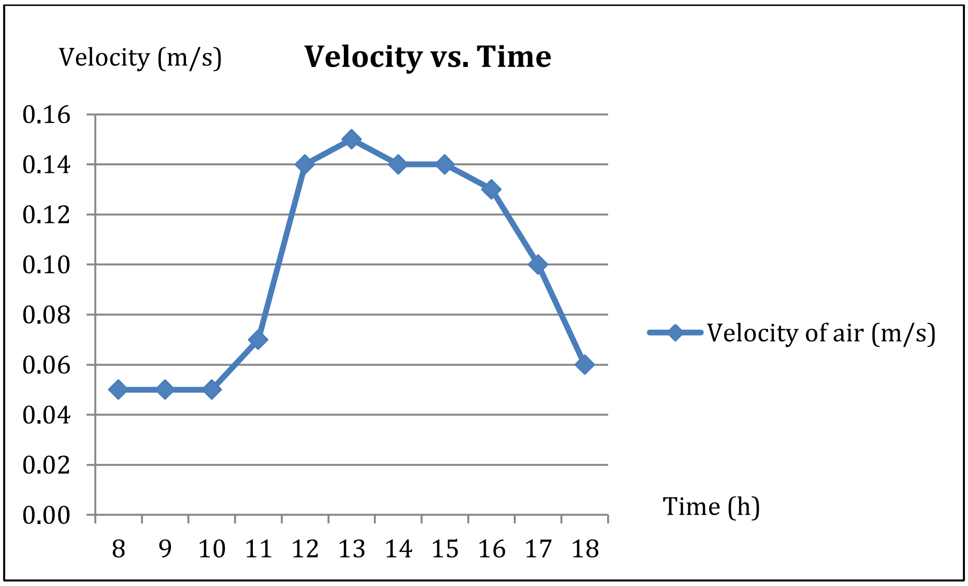

Figure 11: Result for base case analysis (velocity of air).

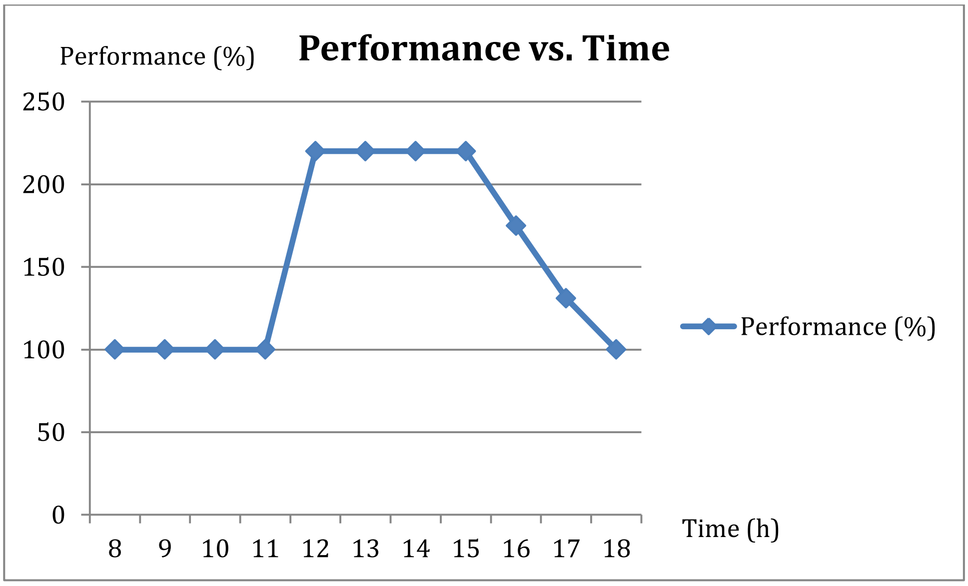

Figure 12: Result for base case analysis (performance).

4.1.2 Stack height analysis

<u>Stack Height = 2.85 m</u>

Table 5: Result for 2.85 stack height analysis.

Time (hour)	Total solar Intensity [W/m^3]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.03	0.01	0.87	43.5
9	630.3	0.03	0.01	0.87	43.5
10	630.3	0.03	0.01	0.87	43.5
11	630.3	0.03	0.01	0.87	43.5
12	1085.9	0.04	0.01	0.87	43.5
13	1090	0.09	0.03	2.6	130
14	1086.9	0.05	0.02	1.7	85
15	1072.5	0.05	0.02	1.7	85
16	1035.4	0.05	0.02	1.7	85
17	945.2	0.04	0.01	0.87	43.5
18	687.5	0.03	0.01	0.87	43.5

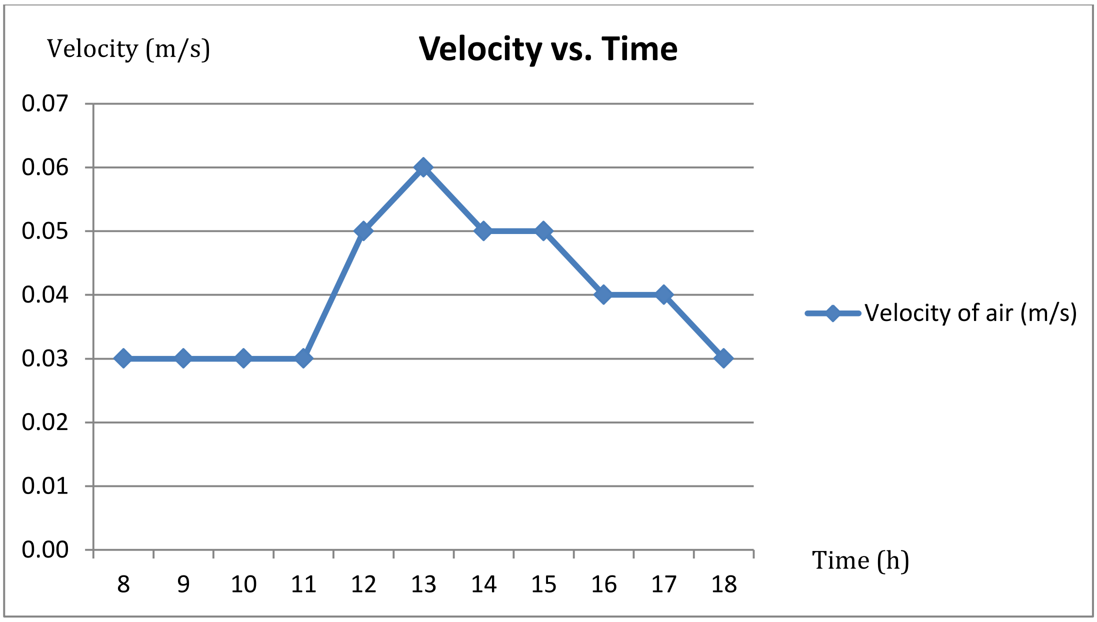

Figure 13: Result for 2.85 m stack height analysis (velocity of air).

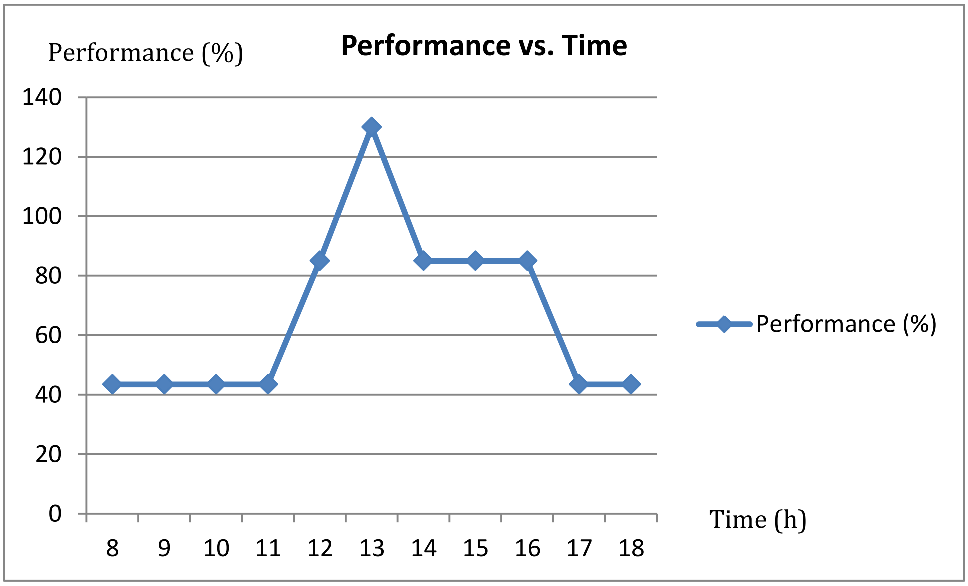

Figure 14: Result for 2.85 m stack height analysis (performance)

Stack Height = 8.55 m

Table 6: Result for 8.55m stack height analysis.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.06	0.02	1.8	90
9	630.3	0.06	0.02	1.8	90
10	630.3	0.06	0.02	1.8	90
11	630.3	0.06	0.02	1.8	90
12	1085.9	0.08	0.03	2.6	130
13	1090	0.12	0.04	3.5	175
14	1086.9	0.12	0.04	3.5	175
15	1072.5	0.12	0.04	3.5	175
16	1035.4	0.10	0.03	2.6	130
17	945.2	0.09	0.03	2.6	130
18	687.5	0.07	0.02	1.8	90

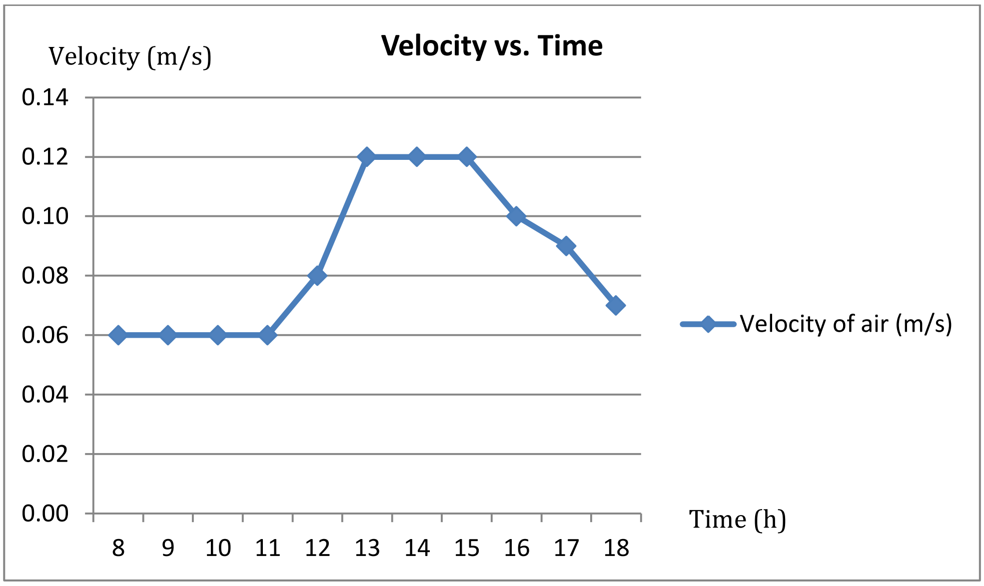

Figure 15: Result for 8.55 m stack height analysis (velocity of air).

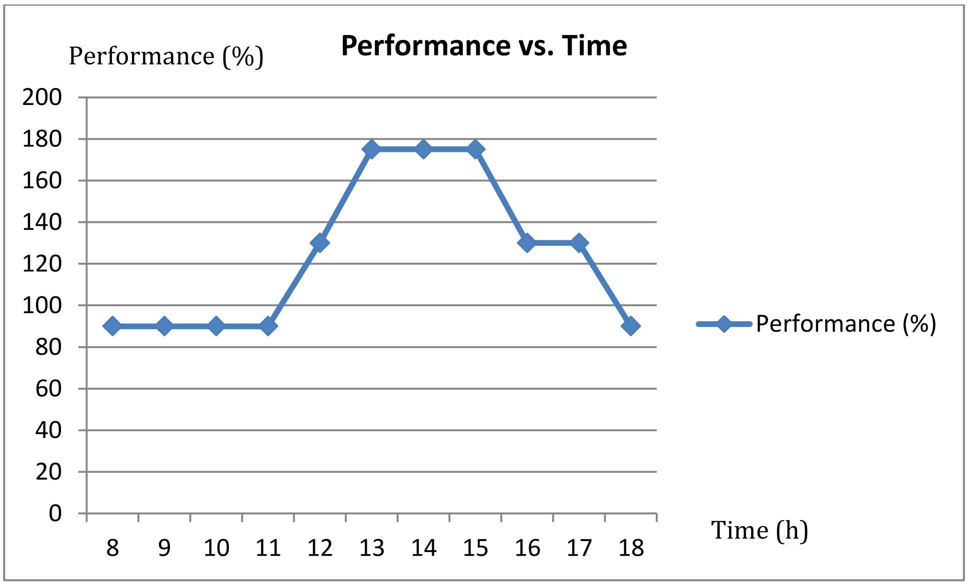

Figure 16: Result for 8.55 m stack height analysis (performance).

Stack Height = 14.25 m

Table 7: Result for 14.25 m stack height analysis.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.05	0.02	1.8	100
9	630.3	0.05	0.02	1.8	100
10	630.3	0.05	0.02	1.8	100
11	630.3	0.07	0.02	1.8	100
12	1085.9	0.14	0.05	4.4	220
13	1090	0.15	0.05	4.4	220
14	1086.9	0.14	0.05	4.4	220
15	1072.5	0.14	0.05	4.4	220
16	1035.4	0.13	0.04	3.5	175
17	945.2	0.1	0.03	2.6	131
18	687.5	0.06	0.02	1.8	100

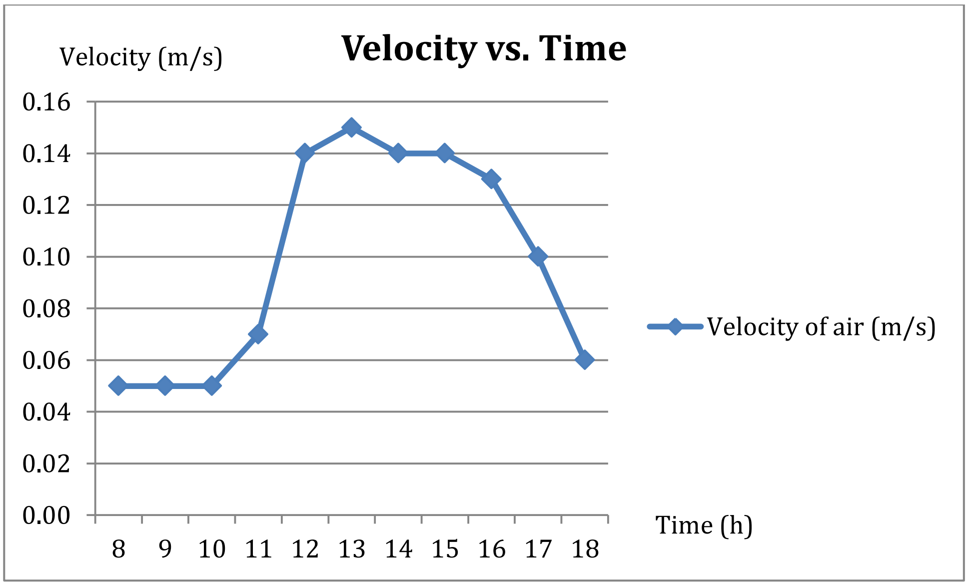

Figure 17: Result for 14.25 m stack height analysis (velocity of air).

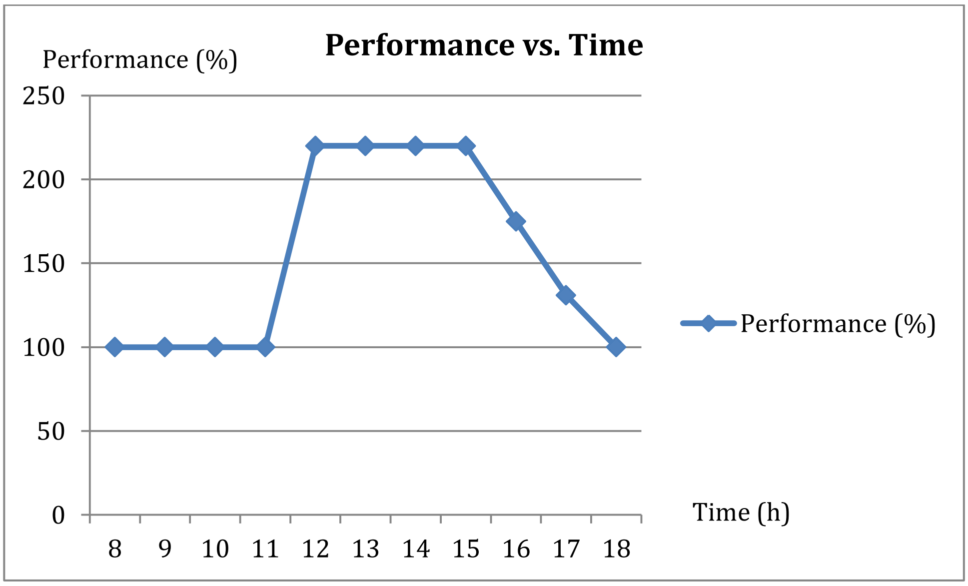

Figure 18: Result for 14.25 m stack height analysis (performance).

The effects of stack height on the velocity of air and performance within the solar chimney and interior are clear, the higher the stack height, the greater the performance of solar chimney outlet air temperature. The greater the stack height and corresponding higher air temperature within the solar chimney results in thermal energy being transferred in greater quantity and hence leads to an increase in the heat transfer coefficient. At the same time, this leads to the increase in air speed within the solar chimney. For all three height tested, the maximum performace is at 1 pm where the solar intensity is the highest. This shows that it correspond with the theory of solar chimney effect where solar intensity can increase the air speed. In addition, the base case analysis also supporting the theory when other parameter is keep constant while the solar intensity is varies. The maximum capablity of solar chimney for rate of air change is 4.4 h^{-1} when the stach height is the highest. This shows that it can supply sufficient ventelation requirment for the room.

4.1.3 Inlet position analysis

Inlet position-1= 0.25m above ground

Table 8: Result for Inlet position-1 analysis.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.05	0.02	1.8	90
9	630.3	0.05	0.02	1.8	90
10	630.3	0.05	0.02	1.8	90
11	630.3	0.05	0.02	1.8	90
12	1085.9	0.08	0.03	2.6	130
13	1090	0.09	0.03	2.6	130
14	1086.9	0.08	0.03	2.6	130
15	1072.5	0.08	0.03	2.6	130
16	1035.4	0.07	0.02	1.8	90
17	945.2	0.06	0.02	1.8	90
18	687.5	0.05	0.02	1.8	90

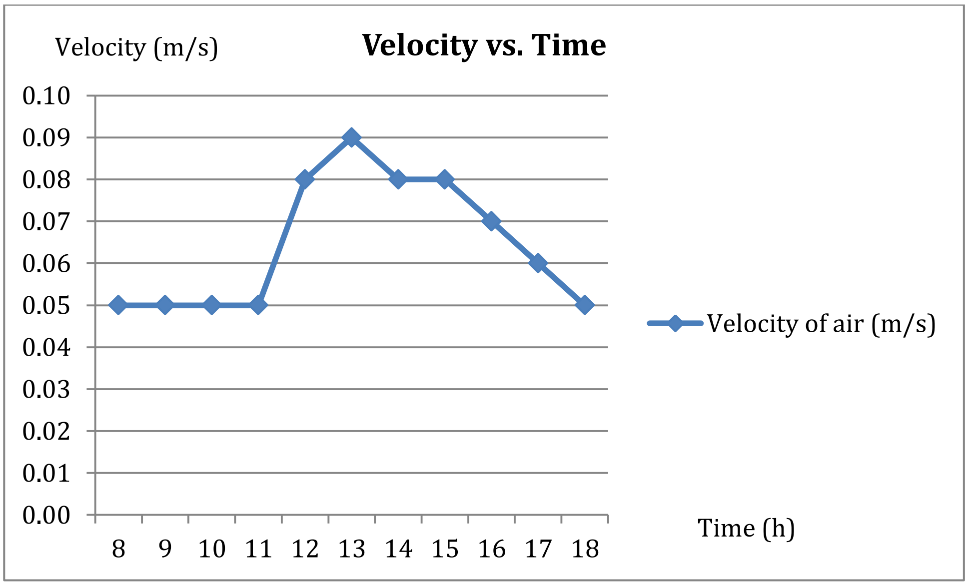

Figure 19: Result for inlet position-1 analysis (velocity of air).

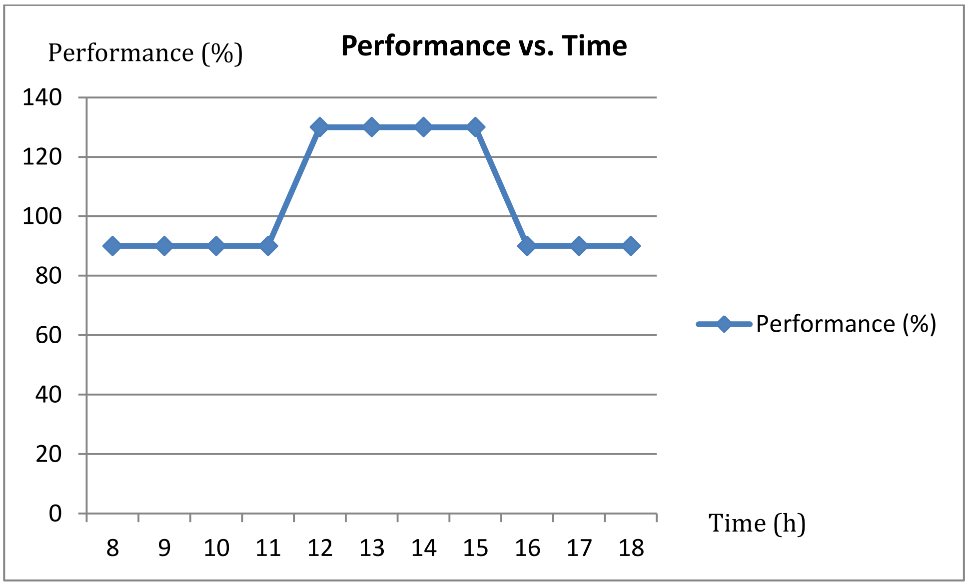

Figure 20: Result for inlet position-1 analysis (performance).

Inlet position-2= 2.13m above ground

Table 9: Result for Inlet position-2 analysis.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.05	0.02	1.8	100
9	630.3	0.05	0.02	1.8	100
10	630.3	0.05	0.02	1.8	100
11	630.3	0.07	0.02	1.8	100
12	1085.9	0.14	0.05	4.4	220
13	1090	0.15	0.05	4.4	220
14	1086.9	0.14	0.05	4.4	220
15	1072.5	0.14	0.05	4.4	220
16	1035.4	0.13	0.04	3.5	175
17	945.2	0.1	0.03	2.6	131
18	687.5	0.06	0.02	1.8	100

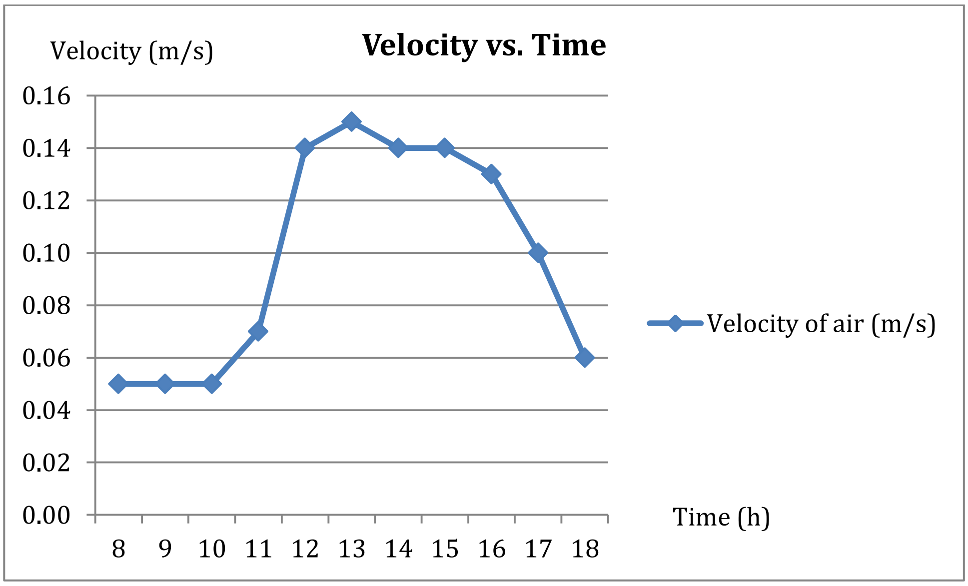

Figure 21: Result for Inlet position-2 analysis (velocity of air).

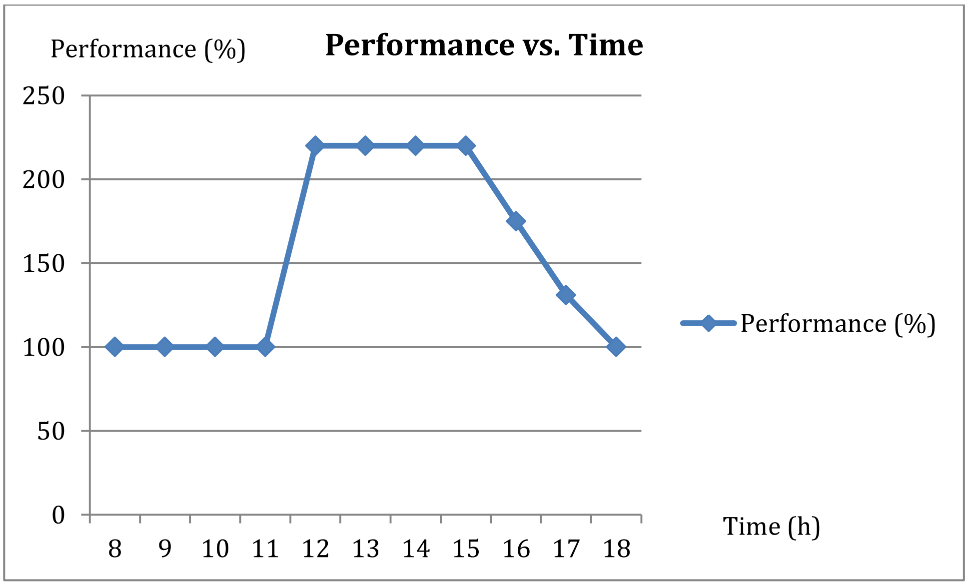

Figure 22: Result for inlet position-2 analysis (performance).

<u>Inlet position-3= 2.6 m above ground</u>

Table 10: Result for Inlet position 3 analysis.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.05	0.02	1.76	90
9	630.3	0.05	0.02	1.76	90
10	630.3	0.05	0.02	1.76	90
11	630.3	0.05	0.02	1.76	90
12	1085.9	0.05	0.02	1.76	90
13	1090	0.05	0.02	1.76	90
14	1086.9	0.05	0.02	1.76	90
15	1072.5	0.05	0.02	1.76	90
16	1035.4	0.05	0.02	1.76	90
17	945.2	0.05	0.02	1.76	90
18	687.5	0.05	0.02	1.76	90

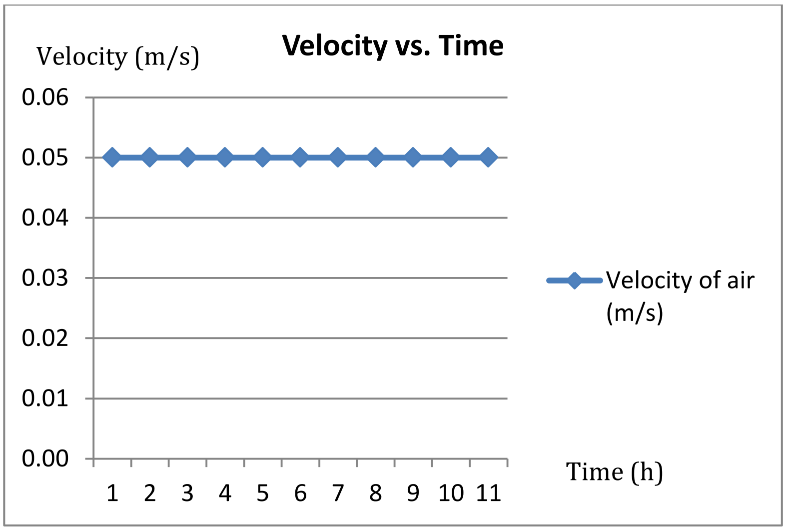

Figure 23: Result for inlet position-3 analysis (velocity of air).

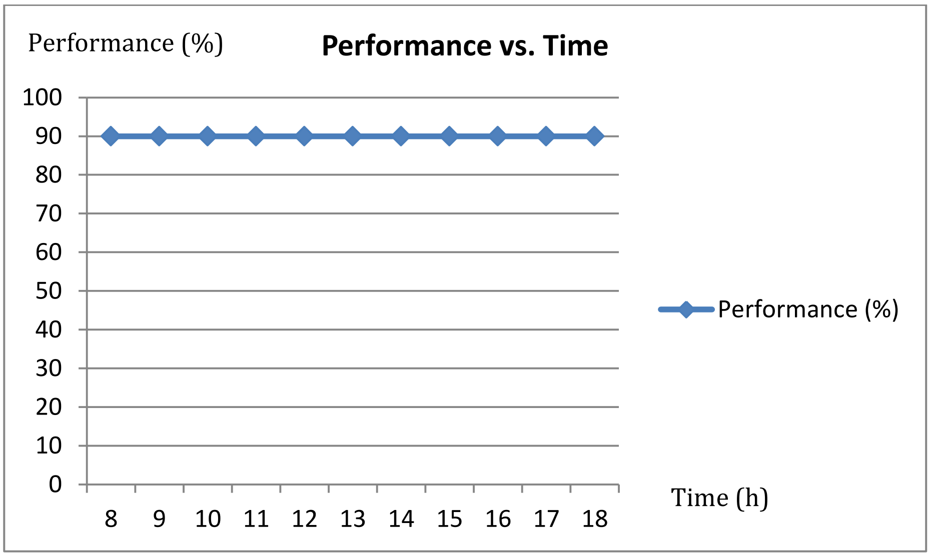

Figure 24: Result for inlet position-3 analysis (performance).

The solar chimney's inlet position is defined as the height of the mid-plane of its inlet above the ground. As the size of the inlet is equal to the solar chimney's depth, the inlet position varies with the solar chimney's depth. On average, the bottom, middle and top position of the inlet are 0.25 m(bottom), 2.13 m(middle) and 2.6 m(top) above the ground respectively. The solar chimney air velocity change drastically due to different inlet position as the air profile changes and affect the movement of air toward the solar chimney inlet.

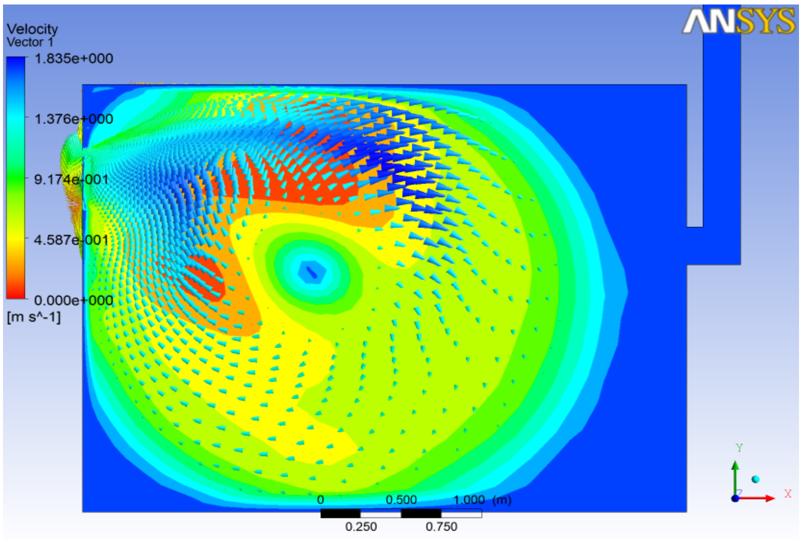

Figure 25: Air profile of velocity vector for Inlet-3 position.

The output velocity of air is the same from literature where lowering the inlet position to the middle position leads to an increase in output air speed significantly[14]. At the top position, the air profile create a back flow thus lowering the inlet position causing can change in air profile. The air velocity along the chimney is remain constant at 0.05 m/s although the solar intensity changes.

4.1.4 Solar chimney depth analysis

Depth = 0.2 m

Table 11: Result for solar chimney depth 0.2 m.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.05	0.02	1.8	100
9	630.3	0.05	0.02	1.8	100
10	630.3	0.05	0.02	1.8	100
11	630.3	0.07	0.02	1.8	100
12	1085.9	0.14	0.05	4.4	220
13	1090	0.15	0.05	4.4	220
14	1086.9	0.14	0.05	4.4	220
15	1072.5	0.14	0.05	4.4	220
16	1035.4	0.13	0.04	3.5	175
17	945.2	0.1	0.03	2.6	131
18	687.5	0.06	0.02	1.8	100

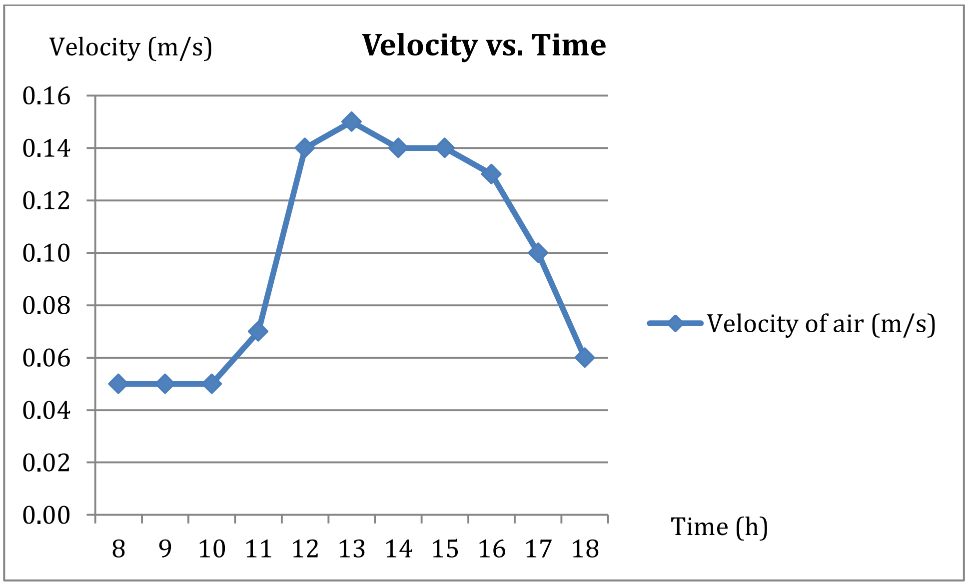

Figure 26: Result for depth of solar chimney 0.2m (velocity of air).

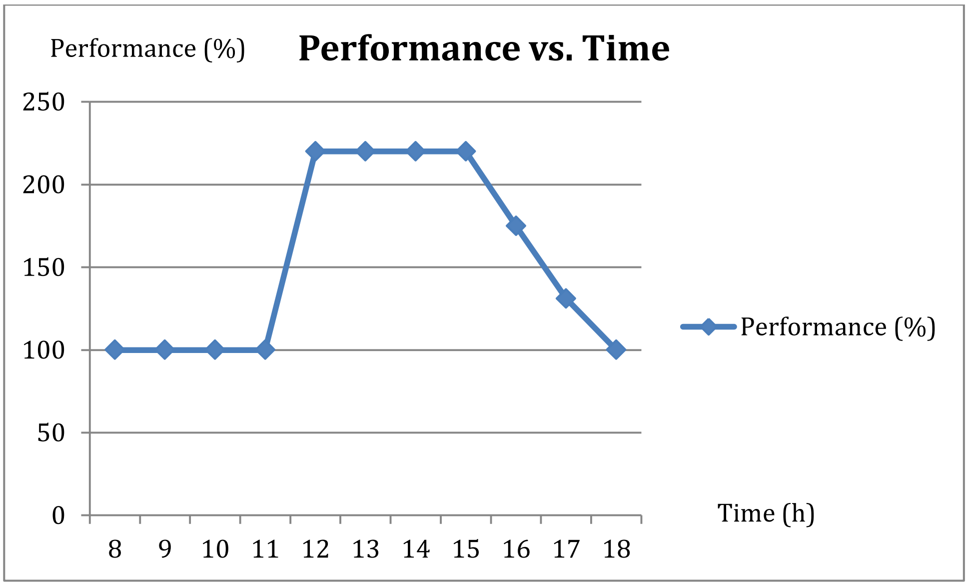

Figure 27: Result for depth of solar chimney 0.2m analysis (performance).

Depth = 0.45 m

Table 12: Result for solar chimney depth 0.45 m.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.04	0.03	2.6	90
9	630.3	0.04	0.03	2.6	90
10	630.3	0.04	0.03	2.6	90
11	630.3	0.04	0.03	2.6	90
12	1085.9	0.05	0.04	3.5	130
13	1090	0.06	0.05	4.4	130
14	1086.9	0.05	0.04	3.5	130
15	1072.5	0.04	0.03	2.6	130
16	1035.4	0.04	0.03	2.6	90
17	945.2	0.04	0.03	2.6	90
18	687.5	0.04	0.03	2.6	90

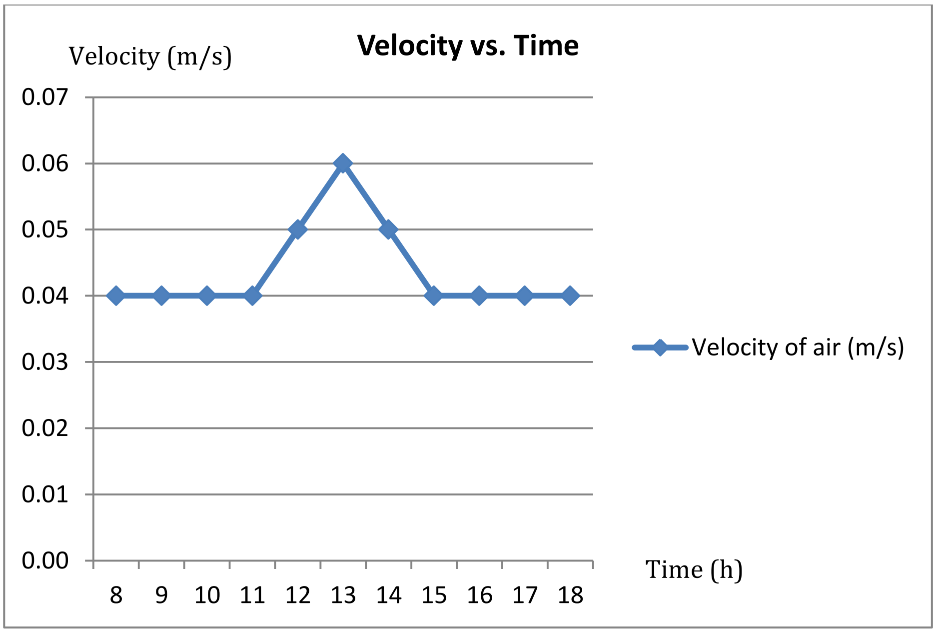

Figure 28: Result for depth of solar chimney 0.45m (velocity of air).

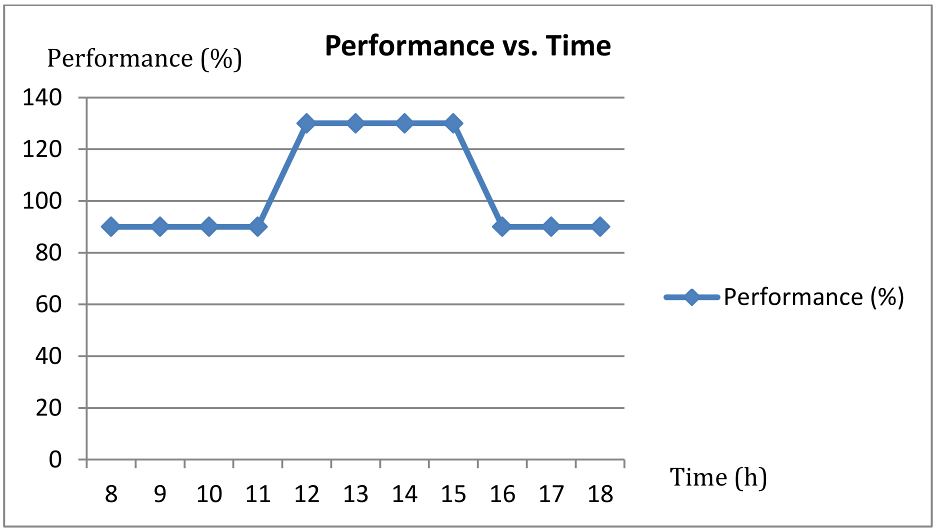

Figure 29: Result for depth of solar chimney 0.45m analysis (performance).

Depth = 0.9 m

Table 13: Result for solar chimney depth 0.9 m.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.09	0.14	12.3	615
9	630.3	0.09	0.14	12.3	615
10	630.3	0.09	0.14	12.3	615
11	630.3	0.09	0.14	12.3	615
12	1085.9	0.09	0.14	12.3	615
13	1090	0.09	0.14	12.3	615
14	1086.9	0.09	0.14	12.3	615
15	1072.5	0.09	0.14	12.3	615
16	1035.4	0.09	0.14	12.3	615
17	945.2	0.09	0.14	12.3	615
18	687.5	0.09	0.14	12.3	615

The effects of increasing the solar chimney's depth influence the cross sectional area of solar chimney. Thus the increase insolar chimney's depth results in an increase in the air volume within the solar chimney. This give effect to the volume flow rate of the air for solar chimney and the room. It also understand that, the higher the depth the higher the outlet area as it is associated with the dimension. The solar chimney depth of 0.2 m give highest performance effect. Results further show that the best solar chimney depth for a small room dimension is 0.2 m which does not againts literature claims [8]. While the increasing the depth to 0.45 m decrease the performance for ventilation but still can compliy with the standard air change rate requirement. For depth of 0.9 m which is the largest, the velocity of the air inside the chimney remain constant at 0.09 m/s. While the air change rate become higher as the cross-sectional area of the solar chimney increases. However, this velocity may not be from the solar chimney effect as air profile shows that the air velocity vector is toward inside of the chimney suggest that there is a reverse flow occur from the ambient air. There is some turbulance at the outlet as illustirate in Figure 8 and the arrow indicates the direnction of air velocity vector. Therefore solar chimney depth of 0.9m is eliminate asone of parameter.

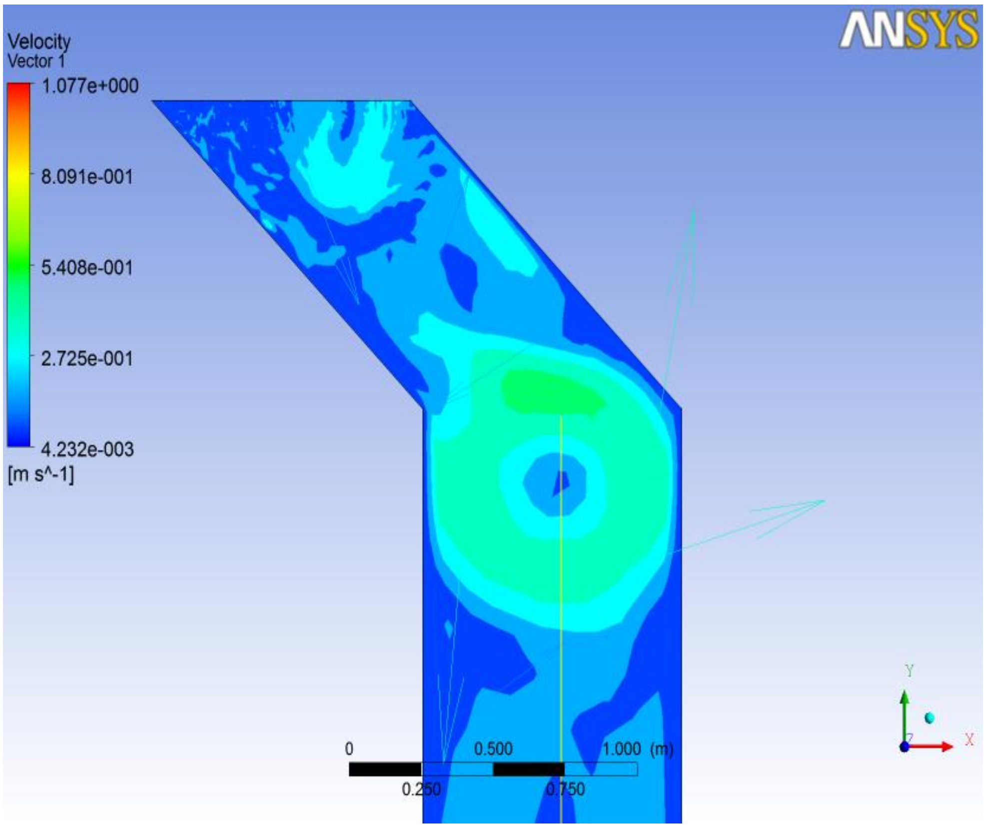

Figure 30: Air profile at the outlet solar chimney depth of 0.9 m.

4.2.0 Optimum solar chimney selection

Since the requirement air rate is 2 /h, it is the best to select the parameter which give performance nearest to 100%. In this matter the average performance for 2.85 m stack height is 68.95%, for 8.44 m is 124% and 14.24 m is 153.3 %. Therefore the only stack height that can give the performance without excessing the requirement 2.85m. After that, the inlet position-3 is eliminated because it creates bad air circulation in the room and the air cannot be transfer into the solar chimney inlet. While the inlet position-2 gives 153.3% which is the highest thus, inlet position-1 is favoured with the average performance value of 104.5%. Lastly, the depth of 0.9m is also eliminated due to the back flow it creates and since depth of 0.45 m gives 104.5% performance; nearest to 100%. However, the dimension is relatively too big for the ratio (Ar), *Ai/As*, so depth of 0.2 m is chosen.

Table 14: Selected Parameter.

Parameter	Value (m)
Stack height	2.85
Depth	0.2
Inlet Position	0.25

4.2.1 Optimum selected parameter for solar chimney testing

Table 15: Result for optimum parameter testing.

Time (hour)	Total solar Intensity [W/m^2]	Velocity of air (m/s)	Volume flow rate (m^3/s)	Air Change rate (/h)	Performance (%)
8	630.3	0.050	0.017	1.49	75
9	630.3	0.050	0.017	1.49	75
10	630.3	0.050	0.017	1.49	75
11	630.3	0.050	0.017	1.49	75
12	1085.9	0.066	0.022	1.9	95
13	1090	0.070	0.024	2.1	105
14	1086.9	0.069	0.023	2	100
15	1072.5	0.064	0.022	1.9	95
16	1035.4	0.061	0.021	1.8	92
17	945.2	0.057	0.019	1.73	86
18	687.5	0.052	0.018	1.58	79

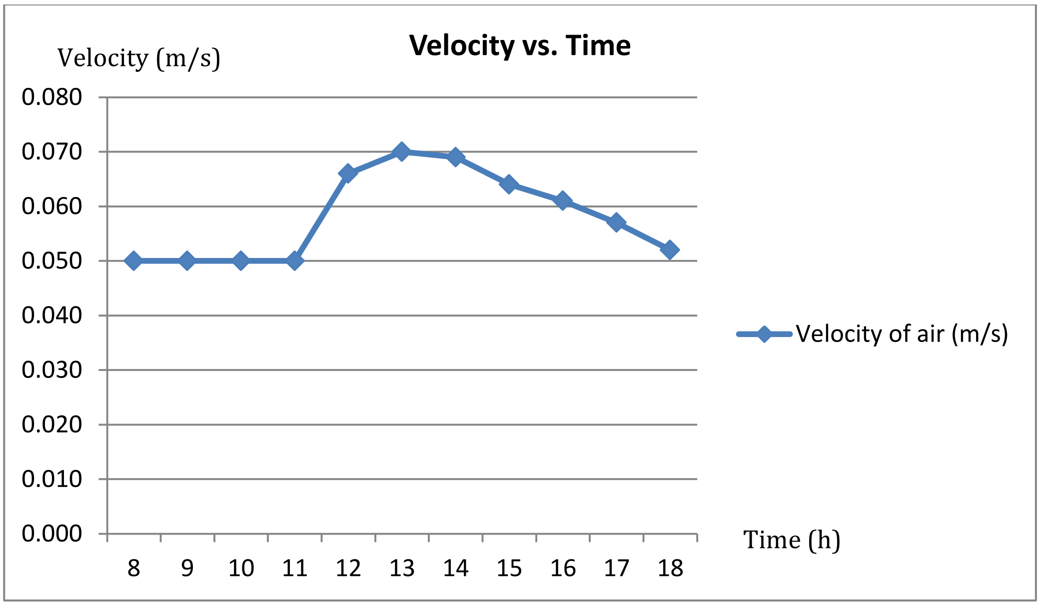

Figure 31: Result for optimum parameter testing (velocity of air).

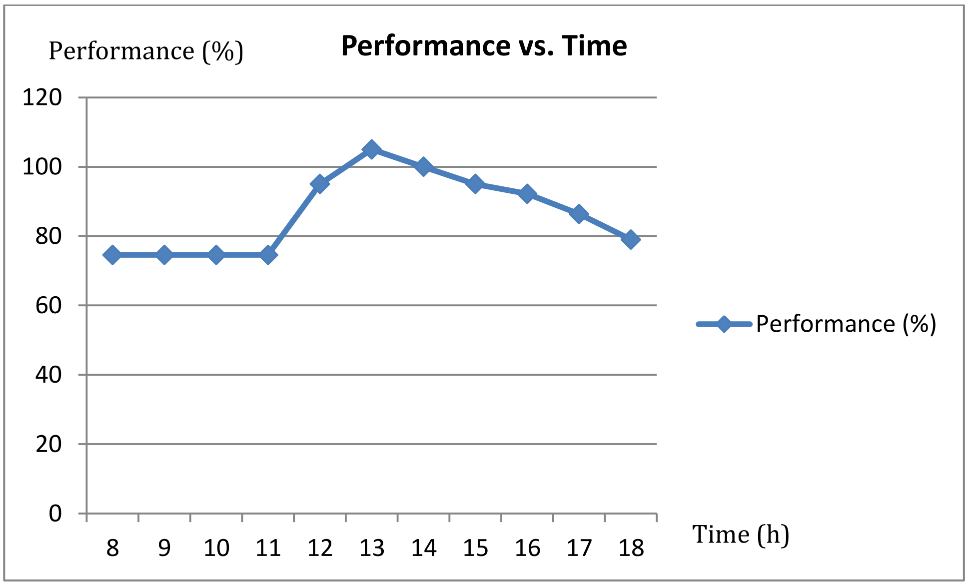

Figure 32: Result for optimum parameter testing (performance).

From the parameter selected, the result shows that the solar chimney can be operating at the local weather condition with an average performance of 86% throughout (8.00 am – 6.00pm). Although, the solar intensity is usually not constant, the local weather advantage is that due to its position near the equator amount of sunlight it receive is approximately sufficient throughout the whole year [23]. To validate this result, pervious study on 27 m^3 room space experimental result is use to comparing the readings. The parameter selected is 0.13 m for inlet position, 0.257 m for depth of solar chimney and 1 m for the stack height [24].

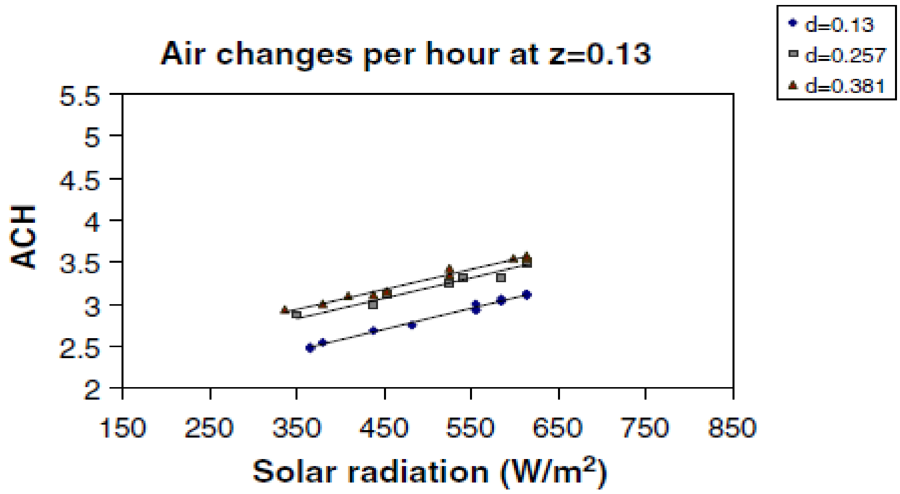

Figure 33: Result from experiment done by Marthur J., Bansal N.K, Jain M. & Anupma.

This investigation was done in India where there is a slight climate different with Malaysia [24]. By using the value of solar intensity in that study which is in the same rage with Malaysia local climate, the result is shown in figure. Since there is different in the room volume for both tests, the maximum velocity of air inside the solar chimney is the same which both have the same value of 0.02 m/s by the following calculations:

1- Velocity of air for optimum parameter

   $[41(m3)\ x\ 1.8\ (/h)]/3600\ =\ 0.02\ m/s$

2- Velocity of air from experimental data

   $[27(m3)\ x\ 3\ (/h)]/3600\ =\ 0.02\ m/s$

The result shows that regression test is approximately the same with experimental data.

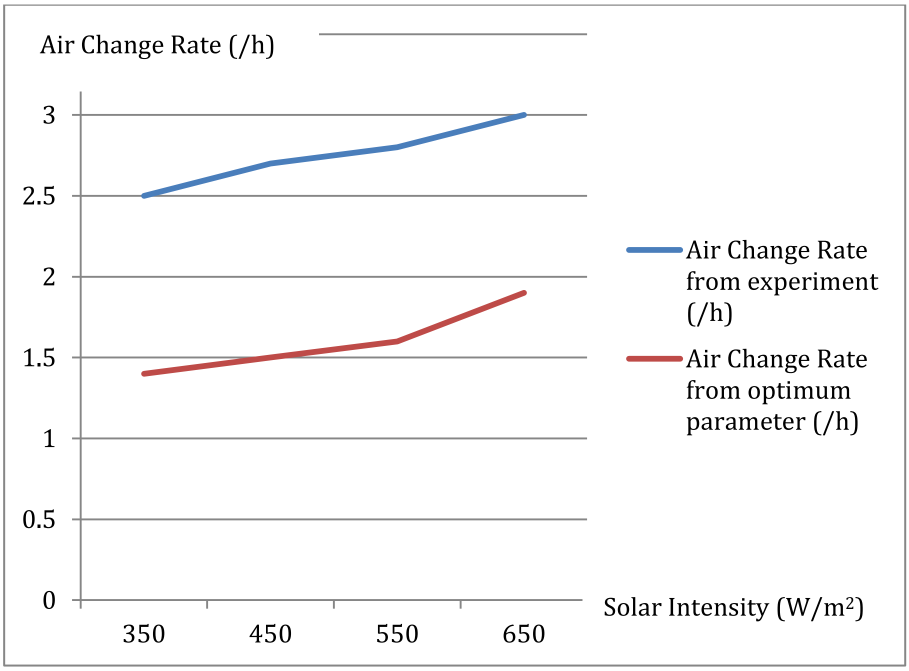

Figure 34: Result comparison for optimum parameter testing and experiment data.

Chapter 5: Conclusion and Recommendation

By varying the three input physical parameters and solar intensity as well as developing the physical and computational models, 10 cases are selected meaning that 110 runs of simulation was generated. Base case analysis were conducted to ensure that solar radiation give effect for solar chimney. All simulations show that the input air temperature which is 301 k remains constant. Simulation results show that the solar chimney's height is the most significant factor influencing the output air speed. Although, the inlet position does not give clear view on its effect to the performance, result suggest that the best inlet position is at the middle position of the room wall height as it significantly affecting the air profile inside the room. Futher study on the air profile is suggested to understand its effect on solar chimney performance. The depth of solar chimney have relationship with the cross-sectional area of the solar chimney which is highly relates with the air change rate. While the stack height gives increase in temperature as it increase the solar chimney surface area without changing the cross-sectional area. As mentioned before, the volume of the interior space, the size of its fenestrations and the inclination angle of the solar chimney are possible input parameters that may affect the performance of the solar chimney. They are not included within the parameterization study as their dimensions are fixed according to their functional uses. The solar intensity is however tested but with least variable because the availability of information on local solar behavior is limited. The result shows that solar energy is capable of producing ventilation in local climate with solar chimney made of aluminium plate. For future recomendation, different material may be tested in order to get the best performance. Overall, Malaysia is suitable for the application of solar chimney as the result shows that solar chimney can provide the ventilation requirment for room as the sample when the parameter is set to be correct. Therefore, the objective of this study is achieved.

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