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Energy Harvesting Potential of Solar Updraft Tower in Don Honorio Ventura State University

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Abstract- The world's expanding need for electrical energy has generated climate change, which is driven by reliance on fossil fuels that increase carbon dioxide. In response to the increased need for electricity, eco-friendly renewable energy sources were established. Renewable energy comes from various environmental sources. Solar Updraft tower combines solar and wind energy. This study looked at SUT generation and DHVSU kilowatt demand. This study assesses Solar Updraft Tower's power output using mathematical equations from related studies. Possible SUT power generation was reduced to the school's kW demand. The study found that SUT can create a little amount of electrical energy and reduce DHVSU's kilowatt consumption by 5.52% yearly.

I. INTRODUCTION

The world needs the energy to maintain our quality of life and underlie all other aspects of our economy. Renewable energy is obtained from a variety of resources that all rely on self-renewing energy sources such as sunlight, wind, flowing water, the earth's internal heat, and biomass such as energy crops, agricultural and industrial waste, and municipal garbage. Although electric energy security continues to be a significant concern due to the high cost and scarcity of fossil fuels, renewable resources have been appealing in world energy-based economies to minimize greenhouse gas emissions. Renewable energy resources come from wind energy, bioenergy, geothermal energy, hydro energy, and solar energy. The global share of renewable energy in electric generation is higher than heat demand and transportation (O. Ellabban et al., 2014). Solar Updraft Tower (SUT), known as solar wind or solar chimney, is another form of renewable energy that can be considered a substitute solar PV cell (solar PV farms) power generation facility. Zhou and Xu (2014) stated that the first idea of using a solar chimney to generate electricity was from a Spanish engineer named Isodoro Cabanyes.

The idea of SUT power generation provided a promising solution for future energy applications utilizing solar radiation. A solar updraft tower power plant (SUTPP), a solar chimney power plant, is a device that generates buoyancy to propel air upward for the generation of electricity. This will play a vital role in addressing one of today's most pressing issues: ensuring a worldwide, sustainable, limitless, and inexpensive energy source. The concept behind this technology is simple: the sun heats the air beneath a vast glass roof (greenhouse effect), which is afterward drawn in by the vertical cylindrical tube in the center (chimney effect). As a result, updraft wind is generated, which powers turbines/generators and creates energy (According to Akhand & Saklayen, 2018)

SUTs can function 24 hours a day on pure solar energy with lower production at night, thanks to the earth beneath the collector, which acts as a storage mechanism that produces natural heat. Simple water tubes buried in the ground improve storage capacity, providing a consistent 24-hour electrical supply. SUTs, which are primarily used for large-scale energy generation in units of 100 MW or more, may be built by local labor using locally accessible materials to a considerable extent. SUTs can be made in desert countries to meet regional demand, save oil, or contribute to Europe's energy supply. The electricity generated by towers in sunny countries can be transported and sold to any location without significant losses, either via transmission lines or as liquid hydrogen by ships (Vourvoulias, 2021).

SUTs are incredibly dependable. The only moving elements in the facility are the turbines and generators. This simple and robust construction ensures low-maintenance operation and, of course, no flammable fuel. In addition, solar Updraft Towers, unlike typical oil/gas-powered and other solar-thermal power plants, do not require cooling water. This is a significant benefit in many sunny places where water supply is already a serious issue. Compared to other solar power plants, electricity generated by Solar Updraft Towers is the most cost-effective. Despite this, the costs of producing electricity are still higher than those of traditional coal or gas-fired power plants. However, a looming shortage of fuel sources and rapidly rising demand will soon balance and, in some cases, reverse the current pricing disparity. This "break-even point" is expected to reach a crude oil price of 60 to 80 dollars per barrel. As a result, the time has come to construct large-scale solar power plants and large-scale Solar Updraft Towers (Weinrebe et al., 2013).

According to Negi & Pal (2022), the Solar Updraft Tower consists of a collector, storage, tower and turbines. The collector collects the greenhouse effect in a primary air collector consisting of a glass or plastic sheet glazing extended almost horizontally several meters above the ground producing hot air for the solar updraft tower. As the glass height rises towards the tower's base, the air is eventually shifted from horizontal to vertical circulation with minimal friction loss. This glazing allows shortwave solar radiation to pass through while allowing longwave re-radiation from the heated earth. As a result, the earth beneath the roof heats up, transferring its heat to the air above, which flows radially from the outside to the tower. The storage is a water-filled black tube or bags are set side by side on the radiation-absorbing soil beneath the collector if more thermal storage capacity is required. The tubes are filled with water once and then sealed to prevent evaporation. Depending on the required power output characteristics, the volume of water in the tubes corresponds to a water layer with a depth of 5 to 20 cm. Because the water has a significantly larger heat capacity (4.2 kJ/kg) than soil (0.75 – 0.85 kJ/kg), the water inside the tubes saves some of the solar heat, which results in a release when the air in the collector cools at night. This allows the facility to function on solar energy 24 hours a day.

Many developing countries cannot afford coal, oil and natural gas, which are current electricity producers. These producers are damaging the environment and are considered non-sustainable. In most places, nuclear power plants pose an unacceptable risk. On the other hand, inadequate energy supply causes or maintains poverty, which is frequently accompanied by population growth: a vicious spiral. Sensible technology for widespread use of renewable energy must be simple, reliable, and accessible to technologically less developed countries that are sunny and often have limited raw material resources and based on environmentally sound production from renewable or recyclable materials. It should not require cooling water or produce waste. The solar updraft tower satisfies these requirements, allowing everyone to take the first step toward a global solar energy economy. Large-scale solar updraft towers (100 MW) could generate energy at costs comparable to conventional power plants, according to economic analyses based on previous experience and knowledge. This alone is incentive enough to expand the use of solar energy in this way, up to massive, economically viable units. Solar updraft towers could thus assist ensure the economic and environmentally friendly provision of energy in sunny places in the future energy economy. (Schlaich Bergermann Solar GmbH, Stuttgart, 2011).

Solar Updraft Tower is more likely to be installed in places with a huge amount of solar radiation, such as deserts. Research shows that a solid ambient crosswind varies in the solar energy generation of SUT. The basis of this statement is the capability of SUT in Manzanares (Spain) to generate electrical energy with high solar radiation compared to SUT in the Orkney Islands in Scotland, which was increased in the wind but mild in solar radiation. SUT in the Orkney Islands is more dominant in efficiency than the SUT in Manzanares (Jafarifar, et al., 2019). The solar updraft power plant is a noble perspective technique among several solar energy technologies that can give power to countries with extensive wastelands or undeveloped desert regions. (Ayub, Akhand, Khan, & Saklayen, 2018).

The Philippines is trying to become an energy-independent country by building more sustainable energy sources. However, as time passes by, the electricity cost starts to demand more, which other consumers are not capable of using freely. In accordance with Casper Bonggaling Agaton and Helmut Karl (2018), in 2040, the world energy generation mix is expected to double because the Philippines is not capable of becoming independent in sourcing electrical energy from its own country. Moreover, the Philippines should import fossil fuels for the use of power plants.

Likewise, the effect of the increase in the price of electrical energy occurs when there is a continued reliance on imported fossil fuels. Because of the most recent Pinatubo eruption, Don Honorio Ventura State University (DHVSU) starts to experience a hot temperature on a normal day which causes the university to suffer losses because of the lahar that has covered the area (K.S. Crittenden and K.S. Rodolfo, 2002). The combustion of fossil fuels such as oil, coal, and gas produce a large portion of the world's energy. Since fossil fuels cannot be replaced once they are depleted, people are now increasingly turning to renewable energy sources. Furthermore, there is renewable energy known as SUT that uses the greenhouse effect and chimney effect to generate electricity in a cleaner and eco-friendly cause.

In a journal titled *Numerical methodology for analyzing the performance of a solar updraft tower in various environmental conditions* by Arkadiusz Brenk, Ziemowit Malecha and Lukasz Tomkow (2020), the study of the simplified and fast numerical understanding of the SUT model has been discussed. The journal focused on the necessary calculations needed in order to validate the feasibility and experimental results of the operations of SUT. As a device that converts solar radiation into electrical power, this tower had a major advantage because of its simplicity that even countries without access to advanced technology will be able to build quickly with the resources available. In addition, the authors highlighted mathematical computations, which are vital in consideration of the geographic regions where SUTs are established. Distinct regions with very different weather conditions, named Africa, Poland and Sudan, were studied and concluded that based on numerical results, African locations are favorable due to considerations of temperature and magnitude.

According to Xinping Zhou and Yangyang Xu (2016), the article titled *Solar Updraft Tower Power Generation*, states that SUT operation can aid in soil rehabilitation, forestry, and desert farming at local levels and reduce greenhouse gas emissions and eliminate the use of potable water for cooling. By spraying water at the SUT outlet to force the airflow downward, the SUTPP can be utilized to reduce pollution in cities. It was also designed to move vast amounts of toxic waste gases from lower to upper levels of the atmosphere, reducing the environmental effects of uncontrolled landfill gas emissions into nearby areas. With the voluminous advantages through the development of SUT, it is essential to note that the high performance of producing electrical power must be accompanied by suitable conditions that should be taken into account, namely - large enough size, good climate conditions, cheap local construction materials and labor force, and vast desert region.

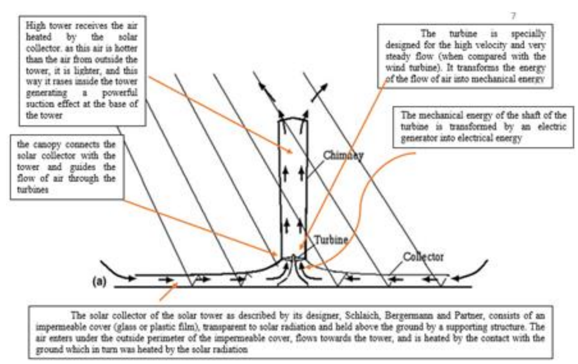

Figure 1. Solar Updraft Tower Principle
(Shadi Kalasha, Wajih Naimeh, Salman Ajib, 2014)

The simplicity of how SUT operates was evidently discussed by Jörg Schlaich, Rudolf Bergermann, Wolfgang Schiel, Gerhard Weinrebe (n.d.), using the above Figure 1. The process initiates on the collection air as it enters and flows through the tower. Afterwards, the air is then heated by the solar radiation.

According to an article from Solaripedia (2011), there were numerous studies in which installation of SUT was considered. The SUT on Jinshawan, Inner Mongolia, China was producing 200 kilowatts of electricity and the greenhouse effect of the SUT placed a huge help in enhancing the climate by preventing sandstorms by covering moving sand. There are also proposed studies such as Ciudad Real Torre Solar, Botswana Test Facility, Turkish Model and Arctic Solar Draft Tower in which the project's goal is to provide sustainable development for each country. The estimated energy produced on a 1000-metre-high tower with a greenhouse of 20 km² is 100 MW. To have a 200MW power plant will also need a 1000-metre-high tower and an area of about 38 km². A 200MW power station can supply at least 200,000 typical households. A solar updraft tower's land use can be combined with other purposes to make it more cost effective and, in some situations, to boost its overall power output. Solar collectors or photovoltaics, for example, can be placed behind an updraft tower collector which could allow the tower to be used in conjunction with agriculture.

According to Shadi Kalash et. al (2014), there was a prototype Solar Updraft Tower built in Damascus University, Syria with 12.5m^2 approximately and 9 meter for the height of the tower. The recorded data has an impact especially the solar radiation for the temperature of the chimney and the collector area to store the thermal energy in order to control the temperature of the chimney to last about three hours after the noon period.

Renewable energy is a topic that experts and the general public are becoming increasingly interested in. Renewable energy research in absolute and relative terms, the use of renewable energy sources has increased in recent years. According to the Republic Act No. 9513 also known as “Renewable Energy Act of 2018”, “Accelerate the exploration and development of renewable energy resources such as, but not limited to, biomass, solar, wind, hydro, geothermal and ocean energy sources, including hybrid systems, to achieve energy self-reliance, through the adoption of sustainable energy development strategies to reduce the country’s dependence on fossil fuels and thereby minimize the country’s exposure to price fluctuations in the international markets, the effects of which spiral down to almost all sectors of the economy” (Section 2). This law has been passed in order to address the country’s problem about the reliance on fossil fuels.

The technology is concise. Steel, concrete, and glass are the most often used construction materials. It's possible that construction sites will be in arid areas. It is available to practically all countries, including those with low technical development. The solar collector then captures both direct and diffuse sunlight. The SUTPP with the natural-additional mixed heat storage system can run on solar energy 24 hours a day, 7 days a week. In tropical places where the weather is regularly gloomy, this is critical for the formation of SUTPPs. Furthermore, the cost of operation and maintenance is quite minimal. Although turbine maintenance and collection cleaning are expensive, extra fossil fuels are not required to replace solar radiation since SUTPP operates reliably at all hours of the day and night. SUTPP functioning does not necessitate the use of cooling water. Other than turbine blades, there are few moving or rotating parts, resulting in a low rate of mechanical failure and a high level of safety. It has a low global warming potential over its full life cycle, including the periods of building, operation, and decommissioning (Zongker, 2013). During operation, it produces almost little pollution. In fact, it operates on a renewable energy source such as solar radiation, avoiding large-scale emissions of greenhouse gases and the need of potable water for cooling. In addition, as its size grows, its power output and efficiency increase, and the cost of energy generation decreases (Schlaich and Kratzid et al., 2013). Carbon credit money generated as a result of lower carbon emissions can assist in cost reduction.

According to the article titled “Numerica Solar Chimneys can convert hot air to energy but is a funding mirage?” by Thomas K. Grose (2014), the advantages of SUT over PV is that the cells cannot function during nighttime. On the other hand, SUT can still function as the soil has become a sun heat collector in which it can still heat up air during night. It was also stated that PV has much less efficiency when covered with only a small portion of dust. Furthermore, SUT is less in terms of maintenance as the only moving parts are the turbines and generator. It was also discussed here that the small experimental SUT was built to last for only 3 years, but it kept generating electricity for 7 years.

The energy harvesting potential of SUTs has not yet been studied for DHVSU. Solar street lights installation and the like are the only projects contemplated and studied in the area and none of which include the SUT consideration. However, the said institution has not been exempted from the emerging effects of the operational cost due to the continuous increase in electricity rates in the Philippines. Therefore, to determine if the SUT is feasible for harvesting energy in DHVSU, the study sought to answer the following, specifically:

1.1. Is there available space for the Solar Updraft Tower in DHVSU to be the researchers' basis? If yes, will the SUT be convenient in the given area?
1.2. Can the power generated by the solar updraft tower contribute to kilowatt demand of DHVSU particularly in the Administration Building?
The research study aims to assess the harvesting potential of the SUT in DHVSU in Cabambangan, Bacolor, Pampanga. The study's particular goals are as follows:
1.1 To determine if there is an available area and with the condition that it's appropriate for the Solar Updraft Tower with the following criteria.

a. Temperature
b. Wind speed

1.2. To calculate the power generated by the Solar Updraft Tower using formulas in instruments
1.3 To reduce the kilowatt demand of DHVSU.
1.4 To determine the percentage of its contribution yearly.

The general objective of this study is to determine the energy harvesting potential of SUT and to provide a table containing SUT energy harvest in kilowatt-hour.

This study is delimited to determine the energy harvesting potential of the SUT in DHVSU located in Cabambangan, Bacolor, Pampanga. In line with these, the researchers' objective is the effectiveness of the study, which will highlight the benefits and worthiness of the project. The study will focus on the energy generation of SUT, the possible contribution and the benefits to the said location

The findings of this study will benefit the school, future researcher, the environment, and it will provide a deeper understanding about Renewable Energy particularly the SUT as the alternative electrical supply feasible solutions:

To the school, the results may be used for the near future and for further knowledge about SUT. The findings may help the school to know if the study is beneficial

To the future researcher, this research can be a source of another study or can be replicated using additional variables in another locale of setting or with different topics that may be connected to our study.

To the environment, it can help to produce clean energy and can lower the heat temperature around the campus

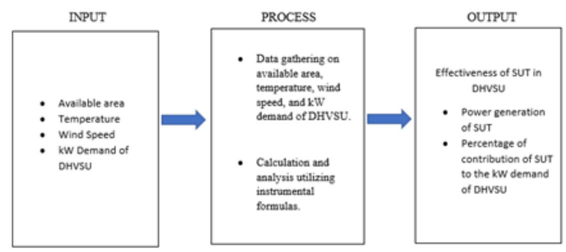

Figure 2. Conceptual Framework

As shown in figure 2, the researchers will gather inputs to perform the necessary processes involved in this study. These inputs are the location and its related temperature analysis, the kilowatt demand of DHVSU, and the energy generation of SUTs. The gathered data will be used to facilitate the analysis and computation during the overall study and finally conclude the effectiveness of the study.

First, it is vital to see if there is any available location for the SUT in order to determine the temperature and other quality considerations that may affect the output. Second, the kilowatt demand of DHVSU shall be identified to aid the estimation of the required power generation and differentiate it from the kilowatt demand of DHVSU. Third, the energy generation of SUT will be vital in the analysis of the effectiveness of the SUT project.

Third, gathering of data will be performed through submission of request letters to the institution and citing related literature and studies for the location, consideration of temperature of the said location, and its kilowatt demand. These data will be used to facilitate the analysis and computation during the overall study. Afterwards, these will be applied to formulas in determining the power generation capability of the SUT. In addition to this, necessary analysis will be performed. Furthermore, the other discussions will be strengthened through the use of the related literature and studies.

Lastly, the output of the study will be the conclusion on the effectiveness of SUT, as a means of energy harvesting project, using the analysis of power generation of SUT.

II. METHODOLOGY

This research is an operational feasibility. Operational feasibility is the capacity of a system or program to be utilized, supported, and execute its required responsibilities. It comprises all individuals who design, operate, or utilize the system (Writer, 2022). A feasibility study is defined as an analysis of whether the plan or project is viable (Hofstrand & Clause, 2020). Also, inclined to Don Hofstrand Gary Wrigth and Mary Holz-Clause (2020), a feasibility study uses the viability of an idea through analysis. The study aims to analyze the potential energy harvesting of the solar updraft tower at Don Honorio Ventura State University specifically at the administration building. The effectiveness of this project has a significant influence on the energy consumption of the locale above. This affects the costs of the usage of electric power. Thus, it's the technical aspect.

STEP 1	*STEP 2*	*STEP 3*	*STEP 4*
DATA GATHERING -Location - kilowatt demand of DHVSU -Temperature	**ESTABLISHED BASE CASE** -Data Analysis	**CALCULATIONS** -Energy generation of SUT	**CONCLUSION** -Effectiveness of SUT

Figure3. Illustration

In step 1, The researchers gathered data about the possible vacant space in DHVSU for the basis of the study. After knowing the availability of the area, the researchers gave the prepared request letter, which contents are for the researchers to have access to the kilowatt demand of DHVSU. In addition to that, the temperature is also a significant factor in the SUT's function. Finally, the researchers sought data from PAGASA located at Clark, Pampanga.

Step 2, Establish the base case. It is established by studying the flowchart that step 1 gave. In addition, location has a vital role in the study as it will determine the SUT's area in diameter and the temperature to ascertain if the place was realistic for SUT.

Step 3, Calculate the energy generation of SUT using the power output formula and differentiate it from the collected data on total kilowatt demand of DHVSU specifically Administration building for the researchers to see the SUT's benefits.

Step 4, Conclude if the study is applicable or not applicable based on attaining the study's objectives.

Furthermore, as the researchers continued to seek the possible power generated from the Solar Updraft Tower in DHVSU. Therefore, formulas from various references helped compute the SUT power generation. Generally speaking, the power output (P_{output}) of the solar tower can be calculated as the solar input (Q_{solar}) multiplied by the respective efficiencies of the collector, building, and turbine(s):

$$P_{output} = Q_{solar} \times N_{coll} \times N_{tower} \times N_{turbine} = Q_{solar} \times N_{plant} \quad (1)$$

Equation 1 was from a journal entitled *"Design of Commercial Solar Updraft Tower Systems – Utilization of Solar Induced Convective Flows for Power Generation* by Jörg Schlaich, Rudolf Bergermann, Wolfgang Schiel, and Gerhard Weinrebe (n.d.). It is a study in which theory, practical experiences, and economy of SUT come into consideration. Also, equation 2,4, and 5 was also written in this study

Solar energy input of the system plays a pivotal role in the eq. (1) as this would be the main source of the SUT in order to generate electrical energy. The solar energy input (Q_{solar}) solar into the system can be written as the product of global horizontal radiation (G_h) and collector area (A_{coll}):

$$Q_{solar} = G_h \times A_{coll} \quad (2)$$

The efficiency of the collector into the system can be written as the quotient of specific heat at constant pressure multiplied by the change of temperature in collector inlet and outlet and the area of the collector multiplied to global solar radiation (horizontal). Using the software named "Energy2d", simulations were run to acquire the data for the Solar Updraft Tower where the temperature of inlet and outlet of the tower are being calculated to obtain the efficiency of the collector. The results of the inlet and outlet and simulations are gathered and analyzed. The efficiency of the greenhouse effect of the collector will be determined using eq. (3).

$$N_{collector} = \frac{C_p \times \dot{m}(T_2 - T_1)}{A_{coll} \times G_h} \quad (3)$$

Equation 3 comes from a journal entitled *Solar updraft tower power generation* by Xinping Zhou and Yangyang Xu (2014). The efficiency of the tower in the system can be written as the quotient gravitational acceleration multiplied by the height of the tower (gravitational potential energy) and specific heat at constant pressure multiplied by the temperature at ground level

$$\mathrm{N_{tower}} = \frac{\mathrm{g \times H_{tower}}}{\mathrm{C_P \times T_0}} \quad (4)$$

Using the Boussinesq approximation, the speed reached by free convection currents can be expressed as,

$$v_{tower,max} = \sqrt{}(2 \times g \times H_{tower} \times \frac{\Delta T}{T_0}) \quad (5)$$

The mass flow rate is the amount of liquid that passes per unit time. In other terms, the mass flow rate is the rate at which liquid passes through a unit area. The mass flow is directly proportional to the density, velocity of the liquid, and cross-sectional area. Mass inflow rate can be acquired by getting the product of the velocity of the air, area of the tower, and density of the air. However, to get the mass inflow rate of the collector, instead of using the velocity of the liquid, the equation suggests using the velocity of the air. Thus,

$$\dot{m} = v_{tower} \times A_{tower} \times p \quad (6)$$

Specific gas constant can be obtained by getting the quotient of universal gas constant and molar mass of the air

$$R_s = \frac{R_u}{M_m} = \frac{8314\frac{J}{(K)(mol)}}{28.98\frac{kg}{mol}}\boldsymbol{v}$$

$$R_s = 287\, J/(kg)(K)$$

From the 1st law of thermodynamics, the formula of specific heat at constant pressure is derived to be.

$$C_p = C_v \times R_s \quad (7)$$

And from the theory of statistical thermodynamics, air can be thought of as a perfect gas whose degree of freedom ≈ 5 , hence specific heat at constant volume would be.

$$C_v = \frac{5}{2} R_s$$

Substituting it to eq. (7)

$$C_p = \frac{5}{2} R_S + R_S = \frac{7}{2} R_S$$

$$C_p = \frac{7}{2} R_S = \frac{7}{2}(287 \frac{J}{(kg)(K)})$$

$$C_p = 1004.5 \frac{J}{(kg)(K)}$$

According to Nils Dlarsson and Leonardo Golubovic (2011), specific heat at constant pressure is the amount of heat necessary to increase the temperature of a unit mass of gas by one degree while keeping the pressure constant throughout heating. The area of the collector could be computed by using the equation below**.**

$$A_{collector} = \pi r^2 \quad (8)$$

At low speeds, turbine efficiency plummets dramatically. This poor efficiency would have lowered the resolution and accuracy of the data gathered. As a result, wind speed was measured instead, and Equation 9 provides the energy equation for air passing through a turbine.

$$P_{Turbine} = N_{turbine} \frac{1}{2}\, p_{air} \frac{\pi}{4} D_{turbine}^3 v_{tower,max}{}^3 \quad (9)$$

Equation 9 comes from a journal entitled *Experimental validation of solar chimney performance models and operational characteristics for small scale remote applications* by Stephen M. Raney, Jeremy R. Brooks, Jared P. Schaffer, Jesse J. French (2012). The estimated max turbine efficiency, N_T, is 20%, this was based on a study entitled *Renewable Energy for Home, Farm, And Business, Pau Gipe (2004).*

The density of air can be calculated by getting the product of the absolute temperature and specific gas constant and using it as a divisor of absolute pressure.

$$\rho = \frac{p}{T_{absolute} R_s} \tag{10}$$

Legends	
P	power in watts, kW, kW-h
Q_{solar}	solar input (heat flux in W/m²)
N_{coll}	efficiency of the collector
N_{tower}	efficiency of the tower
$N_{turbine}$	efficiency of the turbine
N_{plant}	efficiency of the power plant
G_h	global solar radiation (horizontal), W/m²
A_{coll}	area of the collector, m^2
C_P	specific heat at constant pressure, J/(kg)(K)
C_v	specific heat at constant volume J/(kg)(K)
$\dot{m}$	mass flow, kg/s
T_0	temperature in K at ground level
T_1	temperature in K from the collector inlet
T_2	temperature in K from the collector outlet
H_{tower}	height of the tower, m
g	gravitational acceleration, 9.81, m/s^2
R_s	specific gas constant, 287 J/(kg)(K)
R_u	the universal gas constant, 8314 J/(K)(mol)
M_m	the molar mass of air, 28.98 kg/mol
v	velocity of the air, m/s
A_{tower}	area of the tower, m^2
ρ	density of air, 1.225 kg/m³
P	absolute pressure, K
ΔT	change in temperature, K (Tmax-Tmin)
$A_{collector}$	area of the collector, m^2
r	radius, m
$D_{turbine}$	diameter of the turbine, m
T	Temperature in K

FIGURE 4, Legends

In partial fulfillment of the requirement in this research paper, the researchers from the Bachelor of Science in Electrical Engineering program presented this to the faculty of the Department of Electrical Engineering – College of Engineering and Architecture (CEA) of Don Honorio Ventura State University. The collection of data started from the conduction of a letter that includes and indicates the permission to collect the data and the two different instruments used by the university's premises. This letter was addressed to the office of the dean of CEA securely.

Furthermore, the researchers computed the data using the power output formula of the Solar Updraft Tower using Microsoft Excel. The researchers have analyzed the calculated power generation of the Solar Updraft Tower to the given available area and electricity consumption of the Don Honorio Ventura State University.

The researchers also applied the required ethical norms in making the study. The researchers followed the proper citation and have given credentials to the rightful owners of the data upon gathering the review of related literature. Furthermore, before distributing the survey form, the researchers assured that the respondents were given informed consent for their acceptance to participate in the study. In which the process was discussed. The researcher had solemnly sworn that the accessed information from the respondents would be kept confidential. As well as other researchers who are involved pledged that they will not reveal any information without the permission of the respondents. The collected findings were utilized for the research purposes only and only be presented with honesty, objectivity, integrity, and the subject's protection.

III. RESULTS AND DISCUSSION

This section presents the analysis, and interpretation of the study on the possible power output of SUT located at the allotted area which is in front of the Administration building following the methods illustration and using the instruments formulas. The content of this chapter are the calculated parameters in determining if SUT is convenient in the allotted area, and the possible contribution of SUT in DHVSU.

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- Possible Power Output of SUT

Renewable energy is the most convenient form of energy to use nowadays because it is clean and comes from natural sources which can be replenished. There are a lot of renewable energy resources that come in different ways such as sunlight, wind, flowing water, the earth's internal heat, and biomass. Solar Updraft

Tower is renewable energy that uses the combination of sunlight and wind to produce energy. The interpretations and tables below are for the computation of parameters that is a factor in the power output of SUT.

The area of the collector was determined by using equation 8. The parameters of the rectangular-shaped free space that the researchers measured were located in front of the admin building of DHVSU. It has a length of 53.34m and a width of 30.48m. By getting the circular radius of the space, using the width of the rectangle, and multiplying it by ½ of its value the product was 15.24. By getting the area of the circle we can acquire the area of the collector. Additionally, after getting the area of the collector, dimensions of SUT allocated on DHVSU (see appendix K) was established by using different studies about SUT as a reference. The SUT in Manzanares, Spain or the Manzanares Solar Updraft Tower Pilot Plant was mainly used for the ratio in downsizing the SUT in DHVSU because the said tower in Spain is already working and proven to be effective as a power generating facility.

Using equation 6, the mass flow rate was obtained (see appendix A). After the mass flow rate was determined, it was used to calculate the efficiency of the collector. Thus, the parameters needed, namely specific heat at constant pressure that can be determined using equation 7, inlet and outlet temperatures which were obtained by using energy 2D software where the simulation was done until the values became stable, getting the value of the outlet temperature as 283.7 K and inlet temperature as 275.4 K, Global Solar Radiation data (see appendix C) in which were obtained by sending a request to DATA Power Access Viewer which contains meteorology and solar related parameters formulated for assessing and designing renewable energy system, and the product of GSR and the area of the collector determined the solar input of the collector.

Table 1. Daily Average Solar Input of SUT

SOLAR INPUT (Q_solar)			
	2017	2018	2019
January	3110.396	3161.506	3555.782
February	3877.043	4125.291	4380.840
March	4556.074	4577.978	4913.842
April	4855.431	4928.445	5008.760
May	4380.840	4760.513	4293.223
June	4307.826	3124.999	4169.099
July	3198.013	2584.696	3490.069
August	3760.221	2832.943	2767.231
September	3614.193	3774.824	3205.315
October	3212.616	4139.894	4161.798
November	3234.520	3716.413	3117.698
December	2935.163	2876.752	3234.520

Using equation 2, solar input of the tower is determined. Because the collector's area remains constant, the value of global solar radiation is the one that influences the value of solar input. As a result, the month of April 2019 has the most solar input proportionate to the greatest global solar radiation (see appendix C).

Table 2. Daily Average Efficiency of the Collector

EFFICIENCY OF THE COLLECTOR			
	2017	2018	2019
January	0.610	0.593	0.483
February	0.465	0.411	0.326
March	0.401	0.400	0.363
April	0.366	0.299	0.298
May	0.372	0.333	0.343
June	0.373	0.507	0.385
July	0.481	0.613	0.479
August	0.367	0.551	0.605
September	0.370	0.349	0.480
October	0.469	0.383	0.348
November	0.519	0.408	0.465
December	0.707	0.589	0.545

Table 2 is the average daily efficiency of the collector that can be calculated by using equation 3. In the years 2018 and 2019, the collector's efficiency is valued at a minimum of 29.9 percent in the month of April. The collector's greatest efficiency occurred in the month of December of 2017 that has an efficiency of 70.67. As stated in equation 3, mass inflow rate is one of the aspects that contribute to the collector's high efficiency. In the month of December 2017, the mass inflow rate was greater than the others. This explains why the collector's efficiency was better in December, despite the fact of the common knowledge that this month of the year includes frigid temperatures.

After computing the average daily efficiency of the collector, the product of the gravity and height of the tower is divided with the specific heat at constant pressure multiplied by the ground temperature (see appendix B) and determined the efficiency of the tower which can be seen in table 3.

Table 3 is the average daily efficiency of the tower that can be calculated by using equation 4.

Table 3. Daily Average Efficiency of the Tower

EFFICIENCY OF THE TOWER N_tower			
	2017	2018	2019
January	0.00100	0.00100	0.00100
February	0.00100	0.00099	0.00100
March	0.00099	0.00099	0.00098
April	0.00098	0.00098	0.00098
May	0.00099	0.00098	0.00098
June	0.00099	0.00099	0.00099
July	0.00100	0.00100	0.00100
August	0.00100	0.00100	0.00100
September	0.00100	0.00100	0.00100
October	0.00100	0.00100	0.00100
November	0.00100	0.00100	0.00100
December	0.00100	0.00100	0.00100

As we can see in table 3, the tower's efficiency does not satisfy at least one perfect efficiency. This is because the tower's height falls short of the height required to obtain an advantage over its divisor, which is the product of ambient temperature and specific heat of constant pressure. Furthermore, attempting to modify its height to 1500 meters, as employed in SUT on Manzanares, would only result in a 4 percent efficiency. As a result, the tower's capacity to reach great efficiency cannot be realized. After computing the efficiency of the tower, Density of air was calculated using equation 10 and its value is 1.225 kg/m³. In addition, the diameter of the turbine was obtained by getting the mean of d1 and d2 (see appendix F)

Using equation 9, power of the turbine was calculated after computing the average daily efficiency of the tower. In a journal entitled "*EXPERIMENTAL VALIDATION OF SOLAR CHIMNEY PERFORMANCE MODELS AND OPERATIONAL CHARACTERISTICS FOR SMALL SCALE REMOTE APPLICATIONS"* it was assumed in the study that the maximum efficiency of the turbine was 20 percent due to the slow air velocity into the chimney where the turbine efficiency descends at low velocity. The wind velocity that was used in calculating the power of the turbine was obtained in PAGASA and can be seen in appendix E.

Table 4 shows the turbine's daily power production. The tower maximum velocity (see Appendix D) is one of the reasons why the turbine may create the most electrical energy in the month of March of 2019. Thus, the maximum velocity of the tower is important in order to create power output in a turbine.

Table 4. Daily Average Energy Generation of the Turbine

Power generated of Turbine			
	2017	2018	2019
January	153.68	150.80	169.34
February	195.38	204.90	254.04
March	232.16	223.83	257.42
April	222.59	222.59	235.83
May	196.40	218.57	187.95
June	184.35	136.24	194.49
July	137.72	100.51	155.78
August	159.00	100.74	115.63
September	148.00	148.40	128.14
October	148.62	171.79	170.25
November	139.10	170.86	152.17
December	119.04	138.29	160.65

Table 4 was the daily average energy generation of turbine in kW-day in per month. After getting the aforementioned results, the power produced by SUT may be calculated using equation

It is possible to calculate the product of solar input, collection efficiency, tower efficiency, turbine efficiency, and power output of the SUT. Furthermore, the turbine's efficiency may be evaluated by dividing the output power by the input power. Thus,

$$Power\ output\ of\ the\ turbine = input\ power\ \times efficiency$$

Therefore,

$$P_{output} = (Q_{solar} \times N_{collector} \times N_{tower}) + P_{turbine} \quad (11)$$

since equation 9 is independent of the tower and collector efficiencies, the researchers used the power generated by the turbine rather than the turbine's efficiency. Simply add the turbine power to the product of solar input, collection, and tower efficiency after computing the turbine power.

Using the equation 11, Energy generated of the SUT in the year of 2017, 2018 and 2019 in watt-month.

Table 5. Monthly Possible Energy Generation of SUT in DHVSU

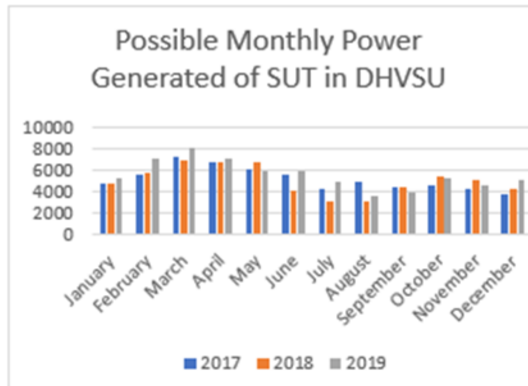
Monthly Power Generated of the SUT			
	2017	2018	2019
January	4.823	4.733	5.303
February	6.113	6.404	7.919
March	7.253	6.995	8.034
April	6.954	6.945	7.356
May	6.138	6.824	5.871
June	5.764	4.272	6.079
July	4.317	3.165	4.881
August	4.972	3.171	3.636
September	4.629	4.641	4.020
October	4.654	5.374	5.323
November	4.364	5.344	4.762
December	3.755	4.340	5.035
Annual	63.736	62.208	68.219

Table 5 is the calculated monthly possible energy generation of SUT in kilowatt-month. The highest monthly possible energy generation was in the year of 2019, month of march. This is caused by the energy generation of turbine in that time (see table 3). Table 5 shows that at least 60 kW-year can be generated by the SUT.

After determining the power output of the SUT in kW-year, the graph chart of the monthly energy generation of SUT in DHVSU (figure 5) can now be generated using Microsoft Excel (preferably MS Excel 2016) monthly energy generated of SUT in DHVSU generated by following the enumerated steps below.

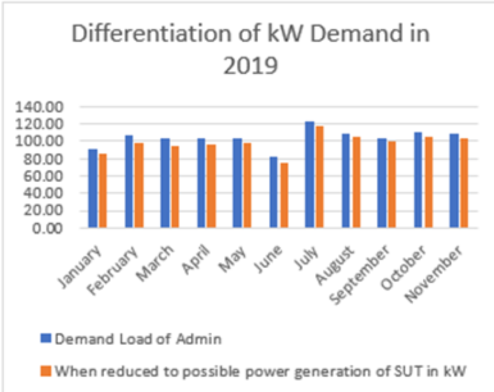
1. Encode the number of days in a month and multiply it to the average daily energy generated of the tower in the first column of the Microsoft Excel sheet.
2. Click and drag the calculated value from the first column up to the third column of the same Excel sheet.
3. Click and highlight the given table.
4. Click "Insert" in the toolbar of the Microsoft Excel 2016 window and click "Column" 5. Select the desired graph to generate the load curve. The Proposed Implementation of Demand 22 The specific graph that the researchers have selected is a "stacked 2-D column", which compares the contribution of each value to a total across categories by using vertical rectangles. After calculation, it can now be generated using Microsoft Excel (preferably MS Excel 2016). Using the power output in kW-month graph chart can now be generated by following the enumerated steps below.

Figure 5 Graph Chart of the Possible Monthly power Generation of SUT in DHVSU



Determining the graph chart of the monthly power generated of SUT in kilowatt-month, the possible maximum generated power outputs of SUT in DHVSU were distinguished based on table 5 and its corresponding graph as shown in the figure 5. It is apparent that the average peak period of SUT power generation in the year of 2017, 2018, and 2019 is in the months of March, April and May which can be identified as the month of summer. On the other hand, the months of July, August, and September have the least average power production since these months are the rainy and cold season in a year.

Figure 6 is the Monthly kW Demand Curve in kW of Administration Building



In figure 6, blue is the kilowatt demand of DHVSU specifically administration building for the year 2019 in months of January to November. The month of December was not included in the data due to the reason that the month of December was being read by the month of next year January. The orange color is the kilowatt demand graph after it was reduced to the possible power generation of SUT in DHVSU.

Getting the sum of kilowatt demand of admin in the year of 2019, months of January to November (see appendix I), and sum of possible power generation of SUT in the year of 2019, months of January to November (see appendix G).

$$\frac{sum\ of\ kW\ demand\ of\ Admin - sum\ of\ possible\ power\ generation\ of\ SUT}{sum\ of\ kW\ demand\ of\ Admin} \times 100\% = new\ kW\ demand\ in\ percent$$

$$\frac{1{,}145.20\ kW - 63.18\ kW}{1{,}145.20\ kW} \times 100\% = 94.48\%$$

The difference of 94.48 percent from 100 percent yields the potential contribution of SUT in lowering the kW demand of the DHVSU Administration building in percent, which has a result of 5.52 percent. Using the months of January to November of 2019, the findings reveal that the kW demand of the said building would drop by at least 5.52 percent yearly.

Using the conversion of units, we can get the energy harvesting potential of SUT in kW-h

$$kW\ month \times \frac{24\ days}{1\ month} \times \frac{24\ hours}{1\ day} = kW\ hour \qquad (12)$$

Table 6 is the Energy Harvesting Potential of SUT in DHVSU (kW-h)

Energy Harvesting Potential of SUT in DHVSU			
January	2.78	2.73	3.05
February	3.52	3.69	4.56
March	4.18	4.03	4.63
April	4.01	4.00	4.24
May	3.54	3.93	3.38
June	3.32	2.46	3.50
July	2.49	1.82	2.81
August	2.86	1.83	2.09
September	2.67	2.67	2.32
October	2.68	3.10	3.07
November	2.51	3.08	2.74
December	2.16	2.50	2.90
Annual	36.71	35.83	39.29

CONCLUSSION

This study sought to determine the energy harvesting potential of the solar updraft tower at Don Honorio Ventura State University. The data collected from the model study were utilized to substantiate the results. Consequently, deriving from the findings of this study, the following conclusions were drawn:

The energy harvesting potential of SUT in DHVSU was truly a topic which still needs a further analysis and understanding in order to manifest its full potential. This study used mathematical instruments in order to calculate the energy harvesting potential of SUT. The calculated parameters are simply based on an open space surrounding. In this study, it was determined that location, temperature and windspeed was appropriate based on the possible energy generation of SUT in the years 2017, 2018 and 2019 and can possibly generate an energy of 36.7 kWh, 35.8 kWh and 39.3 kWh respectively. Likewise, based on figure 6, it can reduce the kW demand of DHVSU by 5.52 percent yearly. Thus, it can be concluded that energy harvesting of SUT was possible with the parking lot in front of Administration building as its location.

RECOMMENDATION

With a goal of flourishing this study and offering substantial output to the society in adding up to the body of knowledge, the researchers are recommending the following:

After having the results of the study, the findings hereby recommend having a much larger space area for the SUT to generate more electrical energy. Additionally, the larger the collector area the higher the tower height. With that, it can generate more electrical energy because energy production of SUT is proportional to the height and area of the collector. The higher the temperature and air acceleration in the location, the higher the efficiency of the tower collector. The researchers' recommended that the dimensions of SUT be larger so it could generate higher electricity. Further research is needed in order for the SUT to be associated with the street lights and be associated with it.

There are other SUT studies which can give more information to know the other factors that may affect the power generation of SUT. Future researchers can use the conceptual framework developed by the researchers as a guide to develop a new method for determining the success of SUT in any desired area.

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REFERENCES

[1] Ellabban, O., Abu-Rub, H., & Blaabjerg, F. (2014). Renewable energy resources: Current status, future prospects and their enabling technology. Renewable and Sustainable Energy Reviews, 39, 748–764. https://www.sciencedirect.com/science/article/abs/pii/S1364032114005656

[2] Zhou, X., & Xu, Y. (2016). Solar updraft tower power generation. Solar Energy, 128, 95–125. https://www.sciencedirect.com/science/article/abs/pii/S0038092X14003284?via%3Dihub

[3] Too, J., & Azwadi, N. (2016). Akademia Baru A Brief Review on Solar Updraft Power Plant. Journal of Advanced Review on Scientific Research ISSN, 18(1), 2289–7887. https://www.akademiabaru.com/doc/ARSRV18_N1_P1_25.pdf

[4] Zhou, X., & Xu, Y. (2016). Solar updraft tower power generation. Solar Energy, 128, 95-125. http://wgbis.ces.iisc.ernet.in/biodiversity/sahyadri_enews/newsletter/issue45/bibliography/Solar%20updraft%20tower%20power%20generation.pdf

[5] Solar Updraft Tower. (2011). SolarUpdraftTower Project. https://architecture.mit.edu/sites/architecture.mit.edu/files/attachments/lecture/SolarUpdraftTower_Project.pdf

[6] Schlaich, J. R., Bergermann, R., Schiel, W., & Weinrebe, G. (2005). Design of commercial solar updraft tower systems—utilization of solar induced convective flows for power generation. J. Sol. Energy Eng., 127(1), 117-124. http://www.fem.unicamp.br/~phoenics/EM974/PROJETOS/Temas%20Projetos/Solar%20Chimneys/solar_updraft.pdf

[7] Jafarifar, N., Behzadi, M. M., & Yaghini, M. (2019). The effect of strong ambient winds on the efficiency of solar updraft power towers: A

numerical case study for Orkney. Renewable energy, 136, 937-944. https://rgu-repository.worktribe.com/preview/297978/JAF ARIF AR%202019%20The%20effect%20of%20strong%20ambient.pdf

[8] Ayub, F., Akhand, S., Khan, A. S., & Saklayen, G. (2018, May). Design and Fabrication of Solar Updraft Tower and Estimation of Power Generation; Initially Focused on Bangladesh. In IOP Conference Series: Earth and Environmental Science (Vol. 150, No. 1, p. 012023). IOP Publishing. https://www.akademiabaru.com/doc/ARSRV18_N1_P1_25.pdf

[9] Solaripedia | Green Architecture & Building | Projects in Green Architecture & Building. Solar Updraft Towers Generate Mega Power. https://www.solaripedia.com/13/371/5025/solar_updraft_tower_in_manzanares_spain.html?fbclid=IwAR0XjEFC17EbaJCBrBtahGE49qxIfo55_EZeIXBTpb_IZNiOAnsPi0uugg

[10] Crittenden, K. S. R. K. S. Environmental Consequences of Lahars, Subsidence, and Human Behavior in Bacolor, Pampanga. https://ieeexplore.ieee.org/abstract/document/8666233

[11] Handbook of Gold Exploration and Evaluation (2017). Feasibility Study - an overview| Science Direct Topics. https://www.sciencedirect.com/topics/chemistry/bill-study

[12] Iowa State University Extension and Outreach AG Decision Maker. What is a Feasibility Study? | Ag Decision Maker. What is a Feasibility Study? https://www.extension.iastate.edu/agdm/wholefarm/html/c5-65.html

[13] Qazi, A., Hussain, F., Rahim, N. A., Hardaker, G., Alghazzawi, D., Shaban, K., & Haruna, K. (2019). Towards sustainable energy: a systematic review of renewable energy sources, technologies, and public opinions. *IEEE Access*, *7*, 63837-63851. https://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=8721134

[14] Dilip Ahuja and Marika Tatsutani, Daniel Schaffer (2009) Sustainable energy for developing countries. https://journals.openedition.org/sapiens/823

[15] BRENK, Arkadiusz Patryk; MALECHA, Ziemowit Miłosz; TOMKÓW, Łukasz Tadeusz. (2020) Numerical methodology for analyzing the performance of a solar updraft tower in various environmental conditions. Journal of Power Technologies, [S.l.], v. 100, n. 2, p. 144-151, june 2020. ISSN 2083-4195. https://papers.itc.pw.edu.pl/index.php/JPT/article/view/1353

[16] Schlaich Bergermann Solar GmbH, Stuttgart (2011). Solar Updraft Tower. https://architecture.mit.edu/sites/architecture.mit.edu/files/attachments/lecture/SolarUpdraftTower_Project.pdf

[17] THOMAS K. GROSE (2014). Solar Chimneys Can Convert Hot Air to Energy, But Is Funding a Mirage? https://www.nationalgeographic.com/history/article/140416-solar-updraft-towers-convert-hot-air-to-energy

[18] John Spacey (2017). 14 Types of Technical Feasibility. https://simplicable.com/new/technical-feasibility

[19] Staff Writter (2020). What Is Operational Feasibility? https://www.reference.com/business-finance/operational-feasibility-300ab6b96428cf68

[20] Constant Volume - an overview | ScienceDirect Topics. (n.d.). Www.sciencedirect.com. Retrieved June 4, 2022, from https://www.sciencedirect.com/topics/mathematics/constant-volume#:~:text=The%20specific%20heat%20of%20a Ahmed, B. (n.d.). *DESIGN AND THERMODYNAMIC ANALYSIS OF SOLAR UPDRAFT TOWER*. Retrieved June 4, 2022, from https://www.theseus.fi/bitstream/handle/10024/33264/babaleye_ahmed.pdf?sequence=2 *Constant Volume - an overview | ScienceDirect Topics*. (n.d.). Www.sciencedirect.com. https://www.sciencedirect.com/topics/mathematics/constant-volume#:~:text=The%20specific%20heat%20of%20a

[21] *Ideal Gases under Constant Volume, Constant*

[22] *Pressure, Constant Temperature, & AdiabaticConditions*. (n.d.). Www.grc.nasa.gov. https://www.grc.nasa.gov/www/k-12/Numbers/Math/Mathematical_Thinking/ideal_gases_under_constant.htm

[23] Hadyan Hafizh, Hiromichi Shirato, and Daiki Yui (2016,) Performance Analysis of Solar Updraft Power Generator in Indonesia. file:///C:/Users/Windows%2010%20Pro%2064Bit/Downloads/512-Article%20Text-3254-3-10-20160920.pdf

[24] Raney, S. M., Brooks, J. R., Schaffer, J. P., & French, J. J. (2012). Experimental Validation of Solar Chimney Performance Models and Operational Characteristics for Small Scale Remote Applications. *ASME 2012 6th International Conference on Energy Sustainability, https://sci-hub.hkvisa.net/10.1115/ES2012-91192*

[25] Solar Energy. (2020). In H. Tyagi, P. R. Chakraborty, S. Powar, & A. K. Agarwal (Eds.), *Energy, Environment, and Sustainability*. Springer Singapore. https://sci-hub.hkvisa.net/10.1007/978-981-15-0675-8

[26] Kalash, S., Naimeh, W., & Ajib, S. (2014). A Review of Sloped Solar Updraft Power Technology. *Energy Procedia*, *50*, 222–228. https://doi.org/10.1016/j.egypro.2014.06.027