Modeling and fabrication of solar updraft tower and estimation of power generation with respect to Bangladesh

A THESIS SUBMITTED TO THE DEPARTMENT OF "MECHANICAL ENGINEERING" IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF BACHELOR OF SCIENCE IN MECHANICAL ENGINEERING

Submitted By

Fayrouz Ayub	**Student No. 201318013**
Arafat Sultan Khan	**Student No. 201318032**
Saarah Akhand	**Student No. 201318061**

Supervised By

Lt Col Golam Saklayen

Associate professor, Faculty of Mechanical Engineering, MIST

DEPARTMENT OF MECHANICAL ENGINEERING
MILITARY INSTITUTE OF SCIENCE AND TECHNOLOGY
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STUDENT DECLARATION

This is to certify that the thesis entitled ,**“Modeling and fabrication of solar updraft tower and estimation of power generation with respect to Bangladesh”** is an outcome of the investigation carried out by the author under the supervision of **Lt Col Golam Saklayen,** Faculty of Mechanical Engineering, MIST. This thesis or any part of it has not been submitted to elsewhere for the award of any other degree or diploma or other similar title or prize.

SUBMITTED BY

Fayrouz Ayub
Student no: 201318013

Arafat Sultan Khan
Student no: 201318032

Saarah Akhand
Student no: 201318061

SUPERVISOR CERTIFICATION

This is to certify that Fayrouz Ayub, Student no : 201318013; Arafat Sultan Khan, Student no: 201318032; Saarah Akhand, Student no: 201318061have completed their undergraduate thesis report on **“Modeling and fabrication of solar updraft tower and estimation of power generation with respect to Bangladesh”** under my supervision. To the best of my knowledge, the report is their original work and was not submitted elsewhere for other purpose.

I wish their ever success in life.

APPROVED BY

Lt Col Golam Saklayen
Associate professor
Dept of Mechanical Engineering
Millitary Institute of Science and Technology(MIST)

Abstract:

In our studies we focused on area of sourcing, converting and delivering sustainable energy. Concentrating at the potential role of solar power. Power generation through a solar updraft tower (SUT) has been a promising novel approach for sustainable generation of renewable energy. Developing nations are faced with the challenge of industrialization, population increase and urbanization. These changes have stressed energy supply generated from conventional fossil fuel. Conventional sources are insufficient to meet the increasing demand of a developing, industrious nation (e.g. Bangladesh). A solution to adequately generate sustainable amount of energy from a renewable source is quintessential. This solution will support the rapidly increasing population and economic development. Our project plays important role in reducing electricity crisis and forming an essential part of the solution. The electricity generated can be supplied to the national grid and available to the population. This will mean reduced cost for the government in the long run and also will allow the government to reduce its dependency on costly and unsustainable fossil fuel. This cost reduction benefit can be passed on to the public as reduced energy cost or preferably through nationwide energy infrastructure development.This technology will not only help with the energy concern of Bangladesh but also will help to improve the situations of other developing countries alike Bangladesh. All in all this technology will be able to contribute towards a better world and form a part of an integrated ecosystem of sustainable energy technology

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CHAPTER 01: INTRODUCTION

1.1 Objective:

Our main objective is to implement practically the concept of generating power by using updraft force of air and solar energy as heating element.And by accomplishing so our aim is to provide this idea of producing electricity for different rural regions of our country,as our country is facing various kinds of energy crisis.Many projects on renewable and sustainable energy are on going process in our country.Government is now highly concerned about the present situation and is taking different necessary steps to reduce this energy crisis issue into some extent.As a well wisher of our motherland we are quite enthusiastic to take some steps,use some ideas and make some projects that will help our country to overcome such crisis,and as we stated earlier we chose the field of using solar energy as power generation source and we also chose SUT as our project to work on and create a model keeping in mind the geographical and weather base factors.

1.2 History:

Solar updraft tower power plant (SUTPP, also called solar chimney power plant, Fig. 1) is a kind of device that produces buoyancy to drive air to ascend for electricity generation (Schlaich, 1995). The concept to fusing a small SUT device for furnishing power first appeared in Bennett(1896)'s patent, and a household SUT device for generating electricity was proposed in a magazine by Cabanyes (1903).In 1926, Dubos proposed the construction of an SUTPP in North Africa with its tower on the slope of a high mountain(Ley, 1954). The SUTPP concept was later described in apublication by Gu¨nther (1931). Lucier (1978, 1979a,1979b, 1981) had a more complete design of an SUTPP,and his patents on SUTPP were granted in Canada ,Australia, Israel, and the USA, respectively.Schlaich together with his colleagues built the first pilot SUTPP prototype in Manzanares, Spain in 1982 (Haafet al., 1983; Haaf, 1984). The pilot prototype had anSUT 194.6 m high and a collector 122 m in radius. The prototype operated with a peak power of about 50 kW for seven years from 1983 to 1989 (Schlaich, 1995). The successful operation of the prototype demonstrated the feasibility and reliability of the SUTPP technology. Since then, many researchers have shown strong interest in it and extensively studied the potential of SUTPP technology all over the world (Zhou et al., 2010b). In order to generate electricity economically, a large-area collector and a high SUT are needed for an SUTPP. Some commercial SUTPP projects have since been proposed in several countries(Table 1). However, until now, this technology has not yet been commercialized.

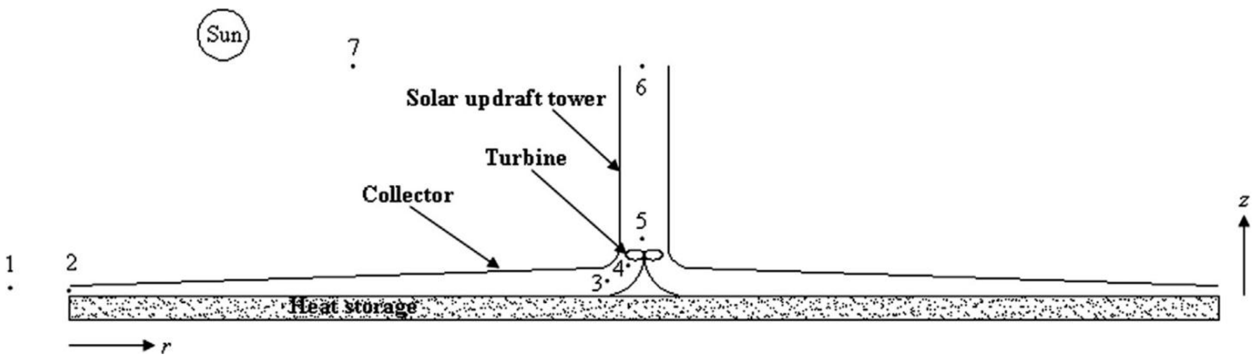


Figure 1: Schematic of a conventional solar updraft tower power plant

(1: surroundings on ground level, 2: collector inlet, 3: collector outlet, 4: turbine inlet, 5: turbine outlet, 6: SUT outlet, 7: atmosphere at the height of SUT outlet).

Table 1

Several selected commercial SUTPP proposals.

Power capacity (MW)	SUT height (km)	Collector area (km$_2$)	Location	References
200[a]	1	38.5	Mildura/Austrailia	Zhou et al. (2010b) and Wikipedia (2014
40[b]	0.75	3.5	Spain	Zhou et al. (2010b) and Wikipedia (2014
400[c]	1.5	37	Namibia	Zhou et al. (2010b) and Wikipedia (2014
-	1	-	China	Zhou et al. (2010b)
27.5[d]	-	2.77	China	Wikipedia (2014
-[e]	1	-	New-zealand/Austrailia	Evans (2011)
200[f]	About 0.8	Over 12.7	Arizona/USA	Spencer (2013)

a Proposed in 2001.
b Planned to be completed by 2010.
c Proposed in 2008.

d It consists of three phases covering a total area of 277 hectares and its total power capacity is expected to reach 27.5 MW. The first phase to build the

Wuhai pilot prototype was completed in 2010, and the final phase was planned to be completed by 2013.eIn 2011, Hyperion Energy planned to build the SUTPP to supply power to Mid-West mining projects.

f It was reported in June 2013 that EnviroMission was progressing through the permitting process and planned to start construction of the project in late 2014

1.3 Motivation:

Bangladesh has very limited nonrenewable energy resources of its own. She is facing energy crisis and serious desertification problem in rural areas. These issues could be removed if renewable energy is used as a primary source of energy in rural areas. It is essential for scientists and researchers to find out the renewable energy resources and effective technologies .Solar energy is one of the greatest means of renewable energy in Bangladesh. Electricity can be obtained from solar energy by two means,the photovoltaic effect and the solar thermal cycle.In our country PV based solar power harnessing method has become quite common and one of the successful projects.We on the other hand,are focusing on solar updraft cycle based power plants or SUTPP (Solar updraft tower power plant).The SUT is one of the thermal plants which produce electricity with very low temperature difference,and the technology for such power plants are way too simple.We are interested in introducing such technology to the rural areas of Bangladesh and help with the energy crisis issues that our country has been dealing with.

1.4 Description:

A conventional SUTPP (Fig. 1) consists of a circular solar collector constructed on horizontal ground, a vertical solid SUT situated at the center of the collector, and turbine generators installed at the collector outlet or at the SUT inlet (Schlaich, 1995). In the solar collector, solar

radiation passes through the transparent roof and is received by the absorber, i.e., the ground or an additional absorber laid on the ground, and thus the indoor air is heated. Some heat is stored in the absorber when solar radiation is strong during day time on sunny days. Theheat is released from the absorber when solar radiation is weak during night time or on cloudy days. The density difference between the warm air inside the SUTand the ambient air creates buoyancy that acts as the driving force and isalso called pressure potential. The buoyancy drives the air to flow in the collector toward the SUT base and rise in theSUT. Finally, the air current drives the turbines power ingenerators to generate electricity. A solar collector consists of support columns, a framework matrix, and a transparent roof made of glass, plasticor other transparent materials. An air collector is formed when the transparent roof is suspended from the framework matrix supported above the ground by the support columns. The roof of a typical collector slowly ascends from the collector periphery to its center to guide indoor airflow with low friction losses.Natural ground has a certain heat storage capacity, butits heat storage capacity cannot always meet the need of SUTPP operation during night time or on cloudy days. Therefore, additional heat storage systems have been proposed to help store solar energy. Since water with large specific heat capacity is a kind of cheap and effective heat storage medium, a water-filled system placed on the ground under the collector roof has been regarded as a typical additional heat storage system (Kreetz, 1997; Schlaichet al., 2005). The water-filled system is closed and airtight to avoid heat loss by evaporation.The SUT situated at the center of the collector is the thermal engine of the SUTPP. The best choice for high SUT structure has been considered by civil engineers(Schlaich, 1995; Kra¨tzig et al., 2009) to be reinforced concrete shell structure due to its long life span and favorable cost amongst many possible structural designs, although aguyed corrugated metal sheet flue was designed by Schlaichand his colleagues for the Manzanares prototype just for experimental purposes. Civil engineers (Schlaich, 1999;Kra¨tzig et al., 2009; Harte et al., 2013) designed highring-stiffened thin-walled reinforced concrete cylindrical or hyperbolic shell SUTs for commercial SUTPPs.Turbines are driven by the air current due to buoyancy to transfer fluid power to shaft power (Fluri and vonBackstro¨m, 2008a). The typical SUT turbine is of the axial flow type, whose characteristics (e.g., the number of rotor blades) lie between those of wind turbine and gas turbine.Its blades are adjustable like those of wind turbine, but

the air flow is enclosed just as in gas turbine, and the SUT turbine may have inlet guide vanes (IGVs) (VonBackstro¨m and Gannon, 2004). The SUT supports could be used as IGVs of the single vertical-axis turbine installed at the SUT base (Gannon and von Backstro¨m, 2003). Turbine configuration is the single vertical-axis, the multiple vertical-axis or the multiple horizontal-axis type (Schlaich,1995). Turbine layout is the single-rotor layout (Gannonand von Backstro¨m, 2003), or the counter-rotating layout with one pair of counter-rotating rotors (DenantesandBilgen, 2006), both with or without IGVs.

1.5 General characteristics

SUTPP is one of the promising renewable energy-based power suppliers on a large scale and can be suitably located in arid and semi-arid zones and remote regions (Zhouet al., 2013c). In general, commercial application of SUTPP has the following advantages:(1) The technology is simple. The construction materials ,mainly steel, concrete and glass, are widely available.Construction sites may be desert areas. It is accessible to almost any countries including the technologically

less developed countries.
2) The solar collector absorbs direct and diffuse solar radiation. The SUTPP with the natural-additionalmixed heat storage system can operate day and night on pure solar energy. This is crucial to the development of SUTPPs in tropical regions where the weather is frequently overcast.

(3) Its operation and maintenance expense is relatively low. Although turbine maintenance and sporadically collector cleaning are costly, additional fossil fuels are not required to substitute solar radiation due to reliable operation of SUTPP day and night. Cooling water is also not required during SUTPP operation .The moving or rotating parts are few other than turbine blades and this would lead to few occurrences of mechanical failures and high safety.

(4) Its global warming potential is low for the entire lifecycle including construction, operation and decommissioning phases (Zongker, 2013). It is nearly pollution free during operation. It uses renewable energy source: solar radiation, and its operation avoids the emissions of large amounts of greenhouse gases and the use of potable water for cooling purposes.

(5) Its power output and efficiency increase with its dimension, and the energy production cost is reduced(Schlaich et al., 2004; Kra¨tzig, 2013). Carbon credit revenue due to carbon emission reduction can improve its cost effectiveness (Fluri et al., 2009; Li

et al., 2014).Therefore, commercial SUTPPs producing electric power with almost no pollution can make the most of abundant solar radiation on vast desert areas. The power produced from commercial SUTPPs is thought to be agood alternative to that from fossil fuels. However, there are also some disadvantages of SUTPPs:

(1) The investment is huge for the construction of a commercial plant due to the cost of its large-area collector and high SUT. The commercial SUTPP construction demands huge amounts of construction materials. Although cooling water is not needed, large quantities of water may be required to work as a medium of additional heat storage.

(2) Its efficiency is low due to the several-process energy conversions and small temperature difference between the hot and cold reservoirs. (The efficiency for a large-scale plant, however, can reach to an acceptable level. Levelized electricity cost (LEC) is actually amore important indicator to determine the economic feasibility of building an SUTPP than the plant investment and efficiency (Schlaich et al., 2004;

Kra¨tzig, 2013).)

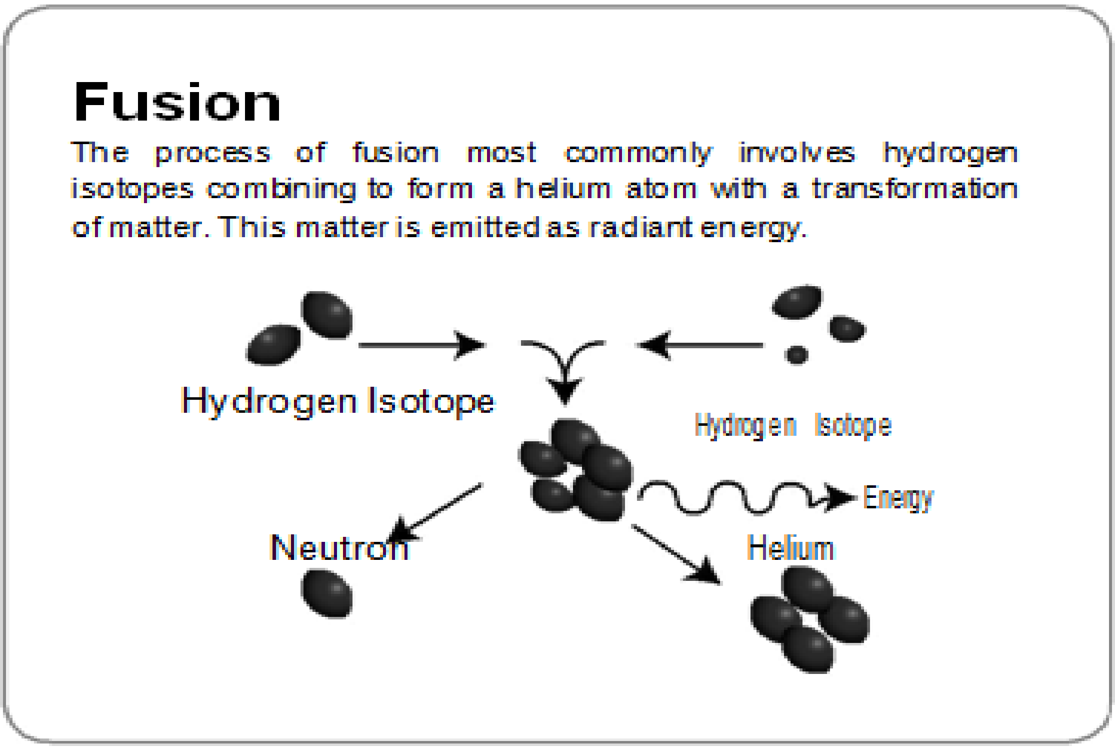
(3) Its SUT height is limited. The reinforced concrete SUT is required to be as high as possible in order to improve the plant efficiency. However, because of the technological constraints and the restrictions on the construction materials, it is difficult to construct a very high SUT. There are also external limitations such as possible earthquakes, which may destroy high SUT.

(4) Environmental concerns may arise. Construction and operation of many commercial SUTPPs may influence the local environment, ecology, and then lives of different plant and animal species. These disadvantages put obstacles in the way of the commercialization of the SUTPP technology.

CHAPTER 2: LITERATURE REVIEW

2.1Solar Energy

Every day, the sun radiates (sends out) an enormous amount of energy—called solar energy. It radiates more energy in one day than the world uses in one year. This energy comes from within the sun Itself.Like most stars, the sun is a big gas ball made up mostly of hydrogen and helium gas. The sun makes energy in its inner core in a process called nuclear fusion.It takes the sun's energy just a little over eight minutes to travel the 93 million miles to Earth. Solar energy travels at the speed of light, or 186,000 miles per second, or 3.0 x 10^8 meters per second.Only a small part of the visible radiant energy (light) that the sun emits into space ever reaches the Earth, but that is more than enough to supply all our energy needs. Every hour enough solar energy reaches the Earth to supply our nation's energy needs for a year! Solar energy is considered a renewable energy source due to this fact.Today, by the help of modern technology solar energy is used in various sectors.



The Earth receives 174,000 terawatts (TW) of incoming solar radiation (insolation) at the upper atmosphere. Approximately 30% is reflected back to space while the rest is absorbed by clouds, oceans and land masses. The spectrum of solar light at the Earth's surface is mostly spread across the visible and near-infrared ranges with a small part in the near-ultraviolet. Most of the world's population live in areas with insolation levels of 150-300 watts/m², or 3.5-7.0 kWh/m² per day.

Solar radiation is absorbed by the Earth's land surface, oceans – which cover about 71% of the globe – and atmosphere. Warm air containing evaporated water from the oceans rises, causing atmospheric circulation or convection. When the air reaches a high altitude, where the temperature is low, water vapor condenses into clouds, which rain onto the Earth's surface, completing the water cycle. The latent heat of water condensation amplifies convection, producing atmospheric phenomena such as wind, cyclones and anti-cyclones. Sunlight absorbed by the oceans and land masses keeps the surface at an average temperature of 14 °C. By photosynthesis green plants convert solar energy into chemically stored energy, which produces food, wood and the biomass from which fossil fuels are derived.

The total solar energy absorbed by Earth's atmosphere, oceans and land masses is approximately 3,850,000 exajoules (EJ) per year. In 2002, this was more energy in one hour than the world used in one year. Photosynthesis captures approximately 3,000 EJ per year in biomass. The amount of solar energy reaching the surface of the planet is so vast that in one year it is about twice as much as will ever be obtained from all of the Earth's non-renewable resources of coal, oil, natural gas, and mined uranium combined,The potential solar energy that could be used by humans differs from the amount of solar energy present near the surface of the planet because factors such as geography, time variation, cloud cover, and the land available to humans limit the amount of solar energy that we can acquire.

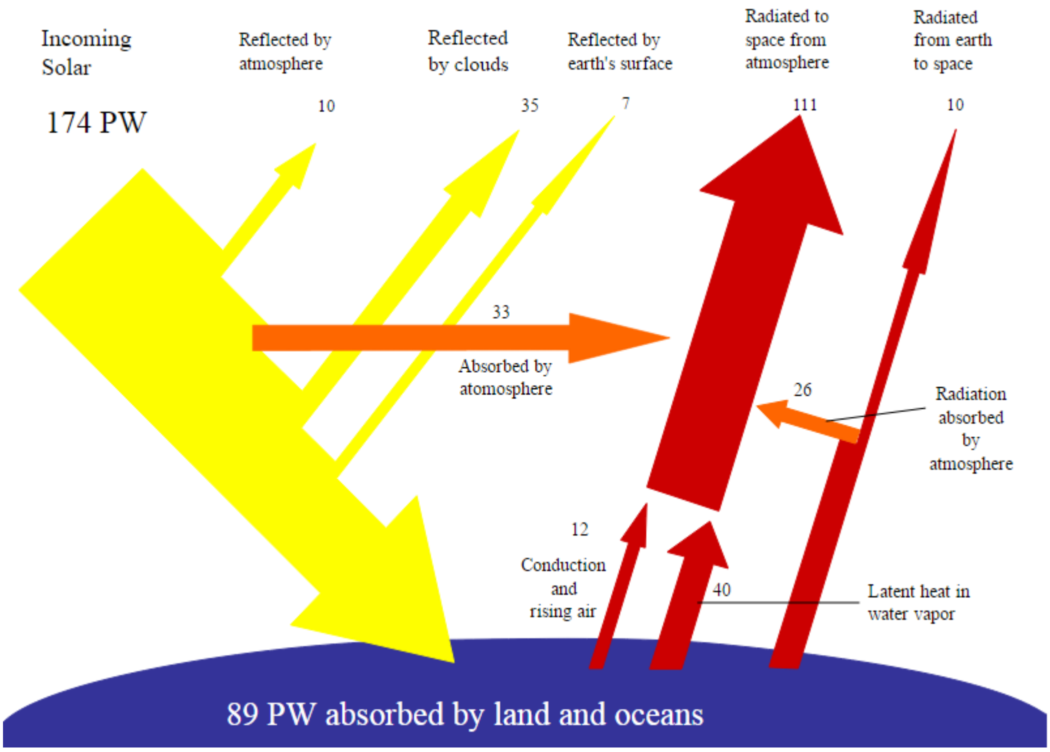


Figure 2: Solar energy flow on earth

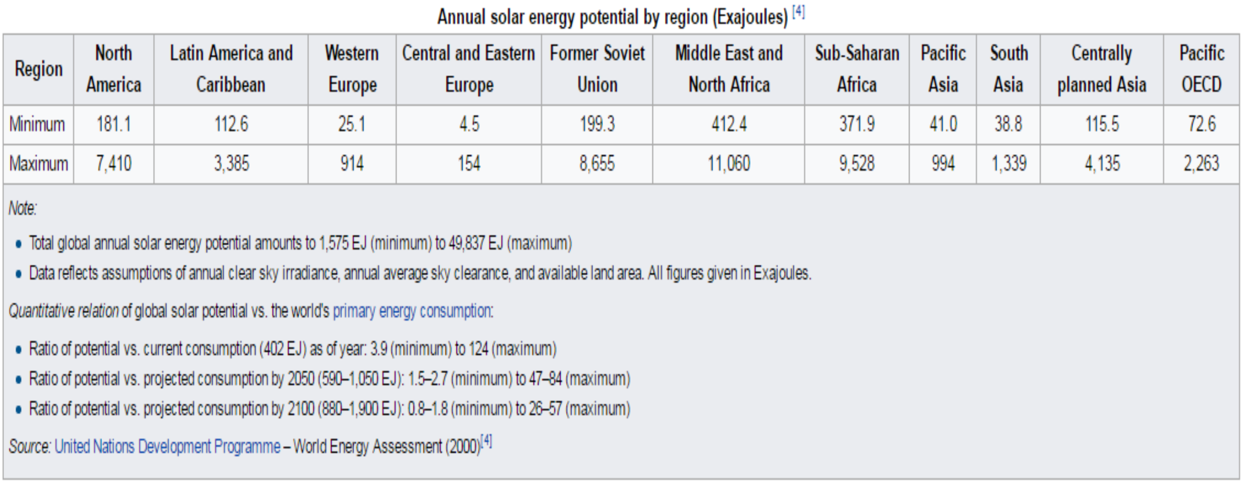
Geography affects solar energy potential because areas that are closer to the equator have a greater amount of solar radiation. However, the use of photovoltaics that can follow the position of the sun can significantly increase the solar energy potential in areas that are farther from the equator.Time variation effects the potential of solar energy because during the nighttime there is little solar radiation on the surface of the Earth for solar panels to absorb. This limits the amount of energy that solar panels can absorb in one day. Cloud cover can affect the potential of solar panels because clouds block incoming light from the sun and reduce the light available for solar cells.

In addition, land availability has a large effect on the available solar energy because solar panels can only be set up on land that is otherwise unused and suitable for solar panels. Roofs have been found to be a suitable place for solar cells, as many people have discovered that they can collect energy directly from their homes this way. Other areas that are suitable for solar cells are lands that are not being used for businesses where solar plants can be established.

Solar technologies are characterized as either passive or active depending on the way they capture, convert and distribute sunlight and enable solar energy to be harnessed at different levels around the world, mostly depending on distance from the equator. Although solar energy refers primarily to the use of solar radiation for practical ends, all renewable energies, other than Geothermal power and Tidal power, derive their energy either directly or indirectly from the Sun.

Active solar techniques use photovoltaics, concentrated solar power, solar thermal collectors, pumps, and fans to convert sunlight into useful outputs. Passive solar techniques include selecting materials with favorable thermal properties, designing spaces that naturally circulate air, and referencing the position of a building to the Sun. Active solar technologies increase the supply of energy and are considered supply side technologies, while passive solar technologies reduce the need for alternate resources and are generally considered demand side technologies.[19]

In 2000, the United Nations Development Programme, UN Department of Economic and Social Affairs, and World Energy Council published an estimate of the potential solar energy that could be used by humans each year that took into account factors such as insolation, cloud cover, and the land that is usable by humans. The estimate found that solar energy has a global potential of 1,575–49,837 EJ per year *(see table below)*.



Annual solar energy potential by region (Exajoules) [4]

Region	North America	Latin America and Caribbean	Western Europe	Central and Eastern Europe	Former Soviet Union	Middle East and North Africa	Sub-Saharan Africa	Pacific Asia	South Asia	Centrally planned Asia	Pacific OECD
Minimum	181.1	112.6	25.1	4.5	199.3	412.4	371.9	41.0	38.8	115.5	72.6
Maximum	7,410	3,385	914	154	8,655	11,060	9,528	994	1,339	4,135	2,263

Note:

- Total global annual solar energy potential amounts to 1,575 EJ (minimum) to 49,837 EJ (maximum)
- Data reflects assumptions of annual clear sky irradiance, annual average sky clearance, and available land area. All figures given in Exajoules.

Quantitative relation of global solar potential vs. the world's primary energy consumption:

- Ratio of potential vs. current consumption (402 EJ) as of year: 3.9 (minimum) to 124 (maximum)
- Ratio of potential vs. projected consumption by 2050 (590–1,050 EJ): 1.5–2.7 (minimum) to 47–84 (maximum)
- Ratio of potential vs. projected consumption by 2100 (880–1,900 EJ): 0.8–1.8 (minimum) to 26–57 (maximum)

Source: United Nations Development Programme – World Energy Assessment (2000)[4]

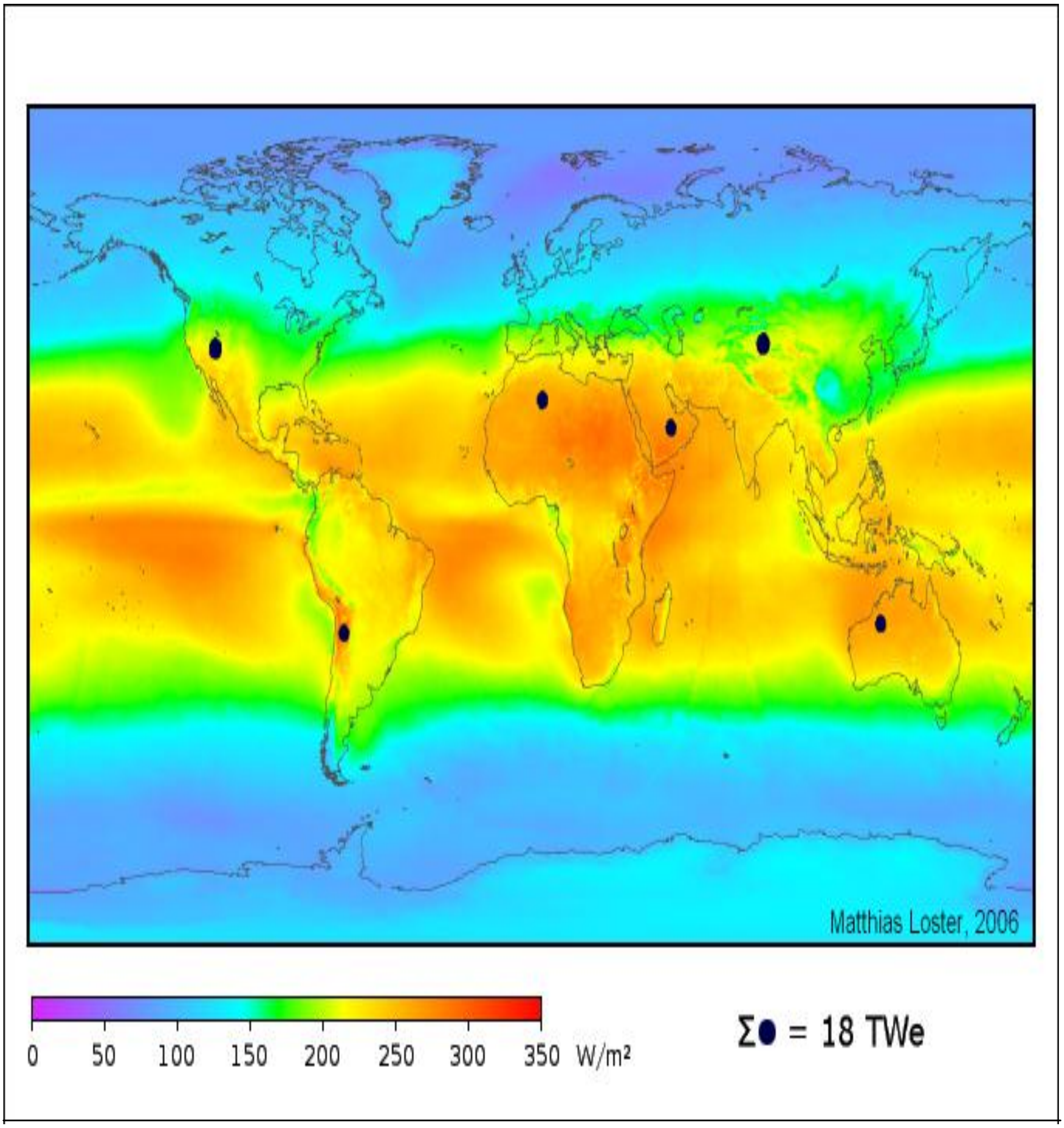


Figure 3: Average Insolation

The theoretical area of the small black dots is sufficient to supply the world's total energy needs of 18 TW with solar power.

Solar energy is harnessed by using a range of ever evolving technologies such as solar heating, photovoltaic ,solar thermal energy,solar architecture,molten salt power plants and artificial photosynthesis.

2.2Solar thermal energy

Solar thermal technologies can be used for water heating, space heating, space cooling and process heat generation.Solar hot water systems use sunlight to heat water. In low geographical latitudes (below 40 degrees) from 60 to 70% of the domestic hot water use with temperatures up to 60 °C can be provided by solar heating systems. The most common types of solar water heaters are evacuated tube collectors (44%) and glazed flat plate collectors (34%) generally used for domestic hot water; and unglazed plastic collectors (21%) used mainly to heat swimming pools.

As of 2007, the total installed capacity of solar hot water systems was approximately 154 thermal gigawatt (GW_{th}). China is the world leader in their deployment with 70 GW_{th} installed as of 2006 and a long-term goal of 210 GW_{th} by 2020. Israel and Cyprus are the per capita leaders in the use of solar hot water systems with over 90% of homes using them. In the United States, Canada, and Australia, heating swimming pools is the dominant application of solar hot water with an installed capacity of 18 GW_{th} as of 2005.

Figure 4: Solar water heaters facing the sun to maximize gain

In the United States, heating, ventilation and air conditioning (HVAC) systems account for 30% (4.65 EJ/yr) of the energy used in commercial buildings and nearly 50% (10.1 EJ/yr) of the energy used in residential buildings. Solar heating, cooling and ventilation technologies can be used to offset a portion of this energy.

Fig 2.4: *MIT's Solar House 1, built in 1939 in the U.S., used seasonal thermal energy storage for year-round heating.*

Thermal mass is any material that can be used to store heat—heat from the Sun in the case of solar energy. Common thermal mass materials include stone, cement and water. Historically they have been used in arid climates or warm temperate regions to keep buildings cool by absorbing solar energy during the day and radiating stored heat to the cooler atmosphere at night. However, they can be used in cold temperate areas to maintain warmth as well. The size and placement of thermal mass depend on several factors such as climate, daylighting and shading conditions. When properly incorporated, thermal mass maintains space temperatures in a comfortable range and reduces the need for auxiliary heating and cooling equipment.

A solar chimney (or thermal chimney, in this context) is a passive solar ventilation system composed of a vertical shaft connecting the interior and exterior of a building. As the chimney warms, the air inside is heated causing an updraft that pulls air through the building. Performance can be improved by using glazing and thermal mass materials in a way that mimics greenhouses.

Deciduous trees and plants have been promoted as a means of controlling solar heating and cooling. When planted on the southern side of a building in the northern hemisphere or the northern side in the southern hemisphere, their leaves provide shade during the summer, while the bare limbs allow light to pass during the winter. Since bare, leafless trees shade 1/3 to 1/2 of incident solar radiation, there is a balance between the benefits of summer shading and the corresponding loss of winter heating. In climates with significant heating loads, deciduous trees should not be planted on the Equator-facing side of a building because they will interfere with winter solar availability. They can, however, be used on the east and west sides to provide a degree of summer shading without appreciably affecting winter solar gain.

Solar cookers use sunlight for cooking, drying and pasteurization. They can be grouped into three broad categories: box cookers, panel cookers and reflector cookers. The simplest solar cooker is the box cooker first built by Horace de Saussure in 1767. A basic box cooker consists of an insulated container with a transparent lid. It can be used effectively with partially overcast skies and will typically reach temperatures of 90–150 °C (194–302 °F). Panel cookers use a

reflective panel to direct sunlight onto an insulated container and reach temperatures comparable to box cookers. Reflector cookers use various concentrating geometries (dish, trough, Fresnel mirrors) to focus light on a cooking container. These cookers reach temperatures of 315 °C (599 °F) and above but require direct light to function properly and must be repositioned to track the Sun.
Solar concentrating technologies such as parabolic dish, trough and Scheffler reflectors can provide process heat for commercial and industrial applications. The first commercial system was the Solar Total Energy Project (STEP) in Shenandoah, Georgia, USA where a field of 114 parabolic dishes provided 50% of the process heating, air conditioning and electrical requirements for a clothing factory. This grid-connected cogeneration system provided 400 kW of electricity plus thermal energy in the form of 401 kW steam and 468 kW chilled water, and had a one-hour peak load thermal storage.Evaporation ponds are shallow pools that concentrate dissolved solids through evaporation. The use of evaporation ponds to obtain salt from seawater is one of the oldest applications of solar energy. Modern uses include concentrating brine solutions used in leach mining and removing dissolved solids from waste streams.[Clothes lines, clotheshorses, and clothes racks dry clothes through evaporation by wind and sunlight without consuming electricity or gas. In some states of the United States legislation protects the "right to dry" clothes. Unglazed transpired collectors (UTC) are perforated sun-facing walls used for preheating ventilation air. UTCs can raise the incoming air temperature up to 22 °C (40 °F) and deliver outlet temperatures of 45–60 °C (113–140 °F).The short payback period of transpired collectors (3 to 12 years) makes them a more cost-effective alternative than glazed collection systems.As of 2003, over 80 systems with a combined collector area of 35,000 square meters (380,000 sq ft) had been installed worldwide, including an 860 m^2 (9,300 sq ft) collector in Costa Rica used for drying coffee beans and a 1,300 m^2 (14,000 sq ft) collector in Coimbatore, India, used for drying marigolds.
Solar distillation can be used to make saline or brackish water potable. The first recorded instance of this was by 16th-century Arab alchemists.A large-scale solar distillation project was first constructed in 1872 in the Chilean mining town of Las Salinas.The plant, which had solar collection area of 4,700 m^2 (51,000 sq ft), could produce up to 22,700 L (5,000 imp gal; 6,000 US gal) per day and operate for 40 years. Individual still designs include single-slope, double-slope (or greenhouse type), vertical, conical, inverted absorber, multi-wick, and multiple effect. These stills can operate in passive, active, or hybrid modes. Double-slope stills are the most economical for decentralized domestic purposes, while active multiple effect units are more suitable for large-scale applications.

Solar water disinfection (SODIS) involves exposing water-filled plastic polyethylene terephthalate (PET) bottles to sunlight for several hours.Exposure times vary depending on weather and climate from a minimum of six hours to two days during fully overcast conditions. It is recommended by the World Health Organization as a viable method for household water treatment and safe storage.Over two million people in developing countries use this method for their daily drinking water.

Solar energy may be used in a water stabilization pond to treat waste water without chemicals or electricity. A further environmental advantage is that algae grow in such ponds and consume carbon dioxide in photosynthesis, although algae may produce toxic chemicals that make the water unusable.
Molten salt can be employed as a thermal energy storage method to retain thermal energy collected by a solar tower or solar trough of a concentrated solar power plant, so that it can be used to generate electricity in bad weather or at night. It was demonstrated in the Solar Two project from 1995–1999. The system is predicted to have an annual efficiency of 99%, a reference to the energy retained by storing heat before turning it into electricity, versus converting heat directly into electricity. The molten salt mixtures vary. The most extended mixture contains sodium nitrate, potassium nitrate and calcium nitrate. It is non-flammable and nontoxic, and has already been used in the chemical and metals industries as a heat-transport fluid, so experience with such systems exists in non-solar applications.

The salt melts at 131 °C (268 °F). It is kept liquid at 288 °C (550 °F) in an insulated "cold" storage tank. The liquid salt is pumped through panels in a solar collector where the focused sun heats it to 566 °C (1,051 °F). It is then sent to a hot storage tank. This is so well insulated that the thermal energy can be usefully stored for up to a week.[54]

When electricity is needed, the hot salt is pumped to a conventional steam-generator to produce superheated steam for a turbine/generator as used in any conventional coal, oil, or nuclear power plant. A 100-megawatt turbine would need a tank about 9.1 meters (30 ft) tall and 24 meters (79 ft) in diameter to drive it for four hours by this design.

Several parabolic trough power plants in Spain and solar power tower developer SolarReserve use this thermal energy storage concept. The Solana Generating Station in the U.S. has six hours of storage by molten salt.

2.3 Electricity Production

From the beginning of the era of electricity,our main concern has been how to produce electricity in a way that is more cost effective,environment friendly with available production source.Such concerns formed a new path for electricity production and that is solar power.
Solar power is the conversion of solar energy into electricity.And this is done either directly using photovoltaics (PV), or indirectly using concentrated solar power (CSP). CSP systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. PV converts light into electric current using the photoelectric effect.And another yet less familiar method is SUT or Solar Updraft Tower which is more cost effective,environment friendly than above two.
In the last two decades, photovoltaics (PV), also known as solar PV, has evolved from a pure niche market of small scale applications towards becoming a mainstream electricity source. A solar cell is a device that converts light directly into electricity using the photoelectric effect. The first solar cell was constructed by Charles Fritts in the 1880s. In 1931 a German engineer, Dr Bruno Lange, developed a photo cell using silver selenide in place of copper oxide. Although the prototype selenium cells converted less than 1% of incident light into electricity, both Ernst Werner von

Siemens and James Clerk Maxwell recognized the importance of this discovery. Following the work of Russell Ohl in the 1940s, researchers Gerald Pearson, Calvin Fuller and Daryl Chapin created the crystalline silicon solar cell in 1954. These early solar cells cost 286 USD/watt and reached efficiencies of 4.5–6%. By 2012 available efficiencies exceeded 20%, and the maximum efficiency of research photovoltaics was in excess of 40%.

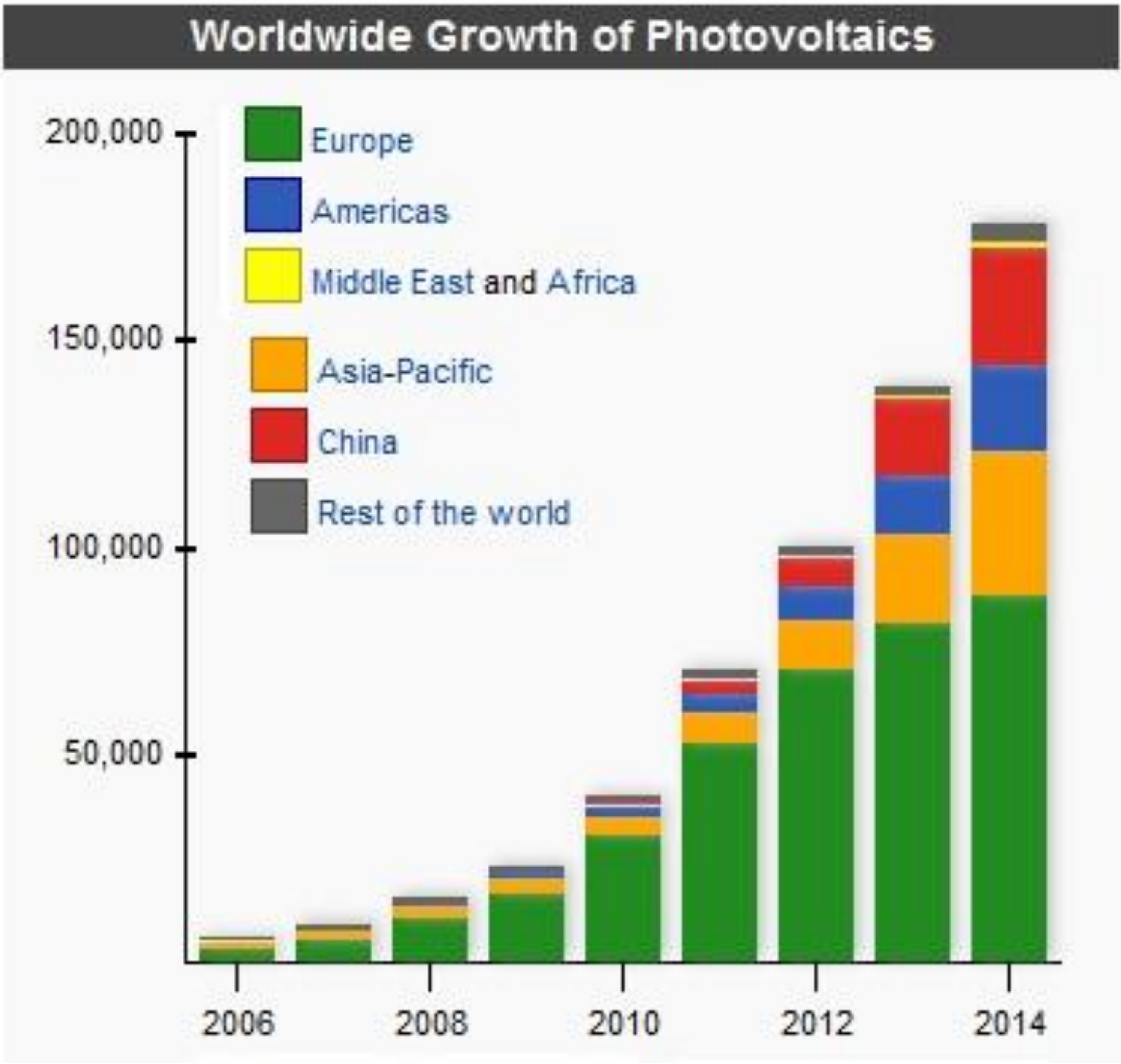


Figure 5: Worldwide growth of photovoltaics

Concentrating Solar Power (CSP) systems use lenses or mirrors and tracking systems to focus a large area of sunlight into a small beam. The concentrated heat is then used as a heat source for a conventional power plant. A wide range of concentrating technologies exists; the most developed are the parabolic trough, the concentrating linear fresnel reflector, the Stirling dish and the solar power tower. Various techniques are used to track the Sun and focus light. In all of these systems a working fluid is heated by the concentrated sunlight, and is then used for power generation or energy storage.

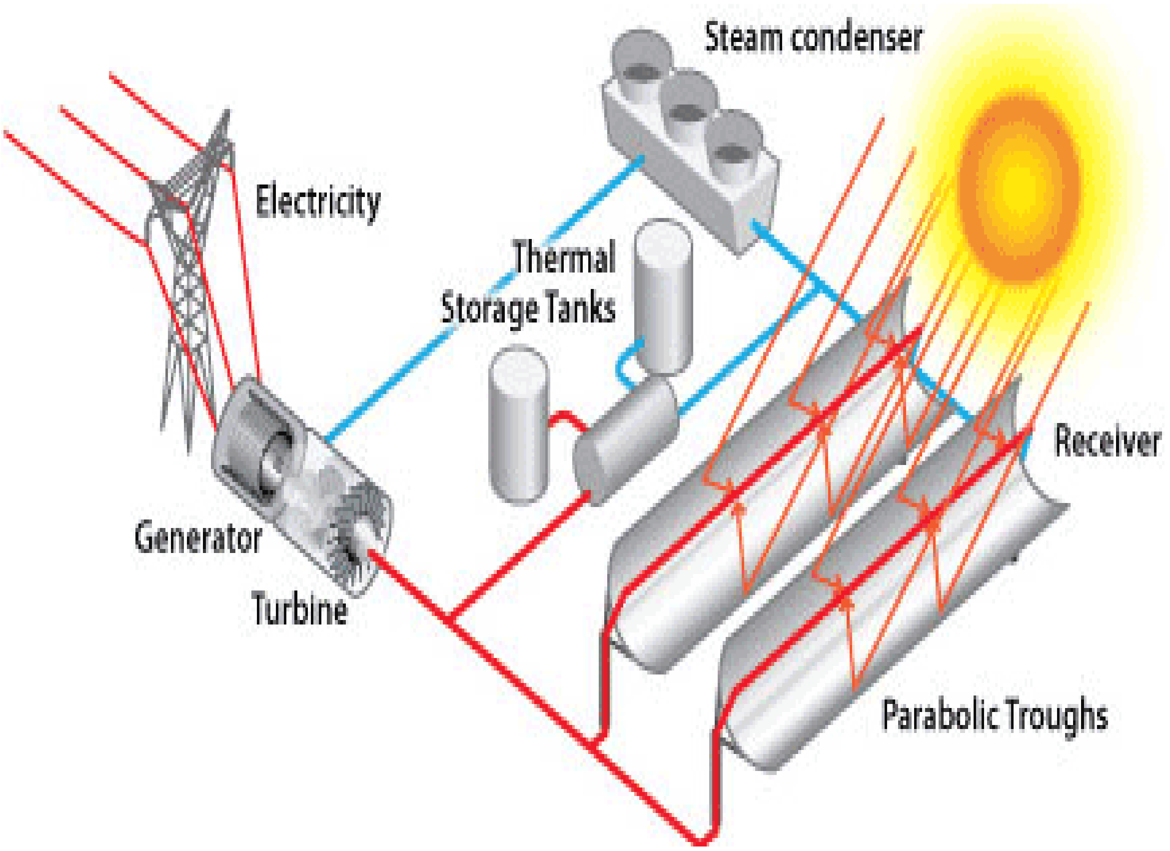
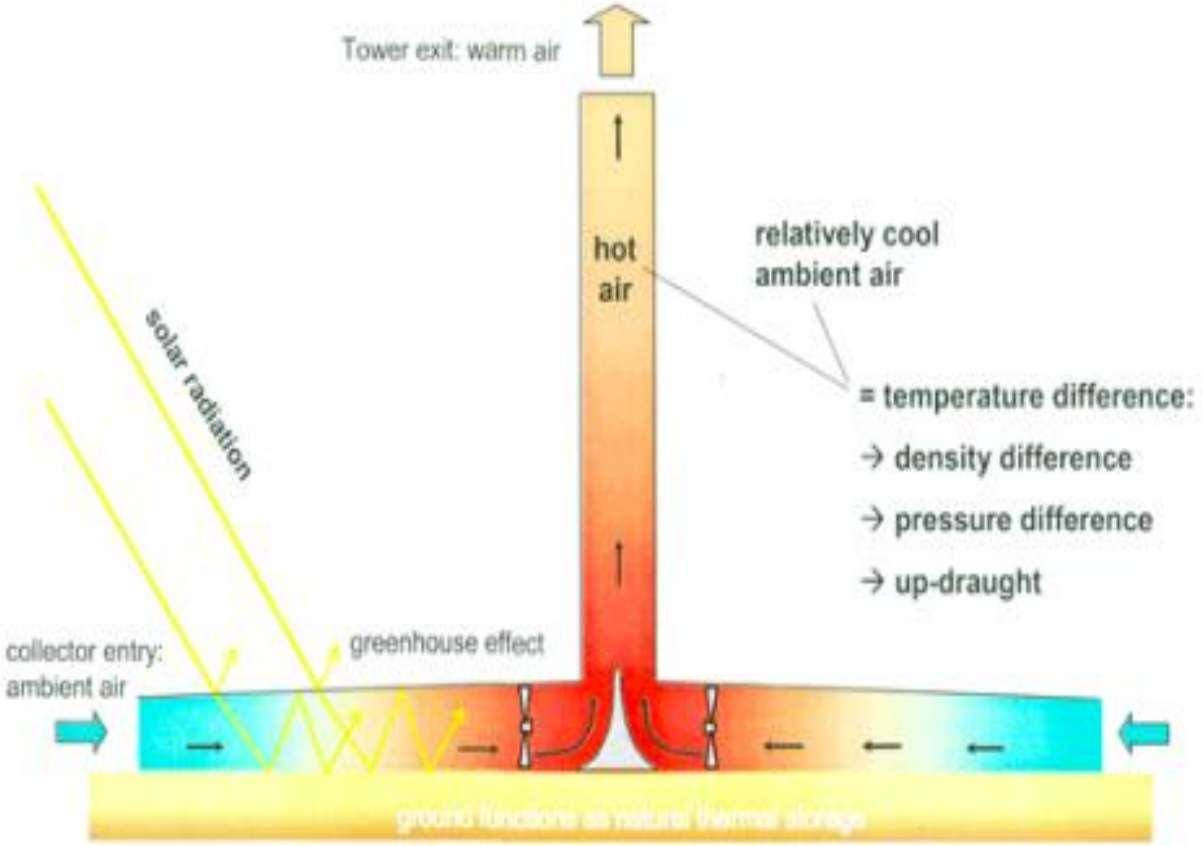


Fig2.6: Block diagram of one of the csp system

The solar updraft tower (SUT) is a renewable-energy power plant for generating electricity from low temperature solar heat. Sunshine heats the air beneath a very wide greenhouse-like roofed collector structure surrounding the central base of a very tall chimney tower. The resulting convection causes a hot air updraft in the tower by the chimney effect. This airflow drives wind turbines placed in the chimney updraft or around the chimney base to produce electricity. Plans for scaled-up versions of demonstration models will allow significant power generation, and may allow development of other applications, such as water extraction or distillation, and agriculture or horticulture.

Commercial investment may have been discouraged by the high initial cost of building a very large novel structure, the large land area required and by the risk of investment, however, there appears to be a renewed interest in solar updraft towers especially in sunny remote areas. A few prototypes have recently been constructed and projects are being proposed for parts of Africa, USA and Australia. An important fact to consider is that solar updraft towers appear to be the only renewable energy technology that can generate electricity from low temperature heat. Functional or mechanical feasibility is not so much an issue now as capitalization.

A comprehensive review of theoretical and experimental aspects of the solar updraft tower power plant (SUTPP) development is available, with a recommendation for commercial development.



Schlaich Bergermann und Partner
13.11.2001

Figure 6: Solar Updraft Tower Power Plant

2.4 Design of SUT

Power output depends primarily on two factors: collector area and chimney height.A larger area collects and warms a greater volume of air to flow up the chimney; collector areas as large as 7 kilometers (4.3 mi) in diameter have been discussed.A larger chimney height increases the pressure difference via the stack effect; chimneys as tall as 1,000 meters (3,281 ft) have been discussed.

Heat is stored inside the collector area allowing SUTs to operate 24 hours a day. The ground beneath the solar collector, water in bags or tubes, or a saltwater thermal sink in the collector could add thermal capacity and inertia to the collector. Humidity of the updraft and condensation in the chimney could increase the energy flux of the system.

Turbines with a horizontal axis can be installed in a ring around the base of the tower, as once planned for an Australian project and seen in the diagram above; or—as in the prototype in Spain—a single vertical axis turbine can be installed inside the chimney.

Carbon dioxide is emitted only negligibly as part of operations. Manufacturing and construction require substantial energy, particularly to produce cement. Net energy payback is estimated to be 2–3 years.

Since solar collectors occupy significant amounts of land, deserts and other low-value sites are most likely. Improvements in the solar heat collection efficiency by using unglazed transpired collector can significantly reduce the land required for the solar array.

A small-scale solar updraft tower may be an attractive option for remote regions in developing countries. The relatively low-tech approach could allow local resources and labour to be used for construction and maintenance.

Locating a tower at high latitudes could produce up to 85 per cent of the output of a similar plant located closer to the equator, if the collection area is sloped significantly toward the equator. The sloped collector field, which also functions as a chimney, is built on suitable mountainsides, with a short vertical chimney on the mountaintop to accommodate the vertical axis air turbine. The results showed that solar chimney power plants at high latitudes may have satisfactory thermal performance

2.5 History and Evolution of SUT:

A chimney turbine was envisioned as a smoke jack, and illustrated 500 years ago by Leonardo da Vinci. An animal spitted above a fire or in an oven could be turned by a vertical axis turbine with four angled vanes in the chimney updraft.

In 1896, Mr. Alfred Rosling Bennett published the first patent describing a "Convection Mill" . Even if in the title of the Patent and in the claims the word "Toy" clearly appears and even if in the overall description made inside the Patent it is evident that the idea was to produce small devices, in page 3 at lines 49-54 Bennett envisions much larger devices for bigger scale applications. A model of this "convection mill", built in 1919 by Albert H. Holmes & Son (London) to demonstrate the phenomenon of convection currents, is on display in the Science Museum, London.

In 1903, Isidoro Cabanyes, a colonel in the Spanish army, proposed a solar chimney power plant in the magazine *La energía eléctrica*. Another early description was published in 1931 by German author Hanns Günther. Beginning in 1975, Robert E. Lucier applied for patents on a solar chimney electric power generator; between 1978 and 1981 patents (since expired) were granted in Australia, Canada, Israel, and the USA.

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 a large mountain. A mountainside updraft tower can also function as a vertical greenhouse.

Figure 7:Manzanares solar chimney viewed through the polyster collector roof

In 1982, a small-scale experimental model of a solar draft tower was built in Manzanares, Ciudad Real, 150 km south of Madrid, Spain at 39°02′34.45″N 3°15′12.21″W. The power plant operated for approximately eight years. The tower's guy-wires were not protected against corrosion and failed due to rust and storm winds. The tower blew over and was decommissioned in 1989.

Figure 8: SUT seen from la solana

Inexpensive materials were used in order to evaluate their performance. The solar tower was built of iron plating only 1.25 millimeters (0.049 in) thick under the direction of a German engineer, Jörg Schlaich. The project was funded by the German government.

The chimney had a height of 195 meters (640 ft) and a diameter of 10 meters (33 ft) with a collection area (greenhouse) of 46 hectares (110 acres) and a diameter of 244 meters (801 ft), obtaining a maximum power output of about 50 kW. Various materials were used for testing, such as single or double glazing or plastic (which turned out not to be durable enough). One section was used as an actual greenhouse. During its operation, 180 sensors measured inside and outside temperature, humidity and wind speed data was collected on a second-by-second basis. This experiment setup did not sell energy.

In December 2010, a tower in Jinshawan in Inner Mongolia, China started operation, producing 200 kilowatts. The 1.38 billion RMB (USD 208 million) project was started in May 2009. It was intended to cover 277 hectares (680 acres) and produce 27.5 MW by 2013, but had to be scaled back. The solar chimney plant was expected to improve the climate by covering loose sand, restraining sandstorms. Critics have said that the 50m tall tower is too short to work properly and that it was a mistake to use glass in metal frames for the collector, as many of them cracked and shattered in the heat.

Figure 9:SUT powerplant prototype in manzanares,Spain seen from a point 8km to the south

A proposal to construct a solar updraft tower in Fuente el Fresno, Ciudad Real, Spain, entitled *Ciudad Real Torre Solar* would be the first of its kind in the European Union and would stand 750 metres (2,460 ft) tall– nearly twice as tall as the Belmont TV Mast, which was once the tallest structure in the European Union, before being shortened by several hundred feet– covering an area of 350 hectares (860 acres). It is expected to produce 40 MW.

Figure 10: Manzanares Solar Chimney-view of the tower through the collector glass roof

In 2001, EnviroMission proposed to build a solar updraft tower power generating plant known as *Solar Tower Buronga* near Buronga, New South Wales. The company did not complete the project. They have plans for a similar plant in Arizona, and most recently (December 2013) in Texas, but there is no sign of 'breaking ground' in any of Enviromission's proposals.

In December 2011, Hyperion Energy, controlled by Western Australians Tony Sage and Dallas Dempster, was reported to be planning to build a 1-km-tall solar updraft tower near Meekatharra to supply power to Mid-West mining projects.

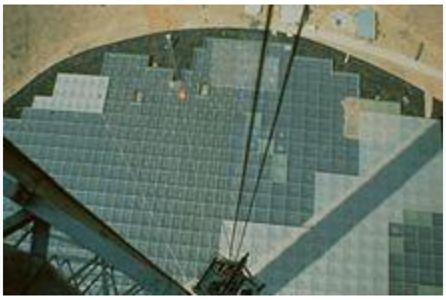


Figure 11: View from the tower on the roof with blackened ground below the collector

Based on the need for plans for long-term energy strategies, Botswana's Ministry of Science and Technology designed and built a small-scale research tower. This experiment ran from 7 October to 22 November 2005. It had an inside diameter of 2 meters (6.6 ft) and a height of 22 meters (72 ft), manufactured from glass-reinforced polyester, with an area of approximately 160 square meters (1,700 sq ft). The roof was made of a 5 mm thick clear glass supported by a steel framework.

In mid-2008, the Namibian government approved a proposal for the construction of a 400 MW solar chimney called the 'Greentower'. The tower is planned to be 1.5 kilometers (4,900 ft) tall and 280 meters (920 ft) in diameter, and the base will consist of a 37 square kilometers (14 sq mi) greenhouse in which cash crops can be grown.

A model solar updraft tower was constructed in Turkey as a civil engineering project. Functionality and outcomes are obscure.

A second solar updraft tower using a transpired collector is operating at Trakya University in Edirne Turkey and is being used to test various innovations in SUT designs including the ability to recover heat from photovoltaic (PV) arrays.

Figure 12: Solar tower incorporate photovoltaic modules on transpired collector

A grade-school pupil's home do-it-yourself SUT demonstration for a school science fair was constructed and studied in 2012, in a suburban Connecticut setting. With a 7-metre stack and 100 square meter collector, this generated a daily average 6.34 mW, from a computer fan as a turbine. Insolation and wind were the major factors on variance (range from 0.12 to 21.78 mW) in output.

2.6 Efficiency of SUT:

The traditional solar updraft tower has a power conversion rate considerably lower than many other designs in the (high temperature) solar thermal group of collectors. The low conversion rate is balanced to some extent by the lower cost per square metre of solar collection.

Model calculations estimate that a 100 MW plant would require a 1,000 m tower and a greenhouse of 20 square kilometers (7.7 sq mi). A 200 MW tower with the same tower would require a collector 7 kilometers in diameter (total area of about 38 km²).[5] One 200MW power station will provide enough electricity for around 200,000 typical households and will abate over 900,000 tons of greenhouse producing gases from entering the environment annually. The glazed collector area is expected to extract about 0.5 percent, or 5 W/m² of 1 kW/m², of the solar energy that falls upon it. If a transpired solar collector is used in place of the glazed collector, the efficiency is doubled. Additional efficiency improvements are possible by modifying the turbine and chimney design to increase air speed using a venturi configuration. Concentrating thermal (CSP) or photovoltaic (CPV) solar power plants range between 20% to 31.25% efficiency (dish Stirling). Overall CSP/CPV efficiency is reduced because collectors do not cover the entire footprint. Without further tests, the accuracy of these calculations is uncertain.[45] Most of the projections of efficiency, costs and yields are calculated theoretically, rather than empirically derived from demonstrations, and are seen in comparison with other collector or solar heat transducing technologies.

The performance of an updraft tower may be degraded by factors such as atmospheric winds, by drag induced by the bracings used for supporting the chimney, and by reflection off the top of the greenhouse canopy.

CHAPTER 3:THE SOLAR UPDRAFT TOWER TECHNICAL CONCEPT

Man learned to make active use of solar energy at a very early stage: greenhouses helped to grow food, chimney suction ventilated and cooled buildings and windmills ground corn and pumped water. The solar updraft tower's three essential elements – solar air collector, chimney/tower, and wind turbines – have thus been familiar for centuries, but are combined now in a novel way. The principle is Air is heated by solar radiation under a low circular transparent roof open at the periphery; the roof and the natural ground below form an air collector. In the middle of the roof is a vertical tower with large air inlets at its base. The joint between the roof and the tower base is airtight. As hot air is lighter than cold air it rises up the tower. Suction from the tower then draws in more hot air from the collector, and cold air comes in from the outer perimeter. Thus solar radiation causes a constant updraft in the tower. The energy contained in the updraft is converted into mechanical energy by pressure-staged turbines at the base of the tower, and into electrical energy by conventional generators. Continuous 24 hours-operation can be achieved by placing tight water-filled tubes or bags under the roof (Figure 3 and Figure 4). The water heats up during day-time and releases its heat at night. These tubes are filled only once, no further water is needed.

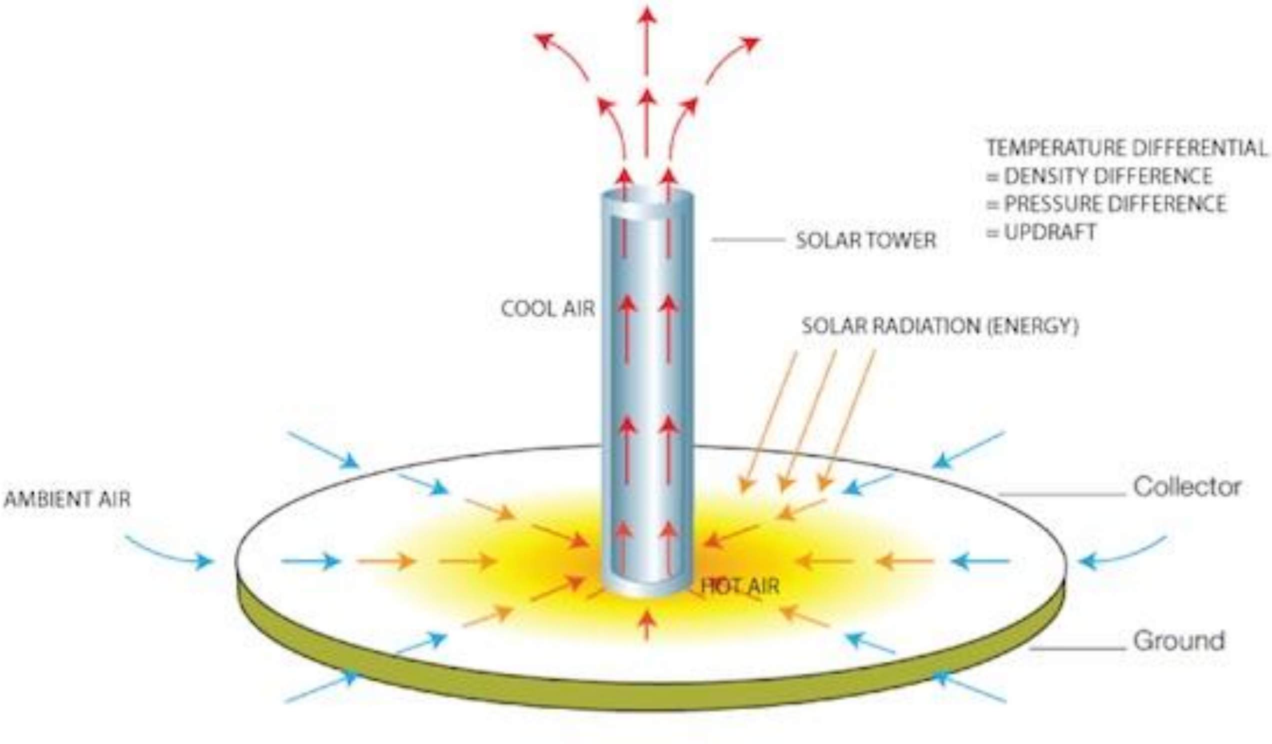


Figure 13: Mechanism of solar updraft tower

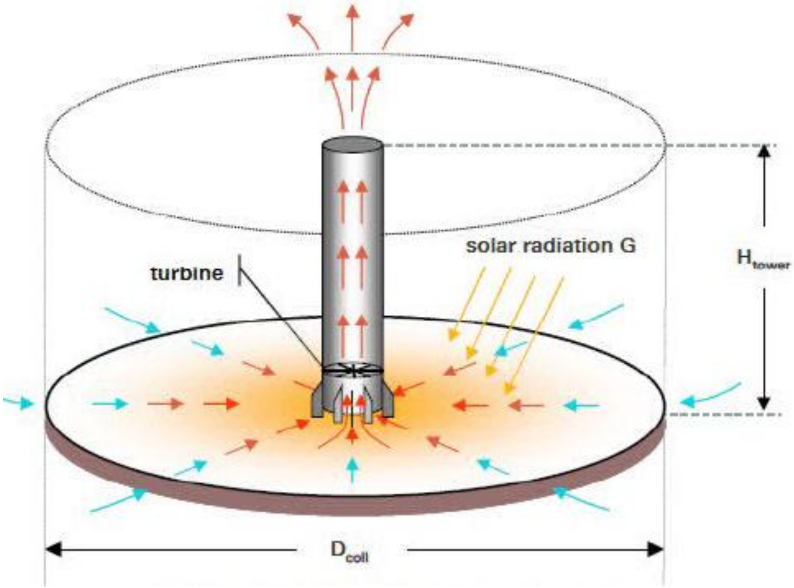


Fig 3.2: Dimension and power

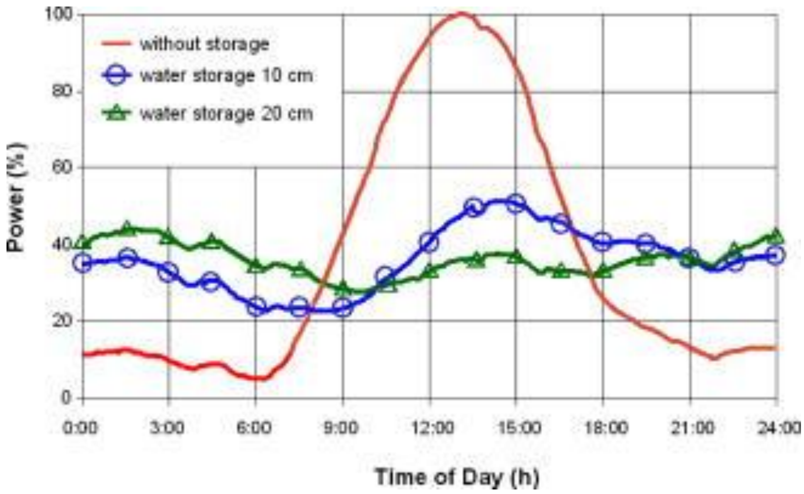


Figure 14: Percentage of power output in different time of the day

CHAPTER 4 : CONSTRUCTION AND DESIGN PARAMETER

4.1 MODEL-1

Before proceeding to main model of SUT(solar updraft tower),construction and simulation of a theoretical ratio base model was done.Which was different from main prototype in sectors of both material and design.

4.1.1 Components and Material:

Main basic components were present in this model but the material of these components were quite different from that of the prototype.The tower of this model was of long hard paper roll,which was black colored externally.It was effective in a way that it had a thermal conductivity of 0.05 W/(m K).

The Collector material used in model was made of talc paper.Talc paper was less effective as a collector base material as thermal conductivity of talc paper is greater than that of plastic polymers.Talc paper of high aspect ratio has greater stiffness and has high deflection temperature which can be noted as reason behind experimenting with it.

The propeller was made of normal paper as the initial torque needed was low.And the rotation speed or RPM of this propeller was measured by tachometer.

The construction base of this model was mainly wooden blocks and wires.The tower was strained over a round wooden block.The round wooden block was balanced over six bar type wooden blocks.The frame of collector was made of steel wires which were about 7mm in diameter.

4.1.2.Output Analysis:

The model was built in a sense to ensure if the project would run in regular temperature range and its variation.There was a certain amount of temperature difference between the temperature of collector and atmospheric temperature and it was about 11 degree celcius.The temperature was measured by Pyrometer.Such temperature difference provided slight rotation of light paper made modified propeller which was about 40RPM.The rpm was measured by Tachometer.

There were many faults in this model which resulted in low temperature difference.The thermal conductivity of talc paper made collector is higher in range than that of plastic that we used later in our prototype.There were a lot of leaks on the collector surface due to frame construction faults and it caused air to pass away from those leaks.The tower height to collector diameter ratio was low which resulted in low thrust force from hot air.The height of collector outer circle from ground base was quite high and for that air couldn’t get trapped for definite time being for it to get heated rather it passed away naturally with its own multi directional flow from other open sides of collector.And overall the base structureof this was not stable.

After experimenting with this theoretical calculation base model ,things to be modified in final prototype was quite clear and the modification of prototype was made exactly based on the result of effectiveness of each and every component of the model.

4.2 Model-2

4.2.1 Components

A. Collector

Hot air for the solar updraft tower is produced by the greenhouse effect in a simple air collector consisting of a glass or plastic film glazing stretched nearly horizontally several meters above theground. The height of the glazing increases towards the tower base, finally the air is diverted from horizontal into vertical movement with minimum friction loss. This glazing admits the shortwave solar radiation to penetrate and retains long wave re-radiation from the heated ground. Thus the ground under the roof heats up and transfers its heat to the air above flowing radially from the outside to the tower.

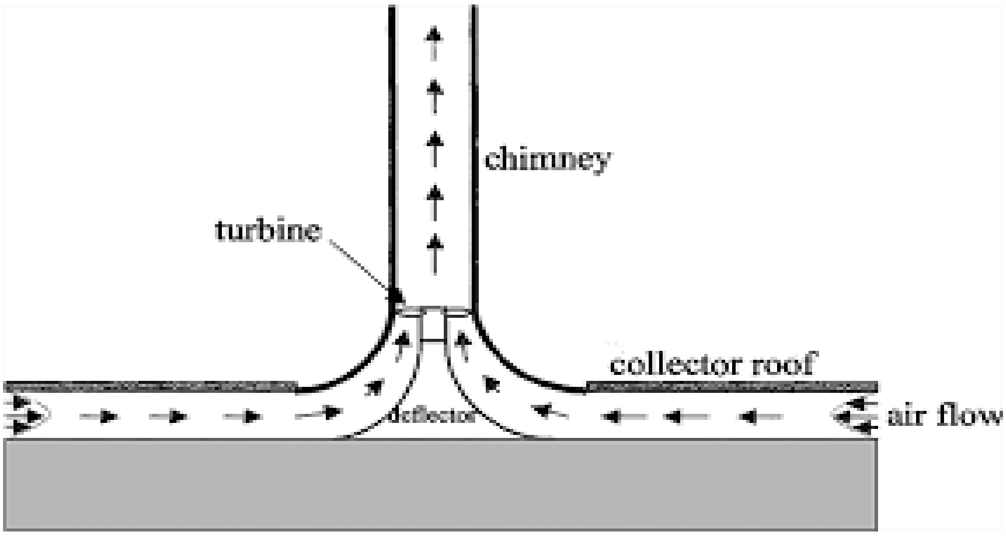


Figure 15: Collector of SUT

B. Storage

In this whole system additional thermal storage capacity is desired,we used white sand as thermal storage system and by doing so we got highest temperature difference in a cloudy day.Another method for thermal storage is water filled bags or tubes.Water filled black tubes or bags are laid down side by side on the radiation soil under the collector. The tubes are filled with water once and remain closed thereafter, so that no evaporation can take place. The volume of water in the tubes is selected to correspond to a water layer with a depth of 5 to 20 cm depending on the desired power output characteristics.

Since the heat capacity of water (4.2 kJ/kg) is much higher than that of soil (0.75 – 0.85 kJ/kg) the water inside the tubes stores a part of the solar heat and releases it during the night when the air in the collector cools down. This enables the plant to run for 24h per day on pure solar energy.

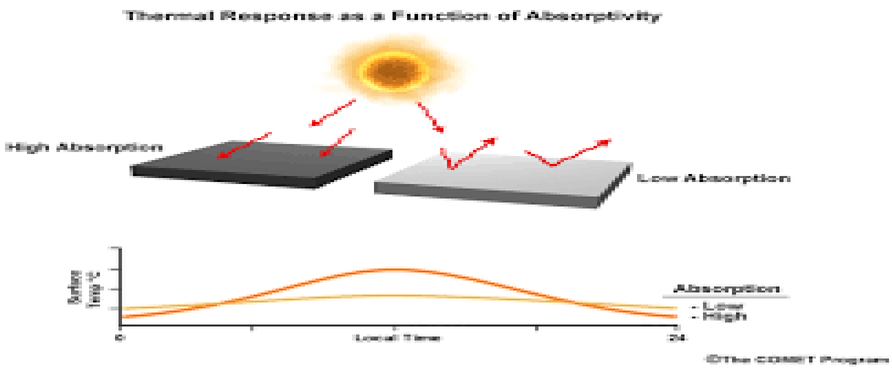


Figure 16: Sand has a higher absorptivity than other materials

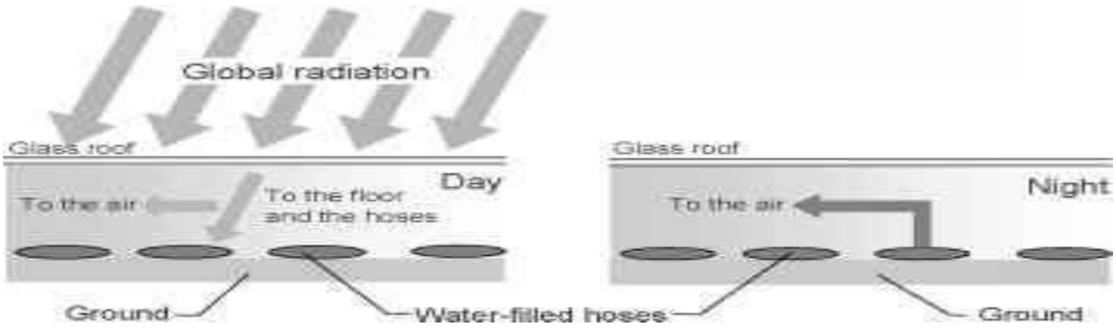


Figure 17: Principle of thermal energy storage with water-filled tubes

C. Tower

The tower itself is the plant's actual thermal engine. It is a pressure tube with low friction loss (like a hydro power station pressure tube or pen stock) because of its favorable surface-volume ratio. The updraft of the air heated in the collector is approximately proportional to the air temperature rise (ΔT) in the collector and to the height of the tower. In a large solar updraft tower the collector raises the air temperature by about 30 to 35 K. This produces an updraft velocity in the tower of about 15m/s at full load. It is thus possible to enter into an operating solar tower power plant for maintenance without danger from high air velocities.

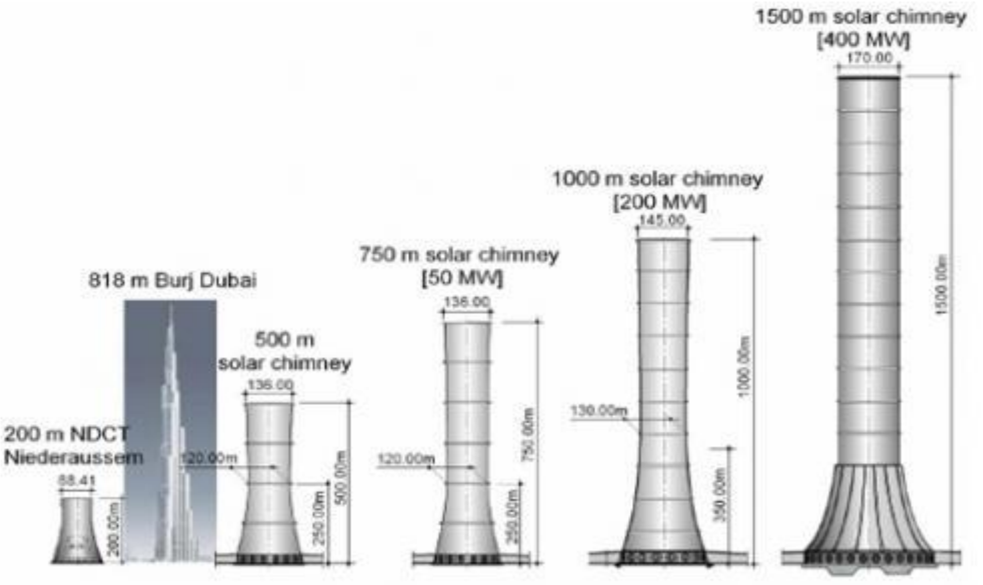


Figure 18: Types of Tower

D. Turbines

Using turbines, mechanical output in the form of rotational energy can be derived from the air current in the tower. Turbines in a solar updraft tower do not work with staged velocity like a free-running wind energy converter, but as a shrouded pressure-staged wind turbo generator, in which, similarly to a hydroelectric power station, static pressure is converted to rotational energy using a cased turbine. The specific power output (power per area swept by the rotor) of a shrouded pressure-staged turbine in the solar updraft tower is roughly one order of magnitude higher than that of a velocity staged wind turbine. Air speed before and after the turbine is about the same. The output achieved is proportional to the product of volume flow per time unit and the pressure differential over the turbine. With a view to maximum energy yield the aim of the turbine control system is to maximize this product under all operating conditions. Figure 5. Tower tube of a solar updraft tower power plant.To this end, blade pitch is adjusted during operation to regulate power output according to the altering airspeed and airflow. If the flat sides of the blades are perpendicular to the airflow, the turbine does not turn. If the blades are parallel to the air flow and allow the air to flow through undisturbed there is no drop in pressure at the turbine and no electricity is generated. Between these two extremes there is an optimum blade setting: the output is maximized if the pressure drop at the turbine is about 80 % of the total pressure differential available, depending on weather and operating conditions as well as on plant design.

4.2.2 Materials of components

a)Collector Material:

Modification of collector material was a compulsory after observing model collector efficiency.After surveying local markets and basing on cost and performance effectiveness we decided to use 8 PVC sheets of 0.9mm thickness and thermal conductivity of this sheet is 0.19 W/m K and specific heat capacity of 840-1170 (J/kg^{o}C). These 8 pieces of sheets were fixed with steel bar type frames.PVC sheets arehighly resistant to oxidative reactions,greater tensile strength and also shows resistance to cracking thus maintains its performance for a long time.

b) Tower Material:

The tower is of PVC and is about 1.7m in height .The pipe is black colored both internally and externally.The tower is supported by steel round frame.

c)Turbine Material:

The turbine is made of polyethylene terephthalate(PET) which is a hard,stiff,strong and dimensionally stiff material.Density of PET is about 1.38g/cm^{3} so it requires less thrust to rotate the fan.

d)Frame Material:

The whole structural layout was designed in such a way that it is strictly stable with steel as its core material.The frame is supporting the whole experimental setup.And we chose steel over other materials after a long market survey keeping in mind various factors like cost effectiveness,welding flexibility,weight etc.

CHAPTER 5: EXPERIMENTAL SETUP AND DATA ANALYSIS

5.1Experimental method:

(a) The outside temperature T_o was measured by pyrometer and thermo couple.And these temperatures were noted down day wise.

(b) The temperature T_i was measured by pyrometer at the same time as the outside temperature and these temperatures were also noted day wise.

(c) The velocity of air at the entrance of the tower was measured by anemometer.

(d) The densities $\beta_o$and $\beta_i$were taken according to the corresponding temperatures $T_o$and $T_{i.}$

(e)The data was taken for different days of six different months and with necessary calculations necessary results were found.

5.2Calculation:

The theory and mathematical expressions for this paper is described below with the aid of Fig.2.The output power of the plant depends upon various parameters presented simply by the following equation.

$$P_{out} = Q_{solar}*\eta_{coll}*\eta_{tower}*\eta_{turbine} = Q_{solar}*\eta_{plant} \quad (1)$$

If the temperature rise in the collector is (Ti – To)then it can be easily expressed as-

$\eta coll *I* Acoll = \dot{m}* Cp* (Ti – To)$ (2)

The tower (chimney) converts the heat-flow produced by the collector into kinetic energy (convection current) and potential energy (pressure drop at the turbine).Thus the density difference of air due to temperature rise inside the collector works as a driving force.The lighter column of the air in the tower is connected with the surrounding atmosphere at the base and the top of the tower,and thus acquires lift.A pressure difference Δp_{tot} is produced between the tower base and the ambient[1]:

$$\Delta p_{tot} = g* \int_0^H (\rho 0 - \rho i)\, dH \qquad (4)$$

This is simplified to,

$$\Delta p_{tot} = g(\rho_0 - \rho_i)\ Ht \qquad (5)$$

The static pressure difference drops at the turbine the dynamic component describes the kinetic energy of the airflow with the total pressure difference and the volume of the air at $P_s=0$ and the power P_{out}contained in the flow is now [2]:

$$Pout = \Delta ptot * vt * Acoll \qquad (6)$$

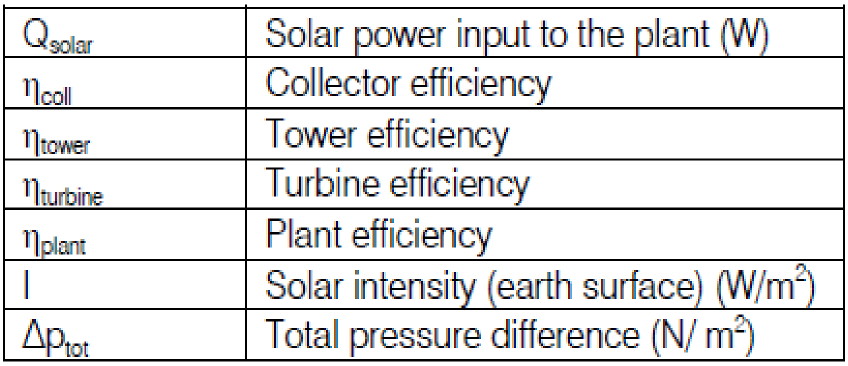
Mass flow rate, $\dot{m} = \rho i * At * vt = \rho i * (\pi/4) * Dt2 * vt \qquad (7)$

Thus without the turbine installed,the total power available to the turbine can be obtained from equation [6].

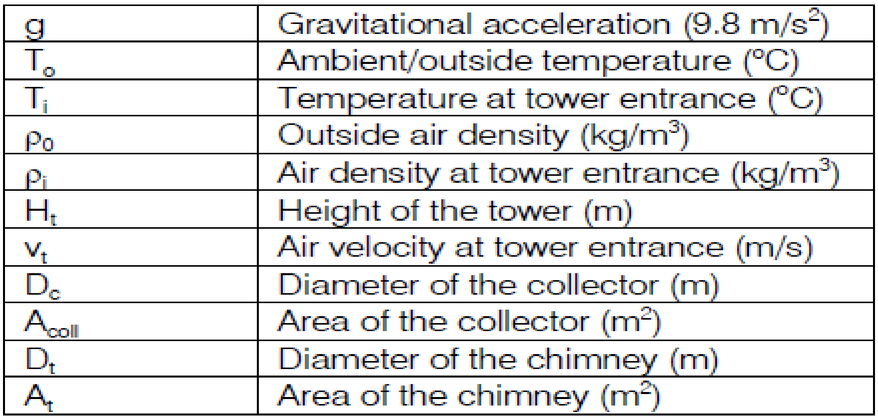
And also the velocity at the entrance can be found by [3]:

$$v_t = \sqrt{\{2gH_t(T_i - T_o)/T_o\}}(8)$$

Nomenclature:



Q_{solar}	Solar power input to the plant (W)
η_{coll}	Collector efficiency
η_{tower}	Tower efficiency
$\eta_{turbine}$	Turbine efficiency
η_{plant}	Plant efficiency
I	Solar intensity (earth surface) (W/m^2)
Δp_{tot}	Total pressure difference (N/ m^2)



g	Gravitational acceleration (9.8 m/s^2)
T_o	Ambient/outside temperature (°C)
T_i	Temperature at tower entrance (°C)
ρ_0	Outside air density (kg/m^3)
ρ_i	Air density at tower entrance (kg/m^3)
H_t	Height of the tower (m)
v_t	Air velocity at tower entrance (m/s)
D_c	Diameter of the collector (m)
A_{coll}	Area of the collector (m^2)
D_t	Diameter of the chimney (m)
A_t	Area of the chimney (m^2)

Design of model-2:

The design of the prototype plant is describedas follows:

Firstly the open ground in front of tower-02 of MIST, Dhaka, Bangladesh was selected as the place for making the prototype considering the availability of sunlight and conveniencesof building the plant.The collector diameter Dc was selected as 1.8283m (6 ft) considering availability of space on the selected place.The ratio of collector diameter to the towerdiameter is called the diameter ratio (DR). The 50 kW plant in Manzanares has DR= 20. For our plant DR=12(approximately) was selected considering availability of tower material in the local market. Thus the tower diameter Dt was selected as = 0.152 m (6in).The height of the tower Ht is proportional to theefficiency of the tower. The higher the chimney is the better is the output. Ht = 2.1m was selectedconsidering availability in the local market and ease ofinstallation and support.The collector inclined angle β was selected 250,as large as possible considering conveniency of work.The larger the angle β higher velocity of air is obtained[4].

Solar intensity I for a normal day was assumed 1353 W/m^2 and temperature To = 303K for designing.Theη_{coll} = 0.005 was assumed. Then from equation (2),

$\eta_{coll} * I * A_{coll} = \dot{m} * C_p * (T_i - T_o) = \rho_i * A_t * v_t * C_p * (T_i - T_o) = \rho_o * A_t * \sqrt{\{2gH_t(T_i - T_o)/T_o\}} * C_p * (T_i - T_o)$ [using equation (7) and (8)].

Here,

$A_{coll=} 1/3\pi r^\wedge 2h$=9.2083 m^2

ρi = ρo was assumed as the density of air changes verylittle with the temperature.

We took 5 temperatures readings from the month May, June, August, September, October, November and December.

Sample calculation for each month is shown below,

May15, from equation (8), v_t=1.4898 m/s

From equation (5),$\Delta p_{tot=}$ 1.317

From equation (6) Pout=18.067 W.

Repeating this process we calculated all the values of the above mentioned months.

Technical Data of model-2:

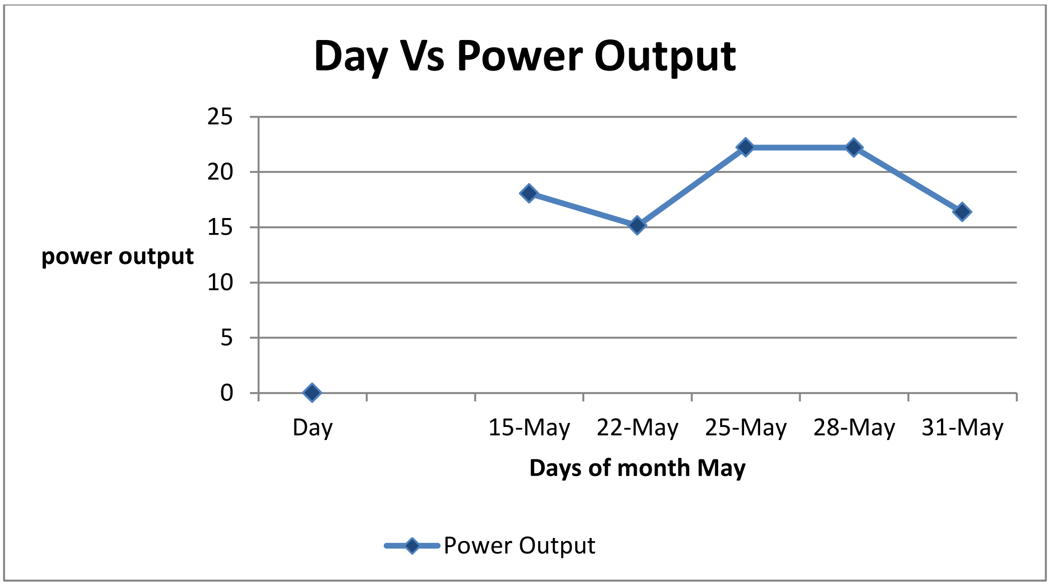
The different technical parameters of model-2 is given below:

Tower height	2.1m
Tower radius	0.76m
Collector radius	1.8283m
Min roof height (at centre)	0.2032m
Max roof height (at centre)	0.587m
Collector slope angle	31.41^o
Typical ΔT	10K
Average output	20W
Tower material	PVC
Collector Material	PVC 0.9mm sheet
Plant frame and support material	Cast iron

Power Analysis:

May 2016

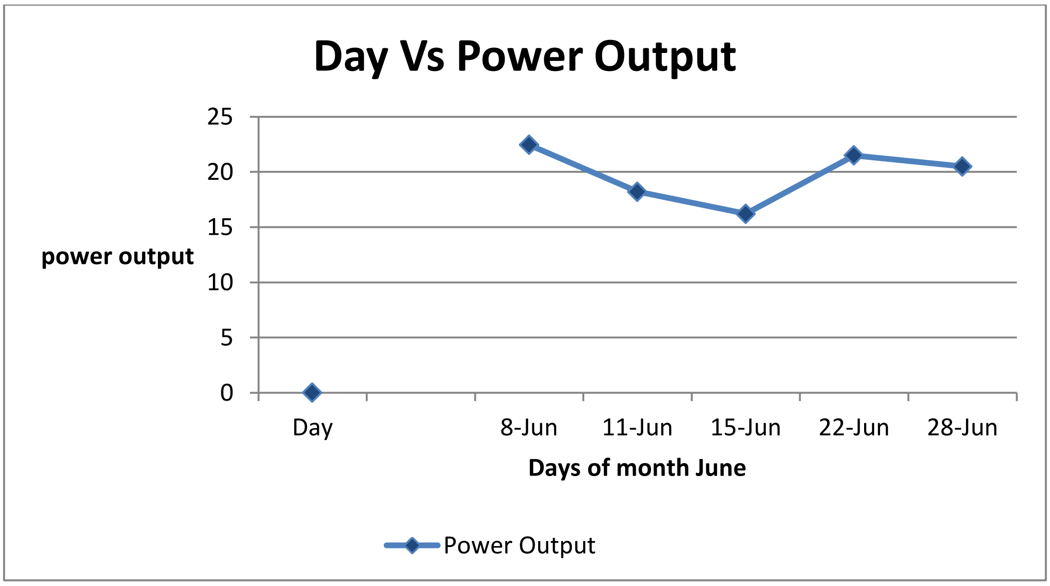
Day Vs Power Output					
Day	15-May	22-May	25-May	28-May	31-May
Power Output	18.067	15.1498	22.213	22.208	16.36



June 2016

Day Vs Power Output

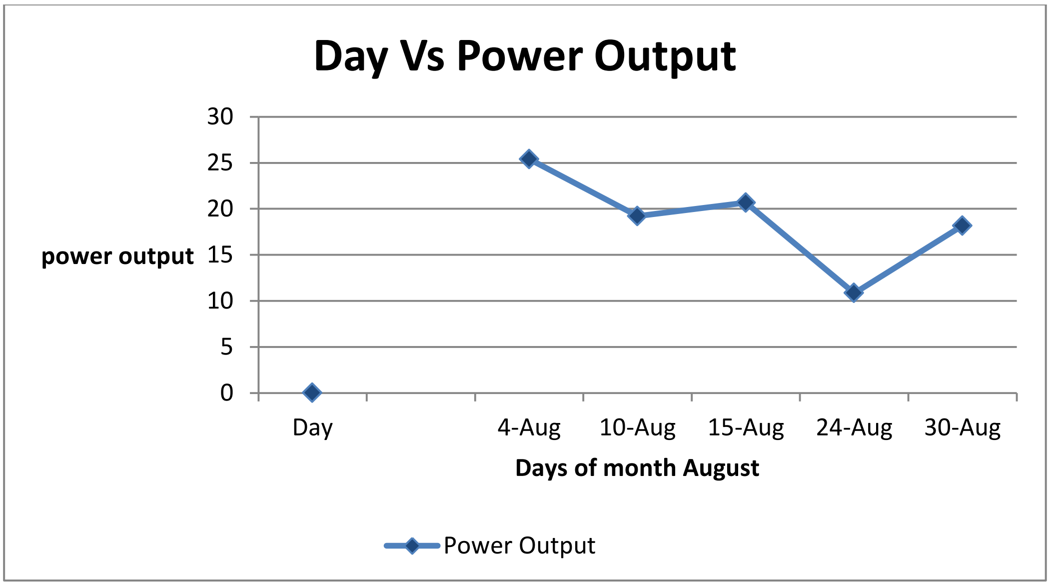
Day	8-Jun	11-Jun	15-Jun	22-Jun	28-Jun
Power Output	22.4499	18.2004	16.203	21.491	20.492



August 2016

Day Vs Power Output

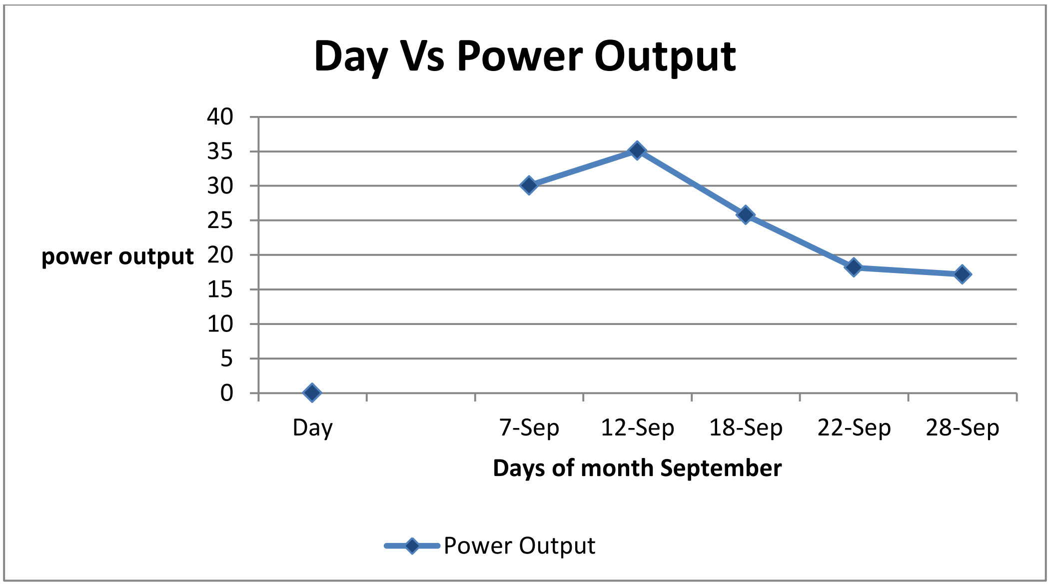
Day	4-Aug	10-Aug	15-Aug	24-Aug	30-Aug
Power Output	25.3898	19.213	20.667	10.8468	18.158



September 2016

Day Vs Power Output

Day	7-Sep	12-Sep	18-Sep	22-Sep	28-Sep
Power Output	30.0584	35.116	25.778	18.179	17.168

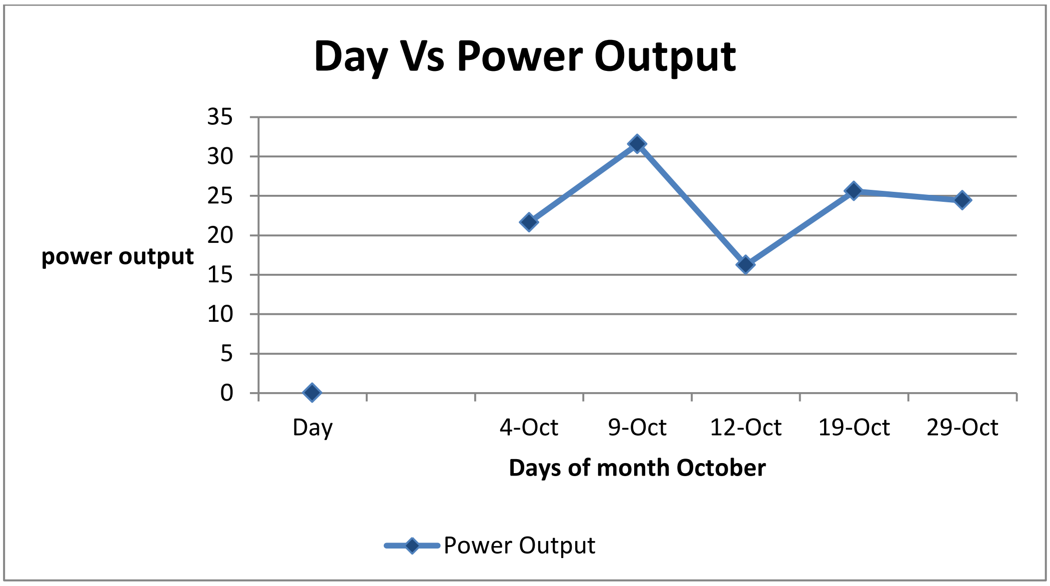


graph 5.3

October 2016

Day Vs Power Output

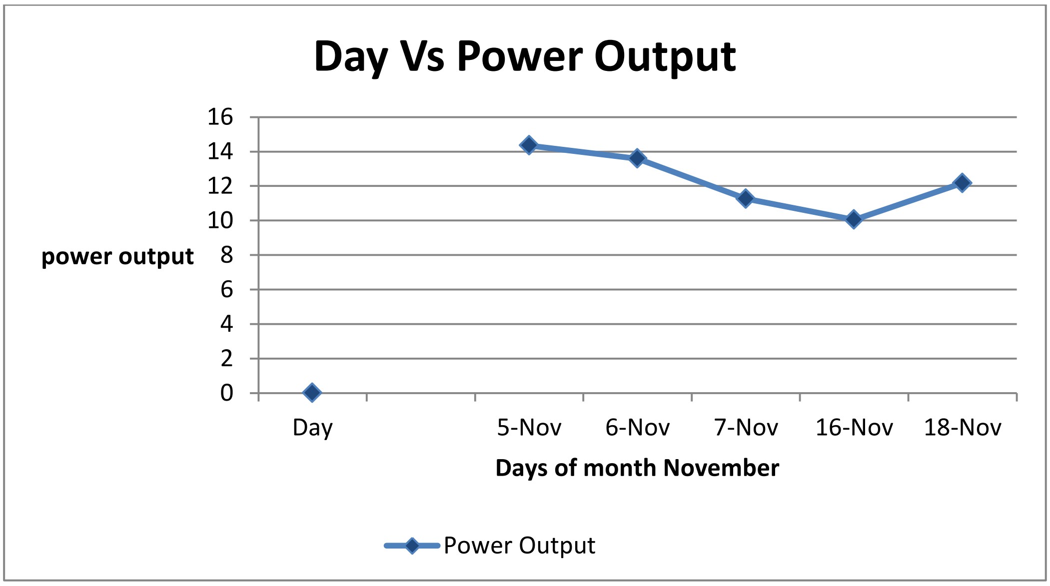
Day	4-Oct	9-Oct	12-Oct	19-Oct	29-Oct
Power Output	21.634	31.558	16.2124	25.588	24.412



November 2016

Day Vs Power Output

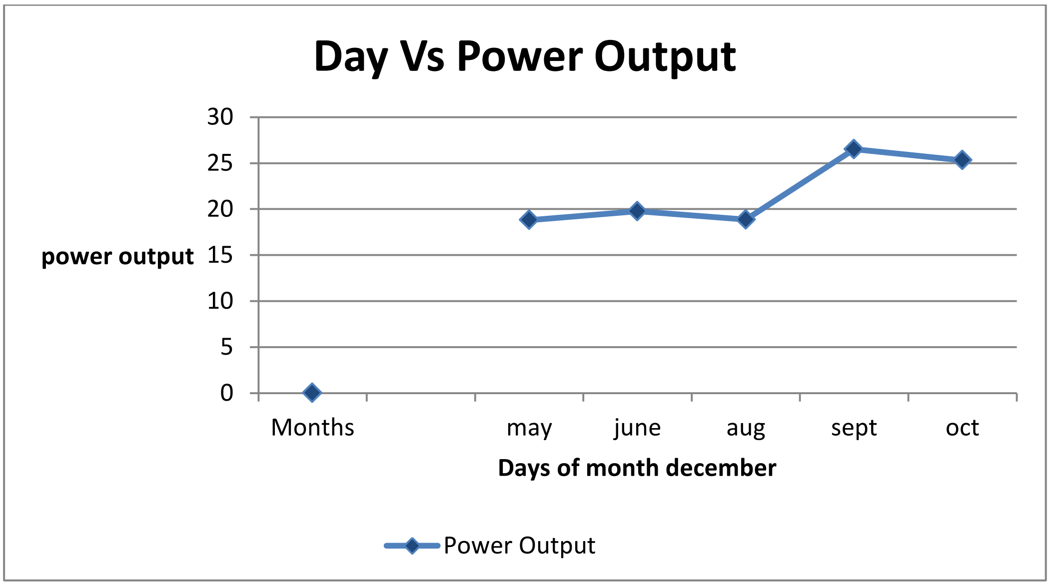
Day	5-Nov	6-Nov	7-Nov	16-Nov	18-Nov
Power Output	14.344	13.588	11.259	10.044	12.1696



December 2016

Day Vs Power Output

Day	21-Dec	22-Dec	23-Dec	24-Dec	25-Dec
Power Output	9.628	9.047	8.637	8.655	9.519



Data table

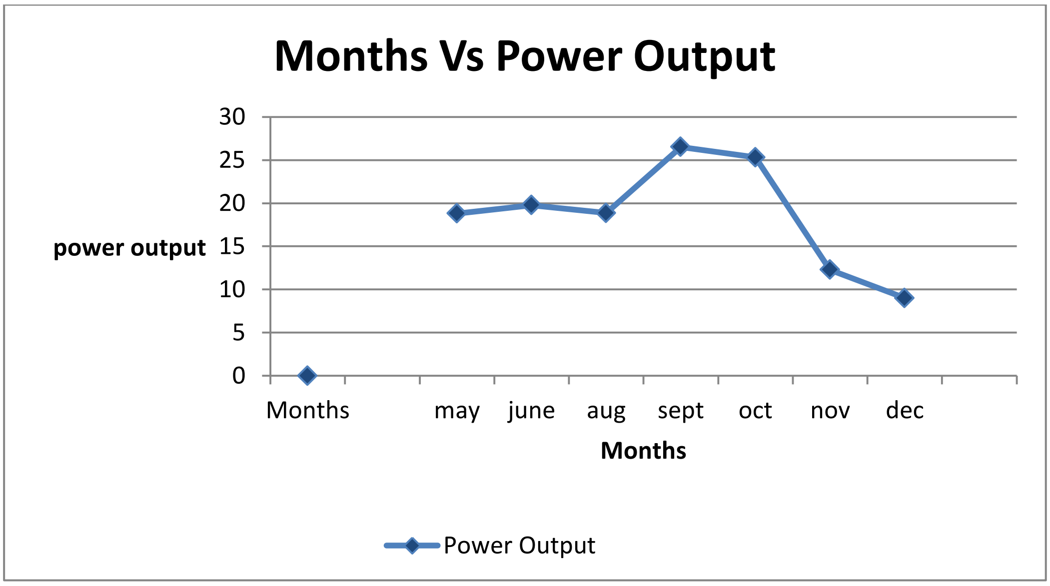
Time	To	Ti	ρo	Pi	ΔPtot	Vt	Pout(Watt)	Avg Pout(Watt)
May 15	33	49.5	1.165	1.101	1.317	1.4898	18.067	
May22	32	48.2	1.163	1.109	1.1124	1.479	15.1498	
May 25	32	50.6	1.163	1.689	1.5229	1.584	22.213	18.79956
May 28	33.5	51.2	1.164	1.088	1.564	1.542	22.208	
May 31	34	50.5	1.161	1.103	1.194	1.488	16.36	
June8	33	51.5	1.165	1.109	1.545	1.578	22.4499	
June 11	32	49.8	1.163	1.101	1.276	1.549	18.2004	
June15	31	48.3	1.165	1.109	1.1536	1.531	16.203	19.76726
June22	33	50.9	1.163	1.090	1.5038	1.552	21.491	
August04	35	52.3	1.158	1.070	1.8128	1.521	25.3898	
August10	28	48.2	1.17	1.109	1.25538	1.662	19.213	
August15	34	51.6	1.161	1.09	1.46118	1.536	20.667	18.85492
August24	34	47.2	1.161	1.118	0.885	1.331	10.8468	
August30	33	50.7	1.165	1.1029	1.278	1.543	18.158	
Sept07	32	52.6	1.163	1.068	1.957	1.668	30.0584	
Sept 12	29	54.2	1.169	1.063	2/058	1.853	35.116	
Sept 18	32	52.9	1.163	1.68	1.708	1.639	25.778	26.50648
Sept22	33	51.7	1.165	1.09	1.544	1.717	24.412	
Sept28	30	48.6	1.165	1.109	1.153	1.617	17.168	
Oct04	35	54.3	1.158	1.187	1.462	1.607	21.634	
Oct 09	31	52.9	1.165	1.06	1.996	1.717	31.558	
Oct12	31	48.2	1.165	1.109	1.153	1.527	16.2124	25.31008
Oct19	35	56.8	1.158	1.079	1.627	1.708	25.588	

Oct 29	30	51.7	1.165	1.090	1.544	1.717	31.558	
Nov05	25	39.2	1.184	1.130	1.1124	1.401	14.344	
Nov06	26	38.3	1.182	1.127	1.1330	1.302	13.588	
Nov07	28	40.9	1.17	1.125	0.92	1.329	11.259	12.28092
Nov16	30	42.9	1.165	1.125	0.824	1.324	10.044	
Nov 18	29	43.3	1.169	1.123	0.9467	1.396	12.1696	
Dec 21	28	38.9	1.169	1.130	0.803	1.221	9.028	
Dec22	31	41.5	1.166	1.126	0.824	1.192	9.047	
Dec23	30.3	40.9	1.165	1.127	0.782	1.199	8.637	8.9772
Dec24	29.2	39.8	1.168	1.130	0.782	1.202	8.655	
Dec 25	27	38.5	1.168	1.128	0.823	1.256	9.519	

Months vs Power output

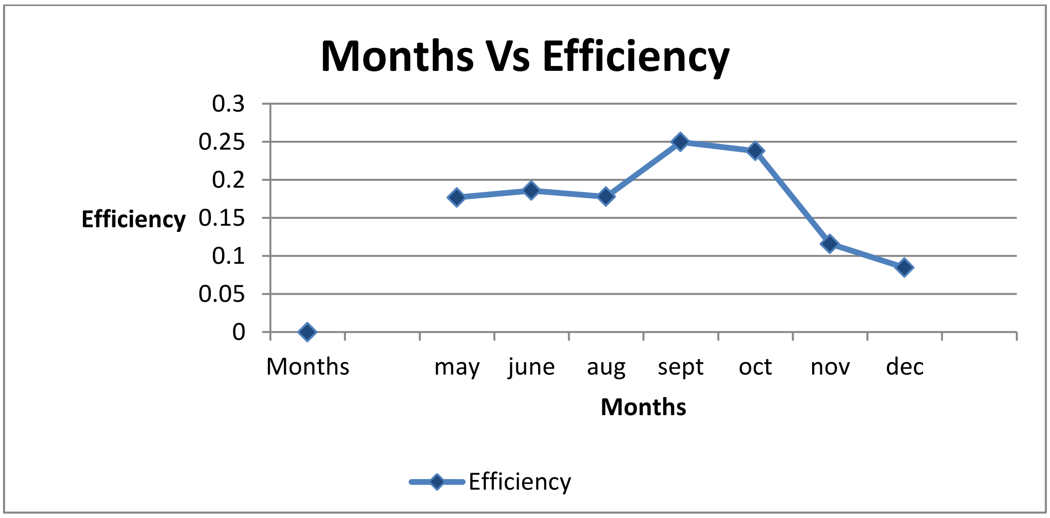
Months Vs Power Output

Months	may	june	aug	sept	oct	nov	Dec
Power Output	18.79956	19.76726	18.85492	26.50648	25.31008	12.28092	8.9972



Months vs Efficiency

months	may	june	aug	sept	oct	nov	dec
Efficiency	0.177	0.186	0.178	0.2497	0.238	0.116	0.0846



CHAPTER 6: DISCUSSIONS

Study from the Experiment

=> Theoretically estimation of power generation from our designed model has been done.

=> Working principle of this project is mainly based on greenhouse effect principle.

=>Air driving force from collector to tower is mainly effected by temperature at outside and inside of the collector,atmospheric pressure,density difference between air inside the collector and outside of the collector and overall buoyancy force.

=>Monthly temperature vs. power output graph has been done.

=> Average temperature of 7 months vs. monthly average power output of these 7 months graph has also been plotted.

=>Average temperature per month and efficiency according to these mean temperature has been plotted.

=> Highest and lowest power output period has been determined.

=> Faults in design and materials of the project are determined.

Characteristics of day versus power output graph

This curve determines the variation of power output with respect to temperature according to the specific days of that specific month.

From the graph of month may it is observed that,there was noticeable stable phase at the near end of the month and it was of a greater value which is about 23W.The lowest temperature of this month was at the starting of the last week and it was of 15W and the month ended also near the same value output.

From the graph of month june it is observed that data was taken from the starting of second week of the month and it was the highest power output of that month and then the power output sharply decreased at the mid of the month.

For the month july and august it is observed that we got the highest power output theoretically at the starting of the month and it is about 23W-25W and the lowest at the end which is about 10-15W

For the month September we get the highest value of all time and it is about 35W and it is around the mid of this month,the lowest of this month is also around 18W.

The decrease in value of power output started gradually from November and at December the lowest of all is determined and it is about 15W.

From these graphs the highest average power output is obtained in the month of September which is to be exact 26.506W.And the lowest average temperature is obtained in the month of December which is around 9W.

Characteristics of month versus power output graph

The average power outputs of different months is obtained from day base data.

From these day base data average power output of that particular month is obtained and than those values are used to plot the graph between those 7 months and average power output per month.

Highest range of power output lies between September and October and the lowest range of power output lies between November and December.

Characteristics of month versus efficiency graph

Efficiency of the model is determined from monthly average power output and is also plotted in a graph so that the highest efficiency and lowest efficiency for a particular period and region can be easily dictated.

From the month versus efficiency graph it is clear that the highest efficiency which is about 0.25 is obtained at the month of highest temperature and the month of highest average power output.September and October both months provides efficient execution of this project on the other hand November and December provides with least efficient execution.

CHAPTER7: PROSPECT OF SOLAR UPDRAFT TOWER IN BANGLADESH

7.1 Geographic profile of Bangladesh

Bangladesh is located in the north-eastern part of south Asia and splits its longest three geographical borders(4000km)with the nearest country Indiawitha241 0' 0″ N latitude in the north (N) and901 0' 0″ E longitude to the east(E).Myanmar is the extreme south east, and the Bay of Bengal is the southern margin Geographically, it is mostly covered by a low-lying land delta by the river zone of Brahmaputra and Ganges and has occupied a land of 147,570 sq km. However, the north-east basin zones from the sea level can be found up to 3–6 min their mean altitude, and some south east and northeast zones are over1000m.

Figure 19:Geographic location of Bangladesh

7.2 The climate of Bangladesh

Bangladesh is a small south Asian country which has an area of 147,570 km2 and located between latitudes 20.59°–26.63°N and longitudes 88.01°–92.67°E. It is a low-lying plain situated on deltas of large rivers flowing from the Himalayas. The climate of Bangladesh is a subtropical climate with high seasonal variations in rainfall, moderately warm temperatures, and high humidity (Rashid 2006).

There are four distinct seasons:
(1) the dray winter season from December to February,
(2) the pre-monsoon hot summer season from March to May,
(3) the rainy monsoon season from June to September, and
(4) the post-monsoon autumn season which lasts from October to November (Shahid2010).

Because of these distinct seasons, Bangladesh receives variable rainfall according to place and time. Rainfall varies from 1400 to 4400 mm from west to east, respectively. The coldest month is January and the hottest month is May in Bangladesh. The lowest average temperature that belongs to January is about 10–15 1C, and the highest average temperature is about33–41 1C between April and July .The typical weather is mostly humid where the rainfall varies annually from 1525mm(60in.) to 5080 mm(200in.) in different locations. The country receives the highest rainfall during June–September whereas little rainfall is predicted in the winter season, and experiences relatively high temperature and humidity with a great variation in rainfall as a sub-tropical zone.

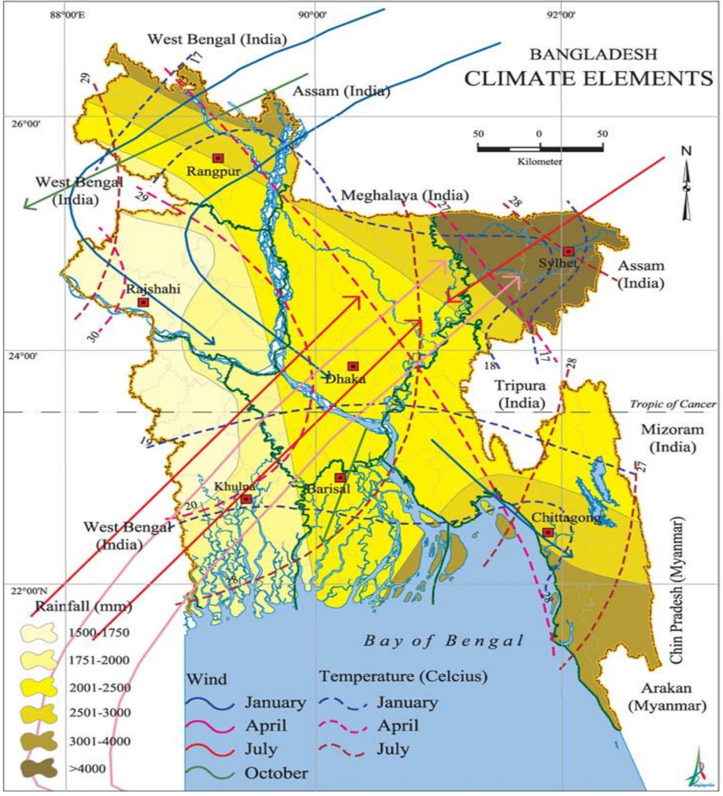


Figure 20: Climate of Bangladesh

7.3 Availability of solar energy in Bangladesh

Bangladesh is a semi-tropical region lying in northeastern part of South Asia gets abundant sunlight year round. The average bright sunshine duration in Bangladesh in the dry season is about 7.6 hours a day, and that in the monsoon season is about 4.7 hours. The highest sunlight hours received is in Khulna with readings

ranging from 2.86 to 9.04hours and in Barisal with readings ranging from 2.65 to 8.75 hours. These are very good statistics when compared to the 8 hours of daylight in Spain which produced 4 GW of energy covering 2.7% of national demand by the end of 2010. Moreover Germany produces 18 GW of energy
which is 2% of their national demand with only half the solar radiation received by Bangladesh. Thus solar power could be a great source of energy for Bangladesh.

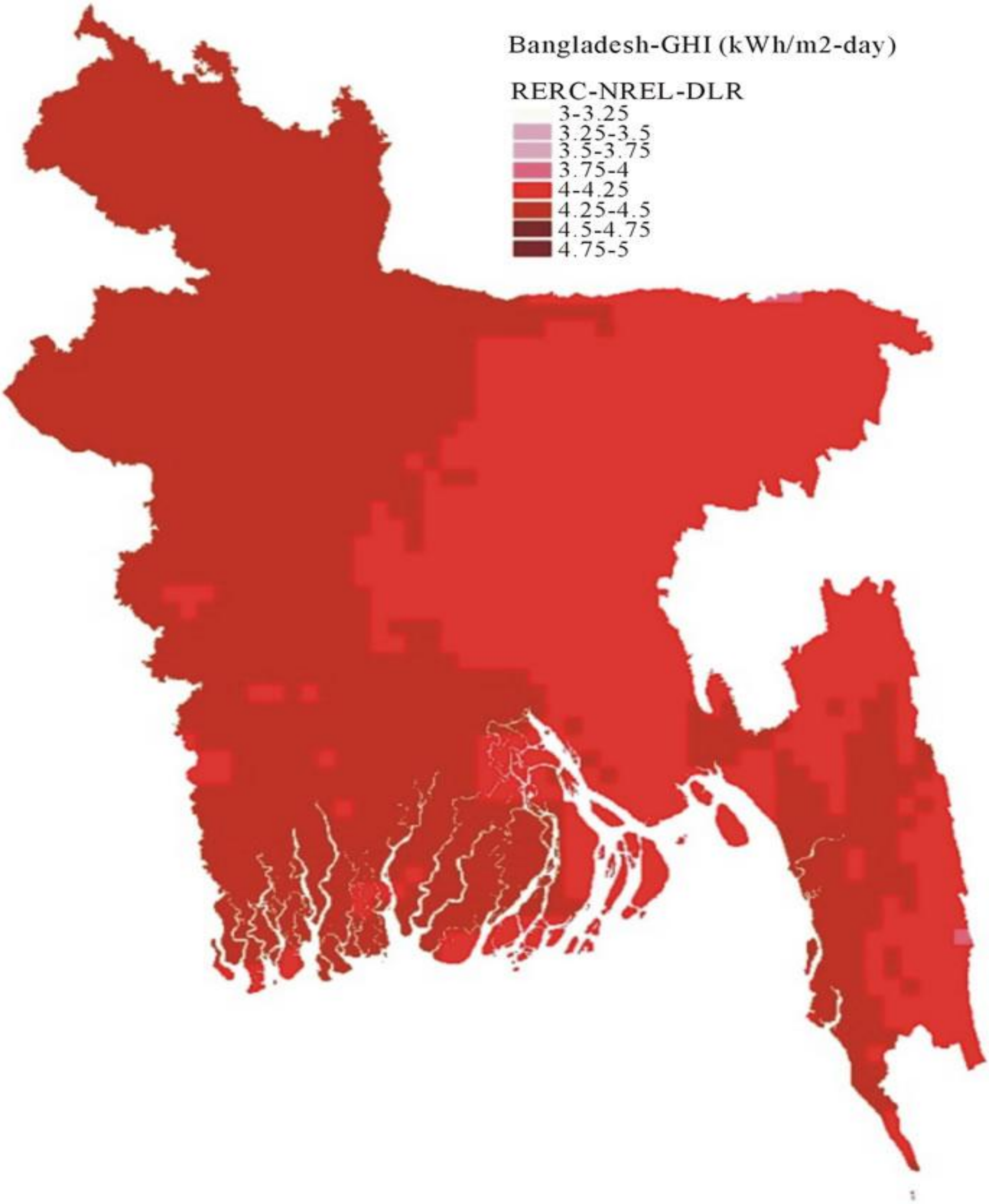


Figure 21: Solar energy available areas

Table1: Showing Data of monthly average sunshine hour in six different divisions over a period of 3 years

Year Months Dhaka Chittagong Khulna Rajshahi* Barisal Sylhet

Year	Months	Dhaka	Chittagong	Khulna	Rajshahi*	Barisal	Sylhet
2008	January	4.68	7.39	5.73	0	6.48	4.94
	February	6.57	8.12	7.26	0	7.6	6.81
	March	5.92	6.57	6.91	0	6.9	6.2
	April	8.49	8.7	9.04	0	8.75	8.52
	May	7.75	8.14	8.34	0	7.53	6.37
	June	4.17	3.88	4.16	0	2.93	3.43
	July	3.1	4.07	2.86	0	2.65	3.26
	August	4.04	4.75	4.38	5	4.14	3.03
	September	4.43	5.55	5.11	5.98	5.01	5.54
	October	5.79	6.91	7.46	7.66	7.39	6.73
	November	7.95	8.47	8.81	8.87	8.61	9.32
	December	3.88	6.11	5.53	4.71	6.49	6.78
2009	January	5.71	7.32	6.19	5.48	6.81	6.52
	February	8.66	8.71	8.91	9	8.47	7.63
	March	7.27	7.44	7.97	7.56	7.51	7.24
	April	8.31	8.69	9.07	8.52	8.77	7.18
	May	6.75	7.76	7.8	7.11	7.2	6.77
	June	5.94	6.28	6.25	7.82	6.43	4.59
	July	4.7	4.45	3.68	5.39	3.66	5.3
	August	3.85	3.62	3.85	3.85	3.97	3.51
	September	4.13	6.01	4.1	6.27	5.31	5.64
	October	6.19	6.39	7.24	7.12	7.13	6.89
	November	6.73	5.62	7.31	6.8	7.67	6.86
	December	4.79	5.26	6.93	5.1	6.97	6.98

2010	January	5.7	7.63	7.5	5.99	7.08	7
	February	6.74	8.55	7.82	8.25	7.54	6.69
2010	March	8.35	7.56	8.41	8.24	8.25	6.65
	April	7.34	7.75	8.99	8.06	8.45	5.46
	May	6.74	6.97	7.08	7.29	6.66	5.26
	June	3.74	3.99	4.3	4.62	3.78	2.19
	July	4.93	5.42	5.14	5.91	4.75	3.52
	August	4.37	5.38	5.04	5.56	4.81	3.88
	September	3.83	6.09	5.49	5.79	5.05	4.32
	October	5.82	6.49	6.4	6.89	7.01	7.03
	November	6.24	8.03	6.63	7.42	6.94	7.39
	December	6.17	7.38	6.24	6.22	6.15	7.18

**Data of first 7 months of 2008 for Rajshahi was unavailable*

Table2: Showing Data of monthly average solar radiation in six different divisions over a period of 3 years

Year	**Month**	**Dhaka**	**Chittagong**	**Khulna**	**Rajshahi***	**Barisal**	**Sylhet**
2008	January	164.9	63.40	213.10	0.00	197.5	125.3
	February	209.8	115.40	281.10	219.30	260.4	176.4
	March	225.7	150.00	276.50	232.30	307.8	196.8
	April	283.3	163.80	310.10	249.10	348.9	237.5
	May	261.1	139.60	318.70	225.30	302.5	212.0
	June	212.4	124.30	201.00	116.40	191.3	158.7
	July	176.2	120.20	158.30	216.20	184.3	140.3
	August	174.1	135.90	222.40	201.30	195.0	147.3
	September	189.6	139.20	212.30	171.30	211.7	166.1
	October	179.7	130.30	223.30	186.70	239.9	154.4
	November	208.1	145.40	233.50	159.50	261.1	168.2

	December	123.7	88.40	193.70	124.00	185.5	117.4
2008	January	165.6	98.10	226.00	134.50	209.3	133.9
	February	219.1	145.70	271.50	178.10	287.1	159.0
2009	March	228.3	138.90	261.40	222.80	292.1	163.0
	April	273.1	167.60	301.80	215.30	335.8	154.7
	May	235.1	169.80	289.10	207.60	317.1	155.0
	June	210.3	143.40	303.60	171.40	321.9	149.7
	July	197.0	90.50	218.80	188.00	218.6	176.9
	August	177.5	83.80	191.50	172.90	196.5	169.2
	September	166.8	114.40	224.70	177.60	242.1	186.1
	October	189.1	101.00	231.60	166.4	210.9	182.5
	November	164.0	95.70	215.40	156.30	241.8	150.3
	December	142.5	80.00	193.70	143.80	224.4	127.5
2010	January	151.5	89.50	216.50	103.27	245.0	119.1
	February	186.7	126.70	234.60	169.85	271.5	74.6
	March	238.2	128.30	264.40	203.10	269.8	171.7
	April	236.7	118.00	276.70	211.93	343.4	197.8
	May	225.8	123.40	252.50	188.70	305.2	171.5
	June	176.0	82.20	199.30	174.35	194.7	133.9
	July	201.6	112.20	191.60	165.30	234.4	171.4
	August	166.3	113.30	209.80	100.43	201.1	161.5
	September	165.5	88.20	186.50	177.39	218.5	125.7
	October	175.2	92.30	193.20	173.69	207.0	158.3
	November	168.0	92.70	195.20	158.97	235.5	139.6
	December	159.2	94.30	180.30	108.00	226.4	124.3

Data for the month of January,2008 for Rajshahi was unavailable

Year	**Month**	**Dhaka**	**Chittagong**	**Khulna**	**Rajshahi**	**Barisal**	**Sylhet**
	January	2.06	1.86	1.43	1.89	1.59	2.55
	February	1.74	1.33	1.14	1.18	1.34	1.82

2008	March	3.78	2.81	3.12	2.2	3.61	4.14
	April	2.78	2.68	2.9	2.2	2.72	3.86
	May	4.58	4.09	4.37	3.41	4.18	5.22
	June	6.44	5.54	6.1	5.79	6.61	7.2
	July	6.9	5.95	6.97	6.36	7.13	7.37
2008	August	6.32	6.04	6.25	6	6.1	7.39
	September	5.56	5.35	5.82	5.15	5.52	6.13
	October	3.94	3.39	2.95	2.85	3	4.07
	November	1.26	1.61	1.22	0.85	1.05	1
	December	1.56	1.45	1.21	2.43	0.89	1.49
2009	January	0.46	0.47	0.61	0.61	0.48	1.21
	February	0.74	0.73	0.6	0.34	0.76	1.02
	March	2.2	2.43	2.07	2.15	2.78	2.96
	April	3.11	3.02	2.43	2.1	2.96	4.78
	May	4.85	4.19	4.01	3.81	4.69	5.57
	June	5.81	5.43	4.76	4.35	5.26	6.7
	July	6.57	6.31	6.63	6	6.71	6.34
	August	6.58	6.25	6.44	6.36	6.62	6.91
	September	5.62	5.66	5.18	6.33	5.25	5.79
	October	3.29	3.08	2.82	2.7	3.16	3.91
	November	2.22	2.22	2.11	1.87	1.99	2.47
	December	0.71	0.84	0.32	0.36	0.55	0.98
2010	January	0.53	0.84	0.96	1.38	0.93	1.31
	February	1.45	1.52	1.25	1.04	1.58	1.6
	March	2.63	2.2	1.95	0.9	2.51	3.51
	April	4.66	3.84	3.75	2.47	4.76	6.03
	May	5.46	4.78	4.45	4.31	7.15	6.44
	June	6.38	6	5.77	6.02	6.62	7.48
	July	6.1	5.85	5.65	5.41	6.09	7.06

2010	August	5.95	6.18	5.67	5.33	5.92	6.88
	September	5.83	5.21	4.9	4.8	5	6.54
	October	3.2	4.55	4.12	3.44	3.89	4.16
	November	1.48	1.6	1.75	1.33	1.38	1.85
	December	1.55	1.38	1.53	1.41	1.41	1.45

7.4 Solar energy available areas

Ideal locations for a solar power plant will have to be arid, flat lands with minimum cloud cover, high solar radiation availability and exhibit high average sunlight hours throughout a year. Mostly three different types of landscapes are found in Bangladesh flood plains, terraces and hills with floodplains being the most frequent (around 80% of the total landscape). Parts of Bangladesh like Khulna, Barisal and Rajshahi shows the trend of receiving a higher than average amount of solar radiation (figure 2 and table 2) when compared to the rest of the country. Although there is a trend of the amount solar radiation received decreasing during the monsoon season the annual average sunlight hour and solar radiation is sufficient in most areas of Bangladesh for the operation of small scale SHS(Solar Home Systems) .In fact the annual solar radiation availability in Bangladesh is as high as 1700kwh/m^2.During the monsoon season the average solar radiation availability across the country is around 174.2 cal/cm^2/min. Some parts of Barisal and Khulna even have high radiation and sunlight hour figures for the ideal operation of grid connected PV’s and even CSP stations(Concentrated Solar Power).Most solar radiation is received in Khulna with readings varying from 180.30 to 318.70cal/cm^2/min and in Barisal with reading varying from 185.5 to 348.9cal/cm^2/min. The above mentioned areas also receive a lot less cloud coverage (figure3 and table 3)except during the monsoon season, throughout the year. The lowest cloud coverage is in Rajshahi and Khulna, with readings varying from 0.34 to 6.36 okta in Rajshahi and 0.32 to 6.97 okta in Khulna. During the monsoon season the average cloud coverage across the country is 5.42 okta.

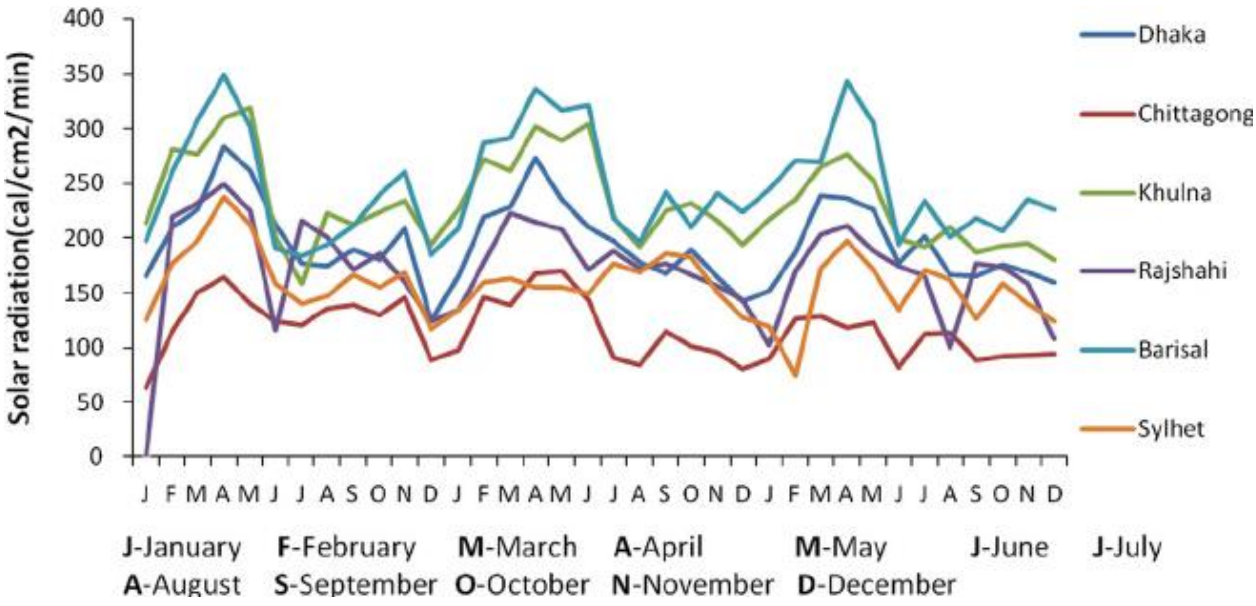


Figure 22: Radiation vs time curve

7.5 Limitations Bangladesh may face in building up a solar tower power plant and there remedies

7.5.1 Limitations :

(a) Construction of solar power stations requires extensive infrastructure and equipment. These require a staggering amount of fund most of which will have to be borrowed from foreign donors.

(b) Maintenance and repairing may also be an issue due to the lack of experience of the technicians
in this sector.

(c).A solar power plant will need hundreds of hectares of area cleared for its construction which
will naturally have adverse effects on the environment.

(d)Also during the winter season and sometimes during the monsoon season cloud cover increases drastically thereby limiting sunlight availability and thus might affect the generation scheme.

7.5.2 Possible Remedies

Training programs conducted by experts from countries notable for their advancement in solar energy sector could be arranged. Government can provide financial incentives, aid packages, offer technical and legal support and even subsidize organizations dealing or wanting to set up in the solar sector. Many countries like Denmark, Spain, and Germany have already declared national policies to generate at least 20% of their national demand through renewable sources and by 2050 become completely powered by renewable energy. The Bangladesh government has also developed a policy to meet 5% of the country’s electricity demand by 2015 and 10% by 2020.Such actions are indeed commendable but even more needs to be done for Bangladesh to meet the increasing demand of electricity for economic development. So, solar updraft tower power plant could be one possibility to achieve the goal.

7.6 Prospect of solar updraft tower power plant

Average amount of solar radiation over a whole year in Bangladesh is quite effective for building up a solar tower power plant. But in case of solar cell, most of the families in the country will not be able to afford solar cells for their home(especially in the rural areas). Moreover, manufacture the photovoltaic cells (PV), reflectors and other auxiliaries, all of which will have to be imported. So, solar tower power plant even if in small scale will be beneficial for the power supply to the rural areas of our country.

CHAPTER8: SOLAR UPDRAFT TOWER POWER PLANT AROUND THE WORLD

Although the principle of an updraft solar tower has been known for long - in particular since it is based on a combination of the well-known chimney effect, wind energy and greenhouse effect - it has not been applied in practice on a large scale yet. Many countries around the world built some prototype and worked on the model of solar updraft tower. Some of those will be discussed in this chapter briefly.

SPAIN

In 1982, a small-scale experimental model of a solar draft tower was built in Manzanares, Ciudad Real, 150 km south of Madrid, Spain at 39°02′34.45″N 3°15′12.21″W. The power plant operated for approximately eight years. The tower's guy-wires were not protected against corrosion and failed due to rust and storm winds. The tower blew over and was decommissioned in 1989. Inexpensive materials were used in order to evaluate their performance. The solar tower was built of iron plating only 1.25 millimeters (0.049 in) thick under the direction of a German engineer, Jörg Schlaich. The project was funded by the German government. The chimney had a height of 195 meters (640 ft) and a diameter of 10 meters (33 ft) with a collection area (greenhouse) of 46 hectares (110 acres) and a diameter of 244 meters (801 ft), obtaining a maximum power output of about 50 kW. Various materials were used for testing, such as single or double glazing or plastic (which turned out not to be durable enough). One section was used as an actual greenhouse. During its operation, 180 sensors measured inside and outside temperature, humidity and wind speed data was collected on a second-by-second basis.[21] This experiment setup did not sell energy.

Figure 23: Manazanarez solar Chimney,Spain

Figure 24: The collector at Manzanares plant in Spain (Schlaich 2005)

The Manzanares plant provided a useful evaluation of the performance of the greenhouse. The roof proved to be insensitive to dust accumulation, with the infrequent rains in the area providing sufficient for self-cleaning (Schlaich 1995). The durability of the glass roof proved to be exceptional, with none of the panes from the collector of the test plant broken during the seven years of operation, while some portions of the plastic roof ripped as early as the first year of operation. An additional benefit of the collector is that the ground area under the collector can be used as a greenhouse for growing plants or as a drying area for plant material.

Lessons from Manzanares

The test facility at Manzanares provided most of the existing practical data on the construction and operation of a solar updraft tower. In addition to providing data on the construction and material choices for solar updraft towers as described in previous sections, the facility also provided extensive operational data that has been used to construct computer performance models. The model allows the results from the Manzanares text plant to be generalized to other geographic areas with differing levels of solar insolation and thermal storage mass. The operational lessons taught by the tower have also proven that the towers are reliable and require very few personnel for regular operation.

China

One study focuses on the possibility of placing solar updraft towers in the Ningxia region of China (Dai 2003). There are a wide variety of reasons that rural villages in the area may be good candidates for solar updraft towers. The Ningxia region is to the southeast of the Gobi Desert (as shown in Figure 8), and has higher solar insolation than many other regions of China. In much of rural northwestern China, grid-connected electricity and the means for many sources of renewable power are unavailable or unreliable. The low operational cost and freedom from external systems are very attractive. In particular, water shortages are a problem in rural China, so the freedom from cooling water systems necessary for traditional solar thermal power systems is a significant advantage. The ability to take advantage low construction and labor costs is another advantage of construction in the area. In general, solar updraft towers can be sized to suit villages, and the dual use of the collector as a greenhouse can be very appealing in a rural setting. In this region of China in particular, the government has encouraged the use of greenhouses to extend the vegetable production season.

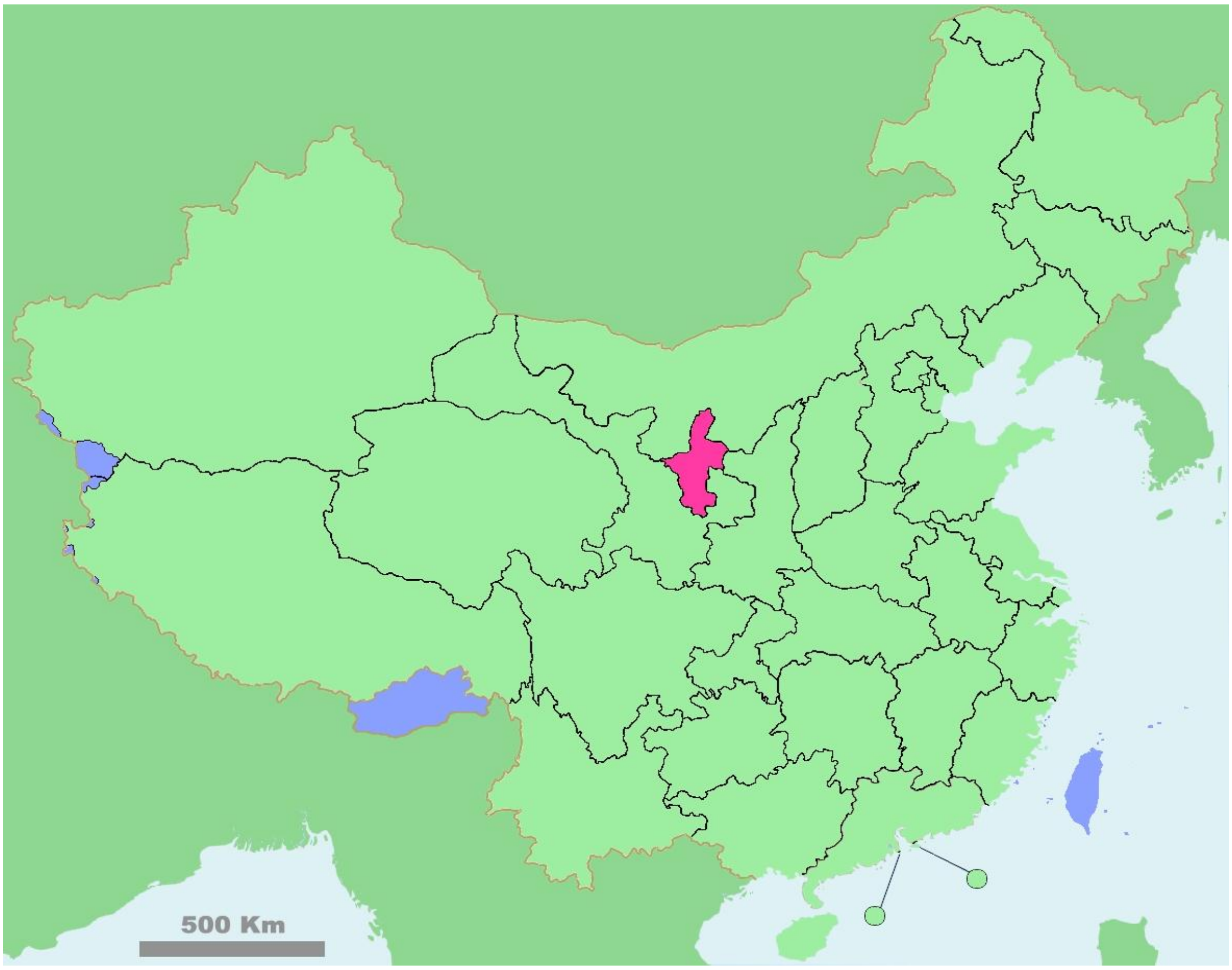


Figure 25: Ningxia region of china in pink

In December 2010, a tower in Jinshawan in Inner Mongolia, China started operation, producing 200 kilowatts.[22][23] The 1.38 billion RMB (USD 208 million) project was started in May 2009. It was intended to cover 277 hectares (680 acres) and produce 27.5 MW by 2013, but had to be scaled back. The solar chimney plant was expected to improve the climate by covering loose sand, restraining sandstorms.[24]Critics have said that the 50m tall tower is too short to work properly and that it was a mistake to use glass in metal frames for the collector, as many of them cracked and shattered in the heat.

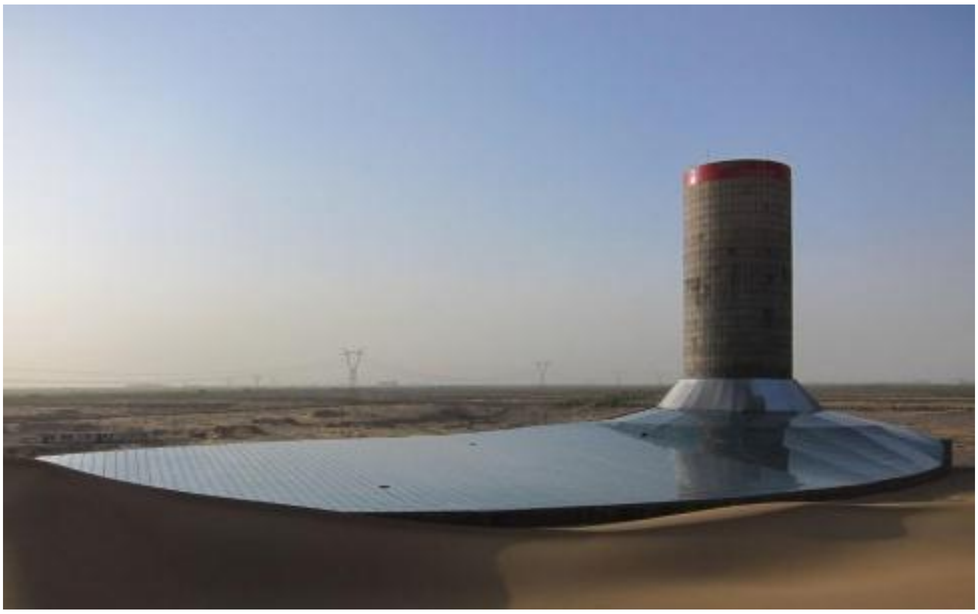


Figure 26: SUTPP in Gobi desert China

The highest previous attempt to master the technology, which has been discussed for decades, ended in failure when a 195-metre tall tower in Manzanares, Spain, collapsed in 1989 due to structural failure.But Professor Wei Yili , the leader of the project at Inner Mongolia University of Science and Technology, said he was confident they could now build safe and efficient towers higher than a kilometer .The structural problem will be no longer a problem for them. They have acquired patents for our technology and design . He said, "The towers will stand for a century, outlasting those who build them or see them built, like the Eiffel Tower."

The 50-metre high test "solar updraft tower" has been running in the Gobi desert in Wuhai for nearly four years.Scientists wanted to build a chimney as high as 200 meters, but had to rein in their ambitions because of a nearby airport."This is the biggest regret of the project," Wei said. "Our power generation capacity and efficiency have been severely restricted by the limited height."The project has managed to generate up to 4,800 kilowatt hours of electricity a day.That is enough to power about 160 homes, based on average electricity usage figures in the United States.Wei said they had used the data from the project to improve their mathematical modelling of the technology and had come up with new designs that could be used in big Chinese cities.

Africa

Studies have also investigated the use of solar updraft towers in Africa (Onyango 2006, Pretorius 2006). Large portions of Africa have high levels of annual solar radiation, as shown in Figure below and are thus good candidates for solar energy. Many of the same issues surrounding the use of solar updraft towers in rural China discussed in the previous section apply in the case of rural Africa as well. Many areas do not have reliable sources of electricity, fuel, or water, so the independent, resource-free operation of the plant is critical to the success of any power plant in the area. The dual use of the collector area for agriculture is an added benefit. Financially, the use of local labor can both reduce construction costs and contribute to the local job pool. The cost of electricity is also improved because higher solar insolation leads to higher energy production, so equivalent yields can be attained with a smaller plant.

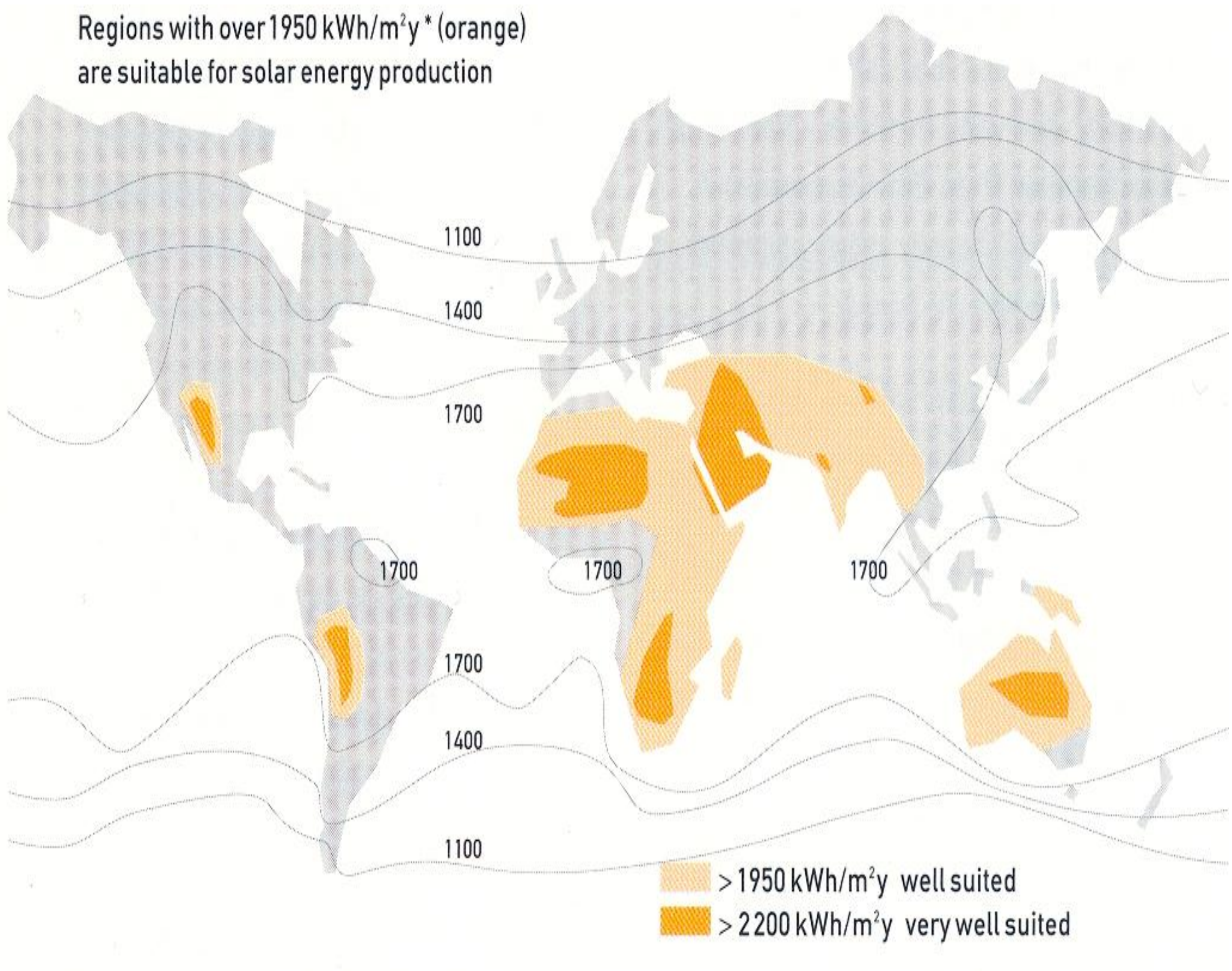


Figure 27: World solar Irradiation levels (Schlaich 1995)

Australia

Australia-based EnviroMission Ltd recently announced plans to build two solar updraft towers that span hundreds of acres in La Paz County, Arizona. EnviroMission Ltd‘s new initiative is not a small project by any means. The towers will each have 2,400 foot chimneys over a greenhouse measuring four square miles.

Estimated cost of the project is $750 million, and the power would be 200megawatt.The Southern California. Public Power Authority recently approved EnviroMission as a provider, but solar updraft hasn’t yet been proven to be commercially viable. That means EnviroMission might have trouble raising enough cash to get started.

Figure 28: proposed Sutpp by EnviroMission Ltd.

Namibia

In mid-2008, the Namibian government approved a proposal for the construction of a 400 MW solar chimney called the 'Greentower'. The tower is planned to be 1.5 kilometers (4,900 ft) tall and 280 meters (920 ft) in diameter, and the base will consist of a 37 square kilometers (14 sq mi) greenhouse in which cash crops can be grown.

Other proposed solar updraft tower power plants

In 2001, EnviroMission[31] proposed to build a solar updraft tower power generating plant known as Solar Tower Buronga near Buronga, New South Wales.[32] The company did not complete the project.

In December 2011, Hyperion Energy, controlled by Western Australians Tony Sage and Dallas Dempster, was reported to be planning to build a 1-km-tall solar updraft tower near Meekatharra to supply power to Mid-West mining projects

Based on the need for plans for long-term energy strategies, Botswana's Ministry of Science and Technology designed and built a small-scale research tower. This experiment ran from 7 October to 22 November 2005. It had an inside diameter of 2 meters (6.6 ft) and a height of 22 meters (72 ft), manufactured from glass-reinforced polyester, with an area of approximately 160 square meters (1,700 sq ft). The roof was made of a 5 mm thick clear glass supported by a steel framework.

A model solar updraft tower was constructed in Turkey as a civil engineering project.Functionality and outcomes are obscure.A second solar updraft tower using a transpiredcollector is operating at Trakya University in Edirne Turkey and is being used to test various innovations in Solar Updraft Tower designs including the ability to recover heat from photovoltaic (PV) arrays.

In developing countries, the technology has been tested in Botswana in 2005 and there are plans to test it in Namibia. In Botswana, a small 22 meter tall chimney was built with a collector area of 160 m^2. The chimney was made of polyester material and the roof of the collector area of glass (Ketlogetswe, 2007).

CHAPTER 9: COMPARISON BETWEEN COMPETING TECHNOLOGIES

Several other solar energy technologies fill the same niche as solar updrafttowers. Similarly to solar updraft towers, these technologies may be self-contained,have little maintenance requirements, no fuel requirements, and arecapital intensive. Concentrating solar power and solar photovoltaic panels areconsidered as alternatives to solar updraft towers.

9.1 COMPETING TECHNOLOGIES

9.1.1 Concentrating Solar Power

Concentrating solar power uses reflectors to concentrate solar radiation to heat a working fluid that is used to drive a thermal cycle. In concentrating solar plants, solar-tracking curved reflectors are used to concentrate direct solar radiation to a central receiver carrying a working fluid. As with solar updraft towers, areas with high solar insolation are best for the operation of concentrating solar plants. Cloud cover should also be minimal, as concentrating solar plants cannot utilize diffuse radiation.

The efficiency of concentrating solar plants for utilizing direct solar irradiance typically falls in the range of 10-30% (Johansson 1993). Trough-style plants, which use parabolic mirrors to focus light on a center-run absorber, typically achieve efficiencies of about 12% (Tester 2005). The plant construction costs typically run about 3000 dollars per kilowatt electric installed capacity (NREL 2003). Plants are built up from series of individual trough units. Trough-style units have a longer operating history than other types of concentrating solar plants, and thus issues with their use are well known. Water use for evaporative cooling, high maintenance costs for the necessary cleaning of the mirrors, repair of the working fluid system, and maintenance of the tracking elements, and lack of energy storage ability are all significant issues for trough plants, some of which are also shared with other concentrating solar plants.

Two emerging concentrating solar power technologies, power towers and dish engines, may also have a role to play in isolated rural communities. Power towers use spherical heliostats to direct power toward a central tower receiver that uses aworking fluid, such as moltensalts. Power tower construction costs are suggested to be in the rage of 3000-4000 dollars per kilowatt electric installed capacity (Tester 2005). Power towers share many of the same issues as trough plants; water use for evaporative cooling, maintenance costs for cleaning and operating the mirrors, and the inability to operate in cloudy conditions. Additionally, power towers have the disadvantage that they typically have to be built as large units, as opposed to many other solar technologies. On the other hand, power towers have the advantage that the working fluid can be used tostore energy for continuous operation, and thus can be built to provide electricity around the clock.

Solar dish engines use a tracking dish reflector to focus solar radiation on a central collector that typically employs a Stirling engine to produce electricity. Solar dish engines are projected to have costs of about 3500 dollars per kilowatt electric installed capacity with efficiencies of up to 30% (Tester 2005). Solar dish engines have very similar disadvantages to trough concentrating solar plants; the most important difference is the self-contained Stirling engine does not require water cooling or other external cycle mechanisms.

9.1.2 Solar PV

Photovoltaic cells use solar radiation to directly produce electricity through the photoelectric effect. The efficiency of contemporary solar photovoltaic panels is roughly 18%, but that performance degrades slowly through the years of use. The cost of these panels is in the range of 7000 dollars per installed kilowatt electric of capacity, however there is very little associated maintenance and operation costs, particularly with non-tracking panels (Tester 2005). Panels can be installed in facilities of any size, but have absolutely no capacity for energy storage, putting them at a distinct disadvantage to solar thermal technologies.

Photovoltaic plants are the current leading solar technology for use in remote locations. Solar photovoltaic panels have been installed in remote communities, such as India and Senegal (Ramana 1997). Relatively speaking, the low maintenance level of the facilities, passive energy collection, easy on site construction, and long development period have all contributed to their popularity as a source of energy for remote communities.

9.2 Comparisons

Several different factors contribute to the final value of a power system. In the context of providing power for rural or remote communities, there are severalimportant factors to consider, which may be different than in the case of grid-connected power. In the case of supplying electricity to a central distributed grid, perhaps the single most important factor is cost. In the case of supplying electricity to disconnected communities, cost is also an important factor, but power reliability and plant maintenance and operation level are also very important factors.

9.2.1 Cost Comparisons

In the case of costs, traditional solar thermal plants, that is, concentrating solar facilities, have a large advantage over solar updraft towers and photovoltaic panels. Construction and installation cost for the different types of concentrating solar plants can be as little as half the cost for solar updraft towers and photovoltaic panels. On the other hand, concentrating solar plants have ongoing maintenance and operating costs that need to be accounted for. Operating and maintenance costs may add up to 2 cents per kilowatt-hour to the cost of electricity for these plants (NREL 2003).

Solar updraft towers have an advantage over the other technologies we are considering here because the unit construction and installation cost can be greatly reduced by using local labor and materials. Schlaich calculated that the cost of building a solar updraft tower in India would be roughly 56% of the cost of building the equivalent tower in Europe, because of the use of local materials and labor. At that price, the construction of a solar updraft tower would be cost competitive with the concentrating solar technologies. The costs of the concentrating solar technologies and photovoltaic panels are driven mainly byexpensive specialty components. The use of local parts and labor cannot significantly improve the costs of those facilities.

9.2.2 Power Reliability

In a remote community, with only one electric plant to rely on, the reliability of the plant can be a critical factor in its utility. All solar technologies have the issue that winter outputs are lower than summer outputs, however, some plants have more day-to-day, hour-to-hour, and minute-to-minute fluctuations in power output. On a related note, some of these plants have more overall predictability.

Solar updraft towers may be at the top of the list for reliability and predictability. The large thermal mass associated with the ground area under the collector provides both a buffer against second-to-second solar irradiation variation and a storage mechanism that allows the plant to keep operating at night. The plant is able to take advantage of the diffuse sunshine of light to moderately cloudy days, giving it a distinct advantage over the other solar technologies discussed, which are completely dependent on direct radiation.

Power towers are the next most reliable source of electricity. Power towers have a large thermal mass and thus are relatively insensitive to momentary fluctuations in solar radiation. The large thermal mass also allows a power tower to provide electricity overnight.

Trough concentrating solar plants have some inherent thermal mass in the system of the working fluid. Additional thermal storage can be created using reserve fluid, but at an additional cost. The thermal storage associated with trough concentrating solar plants is typically on the order of minutes, but can be extended to hours with the current storage technologies.

Photovoltaic panels have no mode of energy storage. Second-to-second irradiation variation has an impact on the performance of the panels.

9.2.3 Maintenance and Operation

The level of maintenance and operation required to run a plant daily can be a make or break issue for electric plants operating in remote communities. Fuel and other consumables may be in short supply, replacement parts may be unaffordable or difficult to obtain, and the skilled labor required to maintain and operate the plant may be difficult to provide. In many ways, the best plant in a remote area would be one with no regular input requirements and low maintenance requirements.

In terms of operation and maintenance, solar updraft towers and solar panels are the easiest plants to run. Neither requires any consumable input. Both are very resistant to environmental exposure. Solar panels have no moving parts, and a broken unit can simply be wired out of a system. The one delicate part of a solar updraft tower, the turbine, is protected from the worst environmental effects at the base of the chimney. The rest of the plant also has very low failure rates. Glass panels from the collector are relatively easily replaceable by local materials, and the plant can function acceptably with a low number of missing panels. Because of these infrequent failure and minimal input requirements, neither type of plant requires the attentions of a group of service personnel. While it is desirable to have a full time maintenance staff, these plants could be tended very infrequently.

Solar dish engines require more maintenance than either solar updraft towers or photovoltaic panels. Solar dish engines use large tracking motors that may require maintenance, and the mirrors require regular cleaning for optimal functionality.

Power towers and trough concentrating solar plants both require the same basic maintenance as solar dish engines; motor maintenance and mirror cleaning,

however, the number of motors per unit power may be significantly larger in these cases. Power towers and trough concentrating solar plants both use heat engines to provide electric power, the most common method of cooling for the heat rejection stage of the cycle is to use evaporative cooling. This requires a regular input of make-up water. The maintenance of the equipment for the power cycle provides an additional maintenance factor for both of these systems. For trough plants in particular, the maintenance of the absorber tubes can require a lot of work. Full time employees are typically required to maintain and manage both of these types of plants.

9.2.4 Other Factors

Land use can be an important factor. Due to their low conversion efficiency, solar updraft towers use a significantly larger land area than other solar technologies (roughly one order of magnitude more). They are not suitable for use in areas where land is at a premium.

Structural integrity issues may also have an effect on making solar updraft towers more or less cost effective. Areas of high magnitude earthquakes are unsuitable for solar updraft towers because the costs of building a high tolerance tower drives up the cost of electricity significantly.

The collector of a solar updraft tower may also be used as a greenhouse area. This can significantly extend the growing season in many areas that are being considered for tower placement.

Plant size can also be an important factor. Solar updraft towers are best built at larger sizes, and thus may be more suitable for medium size remote communities. Power towers have similar issues. Trough concentrating solar plants are built from smaller units but have shared cycle equipment, which also makes them more suitable for medium scale use. Dish engines and photovoltaic panels are discrete units that can be assembled into plants of many sizes.

9.3 Comparison Conclusions

No clear preferable system is found among the systems under consideration by these direct comparisons. Concentrating solar plants may be the cheapest, although solar updraft towers may be able to approach their low capital costs. Power towers and solar updraft towers have the steadiest power generation. Photovoltaic panels have the easiest construction, and, along with solar updraft towers, the lowest maintenance and operational requirements. The choice of a solar power system depends on the weight that you place on each of these functional requirements based on the needs of the local community.

CHAPTER 10 : CONCLUSION

Solar updraft towers have many aspects that recommend them for use in remote, isolated communities. Their predictable and steady power output makes them especially suitable for use in smaller communities that require steady power output for use in small-scale industry. In developing areas, such as our country Bangladesh, western China, Africa, and parts of India, connections to the power grid either do not exist of may be unreliable. The development of small-scale industries requires an uninterrupted power output, which can be provided by solar updraft towers. Solar updraft towers are most efficient at larger sizes; this supports the use of towers for power outputs beyond just the basic provision of electricity for homes. The power output curve of a solar updraft tower can be tuned to provide the appropriate balance of production at different times to satisfy both residential and industrial use.

Solar updraft towers can deliver the required power at as low a price as concentrating solar plants, provided that the towers are built with local parts and labor. This is an additional advantage of solar updraft towers; they can utilize local construction materials, which other types of solar plants cannot. Costs are kept low after construction due to the very low maintenance requirements of the plants.

The low maintenance requirements may also be an important factor in the decision to construct solar updraft towers in remote communities. Specialty replacement parts are not required for these plants; basic maintenance of the collector can be performed by those skilled in construction labor. The feathering turbine of a solar updraft tower is the only complex, actively controlled part in the system, but the turbine can function with the blades set at a fixed angle with a reduction in efficiency. In general, solar updraft towers are very robust.

The fringe benefit of using the collector area for agriculture may also be appealing in some communities.

Overall, solar updraft towers are very suitable for use in remote communities as a power source for both residential and industrial use, based on reliability, cost, and operational factors. They can provide a suitable energy source in many remote areas, including areas that are not currently supplied by conventional means

CHAPTER 11: RECOMMANDATIONS AND LIMITAIONS

11.1 RECOMMENDATIONS:

Our main purpose was to observe and study the process of solar updraft principle and also to do some analysis on structure and materials of components.From the study and by comparing results with ideal system we were able to find out our faults and drawbacks of the path we followed.

The minimum height of the collector base from the ground level was high.Which affected the flow of air.When the air velocity was at a higher rate the air didn't get enough time so that it could get trapped and get heated enough to move upwards rather it passed away through other sides of the collector.Even when the air flow was criss-cross or multidirectional kind of flow it was unable to trap enough air to make the turbine rotate

The ratio of collector diameter to tower diameter was small in a way that the model would have been more effective if the ratio was in a greater range or atleast around the value of manzanares diameter ratio.

We used PVC sheet as collector roof material which has a greater range of specific heat than that of glass.For the proper execution of "greenhouse effect" collector roof made of glass is highly recommended.

The collector area was small as well as the angle of the collector slope was also small which resulted in small amount of air trapping and the outcome of the process was not desirable.

For our second model at first it was too hard to rotate the propeller fan we used at the top of tower which was made of plastic, eventually we realized that our setup was not right and as small amount of air would get trapped the thrust force of hot air reduced gradually before it could even reach the top of the tower so the propeller remained unturned for several weeks. After various experiments we recognized our fault and then we placed a handmade plastic fan at the bottom of the tower which rotated as the air was heated and passed through it at a higher velocity.

As our setup was outside and it remained out on the field all day long a film of dust would often form on the roof of the collector which also effected the greenhouse process and also effects the efficiency of the whole system.Regular cleaning of collector rooftop is also recommended.

11.2 LIMITATIONS

We have had to face various kinds of limitations during this study.

As we were able to execute our main model at the month of May ,we got very insignificant amount of time to upgrade the structure or to experiment with the materials.

There was also financial constrain.As we planned to introduce this model as a cost effective green technology,we had to execute this model at a very low budget so we weren’t actually able to modify this setup.

We started our project from end of the mid summer season so we didn’t get expected amount of temperature difference on the other hand rainy or cloudy day and winter season affected the efficiency of this project a lot.

There were also limitations on materials available. So we had to complete our work basing on the fact that which material will come in handy and which will not rather than selecting materials according to their effectiveness.

REFERENCES

1.vonBackstrom, TW (2003). “Calculation of Pressure and Density in Solar Power Plant *al of Solar Energy Engineering* 125 (1): 101-106Chimneys.” *Journal of Solar Energy Engineering* 125: 127-129.

2.Dai YJ, Huang HB, Wang RZ (2003). “Case study of solar chimney power plants in Northwestern regions of China.”*Renewable Energy* 28: 1295-1304

3.Gannon AJ, von Backstrom TW (2003). “Solar Chimney Turbine Performance.”*Journ*

4.Gannon AJ, von Backstrom TW (2000). “Solar Chimney Cycle Analysis with System Loss and Solar Collector Performance.”*Journal of Solar EnergyEngineering* 122 (3): 133-137

5.Haaf W (1984). “Solar towers, Part II: Preliminary Test Results from theManzanares Pilot Plant.” *Solar Energy* 2: 141-161

6.Haaf W, Friedrich K, Mayr G, and Schlaich J (1983). “Solar Chimneys, Part I: Principle and Construction of the Pilot Plant in Manzanares.” *Solar Energy* 2: 3-20

7.Johansson TB, Kelly H, Reddy AKN, and Williams RH (1993). *RenewableEnergy: Sources for Fuels and Electricity*. Island Press, Washington D.C.

8.Kreetz H (1997). “TheoretischeUntersuchungen und AuslegungeinestemporarenWasserspeichers fur das Aufwindkraftwerk.”Diploma Thesis, Technical University Berlin, Berlin, Germany.

9.Harte, R., Graffmann, M., Kra¨tzig, W.B., 2012. Optimization of solarupdraft chimneys by nonlinear response analysis. In: Zhou, X.P. (Ed.),Proceedings of the 3rd International Conference on Solar UpdraftTower Power Technology. Wuhan, China, pp. 193–202.

10.Harte, R., Ho¨ffer, R., Kra¨tzig, W.B., Mark, P., Niemann, H.-J., 2013.Solar updraft power plants: Engineering structures for sustainable energy generation. Eng. Struct. 56, 1698–1706.
Hartung, C., Marschetzky, H., Link, T., Bauer, M., Ku¨ nzel, M.,Ellwanger, M., Thanh, T.P., Dang, L.N., 2008. (Supervisors: Ruth,J., Gumpp, R.). Solar power plant 2008 <http://www.archineering.de>.

11.Hedderwick, R.A., 2001. Performance evaluation of a solar chimneypower plant.M.Sc.Eng. thesis, University of Stellenbosch, Stellenbosch,South Africa.
Herrick, G., 2013. A Model Solar Updraft Tower Power Plant, February21 <http://www.wxedge.com/articles/20130220a_model_solar_updraft_tower_power_plant>.

12.Bonnelle, D., 2004. Solar Chimney, Water Spraying Energy Tower, and Linked Renewable Energy Conversion Devices: Presentation, Criticismand Proposals. Ph.D. thesis, University Claude Bernard–Lyon 1,Lyon, France.

13.Borri, C., Lupi, F., Marino, E., 2010. Optimum shell design of solarupdraft towers. In: Proceedings of the 2nd International Conferenceon Solar Chimney Power Technology. Bochum, Germany, pp. 155–162.

14.Bugˇutekin, A., 2012. Experimental study of temperature field in a solarchimney plant in Adiyaman.Isi BilimiveTeknigiDergˇisi. J. Therm.Sci. Technol. 32, 73–80.

15.Buonomo, B., Manca, O., Montaniero, C., Nardini, S., 2015. Numericalinvestigation of convective–radiative heat transfer in a building integrated solar chimney. Adv. Build. Energy Res. 9, 253–266.

16.Kra¨tzig, W.B., Harte, R., Montag, U., Wo¨rmann, R., 2009. From largenatural draft cooling tower shells to chimneys of solar upwind powerplants. In: Proceedings of the International Association for Shell andSpatial Structures Symposium 2009. Valencia, Spain.

17.Kreetz, H., 1997. TheoretischeUntersuchungen und AuslegungeinestemporarenWasserspeichers fur das Aufwindkraftwerk.Diplomarbeit,Energie und Verfahrenstechnik der TU Berlin, Berlin, Germany.

18.Davey, R.C., 2006. Device for generating electricity from solar power.Patent, PCT/AU2007/001151/21-08-2006.

19.Dehghani, S., Mohammadi, A.H., 2014. Optimum dimension of geometric parameters of solar chimney power plants – A multi-objective

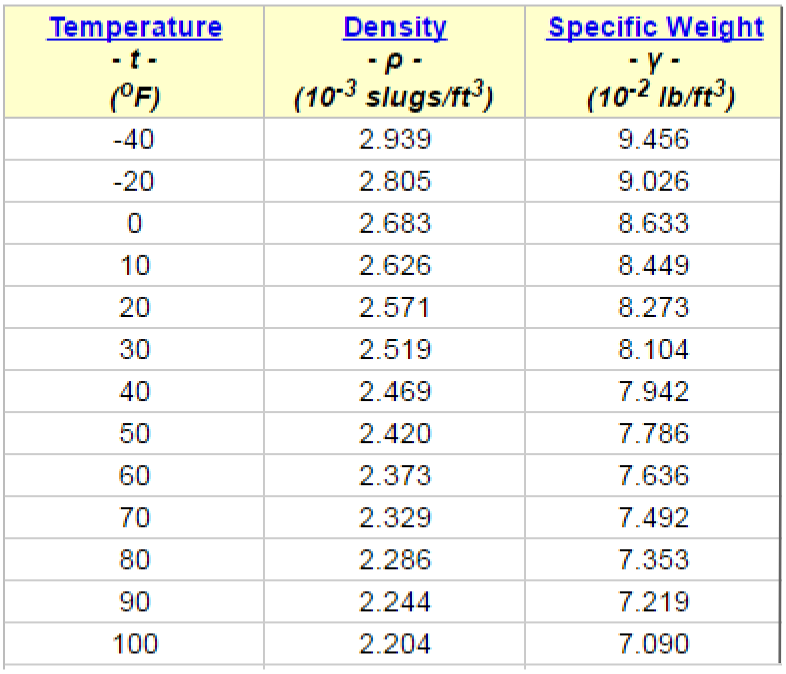
20.EnergyProfileofBangladesh.Encyclopediaofearth⟨http://www.eoearth.org/article/Energy_profile_of_Bangladesh⟩. pdf;2011.. [20]

21.WahidulK,BiswasPB,DiesendorfM.Modelforempoweringruralpoor through renewableenergytechnologiesinBangladesh.EnvironmentalScience and Policy2001;4(6):333–44.

22.Developingrenewables.CountryEnergyInformationBangladesh. ⟨http://www.energyrecipes.org/reports/genericData/Asia/061129%20RECIPES%20coun try%20info%20Bangladesh.pdf⟩; 2006.

23.IslamMR,IslamMR,BegMRA.Renewableenergyresourcesandtechnologies practice inBangladesh.RenewableandSustainableEnergyReviews2008;12optimization approach. Sol. Energy 105, 603–612.

APPENDIX



Temperature **- *t* -** **(^oF)**	**Density** **- *ρ* -** **(10^{-3} slugs/ft^3)**	**Specific Weight** **- *γ* -** **(10^{-2} lb/ft^3)**
-40	2.939	9.456
-20	2.805	9.026
0	2.683	8.633
10	2.626	8.449
20	2.571	8.273
30	2.519	8.104
40	2.469	7.942
50	2.420	7.786
60	2.373	7.636
70	2.329	7.492
80	2.286	7.353
90	2.244	7.219
100	2.204	7.090