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A GIS Analysis on Possible Photovoltaic Cell Use for Energy Reduction During Peak Hours in Huntington, West Virginia

Thesis submitted to
The Graduate College of
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In partial fulfillment of
The requirements for the degree of
Master of Science in Geography

by

James Eric Tadlock

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Marshall University
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ABSTRACT

A GIS Analysis on Possible Photovoltaic Cell Use for Energy Reduction During Peak Hours in Huntington, West Virginia

By James Eric Tadlock

Solar panels are one of the fastest growing renewable energy technologies. This study aims to identify to what extent roof-mounted solar panels can reduce the need of power provided by Appalachian Power Company. Data from the Reliability First Corporation was employed to determine the individual average household power usage. Three study areas in Huntington, West Virginia, were selected to determine if solar panels could be implemented. Roofs in the study areas were digitized to calculate the available area. Based on the average household usage, four different sized photovoltaic systems were determined. Potential power production was computed to identify any offset of consumption from the power grid. The average household roof size is sufficient to sustain a solar panel system that provides 75% or more of the required energy.

ACKNOWLEDGMENTS

I would like to thank my thesis committee for their assistance in my pursuit of a graduate degree, especially Dr. Anita Walz for serving as my advisor and committee chairperson. Her guidance and mentoring has been greatly appreciated. I would like to mention thanks to members of the Geography 530 – Raster Analysis class from the fall 2008 for their help in the digitizing of the study areas and building footprints. Many thanks are devoted to Christine Risch of the Center for Business and Economic Research at Marshall University. Her assistance allowed for this research to be possible by allowing access to the Reliability First Corporation’s regional power usage data obtained by her department. I would also like to recognize the assistance provided by the Appalachian Power Company, Atlantic City Electric, and the Reliability First Corporation. I thank them for the prompt responses they provided to the many questions I asked them.

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CHAPTER ONE: INTRODUCTION

With the increasing demand for energy and concern about carbon dioxide within the United States, it is imperative that alternate energy sources be used to reduce the dependence on fossil fuels. New innovations in “green” technology are needed to implement these changes. One method of harnessing nature technologically is to produce energy through the use of photovoltaic (PV) cells, more commonly called solar cells, which harness sunlight and convert it into electric power. The objectives of this research are to a) compile information on the types of solar panels and their availability to the Huntington, West Virginia area; b) report on current solar panel usage incentives and or regulations made by governments and power industries in the state; and c) to produce examples within areas of Huntington, West Virginia to show feasibility or possible benefits from the installation of solar paneling on the roofs of housing or commercial buildings through Geographic Information System (GIS) Analysis.

Solar Panel Research, Development, and Usage

There are two methods in the realm of collecting the sun’s energy to produce electricity. The first of these methods is the use of parabolic shaped mirrors which concentrate the sun’s thermal energy. The thermal energy is used to heat water into steam which then rotates turbines that are connected to electric generators (Pitz-Paal, 2008). The second method is the collection of the light from the sun in cells made from a semi-conductive material. Energy is produced from the change of the energy state in electrons that occurs when photons from sunlight interact with the semi-conductive material (Wengenmayr, 2008). This research will focus on the latter of the two methods given that they are more compatible with home installation. PV technology is steadily growing in popularity. Currently, PV system use is increasing at a rate of approximately 25% per year (Komor, 2004). The most popular method of use for PV systems is to connect to the already existing power grid to reduce the cost of electric bills. These grid-connected systems represent 50% to 70% of PV sales worldwide (Celik et al, 2008). As with many products, there are pros and cons related to its performance.

Some of the pros of PV systems are that they utilize the most plentiful source for energy, they can be easily moved to and set up in more isolated areas (Komor, 2004), prices for PV systems have decreased to a hundredth of their original costs and will continue to decline as production increases (Aratani, 2005), and finally, PV systems are the most aesthetically pleasing of the renewable sources if located in an urban setting. Some of the cons for solar panel systems include that they are still expensive even with decreases in cost, PV systems do not produce energy during the night (Komor, 2004), and lastly, maintenance costs for replacement of damaged PV modules, storage batteries (if used), electrical systems, and other vital devices can be expensive (Canada et al, 2005).

The first working PV system was created in 1883 by an American by the name of Charles Fritts. Fritts' selenium cell had an efficiency of >1%, which is considered low by today's standards. The first modern PV systems were produced by Chapin, Fuller, and Pearson in 1953 and 1954 under Bell Labs in the United States. Efficiencies produced are limited by the material used and by the fragile balance of cost and intricacy of the cell (Twidell and Weir, 2006). Early silicon cells reached efficiencies between 4.5% and 6%. With continuing research, today's systems are reaching efficiencies of up to 39% (Wengenmayr, 2008). According to Twidell and Weir (2006), more common commercial systems of today stay within the range of 10% to 22% in normal lighting conditions.

Two forms of PV cells are now being produced and researched, crystalline silicon and thin film. There are currently three kinds of silicon systems: monocrystalline, multicrystalline and amorphous silicon. Together, silicon systems account for approximately 92% of the world's PV usage (Aratani, 2005). Monocrystalline PVs are the most expensive units to produce due to the high cost of pure silicon that is used to create the cells. The cells are sliced from blocks of refined silicon called ingots. Ingots are cooled at controlled rates to create the single crystalline form. After cooling is complete, the ingots are sliced to a thickness between 200 and 300 μm. This process wastes over 50% of the pure silicon in the cutting procedure (Hahn, 2008). After cell completion, monocrystalline cells have commercial efficiencies around 15% and laboratory efficiencies at or near 25% (Twidell and Weir, 2006).

Multicrystalline cell production methods were developed to reduce the amount of waste through the production process. This allows more cells to be created; therefore, reducing the cost of the cell itself. In multicrystalline (also called ribbon silicon) production, rather than all of the molten silicon being cooled at a controlled rate, the cell is formed in one of three ways. The first method, which is called Edge-defined Film-fed Growth (EFG), pulls the silicon through a mould via capillary action while attached to a solid (Figure 1a). The silicon is continually pulled vertically at a rate of 1 to 2 cm/min as it cools while it is formed into octagonal columns. The eight sides are cut separately and then cut into smaller, more familiar PV cells (Hahn, 2008).

Not too dissimilar from the EFG method, the second method uses two “strings”, made of a material which manufacturers keep undisclosed, instead of moulds (Figure 1b). The silicon is pulled into sheets vertically, laid out, and then cut with lasers to specified dimensions. Manufacturers are able to pull the silicon into sheets due to its high tension strength. The thickness of these sheets is thinner than its mould formed counterpart due to the stretching between the two strings. This method produces the sheets at similar rates of 1 to 2 cm/min like that of the EFG method (Hahn, 2008).

The final method in multicrystalline cell fabrication is called Ribbon Growth on Substrate (RGS). Instead of the silicon being lifted vertically, it is spread horizontally across a substrate (Figure 1c). A belt rolls the substrate under a crucible containing melted silicon. While being

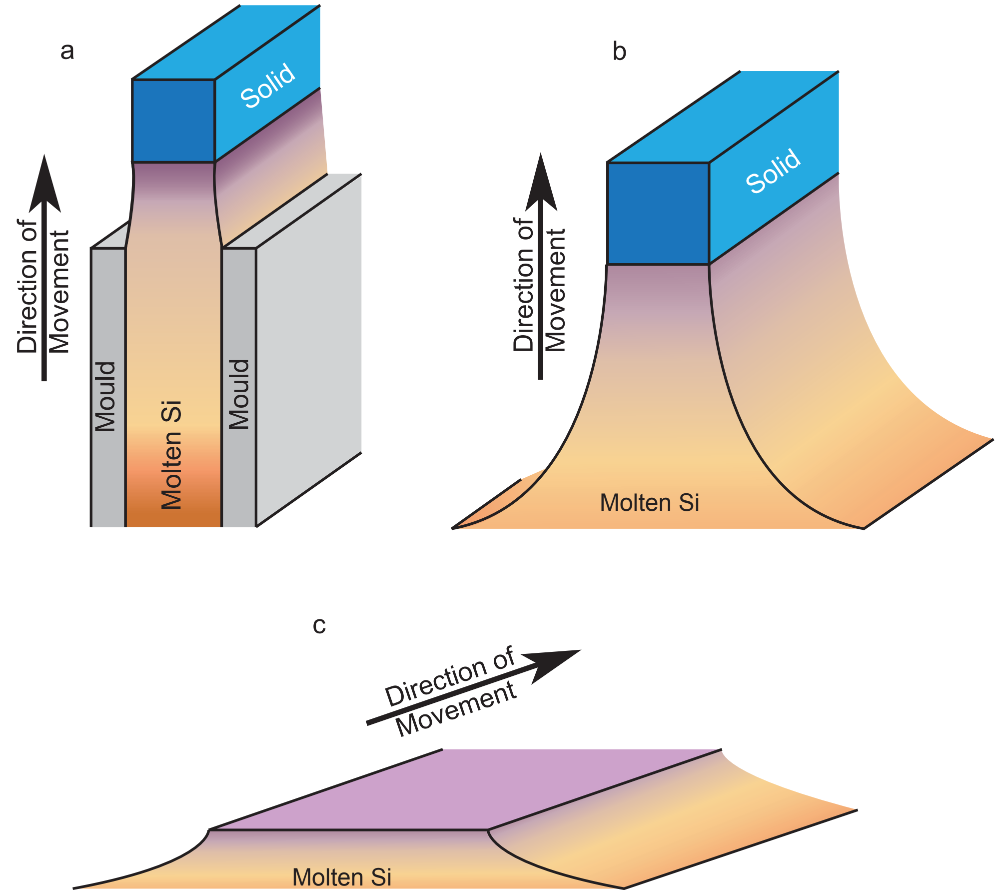

Figure 1. Simplified drawings of the three multicrystalline silicon cell creation methods as adapted from Hahn, 2008. a) The EFG method. b) Vertical pulling method using strings (strings are not illustrated). c) RGS method.

rolled, the melted silicon is poured onto the substrate. As the silicon cools, it separates from the substrate due to differences in the expansion coefficients of the two materials. This method is the fastest of the three production methods for multicrystalline PV cells with rates of 10 cm/s. Unfortunately, this method is not in commercial use due to its being in experimental stages (Hahn, 2008). Twidell and Weir (2006) state that the three types of multicrystalline cells lproduce 8% to 13% efficiencies for commercial users and roughly 16% to 20% efficiencies for laboratory use.

Amorphous silicon cells are created similarly to thin-film cells in that they are both placed on a substrate in very thin layers. Instead of using numerous types of chemical elements like the thin-films, very thin layers of silicon that have had hydrogen added during the preparation procedures are utilized. The use of hydrogen allows for the repair of some defects, such as misalignments in the crystal lattice, that might have formed in normal silicon cooling. Unfortunately, amorphous silicon is the least stable in efficiencies. After the first uses, the efficiencies can drop by as much as 30% from the original efficiency of 15% (Guha and Yang, 2005; Wegenmeyr, 2008). Therefore, even though it is used in building integrated PV systems, it is not commonly employed in commercial PV systems (U.S. Department of Energy, 2009; Wengenmeyr, 2008).

Thin film PV systems were first explored in 1999 by the Hahn-Meitner Institute of Germany. After several years of research, the first thin film units were placed on the market in 2006. Thin film systems are created by the layering of multiple materials on a substrate such as glass (Figure 2). The most common material used for thin film units is a copper, indium, and sulfur ($CuInS_2$) mixture, otherwise known as CIS. This material is able to completely absorb sunlight in layers as thin as 1 μm. More commonly, it is applied to the substrate in a layer of about 1.5 μm. This allows for approximately one hundredth of the material to be used and more to be manufactured as compared to monocrystalline silicon units. With other materials placed

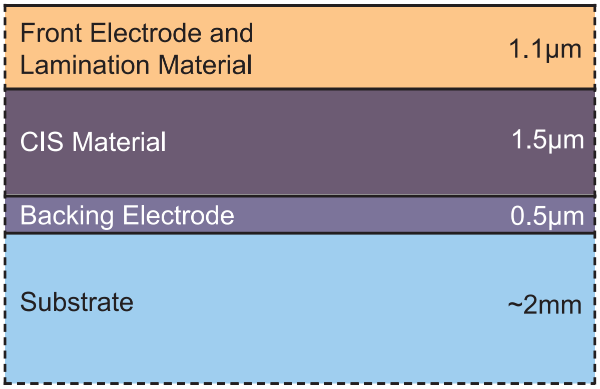

Figure 2. A cross sesction of a CIS PV cell as adapted from Meyer, 2008.

beneath and above the CIS material to complete the circuit, total thickness is near 3 μm (Meyer, 2008).

The benefits of this type of PV cell compared to silicon systems is that thin-film units require two-thirds less energy to assemble and one-third the number of steps. These benefits allow for the overall cost of the unit to be reduced (Meyer, 2008). With thinner systems, more items and buildings can be built with PV systems already incorporated in the building materials. One example of which is roofing materials (Komor, 2004). Efficiencies for thin-film systems range between 8% at lowest, 13% to 15% at its highest, and proposed efficiencies of 25% (Meyer, 2008; Twidell and Weir, 2006).

Performance and maintenance are issues with which all PV system owners must contend. Before any system is made available to the market, the International Organization for Standardization (ISO) tests each model of PV system with a Life Cycle Assessment that is made of four parts. The first of these parts is the goal and scope which is used to identify the limits of each PV system. Inventory analysis is used to research what materials were utilized for the unit. The impact assessment is evaluated to identify any emissions and byproducts that are created in the production process and if they pose any harm to the environment. The final step, interpretation, includes the conclusions associated with the performance of the PV system (Jungbluth, 2004).

Although these steps are implemented, owners of PV systems can still see a 50% malfunction rate mostly due to improper installation. These include, but are not limited to, lack of safety equipment and inadequacies in durability and performance materials. These operational costs can equate to between 5% and 6% of overall cost for the PV system (Canada et al, 2005). It is necessary, however, to maintain the PV system in order to generate sufficient electricity over the years. The main factors that can keep a PV system operational are element quality and the availability of repair services and replacement parts (Díaz et al, 2007).

Research conducted by Dunlop and Halton (2006) suggests that silicon PV systems with proper maintenance can last over 20 years. The systems studied were constructed between the years of 1982 and 1984. Dunlop and Halton compared the functionality of the systems in 2004 to the original functionality from the manufacturer's data. The data from Dunlop and Halton (2006) showed that 80% of the cells tested only lost approximately 9.5% or less of their original electricity production efficiency after 20 years. The 20-year old cells were still capable of producing enough electricity to sustain the user's demands but were not recommended for use beyond 25 years because of the degradational effects of weathering on the cell material. After a PV system has reached the end of its service life, the silicon in the PV cells and the metals for the PV body and brackets can be recycled to decrease the amount of waste (Jungbluth, 2005).

Current Power Production, Supply, and Usage in West Virginia

Power data are collected by the power companies and forwarded to organizations that monitor the fluctuations of usage in regions across the United States. The Reliability First Corporation (RFC), which surpervises the Appalachian Power Company, is one such organization. The RFC creates and imposes regulations for the use and distribution of bulk power systems for its region (Whitely and Gallagher, 2008).

Hourly data per day for every month was used to show peaks that occur during the various hours of the day (Figure 3). In the RFC region, higher peaks occur during the late morning hours, decline slightly in the afternoon, and peak again in the evening. Higher power usage can be seen in the winter and summer months due to combative measures against

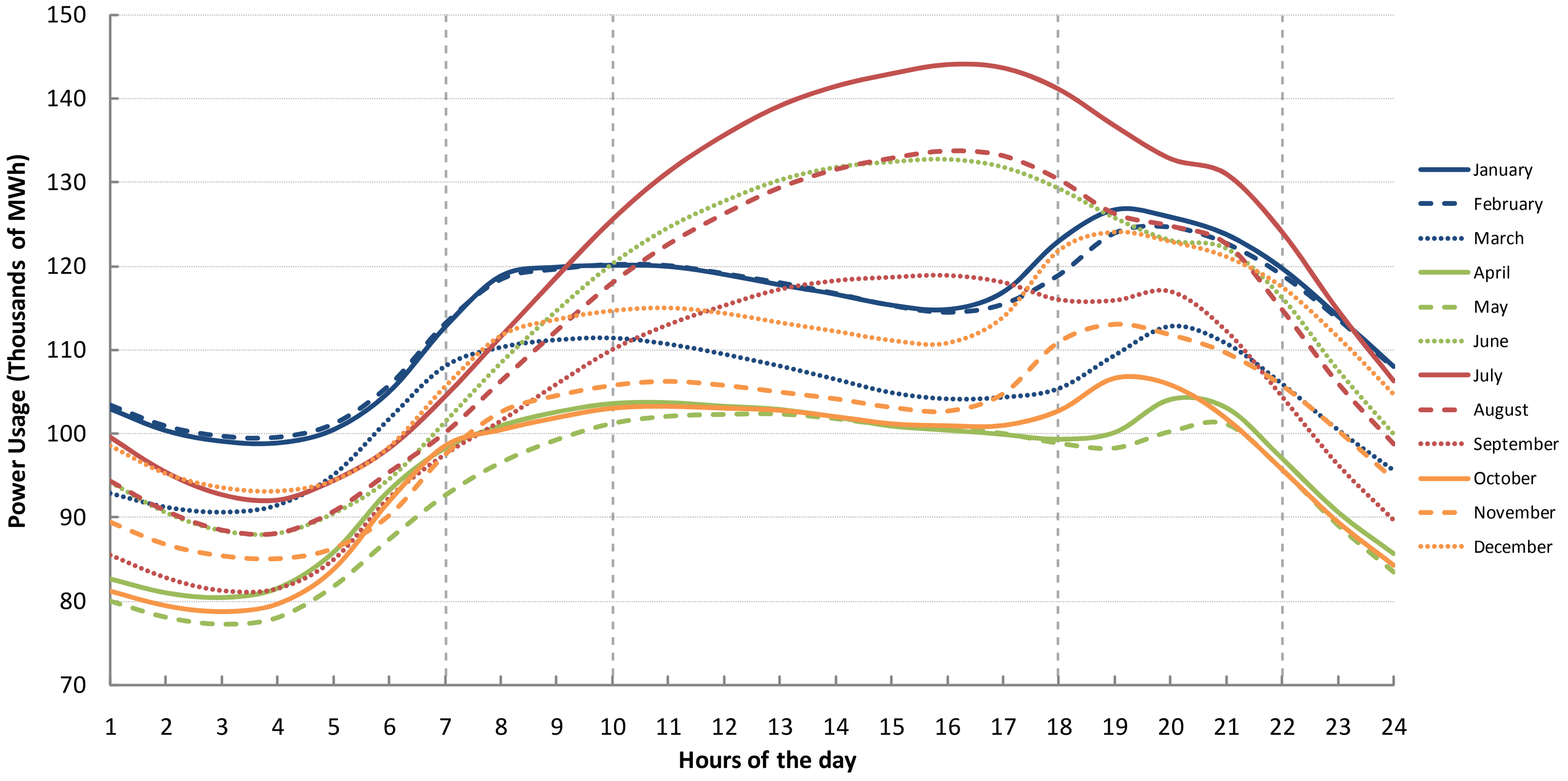

Figure 3. RFC region hourly power use per average day in a month from 2008. Each season has been given a color scheme: blue for winter, green for spring, red for summer, and orange for fall. This color scheme will remain consistant throuhout the study . The vertical dashed lines represent times when peaks in power consumption begin and end.

extreme weather conditions to make a resident's abode more comfortable. The summer months show this trend more prominently with a daily peak that continues to increase throughout the afternoon rather than wane slightly as compared to other monthly afternoons. Power usage for autumnal and vernal months is lower due to the climate being more temperate, although daily peaks are still visible.

The mainstay of power production in West Virginia is through the burning of coal. Table 1 shows the sums of power usage through the various types of energy production methods in the state of West Virginia. The original data utilized for Table 1 shows the values in British Thermal Units (BTUs) which are used to define the amount of work done. The conversion of 3,412 BTUs for 1 Kilowatt hour (kWh) was applied in order to adapt the data to the more familiar kWh. The final energy production total includes the exports and losses since that energy was created in West Virginia. The exports and losses are energy that are transferred or sold to surrounding states or that is lost in the transmission of the power itself. This allows for the creation of percentages of individual power types. As Table 1 shows, West Virginia's predominant source of power is through the utilization of coal. The least deployed methods, which the table names as "others", are that of renewable sources (Energy Information Administration (EIA), 2006).

Appalachian Power Company, which services the southern half of West Virginia, also supplies power to the study area. Table 2 shows the current power plants and their energy production methods. According to information provided in the Appalachian Power Company's 2008 fact sheet, a majority of this company's plants, which are located in and service West Virginia, use coal energy as the primary source of power production (2008).

Although coal is the main source of energy production in West Virginia, incentives to purchase a PV system can be given in the form of tax breaks or rebates and can range from the

Table 1. Totals of power production from varying types of energy sources for the state of West Virginia as adapted from the Energy Information Administration (2006).

Power Production Methods of West Virginia

Fuel Type	BTUs	kWH	%
Coal	9.59E+14	2.81E+11	48.64
NaturalGas	1.28E+14	3.75E+10	6.49
Petroleum	2.92E+14	8.55E+10	14.79
Hydro-Electric	1.56E+13	4.57E+09	0.79
Biomass	4.40E+12	1.29E+09	0.22
Other	1.80E+12	5.28E+08	0.09
Exports/Losses	5.71E+14	1.67E+11	28.97
Total	1.97E+15	5.78E+11	n/a

Table 2. Power plant names, types, and capacities for each plant and power generation type that is operated by Appalachian Power Company in West Virginia (adapted from Appalachian Power Fact Sheet, 2008).

Energy Generation Types by Appalachian Power Co.

Plant Name	Plant Type	Capacity (MW)
John E. Amos	Coal	2900
Mountaineer	Coal	1320
Phillip Sporn	Coal	1050
Kanawha River	Coal	400
Total		**5670**
Ceredo	Natural Gas	**505**
Winfield	Hydro	14.7
London	Hydro	14.4
Marmet	Hydro	14.4
Total		**43.5**

city level to federal relief. In the United States, a federal tax credit of 30% of the system cost is given to a PV system owner when filing income taxes. Some states offer buyers as much as $24,000 in rebates to help reduce the initial cost of a PV system (BP Solar, 2009). The top three states that offer the largest incentives are Louisiana, Oregon, and Connecticut respectively. These states are rated high because of their substantial state tax rebates for purchasing a PV system. Louisiana offers a 50% price reduction on the first $25,000 of the system cost and the federal tax incentive of 30%. Oregon and Connecticut offer similar tax breaks including utility tax breaks of varying amounts from the local utility companies themselves and exemption of sales tax on the systems purchased. West Virginia is ranked last with Tennessee for solar power incentives. No state incentives are offered by either state (Find Solar, 2009). Most of the incentives in West Virginia that are given to buyers of any “green” energy are those who have utilized wind based technologies (West Virginia State Legislature, 2001).

Unfortunately, some power companies limit the amount of power that can be produced from solar cells. Appalachian Power Company allows a homeowner’s PV system to be connected to the company’s grid as long as the system does not exceed a producing capacity of more than 25 kW. The system may be used for partial to complete reduction of the amount of energy purchased from the company. Any power generated in excess of the household’s needs can only be credited to the homeowner for a period of 12 months. Anytime after that period, Appalachian Power claims what has been generated without reimbursement to the producer (Appalachian Power Company, 2007).

As an alternative to purchasing a PV system, some companies have been formed that allow homeowners to rent PV systems. The agreement starts with a down-payment that is returned at the end of the contract. The household remains connected to the energy grid, and monthly payments are made to both the power company and the PV rental company. The payments would be the same or less as if a household were solely dependent on the power company or if a private PV system was owned (Citizenrē Corporation, 2009). The household is liable to be in accordance of the net-metering laws that the utility company has issued and are bound to arrange for any changes that may occur in these laws (Citizenrē Corporation, 2007). The monthly rate owed to the PV rental company is kept constant from the time of signing of the contract. Whenever repairs need to be made, the company will repair the system free of charge. This allows for the use of “green” systems without the aggravations of complete system upkeep (Citizenrē Corporation, 2009).

Assisted by the information researched above, a study for power usage and its reduction via solar panels systems was conducted for several Huntington, West Virginia neighborhoods. Data compiled, including information from the Huntington area, shows how the location could benefit from this renewable energy source.

CHAPTER TWO: MATERIALS AND METHODS

Determination of Roof Areas in Huntington, West Virginia

The maps created in this section were generated using ArcMap 9.3 from ArcInfo™ by Environmental System Research Institute (ESRI). One aerial photograph and one satellite image were employed to complete this task. The SAMB Image, an aerial photograph, contains high resolution cells of 60 cm. The SAMB is a true color image that contains the blue, green, and red color bands. The satellite based IKONOS image was incorporated into this research for two main reasons. It is a multispectral image that contains the near infra-red (NIR) band along with the previous mentioned bands, and the image was taken during a time of the year when vegetation was fully present. The latter fact is beneficial since it gives a good representation of how much sun a roof could receive after being shaded by trees. The resolution is coarser in this image with a cell size of 4 meters.

Three study areas were created and are referred to as the Ritter Park (RP) study area, the Hal Greer Boulevard (HG) study area, and the Downtown (DT) study area (Figure 4). The Downtown study area was chosen to represent the commercial zone of Huntington, West Virginia. The Hal Greer and Ritter Park study areas represent typical residential and wealthy residential zones respectively. Each study area consisted of four individual blocks which were selected randomly. Polygons for the blocks and the buildings in each block were digitized into vector files. Using the calculate geometry tool in ArcMap, the area for each building footprint polygon was measured.

A Normalized Difference Vegetation Index (NDVI) is most commonly used to observe changes in the amount of vegetation globally, but it can be used in a more localized setting (Trishchenko et al, 2002). The NDVI calculation was used to determine the sealed and vegetated areas within the City of Huntington (Equation 1). The NDVI is calculated as follows:

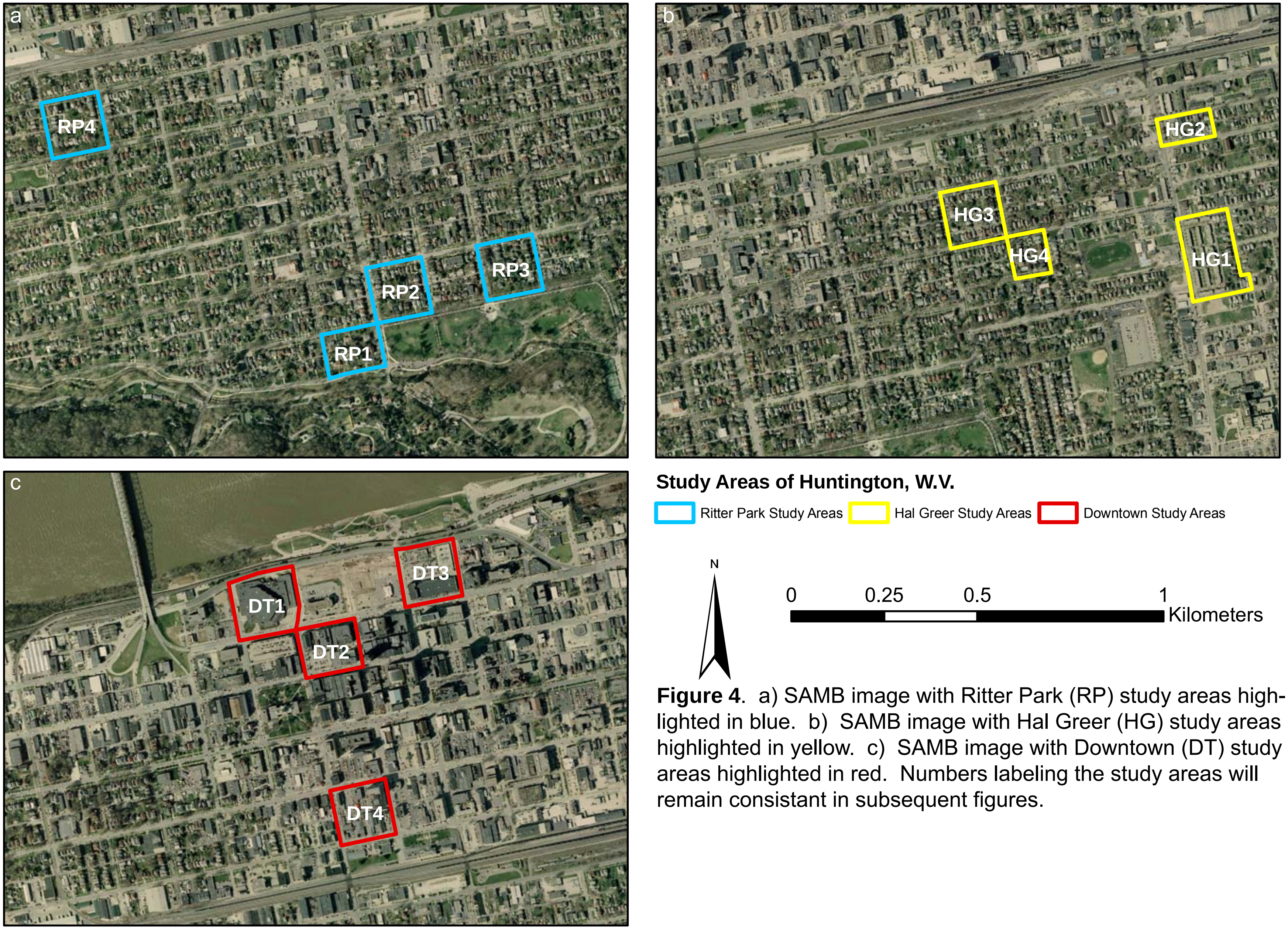

Figure 4. a) SAMB image with Ritter Park (RP) study areas highlighted in blue. b) SAMB image with Hal Greer (HG) study areas highlighted in yellow. c) SAMB image with Downtown (DT) study areas highlighted in red. Numbers labeling the study areas will remain consistant in subsequent figures.

$$NDVI = \frac{\rho_{NIR} - \rho_{Red}}{\rho_{NIR} + \rho_{Red}} \qquad \textit{Equation 1}$$

The ρ_{NIR} represents the wavelength of the NIR band and ρ_{Red} denotes the wavelength of the Red band of the IKONOS image. The NDVI shows the presence and variations of green biomaterials (Jensen, 2005). Cell values range between -1 and 1. The lower values represent mostly sealed or non-vegetated surfaces and water, while the higher values signify presence of vegetation. A cut off value of 0.3 was used to distinguish between the difference of vegetated and non-vegetated surfaces. This cut off value was determined through the comparison of the location of the vegetation in the NDVI result and the original IKONOS and SAMB images. The raster calculator in ArcMap was used to calculate the NDVI. The image was then classified into 1 (NDVI ≥ 0.3; vegetation) and 0 (NDVI ≤ 0.3; sealed surfaces) with the use of a conditional statement.

The NDVI was then clipped to the four blocks of each of the three study areas using the polygons of the blocks that were created earlier. The two colors of the newly clipped NDVIs were darkened to highlight the study areas against the city-wide NDVI. The polygons of the building footprints were included in order to show which sealed surfaces were due to roofing and to show if there was any significant vegetation overlapping the roof's surface that might prevent sunlight from reaching the possible locations of a PV system (Figures 5, 6, and 7 for RP, HG, and DT respectively). Table 3 shows the results of the GIS analysis, which include the amount of surface area that is covered by roofs, concrete or asphalt, total sealed surfaces (roofs and other sealed surfaces), and total area of sealed and vegetated surfaces.

Determination of Average Residential Power Consumption in Huntington, West Virginia

To determine what system is most suitable for a commercial or residential building in the Huntington area, data from power usage, solar irradiance, and photovoltaic system specifications were obtained. Information about the distribution and amounts of power usage

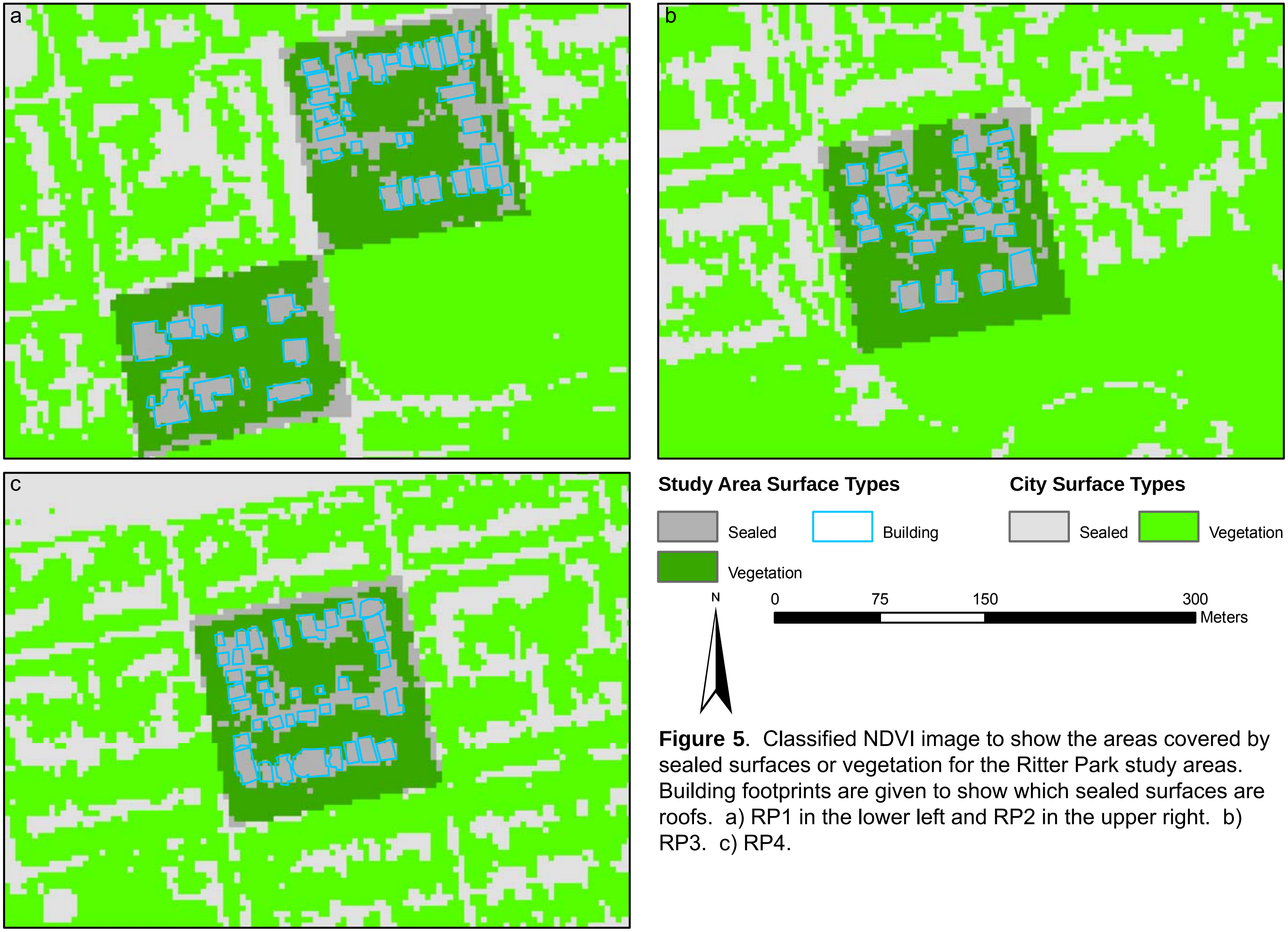

Figure 5. Classified NDVI image to show the areas covered by sealed surfaces or vegetation for the Ritter Park study areas. Building footprints are given to show which sealed surfaces are roofs. a) RP1 in the lower left and RP2 in the upper right. b) RP3. c) RP4.

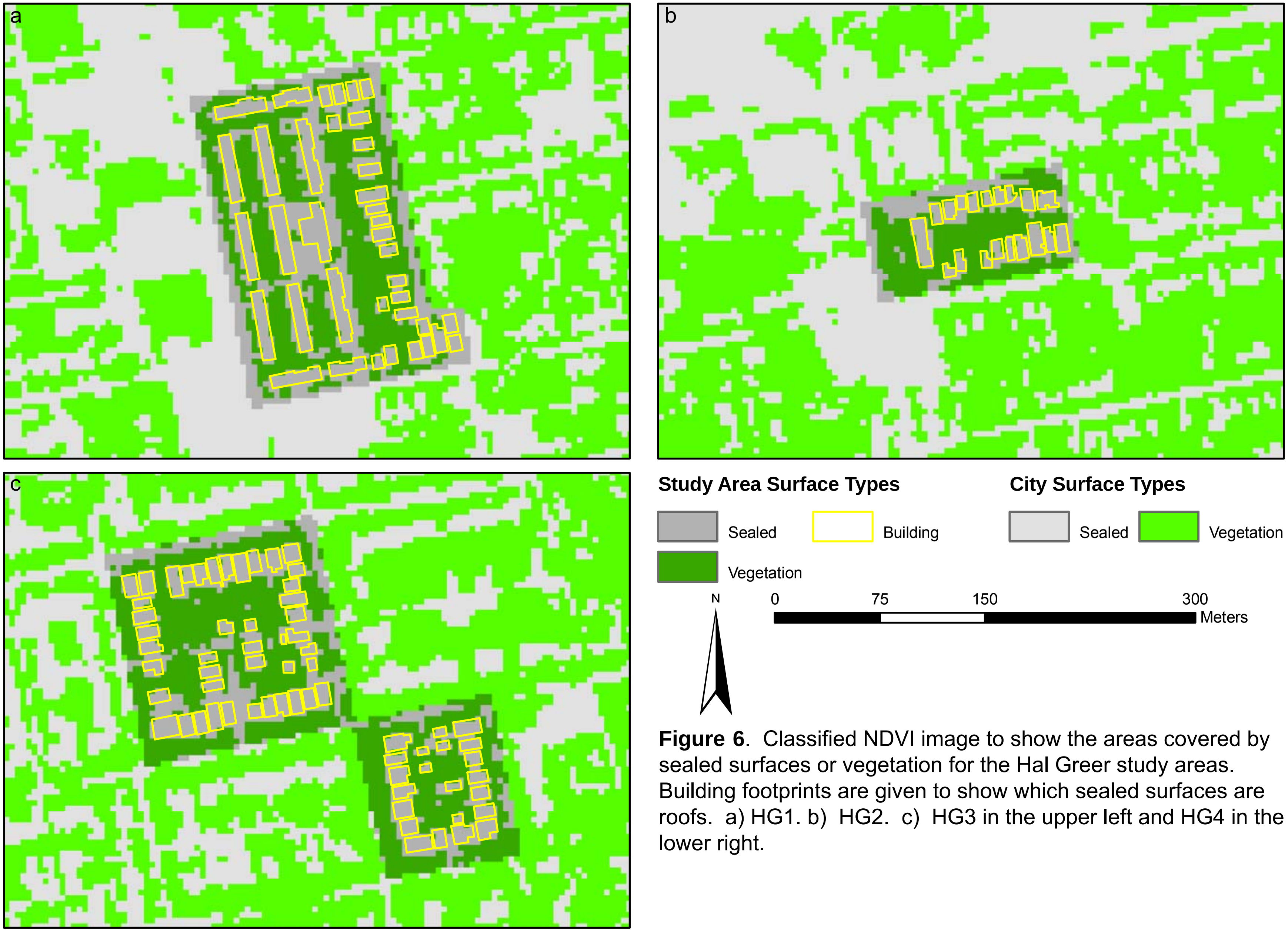

Figure 6. Classified NDVI image to show the areas covered by sealed surfaces or vegetation for the Hal Greer study areas. Building footprints are given to show which sealed surfaces are roofs. a) HG1. b) HG2. c) HG3 in the upper left and HG4 in the lower right.

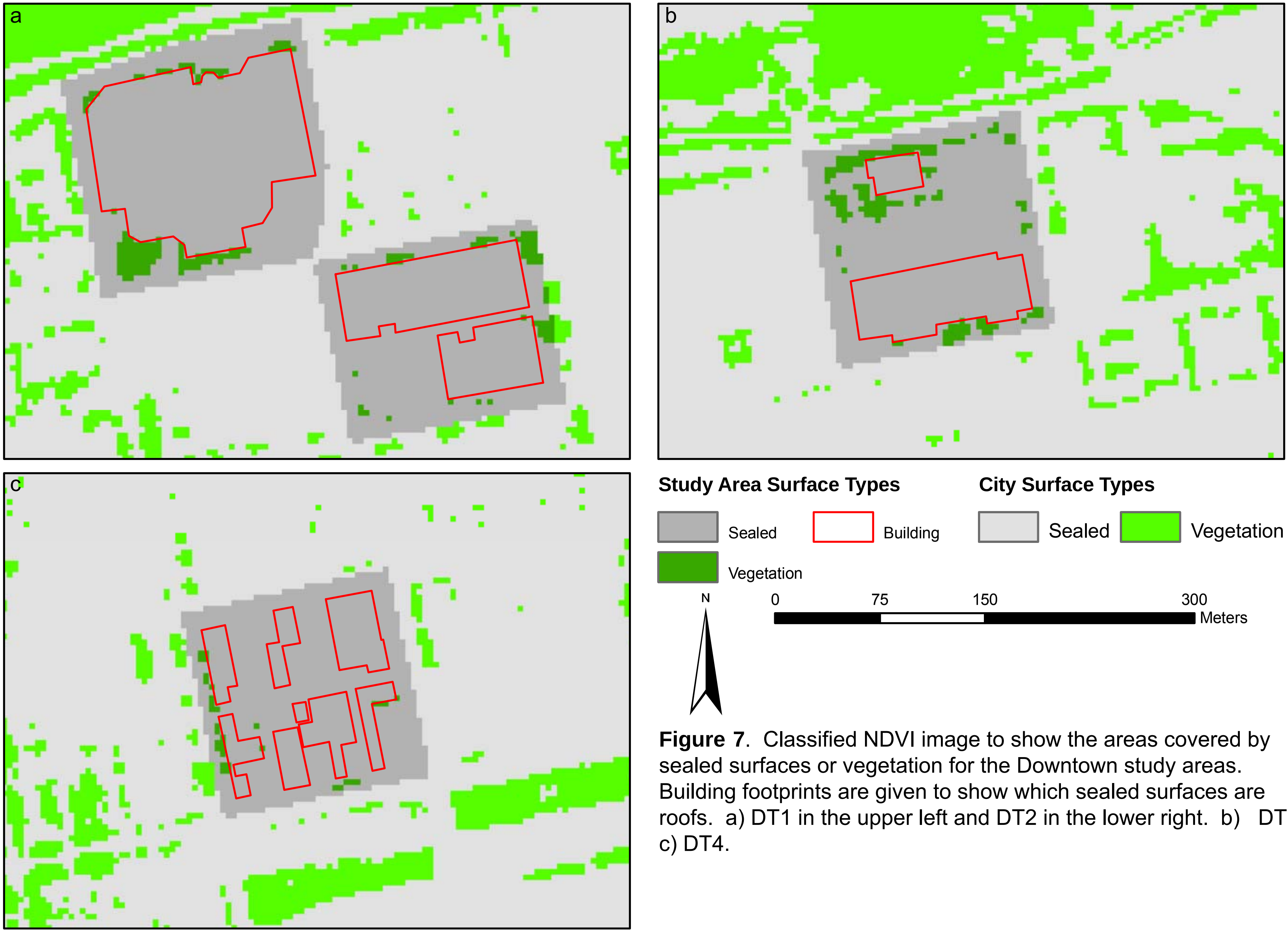

Figure 7. Classified NDVI image to show the areas covered by sealed surfaces or vegetation for the Downtown study areas. Building footprints are given to show which sealed surfaces are roofs. a) DT1 in the upper left and DT2 in the lower right. b) DT3. c) DT4.

Table 3. Raster analysis showing the area covered by roof surfaces, other sealed surfaces, and total sealed surfaces (other sealed and roof) for the Ritter Park (RP), Hal Greer (HG), and Downtown (DT) study areas. Roof values are before division by two to calculate available roof area for PV systems.

GIS Analysis Results						
Study Area	Roof Area (sq-m)	Other Sealed Area (sq-m)	Total Area (sq-m)	% Roof	% Other Sealed	% Total Sealed
RP1	3297.11	2480.84	17846.02	18.48	13.90	32.38
RP2	4177.41	5089.72	22887.72	18.25	22.24	40.49
RP3	3953.33	4081.38	23063.78	17.14	17.70	34.84
RP4	4273.44	5249.77	23527.94	18.16	22.31	40.48
HG1	7842.65	10131.42	32074.82	24.45	31.59	56.04
HG2	2288.77	2768.93	10627.59	21.54	26.05	47.59
HG3	5473.85	5585.88	23223.84	23.57	24.05	47.62
HG4	2704.91	2112.71	11603.92	23.31	18.21	41.52
DT1	16693.63	10195.44	28617.66	58.33	35.63	93.96
DT2	4785.61	10419.52	21015.09	22.77	49.58	72.35
DT3	6546.21	15493.23	24344.21	26.89	63.64	90.53
DT4	7122.40	15093.09	22759.68	31.29	66.32	97.61

were not readily available. If data exist at all, some were not accessible to public use. Some power companies were not willing to release data about the number of customers they served, the distribution of electrical power throughout their service locations, or how much an average commercial customer used in comparison to an average residential customer. Some data could only be retrieved if membership to the corporation was obtained. These memberships could range from $200 to over $1,000. Other forms of data could be purchased, but at prices as steep as $5,000. Prices of that magnitude were beyond the scope of this study.

Three assumptions were made in order to conduct this research. No data corresponding to the number of commercial consumers could be found for the RFC region. Not all power companies release specific values of the number of customers using their services, so an exact number of households could not be determined. Consequently, the first assumption was that the number of households matches general patterns of the RFC boundaries via the county boundaries within its participating localities (Figure 8); therefore, the census data for those counties yield a good estimate of the number of households serviced by the company. In reality, all households use energy at different rates; however, for the purpose of this study, all residences are assumed to use energy at the same rate. The final assumption made is that each household has its own roof. Power usage data for commercial buildings was not available; therefore, the size of the PV system required could not be estimated. Instead, the roof areas of the downtown study area were used to approximate the maximum capacity of the PV system they would be able to support.

The data from the RFC originally was total power usage for every hour of the year of 2008 across the RFC region in Megawatt-hours (MWh). Based on information from the EIA (2009), a total of 96 power plants (Table 4) supply the RFC region with electricity totaling 936,209,202 MWh (RFC, 2009). Within this region there are a total of roughly 26,946,000

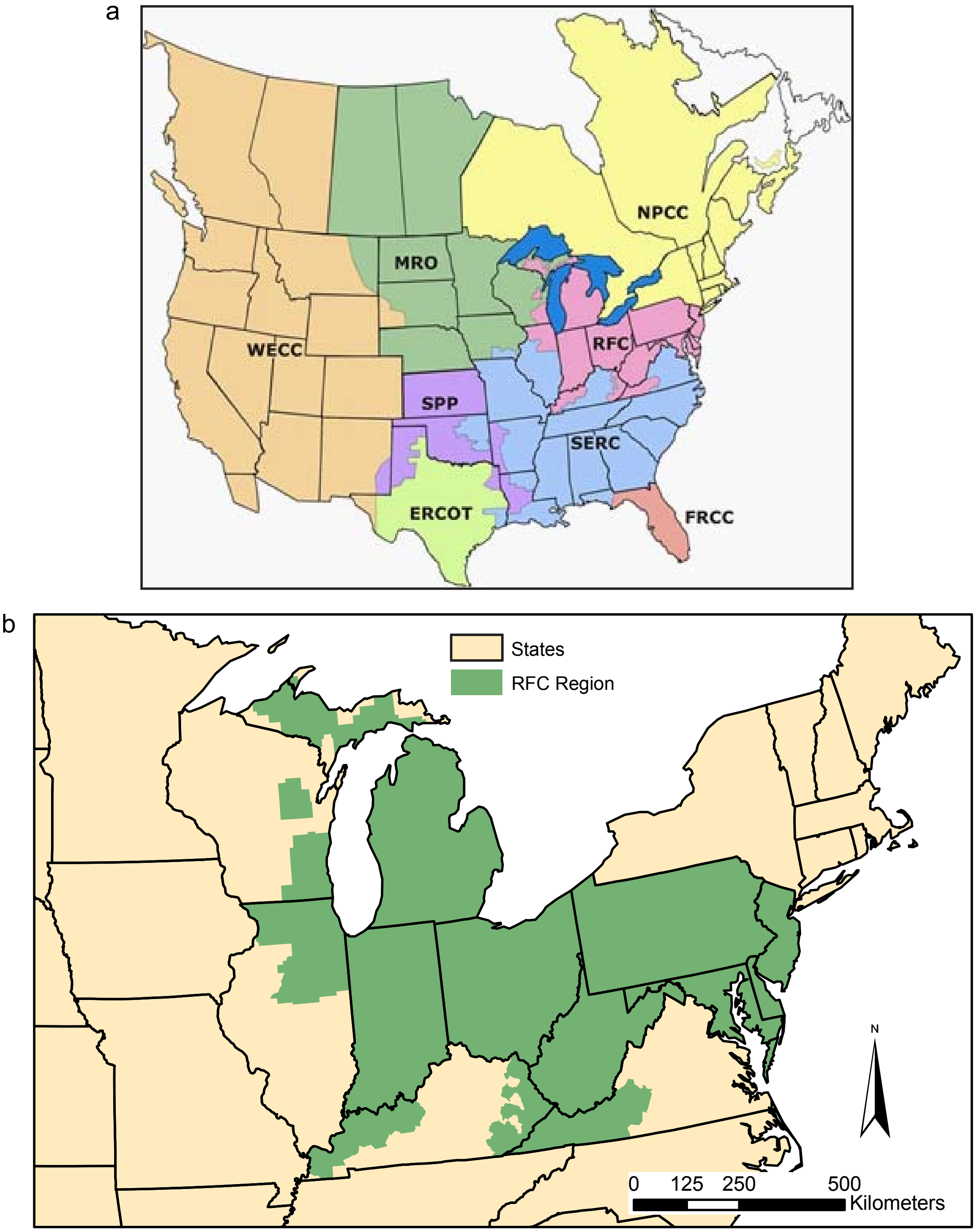

Figure 8. a) A map of the Reliability Corporations of North America including the RFC (North American Electric Reliability Corporation, 2009). b) Map created using ArcMap and TIGER/Line county census 2000 data to gain information about the area covered and the number of households in the RFC region.

Table 4. The numbers and types of power plants present within the RFC region (EIA, 2009).

Powerplants of the RFC Region								
State	**Nuclear**	**Petroleum**	**Coal**	**Natural Gas**	**Geo-thermal**	**Solar**	**Hydro-electric**	**Wind**
VA	0	1	2	1	0	0	0	0
MD	1	7	8	8	0	0	1	0
DE	0	2	2	3	0	0	0	0
NJ	3	6	5	21	0	0	1	0
PA	5	6	24	15	0	0	4	0
WV	0	0	14	3	0	0	0	0
OH	2	3	21	15	0	0	0	0
IN	0	1	21	18	0	0	0	0
KY	0	0	11	2	0	0	2	0
IL	5	2	7	17	0	0	0	0
MI	3	1	13	21	0	0	1	0
WI	0	1	6	12	0	0	0	0

households with an average household size of 2.52 people dispersed across approximately 663,140 km^2. The total number of households and average household size were obtained from county-wide 2000 census data collected by the United States Census Bureau and were based on the shape of the service area of the RFC.

The total power load for each hour was multiplied by 1000 to convert it into kWh. As indicated by the Annual Energy Review by the EIA (2007), 30% of the energy generated by power plants is consumed by residential customers; therefore, the total power load was multiplied by 0.3 to produce the amount of energy that is used by the residents of the RFC. Lastly, the power used by RFC residents was divided by the total number of households from the RFC region to show the average power usage per hour for an average individual residence. Figure 9 shows the peaks of power usage by a typical household on an average day in each month. The peaks show a similarity to that of the regional usage, but at a smaller scale. During the winter, spring, and fall months, peaks occurred between the 7th and 10th hours of the day and the 18th and 22nd hours. In the summer months and one spring month, a peak forms around the 7th hour but continues to increase throughout the day instead of leveling off during the mid-morning and do not decrease until about the 22nd hour of the day.

Estimation of Power Production by PV Systems in Huntington, West Virginia

To see the effects that a grid- connected solar panel system would have on an average household in Huntington, an equation to determine the output of a solar panel based on solar irradiance was used.

$$E_{PV} = P_{PV} \times \eta \times K_{PV} \times (S/I_{STC}) \qquad \textit{Equation 2}$$

The E_{PV} represents the power production by a PV unit at a given time in kWh. P_{PV} is the maximum amount of power the PV system can produce in kW. The symbol η denotes the efficiency of wiring and components used in the system which has a constant of 0.9 for all

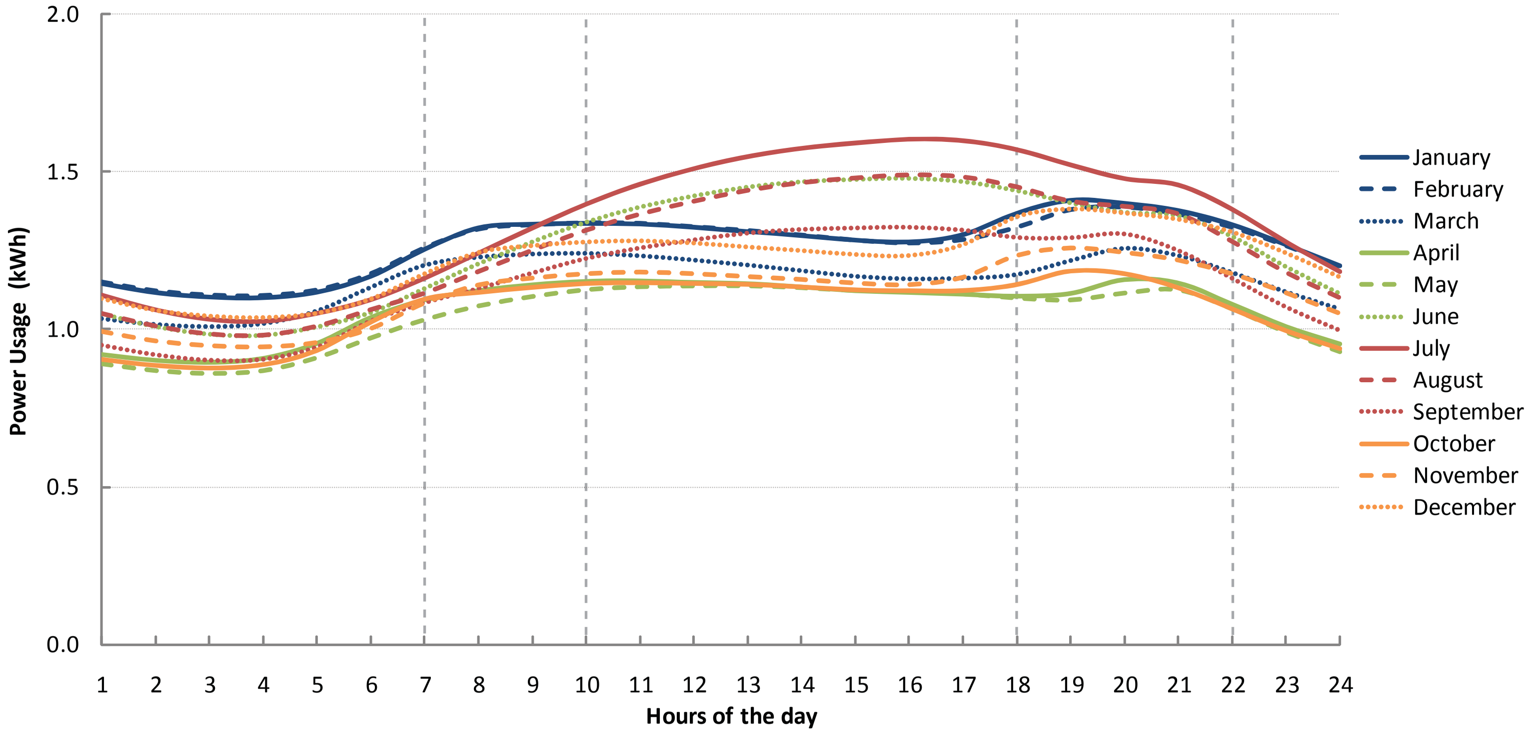

Figure 9. Average household hourly power use per average day in a month. The vertical dashed lines represent times when peaks in power consumption begin and end.

systems. K_{PV} signifies the reduction coefficient for the working conditions of a PV system and has a constant of 0.8. The final ratio of S/I_{STC} is a comparison of the actual average solar irradiance for every month in kWh/m^2 at Huntington, West Virginia (S) divided by the solar irradiance that was generated in standard testing conditions (I_{STC}) which is maintained continually at 1 kW/m^2. The West Virginia solar irradiance data (S) was gained from the Cooperative Networks For Renewable Resource Management (CNFRRM) from a data collection site at Bluefield State College in Bluefield, West Virginia. Data from this collection site was measured from 1997 to 2008. Hourly data for every day from 1997 to 2004 was compiled since it was the most complete data of the years given. These values were calculated into average solar irradiation for an hour per month to correspond with the average hour per month power usage values calculated from the RFC. This was done to construct typical weather conditions for the Huntington area. Since the irradiation data was originally in Watt-hours/m^2 (Wh/m^2), it was diveded by 1000 to convert it into kWh/m^2 which is more compatible with the average residential power usage data.

The system sizes first mentioned were selected using the Solar Calculator, a tool created by the Seattle-based company, Cooler Planet. The calculator requires a zip code, the power utility company used, the average monthly electric bill or an average monthly power usage in kWh, whether the location is residential or commercial, and how much energy offset is desired in percent reduction (Cooler Planet, 2009). For this study, the zip code 25701 was used and the residential button was selected. Appalachian Power was chosen from a drop-down list of utility companies. The average monthly power consumption value of 883.1 kWh, which was calculated earlier from the hourly usage data from the RFC, was utilized for the average monthly power usage. Results of system specifications, which include kW production capacity, area covered, and estimated costs before and after incentives and tax breaks, are returned instantaneously.

Four different power level systems were used for the P_{PV}, which include: 2.1 kW, 4.2 kW, 6.3 kW, 8.4 kW systems. The four mentioned systems represent a 25%, 50%, 75%, and 100% power reduction respectively on an average customer's power usage in the RFC region. The 8.4 kW system hypothetically could fulfill any demands from an average household although, Appalachian Power allows a homeowner to incorporate a system as large as 25 kW (Appalachian Power Company, 2007).

To demonstrate the effect that a solar panel system would have on a household's power usage the following equation was used:

$$P_{Adj} = P_0 - E_{PV} \tag{Equation 3}$$

P_{Adj} represents the adjusted power usage after a PV system has been implemented. P_0 signifies the power usage before the PV system has been installed. The E_{PV}, which was calculated above, stands for the possible power produced by a solar panel. This step was used for every hour of an average day for every month.

CHAPTER THREE: RESULTS

Table 5 shows the number of buildings and their sizes corresponding to each of the study locations and the areas covered by the building footprints. The building footprint is a proxy for the amount of area that can be used to place a PV system. The residential footprint area is cut in half due to the angled nature of a majority of housing roofs that face the proper direction for collection of solar rays. The largest area covered by a building is the Big Sandy Superstore Arena (DT1). The smallest area covered is by houses in the Hal Greer study area (HG3). The average building footprint calculated for all commercial buildings is 6414.27 m^2, while the average building area available for solar panel installation for all residential structures is 81.54 m^2 without garages. Garages have an average area of 29.12 m^2 available for PV system installation.

The area covered by the IKONOS image is roughly 48.9 km^2. The NDVI shows that within this area approximately 68.6% of the surfaces are classified as vegetation, while the sealed surfaces account for nearly 15.4 km^2, or 31.40%. The DT1 study area has the largest percentage of area covered by roof with 58.33%, while the smallest area covered by roofing was in the RP3 study area with 17.14% (Table 3).

Table 6 gives the details of the various solar panels suggested by Cooler Planet. The price range before the 30% tax reduction, the maximum incentive in West Virginia, would be from $16,690.48 for a system that would be able to reduce power usage from the power company by 25%, to $66,761.91 for a PV system that could supply nearly complete independence from the power grid. Calculating the use of the federal tax incentive in West Virginia, the price range of the systems would be from $11,683.34 to 46,733.34. If the incentives from Louisiana were applied to these prices, they would range from $3,338.10 to $34,233.34. The average monthly usage of power per hour in a day would decrease from 1.1867 kWh to 0.9656 kWh with a 2.1 kW system and 0.3025 kWh with a 8.4 kW system.

Table 5. Values collected from the polygons created for the building footprints in ArcMap. The area values for the Ritter Park (RP) study area and the Hal Greer (HG) study area were divided by two due to the nature of angled roofs which reduces the amount of area available for solar panel use. Roofs for the Downtown study area were left undivided due to their flat surface which can receive full sunlight.

Study Area Building Sizes

Study Area		# of Buildings	Max. Area (sq-m)	Min. Area (sq-m)	Avg. Area (sq-m) ± Std
Houses	RP1	9	286.60	53.01	169.89 ± 64.85
	RP2	23	157.61	27.37	82.88 ± 27.55
	RP3	26	194.74	23.77	72.07 ± 39.06
	RP4	34	215.70	16.59	61.35 ± 39.88
Garages	RP1	3	37.49	18.11	27.31 ± 7.94
	RP2	6	28.30	16.71	22.18 ± 3.95
	RP3	1	37.20	n/a	n/a
	RP4	4	31.93	21.85	25.02 ± 4.03
Houses	HG1	36	272.27	38.88	108.55 ± 75.87
	HG2	19	85.06	15.55	30.68 ± 32.83
	HG3	43	132.34	26.20	62.38 ± 19.67
	HG4	19	98.13	26.60	64.51 ± 20.82
Garages	HG1	2	49.44	32.88	41.16 ± 8.28
	HG2	0	n/a	n/a	n/a
	HG3	1	n/a	n/a	n/a
	HG4	3	22.96	20.11	21.85 ± 1.25
	DT1	1	16737.90	n/a	n/a
	DT2	2	6385.15	3150.50	4767.82 ± 1617.32
	DT3	2	5594.85	907.09	3250.97 ± 2343.88
	DT4	8	1823.96	123.88	900.38 ± 463.17

Table 6. PV system specifications for the four units that were used to identify the amount of reduction in power usage (Cooler Planet, 2009).

Photovoltaic System Comparison

% Reduction	System Output (kW)	Initial Cost	Cost After Incentives	Area Covered (sq-m)	Avg. Hourly Power Production (kWh)
25	2.1	$16,690.48	$11,683.34	19.4	0.2211
50	4.2	$33,380.96	$23,366.67	38.7	0.4421
75	6.3	$50,071.44	$35,050.01	58.2	0.6632
100	8.4	$66,761.91	$46,733.34	77.6	0.8842

Figures 10, 11, 12, and 13 show the effects of PV system implementation. With a minimum system of 2.1 kW, a residence can reduce their power usage by approximately 0.2211 kWh per hour during times of sunlight. With the larger 8.4 kW system, power can be reduced on average by 0.8842 kWh per hour during the day time hours.

Table 7 depicts four potential PV systems that may be suitable for a residence by comparing the area the PV system occupies against the area available on the roof. Table 8 illustrates the possible use of garages from the study areas to employ more PV systems if a homeowner wished to produce more energy, either to increase the percentage of independence from the power company or to exceed the 100% independence and store it with batteries should the option be available. The buildings of the downtown study areas far surpassed the available area needed to install the PV systems for a residence in the Huntington area. With this knowledge, Table 9 was created to show the largest PV system that could be installed based on the area available on the roofs of the downtown structures.

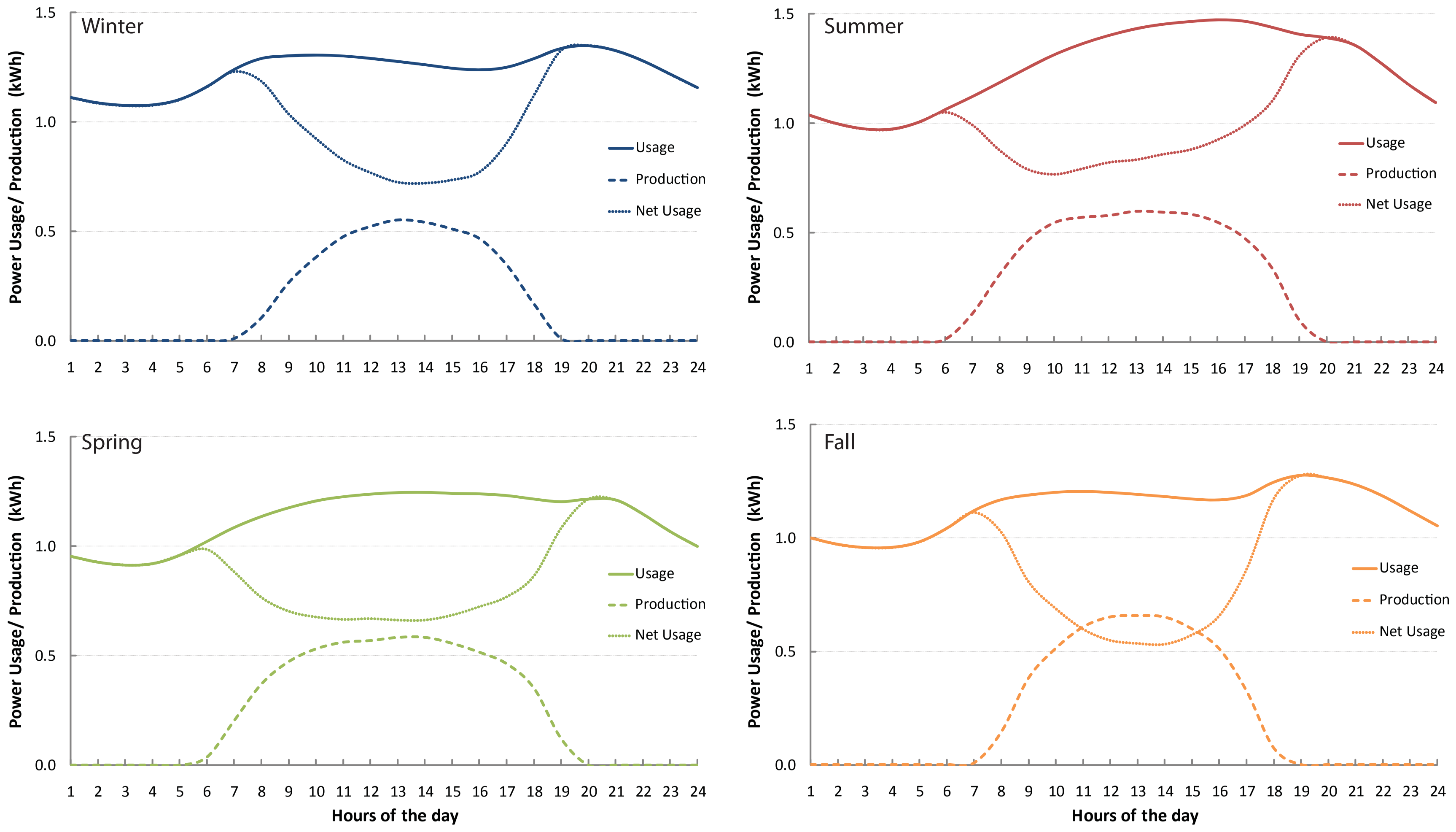

Figure 10. Power usage, production, and net production for the 2.1 kW system.

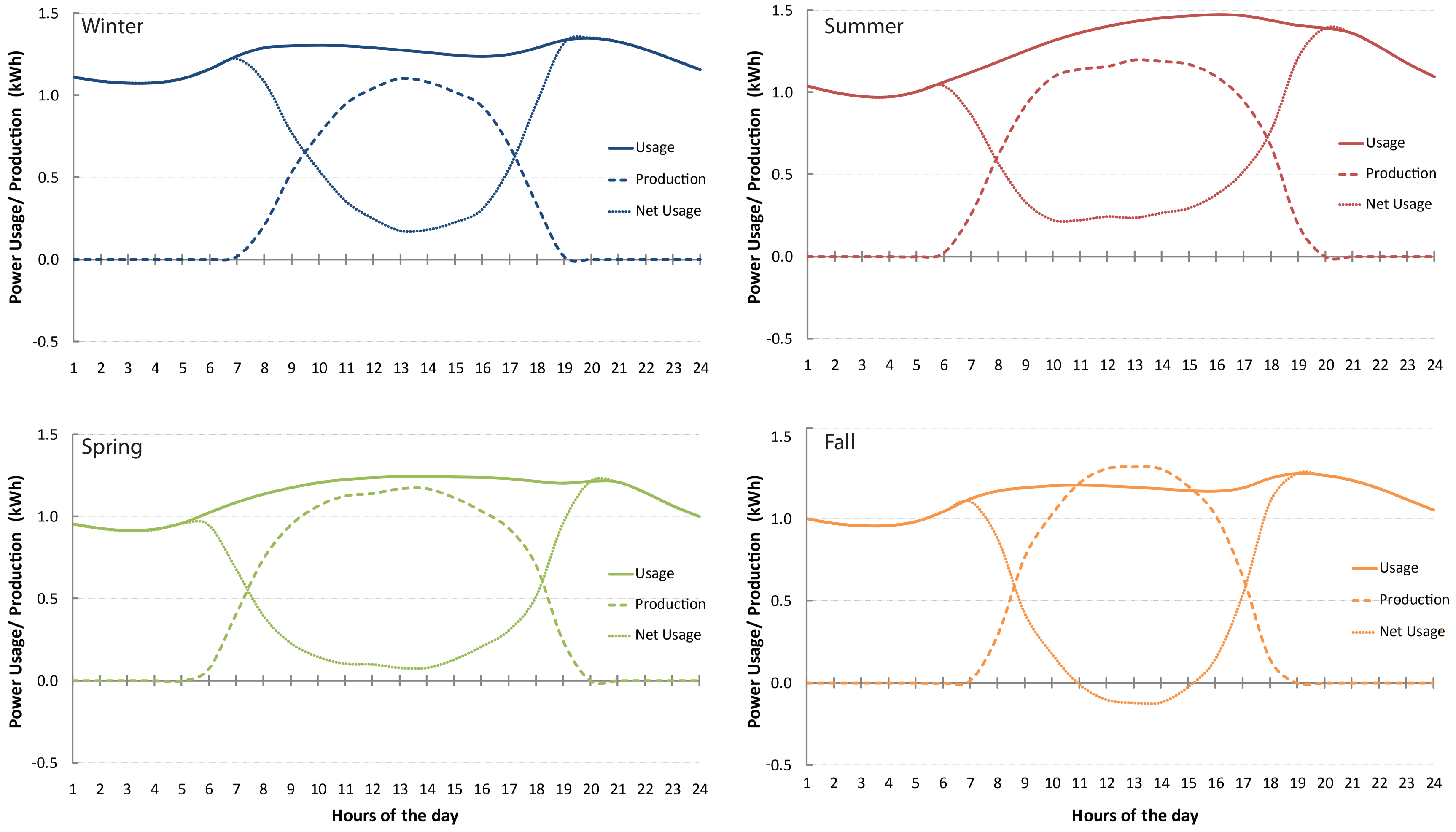

Figure 11. Power usage, production, and net production for the 4.2 kW system.

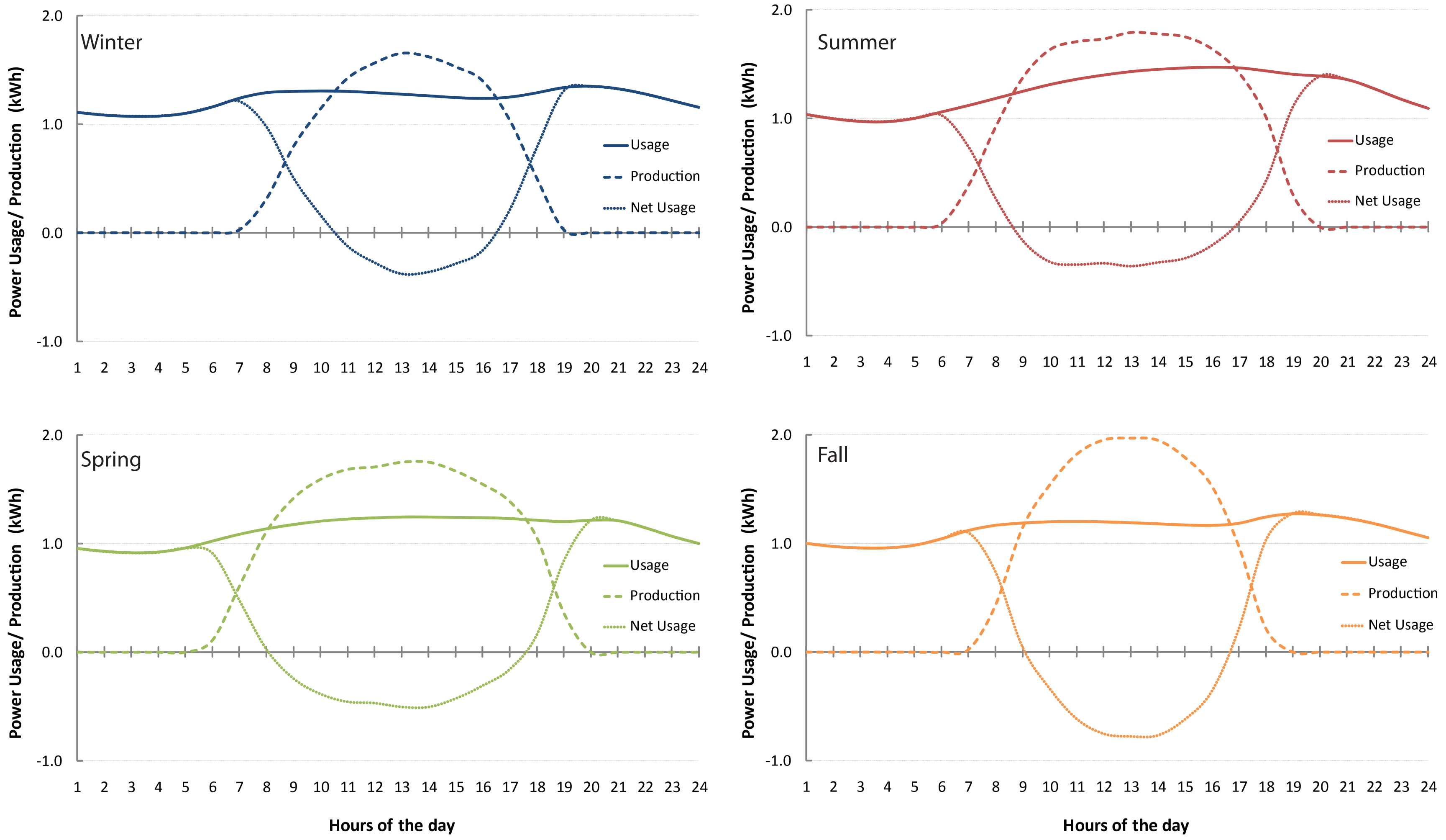

Figure 12. Power usage, production, and net production for the 6.3 kW system.

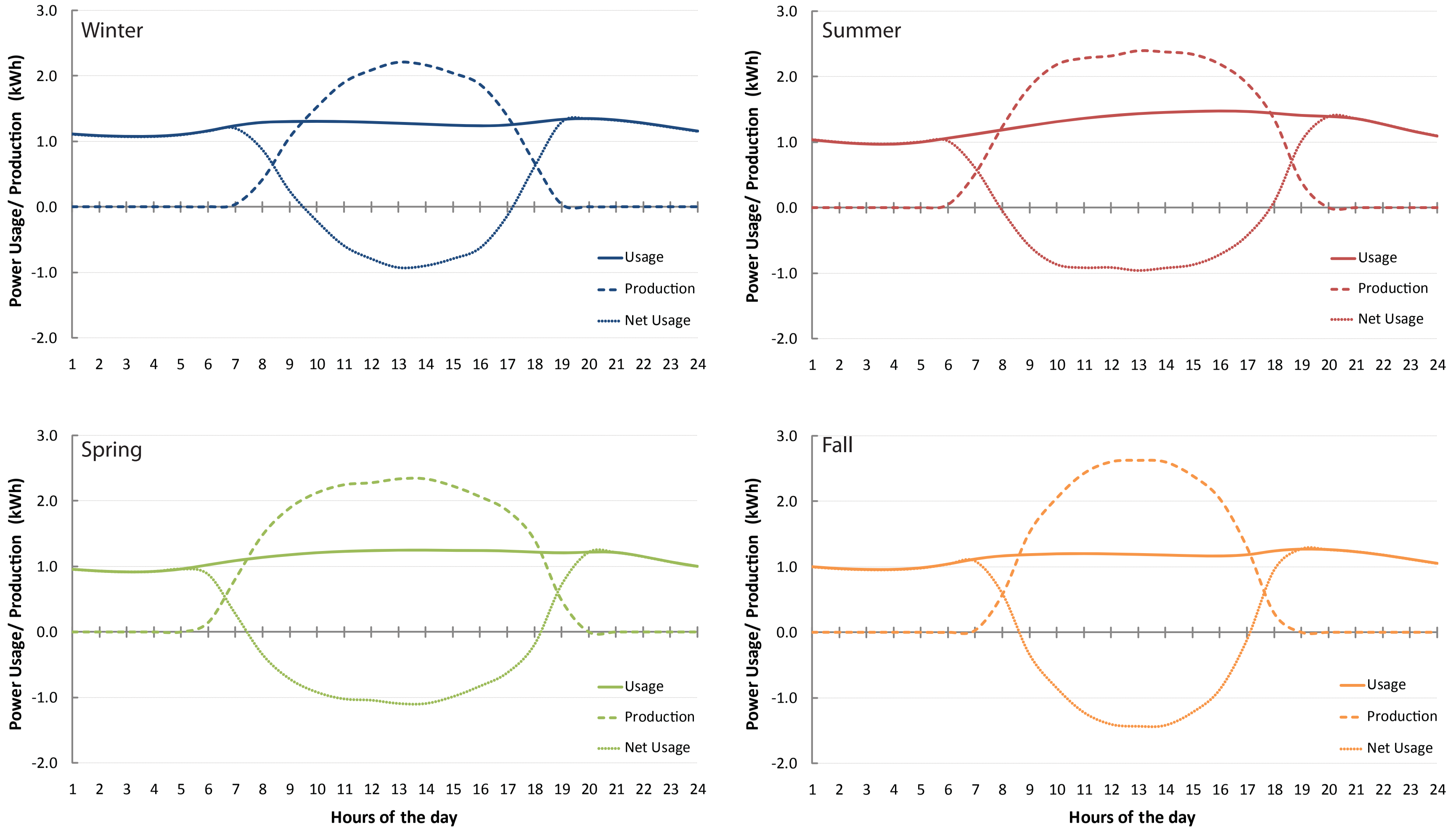

Figure 13. Power usage, production, and net production for the 8.4 kW system.

Table 7. PV systems that could be incorporated to house roofs in the study areas based on the area covered by the PV system and the available area on the roof. The black dots suggest a definite fit onto roofs, while the grey dots imply a conditional fitting. That condition being a roof's size is one full standard deviation larger than the mean roof size of its study area.

Study Area Building Compatibility - Houses				
Study Area	2.1 kW	4.2 kW	6.3 kW	8.4 kW
RP1 Max	●	●	●	●
RP1 Min	●	●		
RP1 Avg.	●	●	●	●
RP2 Max	●	●	●	●
RP2 Min	●			
RP2 Avg	●	●	●	●
RP3 Max	●	●	●	●
RP3 Min	●			
RP3 Avg	●	●	●	○
RP4 Max	●	●	●	●
RP4 Min				
RP4 Avg	●	●	●	○
HG1 Max	●	●	●	●
HG1 Min	●	●		
HG1 Avg	●	●	●	●
HG2 Max	●	●	●	●
HG2 Min				
HG2 Avg	●	○	○	
HG3 Max	●	●	●	●
HG3 Min	●			
HG3 Avg	●	●	●	●
HG4 Max	●	●	●	●
HG4 Min	●			
HG4 Avg	●	●	●	○

Table 8. PV systems that could be incorporated to garage roofs in the study areas based on the area covered by the PV system and the available area on the roof. The black dots suggest a definite fit onto roofs, while the grey dots imply a conditional fitting.

Study Area Building Compatibility - Garages				
Study Area	2.1 kW	4.2 kW	6.3 kW	8.4 kW
RP1 Max	●			
RP1 Min				
RP1 Avg.	●			
RP2 Max	●			
RP2 Min				
RP2 Avg	●			
RP3 Max	●			
RP3 Min				
RP3 Avg				
RP4 Max	●			
RP4 Min	●			
RP4 Avg	●			
HG1 Max	●	●		
HG1 Min	●			
HG1 Avg	●	○		
HG2 Max	NA	NA	NA	NA
HG2 Min				
HG2 Avg				
HG3 Max				
HG3 Min				
HG3 Avg				
HG4 Max	●			
HG4 Min	●			
HG4 Avg	●			

Table 9. Table that shows the maximum PV system size that could be implemented on a downtown study area roof.

Maximum System Based on Size (kW)			
Study Area	Max	Min	Avg.
DT1	1800		
DT2	685	335	510
DT3	600	95	345
DT4	195	10	95

CHAPTER FOUR: CONCLUSIONS AND DISCUSSION

Based on the NDVI of the IKONOS image, there are many locations of sealed surfaces that could accommodate the presence of PV systems. The NDVI also indicates that vegetation does not affect the available roof area in the immediate vicinity of the buildings. Building roofs are only a fraction of the surface area that could be employed to reduce the dependence of the limited fuel sources that power West Virginia. Surfaces such as parking lots could be covered by shading kiosks that are roofed in solar panels and reduce the amount of solar radiation that would be absorbed by the concrete. This would keep cars cooler during intense summer days as well as reduce the urban heat island effect caused by heated concrete and asphalt.

The majority of houses within the Huntington area are capable of supporting a 6.3 kW system. The largest houses within the Ritter Park and Hal Greer study areas are capable of supporting PV systems of 8.4 kW or larger. The smallest roofs of the residential areas were able to accommodate, at most, 4.2 kW systems, but the majority can only support 2.1 kW systems. The roof surfaces of the buildings in the Downtown study area were constructed flat, ergo their entire surface could be used for any placement of a PV system. If a garage is present and the house roof is not large enough to accommodate a system that provides full energy autonomy, the garage roof may be used to include a smaller system that could increase the amount of self-sufficiency. The maximum allowed 25 kW system could be used by farmers or larger properties to supply energy to multiple buildings that use minimal energy as well as the main dwelling where more power is required; however, they might produce impressive amounts of excess energy and never fully use the credit attributed to them based on Appalachian Power’s regulations.

According to this study, implementation of solar panels is possible to at least reduce the amount of energy needed from a power company by 75%. Hypothetically, smaller houses may use less power and the 6.3 kW system could supply the 100% independence ultimately sought, while larger houses may require a system with a higher energy production level, but may have the area available to incorporate a larger system. If a grid connected system is used with Appalachian Power, any excess power generated during the day is credited to the homeowner and may reduce the cost of energy. The credited energy only lasts for 12 months; however, that may provide ample time to use any of this energy during times of lower power production (Appalachian Power Company, 2007). Any PV system used decreases the energy demand peaks that occur throughout the day time hours. Though the demand peaks are reduced with the use of a 2.1 kW system, production of surplus power does not occur until a 4.2 kW system or larger is put into use. The peaks that occur during the evening hours after the sun has set can only be affected by solar panels if the energy created by a PV system is stored in batteries or if the credit from power companies is used.

This project was meant to raise awareness of the options available to the Huntington, West Virginia locale for the reduction of energy dependence based on finite resources. The findings of this study indicate that a grid-connected PV system is not the ultimate answer to power usage needs but would still prove highly beneficial. Although power companies are able to produce a baseline of power throughout the day and import and export energy as needed from other locations, grid-connected systems could reduce the baseline power production and reduce the amount of natural resources needed to equal demand.

This pilot study could be expanded to include all buildings in the Huntington area that are currently in use to gain better average building sizes. Resources that would benefit further studies would be power data for residential use and for commercial/industrial use if it could be retrieved either through donation from power companies or purchased through the use of grants, up-to-date IKONOS, Digital Orthographic Quarter Quads, and SAMB images to determine footprints and areas of newer buildings (such as locations like Pullman Square in downtown Huntington), and finally, more accurate data about the number of households and businesses or corporations within the RFC to help determine a more correct average power usage rate per hour. Other studies that could be derived from this research include the study of other sealed surfaces, such as parking lots, for implementation of solar panel usage as mentioned earlier. In addition, the amount of vacated buildings in the Huntington area that could be converted into flat areas for the establishment of solar power production locations that may reduce the city's power usage costs could be evaluated.

The largest hindrance of PV systems is the initial cost to install the system. It will still be many years before the PV cell becomes a more common tool for the reduction of non-renewable source power production. Battery systems to store produced energy are also very expensive and can increase the price of a PV system considerably. If all households were able to produce 100% of their energy needs without including the use of batteries, large amounts of surplus energy would be generated during daylight hours that could not be stored for later use. For PV systems to be more feasible, battery prices and efficiencies need to be improved. Increasing demand for PV cells would place emphasis on creating new PV production factories that would increase production and decrease cost. The process to reduce cost could be expedited by the use of tax cuts and purchase incentives.

One misconception of PV systems is that power companies would need to build centralized PV power generation plants on large tracts of land, thus reducing the area allowed for agricultural use. This study implies that PV systems can be decentralized and put into service using the "wasted" surface area of roofs of buildings throughout a city.

Awareness needs to be raised about PV systems and other forms of renewable energy sources. Increased familiarity would allow people to question current power production methods as well as increase the understanding of the limits of natural resources. This would draw the interest of government backing to increase the amount of money returned through incentives at the federal, state, and local levels.

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