

Solar Updraft Tower for Energy Generation

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ABSTRACT: The future of this earth and mankind substantially depends on our ability to meet our ever-increasing demand for renewable and environment friendly power sources. Solar energy is one of the prospective solutions; currently, 3 different methods are used to harness solar energy which are photovoltaic solar panels, concentrating solar energy and updraft towers. Updraft is the newest method that both harness solar energy and wind energy. The basic idea uses the concept of chimney effect and green house effect. The base of the solar tower receives solar energy and heats the air inside, decreasing its density and thus evolving in a tower revolving an electric generator inside the tower. The factors affecting the power output of the tower are the area of the base and the length of tower. Updraft tower continue to generate energy at night if the base was supplied by heat sink that absorbs excess heat during day and at night the heat is released. Wind energy can revolve the electric generator if the wind at the base of the tower is strong enough, but the dependency on wind energy is negligible.

KEYWORDS: Energy, Updraft Tower, Solar collector, Chimney effect.

I. INTRODUCTION

With the current energy shortages especially in third-world countries, and fossil fuels are no longer sustainable as well as the emerging environmental pollution resulting from fossil fuels. The world is heading to clean energy and one of the prospective eco-friendly solutions is updraft towers. Updraft towers are adequate in third-world countries especially arid countries where there is plenty of space to build a colossal base, but the towering chimney represents an engineering challenge. The tower can be constructed from cheap fabrics held tightly using balloons looks like tubes filled with lighter gases (like helium). This would decrease the expenses of the construction of solar updraft tower power plants. Although updraft towers have not been tested on a commercial scale, the predications and prototypes are providing prosperous results. The largest prototype was built in Spain with 195-meters-high chimney and 46-hectares base, the tower could generate 50kw power, but in 7 years the tower collapsed due to the lack of protection from corrosion. The tower is based on heating air trapped in a collector made of greenhouse material at the base of a long tube through greenhouse effect. Then the heated air will flow upward through a tall tower tube causing an attached wind turbine generator to rotate and generate electricity. This idea is based on what is known as the Chimney Effect. Chimney effect means the placement of the air flowed out through the tower with another air entering through the base. Chimney effect states that by increasing the elevation of the tower, the speed of air flow increase which indicates more energy generation. Also, a modification is done to the project by adding a salt hydrate pipe to absorb heat from the sun and then release it at night. It guarantees that the project will operate at night albeit less-energy generation. As a consequence, efficiency increases. Later, a prototype has been constructed for tests to be conducted on. These tests have shown acceptable results of a cheaper and cleaner source of power, and a better solution for the energy problems. Furthermore, the greenhouse base is suitable for agriculture, knowing that the base could reach in 37 square kilometres in area. The working principle is illustrated in figure 1 where the air flow through the collector to be heated and rise up in the chimney revolving the turbine, and by flowing the air outside, it is displaced by new air coming from outside the base which guarantees the continuity of air flow. This study focused on building a prototype of the updraft tower and evaluating its success in energy generation as an eco-friendly source. The study discusses the construction, testing of the prototype. In addition, analysis for the principles of the tower operation is provided and the equations governing the predictions of the tower operation is also included in this study. This Study also focuses on the previous trials to construct and operate an updraft tower and previous research work in this field.

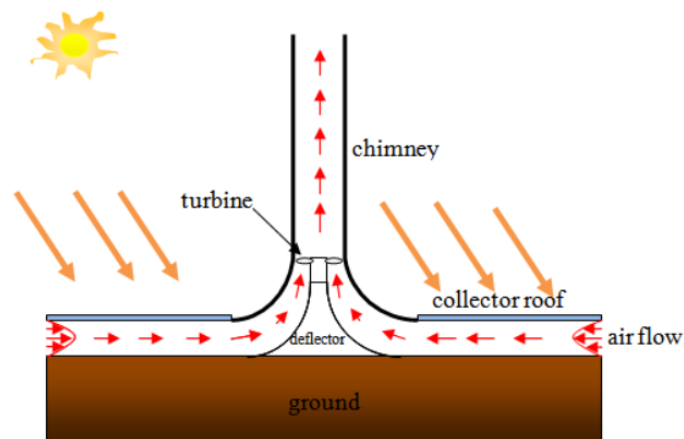


Fig.1 illustration of the working principle of updraft towers.

II. RELATED WORK

The first proposal to the idea of the updraft tower dates back to 1903, but until 1982 there was not any prototype until the first experimental prototype was built in Manzanares, Ciudad Real, 150 km south of Madrid, Spain, but funded by the German government.(Fig. 2) The 195-meters tower could generate up to 50 Kilo watts with 10-meters tower's diameter and 11-acre solar collector, furthermore the base of the tower was used to grow plants. Since then several research papers were discussing the utility of the tower by several institutions, including MIT, University of Basrah, etc.,and individuals. The previous research paper discussed the working principles, the formulas and laws governing the operation of the tower and the technical details such as the tilt angle of the static solar collector and the direction of the opening in the solar collector as well as the materials that can be utilised for construction whether the extortionate, but expensive fiberglass or the cheap, but non-durable polyethylene. Starting from 2008, several countries showed their interests in pursuing the construction of a solar updraft tower including Namibia with its proposed 1.5-km "Greentower" and a Spanish 750-meters tower, which was proposed in 2006, but until now no official construction started. The only operated commercial updraft tower is in China, it started operations in 2015. It is producing 200 kilowatts with a 277-hectares base, and the operating company is planning to build two huge 200-MW towers. Further proposals include building similar towers in the arctic for northern countries and it could yield up to 85% of the desert-built tower.



Fig..2The firstSpanish prototype that was built in 1982 before collapsing in 1989

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III. METHODOLOGY

Building Materials are illustrated as follows in figure 3. The PVC tubes were used to construct the 2.4 chimney with 15.5 mm radius. The PVC pipes and the wood were used to construct probes to uphold the prototype. Polyethylene plastic was used as a greenhouse material to cover the solar collector and trap solar energy to heat the air. The metallic base was centred in the middle of the prototype to hold the chimney as will be further illustrated in the next sections.

Name	Dimensions	Photo
PVC tube	2.4m × 0.155m × 0.4mm	
PVC pipe	2.5cm × 6.8m	
Polyethylene	4.617 m ²	
Wood	3.6m x 10cm x 2.5cm	
Metallic base	4.7 kg	

Fig. 3 illustrates the prototype building materials as well as the specs and photos of each material

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First of all, the project's scientific basis was tested using a simulation model based on "Energy2D" software as depicted in figure 4. Where the wind energy and solar energy is inserted as inputs and the outputs of the solar updraft tower is the energy generated.

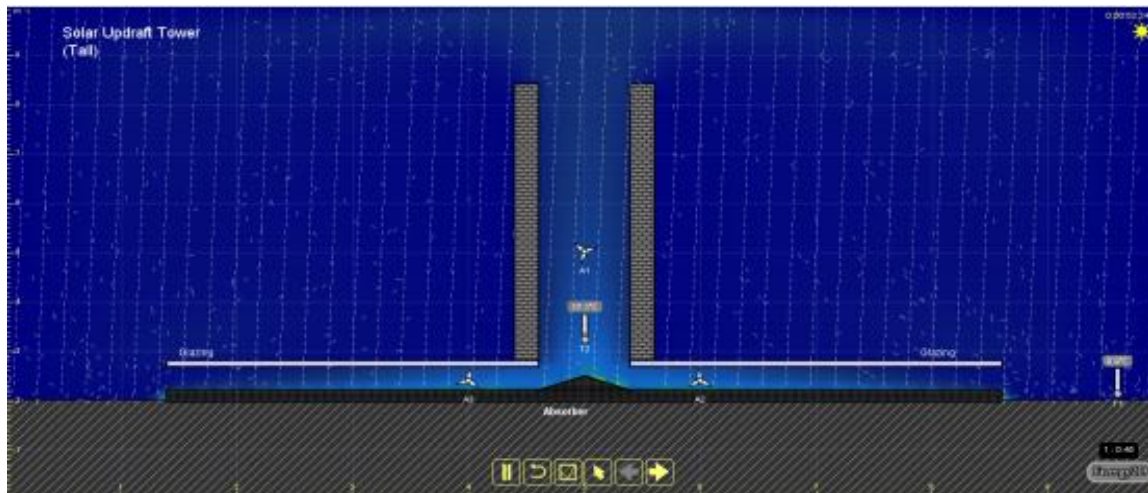


Fig. 4 shows the Energy2D program design where the 3 fans shows the predicted air flow speed and energy generated

The prototype was made with a one-meter radius base collector and a tower height of 2.4 meters.

- 1- a professional 3D design for the planned prototype was made using "Autodesk AutoCAD 2017" as shown in (Figure 5). It showed clearly the right dimensions of all the parts and manifested how the idea will be implemented. The chimney is represented by a black tube, the solar base is represented by the circular, green base in the 3D design while the yellow outermost ring is the prob made of PVC pipes and wood.

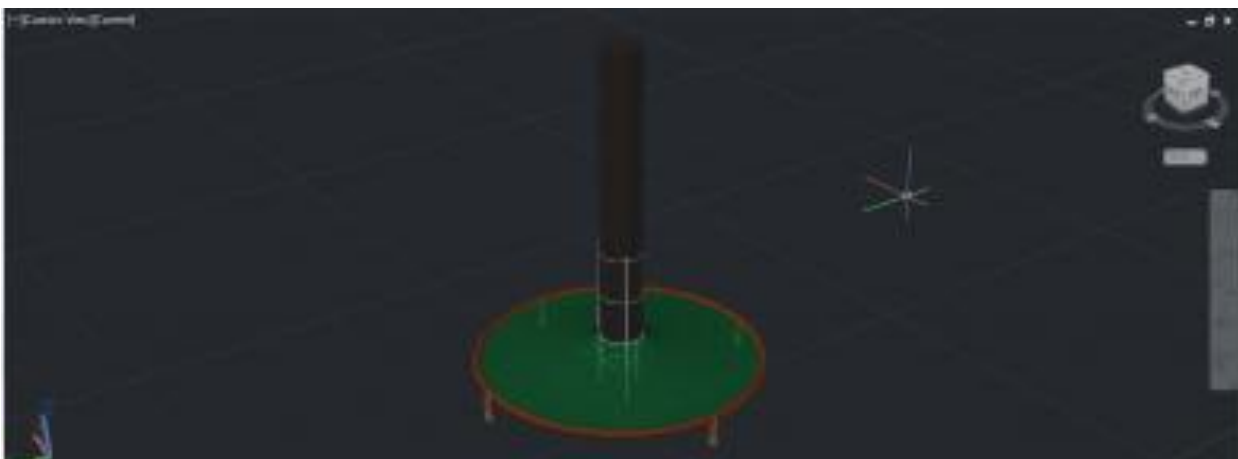


Fig 5. Shows the 3D design using AutoCAD. The green part represents the polyethylene solar base while the black tube represents the tower chimney

- 2- 4 Wooden pieces with dimension (1m * 2.5 cm * 5 cm) are attached in a cross shape as shown in (Figure 6) they are connected with an aluminium extension to form a one wooden, cross-shaped
- 3- 8 wooden pillars with dimensions (20 cm * 5 cm * 2.5) with an aluminium extension with a hollow place for the PVC electricity coating pipe was attached in the 4 wooden pieces as shown in (Figure 7)

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- 4- The PVC pipe was rounded in the hollow space we made in the pillars (figure 7)



Fig.6 the cross shape formed by 4 wooden pieces connected by aluminum extension



Fig.7, wooden pillars were stuck in the ends of the cross shape with PVC tubes

- 5- The iron base which weighted 4.5 kg was put in the centre of the wooden cross shape as in (Figure 8)
6- Pieces of wood with dimensions (1.09m × 2.5 cm × 1.25 cm) were attached between the iron base and the rounded PVC pipe and tied it tightly using Iron wires (Figure 9) iron base is connected tightly with PVC pipes



Fig.8 wood pieces are connecting the metal base with the rounded PVC tubes. Fig..96 wood pieces are connecting the metal base with the rounded



- 7- We cut a piece of the polyethylene plastic and covered the half of the out layer (rounded part) of the collector then we cut another piece and covered the second half. (Figure 10) this the final step in the tower construction
8- An Electric generator was put in the bottom of the PVC pipe.

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Fig..10The final step in covering the solar base with polyethylene

IV. ANALYSIS & DISCUSSION

The scientific idea: The idea of the updraft tower involves the heating of the air at the base by the collectors like greenhouses then the hot air will rise through the tower revolving a dynamo and generating electricity, while new air will enter the collector instead of the air that flow out which is known as draft, and the flow of air inside the tower is known as stack (chimney) effect (figure 11). The ground keeps heat to maintain the working of the tower at night

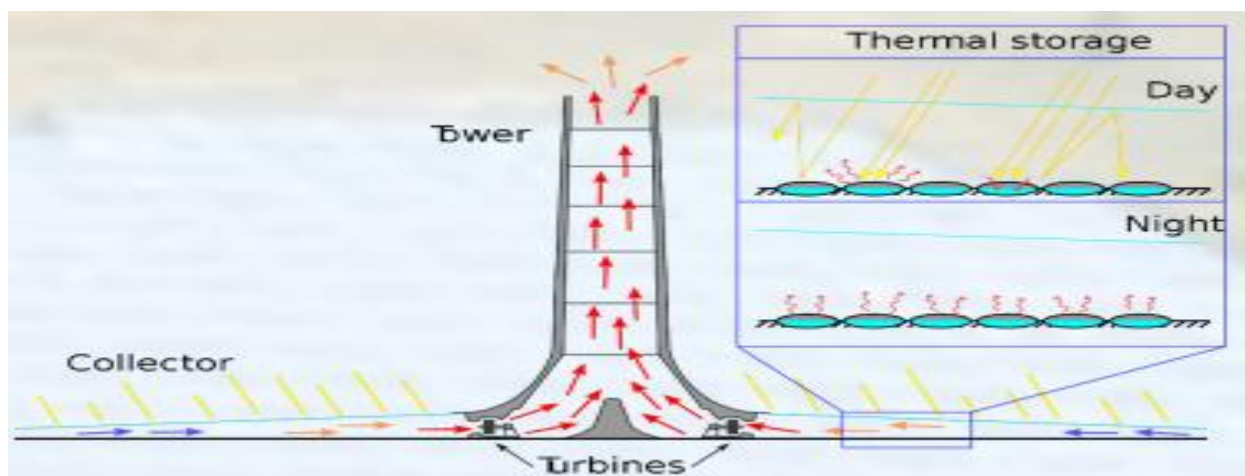


Fig..11The working principle of the updraft tower with the ground working as a heat sink

The symbols of the variables and constants used in the equations explaining the working principles of the prototype in figure 12 where each symbol express a certain variable or a certain constant.

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SYMBOL	MEANING
T_i	The temperature at the entrance of the tower under the collector in kelvins
T_e	The temperature outside the collector in kelvins
A	cross sectional area of the tower in m ²
H	Height of the tower =2 meters
P	Air pressure in pascals =101325 pascals
ρ_i	Air density at the entrance of the tower in kg/m ³
ρ_e	Air density of the air outside the collector in kg/m ³
Q	Volume flow rate in m ³ /sec
M	Mass flow rate in kg/sec
R	Specific gas constant =287.05 joule(kg.kelvin) of dry air
C	The discharge coefficient unit less

Fig..12 Variables and constants with their symbols to facilitate the understand of equations and formulas

- The cross-sectional area of the tower = $\pi \times radius^2 = 3.14 \times 0.725^2 = 0.016m^2 \pm 0.12$
- velocity of the heated air $V = \sqrt{2 \times g \times h \times \frac{T_i - T_e}{T_e}} = 1.046m/sec$
- T_i and T_e are measured where T_i = 316.2 ± 0.3 kelvins and T_e = 307.6 ± 0.3 kelvins
- The air density: $\rho_i = \frac{P}{R \times T_i}$ and $\rho_e = \frac{P}{R \times T_e}$
- $\rho_i = 1.116 kg/m^3$, $\rho_e = 1.147 kg/m^3$
- the mass flow rate: $m = A \times V \times \rho_i = 0.0186 kg/sec$
- The discharge coefficient: $C = \frac{m}{A \times V \times \rho_i} = 0.995$
- For the volume flow rate, 2 equations are used $Q = C \times A \times V = 0.0167m^3/s$, $Q = \frac{m}{\rho_i} = 0.0167 m^3/s$ that is the same result
- Pressure difference: $\Delta P = g \times h \times (\rho_e - \rho_i) = 0.607 pascal$
- Collector area = area of the cylinder excluding the 2 bases + the area of curved part of the cone =
- $(2\pi \times collectorradius \times heightofthecollector\ cylinder) + (collectorradius \times \pi \times slantheight) = 4.617m^2 \pm 0.21$
- The power output: $power = \Delta P \times Areaofcollector \times V = 2.93 watts$
- Power output was calculated in the test plan using the equation $Power = potentialdifference \times currentintensity$
- An equation also has been used to get the output power from the temperature difference, the equation is

$$f(x) = \frac{648\sqrt{\frac{(x - T_e)^3}{T_e}}}{x}$$
- And from this equation we got the exact results collected from prototype.

V. SIMULATION & RESULTS

Test Plan:

- 1- Multimeter (a digital instrument that measures potential difference and current intensity) was used to measure the power output. Power output was measured every two hours from 6:00 AM until 9:00 PM for 2 consecutive days.
- 2-Temperature was measured inside and outside the solar collector by an electronic thermometer. The temperature was measured every 2 hours starting from 6:00 AM to 8:00 PM every two hours for the same 2 consecutive days.

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Results: The power output for the 2 days was 3.1 watts an average and the specific results are illustrated in figure 13. The peak is at noon while decreases at night and at morning due to the direct relation with temperature difference

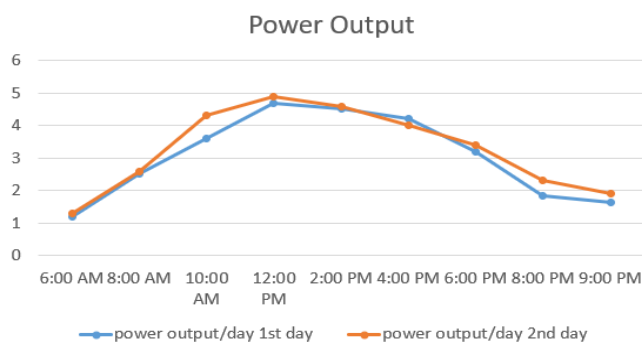


Fig..13 shows the power output for 16 different times

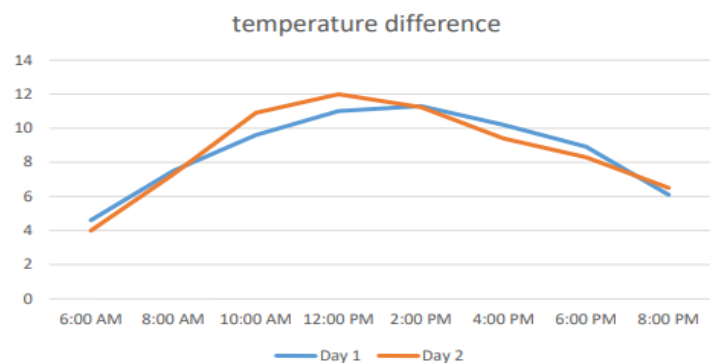


Fig. 14 shows the temperature difference in the same time period

Temperature difference in first day was 8.65 and in second day 8.7. The average of the difference was 8.67. fig. 14 displays the temperature differences for 16 different times. The peak is at noon while decreases at night and at morning

VI. RECOMMENDATIONS

The integration of geothermal energy by introducing a geothermal pump to maintain temperature difference where underground temperature of 50 c° that will be attained at a depth of 1.3 km and water will be circulated through a horizontal pipe at that depth in order to heat the air and increase the temperature difference especially at night and in winter.

VII. CONCLUSION

As demonstrated in the test plan, results and the analysis, it can be concluded how the project satisfied the predicted results, showing results of 3.1 watts as an average of output proving to be renewable, eco-friendly and long durability. Yet, that does not negate the fact that the project is opened to further enhancements included in the recommendations. The project is a prospective alternative to fossil fuels as an eco-friendly energy source utilizing solar energy with negligible assistance from wind.

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