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COMPARATIVE STUDY OF A SUSTAINABLE HYBRID HEATING SYSTEM IN A GREEN INFRASTRUCTURAL BUILDING

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ABSTRACT
Traditional energy production from fossil fuel conversion process creates negative environmental impact and affects human health. Thus, the usage of solar space heating piques the interest of several countries and organizations because it can reduce fossil energy consumption and is environmentally friendly. This paper conducted a comparative study between the advantages and impacts of using a sustainable Hybrid Heating System (HHS) and a Conventional Heating System (CHS) in an infrastructural building. The Centre for the Built Environment and Infrastructure Studies (CBEIS), a GOLD LEED-certified building of Morgan State University (MSU) is currently using an HHS for heating and cooling of electricity production. Several testing and analysis were used to compare and evaluate the performance and advantages of the HHS. The results showed that HHS has a significant edge over the CHS and was able to reduce the annual cost of the electric bill for almost $25,000. The statistical results and Analysis of Variance (ANOVA) confirmed that there was a significant difference during the months of winter and summer season in determining how much Kilowatt (kW) produced during the process.

Keywords: solar energy, heating system, sustainability, renewable energy, regression model

1. INTRODUCTION
The demand for energy is constant and will require newer and more plentiful sources in the future as demand continues to rise. The current practice of using non-renewable resources in the form of natural gas and oil is not sustainable long term. Therefore, it is very prudent to begin the development of other sources of energy. The energy production field requires a massive amount of innovation and vast improvements in technology. Until those alternative fuel sources can be created or discovered, there needs to be the development of readily available sources of energy that can provide sustainability (Bonetti et al., 2017).

The purpose of this research was to compare, evaluate, and analyze data obtained from the sustainable hybrid heating system in the CBEIS building to determine their energy and cost efficiency properties that can be seen in Figure 1. Furthermore, this also aimed at weighing the benefits and advantages of using renewable energy compared to fossil fuel in commercial applications such as residential heating buildings. An increase in renewable energy usage can lead to the improvement of technology in green energy fields and a subsequent reduction in emissions that cause environmental hazards. Future work can be conducted on the topic to compare other systems that use renewable energy to systems that do not. That work can translate to improvement and optimization of renewable energy systems so that they can produce as effectively and efficiently as conventional or traditional systems.

Figure 1. CBEIS Sustainability Hybrid Heating System Diagram (The Freelon Group, 2012)

Heating water at the national levels is how people minimize their expenses. Most of the water heaters usually use two known systems which are solar heating systems and conventional heating systems. In a solar heating system, PV arrays collect solar energy from that sun and convert that energy to heat the water for different applications. Figure 2 shows that other equipment such as pressure gauge, pumps, storage tank, heat exchanger, compressors, and expansion valves which require incorporation into the design process. This extra equipment, in turn, makes the solar water heater expensive to build.

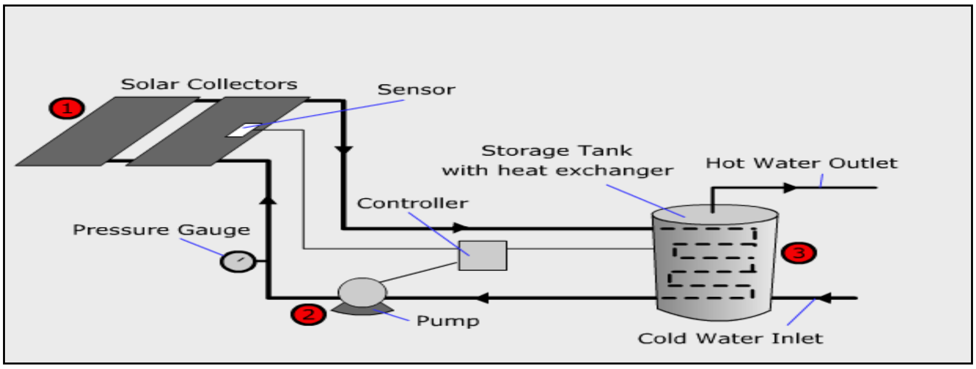

Figure 2. Diagram of a Solar Water Collective System (Bonetti et al., 2017)

Whereas the conventional heating system, it uses fossil fuels to heat the water. Burning fossil fuels emits several air pollutants that are harmful to both the environment and public health. Sulphur dioxide emissions, primarily the result of burning coal, contribute to acid rain and the formation of harmful particulate matter. Thus, with the increased demand for electricity by consumers has impacted the growth of the solar energy sector to explore and venture out different renewable areas that have a minimum environmental impact. Due to the advantages of solar energy, it has received overwhelming support between politician and environmentalists. The article by Huseyin, Benli, and Aydın Durmus (2009) discusses the use of solar collectors and thermal storage to provide adequate heating for a greenhouse. Due to the rising costs of fossil fuels, climate change, and the abundance of solar radiation, the need for a renewable energy source has increased. The rise in fuel costs makes it expensive when heating the greenhouse on severe freezing days. However, due to the limited amount of renewable resources, companies in both public and private are suffering.

Several authors have explored the issue of solar heating and made a comparison of an Electrical Heating System (EHS) and Solar Heating System (SHS) (Lazaar et al., 2015). In the end, they concluded that the SHS was better overall. They carefully analysed the heating conditions at a greenhouse setting. They observed that the Electrical Heating System was able to provide a much higher temperature of 40 ºC, whereas the Solar Heating System was only able to offer 20 ºC. However, although the heating obtained from the SHS is lower compared to EHS, it was deemed to be more economically viable since it was able to lower the energy cost. These findings support the research done by Chaturvedi et al., 2014, who conducted a life cycle analysis of the heat pump in the two systems. They concluded that solar pump was more economically viable and cheaper than an electric pump. These findings by these authors confirm that solar-powered systems for domestic purposes for domestic applications are more financially feasible than electrically powered systems.

The cost of solar-assisted equipment also depends on other expenses, such as the initial costs, installation, and maintenance charges. According to Abdur-Rehman (2016), a typical passive solar water heater requires at least a solar collector; this is aimed to show that there are prerequisite requirements of any solar equipment that is necessary for any project. The authors also identified the need for evacuated tube collectors on top of the project that they were presenting (Chaturvedi et al., 2014).

2. METHODOLOGY

2.1 Solar Panel Placement

The installation of the angles (tilt and azimuth) of the solar panels are facing plays a significant role in how much efficiency of energy is collected. As much as possible, the alignment to where the sun's radiation is binding to quickly achieve of collecting the maximum amount of the sun's energy. The azimuth angle gives the degrees of the solar panel and diverges from the south. The placement is in the Northern Hemisphere facing direction whereas the tilt angle gives the divergence from the horizontal in degrees (Turski & Sekret, 2016). Furthermore, Table 1 is the photovoltaic module used in the CBEIS building is a GEPVp-210-M, which is a 210-watt photovoltaic module for 600-volt applications. There are two main reasons why CBEIS building chose this system. (1) The photovoltaic module has a power tolerance of +/-5% and (2) it has a robust and clean anodized aluminium frame with pre-drilled holes for quick installation. The system has the following characteristics:

a) 54 poly-crystalline cells connected in series
b) Peak power of 210 watts at 27.3 volts
c) Designed for optimum use in residential and commercial grid-tied applications
d) 20-year limited warranty on power output, a 5-year limited warranty on materials and quality
e) Junction box and 1.8-meter cable with easy-click SOLARLOK® connectors included

Table 1: Performance Characteristics of the PV Module

Peak Power (Wp)	**Watts**	**210**
Max. Power Voltage (Vmp)	Volts	27.3
Max. Power Current (Imp)	Amps	7.7
Open Circuit Voltage (Voc)	Volts	3.3
Short Circuit Current (Isc)	Amps	8.3
Short Circuit Temp. Coefficient	mA/ºC	5.6
Open Circuit Voltage Coefficient	V/ºC	-0.12
Max. Power Temp. Coefficient	%/ºC	-0.5
Max. Series Fuse	Amps	15
Max. System Voltage	Volts	600
Normal Operating Cell Temperature (NOCT)	ºC	50

2.2 Energy Cost Equation of the CBEIS Building

The average commercial rate of a unit of electricity is above the national average. This warrant and makes economic sense for installation of a Solar Heating System. By multiplying the electricity units with the price of one unit of electricity in Maryland it can easily calculate the total electricity units in kilowatt-hour consumed by the buildings system. The average cost of energy is also calculated using the same computer programs. According to Electricity Local, the commercial electricity rates in Maryland for a commercial building is 10.43c/kWh, which ranks 16th in the United States. Additionally, the average commercial electricity rate of 10.43c/kWh in Maryland is 3.37% greater than the national average commercial rate of 10.09c/kWh. Moreover, the approximate range of commercial electricity rates in the United States is 6.86c/kWh to 34.88c/kWh. Thus, the cost of solar energy per unit of electricity is 7.8c/kWh. The cost of energy tabulated below gives the total cost that potentially incurred if the building used electricity only and if the building used solar energy only. In this case, the governing system of equations can be written as follows:

Energy Cost for Electricity = Price of Electricity per unit * Meter Reading

$$Cost = \frac{\frac{10.43}{100}}{kWh} * Meter\ Reading\ (kWh) \tag{1}$$

$$Cost = \frac{\frac{7.8}{100}}{kWh} * Meter\ Reading\ (kWh) \tag{2}$$

Energy Cost for Solar = Price of Solar per unit * Meter Reading

The governing system of equations by the cost of energy in CBEIS building, can be written as follows:

Energy Cost for Electricity = Price of Electricity per unit * Meter Reading

$$Cost = 0.3 * \frac{\frac{10.43}{100}}{kWh} * Meter\ Reading\ (kWh) \tag{3}$$

Energy Cost for Solar = Price of Solar per unit * Meter Reading

$$Cost = 0.7 * \frac{\frac{7.8}{100}}{kWh} * Meter\ Reading\ (kWh) \tag{4}$$

The cost of energy in the CBEIS building without solar is simply the total cost assuming that the building was using electricity at 100% with the same meter readings.

3. RESULTS AND DISCUSSIONS

3.1 Cost Analysis

A hybrid system is a combination of both solar and electric, whereas, on the hand, a conventional system is just a pure electric heating system. The meter readings and monthly costs were collected from MSU's Physical Plant Office last 2018. Figure 3 shows the monthly readings collected from the power plant at Morgan State University in kilowatts per hour (kWh). Results indicated that the highest reading was 123,882.79 in July whereas the lowest reading was in January, which was only 77,820.24 kWh. Morgan's CBEIS building paid more during the summer than the Winter season. In certainty, most buildings in cold states (e.g., MD) are paying more energy bills in the winter than the summer. Additionally, this coincides with the research of Xu et al., when their analysis indicated that the influence of building energy efficiency was a factor in a Hot Summer and Cold Winter (HSCW) zone (2013). Notwithstanding, due to the structure and HVAC insulation of the CBEIS building, the data indicated that it has a higher summer bill. Al-Sanea and Zedan's results had a similar finding that the dynamic thermal characteristics of insulated building walls were affected through the usage of one, two and three layers of insulation, and the locations of which they are placed (Al-Sanea et al., 2011). During Winter season, CBEIS does not require that much heat energy to raise the temperate up and make it comfortable to the workers and students. The materials used during its construction phase were carefully planned out to maintain the comfortability of the workers and students while still considering the most effective way to save costs.

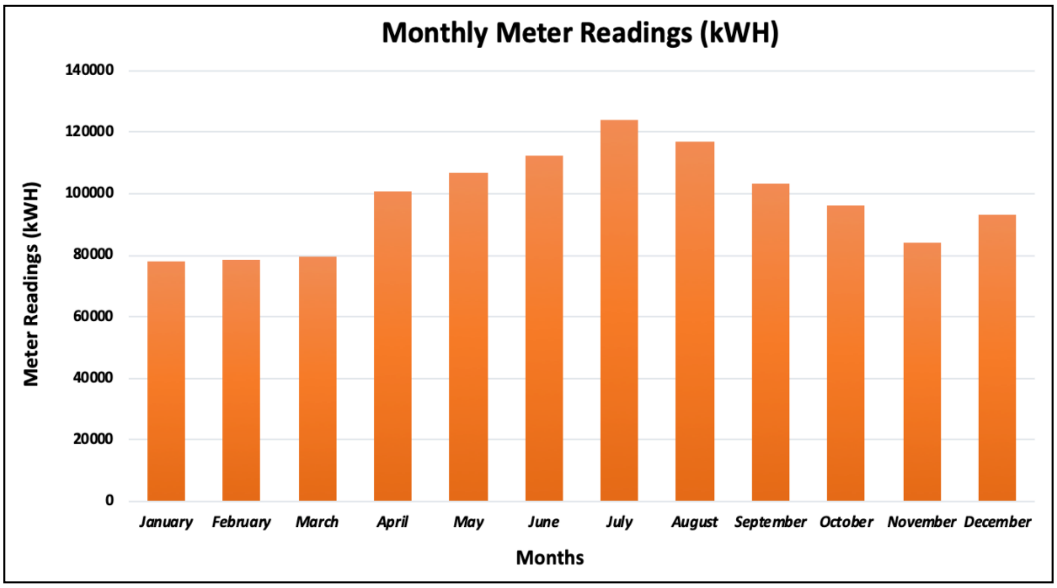

Figure 3. Monthly Meter Readings (kWh)

Last 2013, CBEIS received a Gold Award for Leadership in Energy and Environmental Design (LEED) certification from the U.S. Green Building Council (USGBC) and is now aiming for the Platinum Certification. Certainty, solar power is energy harnessed from the sun and transformed into different types of energy, including thermal and electricity. Figure 4 shows the graph of the Hybrid Heating System of its monthly cost distribution between 70% Solar and 30% Electric. The graph breaks down on how much price and energy that the solar system contributed. Whereas the electric system of CBEIS was only partially working throughout the year. Thus, it indicated that the CBEIS building profoundly practiced in utilizing renewable energy to decrease greenhouse gas emissions and air pollution.

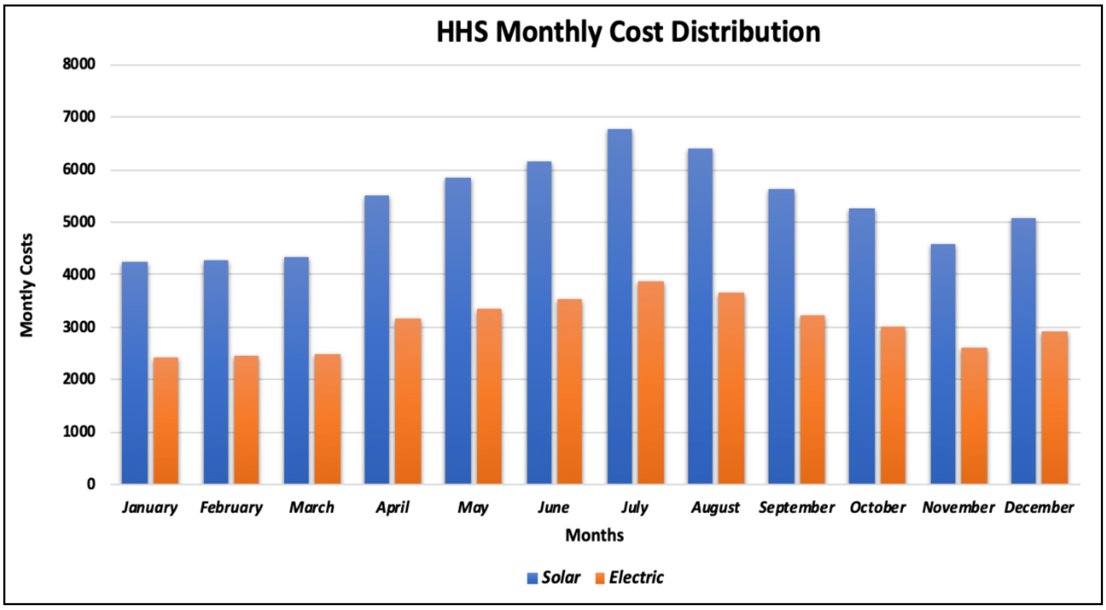

Figure 4. HHS (70% Solar and 30% Electric) Monthly Cost Distribution

The graph in Figure 5 depicts the price comparison between the Hybrid System of the CBEIS building and if ever the CBEIS was using full electric, which is the Conventional Heating System. The orange line in the graph is for the CHS while the blue line is for the HHS. Results indicated that the HHS had some significant edge over the CHS in terms of monthly costs. There is a vast difference in price per month. Based on the analysis of the data collected, the HHS was able to save almost $25,000.00 annually. The CBEIS serves as the ideal and standard building for any upcoming sustainable projects of MSU. The building itself has a vast number of laboratories intended for sustainability in design and engineering. Until now, the Administrators, Architects, and Engineers of the CBEIS building still continually seek for future improvements and look for resources to meet sustainability goals. Currently, the CBEIS building is using multiple forms of daylight harvesters, which are the two green roof systems and a traditional rooftop Photo Voltaic (PV) Panels with curtain wall integrated PV collectors.

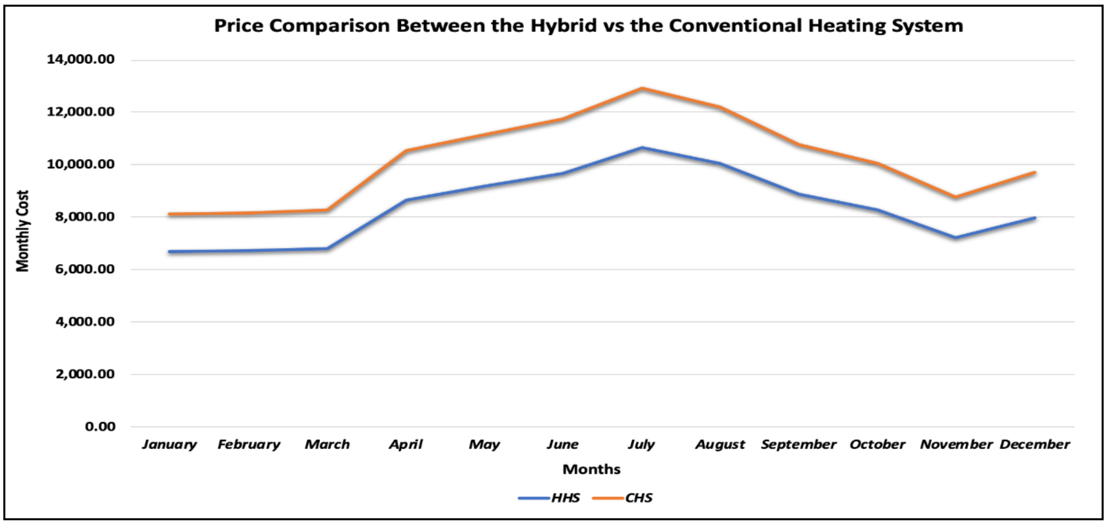

Figure 5. Price Comparison Between the HHS and the CHS

3.2 Descriptive Statistics

As previously mentioned, the two angles, which are the tilts and azimuth, identified the sun's position in the sky and played a significant role in the efficiency and energy captured of the solar panels. Figure 6 shows the mean, the standard deviation, and the range of the hybrid and conventional heating system.

Variable	Total Count	Mean	StDev	Variance	Minimum	Q1	Median	Q3	Maximum
Meter Reading	12	97807	15729	247393234	77820	80588	98718	111152	123883
Sustainable Hybrid System	12	8401	1351	1825226	6683	6922	8479	9547	10640
Conventional System	12	10201	1641	2691259	8117	8405	10296	11593	12921

Figure 6. Descriptive Statistics of Meter Readings, SHHS, and Conventional Heating System

Afterward, a Normal Probability Plot (NPP) was made. It is a graphical technique for assessing whether a data set is approximately normally distributed (Chambers et al., 1983). Based on the graphs in Figure 7, the data collected in both systems do not have any outliers, which means that there are only two following conclusions from the above plot, which are:

1. The NPP shows a strongly linear pattern. There are only minor deviations from the line fit to the points on the probability plot.
2. The normal distribution appears to be a good model for these data.

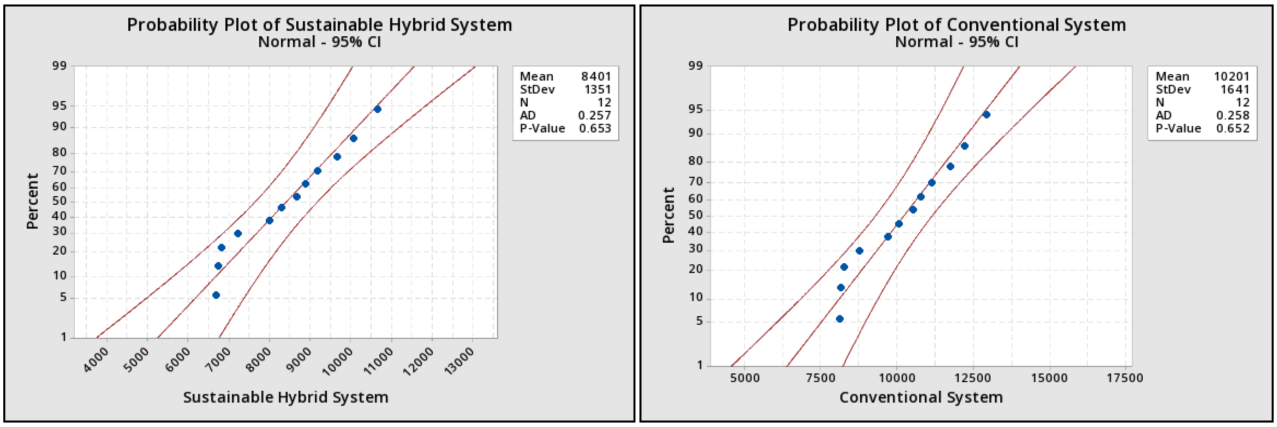

Figure 7. Normal Probability Plot of SHHS and Conventional Heating System

3.3 Inferential Statistics

Figure 8 shows the ANOVA results of the CBEIS building with its theoretical and calculated assumptions. Based on the given results of the ANOVA, the P-value is less than 0.05 in both factors – months and type of systems. Thus, it concludes that there is a significant difference between the factors and the response variable.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Months	11	49220382	4474580	106.78	0.000
Types of Systems	1	19454439	19454439	464.26	0.000
Error	11	460945	41904		
Total	23	69135766			

Figure 8. ANOVA of HHS and CHS

Figure 9 shows the linear regressions for the two systems. Linear regression is used to study the linear relationship between a dependent variable Y, which in this case is the total costs and the independent variables X, which are the types of systems and months. The dependent variable Y must be continuous, while the independent variables may be either continuous or categorical. The initial judgment of a possible relationship between two continuous variables should always be made on the basis of a scatter plot that can be seen above. With that said, the given equation that was made is able to predict the meter reading and costs that is needed to quantify the unknown costs in the future.

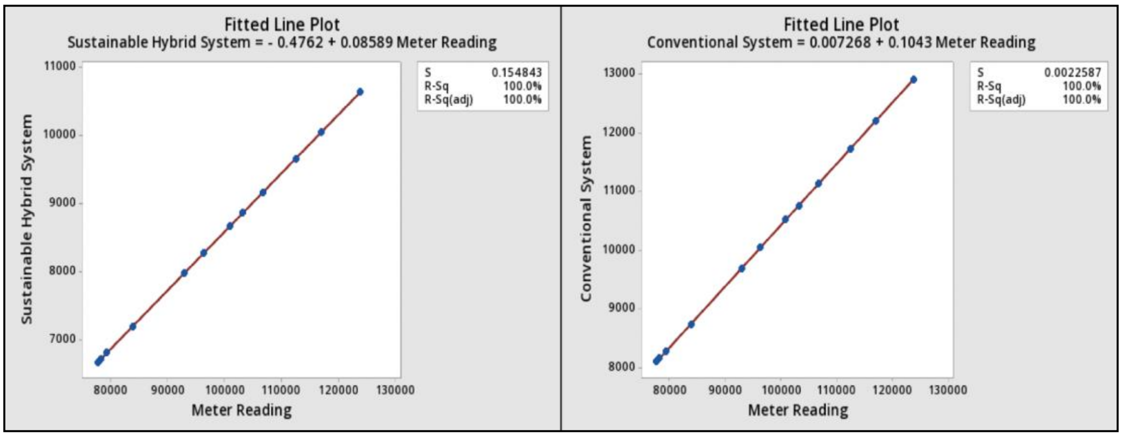

Figure 9. Regression Analysis Equation of the HHS and CHS

4. CONCLUSIONS

In conclusion, the data collected was able to differentiate the results and examined the advantages of using the HHS than the CHS. Based on the data comparison of energy consumption, it indicated that the HHS was more economical and cost-efficient. The results showed that HHS has a notable edge over the CHS and was able to reduce the annual cost of the electric bill for almost $25,000. The results from ANOVA confirmed that there was a significant difference during the months of winter and summer season in determining how much Kilowatt (kW) was produced during the process. Lastly, as the data collected where further analysed and evaluated, it is safe to assume that the factors heavily influenced the response variable. The regression equation was formulated to predict the total costs based on the energy given.

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