NUMERICAL ANALYSIS FOR OPTIMIZING SOLAR UPDRAFT TOWER DESIGN USING COMPUTATIONAL FLUID DYNAMICS (CFD)

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To my beloved Wife, Children & Mother

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ABSTRACT

This master project thesis presents the history and background of the solar updraft tower which explains the working principle of the system and also describes the major components of the solar updraft tower. The system utilizes solar thermal technology by heating up the air below the solar collector through solar radiation, convection and greenhouse effect. The heated up air tends to travel to the bottom of the tower and rise up the chimney due to differential temperature. The upward velocity is used to turn a turbine installed at the bottom end of the tower either vertical or horizontal to generate power. This thesis studies the parametric of the geometry of the solar updraft tower by inclining the solar collector, studying the effects of an inclined chimney and also the effects of different solar radiation for 400 W/m^2, 600 W/m^2, 800 W/m^2 and 1000 W/m^2. A validated model is compared with the experimental prototype constructed by the University of Zanjan, Iran. The study is to maximize the power generation of the existing utilized land for optimum power generation by sloping the collector and updraft tower angle to evaluate the performance in terms on updraft tower velocity and estimated power generation improvement. The result shows a remarkable improvement in the power generated by just sloping the collector and without inclining the updraft tower. The findings and results are discussed and suggested for future works.

ABSTRAK

Laporan projek ini akan menerangkan sejarah dan latar belakang menara " Solar Updraft" tentang fungsi dan prinsip yang digunakan oleh sistem ini dan ia akan menerangkan fungsi komponen utama menara "Solar Updraft". Sistem ini menggunakan teknologi "Solar Thermal" iaitu haba yang dibekalkan oleh matahari akan memnanaskan udara dibawah sistem pengumpul solar melalui kaedah solar radiasi, perolakan dan kesan rumah hijau. Udara yang telah dipanaskan akan mengalir ke bawah menara dan ia akan memecut ke arah atas kerana terdapatnya perbezaan diantara suhu angin dengan suhu luar di hujung menara. Halaju "updraft" akan digunakan untuk memutarkan turbin yang dipasang di paras bawah menara sama ada menegak atau melintang untuk menjana kuasa elektrik. Tesis ini akan mengkaji parametrik atas geometry menara "Solar Updraft" dengan mencondongkan pengumpul solar, mengkaji perbezaan halaju dan suhu untuk menara yang condong dan juga kesan solar radiasi yang berbeza untuk 400 W/m^2, $600W/m^2$, 800 W/m^2 dan $1000W/m^2$. Model ini telah disahkan dengan prototaip experimen yang telah dibina oleh Universiti Zanjan, Iran. Kajian ini bertujuan untuk meningkatkan penjanaan kuasa untuk rizab tanah yang telah disediakan melalui pencondongan pengumpul solar, pencodongan menara "Solar Updraft" dan mengkaji pretasi dari segi halaju di tengah menara dan menganggarkan kuasa yang dapat dijana. Hasil kajian didapati memuaskan dari segi penjanaan kuasa dengan pengubahan sudut pencondongan pengumpul solar tanpa membuat sebarang pengubahsuaai terhadap menara "Solar Updraft". Maklumat yang didapati dan keputusan akan dibentangkan dan pengesyoran untuk kajian yang akan datang.

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LIST OF ABBREVIATIONS

CO_2	-	Carbon Dioxide
PV	-	Photovoltaic
CCGT	-	Combined Cycle Gas Turbine
OCGT	-	Open Cycle Gas Turbine
MW	-	Mega Watt
BIPV	-	Building-Integrated Photovoltaic
TNB	-	Tenaga National Berhad
SEDA	-	Sustainable Energy Development Authority
KeTTHA	-	Ministry of Energy, Green Technology and Water
FiT	-	Feed –in Tariff
kW	-	Kilowatt
kWh	-	Kilowatt-hour
GDP	-	Gross Domestic Product
ktoe	-	Kilo Ton of Oil Equivalent
GWh	-	Gigawatt-hour
MJ	-	Mega Joule
Sq.m	-	Square meters
RE	-	Renewable Energy
kWh/m^2	-	Kilowatt-hour per meter square
Km^2	-	Square Kilometers
K	-	Kelvin (Temperature)
m/s	-	Velocity
PCU	-	Power Conversion Unit
OPEX	-	Operation Expenditure
W	-	Watt

m^2	-	Square Meters
cm	-	centimeters
m	-	meters
DO	-	discrete ordinate
CFD	-	Computational fluid dynamics
3D	-	Three Dimensional
h	-	hours
MW/km^2	-	Megawatt per kilometer square
mm	-	Millimeters
W/m2	-	Solar Radiation
$W/m^2.K$	-	Convection heat transfer

LIST OF SYMBOLS

°C	-	Celsius
ρ	-	Density of air (kg/m3)
v	-	Velocity (m/s)
μ	-	Dynamic viscosity of air (kg/m.s)
D	-	Diameter of pipe (m)
N_{RE}	-	Reynolds Number
σ_k	-	Turbulent Prandtl number for k
$C_{1 \varepsilon}$	-	Constants in the Reynolds stress model
$C_{2\varepsilon}$	-	Constants in the Reynolds stress model
C_μ	-	Constants in the turbulence model
k	-	Turbulence kinetic
ε	-	Dissipation
T1	-	Inlet Temperature
$T_{ambient}$	-	Ambient Temperature
I_o	-	Solar Radiation ($W/^{m2}$)
α	-	Soil Absorption Coefficient
A	-	Turbine Swept Area (m^2)
η	-	Efficiency (%)

CHAPTER 1

1.0 INTRODUCTION

1.1 Background

During the pass few couples of decades, the solar power technology is categorized as a viable source of clean energy. There has been considerable advancement to the solar photovoltaic (PV) power generation system development throughout the years. Currently electricity power generation from fossil fuels such as oil or coal is damaging our environment. Nuclear power stations are an unacceptable risk in most locations [1].Therefore we need to diversify away from this non-renewable energy sources and look for alternatives. Many developing countries including Malaysia cannot fully rely on these conventional methods as we are aware on the damaging effect of the CO_2 emission and try to source for other types of green and renewable energy source. With a good amount of rainfall in our country, hydroelectric is one of our power generation source and we also have good amount of sunlight throughout the whole year where it is a good opportunity for solar harvesting. The need for a green and environmental friendly electricity power generation method is thus obvious and will further expand in near future.As to consider alternative energy source for contributing to the overall power demand of the country, this alternative energy must be sustainable and has minimum ecological impact as it will be costly to modify or upgrade the existing power distribution infrastructure that is being used today. The current existing capacity of power generation in Malaysia is shown in Table 1 1: Installed Capacity by Type.

Table 1-1: Installed Capacity by Type [2]

Type	Fuel	Capacity (MW)
Conventional Thermal	Coal	7,056
Combined Cycle Gas Turbine (CCGT)	Gas	9,200
Conventional Thermal	Gas	564
Open Cycle Gas Turbine (OCGT)	Gas	2340
Hydroelectric	Hydro	1,899
Total Capacity (MW)		21,060

Currently the overall power generation in Peninsular Malaysia is totally relying on coal and natural gas and they have been the mainstay of source of power generation for more than two decades and we foresee that they will continue to be the an important source for years to come unless a more reliable alternative and sustainable power source generation in large scale can be identified. The solar updraft tower is another alternative renewable energy source for areas that are rich in sunlight where it can be also considered as alternative to solar concentrating or solar PV cell (Solar PV farms) power generation facilities. There are several successfully implementations, such as several large towers being constructed in countries with well-developed energy infrastructures. This paper focuses on the potential of implementing a smaller scale solar updraft towers in remote area in Malaysia for power generation [2].The following graph indicates the type of power generation system which is currently adopted in Malaysia and the overall percentage of the various types in terms of total power generation which is shown below.Figure 1-1

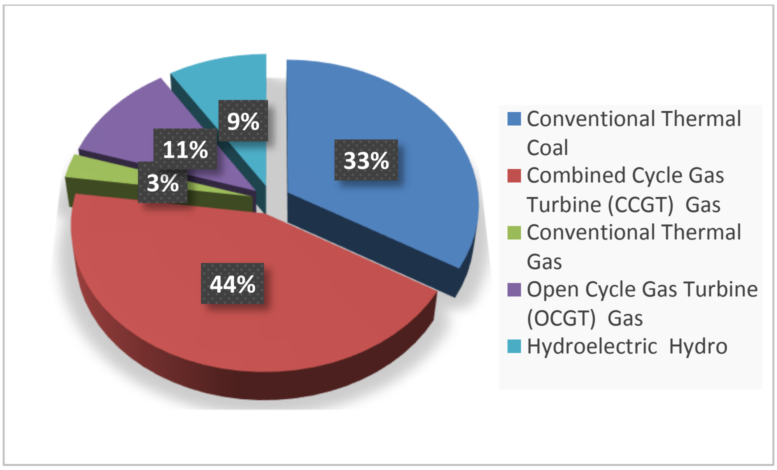

Figure 1-2: Percentage of Type of Power Generation in Malaysia [2]

The new power source must be capable to be fit into the existing power grid. One of the most promising renewable energy available is the Solar PV Power. The Solar PV Power definition is to harvest the sunlight from the sun and convert it to electricity at the atomic level. It is estimated that one hour of solar energy received by the earth is equal to the total amount of energy consumed by humans in one year [3]. Solar PV Power is a technology that allows the conversion of the radiation from the sunlight to be converted into electricity in a green and environmental friendly way. Similar to plants, they use chlorophyll to photosynthesize the sun's irradiation in order to provide energy for their growth. Only 14.4 per cent of sunshine survives filtering from the Earth's atmosphere and falls on the land where it can be harvested. This is however 2,800 times more than our energy needs [3].

In Malaysia, the most widely implemented solar power system is the Solar PV cells. These cells consist of transparent semiconductor based PV cells such as silicon used in the microelectronics industry which is known as solar cells. These cells are installed or sandwiched in between two layers to glass sheets. These specially treated cells form an electric field which consists of positive field on one side and negative field on the other side. When the sunlight successfully lands on the Solar PV Cell, the electrons are loose from the atoms forming an electrical circuit and are captured as form of an electric current. This current is called Electricity.

In 1839, the photoelectric effect was first noted by Edmund Bequerel, who found that certain types of materials would produce small amount of electric current when they were exposed to light. In his experiments, silver chloride was placed in an acidic solution and illuminated while connected to platinum electrodes, generating voltage and current. From his years of research, the photovoltaic effect has also been known as the "Becquerel Effect". In 1905, Albert Einstein described the photoelectric effect which he won a Nobel Prize in physics in 1921 for his discovery of the law of the photoelectric effect. His publication explains the experimental data obtained from the photoelectric effect as the result of light energy being carried in discrete quantized packets. This was later confirmed by Robert Millikan's experiment on Einstein's law on photoelectric effect in 1914 and received his Nobel Prize for his work on the elementary charge of electricity and on the photoelectric effect. The first PV module was built by Bell Laboratories in 1954 but was too expensive for widely implementation. It was until 1970s where the PV technology started to gain recognition and slowly implemented as an alternative solution for power generation.

In Malaysia, current trend is Building-Integrated Photovoltaic (BIPV). This has been successfully implemented for new development to promote green which is in line with our Ministry of Energy, Green Technology and Water. BIPV is where the PV panels are being used to replace the conventional building material such as roof, skylights or facades. For buildings which are planning to apply for Green Building Index, the item for BIPV does contribute to the marks during the certifications. Therefore they are increasingly being incorporated into the construction of new building as a source of electrical power where this can offset the actual electrical bill issued by Tenaga National Berhad (TNB). As part of the Government of Malaysia's initiative to promote Renewable Energy, Sustainable Energy Development Authority (SEDA) of Malaysia, which is a statutory body under the Ministry of Energy, Green Technology and Water (KeTTHA). SEDA is a dedicated and focused agency to serve as a one stop Renewable Energy (RE) center and introduced Feed –in Tariff (FiT), which is a mechanism to catalyze the generation of Renewable Energy. By diverting over to renewable energy, we can minimize millions of tons of carbon emission (CO_2) compared to conventional power generation system. FiT allows electricity produced from renewable energy resources to be sold to power utilities (TNB) at a fixed premium price for a specific duration.

There are several types of solar technologies used throughout the world for harvesting the solar power from the sun. In the last years, an exciting innovation has been introduced by researchers called Solar Chimney. It is a solar thermal driven electrical power generation plant which converts the solar thermal energy into electrical power in a complex heat transfer process [4]. The principle of this technology is rather simple: under a large glass roof the sun warms up the air (greenhouse effect) which is sucked in by the central vertical cylindrical tube (chimney effect). The updraft wind, thus created, drives turbines/generators and so generates electricity [1] . Sensible technology for the wide use of renewable energy must be simple and reliable, accessible to the technologically less developed countries that are sunny and often have limited raw materials resources. It should not need cooling water and it should be based on environmentally sound production from renewable or recyclable materials. The solar tower meets these conditions. Economic appraisals based on experience and knowledge gathered so far have shown that large scale solar towers ($\geq$ 100 MW) are capable of generating electricity at costs comparable to those of conventional power plants [5]. Therefore it is feasible to be further developed and implemented in countries which are sunny throughout the year for an alternative solution for power generation.

1.2 Historical Development of Solar Updraft Tower

Up till date, there are many researchers around the world who have introduced various projects of solar tower. Leonardo Da Vinci made a sketch of a solar tower called a smoke jack. Please refer to Figure 1-2 – The Spit of Leonardo Da Vinci (1452-1519). Later in the year of 1903, Isodoro Cabanyes, a Spanish engineer was the first to propose the idea of using a solar chimney to produce electricity. The following figure shows the concept of solar thermal powering a turbine during the olden days in a chimney system.

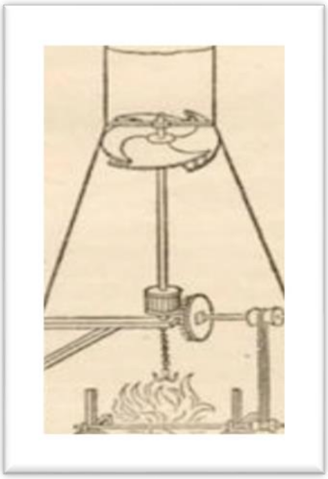

Figure 1-3: The spit of Leonardo da Vinci (1452-1519) (Library of Entertainment and Knowledge 1919)

The following figure illustrates the initial concept of solar engine project by Isodoro Cabanyes

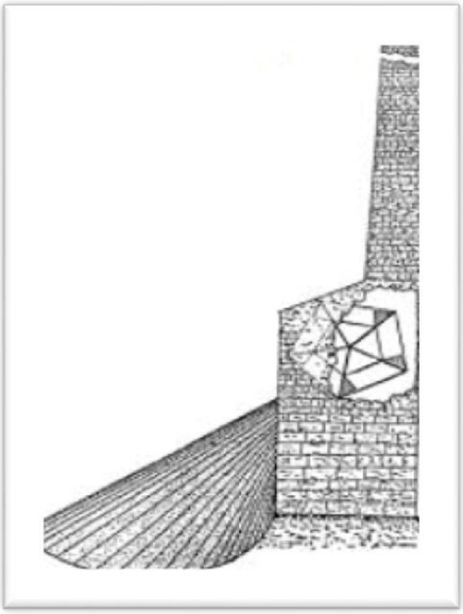

Figure 1-4: Solar engine project by Isodoro Cabanyes (Photo source from [4])

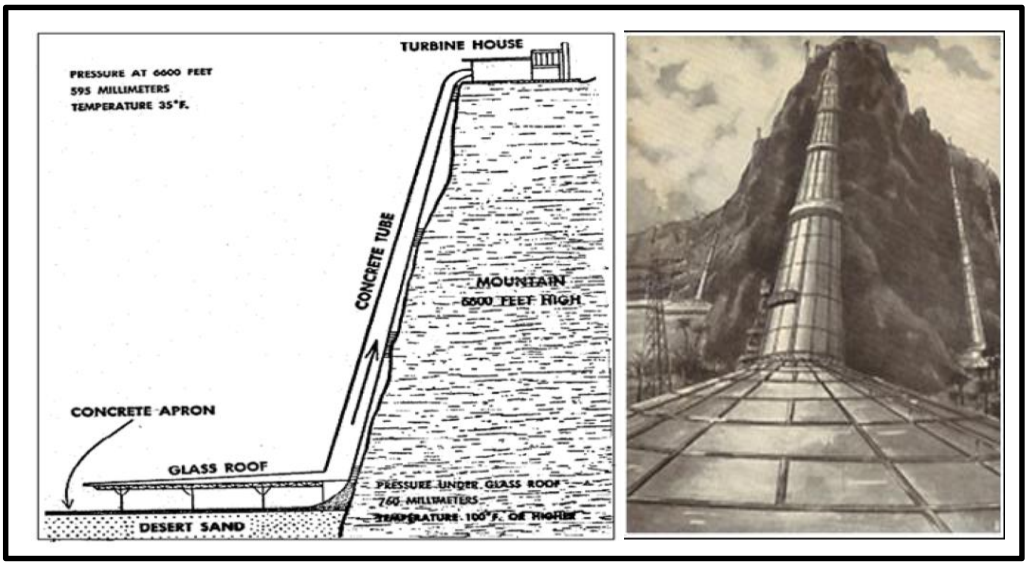

Figure 1-5: Principle of Professor Dubos's power plant

A German Science Writer Han Gunther proposed a design in 25th August 1903 issue of "La Energia Eléctrica", entitled ―Projecto de motor solar. In this bizarre contraption, a collector resembling a large skirt heats air, and carries it upwards towards a pentagonal fan inside a rectangular brick structure vaguely resembling a fireplace (without a fire). The heated air makes the fan spin and generate electricity, before it escapes up a 63.87 meter tall chimney, cools, and joins the atmosphere [6]. In 1926, Prof Engineer Bernard Dubos proposed to the French Academy of Sciences the construction of a Solar Aero-Electric Power Plant in North Africa with its solar chimney on the slope of the high height mountain after observing several sand whirls in the southern Sahara [7]. The following Figure 1-4: Principle of Professor Dubos's power plant shows the principle that was developed by Professor Dubos.

In 1956, Bernard Dubos filed his first patent in Algeria. It was artificially generate ancestry atmospheric vortex in a sort of round-shaped Laval nozzle and recovered some energy through turbines. The solar tower "Nazare" received a French patent for his invention in 1964 [7]. In 1975 the American Robert Lucier filed a patent request based upon a more complete design. This patent was granted in 1981 [7].

In 1982, Jörg Schlaich a German civil engineer and his team took the initiative to construct the first Spanish prototype in Manzanares Spain, with a 200.0 meters high and a maximum power output of 50 kW [8]. The result of the Spanish prototype was successfully put in operation demonstrated the feasibility and reliability of the solar updraft tower power generation technology. Since then, many researchers had shown strong interest and began to conduct extensive studies in experimental, analytical and also numerical on the potential of Solar Updraft Tower technology all over the world.

1.3 Solar Updraft Tower Principle

The Solar updraft Tower utilizes the concept of converting the solar radiation from the sun to electricity by using three types of working principle which consist of the Greenhouse effect, the rising tower and wind turbine generator.

During the sunny day, when the solar radiation falls upon the solar collector which is usually made out of large pieces of glass roof which is similar to glass skylight. Hot air is produced by the sun when the solar radiation lands on the glass roof [9]. Part of the sun light is reflected, absorbed and transmitted as not all of it can be utilized. The amount of solar that is absorbed depends on the optical characteristic of the glass such as transparency index, extinction coefficient and thickness of the glass. The transmitted solar radiation lands on the surface of the ground; a part of the energy is being absorbed while another part of it is being reflected back to the glass roof bottom surface, where it is reflected again back down to the ground. This effect of multiple reflection of radiation continues, resulting in a higher fraction of energy being absorbed into the ground. The heated up ground surface will heat up the adjacent air through natural convection and cause the temperature to increase and to rise up. The buoyant air rises up into the chimney of the solar updraft tower, thereby creates a drawing effect for air from the collector perimeter to enter into the collector region and thus initiating forced convection which heats the collector air more rapidly. Through mixed convection, the warm collector air heats the underside of the collector roof. Some of the energy absorbed by the ground surface is conducted to the cooler earth below, while radiation exchange also takes place between the warm ground surface and the cooler collector roof. In turn, via natural and forced convection, the collector roof transfers energy from its surface to the ambient air adjacent to it.

As the air flows from the collector perimeter towards the chimney its temperature increases while the velocity of the air stays approximately constant because of the increasing collector height. The heated air travels up the chimney, where it cools through the chimney walls. The chimney converts heat into kinetic energy. The pressure difference between the chimney base and ambient pressure at the outlet can be estimated from the density difference. This in turn depends upon the temperatures of the air at the inlet and at the top of the chimney. The pressure difference available to drive the turbine can be reduced by the friction loss in the chimney, the losses at the entrance and the exit kinetic energy loss [9]. As the collector air flows across the turbine, the kinetic energy of the air turns the turbine blades which in turn drive the generator [10]. The following figure shows the air flowing through the collector and solar updraft tower passing through the turbine power generator.

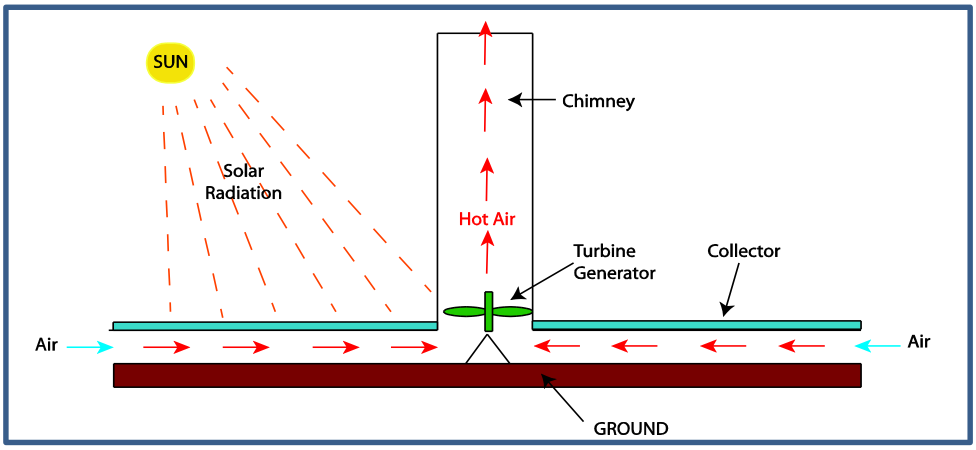

Figure 1-6: Schematic Diagram of Solar Updraft Tower [11]

1.4 Solar Collector

The Solar tower uses a greenhouse effect type of collector to heat up the air entering the collector and drives it up into the center portion where turbine generators are used for power generation. The collector surface gradually rises closer to the tower for directing the heated up air towards the center of the chimney. The collector will tend to curve up at the base of the tower in order for transition of the air flow to rise up the tower. The collector can be any glass or skylight roofing material which has the properties of high transparency to enable the solar spectrum to pass through but will lower transparency to the infrared radiation emitted from the warmed up ground surface [5].

A prototype was built at Manzanares where the collector of the plant is using a combination of glass and plastic materials. It is designed to explore the durability and also the effectiveness of variety of material for studying their different effects. The glass roofing panels were spaced on a 1.0 meter by 1.0 meter lattice and the plastic sections were arranged in a 6.0 meters by 6.0 meters sections. The geometrical shape of the collector is typical design of a solar tower with the outer edge of the solar collector with approximately 2.0 meters height from the ground [5].

The component that takes up the most footprint of the solar updraft tower power generation system is the collar collector. Therefore it is considered the major component of the whole system. The solar collector acts as a heat exchanger that converts the solar radiation energy to internal energy in the air that passes through between the bottom of the collector and the ground [12]. The solar collector utilizes the greenhouse effect. The collector is made out of transparent material such as glass or plastic film where the radiation is allowed to pass through but part of it will be reflected back. The collector allows short wave radiation to pass and prevents them from exiting, and insulation which resists back and rear side heat losses. This heats up the ground / soil under the collector where it acts as a thermal storage and transfers its heat to the air flowing horizontally in between the bottom of the collector and the ground surface [11]. The following figure illustrates the schematic heat flow diagram of the solar collector and ground surface when exposed to solar radiation.

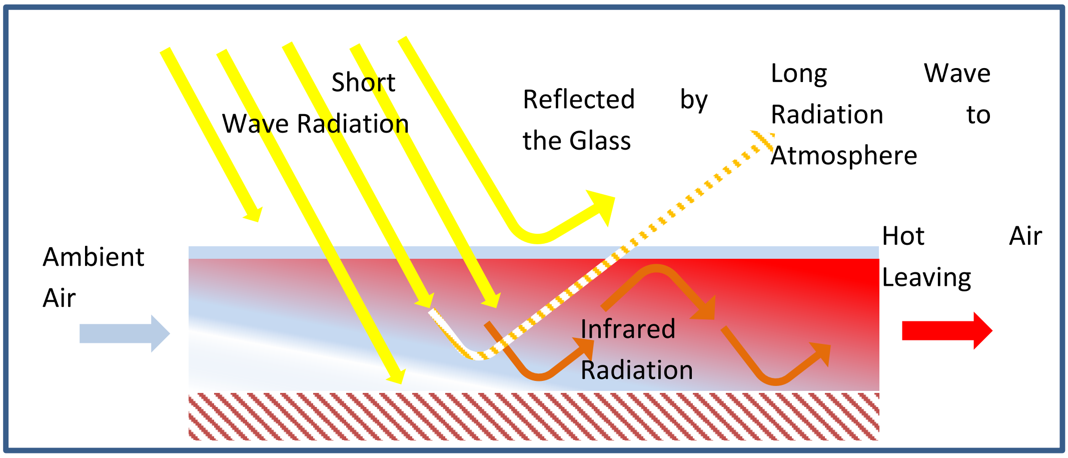

Figure 1-7: Solar Collector Schematic Diagram [11]

The solar collector may extend horizontally to the ground but is separated by a gap for the flow path of the air as shown in Figure 1-6: Solar Collector Schematic Diagram. This is the called the collector height which is usually two to six meters above the ground [4]. For conventional system, there is no slope for the collector and recent studies have shown that sloped collector has the following advantages:

a) Reduce the friction loss at the base of the updraft tower to enable the smooth transition from horizontal flow to vertical flow where the air will pass through the turbine. This can be done by increasing the height of the roof adjacent to the updraft tower base.
b) Sloped collector may increase the efficiency and also power generation comparing to similar footprint of a horizontal collector where smoother air flow and less eddy were observed [13]

The collector will have the capability to retain the short wave solar radiation and the long waves are reflected from the heated ground back to the atmosphere passing through the transparent collector. The collector allows short wave radiation to pass and prevents them from exiting, and insulation which resists back and rear side heat losses. This heats up the ground / soil under the collector where it acts as a thermal storage and transfer its heat to the air flowing horizontally in between the bottom of the collector and the ground surface [11].

The larger the coverage of the solar collector footprint hence the higher the power generation where this is always been a restriction as land use is very important and acquiring the land is difficult although the collectors have low construction costs and minimal effect in pressure drops. It is said that utilizing glazed glass collector is the most efficient as it converts approximately 70% of solar radiation into heat [11].

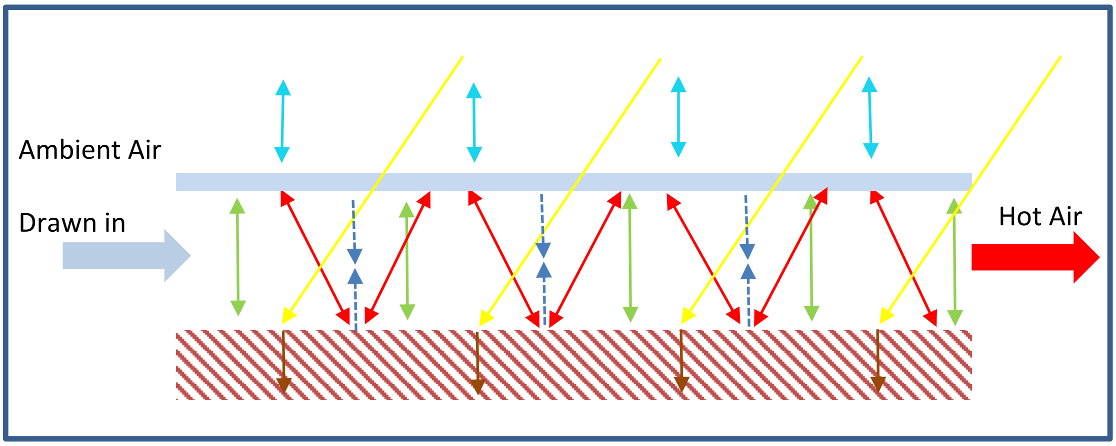

Figure 1-8: Thermal Balance of Solar Collector [11]

Natural Convection with Ambient Air

Solar Radiation

Forced Convection (Greenhouse Effect)

Radiative Exchange Bottom Of Collector and Ground Surface

Natural Convection

Heat absorbed into Ground

1.5 Solar Updraft Tower

The Solar Updraft Tower or Chimney is the key component in the solar updraft tower power plant. Referring to the previous figure 1-5: Schematic Diagram of Solar Updraft Tower, the chimney is located at the center point of the collector. The tower serves as a thermal engine where it consists of a pressure tub where the friction is low similarly to a hydroelectric pressure tube. A temperature differential is achieved within the tower here the cool air at the top of the chimney and the heated air at the bottom where the entrance from the collector. This creates the chimney effect, which sucks air from the bottom of the tower out of the top [4]. The up thrust of the air heated in the collector is approximately proportional to the air temperature rise in the collector and the volume of the chimney.

In simple terms, volume of the tower assuming it is cylindrical is calculated by diameter of chimney multiplies with the height of the chimney and the volume calculated is equal to the volume of the collector. Similarly the radius of the collector multiplies with the height of the collector from the ground; the volume can be worked out as well. In a large solar chimney the collector raises the temperature of the air by about 35 K. This produces an up draught velocity in the chimney of about 15 m/s. It is thus possible to enter into an operating solar chimney plant for maintenance without difficulty. [14]

1.6 Soil Thermal Storage

The soil beneath the solar collector behaves as a storage medium, and it can be heated up by the air for a significant time frame after the sunset until the temperature reach equilibrium with the ambient. The efficiency of the solar chimney power plant is below 2% and depends mainly on the height of the tower. Due to the wide coverage required by the solar collector, the solar updraft tower can only be built on cheap land where it is usually at the outskirt of the city. However the area under the solar collector can be used for agricultural purposes since it utilizes the greenhouse effect [15]. Hedderwick [16] and Pretorius [12] also studies the temperature distribution in to the ground below the solar collector where it is found that the ground plays an important role in the energy consumption. Various types of soil was compared including dry and wet soil. They found out that the solar updraft tower using wet soil and sand had the lowest and highest power output respectively and different materials led to varying power output during the daytime and night time [12].

One of the strange findings from Manzanares was that the solar updraft tower can produce power at night, but not at the same levels as during the day. This is caused by the soil beneath the collector releasing the heat stored in it during the day at night, while the night air cools. In a modern simulation done at Stellenbosch University, roughly a sixth of the maximum power generated at midday is shown to be generated throughout the night [6]. The following figure 1-8: Water Storage Tube Absorbs Heat during Day Time shows how the heat is being absorbed into the thermal storage when exposed to solar radiation.

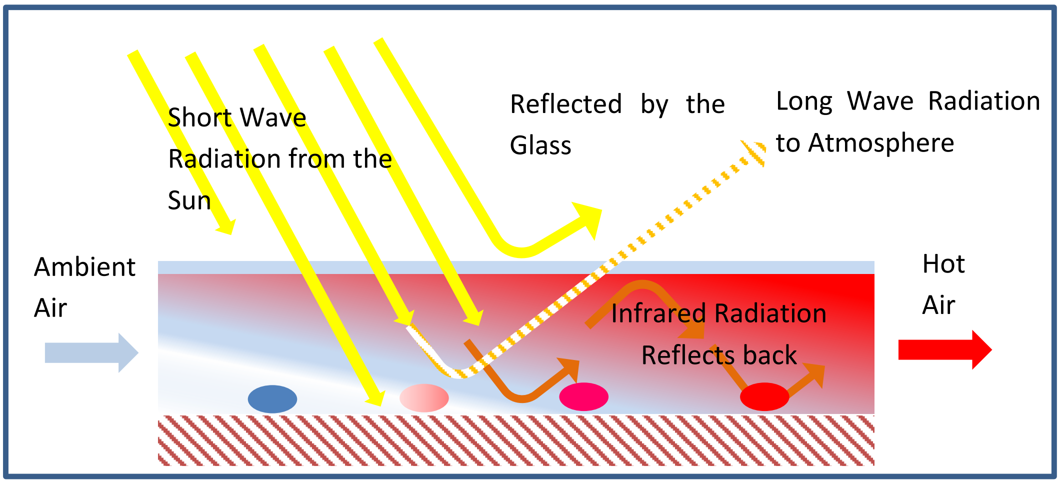

Figure 1-9: Water Storage Tube Absorbs Heat during Day Time

To improve the storage capacity to enable the plant to be run during the night, [5] it is proposed to place coils of black plastic filled with water tube under the solar collector Water is heated up during the day will be pumped into an insulated storage tank where it can be returned back to the coils during the night time allowing the plant to work at full capacity for 24 hours a day. The following Figure 1-9: Water Storage Tube during Night Time shows how the heat is released from the thermal storage during night time shows the stored heat being released back to the special area between the collector and the ground surface hence keeping the solar updraft tower in operation during low solar radiation.

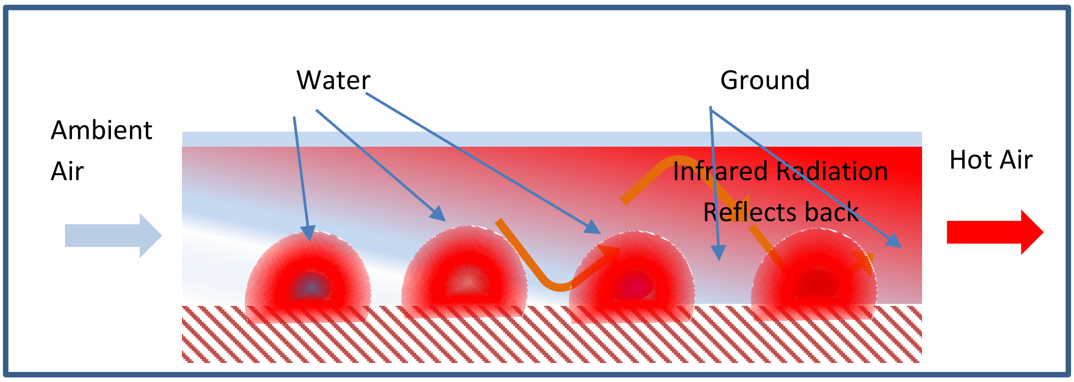

Figure 1-10: Water Storage Tube during Night Time

1.7 The Power Generation Turbine

The most important component for the solar updraft tower power plant is the power generation turbine. The function of the turbine is to convert the energy from the air flow and transmitting it to a generator for power generation. It has significant influence to the turbine pressure drop and transmits it to the generator. The specification of the wind turbine has many similarities to the large wind turbine but the principle of operation is slightly different. The pressure turbine relies on differential pressure which results on the shrouded blades to move and then the conversion of kinetic energy to power. Whereas for the large turbines, there are free movement blades which will spin when the wind flows through the blades. There are no housing or containment to channel the air flowing past the turbine blades. Various turbine layouts and configurations have been successfully installed for the application of the solar updraft tower power conversion unit (PCU). A single vertical axis turbine without inlet guide vanes was used in the pilot plant in Manzanares. There are some setups with multiple vertical axis turbines being proposed as well [8], and an efficiency model at design performance for counter-rotating turbines being developed and validated. Based on the efficiency equations, an off-design performance model for counter-rotating turbines is developed by Denantes [17]. Many other researches were conducted to evaluate the pressure drop across the turbine as a part of the total available pressure difference in the system such as [8] [18] to [19].

1.8 Advantages and Limitation of Solar Updraft Tower Power Plant

The solar chimney power plant has the following advantages over similar in nature types of power plant using solar as the source of energy input.

- The solar radiation lands on the solar collector utilizing beams or diffused solar radiation which the efficiency may slightly drop during the cloudy condition but can still generated power.
- The material of construction is considered low and generally it is readily available. The plant does not require any sophisticated type of material or engineered material. The major component consists of glass for the solar collector and concrete for the construction of the tower.
- Beneath the solar collector is the ground where it can be utilized as a source for thermal storage where the power plant can be operated during the night time although the power generated is much more lesser but this can be improved though secondary thermal storage to cover for the losses during the night time.
- Operation friendly as the plant does not operate using sophisticated control technology except for the turbine generator for power generation.
- The plant does not require any external fuel / power consumption as it can be self-sustainable and most important there are no emissions to contaminate the surrounding environment.
- There are no sophisticated mechanical components as the only maintenance of the plant is the cleanliness of the solar collector and also the maintenance of the turbine generator. Therefore the operation expenditure (OPEX) of the plant is much lower compared to others.

1.9 Problem Statement

The announcement of tariff increase of 4.99 sen/kWh starting from 1st January 2014 has received mixed reaction from the general public. In terms of GDP, the projected growth of around 5% - 5.5% is expected for 2014 compared to forecast electricity peak demand of 3.6% and sales of 3.9% as decoupling of GDP and electricity growths continue.

While most of key energy indicators pointed to a reasonably steady level, electricity consumption per capita increased from 1,101kWh per person in 1990 to 3,902kWh per person in 2012 with compounded growth of 5.9% over the period of 22 years. As the nation is becoming more electrified as a result of economic growth, higher income and technological innovations, demand for energy increased to almost 4 times since 1990. Going by recent trends, the energy demand is still growing and therefore requires timely supply infrastructure upgrades [2].

Table 1-2: Historical data for energy intensity, demand and elasticity [2]

Peninsular Malaysia	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
GDP at 2005 prices (RM million)	453,451	479,450	509,486	534,981	524,726	567,605	597,866	635,163
Population ('000 people)	21,075	21,370	21,662	21,951	22,241	22,656	23,132	23,429
Final Energy Demand (ktoe)	32,195	34,390	37,921	38,530	34,521	35,593	35,968	36,683
Electricity Consumption (ktoe)	6,366	6,669	7,030	7,307	7,567	8,145	8,427	8,791
Electricity Consumption (GWh)	73,987	77,504	81,710	84,924	87,950	94,666	97,939	102,174
PER CAPITA								
GDP at 2005 prices (RM million)	21,516	22,436	23,520	24,371	23,593	25,053	25,846	27,110
Final Energy Consumption (toe)	2	2	2	2	2	2	2	2
Electricity Consumption (kWh)	-	3,627	3,772	3,869	3,955	4,178	4,234	4,361
ENERGY INTENSITY								
Final Energy Consumption (toe/GDP at 2005 prices (RM million))	71	71.7	74.4	72	65.8	62.7	60.2	57.8
Electricity Consumption (toe/GDP at 2005 prices (RM million))	14	14	14	13.7	14.4	14.4	14.1	13.8
Electricity Consumption (GWh/GDP at 2005 prices (RM million))	0.163	0.162	0.16	0.159	0.168	0.167	0.164	0.161

Currently the overall power generation in Peninsular Malaysia is totally relying on coal and natural gas and they have been the mainstay of source of power generation for more than two decades and we foresee that they will continue to be the important source for years to come unless a more reliable alternative and sustainable power source generation in large scale can be identified. As we may aware that conventional thermal using natural gas and coal are less environmental friendly and the CO_2 Emission levels is way increasing throughout the years and we need to look for ways to diversity.

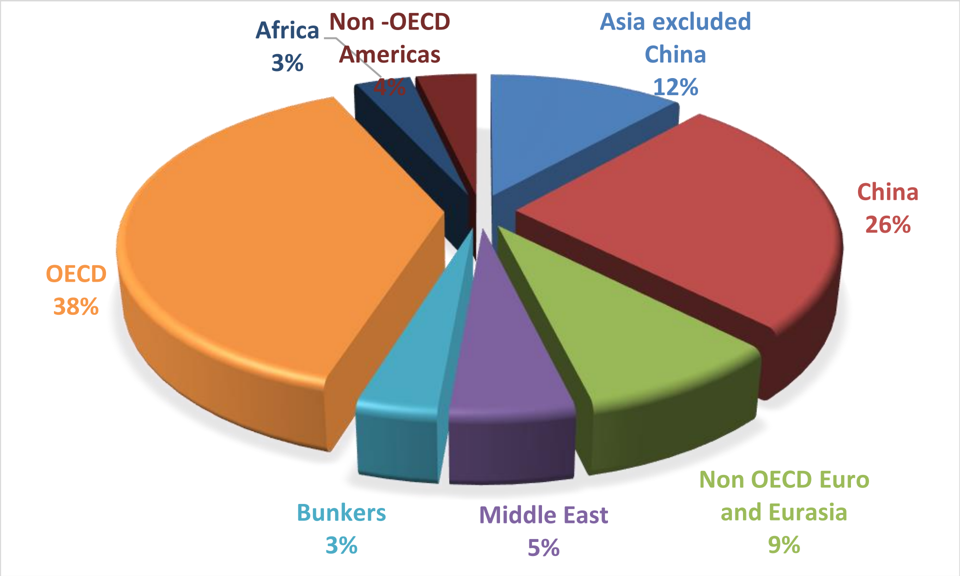

Figure 1-11: CO_2 Emission Level in 1973 (Est. 15,633 Metric Ton) [2]

Based on the figure 1-10: CO_2 Emission Level in 1973 (Est. 15,633 Metric Ton), the estimated CO_2 emission had increased from 15,633 Metric Ton (1973) to 31,734 (2014) which had doubled up within the 41 years and we are still trying to reduce it [20]. It is estimated that approximately there was a linear increase of 413 metric ton of CO_2 emission per year. Based on the energy indicator, Malaysia contributes of 195.89 metric ton of CO^2 Emission, where it is approximately of 5.32% of the total CO_2 Emission from Asia Region. Approximately 6.2 metric ton of CO_2 emission per Malaysian when compared to the statistical data obtained indicated approximately 7.2 metric ton of CO_2 emission per Malaysian. During the United Nations Climate Change Conference 2009, Malaysia announced that they will be adopting an indicator of a voluntary reduction of up to 40 per cent in terms of emissions intensity of GDP (gross domestic product) by the year 2020 compared to 2005 levels

[21]. Therefore we still need to reduce 39.5% before year 2020. The following table shows the overall combination of power generation mix for Malaysia till 2014.

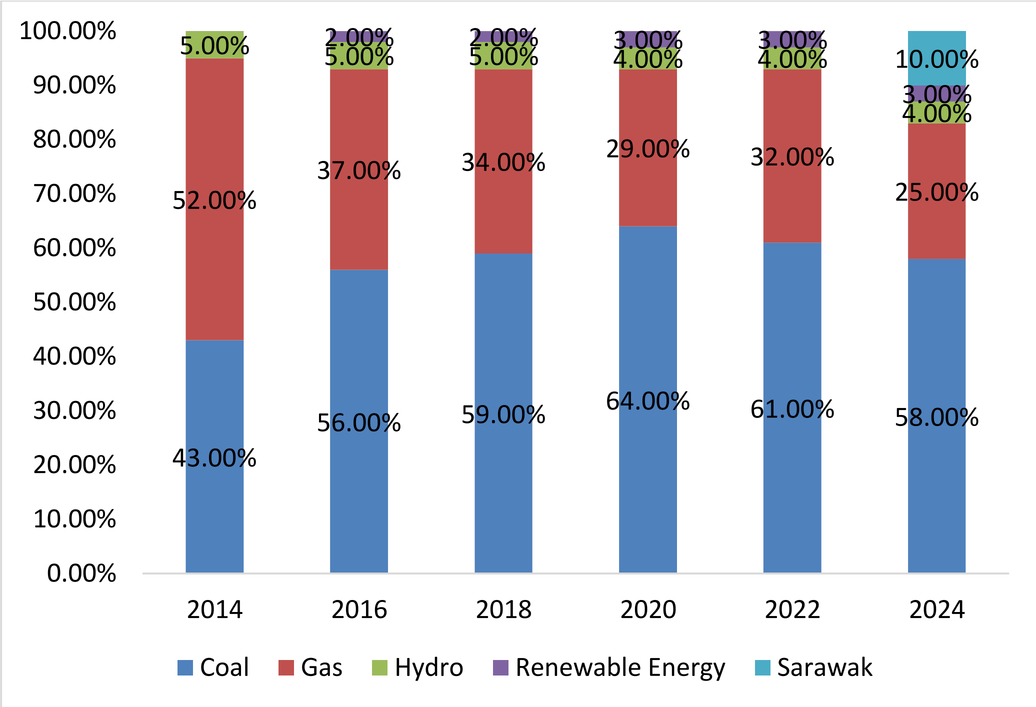

Figure 1-12 Overall Combination of Power Generation mix [2]

Referring to the generation mix for Peninsular Malaysia based on the approved Generation Development Plan, the following figure illustrate the average daily solar radiation zones which is as following:

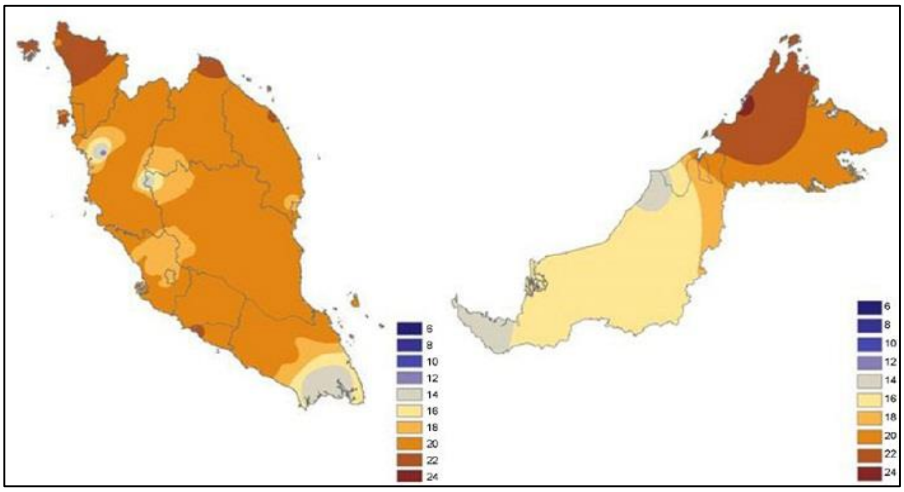

Figure 1-13: Average daily solar radiation (MJ per sq. m) across Malaysia [22]

Up till date, our Renewable Energy share in overall fuel mix is projected to gradually increase up to 3% of total energy generated in 2020. The source of energy relying on Coal and Natural gas is still approximately 93%. However, Renewable Energy is anticipated to play complementary role to fossil fuels due to factors such as output intermittency, location, technology development and potential limitation [2].

The formation of SEDA in the year of 2011 and introduction of the feed-in tariff (FiT) to Malaysia began as early as 2004, and in 2011, the years of effort finally culminated in the passing of the two laws related to sustainable energy. The result is the dawn of a new era for Malaysia in a move towards achieving energy autonomy and mitigating climate change [23]. By 2020, RE is projected to contribute to 3.0% of overall generation mix from the estimated RE installed capacity of 700MW [2].

Malaysia has been a tropical country that received with abundant of sunshine throughout the year with an average of 12 hours of sunshine daily, the average solar energy received is between 1400 and 1900 kWh/m^2 annually with the highest solar radiation estimated at 6.8 kWh/m^2 in August and November [24]. The PV market grew significantly in 2013 at 48.28 MW, up from 22.5 MW in 2012. The total installed capacity in Malaysia now tops 73.3 MW. The residential sector now represents 15.5 MW compared to 57.8 MW for commercial installations. The average irradiation in Malaysia is approximately 1,200 KwH/kW [25].

The Solar Updraft Tower is another alternative renewable energy source for areas that are rich in sunlight where it can be also considered as alternative to solar concentrating or solar PV cell (Solar PV farms) power generation facilities. There are several successfully implemented large towers being constructed in countries with well-developed energy infrastructures. This thesis focuses on the potential of implementing a smaller scale solar updraft towers in remote areas in Malaysia for power generation. This thesis will be describing the principle of Solar Updraft Tower, technological challenges, performance optimizing with a focus on their application to small-scale plants in Malaysia via simulation. Parametric study will be conducted to optimize the performance by maximization of power generation based on the allocated foot print.

1.10 Project Objective

As compared to other types of Renewable Energy Power Plants, the Solar Updraft Tower has the most easiest setup. As described earlier, there are not many complex components where maintenance is only on the turbine generator and the upkeep of the cleanliness of the transparent solar collectors where it may be a problem for tropical country like Malaysia as frequent rainfall may cause higher maintenance for the solar collector. Overall the intial cost of construction is less expensive compared to other power plants. Although the construction of the Solar updraft Tower is cheap and easy for maintenance, we still need to look into the geometry of the solar updraft tower and the collector coverage.

Based on the literature review conducted, we notice that there is a certain amount of requirement for the collector radius inorder to collect sufficient radiation from the sun to enable the minimum air flow veloicty for power generation. As we are aware, land is very valuable and with the increasing population, there may be less land for catering future housing, agricultural and industrial requirements for future development. Therefore a suitable position needs to be identified as the solar collector may take up quite a number of square kilometers (km^2) of land surface in order to produce the power when compared to the other types of solar energy system.

Secondly we must determine location of the installation of the solar updraft tower as it must receive sufficient solar radiation throughout the year where Malaysia should not have a problem to it as we have already been implementing solar PV farms which is one of the Renewable Energy Source.

From the literature review, we also observed that the overall efficiency of the solar updraft tower is lower than the solar photovoltaic system. Therefore we will try to adjust the geometry of the solar updraft tower and look for alternative source of collector to further increase the efficiency of the overall system.

Therefore as explained in the problem statement and to promote new solar renewable energy for reducing the conventional type of power generation, it has motivated us to look for alternative technologies and try to improve existing current system of the solar updraft tower. The project objective is stated as follows. The above limitations and the energy crisis motivate us to

a) Study and derive a numerical model for validation of previous works
b) Conduct a study on the effects of inclination of the angle of the solar collector
c) Conduct a study on the effects of inclination of the angle of the updraft tower with a fixed outlet diameter
d) Conduct a study on the effects of inclination of the angle of the updraft tower with a fixed tower entrance
e) Conduct a study on the effects of solar radiation toward the velocity profile at the center of the chimney.

1.11 Summary of the Thesis

The contents of this master thesis can be summarized into the following chapters where it has been divided into five (5) main chapters which are listed as following:-

Chapter 1: The background and historical development of the solar updraft tower is being introduced. The functionality of individual components of the solar updraft tower is being described. The advantages and limitation of the current system were studied and identifying the problem statement hence deriving the project objective for this thesis.

Chapter 2: The literature review was conducted when analyzing the previous works by researchers in experimental analysis and the suitable experimental prototype for this study. Then the numerical analysis is reviewed to identify the method and findings of previous researches. Based on the literature review information, a summary on the challenges and limitations was compiled and to review the project objective for improvement.

Chapter 3: The theory and governing equations that were used for the modelling. When identifying the material properties, type of turbulent model and solar model including identification of the parameters for initiating the modelling process, the geometry of the existing experimental prototype was used. Next a description on the parametric study was used for studying the effects to the conventional system. The study will adjust the inclination of the collector for determining the best slope angle and follow by inclination of the tower. Method of calculating the power generation of the solar updraft tower was shown and it will be used for calculating the power generation.

Chapter 4: A grid independence study was conducted to identify the best mesh configuration for this modelling work and the results from the experimental prototype and simulations were compared to each other, which is actually the model validation study. Next, the parametric study for the inclination of the collector and tower will be simulated and these results are also shown here. Finally, this chapter will end up with discussions on the results of models in terms of temperature distribution and velocity profile at several locations of the updraft tower followed by conclusions.

Chapter 5: Finally a summary of the findings and conclusion on the overall findings of simulation results is discussed and relating it with the project objective. The improvement in terms of velocity profile and power generation is also discussed. This chapter will end up with some recommendations for further study.

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