UNIVERSITI
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Design Calculations and Experimental Analysis of

"Over Roof Solar Chimney"

By

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(M5811)

Dissertation submitted in partial fulfilment of

the requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

Design Calculations and Experimental Analysis of “Over Roof Solar Chimney”

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A project dissertation submitted to the
Mechanical Engineering Programme
Universiti Teknologi PETRONAS

In partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons)
(MECHANICAL ENGINEERING)

Approved by,

____
(AP DR HUSSAIN AL KAYIEM)
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UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

January 2008

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PETRONAS

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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(NURHUSNA YUSOFF)

ABSTRACT

The Over Roof Solar Chimney uses the simplest technologies to generate power for the needs of a single home. Calculations were based on a house with dimensions of 20ft X 20ft area situated in the Tronoh District. A rooftop with four equal sides has been considered for the system to allow for the air flow to be directed towards the chimney. The solar chimney has 3 main components which are the canopy, absorber (collector) and the chimney. The difference in temperature created by the solar radiations on a collector will cause a current of air in a passage strong enough to operate a conventional wind turbine and generate electricity. This project analyses the mechanism behind a solar chimney to generate sufficient power to sustain a single home and is more directed towards the analytical and experimental aspect of the analysis. From the experimental model, we would be able to obtain data such as the solar intensity above and below the transparent cover, the velocity of the air flow at the outlet, surface temperatures of the collector and the cover. Data was collected in intervals of 2 hours for duration of 3 days during daylight hours. From the data obtained, we could analytically determine the type of flow and the amount of electricity generated by the turbines. The results of the calculations and the experimental model, could, then be compared other similar application that is available to prove the feasibility of the system. Also the velocity of the airflow can indicate the amount of energy that can be generated. A CFD simulation can be attempted as a method of analysis (optional). The design of the system in mind, for the roof solar chimney would be similar to the design of the traditional large scale solar power generators built and commercially used in some countries around the world. Nevertheless, it would be slightly modified to suit the needs and requirements of a small scale unit. From the overall analysis, the performance of the over roof solar chimney is quite low compared to other solar technologies and can be further improved upon given time and research. The system is more suited for large scale structures that can generate a larger airflow velocity.

ACKNOWLEDGEMENT

Alhamdullillah, I have come to the completion of my Final Year Project signalling the nearing of the end of my final semester at UTP.

First and foremost, this is a great opportunity to express my deepest appreciation for my supervisor, **AP Dr Hussain Al Kayiem** whom has given me continuous support throughout my time under his tutelage. I am truly fortunate to have his guidance through the tough times.

A big thank you to my family especially my parents, **AP Dr Yusoff Ali and Mrs Khashiah Mohd Taib** for their prayers and moral support that have kept me strong until the end.

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To my **examiners, Dr Gilani, Mr Ismail Ibrahim, Dr Chalil, Mr Rahmat and Dr Ahmed Maher,** whom have given me feedback and comments that were more helpful that you would have imagined throughout the duration of this project.

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CHAPTER 1

INTRODUCTION

Solar energy is a great source of renewable energy. This is most important at this age as the other natural resources in the world are not renewable and are fast depleting. Experts predict that fossil fuels will only last for the next 30 or so years and so alternative methods of power generation must be found. Since a few decades ago, more and more research has been done on the possibility of generating power from the sun. The Solar Research centre in UKM, Bangi, Malaysia [15] is proof of this fact. From the solar profile [16] that is obtained we could see that the average yearly solar intensity in Malaysia is in the range of 700W/m^2 to 950W/m^2.

One of the methods to extract the solar radiations and converting it to usable power is by using the solar chimney. This system utilizes the basic understanding of energy conversions and heat transfer to reach its objectives.

The main concept of a solar chimney is using the solar energy to generate a condition of difference in temperature that can generate winds strong enough to operate a traditional wind turbine. Basically, the method of power generation is wind generated by solar energy. The main objective is to generate electricity. This applies for the large commercial pilot power plant (explained later in the report) and also the smaller scale system that is proposed through this report.

This final year project is directed solely towards developing a suitable similar system for the average home using Tronoh as its area of study. The average home in this area has a minimum area of 20 ft by 20 ft. From there the calculations are based on the system in that dimension.

From this project, we can expect some data such as the solar intensity that can be used to compare with the profile obtained from the Solar Research Centre. Another factor that is to be analysed is the heat transfer coefficient (convection) calculated from the data collected during the experimental modelling.

There is also an attempt to do some CFD modelling to determine the characteristics of the flow in the roof chimney but the progress has been slow due to some factors that cannot be avoided.

1.1 Background of Study

The domestic application of the solar chimney is a means of reducing the dependency of a single household on the energy derived from non-renewable resource. Power generation using this method is sufficient to sustain the electricity needs of a home and is also very economical and environment friendly. Initially, this project has been initiated by America, Spain, China and Turkey in the effort to find a cleaner and abundant source of energy. These projects have been in the form of large solar power plants that could generate MWatts of power.

Fig. 1.1 Prototype of the Solar Chimney in Manzanares – Spain.

The planning of a pilot power plant has been carried out and its construction started at Manzanares, Spain [6]. Since the sun is free energy, solar chimneys are a great way for underdeveloped or poor countries to generate power at a cheaper rate. Although the initial cost of constructing a solar power plant is large but the payback period would be significantly reduced due to the amount of power generated. In Manzanares, the pilot project has proven beyond doubt that solar energy can be harvested and utilized around the world. Not only is it reliable, it is easy to maintain and requires a maximum of one person to supervise the system. The plant can be kept running daily with little worry of damage, failure or malfunctions.

1.2 Problem Statement:

The cost of electricity is rising as the oil prices are going up. There is also an issue of global warming. Energy generated from alternative sources are always a good way to save and help reduce the effect of global warming and the issue of depleting fossil fuel as well as economical. This method of using the Solar Chimney System and applying it to a roof of a home is a good idea. If the system can be applied commercially, logically, it should be a potential source of electricity for a smaller scale use like a house.

The solar energy can be exploited by converting the house unit roof to a collector covered with glass canopy. There would be two layers of roof. One that is transparent and allows solar radiations to transmit through it and the other absorbs the radiations.

The absorbed solar radiation will be converted to thermal energy in the roof material and then transferred to the adjacent air particles by convection heat transfer. This will cause activation of the air particles and will generate air flow stream. The flow can be guided to operate the wind rotor and produce output power.

1.3 Objectives:

1. To carry out analytical performance analysis of the “Over roof solar chimney system”.
2. To fabricate an experimental model that can be used to obtain data for the analytical modelling.
3. To attempt to use the CFD software to simulate and evaluate the performance of the “Over roof solar chimney system“.

1.4 Scope of Study

A project will be conducted under STRIF fund to establish an experimental model of “Over Roof Solar Chimney”. This project will cover analytical analysis of the system (mainly the roof area) as well as collect data from the experimental model. There is also an attempt to do the computational part of the project by using the CDF software available in the department.

There is also an opportunity to consider other methods that can be integrated with the system such as the use of biomass as fuel during times of limited sunlight in order to make it a sustainable source of power at all times and in all conditions.

1.5 Significance of Study

This study is very important in making an effort to vary the different types of energy resources that can be utilized whether in small scale or large. The world is becoming far too dependant on petroleum that without it, the world may experience a power shortage crisis.

Cost reduction is also a factor that is considered as the cost of everything in the world is gradually increasing. Even the electricity bills could be something of a past if this system is implemented throughout the nation and also the world. It would be very helpful for the poor if they could make use of free resources such as sunlight instead of having the burden of energy bills to worry about.

Unlike the electricity derived from fossil fuels, this system is able to generate power from solar radiations that pose no threat to the environment in any way. The level of pollution in the world is a big threat for mankind and all of the world’s inhabitants and it must be controlled and wherever possible cut down. What other way than to use environmentally friendly ways to generate power.

CHAPTER 2

LITERATURE REVIEW

The Over Roof Solar Chimney is a small scale application of solar power generation using the solar chimney. The main elements are the same - roof collector, absorber, chimney, and wind turbines. Below is a schematic that shows the general idea of the workings of an over roof solar chimney. The focus of the analysis is more directed towards the roof part of the system and less on the chimney. This is due to the fact that the main mechanisms are all occurring in the roof region. The following diagram shows the basic idea of the Solar Roof Chimney.

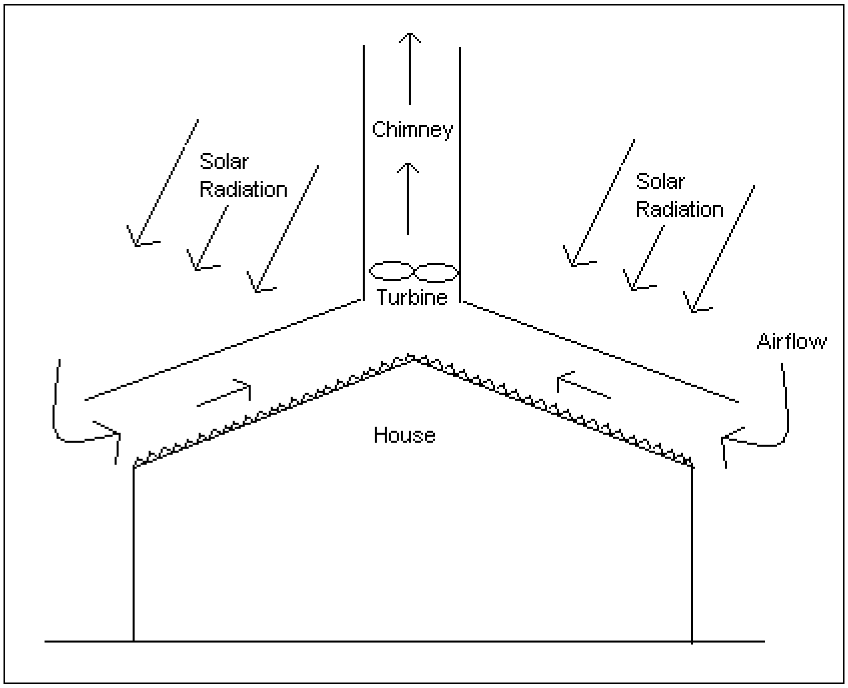


Fig. 2.1 Schematic diagram of roof solar chimney power generating system

Solar radiation that passes through the cover increases the temperature of the air between the cover and the absorber. The cover of the solar collector must be transparent to allow for the transmissivity of the solar radiation through the cover and to the absorber. Materials that would most likely be used as the cover are glass or thick durable plastic sheets.

The absorber would heat up and heat exchanged through the natural convection and radiation process would be the driving force that moves the air in the region.

The airflow that is generated flows upwards due the buoyancy principle of air and is directed by the cover towards the chimney. Since the area of the airflow is gradually decreasing as it travels closer to the chimney, the velocity of the airflow is also increased.

The moving air is estimated to reach a velocity of or more than 5m/s and with this velocity; a turbine situated in the chimney can be operated to generate sufficient electricity to support the household.

The design of the system is similar but different than the average solar collector used in the other application. The ground is used as an absorber in solar collector plants. In this project, since the system is placed on top of the roof, the absorber will be a few layers of metal sheets. The heat absorber is found to be most effective if the material is in the form of corrugated metal sheets. This way, the surface area of the absorber is increased. It would be more effective should the metal sheets be painted a matt (flat) black to allow for maximum heat absorption. The matt black is selected because the chances of the radiation to be reflected back into the atmosphere are greatly reduced.

Also, there should be insulation placed behind the metal sheets so that the heat loss from the metal sheets to the back side of the metal sheets could be reduced.

This is to encourage heat transfer to the air above the metal sheet and also to avoid any affect to the house in the form of increase of temperature inside the home. The insulation of the roof and the insulation on the structure of the roof should be sufficient enough to overcome and heat transfer to the inside of the house.

The design of the roof is also different than the roofs of other houses. Instead of using the two sided roof that is most common in Malaysia, in this project, it is proposed to have a four sided roof. This is to ease the direction of the airflow towards a wind turbine at a single point in the centre of the roof to maximize the velocity of the airflow. The collective airflow would be strong enough to move the turbine.

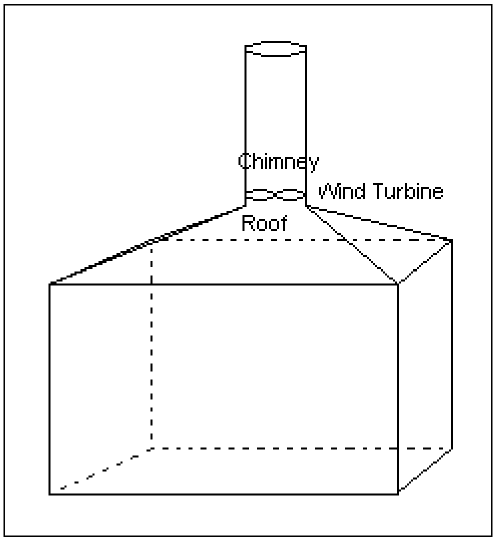


Fig. 2.2 Rough drawing of the design of the house under study

The chimney is also a slightly different than the ones in the solar power plants. The height is greatly reduced to make it proportional to the house and also the direction of the air flow is from all directions.

The mathematical modeling of the system is important in order to analyze the characteristics of the flow and the performance of the whole system. Values from the experimental part of the analysis will act as input and be used in the analytical assessment.

An attempt at the computational simulation will give an insight on the many factors that contribute to the building of the actual modeling. With the simulation, we could also detect weaknesses in the design and further improve on these factors.

The CFD simulation is using the FLUENT and GAMBIT software. This is special software that can display the many different geometries of airflow that can be varied. These differences in parameters may show different characteristics in the configuration that may be an advantage or disadvantage to the system and must be taken into consideration for the actual model.

The output of the solar chimney that is customized in the house model is expected to be sufficient to meet the daily power demands of the single home. The average electricity consumption of a single home is 15kW.

If this method of power generation is as successful as the theoretical calculations and simulations are, it could change everything. In the eyes of the consumer, monthly electricity bills can be significantly reduced if not entirely terminated. This is indeed good news for the general public.

CHAPTER 3

METHODOLOGY

3.1 Analysis Methods

Before using any form simulation software, we must be able to identify the important parameters involved in the calculation of the required or targeted design. The design of the system must be modified to suit the house. The specifics of the house must be as close to the ideal home in Malaysia; more accurately, in Tronoh.

3.1.1 Analytical Analysis/Mathematical Modelling

In order for the system to be in ideal conditions, the proper equations must be found and different geometries could be tested in order to find the most suitable in attaining the optimum power. The coefficient of convection is the most important as it helps in determining the amount of power that could be generated.

The minimum requirements and targeted values that are being attempted to be reached must also be specified in order to determine whether the project is potential marketable. Besides that, specifications of the mechanical components such as the wind turbine must be researched in order to know the minimum velocity of the airflow that could drive it.

Basically, the mathematical modelling involves the basic heat transfer equations and also the data collected from the experimental modelling. This way, the calculations stay as close and accurate to the real conditions during experimentation.

Calculations involve many different constants such as the Nusselt Number, Reynolds Number and Grashoff Number to ultimately calculate the convective heat transfer coefficient of the metal sheet to the airflow under the cover.

Also, the type of flow is determined in order to identify which correlation would suit the conditions. This is because different types of flow require different equations in terms of constants and coefficients.

Finally, the power output that can be generated, based on the velocity of the airflow that has been measured, is determined from basic power equations. In these equations, we apply constants that are suited for such conditions.

3.1.2 Experimental Modelling

The experimental model is built in small scale to measure input that could be useful for the simulation. The model made must be as similar to an actual roof using similar materials that could help in accurately evaluating the factors involved.

These data values are used to feed the calculations and can be used to feed the simulation thus making the simulation based on the actual conditions in the Tronoh region.

The duration for this experiment is three days. For intervals of 2 hours during daylight hours from 800 hours to 1600 hours, data such as:

- Surface temperature of the Collector

  Measurements are taken in 3 constant locations for each time. This is in order to analyse the characteristics of the temperatures on 3 different heights from the ground. (See Figure 3.1).

  This is to determine if there are any temperature differences throughout the metal sheet as the air flows upwards. This is very important factor that sheds some light on the velocity of the airflow that can be generated.

Fig. 3.1 Image of the placement of the thermocouples on the surface of the collector

- Surface temperature of the Cover (canopy)

The measurement of the surface temperature of the cover is taken at three points in the centre of the cover and an average is taken to be used for analytical analysis.

The temperature of the surface is also taken to determine the amount of heat that is lost to the cover instead of to the collector.

- Intensity of the Solar Radiation (above and below the cover)

Using handheld equipment, the intensity of the solar radiation is measured to calculate the amount of heat that can be absorbed by the collector and the transmissivity of the cover.

- Inlet and outlet velocity

The velocity that is measured can be able to assist in the estimation of the amount of power that can be generated and to analyse the increase in velocity of the airflow from the inlet to the outlet.

3.1.3: CFD Simulation

An attempt at CFD simulation is done to determine the parameters and the characteristic of the flow under the cover (canopy). From there, we can identify potential problem areas.

Using CFD, a simulation of the solar chimney under various conditions will be made to determine the most optimum performance of the small scale chimney. These results can be compared to the experimental model and the theoretical hypothesis.

The CFD simulation will show the temperature increase or decrease of the absorber and collector at any given time of day, the velocity of the air in the chimney and also the speed of the turbine and the power generated. The input are all obtained from the experimental modelling.

The intensity of the solar radiations can also be a factor that contributes to the effectiveness of the system and the simulation will be according to the average daily intensity.

3.2 Tools/equipment required:

1. ANSYS or FLUENT, and GAMBIT software.

2. Cutting tools for building the experimental model.

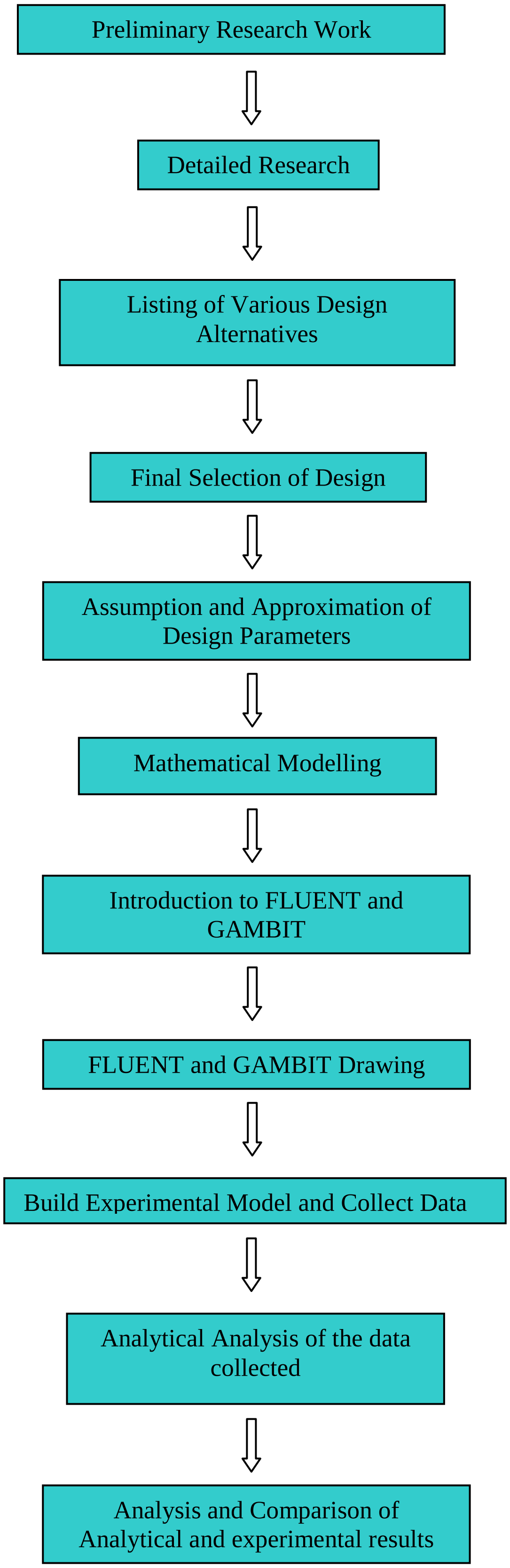
3. Thermocouples

4. Data logger

5. Solarimeter

6. Anemometer

3.3 Work Program:



3.4.1 Time scheduling: Milestone for the First Semester of the Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Selection of Project Topic	■	■													
2	Preliminary Research Work		■	■	■											
3	Submission of Preliminary Report				■											
4	Introduction to FLUENT and GAMBIT				■	■	■	■								
5	Seminar 1 (optional)					■	■	■								
6	Project simulation					■	■	■								
7	Submission of Progress Report									■						
8	Seminar 2 (compulsory)										■	■	■	■		
9	Project model design continues									■	■	■	■	■		
10	Submission of Interim Report Final Draft														■	
11	Oral Presentation															■

3.4.2 Time scheduling: Milestone for the Second Semester of the Final Year Project

No.	Detail/ Week	1	2	3	4	5	6	7		8	9	10	11	12	13	14
1	Project simulation continues	■	■	■												
2	Submission of Progress Report 1				■											
3	Fabrication of the experimental modelling				■	■	■	■								
4	Submission of Progress Report 2									■						
5	Seminar (compulsory)										■	■	■			
6	Data collection for the analysis									■	■	■	■			
7	Poster Exhibition (EDX)											■				
8	Submission of Dissertation (soft bound)													■		
9	Final Oral Presentation														■	
10	Submission of Dissertation (Hard Bound)															■

■ Process

CHAPTER 4

ANALYSIS

This chapter includes Experimental Modeling, Analytical Modeling and CFD Simulation attempts of the system. Below are some of the assumptions used for this analysis:

- The intensity of the solar radiation will be multiplied with a factor of around 0.7 to make the values more viable and the flow inside the system is assumed to be steady.
- The temperature of the cover is constant throughout the entire cover area
- The calculations are based on the assumption that there is constant sunlight throughout the day
- The heat loss through reflection, to ambient air and through the back of the collector is negligible
- There is no back flow is the system and the cover does not have any small gaps where the air could flow through and escape before reaching the outlet
- Transmissivity of the cover is 100%
- The corrugation of the metal sheets are negligible
- The surface area of the collector is required to be multiplied by a safety factor of 0.7 or 0.8 to make up for the approximation due to the corrugated collector.
- The expected velocity of the airflow can be compared to that of a gentle breeze of which leaves and small twigs are in constant motion and streamers extend [1]. **(Refer Table 4.1)**

$$\therefore 5m/s = 11.18mph$$

Table 4.1 Beaufort Scale of Wind Velocities [1]

Description of Wind	**Observation**	**Speed, mph**
Calm	Smoke rises vertically	0-1
Light Air	Smoke drifts slowly	1-3
Light Breeze	Wind felt on face. Leaves rustle	4-7
Gentle Breeze	Leaves and small twigs are in constant motion. Flags and streamers extend	8-12
Moderate Breeze	Raises dust. Small branches move	13-18
Fresh Breeze	Small trees begin to sway	19-24
Strong Breeze	Large branches in motion. Umbrellas difficult to hold.	25-31
Moderate Gale	Whole trees in motion	32-38
Fresh Gale	Breaks twigs off trees. Difficult to walk	39-46
Strong Gale	Slight structural damage to roofs and signs possible	47-54
Full Gale	Trees uprooted. Considerable structural damage occurs	55-63
Storm	Widespread damage	64-72

4.1 Experimental Modeling

The values that are to be used in the calculation can either be obtained from present existing records or be from data collected in the experiment. The method chosen was to collect new data from an experimentation model. This way, the data is more current and can be trusted.

A smaller scaled down version of the roof was made to measure the temperatures of different areas of the roof as well as other points of importance. The roof model must be similar to a larger scale of the system so as to suit the conditions.

The base structure is built to support a metal sheet that is well insulated to absorb and retain the heat. The base structure is similar to that of the base structure of any other roof of a building.

Fig. 4.1 Base Structure of the Experimental Model

The collector is built so that there is a minimum of 5cm height between the absorber and the collector to allow for the airflow. Thus far the collector has been built and placed on the base structure. Notice that the collector is painted black to maximize the absorption of the solar radiation.

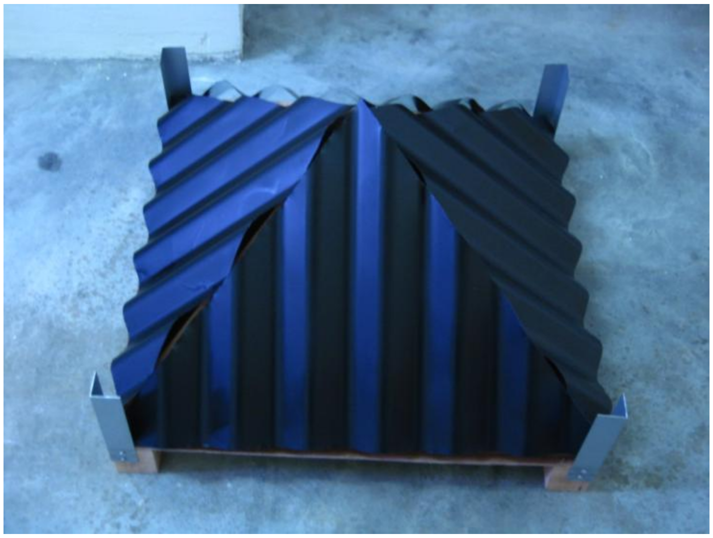


Fig. 4.2 Collector placed on the based structure

The final step before completion is the building of the canopy. In the case of the model, Perspex is used. This canopy will be held by the corners using the bars at the corner with a gap of 5cm. This way; the gap will maintain 5cm throughout the entire model.

The experimental model was placed in a flat open space that is susceptible to sunlight at any time of the day. Thermocouples are placed strategically on the collector and absorber and measurements are taken in hourly intervals. Also, the velocity of the airflow was measured at the outlet of the collector and the intensity of the solar radiations is measured above and below the collector.

For further accuracy of the data, the experiment is conducted during daylight hours (between 8am and 4pm) for three days.

Among the important areas of the roof that must be measured are:

- surface temperature of the collector
- surface temperature of the absorber
- mean temperature of the air flow between the collector and the absorber

There are four sides to the roof and all sides experience different temperatures as the incident angles of the solar radiations differ throughout the day. These differing temperatures are most important for the calculations.

Figure 4.9 and 4.10 show the design drawings for the experimental model from the side view and also the top view for a better understanding of the system.

Data collections sheets have been created to allow for easy recording of various parameters (Table 4.2).

The data that has been collected has been displayed in graphic form. (See Data Collection Sheet for complete results)

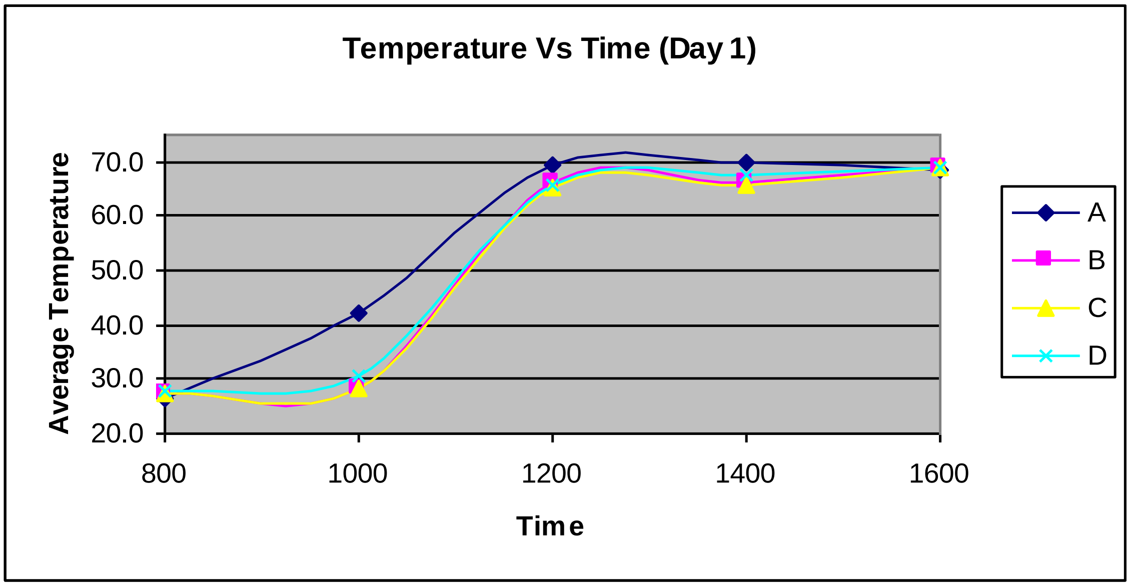


Fig. 4.3 Graph depicting the surface temperature of the collector on all 4 surfaces throughout day 1

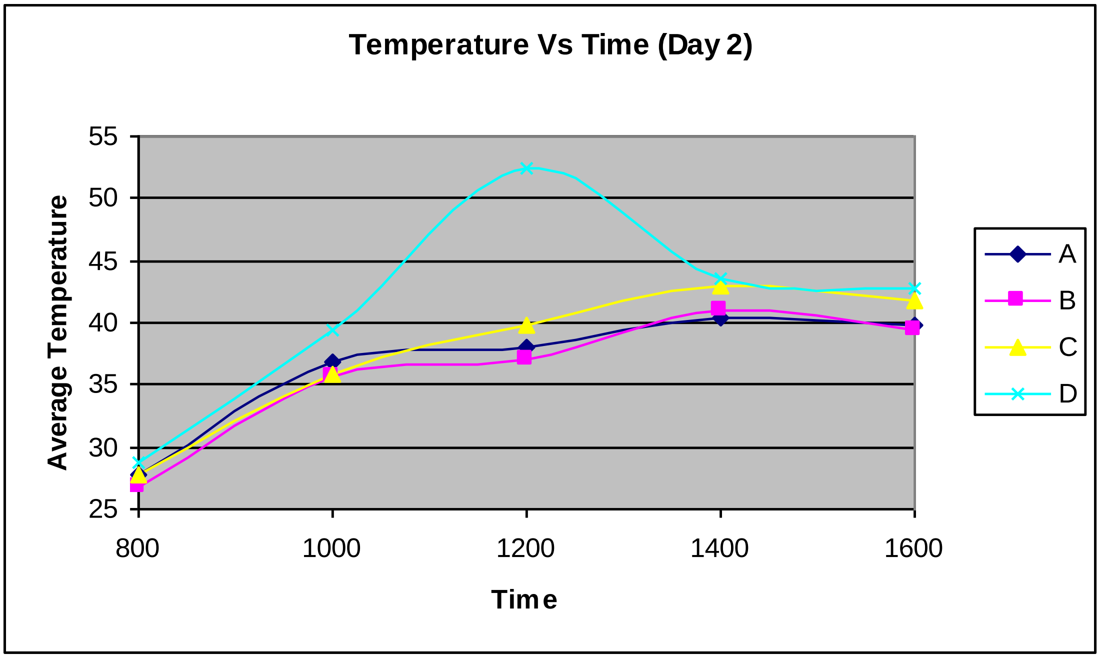


Fig. 4.4 Graph depicting the surface temperature of the collector on all 4 surfaces throughout day 2

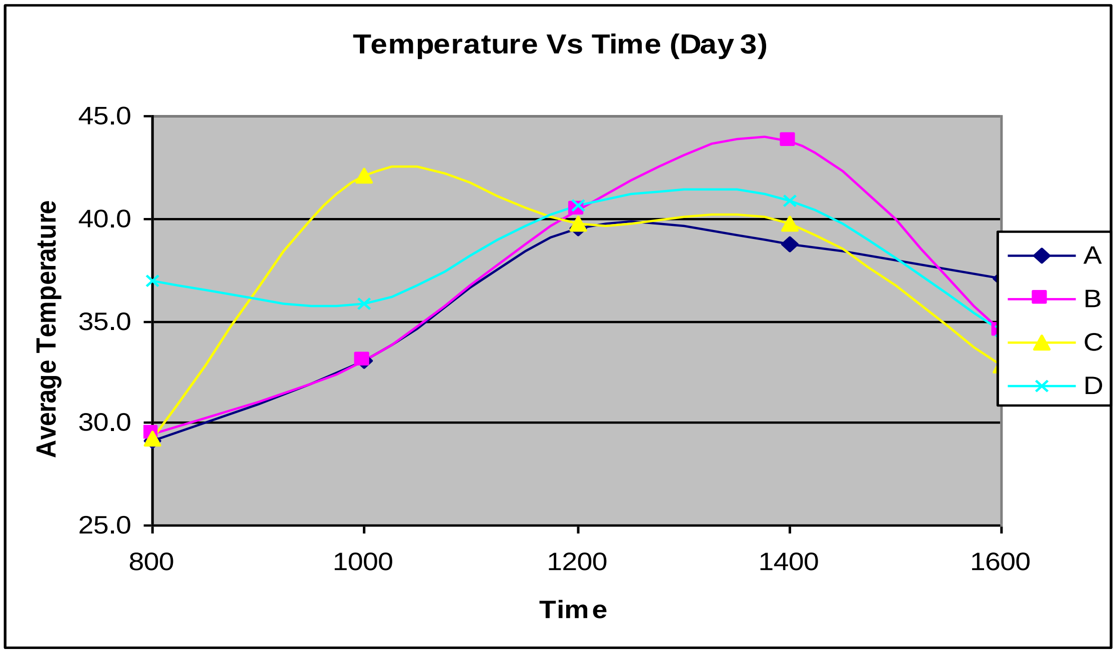


Fig. 4.5 Graph depicting the surface temperature of the collector on all 4 surfaces throughout day 3

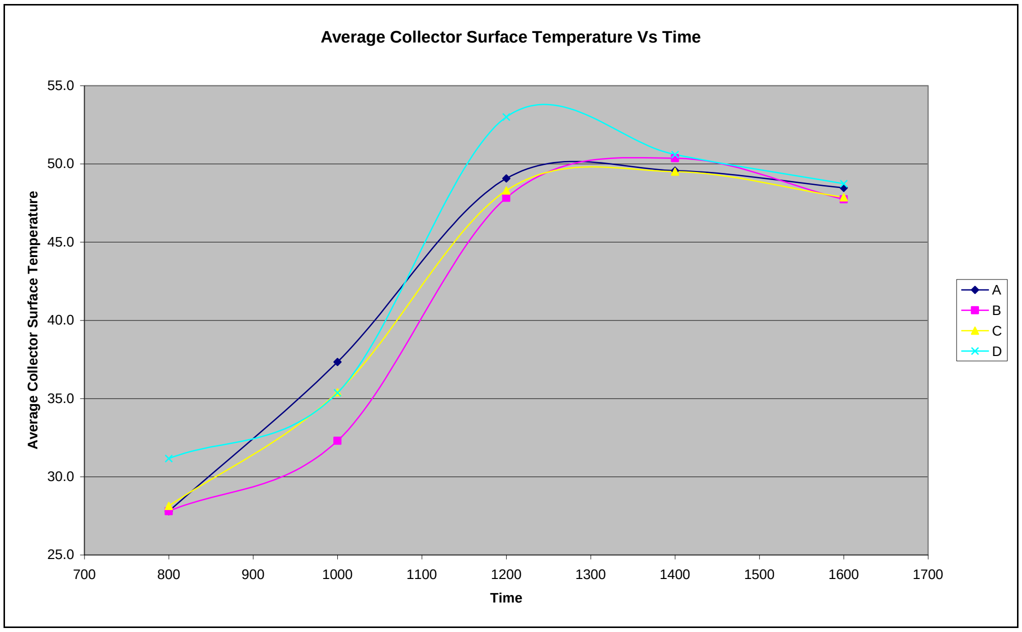


Fig. 4.6 Graph depicting the average surface temperature of the collector on all 4 surfaces for all 3 days

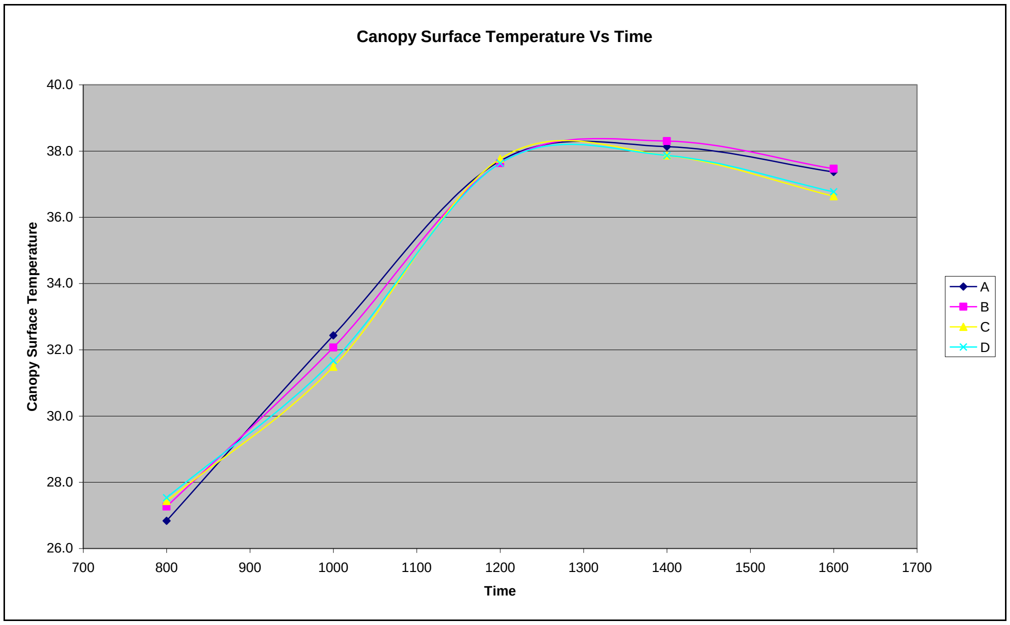


Fig. 4.7 Graph depicting the average canopy surface temperature on all 4 surfaces for all 3 days

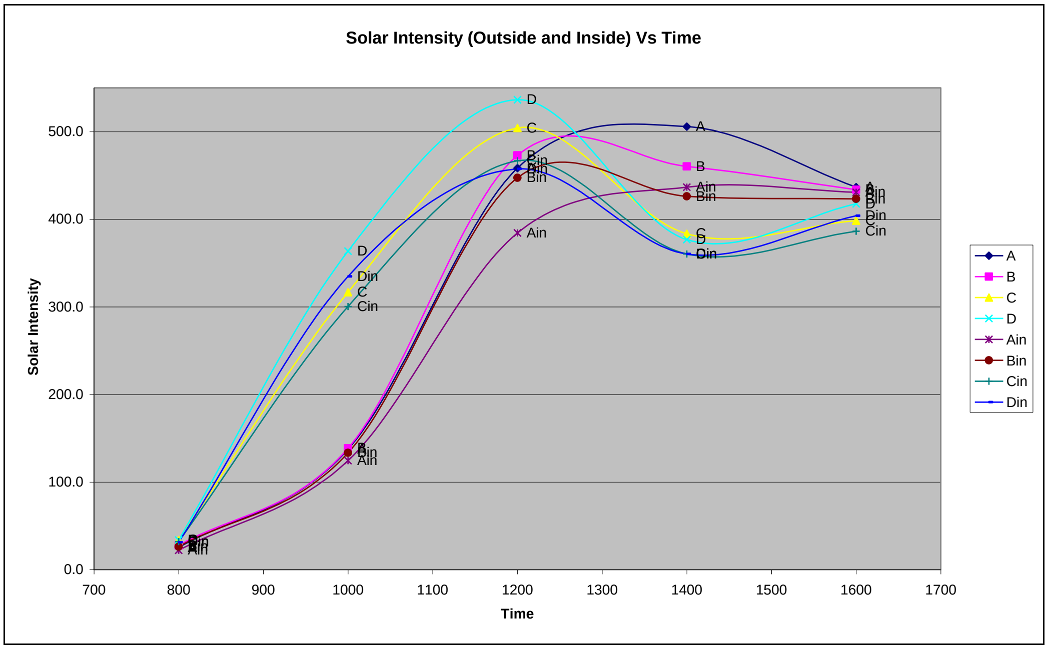


Fig. 4.8 Graph depicting the average solar intensity below and above the cover on all 4 surfaces for all 3 days

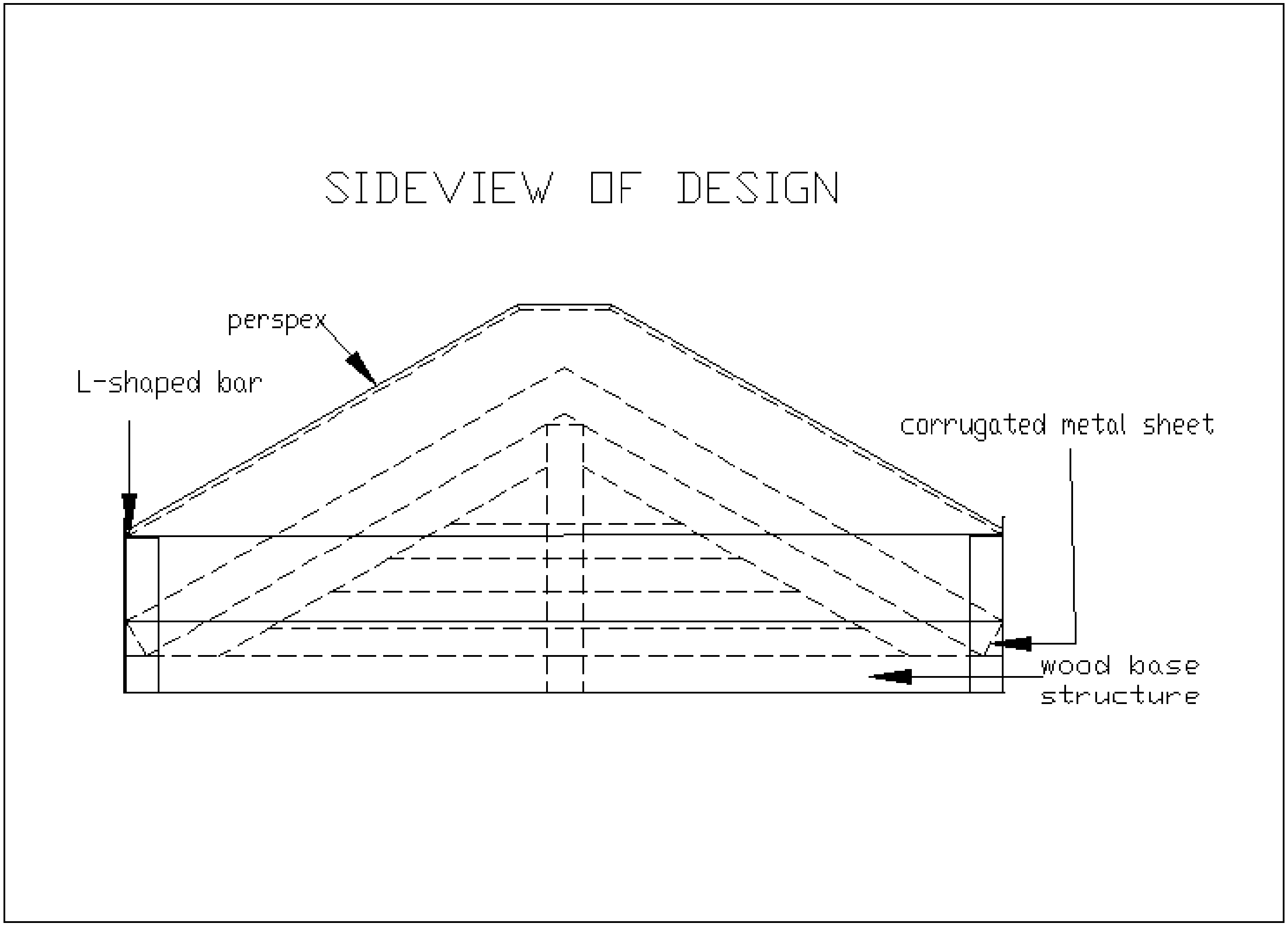


Fig. 4.9 Side view of Experimental Model Design

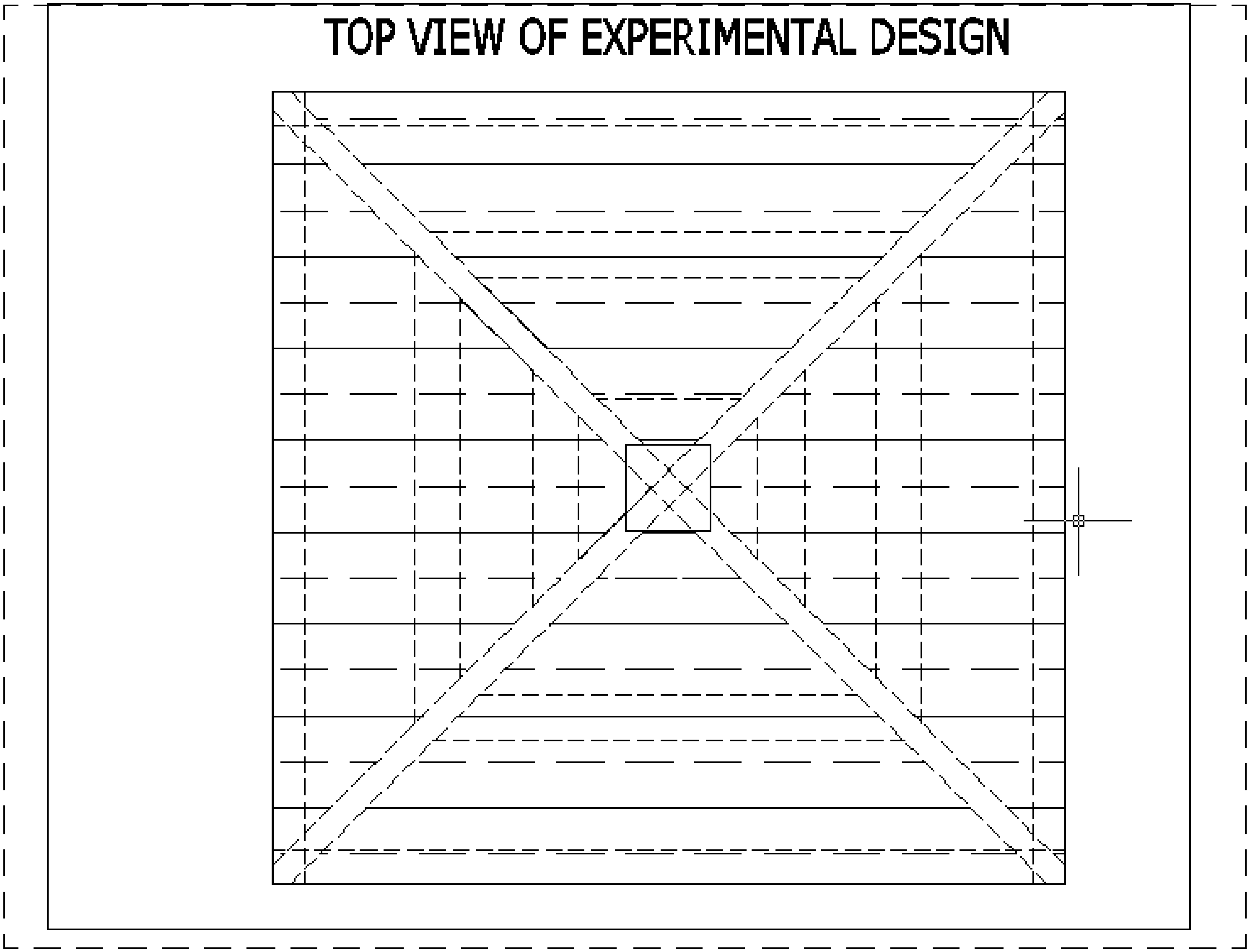
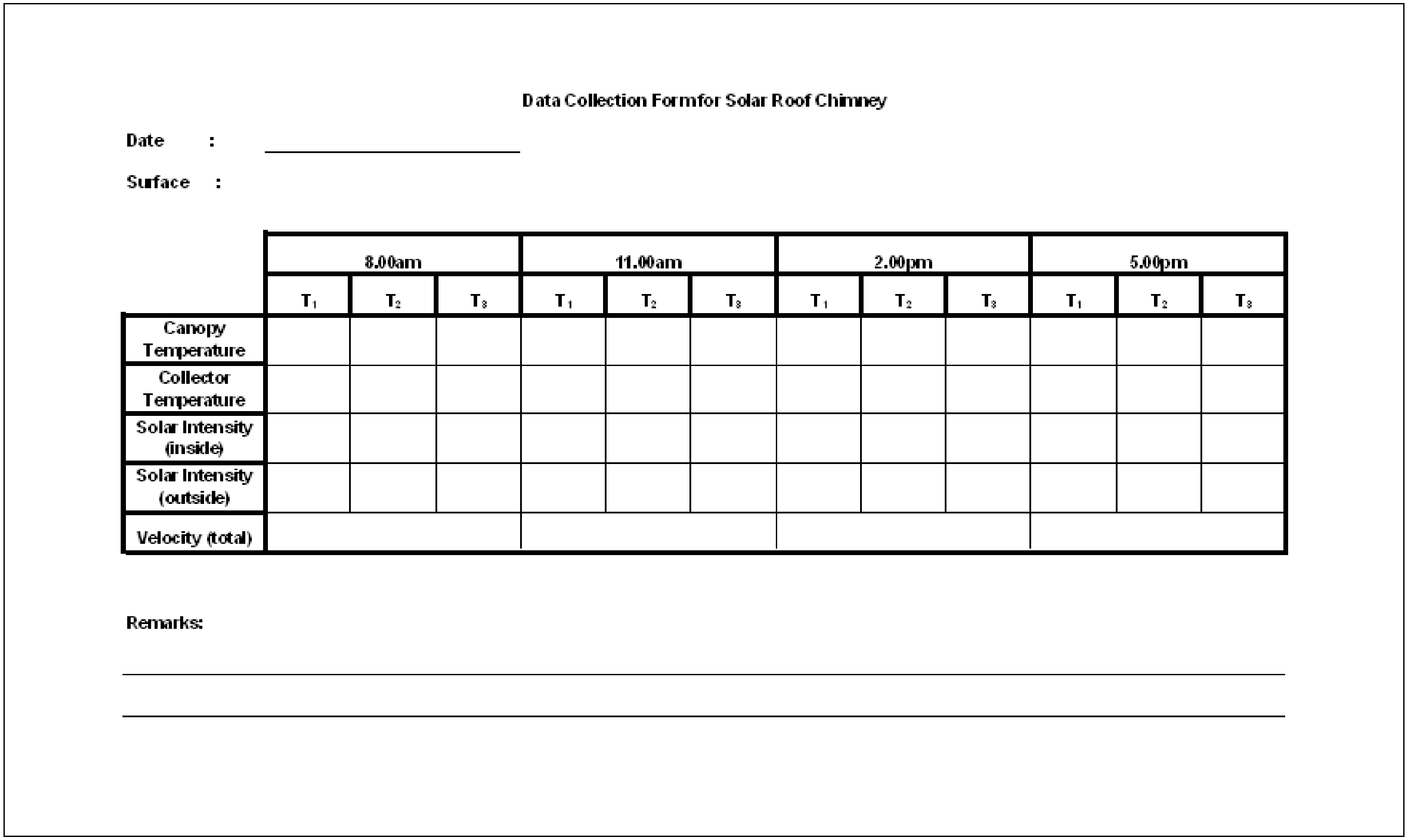


Fig. 4.10 Top view of Experimental Model Design

Table 4.2 Sample of Data Collection Form



Data Collection Form for Solar Roof Chimney

Date : ____________________

Surface :

	8.00am			11.00am			2.00pm			5.00pm		
	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3	T_1	T_2	T_3
Canopy Temperature												
Collector Temperature												
Solar Intensity (inside)												
Solar Intensity (outside)												
Velocity (total)												

Remarks:

____

____

4.2 Analytical Analysis/mathematical modelling

The flow in the system is represented mathematically by application of the equations of motion and the stated equations. Below are the results of preliminary mathematical modeling that has been done. Many dimensions for the analysis have been assumed to get an approximation for the mathematical modelling. These values are:

inlet area	: 0.5m*6m = 3.0m^2
turbine inlet diameter	: 0.5m
solar radiation intensity	: 700 W/m^2
angle of roof, α	: 30^o
chimney height	: 1.5m + 3 sin 30^o = 3m
ambient temperature	: 32^oC
chimney inlet velocity	: 5 m/s (minimum)

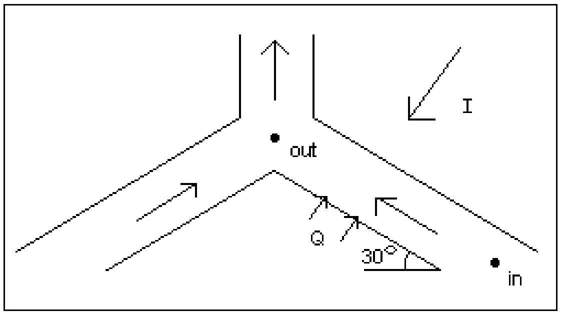


Fig. 4.11 Diagram of heat transfer on the solar collector and roof

From the experimental model, the data collected is as following:

Table 4.3 Table of data collected for a surface (A)

Time	T_∞ (^oC)	T_s (^oC)	T_{canopy} (^oC)	Solar intensity (out)	Solar intensity (in)	Outlet Velocity (m/s)
800	25.7	26.6	26.1	35.86	30.04	0.10
1000	30.0	42.0	33.2	237.88	226.81	0.34
1200	34.0	69.6	37.6	528.80	447.60	0.56
1400	35.2	69.7	40.8	671.20	482.50	0.51
1600	34.5	68.5	40.1	571.67	564.77	0.87

Before any calculations can be done, the values that must be obtained from tables must be found. This is because the values vary with respect to the temperature of the collector surface. These values include:

- Prandtl Number
- Viscosity, μ
- Density, ρ
- Coefficient of Conductivity, k

Here is a sample of the values obtained that was based on surface (A) for the first day of experimentation **(see Table 4.4)**.

Table 4.4 Table of Properties

Time	Pr	Density,ρ	Viscosity, μ	k
800	0.707	1.163	0.0000184	0.026
1000	0.707	1.111	0.0000192	0.027
1200	0.701	1.019	0.0000205	0.029
1400	0.701	1.019	0.0000205	0.029
1600	0.701	1.023	0.0000204	0.029

In calculating the heat transferred through the cover:

$$W_1 = hA(T_s - T_H)\ldots\ldots (1)$$

Where;

*W_1 = Heat energy transferred from the cover

*T_S = surface temperature of cover

*T_H = ambient temperature of air

*h = convective heat transfer coefficient of the cover

The convective heat transfer coefficient is related to the Reynolds and Prandtl number, thermal conductivity of air and the length of the cover by the relation:

h= h (Re, Pr, k, L)

$$\mathbf{h = 0.036\frac{k}{L} Pr^{\frac{1}{3}} Re^{0.8}}$$

k= thermal conductivity of air

Re = Reynolds numbers

Pr = Prandtl number

*A = cover area

The shape of the collector can be assumed as a trapezium. The area of the collector can be calculated as such:

$$A = \frac{1}{2}hl$$

Where;

h = height of collector = 3.85m

l = length of collector (top and bottom) = (0.5 + 6) m = 6.5m

$$A = \frac{1}{2}hl = \frac{1}{2}(3.85)(6.5) = 12.5m^2$$

From equation (1), we can see determine the heat transferred from the cover for each time interval. **(See Table 4.5)**

Table 4.5 h and W_1 values of surface A

Time	h(canopy)	W_1
800	0.195	0.974
1000	0.190	7.600
1200	0.180	8.115
1400	0.180	12.621
1600	0.181	12.651

There are four sides to the collector in this system. Although the sides are of the same size, the amount of solar radiation that each surface receives varies at any time of the day. This is due to the position of the sun at different times of the day and its location relative to each surface. The surface temperature of the respective collector sides are also differing to each other.

Therefore, the heat transferred from each side is different.

The heat transfer from the collector to the flow in the chimney can be calculated using the equation below:

$$\mathbf{W_2 = \dot{m}C_p(T_m - T_s)\ldots..(2)}$$

Where:

C_p = Specific heat capacity at constant pressure (From tables)

T_m = Mean temperature of air between cover and collector

$\dot{m}$ = Mass flow rate inside chimney

The mass flow rate can be found using the following:

$$\dot{m} = \rho_a u A_p \ldots.. \ (3)$$

ρ_a = density of ambient air

u = velocity of air flow

A_p = area of flow inlet

$$\mathbf{A_p = h_i L \ldots (4)}$$

h_i = height of inlet

From equation (2), we can see determine the heat transferred from the collector to the airflow for each time interval. **(See Table 4.6)**

Table 4.6 Values obtained from the property tables, the mass flow rate and the W_2 values of surface A

Time	**T_s (^oC)**	**T_{mean} (^oC)**	**C_p**	**m**	**W_2**
800	26.6	27.1	1.007	0.186	0.094
1000	42.0	42.5	1.008	0.604	0.304
1200	69.6	70.1	1.009	0.913	0.461
1400	69.7	70.2	1.009	0.831	0.419
1600	68.5	69.0	1.009	1.424	0.718

The type of flow must be determined in order to identify the correct relation to use to calculate the heat transfer coefficient for the collector.

The calculations involved the use of Prandtl Number, Nusselt Number and also Reynolds Number. Before that, the hydraulic diameter must be determined.

$$\text{Hydraulic Diameter,}\ldots\ D_h = \frac{4A_p}{P} \qquad \mathbf{(5)}$$

P = Perimeter of flow inlet = 2(0.5 + 3.2) = 7.4m

$$D_h = \frac{4A_p}{P} = \frac{4(0.5)(3.2)}{7.4} = 0.865m$$

Reynolds number can be found for each time interval. Due to the fact that the Inlet velocity is too small to measure, the value used is the mean velocity value calculated from:

Outlet Velocity = 5m/s (Targeted velocity)
Cross section of chimney, A= 0.196
Q = 5*A = 0.982
$Q/4 = Q_{side} = 0.2455$
$Q_{side} = A_p * V_{mean}$
V_{mean} = 0.2455/1.6 = 0.153m/s (constant)

*The above value is used as the inlet velocity to calculate the Reynolds Number. **(See Table 4.7)**

$$\mathrm{Re} = \frac{\rho . V . D_h}{\mu} \quad \text{… (6),}$$

Table 4.7 Values to obtain the Reynolds Number of surface A

Time	Density,ρ	Viscosity, μ	v_{mean}	D_h	Re
800	1.163	0.0000184	0.153	0.865	8341.9
1000	1.111	0.0000192	0.153	0.865	7667.9
1200	1.019	0.0000205	0.153	0.865	6586.5
1400	1.019	0.0000205	0.153	0.865	6582.8
1600	1.023	0.0000204	0.153	0.865	6626.9

Before we can calculate the Nusselt number, the Grashoff Number must be calculated in order to know the type of flow that exists in the system.

$$Gr_L = \frac{g\beta(T_s - T_m)L^3}{v^2} \quad \text{… (7)}$$

When the Grashoff number has been calculated, it is divided by the square of the Reynolds Number.

If $\frac{Gr_L}{\mathrm{Re}^2} \rangle 1$**, then the flow is Natural Free convection.**

From **Table 4.8** below, we can see that the flow is **Natural Free convection.**

Table 4.8 Determination of the type of flow

Time	T_s (^oC)	β	ν	Gr	Gr/Re^2
800	26.6	0.0033	1.6E-05	6.66E+09	95.8
1000	42.0	0.0032	1.7E-05	7.02E+10	1193.6
1200	69.6	0.0029	2E-05	1.42E+11	3283.1
1400	69.7	0.0029	2E-05	1.38E+11	3181.1
1600	68.5	0.0029	2E-05	1.38E+11	3141.7

The equation that is used to calculate the Nusselt number in this type of flow is:

$$\mathrm{Nu} = 0.54(Gr_L.\mathrm{Pr})^{1/3} \ldots \textbf{(8)}$$

By re-arranging equation (8), the heat transfer coefficient of the collector can be determined. (Equation 9)

$$\mathrm{Nu} = \frac{h.D_h}{K} \textbf{ (9)}$$

Ultimately, from the above, the coefficient of convection can be obtained **(See Table 4.9)**.

$$\mathbf{h_{conv}} = \frac{N_u.k}{L_h} \textbf{(10)}$$

L_h = height of the collector = 4.2m

Table 4.9 Nusselt Number and the heat transfer coefficient

Time	D_h	Pr	Gr	Nu	h(in flow)
800	0.865	0.707	6.66E+09	840.5	5.3
1000	0.865	0.707	7.02E+10	1827.8	11.9
1200	0.865	0.701	1.42E+11	2302.3	16.2
1400	0.865	0.701	1.38E+11	2277.6	16.0
1600	0.865	0.701	1.38E+11	2278.5	15.9

From the data collected, the transmissivity of the cover can also be determined using the following equation:

$$\tau = \frac{I_{inside}}{I_{outside}} \ldots \textbf{(11)}$$

Table 4.10 Transmissivity of the Cover

Time	**Solar intensity (out)**	**Solar intensity (in)**	τ
800	35.86	30.04	0.838
1000	237.88	226.81	0.953
1200	528.80	447.60	0.846
1400	671.20	482.50	0.719
1600	571.67	564.77	0.988
Average Value			0.869

The total mass flow rate is the sum of flow rates from all sides of the collector:

$$\dot{m}_t = \dot{m}_1 + \dot{m}_2 + \dot{m}_3 + \dot{m}_4 \ldots\ldots \textbf{(12)}$$

$\dot{m}_t$ = total mass flow rate

From the total mass flow rate, we can find the velocity of the air flow that passes through the chimney and into the turbine.

$$\mathbf{u_{chimney}} = \frac{\dot{m}_t}{\rho A_c} \ldots\ldots \textbf{(13)}$$

$u_{chimney}$ = velocity of flow in chimney

The final touch to the calculation is to find the amount of power that can be generated from the system assuming that the turbine has an efficiency of 0.97.

$$P_o = C_p\left(\frac{1}{2}\rho V^3 A_{rotor}\right) \ldots \textbf{(14)}$$

C_p = Coefficient of power = 0.8

$V = U_{chimney}$ = velocity of flow in chimney

A_{rotor} = cross section area of chimney

The cross section of the chimney is derived from the area of a basic circle:

$$\mathbf{A_{rotor}} = \pi \frac{D_c^2}{4} \text{.....(15}$$

D_c = diameter of chimney = 0.5m

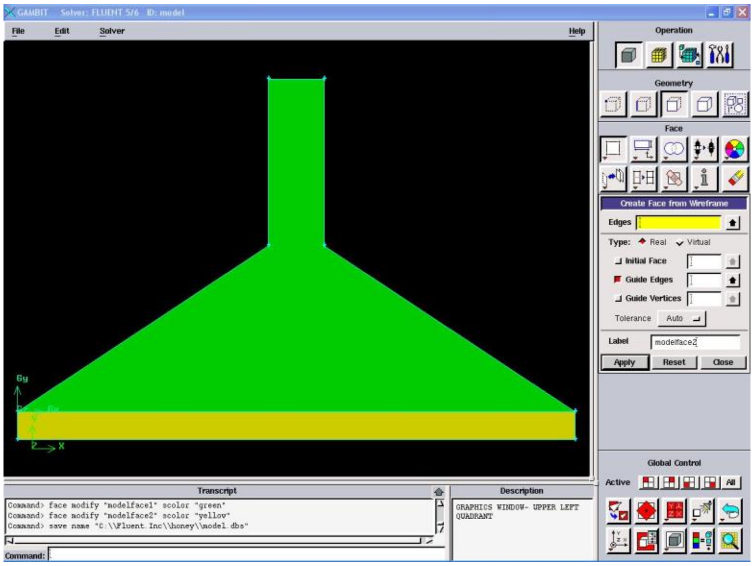
Table 4.11 shows the amount of power that can be generated from the data collected.

Table 4.11 Power generated from the data collected

Time	**V**	**P_o**	**P_{elec}(Watts)**
800	0.82	0.05	0.05
1000	2.78	1.92	1.87
1200	4.57	7.73	7.49
1400	4.16	5.81	5.63
1600	7.10	28.69	27.83

4.3 Model Drawing and Simulation Using GAMBIT and FLUENT

During the introductory classes that have been attended, the method of drawing the design using GAMBIT has become quite clear. Using the basic designs that have been roughly sketched in the earlier reports, a drawing of the solar chimney has been made. These drawings are as indicated in the figures below.

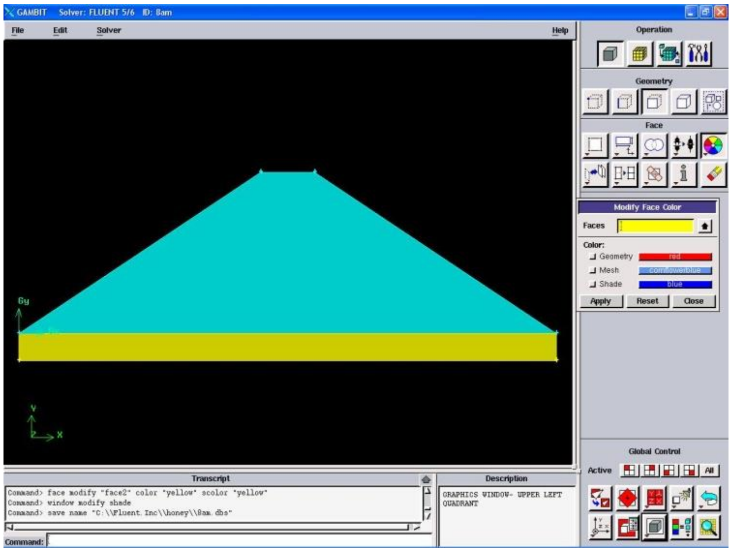


Edges:
Type: ◆ Real ✓ Virtual
Label: modelface2

```
Command> face modify "modelface1" scolor "green"
Command> face modify "modelface2" scolor "yellow"
Command> save name "C:\\Fluent.Inc\\honey\\model.dbs"
```

GRAPHICS WINDOW- UPPER LEFT QUADRANT

Fig. 4.12 2D drawing of the solar chimney (cross section)

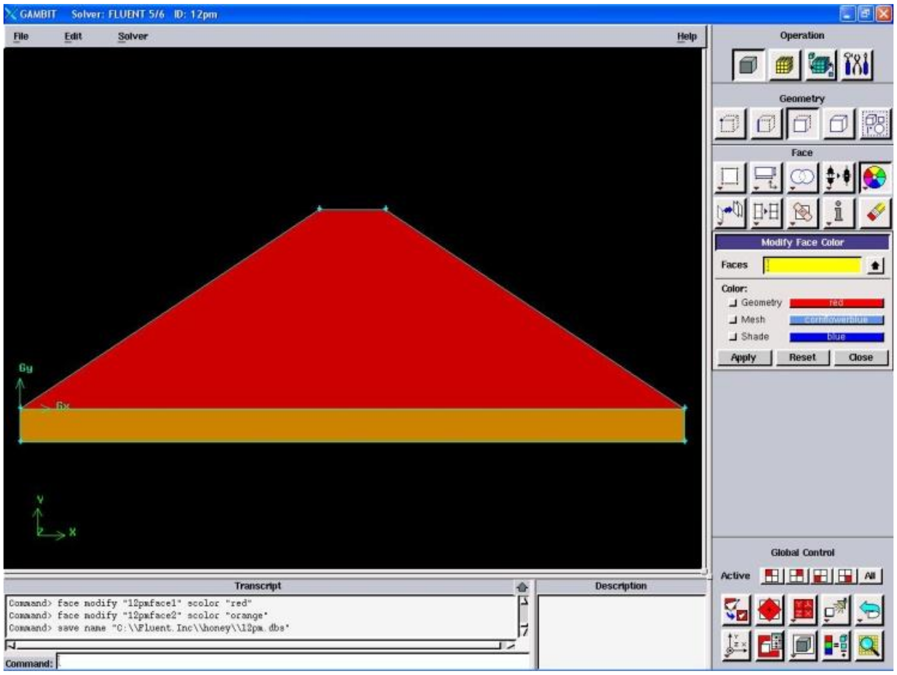


Color:
Geometry: red
Mesh: cornflowerblue
Shade: blue

```
Command> face modify "face2" color "yellow" scolor "yellow"
Command> window modify shade
Command> save name "C:\\Fluent.Inc\\honey\\8am.dbs"
```

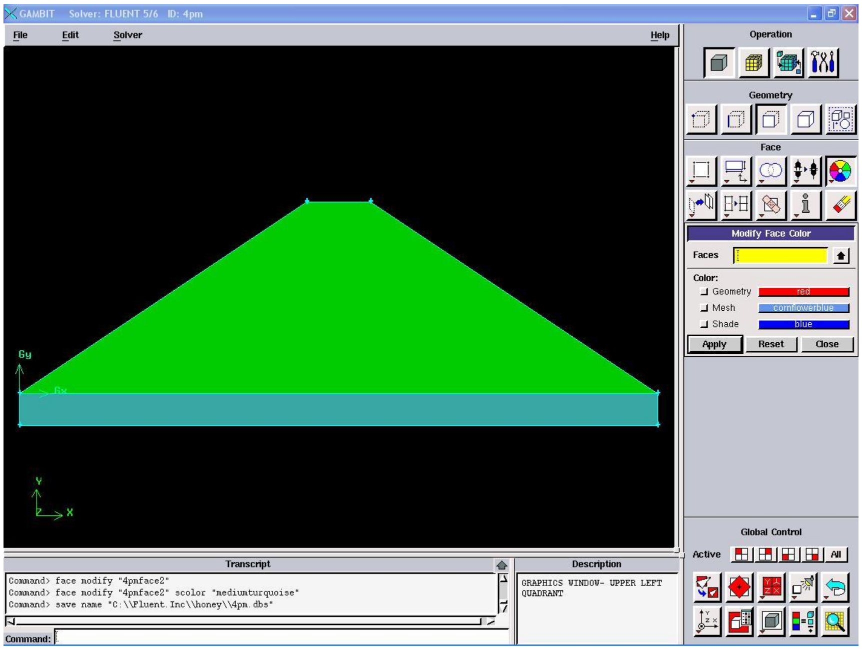
GRAPHICS WINDOW- UPPER LEFT QUADRANT

Fig. 4.13 The surface of the Collector (8am)



```
Command> face modify "12pmface1" scolor "red"
Command> face modify "12pmface2" scolor "orange"
Command> save name "C:\\Fluent.Inc\\honey\\12pm.dbs"
```

Fig. 4.14 The surface of the Collector (12pm)



```
Command> face modify "4pmface2"
Command> face modify "4pmface2" scolor "mediumturquoise"
Command> save name "C:\\Fluent.Inc\\honey\\4pm.dbs"
```

```
GRAPHICS WINDOW- UPPER LEFT
QUADRANT
```

Fig. 4.15 The surface of the Collector (4pm)

The pictures in Figure 4.12 to 4.15 shows the 2D cut of the collector each during a different time of the day. The colours indicate an approximation of the surface temperature. The temperature is assumed to be the coolest in the morning and gradually growing hotter as the goes by.

Since the design of the solar chimney is symmetrical in all directions, the drawing is an illustration of all sides of the collector.

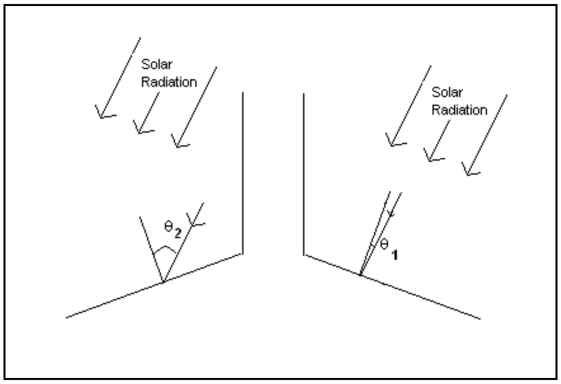


Fig. 4.16 The incident angles that vary with the angle of the sun

In actuality, the surface temperature for each side at each measured time varies due to the difference of the incidence in the solar radiation **(refer Figure 4.16)**.

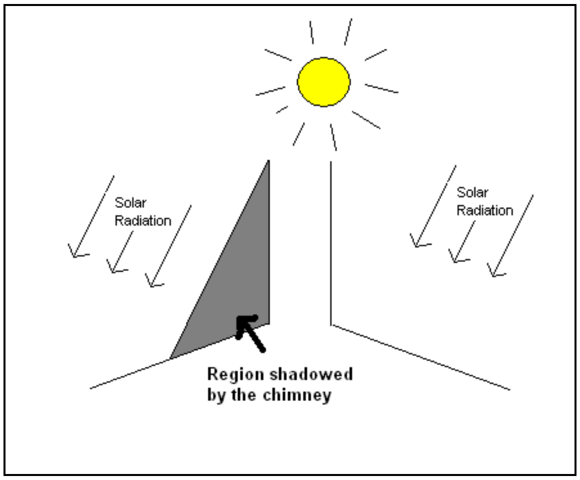


Fig. 4.17 The area overshadowed by the chimney at a given time of day

The shadow of the tower (chimney) is also a factor that affects the amount of solar radiation absorbed by the collector and must be taken into consideration **(refer Figure 4.17)**.

Before being able to make a more detailed simulation of the system in all its controlled boundary conditions, a simplified version of the simulation (2D) for each surface (4 different surfaces) is created in order to make sure that that the equations in the mathematical modelling are equal to the ones used in the simulation. This is done by applying a number of assumptions using ideal conditions in the preliminary simulations. The series of estimated outputs are compared to the outputs from the preliminary simulation that was created to determine whether they are within range of each other.

By taking a 2-Dimensional symmetrical side ways view of the solar roof chimney, the flow of the air, the intensity of the solar radiation and the final exit velocity of the chimney were determined.

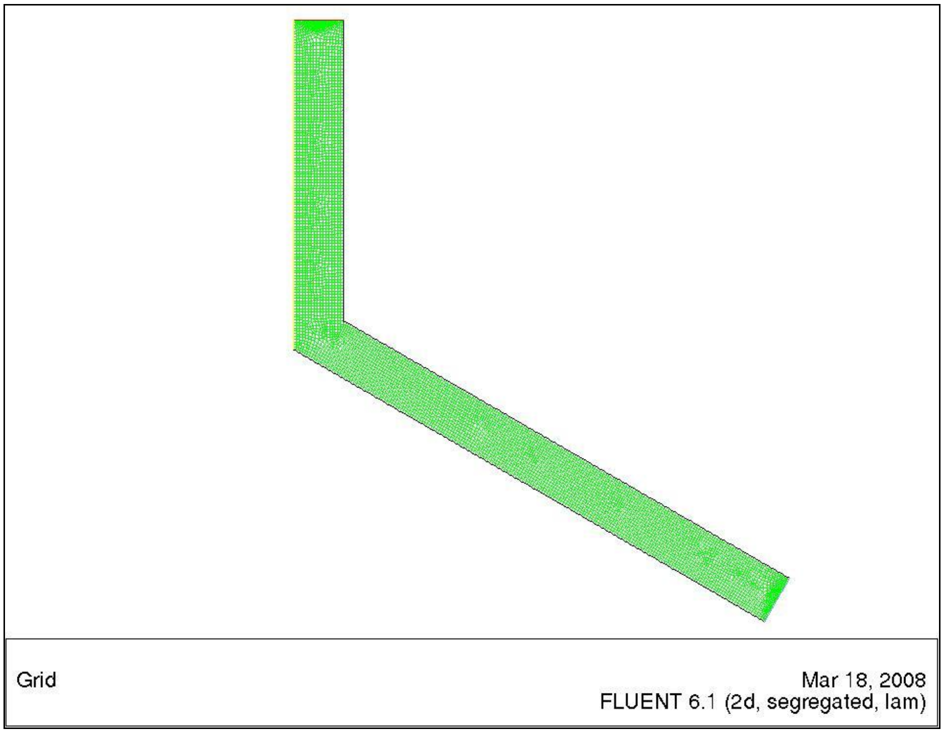


Fig. 4.18 Preliminary FLUENT Simulation of Half of the Roof (2D)

From this preliminary simulation, any errors in the boundary conditions or any other miscalculations can be detected at an early stage and modified accordingly. As up to now, the preliminary simulation has been created but still containing minor inaccuracies pertaining to the final targeted outputs.

After thoroughly examining the conditions and design of the system, it is decided that it would be much more effective if the simulation be done in 3- dimensional view instead of the previously chosen 2-dimension.

The main idea is to section the model into 8 segments as they are all identical. From the segments, only one is drawn and before simulation is done, two of the eight segments will be put together to illustrate a surface.

At the same time, many activities have been done in order to gain further in-depth knowledge on the usage of the softwares, GAMBIT and FLUENT especially in the areas of 3-dimensional simulation but due to lack of resources and expertise regarding these two soft wares, the progress is very slow. As a result of that and the time constraints, the attempt of creating a CFD simulation for the Over Roof Solar Chimney did not reach completion.

The only progress of the simulation is the 3 Dimensional drawing of the 1/8th segment.

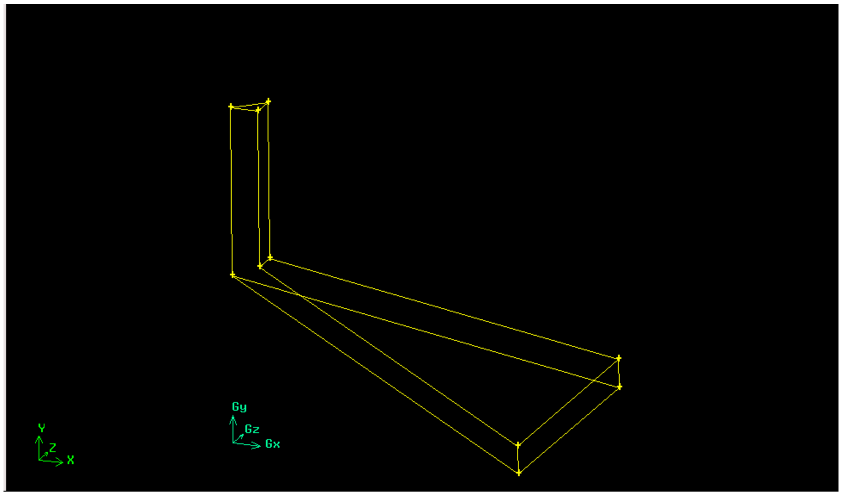


Fig. 4.19 GAMBIT drawing of a segment of the Solar Roof Chimney (3D)

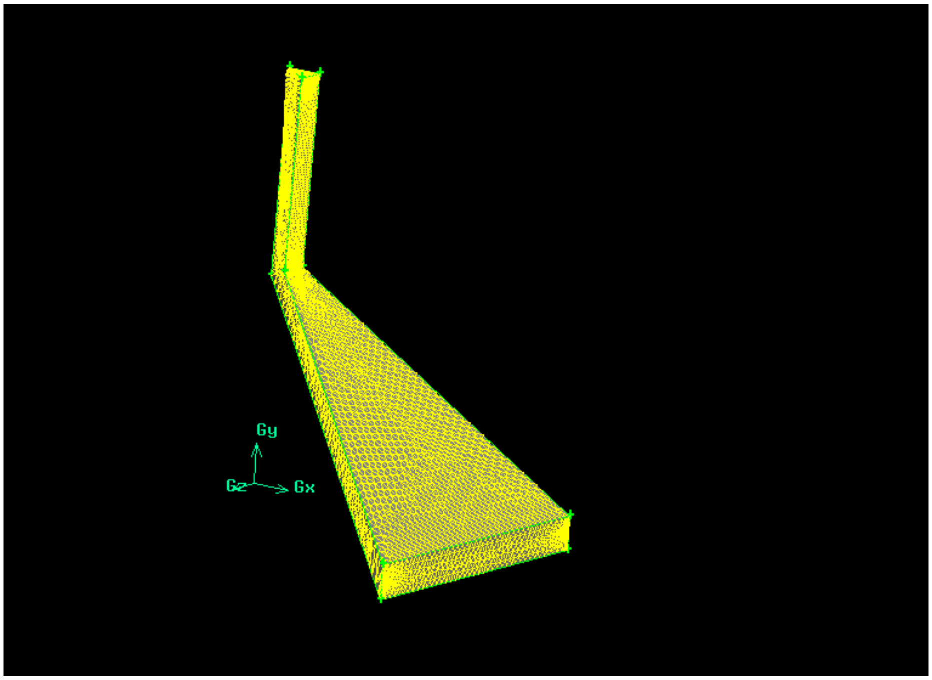


Fig. 4.20 Meshed GAMBIT drawing of the Solar Roof Chimney (3D)

From these drawings, it was planned to create a simulation based on the combination of 2 of the segments for a simulation of each surface. This means that there would have been 4 different simulations for the system. This is done because for each surface, the conditions vary at each time of the day.

The drawback from the four different simulations is that the four simulations cannot be compiled as one. The system cannot be seen as one.

4.4 Discussion

Measurements of the dimensions of the house are variables that have been assumed in order to obtain the equations stated in the literature survey previously. The design and calculations of the building has been made taking into the consideration the minimum requirement for the velocity of the moving air. Values lower than that would not be sufficient to move the turbine and generate any power. In order to determine the success of the project, it is must better to also target a specific amount of power to be generated. The comparison of the power generated and the targeted value could be an indication of whether the project is feasible for application.

From the model, the air flow that has been recorded at the inlet is too small and thus could be negligible although the airflow velocity at the outlet is surprisingly big. This proves that the theory of difference in temperature generating wind is true although the theory of generating power from the airflow is questionable.

The amount of power that has been estimated **(see Data Collection Sheets)** is seen to be insufficient for the use of even a single appliance much less a domestic household. Nevertheless, the main objective is to analyse the performance of the system rather than to wholly measure the amount of power than can be generated (although it is indirectly related to the performance analysis).

The assumptions pertaining to the equations such as the coefficient of power and the efficiency of the turbine is an area that could be further developed as these values are taken from similar although not same applications.

Another option to increase the efficiency of the roof chimney is to increase the thickness of the collector so that more heat could be absorbed and stored in the collector. This heat would slowly dissipate during the night and still manage to create airflow. The efficiency of the system would be lower than the daytime and the air flow would still be slightly lower in velocity due the smaller temperature difference but it is airflow nonetheless that could operate the wind turbine.

When mentioned about the efficiency, there is concern regarding the amount of surface area of the collector that is available. Usually in the large power plants, the surface of the collector would be flat. In this project, in an effort to increase the surface area of the collector, corrugated metal sheets would be more suitable. The more surface area that is exposed to the solar radiation, the higher the efficiency of the system. This is most important in the small scale project such as this. This is also assuming that no shadows are created from in between the corrugations. If these corrugations are positioned closer together, the possibility of shadowing is greater.

The thickness of the collector used in the model is of the average thickness of corrugated metal sheets available in the current market. This thickness is suitable for a small scale design but must be thicker for bigger applications.

There must also be some layers of insulation so that the effect of the heat absorption of the collector does not enter the house. The question of heat transferring downwards through convection into the house is the main reason double insulation of the roof is important. The first layer of insulation is the original insulation of the roof and the second layer is an added layer underneath the collector. Besides this function, the second layer also acts as a heat storage facility.

There has been a doubt if the velocity of the flow in the chimney might not be able to operate the wind turbine but instead pass through between the turbine blades and not generating power. This study has been done in the Middle East and the results indicate that in flow generated in open spaces were more likely to experience this problem. As the flow in the chimney is in closed spaces, the possibility of this occurring is quite low. Furthermore, the inlet of the air flow comes from 4 directions and all of them converge to one point increasing the velocity.

The CFD simulation would be much better to indicate the air flow and the characteristics of the flow but due to many reasons, the attempt at creating the simulation had to be cut short.

The results obtained during the rainy days and also the cloudy days were not as satisfactory as other days. The sudden spikes on the graph indicate this fluctuation.

The Over Roof Chimney does have its limitations. The performance of the system during rain has not been tested as the main focus is the time of maximum solar radiation. There could be more room for improvement in that arena.

CHAPTER 5

CONCLUSION

The solar roof chimney is a slightly modified version of the solar chimney power plants that have been built around the world. In order to generate the equations needed in the modelling, many assumptions have been made. The target velocity that we wish to gain is at least 5m/s and from the many journals and reference, the basis of equations for the system is formed. These equations include the basic energy transfer and fluid flow equations. The type of flow is also very relevant in determining the type of equations used.

To make the system more efficient, there are certain properties or material that can be used to increase the absorption of the solar radiations. Experimental modelling of the system is very important to obtain the vital data that can be interpreted into characteristics of the flow. An experimental model is built in for reliable data to be measured. The data obtained indicate that the potential utilising of the solar system can be effective in providing power especially for the use sites of housing units and large roof area. Of course, more improvements can be done in the future to further increase the efficiency of the system.

The targeted wind velocity approaching the turbine required to be increased to the range of 8 to 10 m/s and the turbine diameter to be around 1m.

There has been preliminary simulation done of the system but created in 2 dimensional views. This is not very suitable for this type of system and so 3D simulation has been attempted. The progress of the CFD simulation has been very slow due to some circumstances and finally had to be cut short due to many constraints.

From the overall of the project, I can say that the Over Roof Solar Chimney is not suitable for a small scale application especially if it is used solely without any support from any other systems. If it is to be implemented, the surface area is to be increased a whole lot more (tenfold, perhaps).

There are other areas that can be further analysed in order to increase efficiency as well as improve on. These are further explained in the future tasks page.

There are also other options such as the use of biomass that could be integrated with the system to make it more efficient but that could only be further studied after the analysis simulation of the main system is complete.

RECOMMENDATIONS

Throughout the whole year doing the Final Year Project, there have been many observations on the ways of the management of the facilities in UTP. Here are some suggestions:

- The labs and workshops should have longer operational hours.

The Final Year Students have to plan their time around classes and also try to fit in some hours in the labs and workshops. This is very inconvenient as we have full classes during office hours. This is a limitation that slows down the progress of the project.

I suggest that the operation hours for the labs and workshops are extended or special permission is given for the final year students to enter the labs after office hours.

- Limited technicians with the knowledge of using the soft wares required for the project

This is very frustrating as without any guidance from the technicians, the process of learning and exploring the soft wares are slow and added with the fact that lab hours are short, this complicated things more.

I suggest that the technicians are sent for training that involves the use of advanced and complicated soft wares.

- The availability of the workshop

The workshop has only one technician. When the technician has to do some tasks outside the workshop or he has training, he is not allowed to leave the workshop unlocked and thus has to close down. There is no one replacing his duties to ensure that the workshop stays open. This has become very inconvenient as the hours of operation are limited coupled with the fact that the workshop hours are inconsistent. This slows down the process of manufacturing the experimental model.

I suggest that for each lab or workshop, there is more than one technician assigned. Especially for the critical ones that are often used.

- Simplify the process of borrowing equipment

I experienced some difficulty in obtaining the equipment due to the many restrictions and documents that has to be produced to borrow the said equipment. This has delayed my experimental data collecting by a day. Finally after talking with my supervisor was I able to use the equipment.

I understand that there is a reason for all the documentations but this makes it difficult for the students to apply for anything at all. This hampers the process of experimentation.

- Provide suitable experimentation grounds

This would be very helpful in experimentation as this provides a secure place to leave the instruments that have to be used. This also helps in maintaining privacy to conduct experiments without fear of interruption and worry of sabotage. This has become an issue because there have been cases of sabotage of experimental models during the times the models are in use.

- The use of the weather station in UTP

It is strongly suggested that the usage of the weather station in UTP be fully utilized by all who wish to do their analysis regardless of program or level. It is understood that the station is currently not in use even though all the equipment are fully functional. As of now, the weather station is under the keep of the Civil Department. I must point out that other departments such as the Mechanical Department also have need of the station as there is an Energy Specialization that require weather data.

FUTURE TASKS

These are a few suggestions that can be a continuation of my Final Year Project:

- CFD Simulation of the flow between the canopy and the collector in 3D

Since the flow of the simulation is free natural convection, this requires a solid knowledge of the usage of the Fluent and Gambit soft wares. This is because the free natural convection is very difficult to simulate due to the random characteristics of the flow. Input from my experimental modelling can be the initial information. Other parameters can be changed to see what happens in the simulation and further analysis can be done comparing the various changes.

- Analysis of the Over Roof Solar Chimney with Partitions Between each Surface

One of the observations from this project is that the airs between the two layers of the roof tend to propagate in random directions before moving towards the chimney. What is suggested is a partition that can help direct the flow towards the chimney. A theory that can be tested is whether the application of partitions between the four surfaces could minimize the amount of circulation air and increase the velocity at the outlet or create other implications.

- Analysis of Performance of Over Roof Solar Chimney Integrated with the Incineration of Bio Mass System

The Biomass system is suitable application that can be integrated with the over roof solar chimney. This system can be a used during times when there is no solar radiation or insufficient airflow to operate the turbine. An experimental model can be made to collect data related to the analysis of the system.

- Analytical and experimental studies on the chimney height and configuration

It is important to take into consideration the height of the chimney in analyzing the performance of the solar chimney system. Does the chimney height affect the overall performance of the system? What happens if the height of the chimney varies? These are questions that are the basis of the topic.

- Experimental investigation on the performance of the ducted wind rotor

This experimental work could shed some more light on the significance of having a ducted wind rotor. There are many types of wind rotors that can be used for the solar chimney system. In analyzing the different types, we could identify the most suitable and effective of them.

- The analysis of the type of material for the Canopy of the Solar Chimney

The materials used for the canopy is very important as it has specific criterion to fulfil before it can be deemed suitable. The analysis of the type of material is very relevant. There are many types of materials that could be used but each one has its respective advantages and disadvantages. A well documented list of such materials could be very helpful in many other levels.

- Full scale construction of the Over Roof Solar Chimney

The construction of a full scale model could be beneficial in determining the weaknesses and strength of the system. This model could be used many times for further analysis of the system and also for other types of analysis such as for the solar intensity measurements or solar panel efficiency in other projects.

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