Experimental Analysis Of Modified Roof Extractor For Wind Power Conversion In Solar Chimney Application

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CERTIFICATION OF APPROVAL

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August 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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Puventhan A/L Krishnasammy

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ABSTRACT

Solar chimney is one of the methods that is used to improve the existing natural ventilation of buildings by using the convection of air principle that occurs due to passive solar energy that transferred from the sun. The solar chimney principle and the awareness of wind power generation lead to the usage of turbine in the solar chimney to generate electricity from the wind currents that occur in the solar chimney and accordingly it is termed as a solar chimney power plant. The principles of solar chimney works by using the thermal energy that is obtained from the sun to increase the temperature of the air directly under the sunrays which causes the heated air to move upwards. This updraft is guided in a way that the wind flows into the chimney and cool air replaces the flux of heated air. Using this wind, turbine is placed in the path of the updraft and used to generate electricity.

The objective of this study is to investigate the ways to improve the output of the electricity produced by the turbine generator by manipulating the variables that are present in the solar chimney such as inlet height. This is done so that the solar chimney can be presented as a feasible alternative energy source that is more efficient than the existing alternative energy sources, which usually have a low efficiency.

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CHAPTER 1
INTRODUCTION

1.1 Background of Study

Cooling plays an important role in maintaining suitable environment for human interactions and living. For countries that are located in a tropical climate areas, cooling plays a very important role since the temperature can rise to a very comfortable temperature, inhibiting comfort and productivity in certain cases. Out of many solutions, a green, environmentally conscious is where they use solar chimney to provide passive cooling for the place. The traditional design is where a tower is used to channel the wind from the transparent base that covers a very large surface area.

Air is heated by solar radiation under a low circular glass roof open at periphery; this and the natural ground below it form a hot air collector. In the middle of the roof is a vertical chimney with large air inlets at its base. The joint between the roof and chimney base is airtight. As hot air is lighter than cold air, it rises up the chimney. Suction from the chimney then draws more hot air from the collector, and cold air comes in from the outer perimeter. Thus solar radiation causes a constant updraft in the chimney. This energy this contains is converted into mechanical energy by pressure staged wind turbines at the base of the chimney, and into electrical energy by conventional generator.

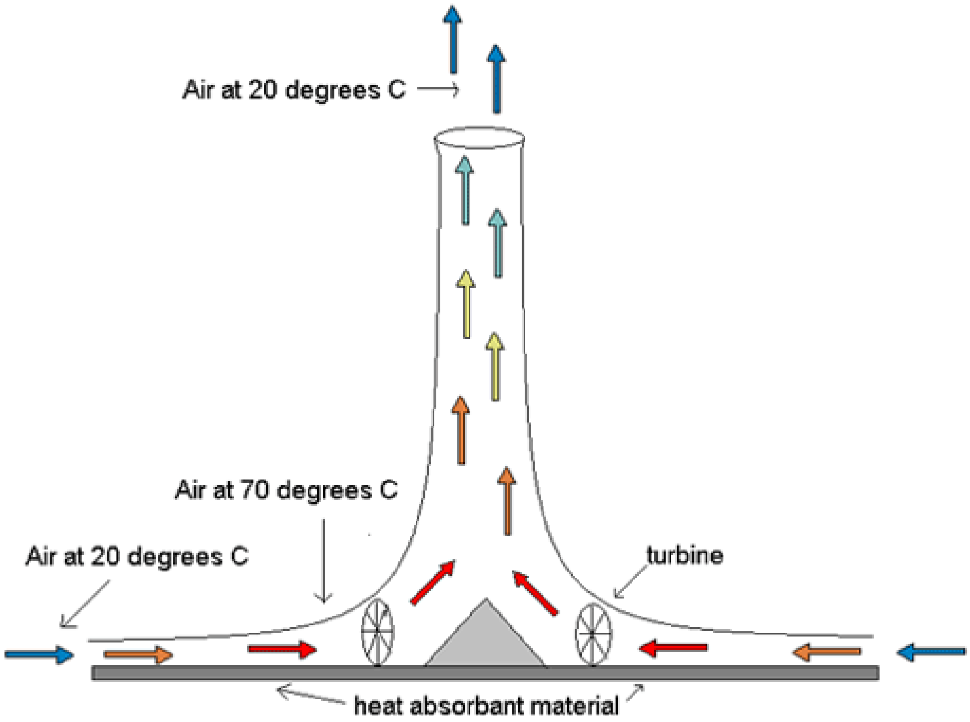

Figure 1: Concept of a solar chimney power plant

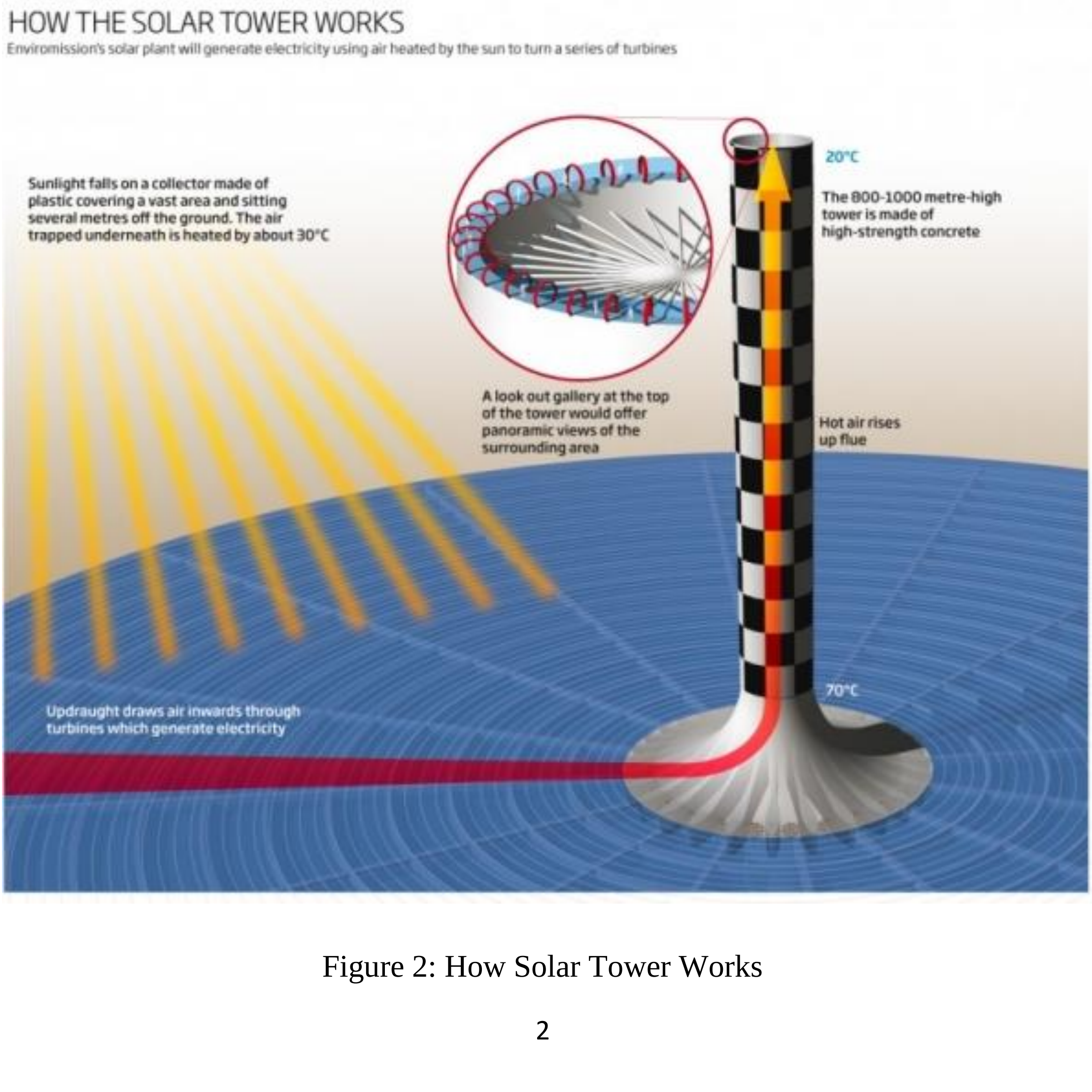

Figure 2: How Solar Tower Works

1.2 Problem Statement

The solar chimney uses conversion of energy from solar thermal energy to kinetic energy, commonly referred to as wind energy, which turns the turbine through the updraft that is created from the movement of hot air. The existing design requires about 6m/s of wind speed to operate at optimum level. The efficiency of the existing design leaves spaces for improvement for a better output of electricity generated from the wind turbine.

1.2.1 Problem Identification

Operating solar chimney to generate wind speed of 6m/s is very difficult to achieve. Hence, downscaling the model and using a lower wind speed is the more viable option rather than creating a large footprint to generate electricity at a low efficiency. Using a lower wind speed however creates a very small output of electricity from the generators. The main insight parameter is to modify the flow angle of the air of the turbine blades, which is then in turn optimized to enhance the turbine performance.

1.2.2 Significance of the Project

By improving the output of the generator using a low wind speed, the efficiency of the more large scale solar chimney can be improved.

1.3 Objectives

The objectives of the project is to experimentally test the effect of different height of canopy on the output of the power generated by the turbine in the solar chimney power plant.

1.4 Scope of Study

Modification and improvement work of the existing solar chimney model will be the primary focus of the research. The different factors will be tested to determine the most suitable method to increase the efficiency of the turbine and increasing the output of electricity.

1.5 Project Relevance

The relevance of the project is thus because it will improve the efficiency of the existing solar chimney output and give more reason to use solar chimney as a method for alternative energy source. This is important as the existing large scale solar chimney around the world can benefit from the modification that gives evidence that there is improvement from the output with it.

1.6 Project Feasibility

The project is feasible since it is within the scope and the time frame that is given. The author has planned to complete the research and literature review by the end of the first half of the first semester while getting the results from the modification throughout the first and second semester to determine the effects from the modification and whether are they suitable to be implemented.

CHAPTER 2
THEORY AND LITERATURE REVIEW

2.1 Theory

Solar chimney consists of 3 main parts, the solar heat collector, the wind turbine and the chimney for the flow of air updraft.

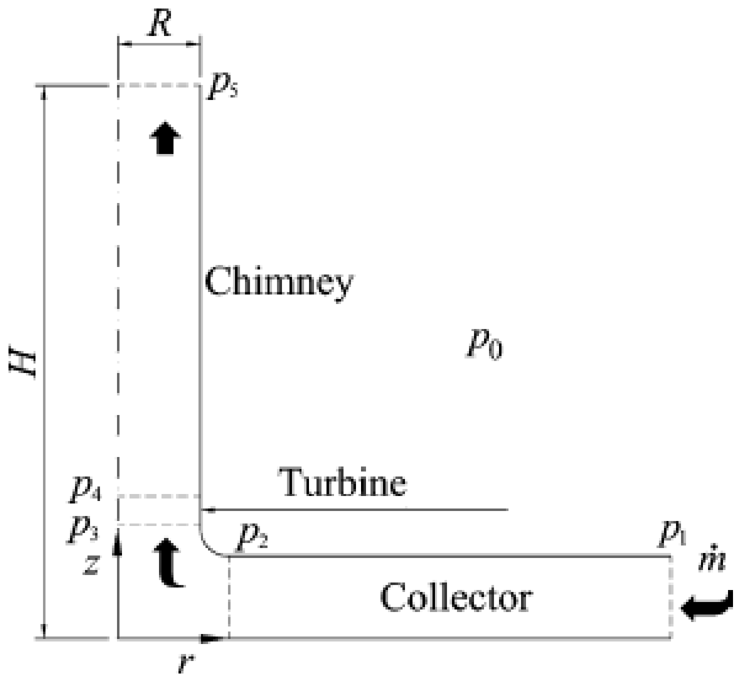

Figure 3: Flow of hot air in the solar chimney (Bernardes, Voß, & Weinrebe, 2003)

Nomenclature;

$\dot{m}$ = mass flow rate of air [kg s-1]

r = radius of the solar chimney [m]

p_0 = surrounding air pressure [Pa]

p_1 = collector inlet air pressure [Pa]

p_2 = collector outlet pressure [Pa]

p_3 = turbine inlet air pressure [Pa]

p_4 = turbine outlet air pressure [Pa]

p_5 = chimney outlet air pressure [Pa]

H = height of the chimney [m]

R = radius of the chimney [m]

2.2 Literature Review

As with so many other inventions, it was Leonardo da Vinci (1452-1519) who created the earliest system, which uses hot air rising in a chimney to drive an apparatus; one of his sketches depicts a roasting spit driven by a turbine located in the chimney above a fireplace (Calder, 1970).

The first person to propose to use a solar chimney to generate electricity was a Spanish colonel, Isidoro Cabanyes in 1903. He made a proposition known as *Proyecto de motor solar* which describes a model with heater attached to a house chimney with a wind propeller attached on it for electricity generation through the draft (Cabanyes, 1903).

A similar concept to that of the modern solar chimney power plant can be found in a patent of Ridley (Ridley, 1956). The inventor suggests to create a large vortex by adding swirl to the air flow in the collector and injecting a stream of cold air in the centre of the chimney. It is hoped that, with the help of coriolis forces, the created vortex can be sustained even far beyond the chimney exhaust and that this will lead to a good system performance without the necessity of a very tall chimney.

The major player in recent SCPP development, the German structural engineering company Schlaich Bergermann and Partners (SBP), designed, built and tested a solar chimney pilot plant in Manzanares, Spain. With its 195m tall chimney and a 40m diameter collector this is the largest SCPP to date. After an experimental phase it fed the Spanish grid in fully automated operation from July 1986 to February 1989 during a total of 8611 hours (Schlaich, et al., 1995). Even though the nominal power output of an economically viable plant is three to four orders of magnitude higher, the results from Manzanares show that this concept is a possible alternative to conventional power plants and warrant further investigation.

The main fields of research in context in solar chimney power plants are the chimney structure, collector performance, the power conversion unit and the system performance. According to Schlaich (1995) the chimney of an economically viable SCPP is 950m high and has a diameter of 115m. The tallest free-standing structure on land to date is the CN Tower in Toronto and is 553m high. This makes it clear that the chimney structure alone is an engineering challenge. Schlaich (1995) discusses several ways of building the chimney and proposes to use a steel reinforced concrete tube for large scale plants. For the pilot plant in Manzanares a guyed sheet metal tube was used.

Goldack (2004) introduces several wind load cases and investigates the influence of different stiffeners and wall thickness distributions on the structural behaviour of large solar chimneys of 1000m height. He points out that more work is necessary to establish the appropriate wind load cases and to evaluate the influence of the temperature variation on cracking, and he suggests to do empirical studies, e.g. on large cooling towers, to assess the influence of geometrical imperfections on local loads.

A preliminary study on the support struts of a 1500m high solar chimney is presented by Van Dyk (2004). Rousseau (2005) looks at wind loads on a chimney of the same height located in the Northern Cape province of South Africa. He proposes a revision of the static wind load profile and predicts that resonance will occur at yearly recurring gusting speeds. Alberti (2006) investigates the stabilizing effect of vertical ribs on a solar chimney structure. For the present dissertation it is assumed that chimneys of up to 1500m height are feasible.

According to Bernardes (2004) the collector accounts for more than 50% of the investment cost and about 50% of the overall system losses. Improving its performance offers a big potential to make the SCPP cost competitive. Pretorius and Kröger (2006) investigate a variety of glass qualities and various types of soil and the impact of using a convective heat transfer equation, which was recently developed by Kröger and Burger (2004) .

The power conversion unit of a large solar chimney power plant is the part in which the fluid power gets converted, first into mechanical power and then into electrical power, ready to be fed into a larger regional or national grid. It consists of one or several turbo generators, power electronics, a grid interface and the flow passage from collector exit to chimney inlet.

In order to predict SCPP performance various mathematical models have been developed since the early 1980s. As much as they may vary concerning modelling approach and computational implementation, they share some important trends: with all models the power output increases with the size of the chimney and the collector area, and they all show a large daily and seasonal fluctuation in power output. Unfortunately, the amount of experimental data available for validation of these models is very limited, and in most cases data from the Manzanares plant have been used. Haaf *et al.* (1983) present a simple model, which they used for the design of the pilot plant in Manzanares. Pasumarthi and Sherif (1998) show a more detailed model, which they verify against their own experimental results and results of the Manzanares pilot plant (Pasumarthi & Sherif, 1998). Gannon and Von Backström (2000) adapt the standard gas turbine cycle to define a standard solar chimney cycle. They also compare the results from that simple model to experimental results of the Manzanares plant.

The most comprehensive SCPP performance model is presented by Pretorius and Kröger (2006). It is based on the model of Hedderwick (2001). As mentioned earlier, various types of soil for the collector ground and a variety of glass qualities for the collector roof can be simulated (Pretorius & Kröger, 2006). For the dissertation of Pretorius (2006) the model has been modified to allow for ambient wind, various temperature lapse rates, nocturnal temperature inversions and the use of the collector as a greenhouse. The impact of these parameters on the performance of the plant has been investigated. Modifications to enable peak or base load operation of the plant are also proposed and implemented in the model. In contrast to Bernardes (2004), Pretorius (2006) finds that the properties of the collector ground have a significant impact on the daily power distribution, and that the use of double glazing for the collector roof increases the annual power output by at least 32.3%. Pretorius *et al.* (2004) present an earlier version of their model and find that the SCPP performance deteriorates with the presence of ambient winds but is not significantly affected by the shadow of the chimney.

When it comes to the flow of air and the angle of attack on the turbine blades, there hasn't been a study on it until now. This is probably due to the different type of turbine used in the large scale power plant. The turbine usually uses the multiple bladed turbine that is arranged horizontally and the wind flows through them, spinning them due to their curved blade form. However, our solar chimney power plant uses a different kind of turbine. This turbine is believed to be more efficient due to its shape that uses multiple blades that is formed as a cage to trap air that move across it. Typically used in domestic usage, using it in the solar chimney is believed to be able to give the solar chimney power plant a more efficient output. My previous colleague, Muhil Prakash managed to install the turbine in the solar chimney power plant, however, the orientation is observed to encounter a lot more resistance that it would if it was installed in a 90 degree orientation.

Another effect that hasn’t seen the light of the day is the height of the canopy and the effect on the performance of the solar chimney. The previous student before Muhil, Jia Lin, has studied the height of the canopy when it is increased and the effect on the solar chimney performance but didn’t manage to do a comparison with the effect of a lower canopy height. This is to determine the optimum level of the canopy heights in regard to the size of the solar chimney power plant which can be used to increase the overall efficiency of the solar chimney power plant.

CHAPTER 3

METHODOLOGY

3.1 The System

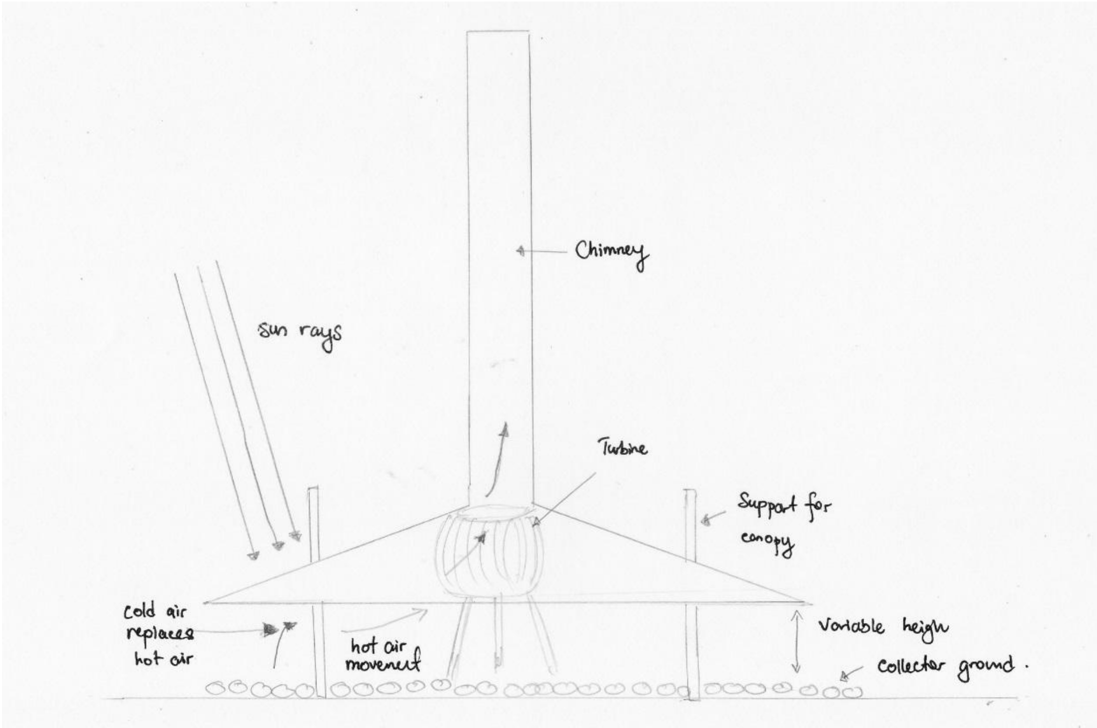

Figure 4: Sketch of the system

The picture above shows the sketch of the system that is used in the experimental analysis. The system consists of 3 parts, the chimney, the canopy and the collector ground. The chimney is measured to be 6m in height, and is made of PVC. The height is able to be adjusted by using different chimney with the connector for the appropriate chimney is used. In this experiment, the connector with 6”X6” is used to help the chimney stand on the solar chimney power plant. The collector is made of iron frame covered with Perspex glasses for the spaces between the iron frames. The canopy is very important as it helps to gather the heat energy from the sun and redirects the flow of the hot air that rises up the air into the chimney funnel by curving down from inside out. This shape helps to guide the hot air into the chimney funnel easily and the air flow turns the turbine in order to generate electricity. The collector ground is the most important aspect of the solar chimney power plant. This ground is covered with black stones that helps to store the radiation heat from the sun and heats up the air directly above it. As the stones heat up the air, air convection helps to move the cooler air to be heated up while the hot air moves up. The movement of hot air is restricted by the shape of the canopy and the canopy redirects the hot air to the centre of the solar chimney power plant, where the air turns the turbine and flows upward into the funnel.

Figure 5: Picture of the system

3.2 Instruments for Measurement

The conduct the experiment, there are certain instruments that needed to be used in order to obtain the date. The instruments that are used are such as:

Infrared Thermometer

Figure 6: Infrared Thermometer

An infrared thermometer is a thermometer which infers temperature from a portion of the thermal radiation sometimes called blackbody radiation emitted by the object being measured. By knowing the amount of infrared energy emitted by the object and its emissivity, the object's temperature can often be determined.

Anemometer

Figure 7: Anemometer

An anemometer is an instrument that is used to determine the wind speed by using a probe that is inserted into the opening in the funnel where wind flows upwards. Using the speed measured in the funnel, it can be determined whether the speed of the wind is faster compared to other variables or not.

Multimeter

Figure 8: Multimeter

A multimeter is an electronic measuring instrument that has the ability to measure voltage, current and resistance. This multimeter can be used to measure the power generated by the motor that is turned by the turbine in the solar chimney power plant.

Table 3.1: The Project Activities Flow

Activities	Description
Research and Review Literature	• Extract relevant parameters and procedures • Obtain existing result and modification done
Testing the effectiveness of the generator	The existing generator will be used and the current output is determined on average. This is to be used as the constant for the future experiments and to determine the effectiveness of the modification
Changing the materials used as the absorbing ground	Black matte paint will be used to determine the effectiveness over the existing absorbing ground materials.
Testing with different heights of the canopy	Different heights will be used for the canopy to see whether the height affect the output of the electric generation of the solar chimney.
Analyse the Results	The findings are discussed and conclusions are drawn.
Report Writing	Compilation of all works into a final report.

3.2.1 Process Flow

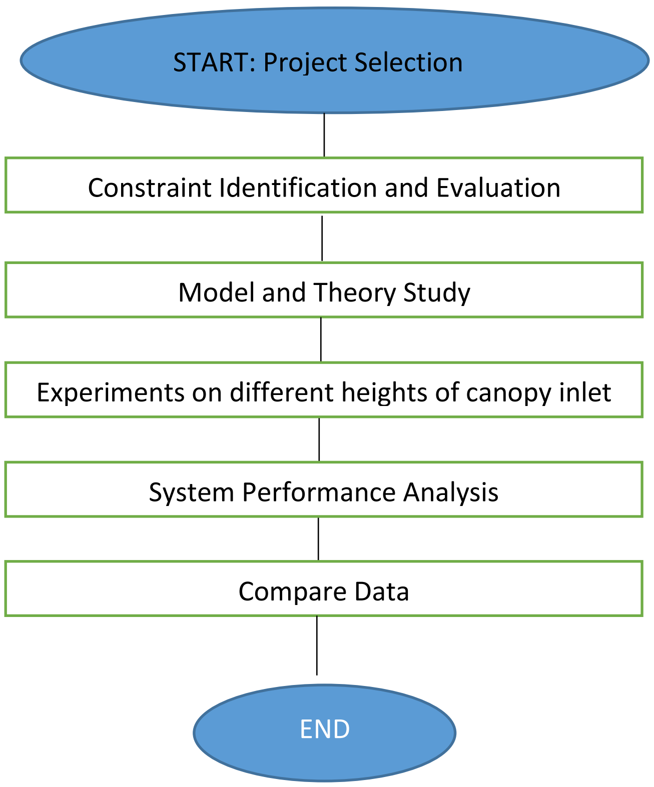

Figure 5: Process Flow

3.2.2 Key Milestone

The duration of the FYP 2 is 14 weeks. The following shows the key milestones of the project.

FYP 2		
No.	Detail	Week
1	Submission of Progress Report	8
2	Testing of different heights of canopy effect	9-10
3	Pre-SEDEX Poster & Presentation	11
4	Submission of Draft Report	12
5	Submission of Dissertation (soft bound) & Technical Paper	13
6	Oral Presentation	14
7	Submission of Dissertation (hard bound)	14

3.3 Gantt Chart and Key Milestones

Tasks/Weeks	3	4	5	6	7	8	9	10	11	12	13	14
Project Title Selection & Approval												
Research Work & Data Gathering												
Study on the model and the theory												
Submission of extended proposal defense												
Proposal defense												
Experiment set up and calibration												
Experimental work												
Submission of Interim Draft Report												
Proposal Submission				22-Feb-13								
Proposal Defense						4-Mar-13	10-Mar-13					
Interim Report Submission												21-Apr-13

Table 3.2: Gantt Chart and Key Milestone for FYP I

Tasks/Weeks	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Modification of the turbine														
Expansion of the absorbing ground														
Implementation of new turbine and data loggers														
Data collection and analysis														
Writing of draft report														
Completion of dissertation (softbound)														
Writing of technical paper														
Preparation for oral presentation														
Completion of dissertation														

Table 3.2: Gantt Chart for FYP II

3.4 Tools and Software Required

In this section, the materials needed to construct the extension of the canopy will be listed and then the tools and software needed for the experiments using the solar chimney will be listed separately.

3.4.1 Tools for Experiments

- Variable Solar Chimney
- Extractor-turbine
- DC Motor/Generator
- Multimeter
- Solar Meter
- Portable hot wire anemometer
- Thermocouple wires
- Data Logger

3.4.2 Tools for Maintenance

- WD40
- Saw
- Kerosene

3.4.2 Software for Documentation

- Microsoft Office Excel
- Microsoft Office Word

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Data Gathering

This section contains the sample data collected for the different heights tested. As the heights results are shown, the discussion and the inference are written down before the results illustration are shown.

15cm Height Canopy

From the results shown below, we can see that the wind movement in the funnel peaks at 12pm. This is because the sun is directly above the solar chimney power plant and the incident ray is 0° from the canopy Perspex which allows less refraction to occur. As the ray hits the ground, the collector ground absorbs the radiation heat and heats up the air. The sun rays that pierce through the Perspex glass also helps to heat up the air inside the canopy thus providing the solar chimney power plant with more heat for the canopy to utilize. However, around 3pm, the days become very cloudy and starts to drizzle. Due to that, the wind speed after 3pm are very much nonexistent due to the heat being absent from the solar chimney power plant. The cooler air and the movement of the air around the solar chimney power plant removes the heat before the heat can sufficiently heat up the air to move the air up towards the funnel. As such, the solar chimney power plant doesn't record any movement of air at that period of time.

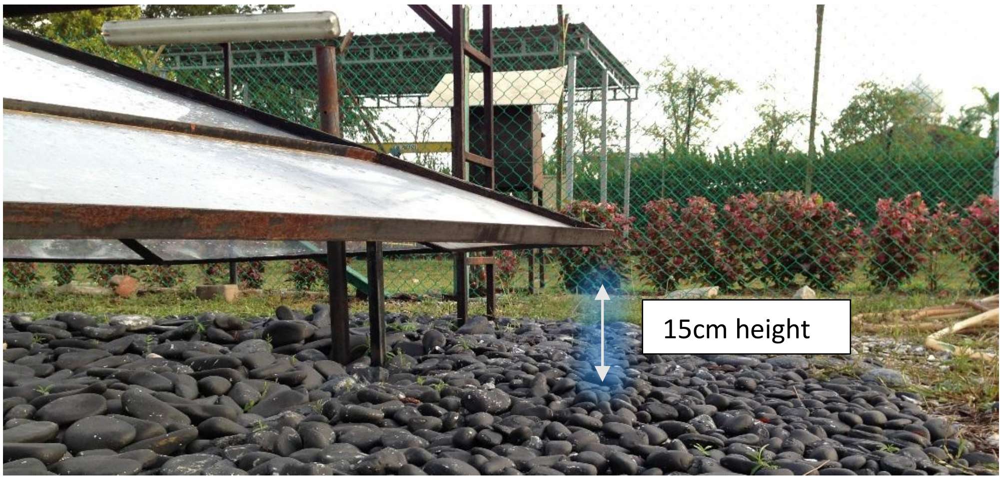

Figure 9: Variable Height 1

Time	$T_{ambient}$ (°C)	T_{funnel} (°C)	T_{canopy} (°C)	T_{ground} (°C)	V_{wind} (m/s)
8am	25.6	27.6	27.7	28.7	0
9am	27.2	28.2	28.3	29.5	0
10am	29.7	33.4	32.1	33.2	0.13
11am	30.2	37.5	37.4	41.6	0.16
12am	31.1	41	42.1	47.4	0.23
1pm	32.2	40.3	41	47.2	0.2
2pm	33.7	39.7	40.3	44.2	0.1
3pm	28.2	27.2	26.9	27.5	0
4pm	26.5	26.8	25.6	26.1	0
5pm	25.3	27.2	27	27.2	0

Table 4.1: Canopy Height of 15cm

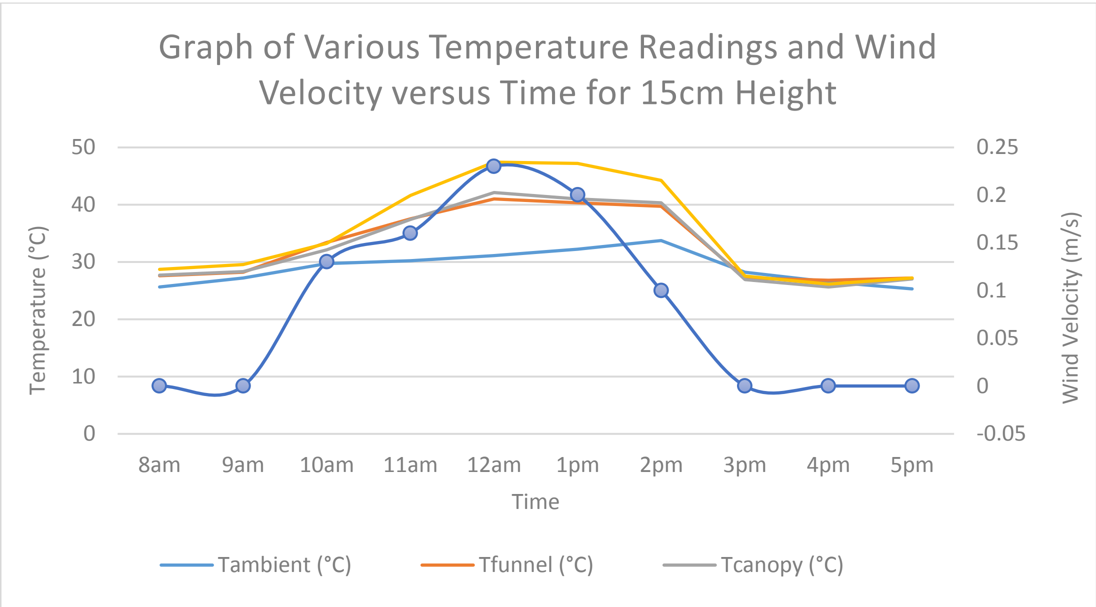

Figure 10: The Graph of Temperature Versus Wind Velocity Versus Time for 15cm Height

25cm Height Canopy

At 25cm height, the graph shows that the wind speed peaks at 12pm too. This is similar to the 15cm height results where the sun rays are at 0° from the solar chimney power plant and thus the total refractions that the canopy handles are much less than at other times. As the heat peaks up at 12pm, the wind speed is recorded the highest in that period of time, which shows that the heat transfer from the ground to the air is the highest at this point of time where the transfer of heat between the air and the ground are at the highest.

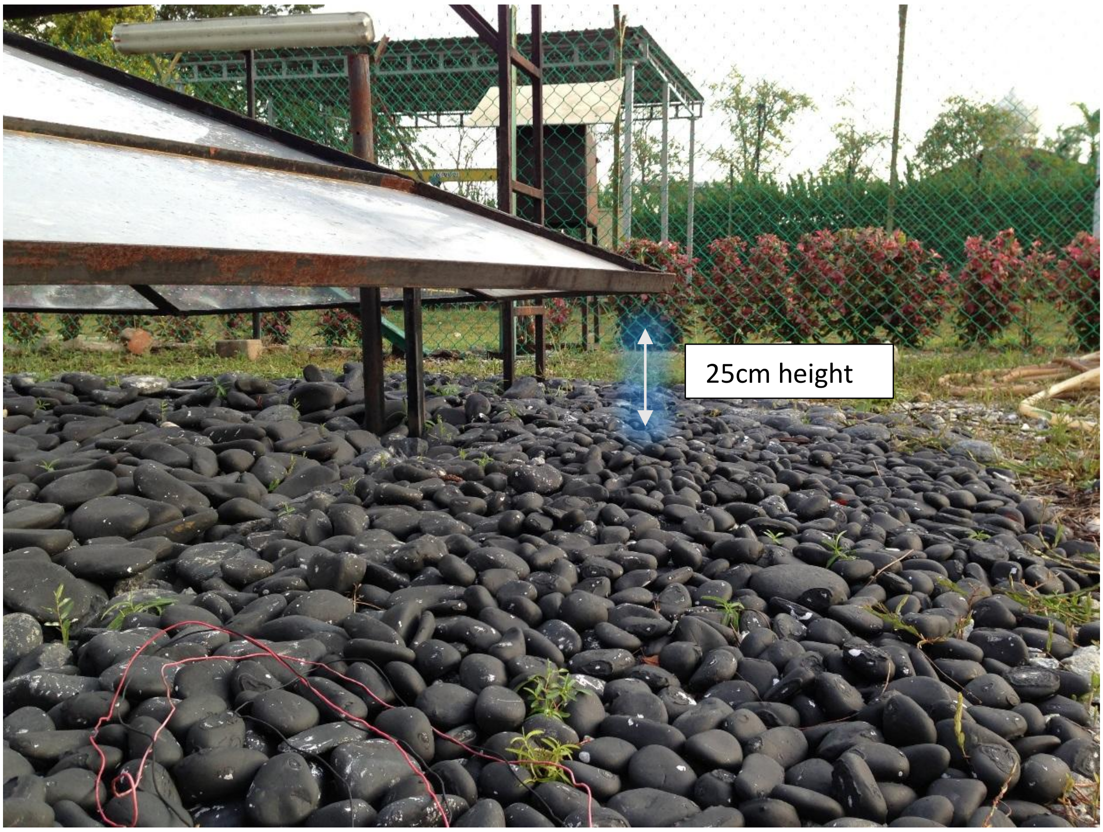

Figure 11: Variable Height 2

Time	$T_{ambient}$ (°C)	T_{funnel} (°C)	T_{canopy} (°C)	T_{ground} (°C)	V_{wind} (m/s)
8am	25.5	27.5	27.6	28.8	0
9am	27.3	28.1	28.3	29.2	0
10am	30	32	32.2	33.5	0.06
11am	31.2	37.2	38.1	41.4	0.16
12am	31.7	42	42.5	50.3	0.23
1pm	32.5	40.1	41	51.2	0.2
2pm	33.5	39.1	41.2	45.9	0.16
3pm	32.1	40.7	41.5	44.6	0.16
4pm	29.64	38.5	39	41.3	0.13
5pm	28.5	37.2	38.4	40.2	0.1

Table 4.2: Canopy Height of 25cm

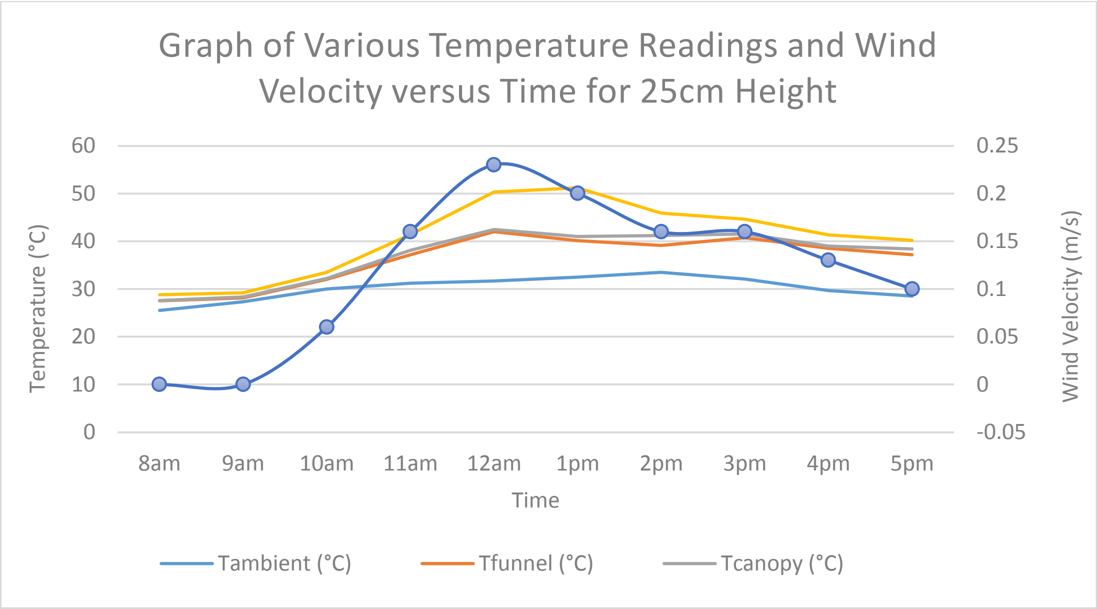

Figure 12: The Graph of Temperature Versus Wind Velocity Versus Time for 25cm Height

35cm Height Canopy

From the last variable, the height of 35cm is used. From the graph, we can see that the wind velocity is at higher range when the height is at 35cm from the ground. This shows that the wind moving in the funnel is at a higher value than the wind movement in 25cm height. Similar to the previous trend, we can see the highest wind movement are recorded at 12pm. The 35cm height records the highest wind movement compared to the 3 different variables. This can be accounted for the higher opening space that allows more air to enter rather than being restricted. However, the ambient wind also may play a part in the higher movement of wind in the 35cm height variable.

Figure 13: Variable Height 3

Time	$T_{ambient}$ (°C)	T_{funnel} (°C)	T_{canopy} (°C)	T_{ground} (°C)	V_{wind} (m/s)
8am	24.9	27.5	26.4	26.8	0
9am	27.4	27.4	28.2	28.9	0.06
10am	29.3	32.3	34.5	33.2	0.13
11am	31.1	34.6	38.6	45.2	0.23
12am	31.2	39.1	41.8	47	0.4
1pm	32.2	40.8	43.6	48.2	0.3
2pm	32.4	39.4	42.5	44	0.23
3pm	32.3	40.5	42.9	45.2	0.16
4pm	31.4	40.1	41.4	44.4	0.2
5pm	31.8	38	40.5	42.7	0.1

Table 4.3: Canopy Height of 35cm

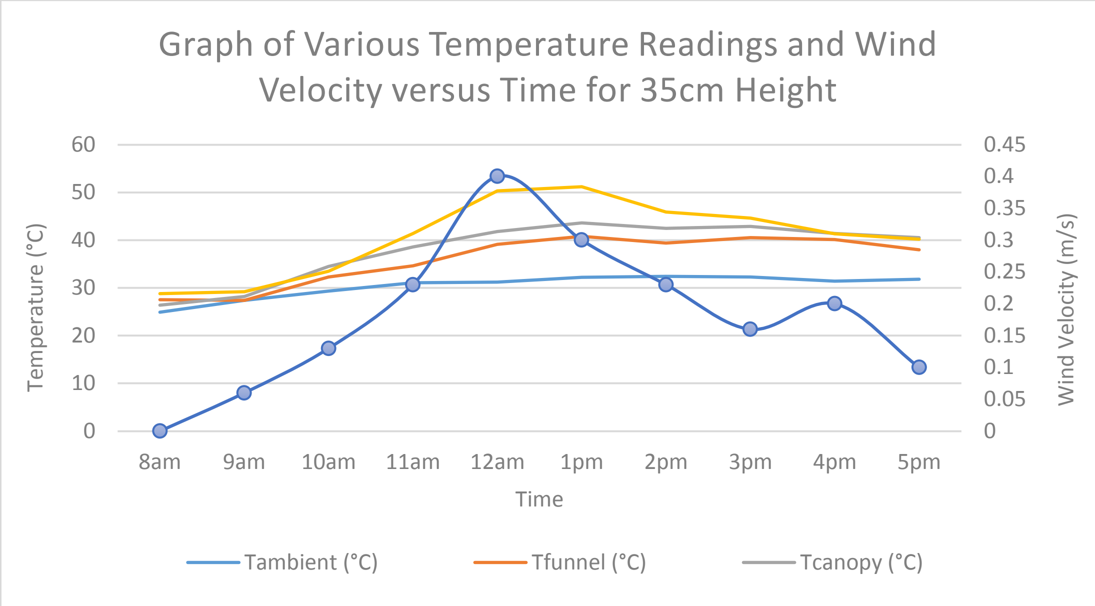

Figure 14: The Graph of Temperature Versus Wind Velocity Versus Time for 35cm Height

Comparisons of the Heights

From the results that are obtained from the 3 experiments, the results that are taken from each experiment are tabulated and a graph is formed from the results to show the different effects of the height on the wind speed in the funnel. From the graph, we can see that the 35cm height gives the highest speed in the wind funnel. However, this can be due to the high periphery inlet, the wind has no obstruction and thus the wind can flow much more easily due to the higher inlet, leading to a higher wind speed in the funnel. However, from the experiment, we can see that the effects of the height does affect the performance of the solar chimney power plant. Thus, from the height of 15cm till 35cm, the highest canopy shows that the power generation will be higher in that range. However, the experiment can still be improved upon due to the fact that when during the testing of the 15cm height, the days weren't optimized due to the arriving monsoon season to the west coast and thus impaired by the cloudy days in the evening.

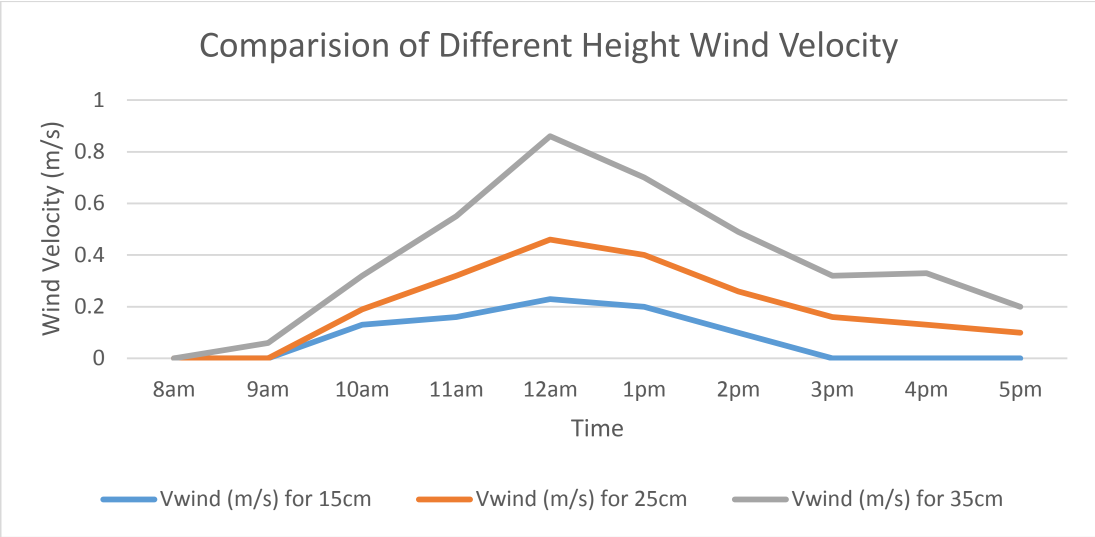

Figure 15: Graph of Comparison of Different Height Wind Velocity

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

In conclusion, it is proven that the between the height of 35cm to 15cm, the 35cm height gives a better power output compared to the other height canopy. The experiment shows that within the range of 15cm to 35cm, for the current scale model, the higher height will provide a better airflow to generate more power. The modified turbine helps also to decrease the cross flow of air in the solar chimney and increase the wind velocity.

5.2 Recommendations

It is a recommendation that a longer study is conducted in order to test the effectiveness of a higher range of height values and to prove the parabolic shape of the graph if a high enough range is tested. Another recommendation is to develop the experimental setup by employing a DC data logger. Flue gas is a component that can be used to increase the temperature in the canopy so that the temperature difference can be increased further.

Further recommendation is that a bigger diameter canopy can be employed to test whether the diameter affects the rate of power generation to what extent. Different paint using different materials can also be used to test which paint type gives a higher value of temperature difference.

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