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A Feasibility Report on Rooftop Photovoltaic Solar Arrays at the University of Mississippi

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A FEASIBILITY REPORT ON ROOFTOP PHOTOVOLTAIC SOLAR ARRAYS AT THE UNIVERSITY OF MISSISSIPPI

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Abstract

The following project is a feasibility report for rooftop photovoltaic (PV) solar panel installations on select building across the University of Mississippi's campus. The purpose of this report is to determine the value of the energy that a rooftop solar system is capable of producing and the effect this generated energy will have on the energy needs of the building. As an entity with a stated commitment to sustainability and good stewardship of its resources, the University of Mississippi is on its way to become the state's leader in sustainability, boasting the state's largest roof-mount solar system. The analysis utilizes data collected from that system, architectural footprints of additional buildings across campus, and an online photovoltaic energy system calculator to determine the size and potential generation of solar system. The potential generation of each building's system was then analyzed based on economic parameters. From the results of the study, recommendations are given to the university on how to best pursue its goal of sustainability and responsible use of its resources. The results of this report emphasize that the current costs associated with rooftop solar systems make the projects undesirable and that energy efficiency building operation and reduced energy demand can be much more beneficial in terms of resource stewardship.

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LIST OF ABBREVIATIONS

AC	Alternating current
CME	Haley Barbour Center for Manufacturing Excellence
DC	Direct current
DCFROR	Discounted cash flow rate of return
GCR	Ground coverage ratio
HVAC	Heating, ventilation, and air-conditioning system
LEED	Leadership in Energy and Environmental Design
NREL	National Renewable Energy Laboratory
PV	Photovoltaic
UM	University of Mississippi

Introduction

In 2012, the University of Mississippi adopted the UM Creed, a statement of the values that every member of our university promises to uphold. The penultimate line of this pledge reads, "I believe in good stewardship of our resources." The word "resources," in this case, covers many elements from our time and talents to the facilities, land, and financial resources around our campus. For this thesis, I took a look into our University to determine a way to be better stewards of its energy resources, hoping to offset some of energy needs by producing renewable energy through rooftop solar arrays.

This report details the analysis of the energy generation potential of photovoltaic systems, or arrays, on a selection of campus buildings and summarizes the effectiveness of each building's system. The study analyzed specific buildings for the purpose of comparing the varied energy usage patterns of structures that serve different purposes on campus. The buildings chosen for analysis are Coulter Hall; the Turner Center; and Residence Hall 1, which operate as an academic building, a student life center, and a residence hall. An existing rooftop photovoltaic array, located atop the Haley Barbour Center for Manufacturing Excellence (CME) on campus, was the fourth system modeled. The CME system has recorded hourly energy production data since 2012 was chosen to validate the methods of estimating energy generation for the proposed arrays.

A preliminary investigation into the possibilities of a rooftop system used each building's rooftop area and scaled the generation data of the CME accordingly. Further analysis of the energy production capabilities by each proposed photovoltaic system data was performed using the *PVWatts* Calculator, a web application created by the National Renewable Energy Laboratory (NREL). *PVWatts* uses several user inputs such as decades of weather data and panel tilt, as well as additional built-in parameters to determine the electricity production capabilities of a solar system. The results from the CME's system simulation were compared to the actual data recorded over the system's life in order to confirm the chosen parameters.

Renewable Energy

Renewable energy is commonly defined as energy derived from replenishable sources. Although the United States Department of Energy government has yet to define what renewable energy is, it has outlined what renewable energy is not: nuclear energy or energy from fossil fuels (coal, petroleum, and natural gas). [6] Looking at energy production in the U.S., the forms of energy production that consequently fall into the renewable energy category are as follows: biomass, solar, wind, hydroelectric, and geothermal power. The leading forms of renewable energy, both globally and in the United States, are wind and solar power. [3]

Renewables and the University of Mississippi

The University of Mississippi has many reasons to look into the possibility of on-campus renewable energies. First, as previously mentioned, offsetting the energy demand of our campus is a palpable way for the University to personify its Creed and be a good steward of its resources. Secondly, as the fastest growing part of the energy sector, renewable energy will continue to require more employees, including researchers, engineers, and operators. [10] Showing a strong commitment to renewable energies will enable Ole Miss to recruit both students and faculty with an interest in this up and coming industry.

When pursuing a method for renewable energy generation on a college campus, rooftop solar installations prove to be the best fit for several reasons. The two most common forms of renewable energy are wind and solar power. Wind power is not be suitable for the University of Mississippi because the towering turbines that generate the energy would interfere with Ole Miss's historic and recognizable skyline. Solar power also has its own disadvantages; current commercial modules average an efficiency around 16%, meaning a photovoltaic cell only absorbs 16% of the power from the sun's electromagnetic radiation (i.e. photons). [10] Due to this low efficiency, solar arrays often require enormous amounts of land area compared to other forms of both renewable and non-renewable energy sources and are best suited for locations such as deserts and abandoned air fields. The installation of modules on rooftops circumvents this problem since the ground area can now serve an additional purpose and the roof typically serves no other purpose. In fact, the CME is currently equipped with Mississippi's largest roof-mounted solar array.

Installing rooftop solar systems on current buildings can be problematic if the existing structure in not sufficient to support the modules. However, as the University expands (with approximately 20 construction projects slated over the next 15 years), new buildings can be designed with energy saving measures in mind. By defining energy efficiency goals now, the University of Mississippi can implement a strategy of designing its buildings for sustainability and minimize the campus's energy consumption.

Photovoltaic Cells and Electricity

Photovoltaic cells are devices that convert sunlight into direct current electricity. The photons of sunlight will contact the semiconductor in the cell (typically a form of crystalline silicon), and the collision frees electrons in the semiconductor. An applied electric field sends the electrons in a particular direction through a circuit, producing direct electric current. Many cells are grouped together to form a photovoltaic module, and many modules are connected to form a photovoltaic system or array. An inverter that is attached to the system converts the direct electric current to alternating current that can be used immediately, used to charge a battery, or plugged into the power grid. [10] The electricity generated by the CME solar system is recorded separately from the building's usage. The electricity is consumed by the CME except during periods of higher generation than consumption, at which point the electricity enters the University of Mississippi's power grid.

Procedure

The electricity generation of each of the three proposed projects was determined in this report by two methods. The first of these methods used a surface area analysis of the current rooftop installations atop the Haley Barbour Center for Manufacturing Excellence as a basis for potential electricity generation. This preliminary method indicated that each chosen building, regardless of roof area, possessed electricity generation potential and also provided an estimate of the results of the second, more detailed calculation. The second method considers additional factors−such as the panels' orientation, tilt, and array− by using a modeling tool based on meteorological data to estimate the potential generation of a system for a sample year. This report presents the electricity generation estimated by this second method.

The detailed predictions of the generation of each of the three proposed project utilized *PVWatts*, a solar modeling tool provided by the National Renewable Energy Laboratory (NREL), a laboratory of the United States Department of Energy. *PVWatts* online calculator uses national weather data to model monthly photovoltaic energy production and calculate the yearly collection potential of the solar panels based on the following user inputs: system size, system losses, array tilt angle, and azimuth angle. Each input and its justification are included in the following paragraphs.

System Parameters

Weather Data

Weather data collected at C.D. Lemons airfield in Tupelo, Mississippi, provided the solar data used in calculations. The NREL National Solar Radiation Database provided the data from a record of hourly solar resource data collected from 1991 to 2010 at thousands of locations around the country. This data set was selected because the airfield was geographically the closest data collection facility to the University of Mississippi campus. This data describes the solar radiation experienced by the collection site on an hourly basis over a twenty-year period and accounts for meteorological conditions such as cloud cover, ambient temperature, and wind speed. *PVWatts* uses the weather data to estimate the hourly solar radiance sustained by the system in a typical year. The performance of a photovoltaic cell depends on the temperature of the module. Therefore, the weather data also includes hourly data of ambient temperature and wind speed to estimate the temperature of a module.

System Size

The system size, based on direct current, was determined using Equation (1)

$$\text{Size (kW)} = \text{Module Nameplate Size} \times \text{Number of Modules} \tag{1}$$

where the nameplate size is 250 Watts. This is both the size of the modules atop the CME, and the most common size sold commercially.

Since the nameplate size of the modules stayed the same for each building, the number of panels that could fit on each roof determined the size of the system. The existing system's layout and the rooftop area of the CME building served as the basis for determining the number of modules capable of fitting on each building. Using architectural footprints of the buildings, the rooftop surface area of each building was determined. The total estimate excluded area where sunlight is obstructed due to structures such as vents, electric boxes, or walls to the south.

In order to account for varied panel density on different parts of the system, blocks of rooftops were classified in one of the following categories, listed in order of decreasing panel density: (i) square, (ii) irregular, (iii) obstructed. Square sections are unobstructed sections of a system where panels are aligned squarely with the edges of a building. Irregular sections account for the roof area lost when panels are not aligned squarely with the edges of a roof. Obstructed sections are those with rooftop walkways, small air conditioning units, or skylights that interfere with the normal pattern of the installation. After dividing the CME's system into blocks based on their panel arrangement, each block was analyzed to determine a value for roof surface area per panel need for each style of panel arrangement. This per-panel area includes any clearance from the edge of the roof. Based on the architectural footprints of the other buildings, the appropriate panel density for each of the tested buildings was chosen. Dividing the total roof area of each building by the calculated area per panel gave the number of panels that could be installed per building. Using the standard commercial module size and efficiency of 250 W and 16% [3], the number of panels provided the DC system size.

The system sizes used for the simulation of each system are listed below.

Table 1. System size of existing CME system and proposed systems

System	Direct Current System Size (kW)
CME	108.52
Turner Center	240
Residence Hall	50
Coulter	76

System Losses

System losses are any loss that results in the energy production of the system being less than the solar radiation experienced by the system. The categories of system losses that were accounted for are listed in Table 2.

Table 2. Estimated system losses

Category	Loss Value (%)
Soiling	2
Shading	3
Mismatch	2
Wiring	2
Connections	0.5
Degradation	1.5
Nameplate Rating	1
Availability	3

Soiling occurs when matter such as leaves, snow, or grime accumulates on a panel's surface reducing the amount of radiation reaching the photovoltaic cells. Shading losses account for nearby trees or buildings, as well as shading caused by adjacent panels. Mismatch losses stem from imprecisions in the panels' manufacturing that give the panels varying current-voltage characteristics. Wiring losses account for energy lost due to resistances in the wires connecting the panels to the inverter. Similarly, connection losses are minor losses due to resistances in the electrical connections between panels. Degradation accounts for the initial loss of power during the first few months of a panel's life due to the high amount of solar radiation that it experiences. Although photovoltaic modules are built to withstand high amounts of radiation over its lifetime, the initial solar radiation will affect the modules for a short period after startup. Nameplate rating losses account for discrepancies between the manufacturer's nameplate size (given in kW) and the actual power a panel produces. The time that a system will be offline because of power outages or maintenance is also included as losses due to availability. *PVWatts* estimated the total system losses to be 14%, a result that fits within known values for losses of systems at similar latitudes. [1,3] The total was calculated from the numbers in Table 2 by the following equation.

$$100\% - (1-0.02)\times(1-0.03)\times(1-0.02)\times(1-0.02)\times(1-0.005)$$
$$\times(1-0.015)\ \times(1-0.01)\times(1-0.03)\ = 14\%$$

Array Tilt

The array tilt is the angle from horizontal at which a module is mounted. This was chosen to be 20°, the best estimate that can be made given the latitude of campus and the depth of this study. [3]

Azimuth Angle

For solar systems, the azimuth angle is the angle from true north to the direction the module is facing. For an array facing south, the azimuth angle would be 180°; an east-facing array, 90°; west, 270°. For arrays in the northern hemisphere, an azimuth angle of 180° is considered ideal. [1] The azimuth angle for each system modeled was chosen based on the orientation of each building, selecting the angle closest to 180° that would enable the largest system size. For example, an azimuth of 200° for the Turner Center system would align the modules squarely with the sides of the roof, permitting a larger system to be installed. For the Residence Hall, an east-facing system was modeled since orientation of the building and the slant of the roof would only allow for a system facing east or west. The east-facing system was selected due to probable shadowing by trees on to the west. The following table lists each building and the azimuth angle used to calculate the potential generation its system.

Table 3. Azimuth angle of existing CME system and proposed azimuths of modeled systems

System	Azimuth Angle
CME	190°
Turner Center	200°
Residence Hall	115°
Coulter	190°

PVWatts combines the latitude, longitude, and elevation of the weather data collection site with the tilt and azimuth angle of the array in order to estimate the net solar radiation experienced by the system. That radiation number is combined with the efficiency of PV technology and the estimated system losses to determine the electricity generation for a sample year.

Additional Inputs

This online calculator makes several assumptions in calculating the yearly generation of a system based on the given specifications. These assumptions are explained in this section.

In order to calculate a system's energy generation from the amount of solar radiation it receives, the efficiency of the panels must be assumed. The panel efficiency relates maximum power output of a panel to the radiation and area required to achieve that maximum power. For the performed calculations, an efficiency of 15% was used. [1] This efficiency corresponds to standard glass-covered poly- or mono-crystalline silicon panels and has been verified by a number of sources. [3, 5, 7]

The next assumptions involved a system's inverter, the device that converts the direct current power from the modules into the alternating current fed to the power grid. *PVWatts* assumed the efficiency of this conversion to be 96%. Because the DC-to-AC conversion is never 100%, many systems will install an inverter smaller than the system's DC systems size. *PVWatts*' default DC-to-AC Size Ratio is 1.1, meaning the 50 kW DC system on the Residence Hall would have a 45.5 kW AC inverter rating. [1]

The next assumption pertains to the ground coverage ratio (GCR), a term relating the area occupied by modules in an array to the total ground area occupied by the array. By definition, this value will always be less than 1. A higher GCR corresponds to tighter spacing, enabling a greater system size and coverage at lower yield-per-module due to shading from other modules. Lower GCRs indicated greater spacing between modules, maximizing the yield of individual modules with a smaller system and decreased ground coverage. Typical rooftop systems have a GCR between 0.3 and 0.6. [3] A groundcover ratio of 0.4 is the default value used by *PVWatts* and fits the stated heuristic. [1] A complete list of the *PVWatts* inputs is located in the attached appendix.

The CME system was analyzed to validate the assumptions made for these inputs, as well as the choice of weather data and system losses. The current version of *PVWatts* Calculator used for this report has a stated uncertainty of +/- 10%. [1] The data from the existing solar system atop the CME validated that the average yearly electricity generation since 2012 is within the stated uncertainty limits of the yearly electricity generation estimated by *PVWatts* as shown in Table 4. The complete data tables used in the validation of the *PVWatts* calculator are listed in the appendix.

Table 4. Comparison of Actual and Estimated Electricity Generation of the solar array atop the CME (kWh/yr.)

Actual Generation	Estimated Generation	Error
130,700	142,500	+9%

Economic Parameters

The estimated annual electricity generation of each photovoltaic system enabled the calculation of the energy cost offset by each system using the average commercial energy price in Mississippi. The U.S. Energy and Information Administration, an agency within the U.S. Department of Energy that provides statistics related to energy, economics, and the environment, most recently published the average commercial electricity price in the state of Mississippi as ¢10.25/kWh. [9] In this way, a larger system leads to more panels, which leads to greater generation, which would increase savings.

The installation cost — which includes module, hardware, and inverter costs as well as the cost of labor to install and maintain the system – of each system was determined using the 2015 national average price per kilowatt determined by the U.S. Department of Energy. These averages account for economies of scale, so the cost per kilowatt gradually decreases as the total system size increases. [2] The payback period, discounted cash flow rate of return (DCFROR), and break-even price of electricity for each system was calculated from its installation cost and projected yearly energy savings. An interest rate of 2% was used to account for inflation in the determination of payback period and break-even price. The break-even price considered a project life of 25 years, and the net worth of each project was calculated at the current year.

In order to provide an additional scale against which each system could be analyzed, the electricity generation of each building was compared to the electricity used by each building on a yearly basis. The University of Mississippi Facilities Management provided yearly data for the electricity usage of the CME, the Turner Center, Coulter Hall, and a residence hall. Complete tables of the data provided by the CME's existing solar system and Facilities Management are listed in the appendix.

Results and Discussion

Using the methods prescribed above, the CME solar system was modeled in the *PVWatts* calculator to validate the weather data set from C.D. Lemons airfield in Tupelo and other calculator inputs. System inverters recorded the daily AC electricity generated by the system from January 2012 to February of 2015. A yearly average of this data was taken and compared to the yearly estimated generation of the *PVWatts* calculator. As shown in Table 4, the *PVWatts* estimate matched the actual amount of electricity generated by the array since 2012 within the stated error range of ±10%.

From the stated inputs and system sizes listed in Table 1, the generation of the proposed systems, shown in Figure 1, was found.

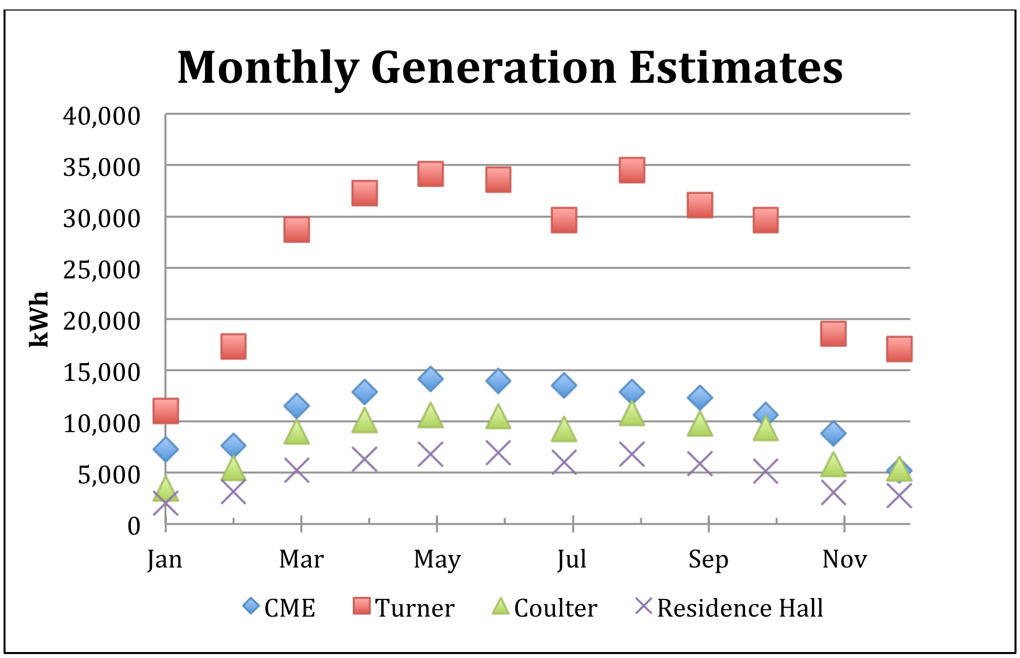

Figure 1. Monthly Electricity Generation of Each Proposed Solar System (*PVWatts*)

The generation curves of each system appear to follow the same trajectory of greater generation during the summer months (May- July) and reduced during the winter months (Dec- Feb). This is due to the average latitude of the sun's incident light at the given season and is the typical generation pattern for systems in the Northern hemisphere. As expected, the larger systems generate a greater amount of electricity.

Multiplying the yearly generation of these systems by the energy rate produces the yearly energy savings of each system, listed in Table 5 next to each system's estimated installation costs. Also listed in Table 5 are the results of two methods of determining project feasibility, the discounted payback period and the discounted cash flow rate of return (DCFROR.) It should be noted that most solar modules typically have warranties lasting 25 years. Although a module may continue to generate energy after that period, for the evaluation of these solar projects, the life of the project was assumed to be 25 years.

Table 5. Installation Costs, Yearly Energy Savings, Discounted Payback Period, and the Discounted Cash Flow Rate of Return of Proposed Solar Systems

	Installation Cost	Yearly Savings	Payback Period (years)	DCFROR
Turner Center	$880,000	$33,000	39	-0.55%
Coulter Hall	280,000	10,000	41	-0.78%
Residence Hall	190,000	6,000	47	-1.41%

An economy of scale is apparent as the larger projects return a profit more quickly as shown with the payback periods of each project. The DCFRORs of the projects reinforce the economy of scale, with the larger projects having greater values. Notice that each DCFROR is negative. The DCFROR is the interest rate at which a project has a net worth of $0. A negative DCFROR is the equivalent of placing an investment in a bank and instead of receiving interest, paying to store your investment at the bank. Thus, none of the proposed projects would be profitable during the 25-year period covered by a manufacturer's warranty.

Although these projects are not currently feasible, improved technology and manufacturing methods for solar modules or a change in market conditions may allow these projects to be profitable in the future. Trends show that the costs — both for equipment installation and maintenance — have decreased substantially for the past 15 years and are expected to continue this trend for at least the next three years. [2] Decreasing the initial investment could potentially change the economic outlook of this project, and increasing the revenue from the panels will likewise improve the situation. Research is ongoing to produce more efficient panels that could convert a greater percentage of solar energy to electricity. Additionally, an increase in the cost of electricity could make these projects more profitable, as shown in Figure 2. With current technology and costs, the break-even price of electricity that would make these projects profitable is 14¢ for the Turner Center system, 15¢ for Coulter Hall's system, and 16¢ for a system on a residence hall. All break-even prices are roughly 50% higher than the current price for Mississippi businesses. Complete results of the break-even price analysis are listed in the appendix.

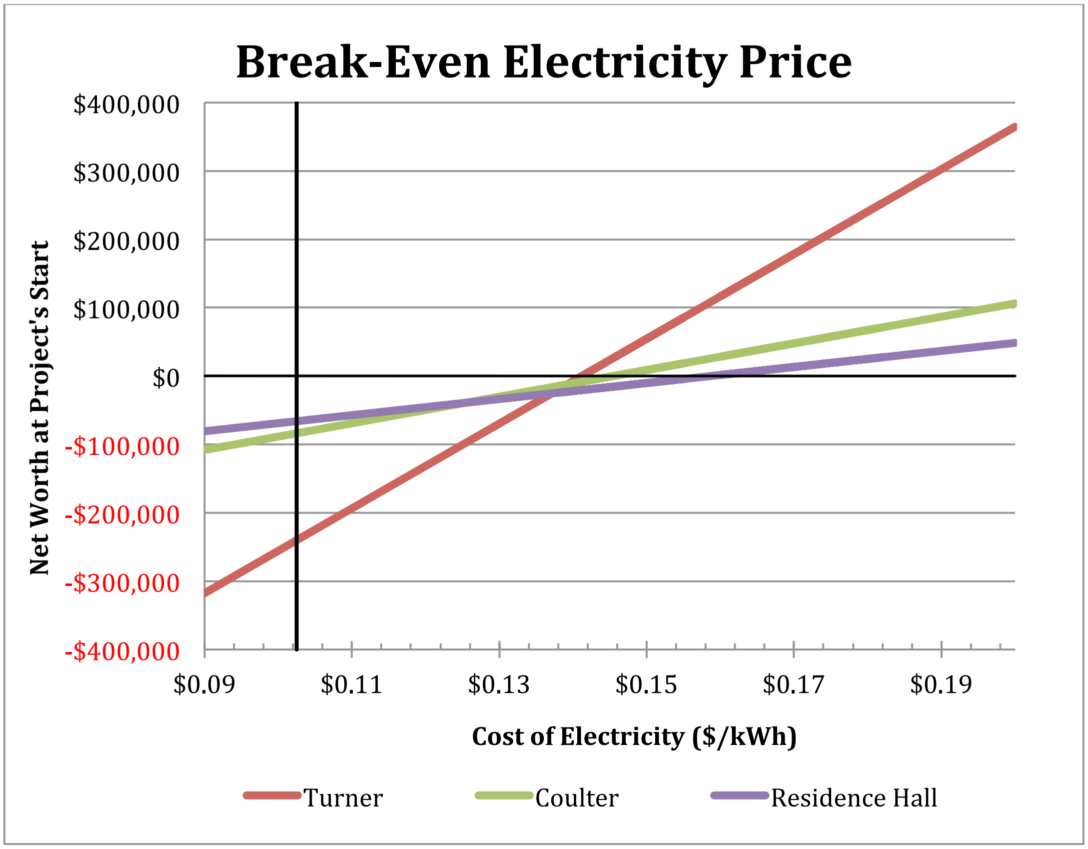

Figure 2. Effect of the Price of Electricity on the Net Worth of Each Proposed Project with the Current Price Point in Black

Despite the present unprofitability of these systems, additional analysis was done on the buildings to determine what percentage of the energy consumption of each building could be offset by a rooftop solar system in order to determine if a dramatic usage offset could otherwise justify the installation of the systems. The monthly electricity usage of a sample year and the percentage of that usage that could be offset by a rooftop solar system are shown in Figures 3 and 4, respectively. In accordance with the electricity generation patterns, one would expect to see buildings use more electricity the larger they are. However, in Figure 3, this trend is broken by the CME, which uses the least electricity of any of the studied buildings. Likewise, the CME is capable of producing a greater percentage of its usage, often generating over half of the electricity it uses. The CME is LEED (Leadership in Energy and Environmental Design) certified by the U.S. Green Building Council and as such, uses energy much more efficiently. LEED sets globally recognized standards for green building leadership in design, construction, and operation. [4] The pursuit of this certification led to the several measures that improved areas from water conservation to a reduced environmental impact of its materials of construction. In the area of energy usage, the CME increased its efficiency by installing energy efficient lighting equipped with motion sensors, extensive use of natural lighting, and the recovery of thermal energy through its heating, ventilation, and air-conditioning (HVAC) system.

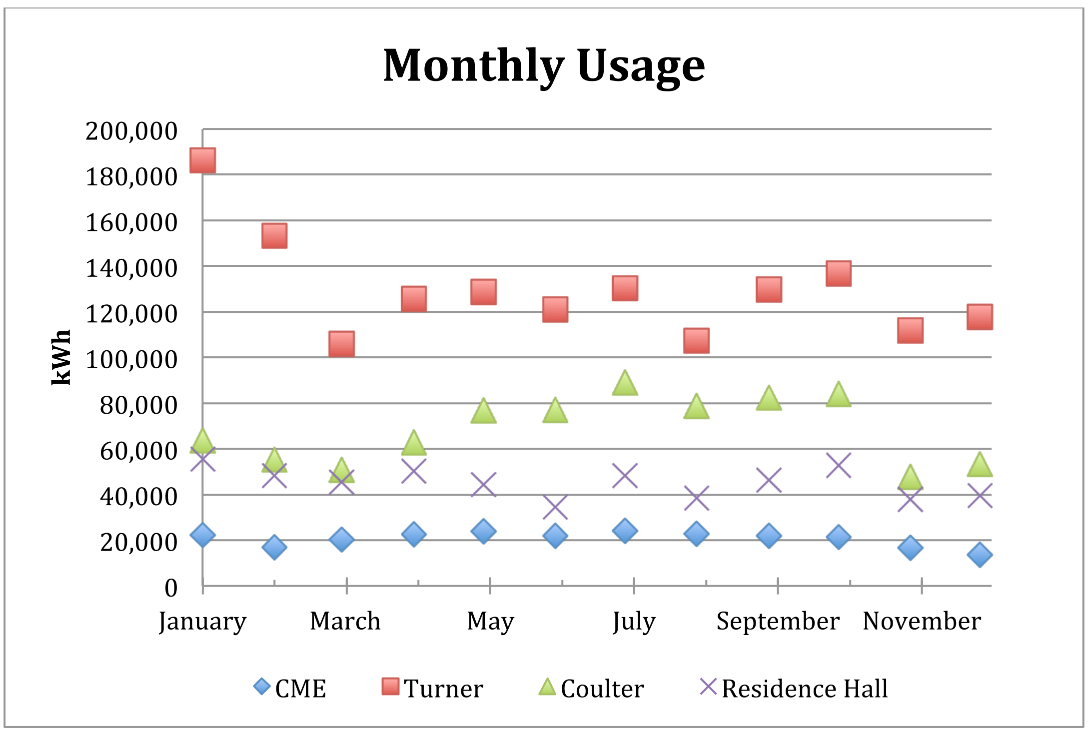

Figure 3. Monthly Electricity Usage of Buildings with Proposed Systems. Due to the unavailability of usage data on Residence Hall 1, the electricity usage of Burns Hall was used. Burns Hall is a residence hall of similar size. (UM Facilities Management)

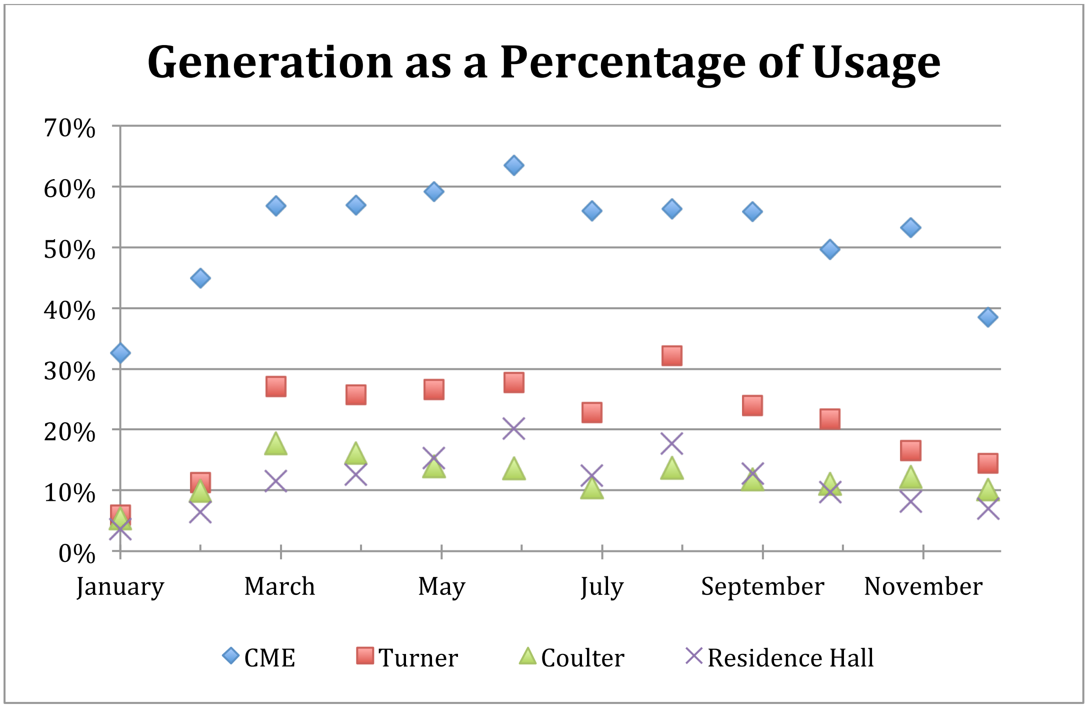

Figure 4. Monthly Electricity Generation of Each Proposed Solar System as a Percentage of the Building's Usage.

By looking at the electricity generation as a percentage of the electricity used by the building supporting the system, one can see that once again, the sustainable construction of the CME enables the building to produce a greater percentage of the electricity it consumes than any of the proposed systems. The CME system generates 52% of the building's yearly electricity needs. The next best result is the Turner Center system that could generate around 20% of the building's electricity demand over a yearlong period. The final two systems, Coulter Hall and the sample residence hall, each potentially generate about 12% of the buildings' yearly electricity need. Since the Turner Center generated the greatest percentage of its energy needs, indicating that larger buildings are better suited for rooftop solar arrays. However, the CME system is capable of generating a greater percentage of its electricity needs on a yearly basis, not due to its size, but because of the sustainable operation of the building. Therefore, we realize that energy efficient design and operation a more effective way to reduce a building's energy needs than offsetting the amount of outside energy it consumes by generating its own electricity. In addition to the energy saving measures currently utilized by the CME, the University needs further research into additional energy-saving building design features.

Recommendations

In the quest for sustainability and good stewardship of its energy resources, the University of Mississippi has two broad options, generate renewable energy or increase the efficiency with which it uses non-renewable energy. The optimum strategy involves a balance of both options. However, after this study, increased energy efficiency should be the foremost priority. Due to the low efficiency and high costs of current photovoltaic module technology and the finite surface area of rooftops, the amount of solar power that can be collected is limited and, in the case of normal building operation, dwarfed by the electricity a building will consume. Based solely on economic feasibility, the recommendation to pursue these systems cannot be made without a nearly 50% increase in the cost of electricity.

By estimating the potential electricity generation of solar installations and analyzing the electricity consumption of buildings, this report proves that it a more sustainable use of financial resources to invest in buildings that use energy efficiently than to offset consumption through electricity generation. Even for large buildings such as the Turner Center, with ample open space for modules, the electricity generated from a large system would only cover a small fraction of the power used by this building. Whereas the Center for Manufacturing Excellence, a building certified by the Leadership in Energy and Environmental Design program, can generate over half of its electricity needs through the rooftop solar array nine months out of the year. This is not solely because the CME generates a large amount of electricity, but because it uses much less electricity due to energy efficient design and operation.

Due to the findings of this report, the University of Mississippi should place greater emphasis on energy efficient construction and operation of its buildings when pursuing its commitment to be a good steward of its resources. The University can accomplish this goal through the use of energy efficient and natural lighting in its buildings, improved insulation, optimized HVAC systems, and other energy saving measures.

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APPENDIX

Table 1. Recorded Electric Generation of CME Solar System.

	2012 Generation (kWh)	2013 Generation (kWh)	2014 Generation (kWh)
Jan	6,204.90	6,541.20	9,036.66
Feb	8,422.38	7,781.70	6,643.09
March	12,568.38	10,975.86	10,930.68
April	14,055.60	12,471.49	12,035.94
May	14,932.32	13,276.50	14,107.27
June	15,085.56	13,989.84	12,669.36
July	13,046.46	13,695.54	13,718.03
August	13,006.32	12,861.12	12,799.44
Sept	12,621.12	12,187.51	12,117.14
Oct	11,559.72	9,480.96	10,877.28
Nov	10,070.22	7,988.88	8,393.52
Dec	5,631.18	5,094.35	4,926.95
Year	137,204.16	126,344.95	128,255.34

Table 2. Proposed Array System Sizes.

System	Number of Panels	System Sizes (kW)
Coulter	970	240
Turner	304	76
Residence Hall	200	50

Table 3. *PVWatts* Calculator Inputs.

Input	CME	Coulter	Turner	Residence Hall
DC System Size	108.52	76	240	50
Module Type	Standard	Standard	Standard	Standard
Array Type	Fixed (roof mount)	Fixed (roof mount)	Fixed (roof mount)	Fixed (roof mount)
System Losses (%)	14.08	14.08	14.08	14.08
Tilt (deg)	20	20	20	19
Azimuth (deg)	190	190	200	115
DC to AC Size Ratio	1.1	1.1	1.1	1.1
Inverter Efficiency (%)	96	96	96	96
Ground Coverage Ratio	0.4	0.4	0.4	0.4

Table 4. Generation for a Sample Year Estimated by NREL's *PVWatts* Calculator (kWh).

	CME	Coulter	Turner	RH
Jan	4,950	3,470	10,990	2,000
Feb	7,810	5,470	17,290	3,140
Mar	12,890	9,030	28,750	5,240
Apr	14,470	10,140	32,300	6,300
May	15,230	10,660	34,190	6,800
June	15,000	10,500	33,580	6,960
July	13,260	9,290	29,690	6,030
Aug	15,460	10,830	34,530	6,810
Sept	13,980	9,790	31,070	5,920
Oct	13,360	9,360	29,660	5,150
Nov	8,370	5,860	18,540	3,060
Dec	7,730	5,410	17,050	2,770
Total	**142,510**	**99,810**	**317,600**	**60,180**

Table 5. Comparison of Actual CME System Generation and the Sample Year Estimated by NREL's *PVWatts* Calculator.

	Actual Average Generation (2012-2014)	*PVWatts* Sample Year	Error
Jan	7,260	4,950	- 32%
Feb	7,660	7,810	+ 2%
Mar	11,490	12,890	+ 12%
Apr	12,850	14,470	+ 13%
May	14,100	15,230	+ 8%
June	13,920	15,000	+ 8%
July	13,490	13,260	- 2%
Aug	12,890	15,460	+ 20%
Sept	12,310	13,980	+ 14%
Oct	10,640	13,360	+ 26%
Nov	8,820	8,370	- 5%
Dec	5,220	7,730	+ 48%
Total	**130,650**	**142,510**	**+ 9%**

Table 6. The Net Worth of Each of the Proposed Systems Based on the Cost of Electricity.

Energy Cost (¢ per kWh)	Turner Center Net Worth	Coulter Hall Net Worth	Residence Hall Net Worth
8.0	$ -379,600	-127,600	-92,500
8.5	-348,600	-117,900	-86,600
9.0	-317,600	-108,100	-80,800
9.5	-286,600	-98,400	-74,900
10.0	-255,600	-88,600	-69,000
10.5	-224,600	-78,900	-63,100
11.0	-193,600	-69,200	-57,300
11.5	-162,600	-59,400	-51,400
12.0	-131,600	-49,700	-45,500
12.5	-100,600	-39,900	-39,600
13.0	-69,600	-30,200	-33,800
13.5	-38,600	-20,400	-27,900
14.0	-7,610	-10,700	-22,000
14.5	23,400	-960	-16,100
15.0	54,300	8,790	-10,300
15.5	85,400	18,500	-4,390
16.0	116,400	28,300	1,490
17.0	178,400	47,800	13,200
18.0	240,400	67,200	25,000
19.0	302,400	86,700	36,700
20.0	364,430	106,200	48,500

Table 7. Yearly Electricity Usage (kWh) of Buildings with Proposed Arrays. (Due to the unavailability of usage data on Residence Hall 1, the electricity usage of Burns Hall was used. Burns Hall is a residence hall of similar size.)

	Coulter	Turner	RH	CME
Jan	63,680	186,240	55,500	22,320
Feb	55,280	153,280	48,300	17,040
Mar	50,880	105,920	45,600	20,210
Apr	62,960	125,440	50,100	22,590
May	76,720	128,640	44,400	23,870
June	77,120	120,960	34,500	21,950
July	89,040	130,240	48,300	24,120
Aug	78,800	107,200	38,400	22,880
Sept	82,560	129,600	46,200	22,040
Oct	84,160	136,640	52,800	21,440
Nov	47,760	111,680	37,800	16,550
Dec	53,360	117,760	39,600	13,570
Total	**822,320**	**1,553,600**	**541,500**	**248,580**

Table 8. Ratio of Each System's Electricity Generation to the Electricity Consumption the System's Building

	Coulter	Turner	RH	CME
Jan	0.05	0.06	0.04	0.33
Feb	0.10	0.11	0.06	0.45
Mar	0.18	0.27	0.11	0.57
Apr	0.16	0.26	0.13	0.57
May	0.14	0.27	0.15	0.59
June	0.14	0.28	0.20	0.63
July	0.10	0.23	0.12	0.56
Aug	0.14	0.32	0.18	0.56
Sept	0.12	0.24	0.13	0.56
Oct	0.11	0.22	0.10	0.50
Nov	0.12	0.17	0.08	0.53
Dec	0.10	0.14	0.07	0.38
Average	**0.12**	**0.21**	**0.11**	**0.52**