Solar Potential at Treasure Valley Scout Reservation

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Authors:
James Maxwell
Lillian Neff
Huyen Anh Nguyen

Advisors:
Professor Fred Looft
Electrical and Computer Engineering
fjlooft@wpi.edu

Professor Derren Rosbach
Civil and Environmental Engineering
drosbach@wpi.edu

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LIST OF ABBREVIATIONS

A -	Amperes (Amps)
AC -	Alternating Current
Ah -	Ampere-hour
AWG -	American Wire Gauge
BSA -	Boy Scouts of America
CSAC -	Cub Scout Adventure Camp
DC -	Direct Current
DoD -	Depth of Discharge
Ea -	Each
HP -	Horsepower (power)
IQP -	Interdisciplinary Qualifying Project
kWh -	kilo-Watt-hour (energy)
LED -	Light Emitting Diode
MQP -	Major Qualifying Project
NFPA -	National Fire Protection Association
No. -	Number
PCB -	Polychlorinated Biphenyl
PV -	Photovoltaic
PWR -	Power
SLA -	Sealed Lead Acid
SME -	Subject Matter Expert
STEM -	Science Technology Engineering and Mathematics
TVSR -	Treasure Valley Scout Reservation
V -	Volt
W -	Watt (power, or energy over time)
Wh -	Watt-hour (energy)
WKND -	Weekend
YR -	Year

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ABSTRACT

The intent of this Interdisciplinary Qualifying Project was to provide Treasure Valley Scout Reservation (TVSR) recommendations for sustainable energy solutions. This was completed to address concerns of future failure of the current underwater power cable. The project worked toward the development of a sustainability plan for TVSR's West Camp and the future reduction of energy use in West Camp. Based on the collected and proposed building inventories, the hardware requirements for the recommended installations were determined. Recommendations included the optimal solar energy system to install, the best location(s) for potential installments, and a cost and risk assessment for installment.

1. INTRODUCTION

Treasure Valley Scout Reservation is a 1,600-acre woodland camp used by both Boy Scouts and Cub Scouts [1]. The entire camp is roughly divided by Browning Pond into what are called East Camp and West Camp. Currently, East Camp has multiple solar installments on the hard shelters and latrines (Figures 1 and 2) of individual campsites, as well as grid-tied electricity supplied to the major buildings. West Camp does not have solar installed at any campsites, except for one latrine, and the electricity to West Camp is supplied via an underwater cable that spans Browning Pond (purple dashed line in Figure 3). This underwater cable was installed in 1983 and was rated for a life span of approximately 30 to 40 years. Since the cable is now 36 years old, there is concern that the cable might fail in the near future and result in a total loss of power and the resulting likely cancelling of any camp programs in the West Camp area. It has been estimated that replacing the cable, associated transformers, and other system components would cost upwards of $200,000.

Figure 1: Camp Hard Shelter with Solar Installment (Yellow)

Figure 2: Camp Latrine with Solar Installment (Yellow)

The purpose of this project was to provide Treasure Valley with a detailed assessment of the electrical needs of West Camp (the area below Browning Pond in Figure 3, north is to the left in the image) and, based on this assessment, provide recommendations for the best type of solar system to install, a cost and risk assessment for each possible installation, and the best locations for solar installments. The recommendations aimed to offer a guide for alternatives to the current power system which is dependent on an underwater cable (purple dashed line in Figure 3), while also maintaining the functionality and capabilities of West Camp.

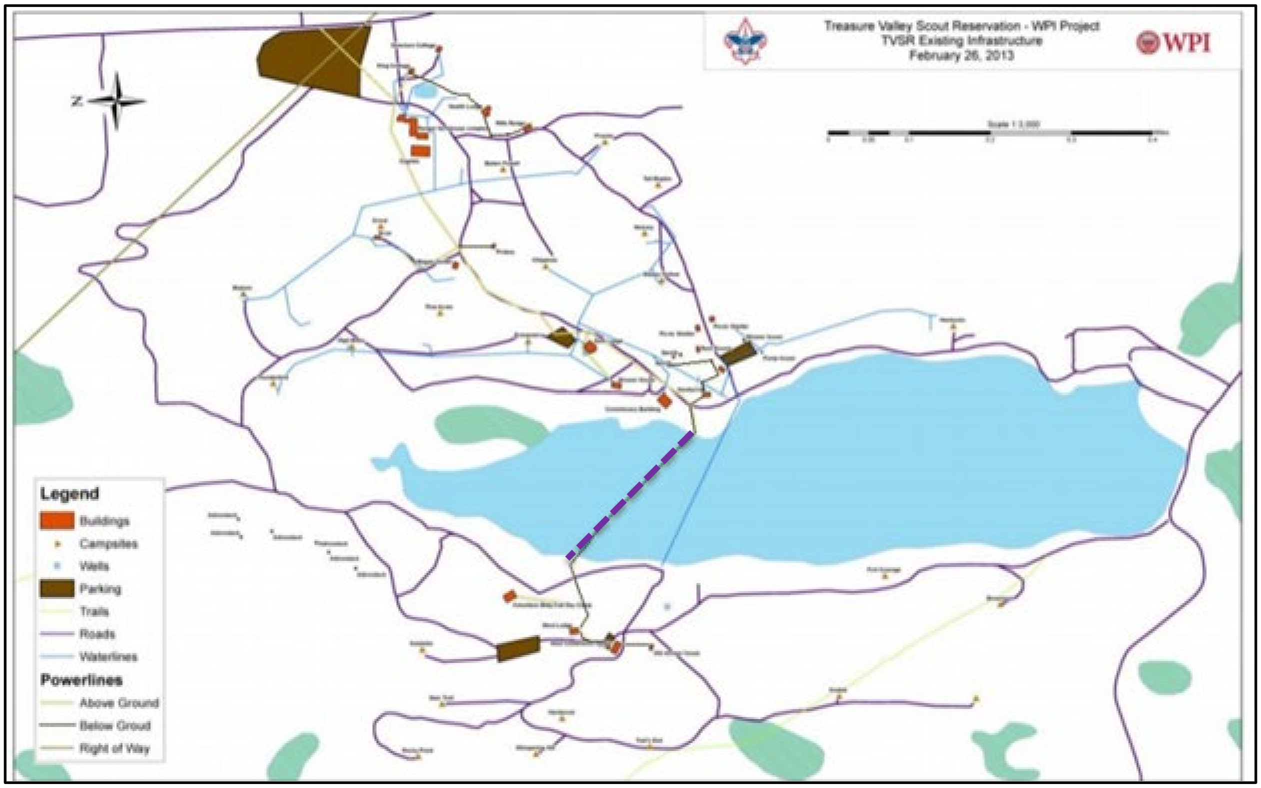

Figure 3: TVSR Infrastructure Map [2]
Note: East Camp is Above the Pond and West Camp is Below the Pond

2. BACKGROUND

2.1 Treasure Valley

"Founded in 1926, Treasure Valley Scout Reservation (TVSR) is a beautiful 1,600-acre woodland camp that offers over 70 miles of hiking/biking trails, a variety of ecosystems and wildlife habitats, and a nocturnal view of the solar system that will inspire the imagination" [1]. Encompassing Browning Pond, Heron Marsh, and Seven Mile River, the reservation (shown in Figure 4) spans over the towns of Rutland, Paxton, Oakham, and Spencer [1].

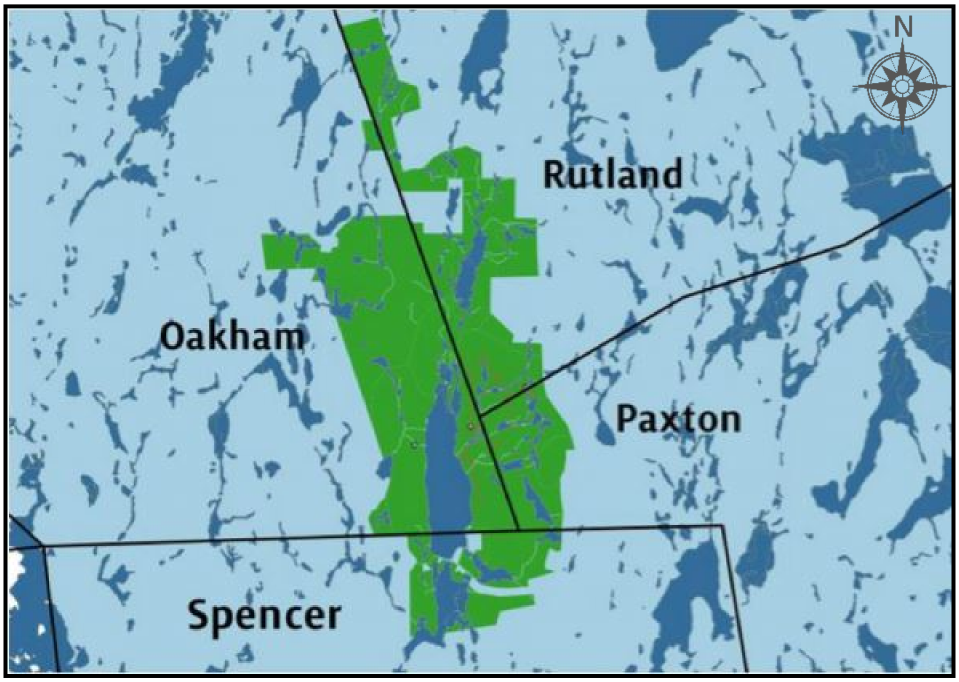

Figure 4: Treasure Valley Scout Reservation Shown in the Four Towns of Rutland, Paxton, Oakham, and Spencer [3]

TVSR strives to aid Scouts and individuals of all kinds in their discovery of adventure, to provide opportunities to develop and display leadership and self-governance, and to encourage students as well as adults to enjoy the outdoors [1]. As shown in Figures 5 and 6, the reservation is logically divided into two camps: Treasure Valley East and Treasure Valley West. Treasure Valley East, the eastern side of the Browning Pond, is home to the Boy Scout Resident Camp. This part of the reservation has multiple campsites, each with solar powered lighting systems, shooting sports ranges, the Carr Waterfront, and other locations designed for specific programs (e.g., ropes course, wood working, etc.) [1]. On the other side of the Browning Pond is the Treasure Valley West Camp. The Treasure Valley West side caters primarily to the Cub Scouts and the Cub Scout Adventure Camp. This side includes a waterfront area, shooting sports ranges, and the new Adventure Area. The West Side also has miles of trails including the Mid-State trail and Sampson's Pebble, a popular landmark along the Mid-State, located at the junction of several trails [1].

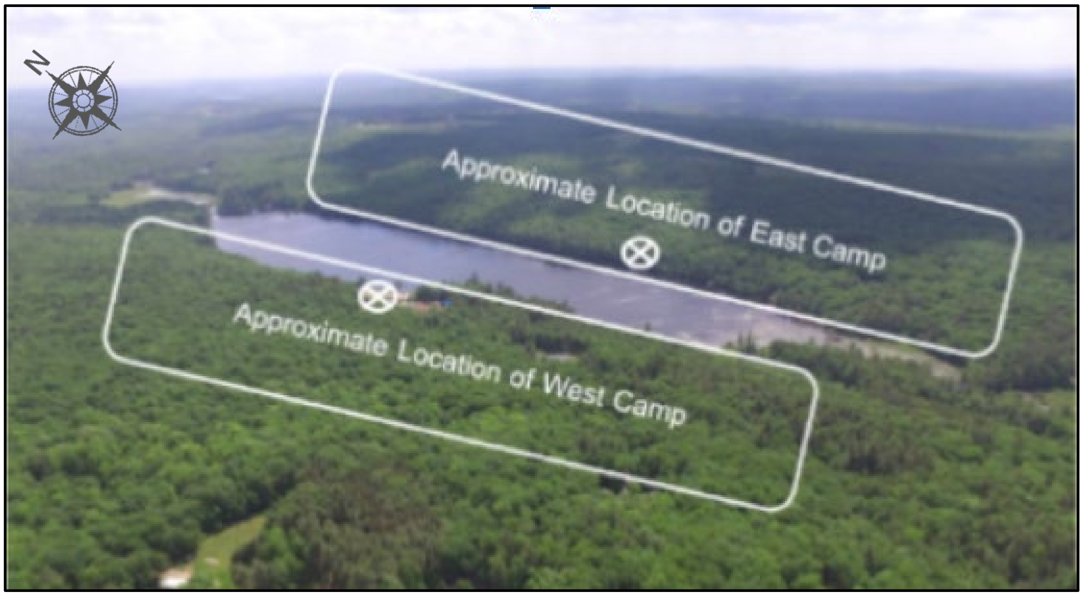

Figure 5: TVSR East and West Camp [4]

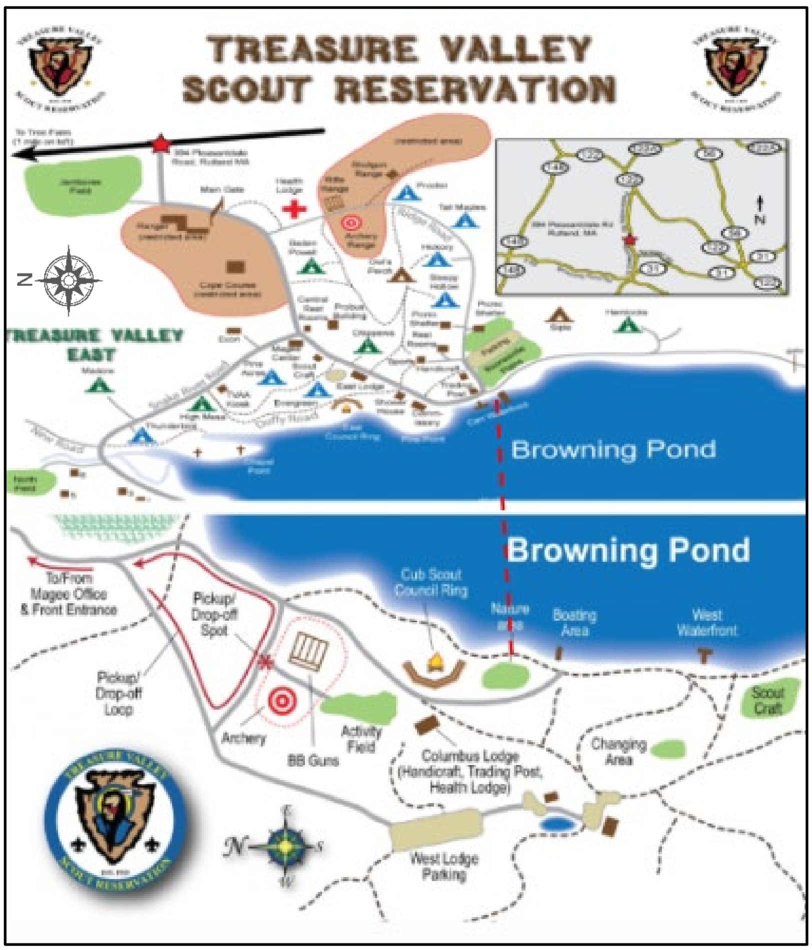

Figure 6: Treasure Valley East (Top) and West (Bottom) Camps (North is to the Left in this Image)

Note: Red Dashed Line is the Power Line [5]

2.2 Boy Scouts of America - A Brief History

The mission of the Boy Scouts of America is to prepare young people to make ethical and moral choices over their lifetimes by instilling in them the values of the Scout Oath and Scout Law [6].

Scout Law:

On my honor I will do my best to do my duty to God and my
Country and to obey the Scout Law; to help other people at all times;
to keep myself physically strong, mentally awake, and morally straight [7].

Scout Oath:

A Scout is: Trustworthy, Loyal, Helpful, Friendly, Courteous, Kind,
Obedient, Cheerful, Thrifty, Brave, Clean and Reverent [7]

The Boy Scout concept was founded in Great Britain in 1908 by Lieutenant General Robert S.S. Baden-Powell, author of the book *Scouting for Boys* (1908), and quickly gained popularity amongst the young males of Great Britain. The Lieutenant General's idea was to organize the young males into subgroups (patrols) of six or seven individuals under a single adult male leader with the title patrol leader and was originally open to males ages 11 to 15 years of age. The adult "scoutmaster" mission was to proctor the young men in their development. Skills acquired from the training include tracking and reconnaissance, mapping, signaling, knotting, first aid, and other skills that arise from outdoor activities. To become a scout, the young male must promise to be loyal to his country, help others, and obey the code of chivalrous behavior [6]. As the male individuals progressed through training, the scout was rewarded by the granting of certain badges.

In 1916, Baden-Powell founded an organization for males under the age of 11 called the Wolf Cubs, now commonly referred to as the Cub Scouts. By 1967, the word "boy" was dropped from the British Scout organization and by the 1980s, the organization was open to both males and females [6]. Although the Boy Scout organization's origins traces back to Great Britain, by 1910, the movement had reached the United States and other countries. Indeed, by the 21st century, there were Boy Scout organizations in approximately 170 countries [6]. Entering a new era, the Boy Scouts of America sought to rebrand its Scouts program with a new campaign — "Do a Good Turn Daily — designed to appeal to both boys and girls [6]. The program of the Boy Scouts of America is now open to young women as well as young men, all of whom will have the chance to earn Scouting's highest rank, Eagle Scout. In the past few years, the Boy Scouts of America faced much controversy over the program's admission for both male and female scouts. To reflect the decision to admit young women, the Boy Scouts of America renamed its organization to the Scouts BSA [6].

2.2.1 BSA Organization Government

The Boy Scouts of America (BSA) is a national organization that includes a council, which is comprised of chartered organization representatives as well as council-members-at-large. The bylaws are the governing rules of the council. Aside from the council is the executive board, which governs the council. This is typically between 25 and 50 members. For example, the Heart of America Council, which services the youth of Central Massachusetts, is governed by its own executive board and committee members. The officers of the council are elected by the executive board and are responsible for jobs such as the president, council commissioner, treasurer, one or vice presidents, and a Scout executive as secretary. The executive committee, which consists of the officers and Scout executive, handles business between executive board meetings. District chairmen are elected through bylaws and chair their district committees as well as represent their district to the council executive board. At the annual council meeting, elections are held, financial reports are created and approved, and prior meeting minutes are documented [8].

2.3 Merit Badges and STEM Awards

Merit badges play an important role in the Scout's mission to instill and encourage excellence. There are more than 135 merit badges, each awarded based on the fulfillment of requirements that are unique to each badge. Each merit badge has a published pamphlet (booklet, example in Figure 7) associated with it. The pamphlet contains information on completing the requirements for the badge. Guidance is offered to all Scouts by of a Scoutmaster or a merit badge counselor who are experts in the field. The Merit Badge Counselors facilitate learning and follow the guidelines set forth by the Scouts of the Boy Scouts of America. The Scouts must first meet with their Scoutmaster in order to begin working on a merit badge, and then contact an adult who is registered as a counselor for that merit badge to learn more details of the badge requirements. Once the requirements are met, the Scout meets with the counselor again to demonstrate that s/he has completed the requirements. After completing the merit badge, the Scout can then buy the corresponding merit badge patch, such as the one illustrated in Figure 8 [9]. Finally, badges are displayed on a sash which is part of the uniform and is worn during formal occasions.

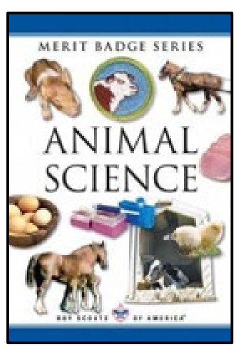

Figure 7: Animal Science Booklet [9]

Figure 8: Animal Science Badge [9]

Scouts of all ages have the opportunity to earn their badges. The badges available for Scouts are organized into distinct categories ranging from Energy to Gardening to Water Sports and to Business. The Nova and Supernova Awards Program are two programs put in place to reward Scout members for STEM related achievements [10]. The programs incorporate learning and exposure to science, technology, mathematics, and engineering for Cub Scouts, Scouts BSA members, and Venture Scouts [10]. The Nova and Supernova programs foster an academic environment to instill interest in STEM-related fields and demonstrate how science, technology, engineering, and mathematics apply to everyday life. There are two types of awards offered – the Nova Awards and the Supernova Awards. Each award is granted by fulfilling the requirements of one STEM related field – science, technology, engineering, or mathematics. Scouts earn the distinctive Nova award patch for their first award. Additional Nova awards are recognized with a separate pi (π) pin-on device that attaches to the patch [10].

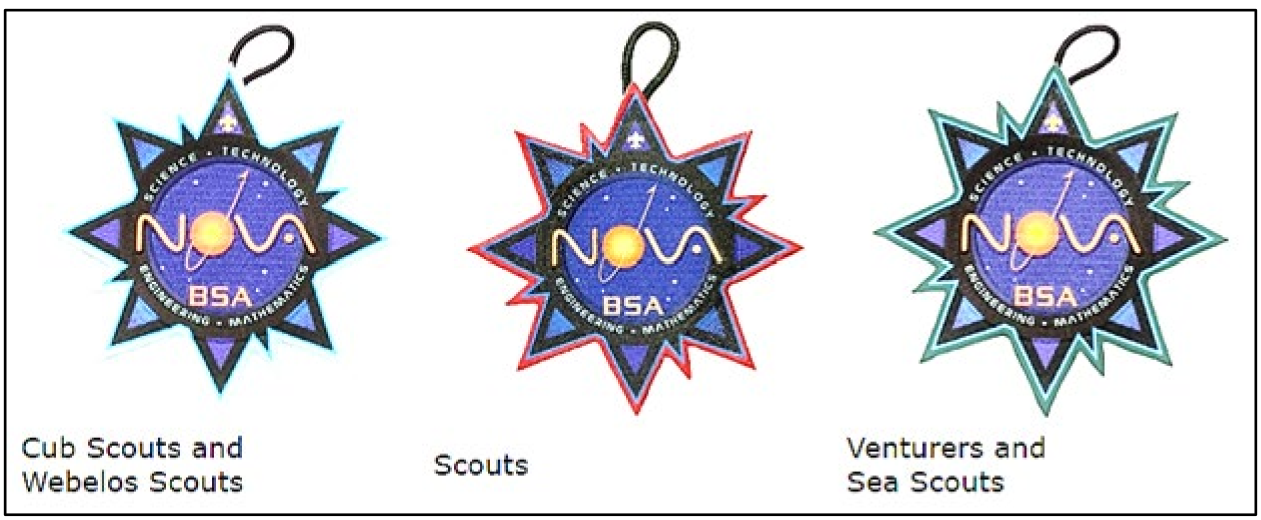

Figure 9: Nova Awards Program Merit Badges [10]

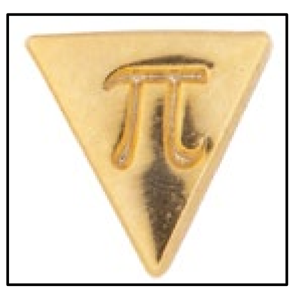

Figure 10: Nova Awards Pi [10]

The Supernova Awards require more “rigorous” requirements for learning within STEM disciplines. The requirements are designed to motivate youth and recognize in-depth and advanced achievement in STEM-related activities [10]. The awards are as follows:

1. Wolf and Bear Cub Scouts: Dr. Luis Alvarez Supernova Award
2. For Webelo Scouts: Dr. Charles H. Townes Supernova Award
3. For Scouts BSA: Dr. Bernard Harris Supernova Bronze Award, Thomas Edison Supernova Award
4. For Venture Scouts: Dr. Sally Ride Supernova Bronze Award, Wright Brothers Supernova Silver Award, Dr. Albert Einstein Supernova Gold Award

Figure 11: Supernova Award Badges [10]

2.4 Solar Power at Treasure Valley

Treasure Valley makes use of solar energy at multiple campgrounds in East Camp. Standalone solar systems power lighting in latrines, hard shelters, and meeting areas (Figures 1, 2, and 12) at various campgrounds and provide comfort and security to scouts and their leaders. The lighting within the hard shelters provides a space where evening or nighttime meetings can take place and where summer camp scouts can work on their merit badges in the evening. At the latrines, the solar powered lighting eases the minds of Scouts (especially younger Scouts) in nighttime trips to the restroom. Increasing the availability and expanding the use of solar power elsewhere at Treasure Valley Scout Reservation will result in a more inviting stay for the Boy Scouts and other groups coming to visit the reservation.

Figure 12: Camp Pavilion with Solar Installment (Yellow)

2.4.1 Previous Studies

In previous years, Worcester Polytechnic Institute (WPI) has conducted various studies on the sustainability and development of TVSR. The studies focused on improving TVSR in ways such as assessing the roads to draft an improvement plan and installing small-scale solar systems on hard shelters and latrines in East Camp. One example includes a major qualifying project (MQP) completed in 2014 that mapped and assessed several environmental sites in West Camp to both preserve and develop the camp [11]. Another example is an MQP conducted in 2015 which was focused on two main components: development of STEM education curriculum, and the electricity usage of one specific building at TVSR. The project aimed to develop a STEM related curriculum for the Scouts and focused its assessment of electricity usage on the Ecology Conservation building to create a future off-grid solar installations and sustainability plan. Reports such as these provided valuable insight on sustainability and the implications of technology and renewable energy [2].

2.5 Solar Energy System - Basics

Solar power is the cleanest, most abundant renewable energy source available. Solar power is energy derived from the sun that is converted into thermal or electrical energy for a variety of uses, including generating electricity, providing light or a comfortable interior environment, and heating water for domestic, commercial, or industrial use [12]. Using solar energy has two main benefits: solar energy systems do not produce air pollutants or carbon dioxide and solar energy systems have minimal effects on the environment [13]. Along with these environmental benefits, solar power has other advantages such as power flexibility, reliability, low maintenance, and energy independence [14].

However, solar energy systems also have some limitations. One limitation is that the amount of sunlight that arrives at the earth's surface is not constant, and the amount of sunlight varies depending on location, time of day, season of the year, and weather conditions [13]. As a result, the power produced by a solar system is subject to the vagaries of the weather and nature. Another limitation is that the amount of sunlight which reaches Earth's surface is relatively low, so a large surface area is necessary to absorb or collect a useful amount of energy [13]. Finally, although obvious, solar systems only produce usable energy during hours of daylight. As a result, a building, home, or other entity that relies on solar power must have a back-up grid-tie for evening use or when the system is not producing sufficient power, or have a means of storing the generated energy (e.g., the most common form being storage batteries) for use when the system is not converting sun energy into electrical power.

2.5.1 Photovoltaic Systems

Solar photovoltaic (PV) devices, or solar cells, are made of semiconducting materials that change sunlight directly into electricity. Small PV cells can power calculators, watches, and other small electronic devices, while solar cells in PV panels and multiple PV panels arranged in PV arrays can produce electricity for an entire house [13].

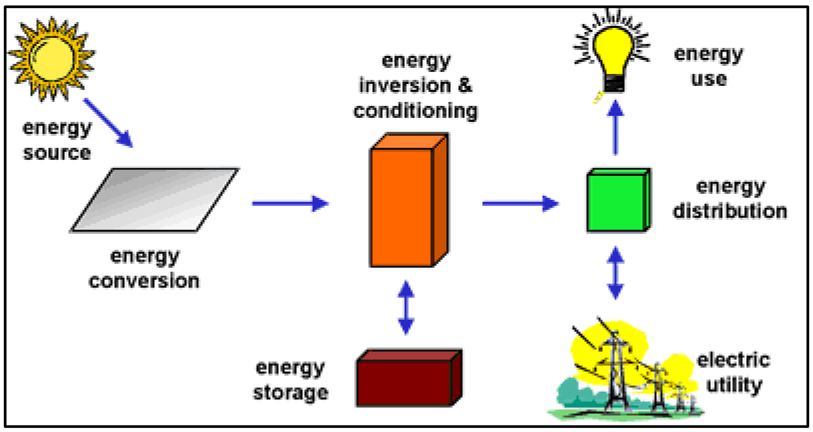

Figure 13: Major Photovoltaic System Components [15]

As shown in Figures 13 (system components) and 14 (wiring), basic solar photovoltaic systems are not particularly complex. Apart from the initial installation costs, PV panels are relatively inexpensive costing anywhere from \$0.36 per watt to \$0.75 per watt, where most large installations use 200-350W panels [16] - [17]. Along with solar panels, each PV system needs a charge controller for controlling the charging and discharging of the system battery(ies), an inverter to convert battery voltages into normal 115V AC household power, one or more batteries for energy storage, and various other components such as copper wire, MC4 connectors, a power meter, and either circuit breakers or fuses [18].

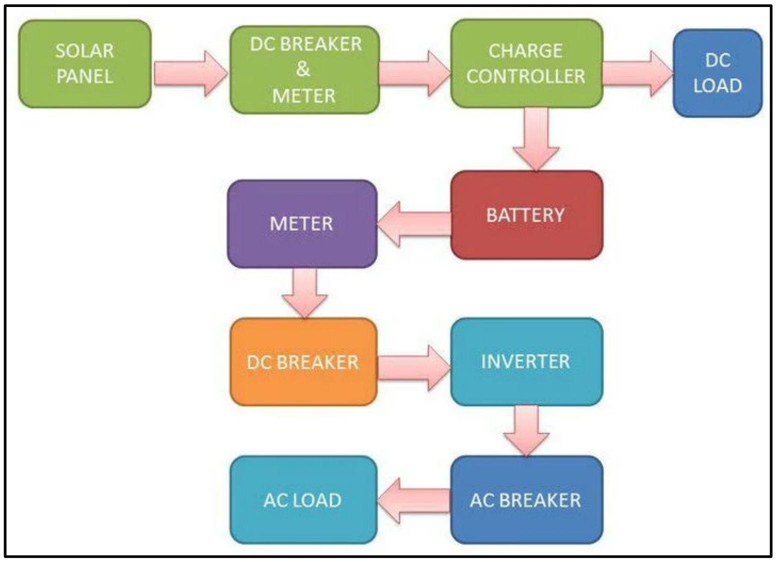

Figure 14: Wiring in a PV System [18]

Photovoltaic panels are often split into two categories, monocrystalline and polycrystalline [18]. Monocrystalline PV panels are those which are made of monocrystalline silicon and consist of cylindrically shaped wafers. These panels are of high efficiency and thus have the greatest power rating but are also more expensive than their counterpart. Polycrystalline panels, which are made from polycrystalline silicon, are more rectangular in shape due to the manufacturing process and less silicon is used in the making of these panels. As a result, they are less expensive, though slightly less efficient and require more space for a given amount of power to be produced compared to monocrystalline panels [19].

2.5.2 Solar Panel Placement

Placement of solar panels is of the utmost importance because the more sunlight that reaches the solar panels, the more electricity is generated. In general, solar panels in the United States should face true south to receive the most light. After finding the best unobstructed location facing true south to install the solar panels, the next consideration is the ideal tilt of the panels. A solar panel will harness the most power when the Sun's rays hit its surface perpendicularly [20]. The angle of tilt is calculated based on latitude, a simple rule to follow is setting the solar panel tilt angle equal to the geographical latitude of the location [20]. In general, the closer the location is to the equator, the more the solar panels need to face straight up, and vice-versa [21]. Ensuring that solar panels face the correct direction and have an appropriate tilt will help ensure that they produce maximum energy as they are exposed to the highest intensity of sunlight for the greatest period of time [20].

2.5.3 Solar Pathfinder

An accurate solar site analysis can be made using a device called a Solar Pathfinder. The Solar Pathfinder is non-electronic and requires no special skills to operate, the user simply traces the path of the sun on the sunpath diagram (Figure 15 (a) and (b)). The Solar Pathfinder uses a highly polished, transparent, convex plastic dome to give a panoramic view of the entire site (Figure 15 (c)) [22]. The sunpath diagram is seen through the transparent dome, as well as all trees, buildings, or other obstacles to the sun. By tracing the outline of these obstacles onto the paper, an estimate for the “solar potential” of the location may be determined. Because the Solar Pathfinder works on a reflective principle rather than showing shadows, it can be used anytime of the day, anytime of the year, in either cloudy or clear weather [22]. The sunpath diagrams are application and latitude specific, and the rays depict solar time. A magnetic declination tab is also included to adjust for magnetic declination. The Solar Pathfinder will be further discussed in §3.3.3 and §4.3.

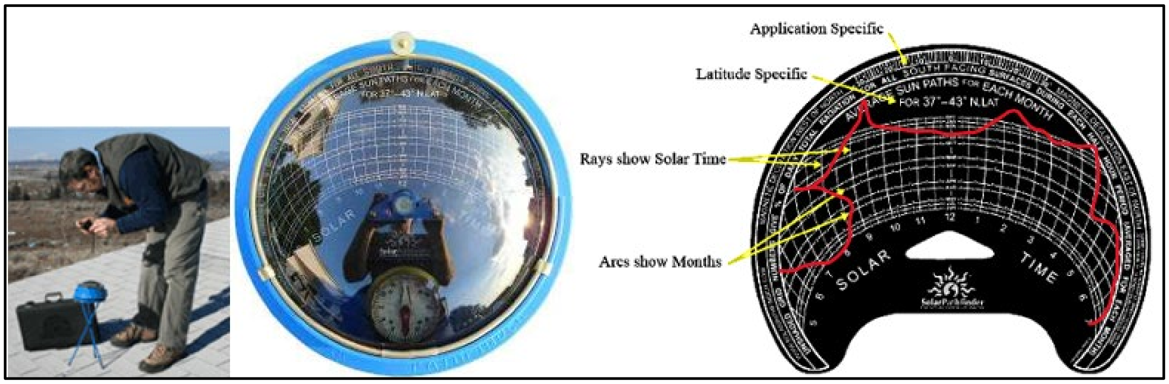

Figure 15: (a) Site, (b) Solar Pathfinder Dome, and (c) Sunpath Diagram [22]

2.6 Grid-Tied Solar Systems

Grid-tied, also commonly referred to as on-grid, are terms used to describe a common concept – a solar system connected to the electrical grid. Grid-tied systems are the most common type of solar PV system. Grid-tied systems use electricity from both the solar panel system and the electrical grid to provide power to the home or other building where the system is installed. For solar energy systems, the system’s DC electricity is generated by the photovoltaic (PV) panels.

When DC power is generated by the photovoltaic (PV) panels, it is converted to AC power by a grid-tied inverter which is a component of the grid-tied solar system. Grid-tied solar systems do not require a battery to store energy. Instead, the utility grid functions as a “virtual battery” [23]. The grid-tied system has several advantages over the off-grid system. Grid-tied solar systems are the simplest and most reliable to install. Grid-tied solar systems require little maintenance, do not need to produce 100% of the energy demand for a home or business, and allow access to backup power from the utility/electricity grid. Therefore, these systems are commonly known to be a more reliable way to obtain electrical energy, particularly when there is limited or no solar energy being generated (e.g., night times, cloudy days, etc.) Grid-tied systems are stable and allow efficient usage since it does not require a battery to store the energy that has the potential to degrade over time.

Owners of the grid-tied systems must complete a net metering agreement with their utility grid. According to the US Department of Energy, there are two types of agreements – net metering or net purchase and sale. The Net Metering Agreement provides a single, bi-directional meter. This meter is used to record both the electricity drawn from the grid and electricity fed back into the grid. Net metering is commonly known to provide the greatest benefits to the consumer. The meter spins forward when electricity is drawn and in the opposite direction when excess electricity is fed back to the grid. Therefore, if more electricity is used than what the grid-tied solar system provides, a payment is required for the extra electricity at a retail price [24]. However, net metering is a billing process that credits the owners of the grid-tied system when energy production exceeds energy consumption. This is a key concept and major advantage as it permits the ability to feed excess power back to the grid to receive credit which can be used to offset payments for future power usage [25]. By comparison, a net purchase and sale agreement include two uni-directional meters. One meter records the electricity drawn from the grid while the other records the excess electricity generated and fed back to the grid. A retail rate applied to the electric bill for electricity used while the electric company purchases the excess electricity at a wholesale rate which may be significantly a different rate.

As shown in Figure 16, the main components of the grid-tied system include the photovoltaic panels (PV), power meter, and grid-tie inverters (GTI) or Micro-Inverters [23]. The power meter, also referred to as a net meter or two-way meter, measures the power travelling from the grid to the house and vice versa. The Grid-tie inverter regulates the voltage and current received from the solar panels. The direct current (DC) from the solar panels is converted to alternating current (AC) to permit energy utilization by the appliances. These inverters synchronize the phase and frequency of the current to fit the utility grid, 60 Hz. The output voltage is also adjusted slightly higher that the utility grid voltage to allow for excess electricity to flow outwards to the grid [23]. An alternative option to a single GTI, per panel micro-inverters are generally more expensive than GTI, but tend to have higher energy conversion efficiency rates. The micro-inverters are placed on the back of each solar panel and are recommended for locations where shading is an issue.

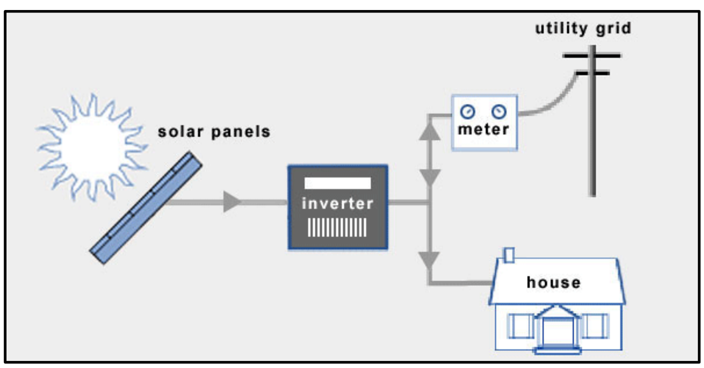

Figure 16: Grid-Tied Solar Energy System [23]

2.7 Off-Grid Solar Systems

Off-grid solar powered systems, in contrast to grid-tied, are solar systems which are not connected to the power grid. These systems rely on batteries for electrical energy storage and can range in peak power from less than 100W to more than 5kW [26]. The benefits of having an off-grid system include no power loss due to downed cables or grid disruption, being independent of utility companies, and long-term savings. Disadvantages include a higher initial cost (mostly batteries), limited energy storage capabilities, and the need to constantly manage power use versus solar power generation [27].

The first step in setting up an off-grid system is to determine the power/energy needs. This needs assessment includes the average energy used per day, the peak power demand, and the availability of solar energy. By taking the wattage of each electricity-using appliance and multiplying it by the average number of hours it is used per day, an estimate for energy need can be determined. It is also important to consider the power requirements of appliances that are used seasonally or perhaps not every day, such as heating systems, air conditioners, and washing/drying machines. Once this has been done, the solar mapping of the region must be done, typically with a Solar Pathfinder as explained in §2.5.3. Assuming an annual average of peak-equivalent hours between 3.5 - 6.5 hours and allowing for a 25-50% buffer range to account for cloudy days and other solar power limiting events, the sizing of the PV panels can be determined.

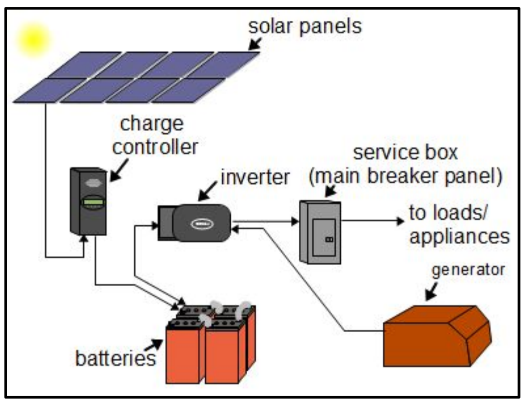

Figure 17: Off-Grid Solar Power System [28]

Once the needs of the system have been properly determined, the hardware must be selected. As shown above in Figure 17, an off-grid system includes PV panels, a charge controller, an inverter, and batteries. An optional generator can be added to compensate for cloudy days or if more power is needed [28].

Perhaps the most important component of the off-grid solar system is the energy storage system. This energy storage is what distinguishes off-grid from on-grid systems, as on-grid systems do not require physical batteries. For an off-grid system to function, batteries must be used to store electric energy that is not used during the day. Due to the constant use of these batteries, deep-cycle batteries “made to tolerate frequent depletion of as much as 80% of the battery capacity before recharging” [26] are recommended over something such as car batteries which are not meant to be depleted to that extent. Expensive lead-acid batteries may last for up to 15 years if properly maintained [26].

The charge controller is used to regulate voltage and current into the batteries. This is done to avoid overcharging the batteries. This allows for greater efficiencies and longer-lasting system components, and in particular, the life cycles of the system batteries. Common types of charge controllers include the maximum power point tracking (MPPT) and pulse width modulation (PWM). MPPT charge controllers form indirect connections between the PV panel and battery bank which "can take excess PV voltage and convert it into extra current at a lower voltage without losing power" [29]. These charge controllers have the highest efficiency, up to 30% additional charging efficiency, and can be used in 60-cell panels [30]. Drawbacks of the MPPT charge controller include being much more expensive (up to twice the cost of a PWM charge controller, which typically cost less than $350) and having a lower life expectancy than PWM charge controllers [30]. MPPT charge controllers also prevent reverse current by opening the circuit, but are physically larger than their PWM counterparts [30]. The PWM charge controller quickly switches on and off the connection between the PV panel and array in order to keep the batteries charged and protected from overcharging [29]. PWM charge controllers very durable, but cannot be efficiently used with 60-cell panels and require more careful sizing of the PV panels and batteries. This type of charge controller is well tested and has been commonly used in PV applications for years, but is only available in sizes up to 60 amps, versus the maximum 80 amps size of MPPT charge controllers [30].

Finally, the inverter takes the direct current (DC) power from the PV panels and energy storage batteries and converts it to alternating current (AC) to match what is used by common household appliances and lighting. Inverters are chosen based upon the peak power that must be supplied, and work through the principle of electromagnetic induction [31]. A given system may have a small average power usage but if it includes something which requires a large peak power an appropriately rated inverter will have to be used.

Off-grid systems may be installed in a number of ways. When mounting the PV panels, they should be oriented in such a way that allows for the maximum equivalent peak sunlight exposure. These panels may simply be mounted on a standalone pole, on the ground, or on the roof of a building. If mounted on a dwelling, the system must include a ground-fault protection device (GFPD), which is used to protect from shock [32]. The installation process must be done according to National Electric Code (NEC) standards, to include the coloring of the wires, wire size and capacity, grounding of the system, providing disconnects to the system components, and that all positive wires are supplemented with overcurrent protection [26]. Keeping the wiring clean and orderly is vital for safety reasons, and can lead to much easier changes and later implementations.

2.8 Tesla Powerwall

The first-generation Tesla Powerwall was launched in April 2015 to expand the company's vision and sustainability efforts, and by October 2016 an updated Powerwall 2.0 was developed and released. The Powerwall is a stationary rechargeable lithium ion battery with liquid thermal control [33]. Paired with a solar panel system (Figure 18), the Powerwall functions as an energy storage solution that enables sustained power both day and night (Figure 18) by storage of excess/surplus solar energy for use when the PV panels are not producing enough electricity.

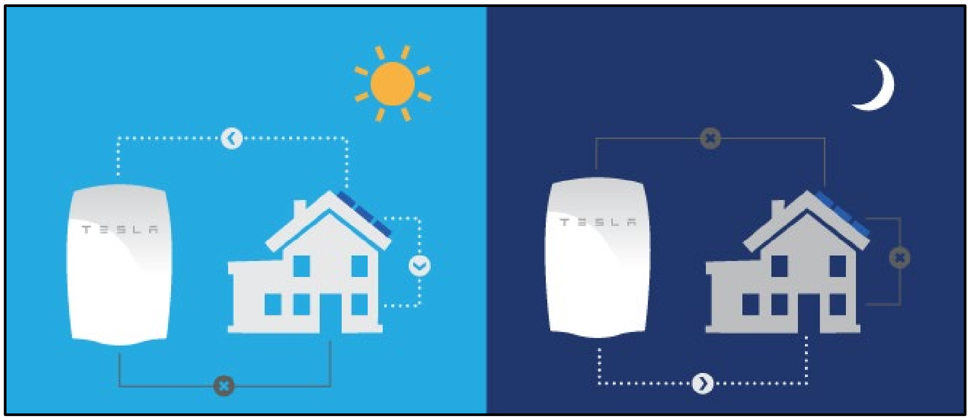

Figure 18: Tesla Powerwall Home System [33]

The Tesla Powerwall is a rechargeable battery system with multiple modes of operation, usually operating in the most basic self-powering mode [34]. The self-powering mode allows for storage of surplus energy produced by the solar system and the release, as needed, of the stored battery energy to power electrical loads and supplement the electrical needs of the consumer. Additionally, the solar storage system allows for complete independence from the utility. The corresponding Tesla cell-phone app allows the user to monitor power flow, manage the Powerwall modes of operation, manage solar panels, and control the overall operation of the PV/Powerwall system from anywhere.

The Powerwall itself is an integrated AC coupled energy solution and therefore, can convert AC to DC power and vice versa. The depth of discharge is programmed into the battery and thus, only allows energy use until the programmed value is reached.

2.8.1 Specifications

At a weight of 276 pounds, the Powerwall can be floor- or wall-mounted. In addition, up to ten Powerwalls can be stacked and mounted, and configured for parallel power in/out operation. The dimensions of the battery are: 45.3 inches x 29.7 inches x 6.1 inches. Powerwalls have a ten-year period warranty and do not require any ongoing maintenance.

Unlike the previous version of the Powerwall, the Tesla Powerwall 2.0 contains its own battery inverter and battery management system [35]. Therefore, the system is able to take AC electricity from either the standard grid connect solar inverter or the grid itself by converting excess energy to DC electricity for battery storage and later converting it back to AC electricity to meet the needs of the building [36]. The battery is split phase with the ability to provide AC voltage at 120V and 240V without the need of a transformer.

The battery is able to store up to 14 kWh of energy, however, only 13.5 kWh is usable due to depth of discharge limitation and where the depth of discharge (DoD) is an indicator of the percentage of energy that has been discharged relative to the overall capacity of the battery [37]. The DoD for a Tesla Powerwall 2.0 is ninety-six percent with a round-trip efficiency of ninety percent. The programmed DoD limitation of the Tesla Powerwall is crucial as it prevents the battery from fully discharging and, if such an event were to happen, the battery life would be drastically shortened. The rate at which the Powerwall will discharge power is limited to a constant output of 5 kW and a maximum peak of 7 kW for approximately ten seconds [35]. Therefore, if the system is operating in backup modes, appliances with a total draw of more than 5 kW are not recommended.

The Tesla Powerwalls are indoor and outdoor rated as they are water-proof and dust-proof. The recommended operating temperatures for the battery is between -4°F to 122°F, with optimum temperatures between 32°F to 86°F [35]. The battery can operate at 100% humidity, condensing. However, it is recommended that the batteries are stored in the conditions as follows: temperatures between -4°F to 86°F and up to 95% humidity, non-condensing [35].

2.8.2 Pricing

With a storage capacity nearly doubling the first-generation Powerwall, the cost of the Tesla Powerwall 2.0 is estimated at $6,700 per Powerwall [35]. A typical installation cost ranges from $1,000 to $3,000, not including solar installation, electrical upgrades, taxes, permit fees, or any retailer or connection charges that may apply [35]. Additionally, the cost of supporting hardware is approximately $1,100, bringing the total cost to install one Tesla Powerwall to approximately $9,000.

While the cost of a Tesla Powerwall may seem expensive, the equivalent cost for sealed lead acid (SLA) batteries with a 5-kWh capacity would be on the order of about $2,800 and specifically not include AC/DC interfaces, power monitoring, or remote access control[1]. Also, the SLAs would only have a service life time of about 5 years and require constant maintenance for best performance. Finally, the size/interconnects of the SLA system would be more complex and take up significantly more space.

2.8.3 Safety

Lithium-ion batteries have higher power-to-density ratios than the typical lead batteries, allowing them to store large amounts of energy and are primarily used in the market where high energy, power density, and superior cycling abilities are summoned. All lithium-ion technologies are based off the same principle: lithium is stored in the anode (negative electrode) and transported during the discharge of the cathode (positive electrode) via an organic electrolyte and vice versa when charging [38]. The lithium-ion batteries contain electrolytes which act as the catalysts for the reactions and are typically a mixture of organic carbonates such as ethylene carbonate or diethyl carbonate, which exemplify flammable characteristics between the temperatures of 64°F to 293°F [39]. With higher energy densities coupled with the flammable organic electrolyte contents, the lithium-ion battery fire hazards pose a serious challenge for handling, use, and storage.

There are two basic types of lithium ion battery failure. The first type of battery failure results from defects within the manufacturing of the battery. When the defect is discovered the batteries are typically recalled. The second type of battery failure is typically difficult to pinpoint and is usually the result of a stress event such as vibration, an electrical short, or could simply be an unusual event [40].

[1] Assuming a basic system SLA with a 30% discharge limitation would require about 14 batteries at $200 or more for each battery.

When a lithium-ion battery catches fire, it is the stored energy along with the materials in the battery that make it so difficult to suppress or extinguish.

Lithium-ion batteries contain liquid electrolytes that provide a conductive pathway, so the batteries receive a B fire classification, the classification given to flammable liquids. Because of a Class B fire classification, a standard ABC or BC dry chemical fire extinguisher should be used [40].

Tesla built its Powerpack with safety in mind and was willing to put its battery system to the test. With safety as the primary concern, Tesla partnered with the National Fire Protection Association (NFPA) to extensively test the Powerwall system. The company's goal was to observe and demonstrate the degree of durability and fire containment of the lithium-ion batteries when exposed to high temperature conditions. To test the potential destructive impacts of the Tesla Powerwall, the company constructed the Tesla Powerpack, consisting of 16 individual energy storage pods, the same ones that are used in the Powerwall. However, with one energy storage pod per Powerwall [41]. The Powerpack contains approximately 900 battery cells separated into two modules, for a total of approximately 14,400 battery cells or 100 kWh of energy capacity per Powerpack as displayed in Figure 19 below [41].

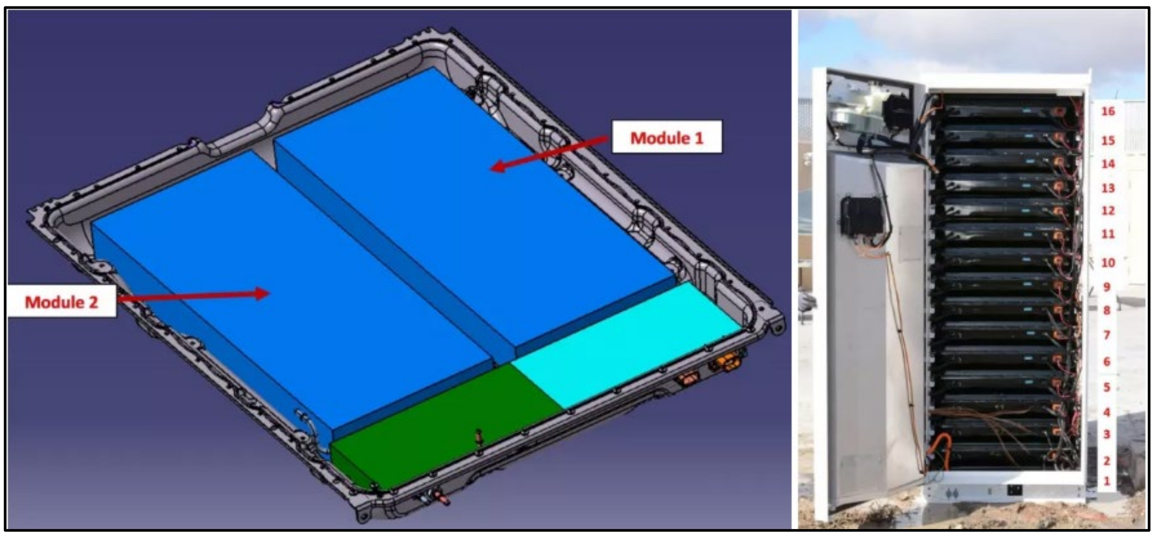

Figure 19: Tesla Powerpack with 16 Energy Storage Pods [41]

The NFPA conducted several tests to simulate possible phenomenon that can cause the batteries to catch fire or explode. The overall conclusion from both tests was as follows: if a fire starts from inside a pod, it does not propagate to the rest of the Powerpack, and if a fire starts outside the Powerpack, it will not spread to other Powerpacks around it [41]. The first simulation explores the possibility explosion when thermal runaway occurs in one or several cells within a single pod. To test this scenario, the NFPA installed a heater cartridge inside one of the modules of the pod which was then placed in the middle of the Tesla Powerpack with the intent to push the cooling system past its limit resulting in the system overheating. The experiment lasted for a total of one hour and thirty minutes with "popping" sounds of the cells but no explosion. The Powerpack did not catch on fire nor did it explode. In addition, fifteen out of the sixteen pods were functional as the fire created by the heater was contained in the single pod it was placed in and did not propagate to the other pods. The initial test concluded that, the "Powerpack cannot start a fire: even in the unlikely event that one or a few cells explode, it will be contained within the pod and will not unleash the entire 100 kWh of energy capacity of the Powerpack."[41]

To demonstrate the degree of durability and fire containment of the lithium-ion batteries, the NFPA conducted an additional experiment exploring the possibility of explosion due to a fire surrounding the Powerpack. A propane burner was installed to simulate a fire on the side of the Powerpack. Intense burning was observed for the first thirty-five minutes of the experiment followed by the popping sounds. The physical experiment was conducted for a total of one hour, but observations continued for an additional three hours as the cascade of chemical reactions continued, resulting in thermal runaway. At the end of the experiment, an explosion did not occur, and all pods were reported to be damaged with no stranded energy within the Powerpack [41]. The test concluded, "that a prolonged fire outside the Powerpack could definitely induce the Powerpack into thermal runaway, but they found that the consequences were confined to the pack and didn't." [41] The NFPA also noted that the exterior temperatures at the Powerpack cabinet would not pose a fire spread hazard if the Tesla's installation recommendations are followed.

2.9 Power Cables and Cable Failure

Determining the root cause of wire and cable failure can prevent future failures therefore, permitting better maintenance practice and allowing for more reliable operations. Wires and cables fail due three main causes: water ingress, joints/connections, and damage from anchors and other objects [42] - [45]. To effectively analyze the root cause and diagnose the problem, a systematic approach is required.

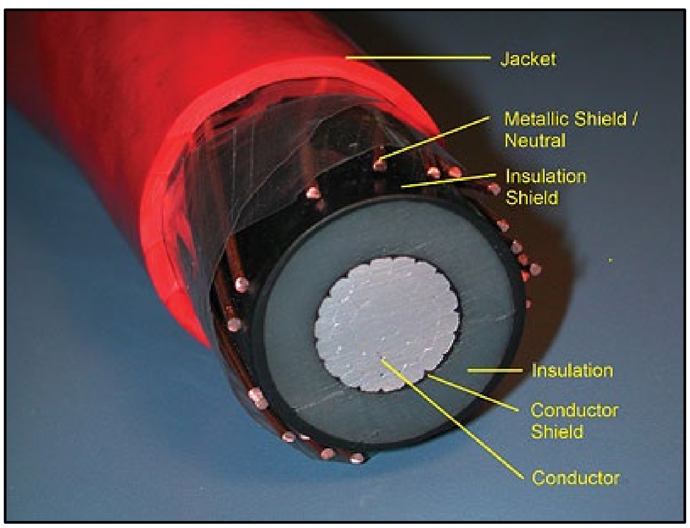

Figure 20: Primary Distribution Cable Displaying Cable Components [42]

Various components make up an energy supply cable system. To determine the root cause of failure, understanding the components of the system and their specific functions is crucial. The most common insulations are polymeric insulations: polyethylene or ethylene propylene rubber [42]. The basic components of a cable used in a 25kV system consists of a conductor, conductor shield, insulation, insulation shield, metallic shield, and an optional jacket/sheath. Figure 20 above illustrates these cable components. The conductor, conductor shield, and cable failure mechanisms relating to the conductor are further described below.

The size of the conductor is determined using ampacity tables or computer based studies, and depends on current carrying requirements and cable surroundings [42]. Wire ampacity rating is important when determining or selecting a cable for a specific application. These ratings are determined by the National Electrical Code (NEC). The rating is the maximum current allowed at ambient temperatures for the specific conductor to carry without compromising safety. It is crucial to abide by these values because as current travels through the cable heat is created and if the heat exceeds the cable's rating, the cable could potentially fail or catch on fire [46]. Therefore, to avoid the damaging occurrence, heat must be effectively dissipated. Should the temperatures differ from the reference's ambient temperature, a correction factor is required to adjust the ampacity. A correction factor is a multiplier applied to the ampacity rating to adjust the value based on a specific condition. The multiplier may be less than, equal to, or greater than one [46]. If heat is generated in the cables and application temperature rise above ambient, the ampacity value is reduced, and vice-versa to compensate to the heat added or lost within the conductors. It is important to understand the application and choose the corresponding and most appropriate conductor size for the specific application to reduce time, cost, and unnecessary repairs. For cables with medium and high voltages (above 5 kV), a conductor shield, the second component, is required to provide a radial electric field. The conductor shield is typically made from the same material as the insulation, but are semiconductors due to the presence of carbon impregnated into its composition.

Power cable systems can be installed in locations which include underwater, trays, troughs, can be directly buried, or suspended from poles or walls. When examining cable failure, knowing the method of installation can help to determine the cause of failure. The easiest way to determine how a cable failed is to physically inspect it. Cutting wafers off the cable, performing tests on the insulation, and making metallurgical examinations of the conductor are but a few ways to help determine the cause of failure [42]. Overheating of the cable will show discoloration and "cracked and distorted polymers" while manufacturing errors of a cable will cause voids in the insulation [42]. These voids can cause unwarranted discharge within the cable. If a cable exceeds its maximum allowable current, the surrounding material around the conductor may fail. When power is passed through a cable, it heats up. The constant heating and cooling of cables due to varying electrical current induces heat-related stresses which cause ware and creep on the material [46].

Any cable may fail due to loss of conduction. If this is the case, it likely means that the copper conductor was severed or broken. When a cable is twisted incorrectly, the load carrying capacity of the cable is compromised. Additionally, cables may fail due to the corkscrew effect caused by torsional forces. If the outer jacket of the cable is compromised due to abrasion, swelling, or cracking, the cable may also fail [43]. Jacket cracking results from large temperature gradients, and causes the wearing of the jacket to the insulation shield. Specifically, underwater cables may the failure possibilities marine life chewing on the cable and thus grounding it with the water. In shallow water, cables may also be disrupted by boat anchors [44]. All cables exposed to moisture may fail due to water ingress. Water that penetrates the insulation or further can “impair the electrical characteristics of capacitance, power factor, insulation resistance and dielectric strength” [45]. If a cable can be protected from the three main dangers of conduction interruption, water ingress, and exterior damage from anchors and other sources, the risk of failure is lowered considerably.

3. PROBLEM STATEMENT and METHODS

3.1 Introduction

The Treasure Valley Scout Reservation leadership intends to expand their scouting programs and improve and/or modernize the power infrastructure of West Camp. In particular, multiple small-scale solar power generation systems have been implemented to satisfy specific power needs of various campsites and buildings throughout the East Camp of the reservation. Treasure Valley has a desire to similarly expand the use of solar power for campsites and buildings, and thus increase sustainability, throughout West Camp.

Vital to the operations of West Camp, an underwater grid power cable was installed in 1983. This cable is near its estimated lifespan and camp staff are concerned that the cable might fail within the next five to ten years. Along with this cable, TVSR also has two older PCB (polychlorinated biphenyl)-filled transformers installed in 1973 that need to be replaced and any related carcinogenic content from the older transformers cleaned and disposed of properly.

The cost of replacing the cable is estimated to be around $92,000 and the cost of replacing the transformers and the associated clean-up is estimated to be around $52,000 each. As a non-profit organization, the cost of repairs is of great concern to TVSR. As a result, TVSR management is looking at other options for powering West Camp, other than replacing the cable and transformers.

3.2 Problem Statement and Specific Objectives

The purpose of this project was to perform a detailed assessment of the power needs of West Camp and, based on this assessment, provide recommendations for the best type of solar system to install, a cost and risk assessment for each possible installation, and the best locations for solar installments as expressed by the following objectives list.

1. Identify and understand the specific power needs of Treasure Valley Scout Reservation and its stakeholders. This will include assessing current power usages of buildings, future installations of power-requiring appliances, and the lifespan and load of the underwater cable.
2. Determine whether a grid-tied or off-grid system will best meet the needs of West Camp. This will be determined by comparing the types of solar options by analyzing their advantages and disadvantages in terms installation, cable reliance, and ease of use.
3. Determine optimum sites for solar panels for each West Camp option considered.
4. Develop a cost and risk assessment of potential solutions addressing the problem of the aging power cable.

3.3 Methods

To fulfill the objectives mentioned above, the means by which the recommendation to TVSR will be made are separated into three main categories:

- a needs assessment of power usage and requirements,

- the determination of what type of solar system is to be implemented (grid-tied or off-grid), and
- establishing which sites in West Camp are best suited for PV panel placement.

To effectively achieve these objectives, camp visits, research, interviews with TVSR administrators and other personnel (e.g., camp ranger, chair of the facilities board, etc.) as well as interviews with selected solar subject matter experts (SMEs), and other forms of information gathering are required and are detailed below.

3.3.1 Needs Assessment and Power Usage Analysis

In order to determine the optimal solar energy system for West Camp, a study of the current power usages of buildings and future installments of power-requiring appliances was completed. An inventory of every power-requiring appliance and piece of electrical energy hardware in each building was conducted. This assessment of electric consumption enabled the calculation of the approximate load on the underwater cable. From this load assessment and the specifications of the cable, we determined whether the cable was currently operating past its capacity, and therefore stressed.

3.3.2 Determination of Optimal Solar Energy System

Following the needs assessment and power usage analysis of Treasure Valley's West Camp, an assessment of both grid-tied and off-grid solar systems was performed. This assessment consisted of a comparison between both solar energy system types in terms of advantages and disadvantages of each. This comparison analyzed their installation requirements, upkeep and maintenance, and reliance on the underwater power cable. Following this comparison, the optimal solar energy system for TVSR West Camp was determined.

3.3.3 Ideal West Camp PV Panel Placement

To begin the assessment of optimal PV placement sites in West Camp, qualitative visual assessments of the areas surrounding the three lodges was made. After this initial visual assessment, the Solar Pathfinder was used to generate sunpath diagrams for the best locations chosen by this "eyeballed" estimation. These sunpath diagrams mapped all obstacles to the sun and were compared to each other to determine optimal placement sites. If a campsite appeared to have too many obstacles between the PV panel and the sun, the option of cutting select trees to improve PV exposure was provided.

4. RESULTS

The purpose of this section was to provide an organized and concise summary of all data gathered for this study. The presentation of the results follows the four objectives as noted in §3.2 above and was organized accordingly:

Objective	Summary
1.	Identify and understand the specific power needs and constraints of TVSR and its stakeholders.
2.	Determine whether a grid-tied or off-grid system will best meet the needs of West Camp.
3.	Determine optimum sites for solar panels for each West Camp option considered.
4.	Develop a cost and risk assessment of potential solutions addressing the problem of the aging power cable.

4.1 Needs Assessment and Power Usage Analysis Results

To provide TVSR with accurate recommendations, it was crucial to first identify and understand the specific needs and constraints of TVSR and its stakeholders (Appendix A). This included an assessment of power usages of the buildings in West Camp, possible future installations of power-requiring appliances, and the current load of the underwater power cable.

Over the course of two to three weeks, data collection was performed on the three main lodges in TVSR West Camp – Columbus Lodge, West Lodge, and Venture Lodge. For each lodge, a floor plan of the building (Appendix B) and an inventory of power-requiring appliances (including lights) were developed (Appendix C), and power ratings and estimated frequency of use for each appliance were also determined.

Below are tables summarizing the inventory (Table 1) and power and energy usage of each lodge (Table 2). Power and energy values were divided into two time periods – CSAC (Cub Scout Adventure Camp, five summer weeks) and weekends (all weekends during the year, minus those included in CSAC).

Table 1: West Camp Inventory Summary

	Lights	Appliances	Other	Total
Venture Lodge	76	8	18	102
West Lodge	115	13	28	156
Columbus Lodge	28	4	9	41

Total West Camp power usage was calculated based on assumptions made for the potential power used during the CSAC, weekend rentals, and year-round utilities. To account for all possible power needs of TVSR West Camp, the total power usage for each building were categorized and summarized in three main components, as shown below in Table 2 – Average Power (W), 2-Day Energy (kWh), and the Total

Energy (kWh). To determine accurate energy usage estimates, the total annual energy usage for all appliances was determined through the consideration of the following criteria – number of each appliance, the wattage of each appliance, estimation of the run-time of each appliance per day, and the total number of days used.

Table 2: West Camp Load Assessment Summary

		CSAC	Weekends
Columbus Lodge	**Average Power (W)[2]**	1023.0	8.0
	1-Day Energy (kWh)[3]	24.6	0.2
	2-Day Energy (kWh)	49.1	0.4
	Total Energy (kWh)	745.6	18.0
Venture Lodge	**Average Power (W)**	3328.6	1912.4
	1-Day Energy (kWh)	79.9	45.9
	2-Day Energy (kWh)	159.8	91.8
	Total Energy (kWh)	2796.0	4186.8
West Lodge	**Average Power (W)**	2916.2	1864.5
	1-Day Energy (kWh)	70.0	44.7
	2-Day Energy (kWh)	140.0	89.5
	Total Energy (kWh)	2449.6	3951.4

To provide a more precise power estimation for each building, the total energy (kWh) of each appliance was independently determined for the 5-week CSAC and the weekends. Based on assumptions and data retrieved via internet research or specifications provided on the appliances, using (1), calculations were performed for all appliances in all three buildings during the three different time periods. A summed value of yearly use (kWh) was then determined using (2). However, it is important to

[2] 'Average Power' is defined here as the total energy (kWh) over the given time period divided by the length of time for that time period.
[3] Periods for energy values are defined as the energy used over either a one-day span (1-Day), two-day span (2-Day), or the full period (CSAC or weekends).

note that the calculations performed for the appliances were not all as abstract. For the appliances with unknown specifications, the Kill-A-Watt meter functioned as the primary tool for determining the unknown values. For such appliances, values of energy (kWh), current (amps), maximum and minimum power (W), and length of time were measured. Using (3), yearly energy usages for such appliances were determined.

$$\frac{(\#\ of\ Appliances) * (Power\ [W]) * (\#\ of\ days) * (Estimated\ Run\ Time\ per\ day)}{1000} \tag{1}$$

$$\sum[\ (Total\ CSAC\ Energy) + (Total\ WKND\ Energy) + (Total\ YR\ Energy)\ ] \tag{2}$$

$$\frac{(Estimated\ Run\ Time\ per\ day)}{(Measured\ Run\ Time)} * (Measured\ kWh) * (days\ run) \tag{3}$$

As part of the data collection, the surge power of various appliances was determined. The surge power is the peak electrical power drawn by motor-based appliances upon start-up and is typically in the range of 3-5x the steady-state operating power value (a factor of 3x was used). Table 3 below details the corresponding surge power for each listed appliance within Venture, West, and Columbus Lodges. Based on the total power usage of West Camp, in Table 2 and the surge power of inductive appliances in Table 3, the percentage of total energy, maximum non-surge power, and maximum surge power of each West Camp building were determined and listed in Table 4 below.

Table 3: Power and Energy of Motor Appliances by Building

	Appliance	Steady State Power (W)	Surge Power (W)[4]	Wh/day[5]	Wh/day (Energy Star)[6]
Columbus Lodge	Ridge Fan	250.0	750.0	6000.0	
	Polar Fridge	167.3	1440.0	2254.0	1200.0
	Ice Cream Freezer	110.2	500.0	818.0	650.0
Venture Lodge	Refrigerator	189.5	2130.0	614.0	1411.0
	Well Pump	Unknown	2250.0	Unknown	
	Blower System	375.0	1125.0	3750.0	
	Air Conditioner	361.0	1560.0	6883.0	2075.0

[4] For motor appliances, the surge power is defined as 3x the maximum normal running power
[5] Watts * hours per day; the amount of energy the appliance uses per day (=kWh/day * 1000)
[6] The energy used by a more efficient Energy Star appliance per day [47].

West Lodge	Polar Refrigerator[7]	163.5	1620.0	2007.0	1200.0
	Hot Point Refrigerator	500.0 (compressor)	1500.0	4861.0	1200.0
	Freezer	120.2	1350.0	2776.0	1240.0
	Blower System	375.0	1125.0	3750.0	
	Air Conditioner	361.0	1560.0	3441.5 (12 hrs)	2075.0

In Table 3 above, steady state power is defined as the average running power over time. For the fridges and freezers, a 3:1 fan vs compressor runtime was used (4). For air conditioners, 16 hours of compressor operation per day was used. This implies that the surge power listed is not merely three times the value of the steady state power. An example calculation for the Polar refrigerator is shown below (5).

$$\frac{(18\,hr*idle\ pwr)+(6\,hr*comp.pwr)}{24\,hr} = Steady\ State\ PWR \tag{4}$$

$$\frac{(18\,hr*63W)+(6\,hr*480W)}{24\,hr} = 167.3W$$

(5)

Table 4: West Camp Energy Use and Maximum Power (Surge and Non-Surge) by Building

	Yearly Energy Use (kWh)	**% Total Energy Use**	**Max Power Non-Surge (W)**	**Max Power Surge (W)**
Columbus Lodge	1166.0	6.3	3889.6	4389.6
Venture Lodge	7686.9	41.7	20174.7	28004.4
West Lodge	9593.7	52.0	15979.0	21499.0

[7] Note that this Polar refrigerator model is rated differently than the one in Columbus Lodge.

4.2 Determination of Optimal Solar Energy System

Based on the comparison below, off-grid was determined as the optimal solar energy system due to its lack of reliance on the underwater power cable and transformers, as well as the option for self-installation and used equipment and hardware.

Grid-Tied

- Reliance on underwater power cable and transformers
- Professional installation and labor
- No batteries, but relies on underwater cable
- Any power not used on a yearly basis credited at wholesale rate
- Power not used instantaneously is credited at standard TVSR (retail) elec. rate
- Likely not eligible for tax advantages since TVSR is a nonprofit organization

Off-Grid

- Can reduce the load on the cable over time to eventually achieve no cable reliance
- Power is maintained if the grid loses power
- Self-installation
- Batteries need maintenance and replacement (if SLA)
  - No maintenance if using Tesla Powerwall system
- Purchase of used one generation older PV panels
- Independent of grid rate changes

4.3 West Camp PV Panel Placement Analysis Results

Six potential locations for solar panels were analyzed with the Solar Pathfinder (Figure 21). Appendix D details the data for each month in each location. Table 5 summarizes the average percent solar radiation over the span of twelve months for each location. Based on the data presented in Table 5, of the six potential locations, it was determined that the West Camp Parking Lot was the most optimal location for solar panels of the six potential locations as it has an average of 71% solar radiation.

Table 5: Solar Pathfinder Data Summary

	Average % Solar Radiation
West Lodge (Front, birch trees removed[8])	41
West Camp Parking Lot	**71**
Columbus Clearing	53
Venture Lodge (Front)	58
Venture Lodge (Back)	35
Venture Lodge Roof (Average)[9]	**65**

[8] There are currently two small decorative birch trees at the entrance to West Lodge. Due to their direct proximity to the potential solar panel location, we recommend the removal or relocation of these trees. Our Solar Pathfinder results account for their removal.

[9] This average is comprised of three readings done on the top left, bottom middle, and top right of the roof of Venture lodge. This assumes that a cluster of several trees are taken out, which would increase the average solar exposure significantly.

Figure 21: West Camp Potential PV Panel Locations (Yellow) [48]

4.4 Underwater Cable

Throughout this project, the underwater power cable to West Camp was an important factor. The cable, which spans from Pine Point (East Camp) to the shores of West Camp, was determined to be 1 AWG 4C Type P Power Cable (Figure 22) [49]. This cable is rated for regular use at 600V with a peak voltage of 1000V. At 600V, the cable operates at 153A. At these values, the steady state power rating of 91.8kW. By multiplying this by a power factor of 0.8 (to account for inductive loads), the maximum operating power was found to be 73.4kW. Luckily, this value is 33.3kW higher than the peak non-surge load and 10.9kW higher than the peak surge load. Based on these calculations, it was determined that the cable is currently operating at 68% of capacity, and therefore is not currently stressed.

Figure 22: Pine Point Meter Power Cable

Although we believe this to be the underwater power cable, it must be noted that this is not necessarily the power cable which runs under Browning Pond. The data provided is for a cable which feeds into the meter at Pine Point, where the cable enters the ground. It may be that this is only a feeder cable to the meter, and not necessarily the same cable which is buried underwater.

4.5 Results Summary

Based upon Tables 2 and 4, the following table was created. Table 6 includes rounded estimates (with an additional 15% safety factor) of worst-case surge power and energy used per day for each building. This serves to provide current peak values for power and daily energy use.

Table 6: Maximum Daily Energy Use and Peak Power

	Adjusted Maximum Daily Energy Use (kWh)[10]	**Adjusted Maximum Power Surge (W)**
Columbus Lodge	28.3	5048.0
Venture Lodge	91.9	32205.0
West Lodge	80.5	25298.9

[10] 'Adjusted' refers to the 15% factor of safety.

It is important to note that these peak values would only occur during the Cub Scout Adventure Camp. Peak values such as these are not likely to be reached, as it would require all electric appliances and lighting to be used simultaneously throughout the camp.

5. ANALYSIS, DISCUSSION, and RECOMMENDATIONS

5.1 Analysis

The purpose of this section is to present the overall cost of the required hardware components to convert TVSR West Camp to an off-grid solar system. A cost estimation for a completely independent off-grid system and an off-grid system with the Tesla Wall battery are provided. Analysis of the power usage of West Camp is crucial to provide an accurate cost estimate for TVSR. To do so, independent calculations for each building were performed (§5.1.3). The three buildings – Columbus, Venture, and West – were analyzed individually and estimation for the cost of hardware are provided separately for each building (§5.1.2). Outlined in this section are the assumptions made for each building. Based on the assumptions, the overall average power (W), 1-day energy (kWh), 2-day energy (kWh), and total energy (kWh) were re-calculated (§5.1.3). The updated power usage values illustrate the significant reduction of the power usage via appliance upgrade or removal.

5.1.1 Current West Camp Hardware Requirements

Given the power and energy requirements of West Camp listed in §4.1, the hardware requirements for converting each building to an off-grid solar power system were determined. As shown by Appendix E, the total estimated cost to fully convert West Camp to an off-grid solar system would be $247,608. This estimate is based upon buying used 250W polycrystalline PV panels for $100 each and 12V 100Ah sealed lead acid batteries for $200 each. Inverters were sized and priced based upon the peak load required. Charge controllers were sized by dividing the maximum surge power by the voltage of the batteries for each building. Columbus lodge was assumed to be 12V while both Venture and West Lodges were assumed to be 48V. By adding the 8A current from the PV panels and rounding up accordingly, Columbus Lodge was sized with a 30A charge controller. Similarly, Venture Lodge was sized with two 100A charge controllers, and West Lodge was sized with four 60A charge controllers. To simplify calculations, the number of 250W PV panels and 12V 100Ah batteries required per kWh/day of energy use were calculated. Using these values, the number of individual PV panels and batteries per building were calculated. It is important to note that the kWh/day energy usage was rounded up to include a 15% factor of safety for each building. Additionally, a price estimate of $225,768 was determined assuming that Tesla Powerwalls would be utilized for energy storage in all three buildings. It should be noted that a Tesla Powerwall solution for the current load in West Camp requires more than the Tesla standard limit of ten Powerwalls for both Venture and Columbus Lodges.

The analysis of the current West Camp load assessment necessitates that certain assumptions be made in order for the system to be feasible. Without the assumptions listed in §5.1.2, the cost of an off-grid system for West Camp ($247,608) would likely make off-grid unrealistic, especially compared to the cost and lifetime of a new underwater power cable and transformer replacement project ($196,000).

5.1.2 System Feasibility Assumptions

Columbus Lodge

Located near the waterfront of the Browning Pond, Columbus Lodge serves as the trading post and storage area for the TVSR's West Camp. Consisting mainly of 120V outlets, lights, a ridge fan, and a few appliances which include a freezer, fridge, and two slushy machines, Columbus Lodge uses the least amount of power. Therefore, an off-grid solar system is most applicable to Columbus Lodge. Below is a list of assumptions made to further reduce energy consumption of the Columbus Lodge (by a factor of twenty-eight) that would significantly reduce the complexity of making the building completely off-grid. Option A is provided for if Columbus lodge is taken off-grid with SLA batteries. Option B is provided for if Columbus Lodge is taken off-grid with the Tesla Powerwall.

Assumptions

1. Removal of ridge fan
2. (A) Removal of slushy machines
3. (A) Removal of fridge and freezer
4. Replacement of all indoor lights with low voltage (12V) LED lights
5. Replacement of all outdoor lights with 10W LED lights
6. (A) The entire building is run on 12V
7. (A) Removal of outlets
8. (B) One slushy machine is run for two hours per day
9. (B) The freezer replaced with an Energy Star appliance
10. (B) The building is kept at 120V and the outlets are used
11. Conversion of emergency detection devices from power supply to 10-year batteries
12. Outdoor lights run only at night (12-hour runtime)
13. Lighting may or may not be turned off by staff (average 12-hour runtime)
14. Building power is only used for lighting

Venture Lodge

Venture Lodge is the center of operations of TVSR's West Camp as it has various amenities which includes multiple appliances, a kitchen, multiple bathrooms, and showers. In addition, Venture Lodge serves as an infirmary, therefore requiring multiple AC units. Highlighted in the results section of the report, the well-pump is located in Venture Lodge and must be accounted for in the analysis. Below is a list of assumptions made for Venture Lodge to reduce the energy use (in kWh) of Venture Lodge by a factor of three.

Assumptions

1. One room is used as an infirmary and, therefore, only one AC unit is required
2. Conversion of emergency detection devices from power supply to 10-year batteries
3. Lighting may or may not be turned off by staff (average 12-hour runtime)
4. Replacement of electric stove with gas stove
5. Replacement of the Whirlpool fridge with an Energy Star appliance

6. Replacement of microwave with a half-power microwave
7. No projectors are used
8. Replacement of all lighting with 18W LED 3' lamps
9. The well pump is relocated to East Camp and water is pumped to West Camp via underwater high capacity water pipes

West Lodge

West Lodge functions as the main conference center in West Camp. The lodge has a full kitchen available for the camp staff. In addition to the full-sized kitchen, the lodge also has various appliances, one of which is the food warmer that runs for 8-12 hours per day at approximately 1500W. Based on the data collected and the consolidated results, West Lodge has various appliances that run on high wattages or all year-round. Outlined below is a list of assumptions made to reduce the power usage of West Lodge by a factor of two.

Assumptions

1. One small coffee pot
2. The food warmer runs on average 8-12 hours per day during the Cub Scout Adventure Camp
3. Lighting may or may not be turned off by staff (average 12-hour runtime)
4. Removal of Polar fridge
5. Replacement of Hot Point fridge with an Energy Star appliance
6. Replacement of Kenmore freezer with a mini-freezer
7. Removal of dishwasher (or left unfixed)
8. Replacement of all lighting with 12V LED lights
9. No AC units are used
10. No projectors are used
11. One half-power microwave is used

5.1.3 West Camp Updated Load Assessments

Based on the assumptions listed above the updated power usage calculations for the duration of the CSAC and weekends are displayed below. For each time period, the average power (W), 1-day energy (kWh), 2-day energy (kWh), and total energy (kWh) were determined using the same method and formulas from the previous calculations (§4.1).

Table 7: Updated West Camp Inventory Summary

	Lights	**Appliances**	**Other**	**Total**
Venture Lodge	76	3	5	84
West Lodge	94	8	9	111
Columbus Lodge	23	0 (A) 2 (B)	0	23 (A) 25 (B)

Table 8: Proposed West Camp Load Assessment Summary[11]

		CSAC	Weekends
Columbus Lodge	**Average Power (W)[12]**	78.5	0
	1-Day Energy (kWh)[13]	1.9 (A) 4.3 (B)	0
	2-Day Energy (kWh)	3.8 (A) 8.6 (B)	0.4
	Total Energy (kWh)	66.0	0
Venture Lodge	**Average Power (W)**	809.6	675.8
	1-Day Energy (kWh)	19.4	16.2
	2-Day Energy (kWh)	38.9	32.5
	Total Energy (kWh)	680.0	1397.0
West Lodge	**Average Power (W)**	1676.4	1009.2
	1-Day Energy (kWh)	40.2	24.2
	2-Day Energy (kWh)	80.5	48.5
	Total Energy (kWh)	1408.2	2021.7

Table 9: Proposed West Camp Appliance Power and Energy by Building

	Appliance	**Steady State Power (W)**	**Surge Power (W)**	**Wh/day**	**Wh/day (Energy Star)**
Columbus Lodge (B)	Slushy Machine	1100.0	3300.0	2200.0 (2 hrs)	
	Mini Freezer	Unknown[14]			216.0

[11] This table may be compared to Table 2 for decreases in power and energy values resulting from assumptions in this analysis.
[12] 'Average Power' is defined here as the total energy (kWh) over the given time period divided by the length of time for that time period.
[13] Periods for energy values are defined as the energy used over either a one-day span (1-Day), two-day span (2-Day), or the full period (CSAC or weekends).
[14] This mini freezer is a newly proposed appliance which uses significantly less energy than its current counterpart.

Venture Lodge	Refrigerator	189.5	2130.0	4548.0	1411.0
	Blower System	375.0	1125.0	3750.0	
	Air Conditioner	361.0	1560.0	6883.0	2075.0
West Lodge	Hot Point Refrigerator	155.0	1500.0	4861.0	1200.0
	Mini Freezer	Unknown[15]			216.0
	Blower System	375.0	1125.0	3750.0	

Table 10: Proposed West Camp Energy Use and Maximum Power (Surge and Non-Surge) by Building

	Yearly Energy (kWh)	**% Total Energy Use**	**Max Power Non-Surge (W)**	**Max Power Surge (W)**
Columbus Lodge	66.0 (A) 150.0 (B)	0.9 (A) 2.0 (B)	157.0 (A) 1347.0 (B)	157.0 (A) 3727.0 (B)
Venture Lodge	2713.3	36.6 (A) 36.2 (B)	3904.7	8614.7
West Lodge	4634.4	62.5 (A) 61.8 (B)	6966.0	10366.0

Just as in §4.5, Table 11 was created to outline maximum daily energy use and peak power surge and is shown below. This may be compared to Table 6.

Table 11: Proposed Maximum Daily Energy and Surge Power

	Adjusted Maximum Daily Energy Use (kWh)	**Adjusted Maximum Power Surge (W)**
Columbus Lodge	2.2 (A) 4.4 (B)	180.6 (A) 4286.1 (B)
Venture Lodge	22.3	9906.9
West Lodge	46.2	11920.9

Again, it is important to note that these peak values would only occur during CSAC and would likely never be reached.

[15] See footnote 14.

5.1.4 Off-Grid Solar Analysis

Given the assumptions made for each building and the resultant load assessment, updated calculations for hardware and price estimates of an off-grid system were conducted. Tables 12-14, similar to those for §5.1.1 found in Appendix E, outline the required hardware for a system under those assumptions. If traditional sealed lead acid batteries were used, the estimated cost of the system would be $88,113. By using the Tesla Powerwall for battery storage, the price of the system would be $86,946 (Option B, all Tesla Powerwall) before accounting for additional hardware and installation costs. It is important to consider is the fact that the Tesla Powerwall comes with a ten-year warranty, while traditional sealed lead acid batteries would require replacement every three to five years as well as continued maintenance.

Similar to the estimates for an unaltered load assessment of West Camp, another cost analysis (below) was conducted with consideration of over-estimated energy use.

Table 12:Off-Grid Hardware Requirements

	kWh / Day (Upper Estimate)[16]	**PV Panel/(kWh/day) (250W)**[17]	**Battery/(kWh/day) (12V 100Ah)**[18]	**No. Panels (250W)**	**No. of 100 Ah Batteries (2-Day)**	**Charge Controller (A)**[19]	**Minimum Inverter Required (W)**
Columbus Lodge	2.2	0.7	5.6	2	13	30	200
Venture Lodge	22.3			16	125	200	9,000
West Lodge	46.2			33	259	240	11,000

Table 13:Off-Grid Hardware Costs (with Batteries)

	Cost per PV Panel (250W)	**Cost per Battery (12V,100Ah)**	**Total PV Panel Cost**	**Total Battery Cost**	**Inverter Cost**[20]	**MPPT Charge Controller Cost**	**All Hardware**
Columbus Lodge	$100	$200	$200	$2,600	$90	$80	$2,970
Venture Lodge			$1,600	$25,000	$678	$788	$28,066
West Lodge			$3,300	$51,800	$1,017	$960	$57,077
West Camp Total			$5,100	$86,400	$1,785	$1,828	$88,113

[16] These three values are including a 15% factor of safety.
[17] The number of 250W PV panels needed for 1 kWh/day of energy use. Sample calculations in Appendix F.
[18] The number of 12V 100Ah sealed lead acid batteries needed for 1 kWh/day of energy use. This assumes a 2-day battery storage with 30% battery depletion. Sample calculations in Appendix F.
[19] Refer to Appendix F for a sample calculation on charge controller sizing.
[20] Refer to Appendix G for pricing on inverters and charge controllers. Columbus Lodge was assumed to use a 500W inverter, Venture Lodge two stacked 5kW inverters, and West Lodge three stacked 5kW inverters.

Table 14:Off-Grid Hardware Costs (with Tesla Powerwall)[21]

	Total PV Panel Cost[22]	Inverter Cost	No. of Tesla Wall[23]	Cost per Tesla Wall	Total Battery/Tesla Wall Cost	All Hardware
Columbus Lodge	$400	$229	1	$6,700	$6,700	$7,329
Venture Lodge	$1,600	$339	4		$26,800	$28,739
West Lodge	$3,300	$678	7		$46,900	$50,878
West Camp Total	$5,300	$1,246			$80,400	$86,946

5.2 Discussion

Expanded upon below are eight points of interest which, following §4.1-§5.1, require further explanation and discussion.

1. **TVSR's Plans to Expand the Use of Columbus Lodge**

    The Staff of TVSR are looking to repurpose and possibly expand the functionality of the Columbus Lodge. Currently, the building functions as a storage room for West Camp during the fall, winter, and spring months and as the trading post during the summer months. Specifics have not been clearly defined on what the expansion would entail. Nevertheless, it is likely that the power usage of the building will increase and therefore, must be accounted for if TVSR wishes to implement an off-grid solar system for this building.

2. **Additional Air Conditioners**

    The possible installation of more AC units is concerning as they use roughly 3.8 kWh of energy per day each (est. 12 hours of runtime). The AC units are primarily used during CSAC and are estimated to run for 12-24 hours per day during this time period. Increasing the number of air conditioners in West Camp would significantly increase system requirements and quickly drive up the cost of an off-grid solar system, perhaps even making the consideration of off-grid solar untenable.

3. **The Benefits of Appliance Upgrades**

    Electrical appliances such as refrigerators, air conditioners, water heaters, lights, dishwashers, etc. are reported to account for over 30% of the energy bill charges [50]. However, modern energy efficient appliances are designed to utilize and minimize the amount of energy

[21] Option 1: Columbus Lodge would require 2 PV panels, a 500W inverter, 13 SLA batteries, and a 30A charge controller at a total hardware price of $2,970.
[22] Two additional panels are required for the conversion of Columbus Lodge to off-grid solar using the Tesla Powerwall.
[23] Assumes 13.5 kWh of usable capacity per Powerwall.

required to operate. Usage of energy efficient appliances also contributes to the environment and sustainability as it significantly minimizes the use of natural resources such as natural gas, oil, and coal and reduces pollution.

4. West Camp Well Pump

The West Camp well pump was not considered in any calculations for hardware or energy storage due to the fact that not enough about the pump is known. Before being rendered useless after a tornado in 1979, there was a water line running from East to West Camp. If a new line could be installed, water could be pumped to West Camp by using energy from the grid in East Camp. In an grid-tied system, this would reduce the load of the cable (and thus help prolong its lifespan). In an off-grid system, this would decrease the amount of battery storage needed as well as reduce the power demand on all associated electrical hardware as well as the number of PV panels required for the system.

Though distinct data on the well pump was not collected, inferences based upon research were made. It is known that the well pump is a 1HP motor and is submerged [3]. From this, it may be assumed that the pump runs off of 220V and is single phase. [51]

Assuming a 1HP (746W) 220V, single phase pump that (worst case) runs 30% of the time during CSAC, the following is implied:

Peak Power (non-surge)	746W
Peak Power (surge)	2.2kW
1-Day Energy	5.4kWh (10.8kWh for a 2-day reserve)

Clearly, except for a few high energy usage items (the food warmer, for example) the well pump is one of the highest energy using items in West Camp. Because specific data on the pump was not gathered, the well pump was left out of all analysis calculations.

5. Transformers and Disposal

The transformers, at an estimated cost of $52,000 each to replace, are of great concern. If an off-grid system is set in place, the transformers would merely have to be disposed of rather than replaced. However, if TVSR is to stay connected to the power grid, $104,000 would be needed to bring West Camp transformers up to code.

6. Sealed Lead Acid Batteries vs Tesla Powerwall

Both immediately and over time, the Tesla Powerwall is a less expensive energy storage option. With a ten-year warranty, the Powerwalls would not have to be replaced nearly as often as the sealed lead acid batteries (SLA), which need replacing every 3-5 years [52]. Additionally, the Powerwalls would not require the maintenance that the SLA batteries do. Figure 23 below outlines the dropping cost of all battery types over time, particularly that of lithium-ion batteries and Figure 24 outlines the cost over time for a 25-year span.

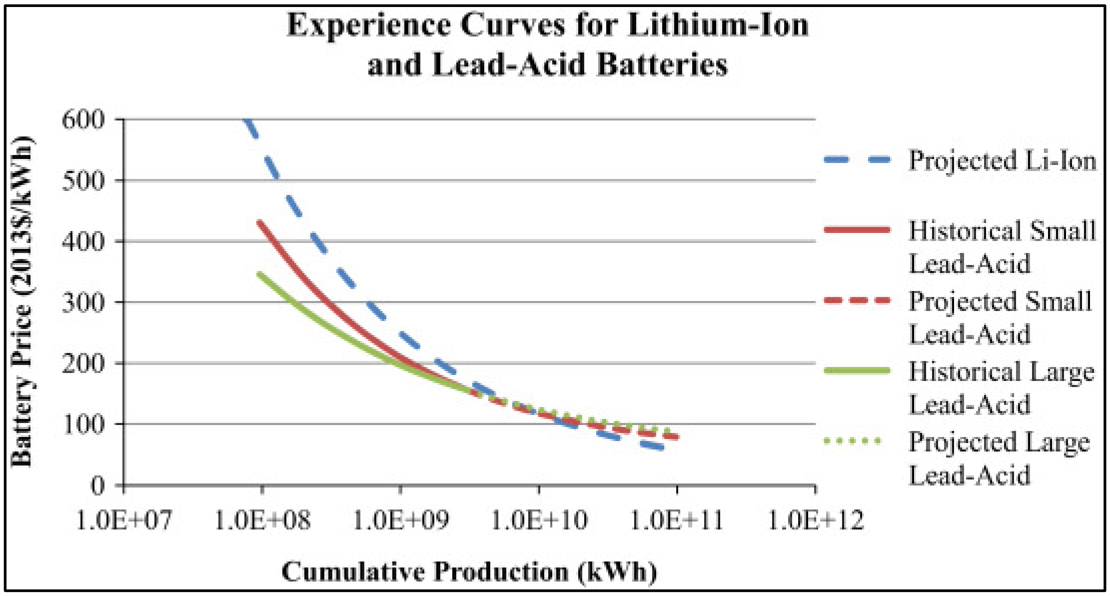

Figure 23: Battery Prices Over Time [53]

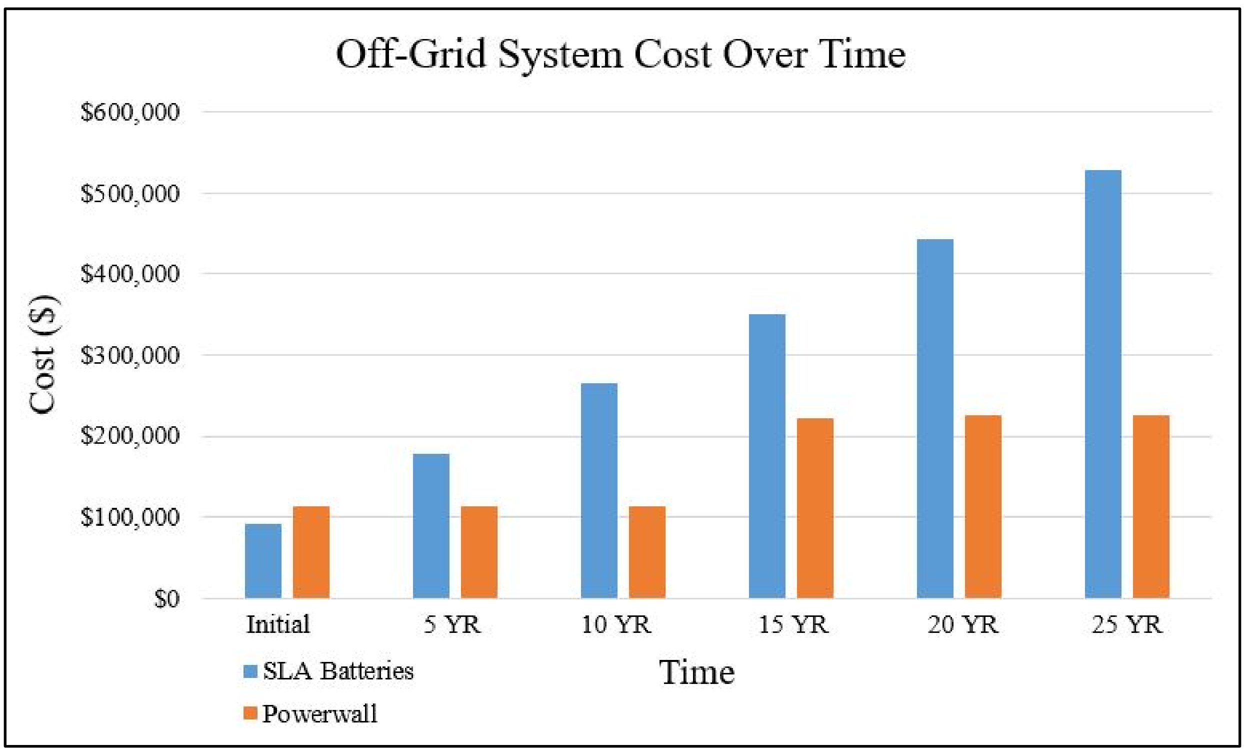

Figure 24: SLA Battery vs Powerwall Cost Over Time

7. Mass Save Program

The Mass Save Program is Massachusetts' Energy Efficiency Program. The program was created by the state as an initiative to provide a wide range of services, incentives, training, and information to promoting energy efficiency that helps residents and businesses manage energy use and related costs [54]. Mass Save is sponsored by various electric utility companies and energy efficiency providers including the following: Berkshire Gas Company, Blackstone Gas Company, Cape Light Compact, Columbia Gas of Massachusetts, Eversource, Liberty Utilities, National Grid, and Unitil. The program is funded by the monthly energy efficiency charges on the customers' gas and electric bills. Available to renters, homeowners, and businesses across Massachusetts, the customers are encouraged to take advantage of the deals and incentives offered.

One of the simplest actions that can be taken to reduce energy use is to remove and replace old lighting and appliances with updates and efficient models. The program offers rebates and discounts for appliances, lighting, and heating and cooling systems. The replacement of old incandescent lights with new LEDs not only reduces the energy use, but also reduces the amount of byproduct, in the form of heat, that is released into the environment. Price discounts are automatically applied to LED light bulbs if purchased through Energy Star. The Income Eligible Program is also offered through the Mass Save Program. If eligible, the program offers light bulbs at no cost. Mass Save also offers rebated for household appliances which include washers, dryers, refrigerators, and freezers. According to the Mass Save website page on rebates, up to a $1,000 rebate will be granted for commercial gas equipment (such as a stove) and up to $200 will be granted for an energy star refrigerator. [55-56]

8. PV Panel Location and Mounting

At roughly 18 ft^2 per 250W panel [57], the total area for the number of PV panels given in §5.1.4 is estimated to be 954 ft^2. The optimal location for solar panel mounting, according to Table 5, is the West Camp parking lot with 71% radiation exposure. The mounting of these panels on top of wooden platforms and the clearing of nearby trees (depending on TVSR approval) would increase this exposure and further optimize the location.

Another option is to mount the panels on the roof of Venture Lodge. With an area of approximately 2,080 ft^2 and the second highest exposure at 65%, the Venture Lodge roof is a viable option. The roof of Venture Lodge is due to be replaced in 2022. Mounting panels simultaneously would ease the process and cut down on costs. An important consideration is the distance between the panels and the building which they power – longer distances will show greater energy losses and necessitate long cables running around West Camp.

5.3 Recommendations

Based upon the results and analysis above, four recommendations for TVSR have been formulated. These recommendations have been categorized based upon the costs and risks associated with implementation. The categorized recommendations are shown below in Table 15.

Table 15: Categorized Recommendations

	Low-Risk	Moderate-Risk	High-Risk
Low-Cost	Appliance Upgrades and Removal $5,500-$6,000	**1.** Columbus Lodge Off-Grid Solar (SLA Batteries) $2,970 **2.** Columbus Lodge Off-Grid Solar (Tesla Powerwall) $9,629	
High-Cost	Cable and Transformer Replacement $196,000		West Camp Completely Off-Grid $112,246

5.3.1 Low-Cost Low-Risk

Energy consumption can be vastly reduced at TVSR through the addition of new, energy efficient appliances and the implementation of recommended behavioral changes (Figure 25). The low-risk and low-cost recommendation entails TVSR removing or updating existing appliances within the three lodges. Replacing old lighting and appliances will reduce the utility bill of West Camp and the power drawn from the cable. The estimated cost to replace and upgrade both appliances and lighting in West Camp is projected to be between $5,500 and $6,000[24]. Many companies, such as National Grid, have incentive and rebate programs in place to assist local schools and non-profit organizations in replacing outdated appliances with new appliances for a fraction of the cost (§5.2, Mass Save Program).

[24] Price referrals may be found in Appendix G and Appendix H (summary). This price estimate is without rebates, which would significantly lower the total replacement cost.

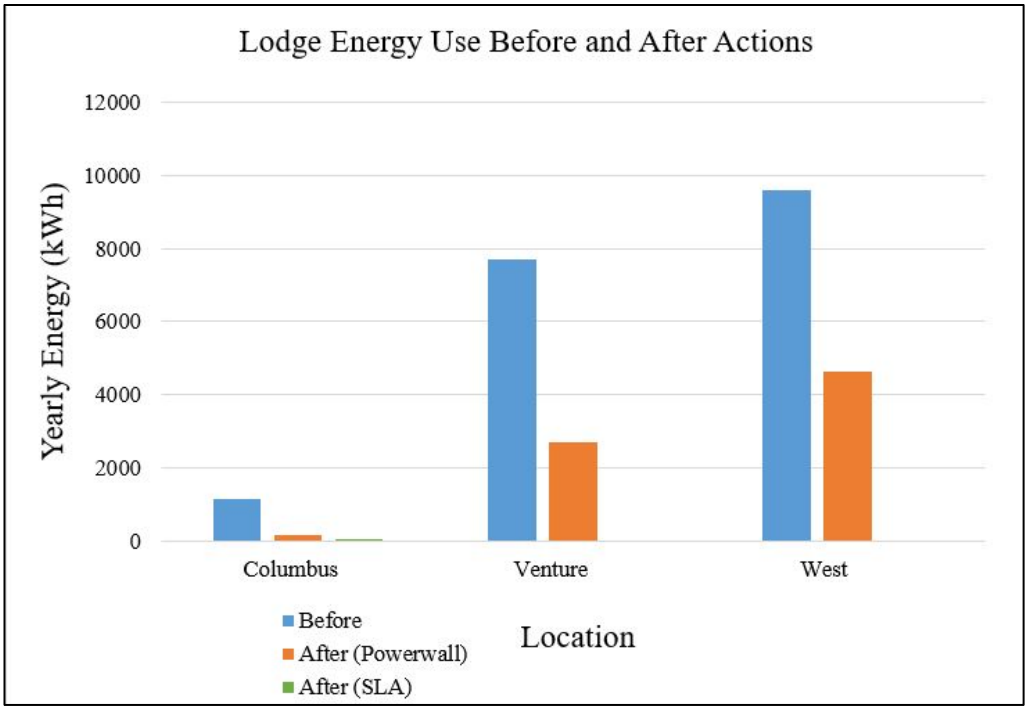

Figure 25: West Camp Lodge Energy Use Before and After Energy Reduction Actions

Based upon the assumptions listed in §5.1.2, recommendations detailing the removal and upgrade of appliances are provided below for each individual building. If these recommendations and the assumptions are followed, TVSR could reduce its peak daily energy use during CSAC from 200 kWh/day to as low as 80 kWh/day.[25]

Appliance Changes - Columbus Lodge

1. Remove the ridge fan
2. Replace the ceiling fan with a 12W fan
3. Run the slushy machines, refrigerator, and freezer on a generator
4. Replace all lights (indoor and outdoor) with 12V LED lights
5. Place all emergency detectors on batteries

Appliance Changes - Venture Lodge

1. Replace the electric stove with a gas stove
2. Use only one air conditioning unit for the infirmary (can be run 24/7)
3. Relocate the 1HP well pump to East Camp for cable load reduction
4. Replace current refrigerator with an Energy Star appliance
5. Use a half-power microwave (600-700W)
6. Replace any current lighting with 12V LED lighting

[25] §4.1, §5.1.3

Appliance Changes - West Lodge

1. Remove any air conditioners currently in use
2. Remove the dishwasher
3. Remove the Polar refrigerator
4. Replace the Hot Point fridge with an Energy Star appliance
5. Replace the Kenmore freezer with a mini-freezer (multiple is fine)
6. Use only one small coffee pot
7. Replace any current lighting with 12V LED lighting

Along with the appliance changes noted above, it is also recommended that TVSR develop and implement a set of rules encouraging the staff and faculty to turn off appliances and lights if not in use, to take shorter showers, and to limit the amount of AC units installed. Proper education of staff and awareness of energy use can further reduce West Camp's electrical usage and, consequently, its electric bill.

5.3.2 High-Cost Low-Risk

The highest cost of the four options is replacing the underwater power cable and subsequent transformer replacement and PCB clean-up. This has been estimated to be around \$196,000 total, based on a \$92,000 estimate for cable replacement and a \$52,000 estimate for each of the two transformers[26]. While costly, this option may be seen as the lowest-risk, given that the current cable has lasted since 1983 and the two transformers have lasted since 1973.

If this option is considered, TVSR must size the new cable based on current and future electrical needs. Proper sizing will ensure that the new cable is capable of supporting the electrical load of West Camp and will avoid any stress or potential failure to the cable.

5.3.3 Low-Cost Moderate-Risk

Option 1 – Columbus Lodge Off-Grid Solar (SLA Batteries)

Given our assumptions outlined in §5.1.2, Columbus Lodge is the simplest of the three buildings to convert to a solar energy system. Requiring only two PV panels and thirteen sealed lead acid batteries, the estimated cost for conversion of this building to solar is \$2,970.

While this is a relatively low-cost conversion, this recommendation still poses some risks. Converting only Columbus Lodge to solar implies that both Venture Lodge and West Lodge are still reliant on the underwater power cable. Reliance on the cable still presents a risk because, as stated in §3.1, this cable is near its estimated lifespan and may fail in the near future.

[26] Information provided by M. McQuaid 26 January 2019.

Option 2 – Columbus Lodge Off-Grid Solar (Tesla Powerwall)

As the simplest of the three buildings, energy consumption of Columbus Lodge is relatively low compared to Venture Lodge and West Lodge (Table 10). The cost to install an off-grid power system for Columbus Lodge via the Tesla Powerwall is estimated to be an upwards of $10,000. This estimation includes the cost of four PV panels required, the Tesla Powerwall and its associated hardware and installation, and a 5kW inverter. Although this projected cost is higher compared to the Option 1, using the Tesla Powerwall enables Columbus Lodge to retain the operation of some current appliances. This includes the use of the ice cream freezer, as well as using one slushy machine for two hours per day. The installation of the Powerwall further allows for a buffer of approximately 0.75 kWh per day which may be reserved for 120V outlet use.

5.3.4 High-Cost High-Risk

The total energy consumption of West Camp per day is approximately 80 kWh. As displayed in §5.1.4, a total of 53 photovoltaic panels (polycrystalline at 250W each) are required to meet the power needs of West Camp, with an estimated cost for full conversion of all three buildings at $87,734. Provided the number of PV panels required to supply energy to West Camp and based on the data collected via the Solar Pathfinder, it is recommended that TVSR mount the required PV panels in two separate locations.

The first location for PV panel installation is the main parking lot in West Camp (Figure 26). The parking lot is an open and ideal area as it can accommodate hundreds of PV panels, however we would aim to retain as much space as possible for parking. Approximately 36 PV panels are required to supply energy to both Columbus and West Lodge, and mounting these panels would require approximately 650 ft^2 of the parking space, which is only 3.3% of the total parking area[27]. Mounting panels for both buildings in this location would require TVSR to run various cables from the PV panel site to the buildings. In addition, the installation of two separate inverters per building is also required.

[27] This is based upon an estimated parking lot area of 20,000 ft^2 via Google Earth.

Figure 26: West Camp Parking Lot

The second location for PV panel installation is the roof of Venture Lodge (Figure 27). To supply and meet the energy needs of Venture Lodge, it is recommended that the 17 required PV panels are mounted on the rear, south-facing side of the roof. With the roof facing the true south and the ability to accommodate an upwards of 110 PV panels, Venture Lodge's roof is an ideal location to mount the PV panels required to operate Venture Lodge.

Figure 27: (a) Venture Lodge Roof and (b) Venture Lodge Roof with Tree Obstruction (Yellow)

6. SUMMARY and CONCLUSIONS

This Interdisciplinary Qualifying Project (IQP) aimed to provide Treasure Valley Scout Reservation (TVSR) recommendations for sustainable energy solutions. The purpose of this project was to provide Treasure Valley with a detailed assessment of the electrical needs of West Camp and, based on this assessment, provide recommendations for the best type of solar system to install, a cost and risk assessment for each possible installation, and the best locations for solar installments. Over the course of seven weeks, the team worked towards the fulfillment of the aforementioned objectives. The team provided recommendations serving as a guide for alternatives to the current power system and future energy reduction.

Currently, TVSR plans to increase and expand the functionality of West Camp through the development and implementation of new installations and restructuring of the property. This IQP laid the groundwork for future projects that will follow the course of the recommendations provided by this project. Future projects will aim to update the current recommendations to ensure Treasure Valley is provided with the most accurate information regarding future operations of West Camp in addition to alternative energy solutions.

Moving forward, it is crucial for TVSR to discuss and establish a thorough strategic plan for the operations of West Camp. It is highly encouraged TVSR take a closer look at the Mass Save Program to take advantage of the rebates and incentives offered for the replacement of old appliances with new energy efficient lighting and appliances. It is also highly encouraged that the electric stove in Venture Lodge is replaced with a gas stove to greatly reduce the energy consumption of Venture Lodge. Additionally, if TVSR plans to expand the operations of Columbus Lodge to allow for rentals, the low-cost moderate-risk recommendation provided will no longer be viable as a low-cost option.

A strategic plan for West Camp is vital to the future of Treasure Valley. Regardless of solar implementation, steps must be taken to reduce energy consumption in West Camp. Doing so will ensure that TVSR both saves money and prolongs the lifespan of the cable by reducing the load and stress on the cable. The results and recommendations provided in the project lay the foundation for TVSR's strategic plan for the continued operations of West Camp. We hope TVSR will greatly consider and implement the recommendations provided.

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APPENDIX A – PROJECT STAKEHOLDERS

Below is a list of the potential stakeholders for our IQP:

1. Stakeholders that will have an interest in the project:
    - Mike McQuaid: Chair of TVSR facilities and maintenance committee
    - Matt McLaughlin: Camp ranger
    - Campmasters
    - Heart of America Council: Executive Board and Council Staff
    - Tom Chamberland: liaison between WPI and TVSR
    - Worcester Polytechnic Institute
2. Stakeholders that will be impacted by the decisions made:
    - The local council members and camp facilities board members of the Heart of New England Council, Boy Scouts of America (BSA)
    - All scouts and visitors who use or visit West Camp
    - Scout Troops and visitors (extra programs as well)
    - Mohegan Council: Executive Board and Council Staff
    - National Grid
    - Local communities that might have oversight on licensing and certification of construction and electrical work

APPENDIX B – BUILDING FLOOR PLANS

Below are rough floor plans for the three buildings in West Camp, detailing all lighting and appliances in each building. Note that the images are not to scale.

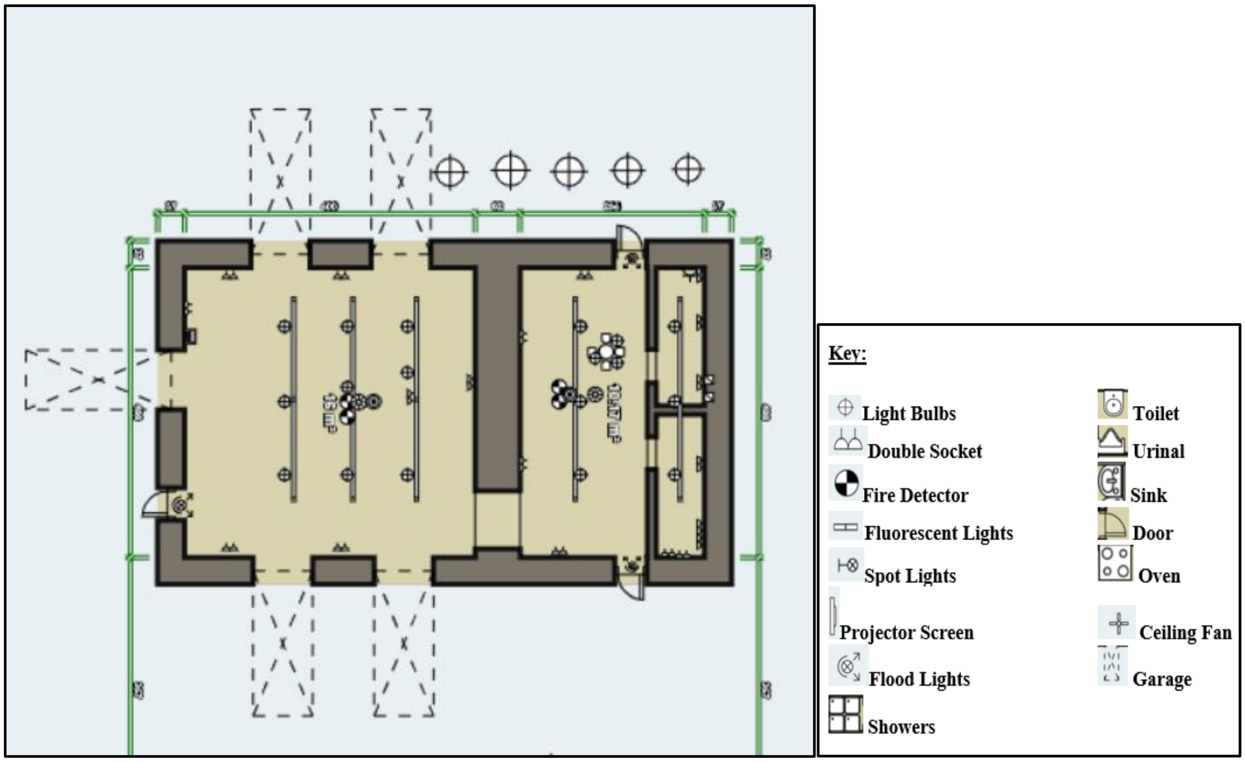

Figure 28: Columbus Lodge Floor Plan

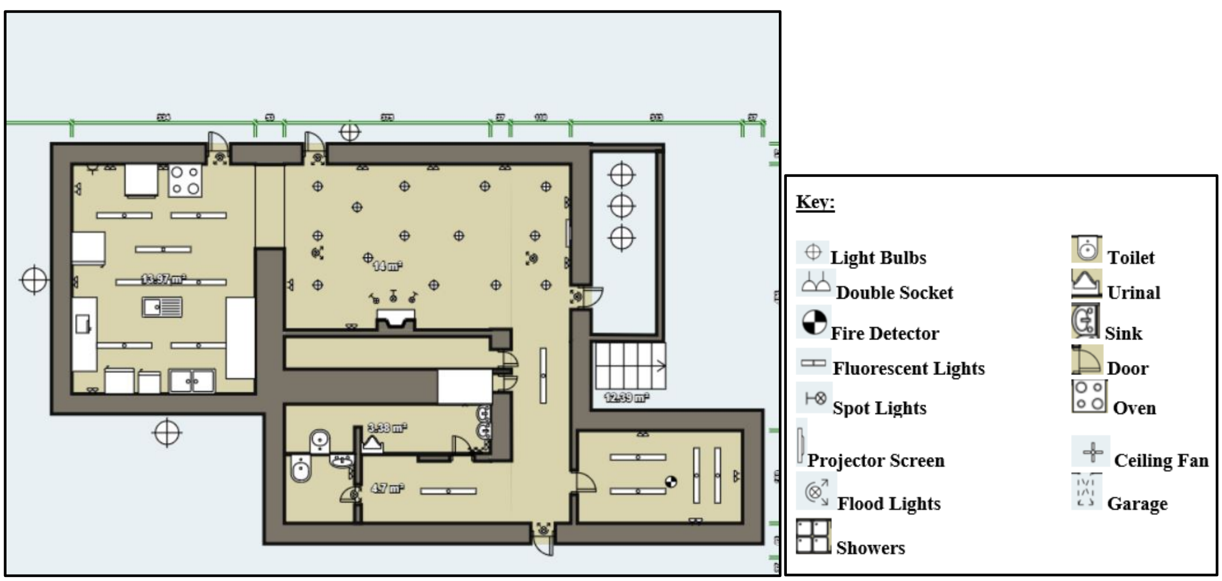

Figure 29: West Lodge Floor Plan

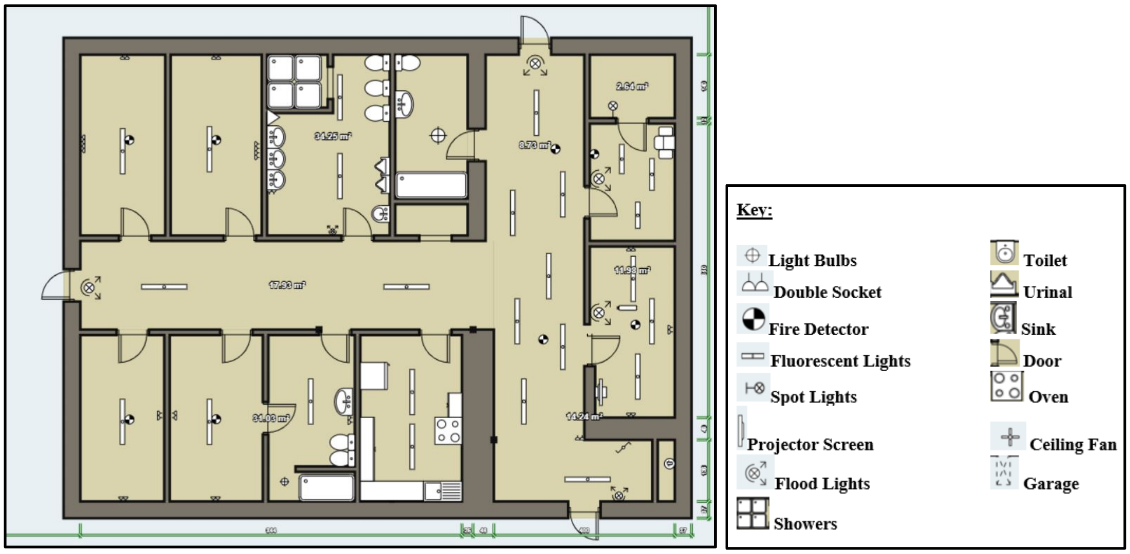

Figure 30: Venture Lodge Floor Plan

APPENDIX C – WEST CAMP INVENTORY

Below is an inventory of all power-requiring appliances (including lights) in each of the three buildings in West Camp – Columbus Lodge, West Lodge, and Venture Lodge. The number of appliances, wattage, estimated run times, energy usage, power usage, 1-day energy usage, and 2-day energy usage are included for each building. For CSAC, WKNDs, and YR Round, a "Y" denotes that this appliance or light operates during this whole period of time. An "N" in one of these categories implies that the appliance or light does not run for the full period of time.

Table 16: Columbus Lodge Inventory

Lighting													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR (W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Flood Lights	2	50.0	Y	N	N	12	0	0	42.0	0	0	42.0	50.0	0	4.8	100.0
Outdoor Lights	5	23.0	Y	N	N	12	0	0	48.3	0	0	48.3	57.5	0	5.5	115.0
Indoor Lights	15	20.0	Y	N	N	12	0	0	126.0	0	0	126.0	150.0	0	14.4	300.0
Christmas Lights	2	40.8	N	N	N	0	0	0	0	0	0	0	0	0	0	81.6
Ceiling Fan Lights	3	60.0	Y	N	N	12	0	0	75.6	0	0	75.6	90.0	0	8.6	180.0
Ceiling Fan	1	75.0	Y	N	N	12	0	0	31.5	0	0	31.5	37.5	0	3.6	75.0

Other													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR (W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
CO Detector	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5	2.0	2.0	2.0	2.0
Smoke Detector	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5	2.0	2.0	2.0	2.0
Emergency Exit Signs	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5	2.0	2.0	2.0	2.0
Emergency Light (Single)	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5	2.0	2.0	2.0	2.0
Ridge Fan	1	250.0	Y	N	N	1 wk full time; 3 months 12 hr/day; 2 months 6 hr/day						357.0	135.4			250.0

Table 18 (cont.)

Appliances												
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**
Frosty / Slushy Machine	2	1100.0	Y	N	N	4	0	0	308.0	0	0	308.0
Water / Soda Fridge	1	63-480.0	Y	N	N	24	0	0	78.9	0	0	78.9
Ice Cream Freezer	1	6-100.0	Y	N	N	24	0	0	28.6	0	0	28.6

Power			
Avg CSAC PWR (W)	**Avg WKND PWR (W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
366.7	0	35.2	2200.0
93.9	0	9.0	480.0
34.0	0	3.3	100.0

Sum (kWh)	745.6	18.0	70.1	1166.0
Percent Yearly	63.9	1.5	6.0	

Sum (W)	1023.0	8.0	92.3	3889.6
1-Day Energy (kWh)	24.6	0.2	2.2	93.4
2-Day Energy (kWh)	49.1	0.4	4.4	186.7

Table 17: Venture Lodge Inventory

Lighting													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Bedroom Lights	16	32.0	Y	Y	N	4	4	0	71.7	192.5	0.0	264.2	85.3	85.3	30.2	512.0
Hallway/Other Lights	46	32.0	Y	Y	N	10	10	0	515.2	1383.7	0.0	1898.9	613.3	613.3	216.8	1472.0
Bathroom Lights	10	32.0	Y	Y	N	4	4	0	44.8	120.3	0.0	165.1	53.3	53.3	18.8	320.0
Ceiling Light w/ Vent	1	100.0	Y	Y	N	4	4	0	14.0	37.6	0.0	51.6	16.7	16.7	5.9	100.0
Outdoor Lighting	3	40.0	Y	Y	N	12	12	0	50.4	135.4	0.0	185.8	60.0	60.0	21.2	120.0

Other													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Emergency Lights	3	1.0	Y	Y	Y	24	24	24	2.5	6.8	26.3	26.3	3.0	3.0	11.6	3.0
Smoke/CO Detector	9	1.0	Y	Y	Y	24	24	24	7.6	20.3	78.8	78.8	9.0	9.0	34.9	9.0
Pest Control	3	1.9	Y	Y	Y	24	24	24	4.8	12.9	49.9	49.9	5.7	5.7	22.1	5.7
Water Boiler Monitor	1	2-168.0	Y	Y	N	4	2	0	5.6	7.5	0	13.1	6.7	3.3	1.5	168.0
Heating System	1	0.2 - 0.5 HP	N	Y (minus summ)	Y (minus summ)	0	10 (7 months)	8 (7 months)	0	225.0	684.0	684.0	0	156.3	133.9	375.0
Well Pump	1	1 HP	Y	Y	Y (much less)	Not enough information							Not enough information			750.0

Table 19 (cont.)

Appliances												
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**
Electric Stove	1	9-12 (kW)	Y	Y	N	4	2	0	1400.0	1880.0	0	3280.0
Refrigerator	1	16-710.0	Y	Y	Y	24	24	24	21.5	57.7	224.1	224.1
Microwave	1	1100.0	Y	Y	N	1	1	0	39.9	107.2	0	147.1
Air Conditioner	4	35-520.0	Y	N	N	24 (1); 12 (3)	0	0	602.3	0	0	602.3
Projector	1	450.0	Y	N	N	1	0	0	15.8	0	0	15.8

Power			
Avg CSAC PWR (W)	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
1666.7	833.3	374.4	12000.0
25.6	25.6	25.6	710.0
47.5	47.5	16.8	1100.0
717.0	0	68.8	2080.0
18.8	0	1.8	450.0

Sum (kWh)	2796.0	4186.8	1063.1	7686.9
Percent Yearly	36.4	54.5	13.8	

Sum (W)	3328.6	1912.4	984.3	20174.7
1-Day Energy (kWh)	79.9	45.9	23.6	484.2
2-Day Energy (kWh)	159.8	91.8	47.2	968.4

Table 18: West Lodge Inventory[28]

Lighting													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Emergency Light	4	1.0	Y	Y	Y	24	24	24	3.4	9.0	35.0	35.0	4.0	4.0	4.0	4.0
Emergency Exit with 2 Lights	5	1.0	Y	Y	Y	24	24	24	4.2	11.3	43.8	43.8	5.0	5.0	5.0	5.0
Entrance Light	1	50.0	Y	Y	N	4	2	0	7.0	9.4	0	16.4	8.3	4.2	1.9	50.0
Porch Lights	3	11.0	Y	Y	N	12	12	0	13.9	37.2	0	51.1	16.5	16.5	5.8	33.0
Outdoor Light	2	13.0	Y	Y	N	12	12	0	10.9	29.3	0	40.2	13.0	13.0	4.6	26.0
Back Outdoor Light	1	16.0	Y	Y	N	12	12	0	6.7	18.0	0	24.8	8.0	8.0	2.8	16.0
Hallway Lights	8	32.0	Y	Y	N	18	12	0	161.3	288.8	0	450.0	192.0	128.0	51.4	256.0
Kitchen Lights	14	32.0	Y	Y	N	12	2	0	188.2	84.2	0	272.4	224.0	37.3	31.1	448.0
Bedroom Lights	8	32.0	Y	Y	N	14	14	0	125.4	336.9	0	462.3	149.3	149.3	52.8	256.0
Male Bathroom Lights	4	32.0	Y	Y	N	12	10	0	53.8	120.3	0	174.1	64.0	53.3	19.9	128.0
Female Bathroom Light	1	25.0	Y	Y	N	12	10	0	10.5	23.5	0	34.0	12.5	10.4	3.9	25.0
Emergency Light (small)	1	1.0	Y	Y	Y	24	24	24	0.8	2.3	8.8	8.8	1.0	1.0	1.0	1.0
Ceiling Lights (steady)	10	14.5	Y	Y	N	18	12	0	91.4	163.6	0	254.9	108.8	72.5	29.1	145.0
Ceiling Lights (variable)	4	14.0	Y	Y	N	18	12	0	35.3	63.2	0	98.4	42.0	28.0	11.2	56.0
Spot Lights	3	8.0	Y	Y	N	18	12	0	15.1	27.1	0	42.2	18.0	12.0	4.8	24.0
Storage Closet Light Bulb	1	60.0	Y	N	N	1	0	0	2.1	0	0	2.1	2.5	0.0	0.2	60.0
Basement Emergency Lights	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5	2.0	2.0	2.0	2.0

[28] Items in West Lodge that do not require power include a gas stove, hot table, and a water boiler.

Table 20 (cont.)

Lighting													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Basement Emergency Exits	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5	2.0	2.0	2.0	2.0
Basement Fluor. Lights	28	32.0	Y	Y	N	10	10	0	313.6	842.2	0	1155.8	373.3	373.3	131.9	896.0
Basement Smoke Detectors	3	1.0	Y	Y	Y	24	24	24	2.5	6.8	26.3	26.3	3.0	3.0	3.0	3.0
Basement CO Monitor	1	1.0	Y	Y	Y	24	24	24	0.8	2.3	8.8	8.8	1.0	1.0	1.0	1.0
Basement Misc Lighting	3	13.0	N	N	N	0	0	0	0	0	0	0	0	0	0	0
Basement Lights (Dirt Foor)	6	17.0	N	N	N	0	0	0	0	0	0	0	0	0	0	0

Other													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
AC Unit	1	35-520.0	Y	N	N	12	0	0	120.5	0	0	120.5	143.4	0	13.8	520.0
Thermostat	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5	2.0	2.0	2.0	2.0
Loudspeaker	4	50.0	Y	N	N	0.5	0	0	3.5	0	0	3.5	4.2	0	0.4	200.0
Basement Heating System	1	0.2 - 0.5 HP	N	Y (minus summ)	Y (minus summ)	0	10 (7 months)	6 (7 months)	0	225.0	569.3	569.3	0	156.3	111.4	375.0
Upstairs Heating System	1	0.2 - 0.5 HP	N	Y (minus summ)	Y (minus summ)	0	10 (7 months)	8 (7 months)	0	225.0	684.0	684.0	0	156.3	133.9	375.0
Projector	1	450.0	Y	Y	N	2	1	0	31.5	42.3	0	73.8	37.5	18.75	8.4	450.0

Table 20 (cont.)

Appliances													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Polar Fridge	1	40-540.0	Y	Y	Y	24	24	24	70.3	188.7	732.7	732.7	83.6	83.6	83.6	540.0
Hot Point Fridge	1	200-500.0	Y	Y	Y	24	24	24	170.1	457.0	1774.3	1774.3	202.6	202.6	202.6	500.0
Kenmore Freezer	1	10-450.0	Y	Y	Y	24	24	24	97.2	261.0	1013.5	1013.5	115.7	115.7	115.7	450.0
Large Microwave	1	1300.0	Y	Y	N	1	1	0	39.9	107.2	0	147.1	47.5	47.5	16.8	1300.0
Kitchen Coffee Pot	1	1500.0	Y	Y	N	0.5	0.5	0	25.2	67.6	0	92.8	30.0	30.0	10.6	1500.0
Toaster	1	680.0	Y	Y	N	0.5	0.5	0	10.9	29.3	0	40.2	13.0	13.0	4.6	680.0
Out of Service Dish Washer	1	1500.0	Y	Y	N	2	1	0	105.0	52.5	0	157.5	125.0	23.3	18.0	1500.0
Storage Coffee Machine	1	1600.0	Y	Y	N	0.5	0.5	0	26.3	70.5	0	96.8	31.3	31.3	11.0	1600.0
Storage Coffee Pot	1	900.0	Y	Y	N	0.5	0.5	0	15.1	40.6	0	55.7	18.0	18.0	6.4	900.0
Food Warmer	1	1500.0	Y	N	N	12	0	0	646.6	0	0	646.6	769.7	0	73.8	1500.0
Storage Microwave	1	1150.0	Y	Y	N	1	1	0	35.7	95.9	0	131.6	42.5	42.5	15.0	1150.0

Sum (kWh)	2449.6	3951.4	4948.9	9593.7
Percent Yearly	25.5	41.2	51.6	

Sum (W)	2916.2	1864.5	1197.4	15979.0
1-Day Energy (kWh)	70.0	44.7	28.7	383.5
2-Day Energy (kWh)	140.0	89.5	57.5	767.0

APPENDIX D – SOLAR PATHFINDER DATA

Below is a table containing the percent of solar radiation per month of a southward facing PV panel in each location and the eight Sunpath diagrams obtained from the Solar Pathfinder.

Table 19: Percent Solar Radation per Month and Yearly Average

	% Solar Radiation by Month												
	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**	**Average**
West Lodge (Front, birches removed)	0	0	45	75	86	76	81	81	46	0	0	0	41
West Camp Parking	56	69	71	75	83	85	87	80	75	67	55	49	71
Columbus Clearing	41	43	54	54	67	66	67	68	55	46	41	39	53
Venture (Front)	57	62	54	60	59	57	59	65	60	56	57	53	58
Venture (Back)	0	22	40	44	60	61	60	47	42	31	7	0	35
Venture Roof (Right)	47	45	62	83	78	78	77	80	63	46	47	39	62
Venture Roof (Middle)	37	41	78	82	84	85	87	81	77	45	34	33	64
Venture Roof (Left)	39	71	76	78	88	87	88	82	76	70	39	40	70

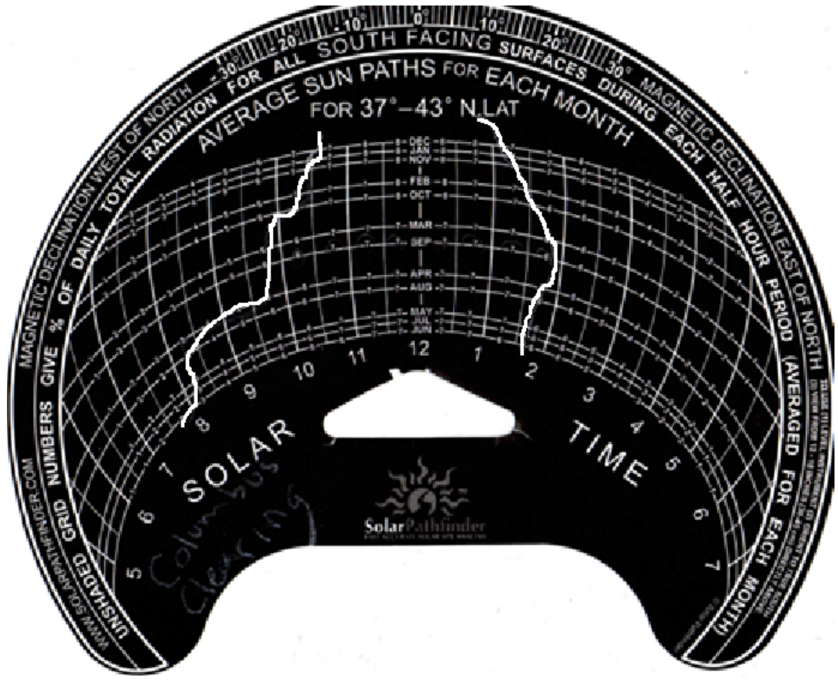

Figure 31: Sunpath Diagram for Columbus Clearing

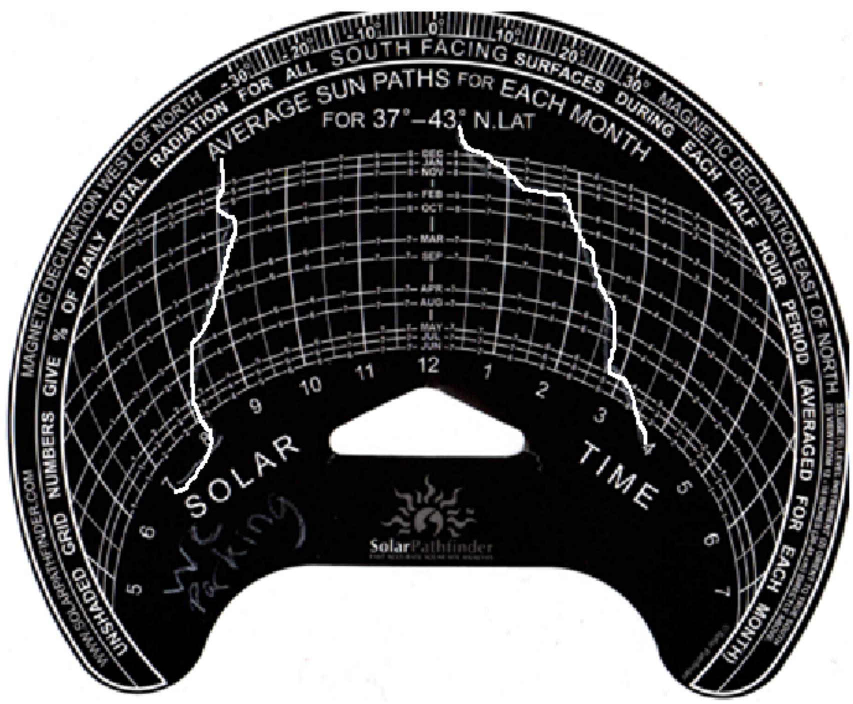

Figure 32: Sunpath Diagram for West Camp Parking

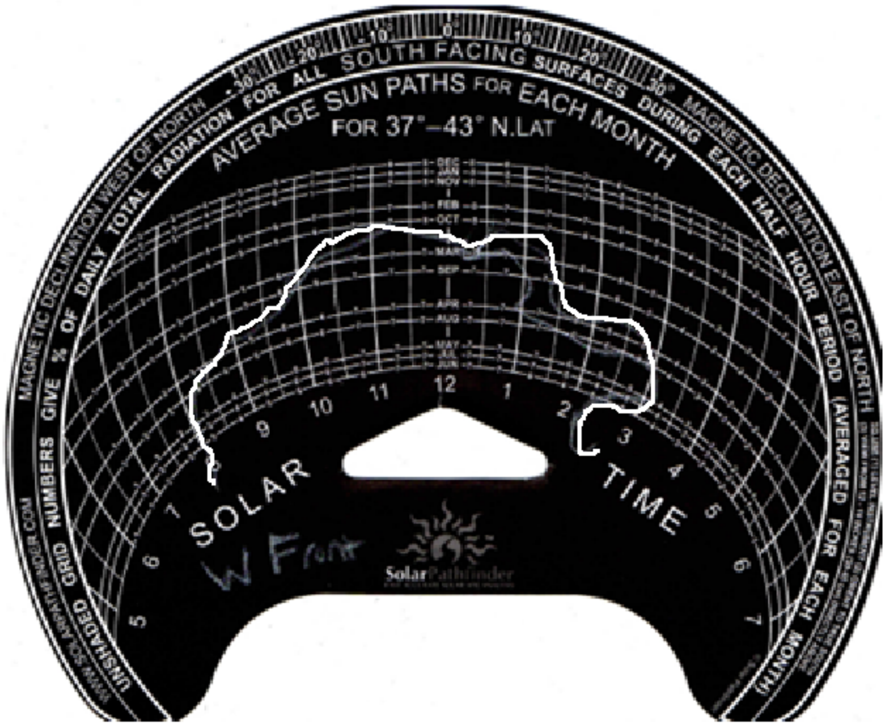

Figure 33: Sunpath Diagram for West Lodge (Front)

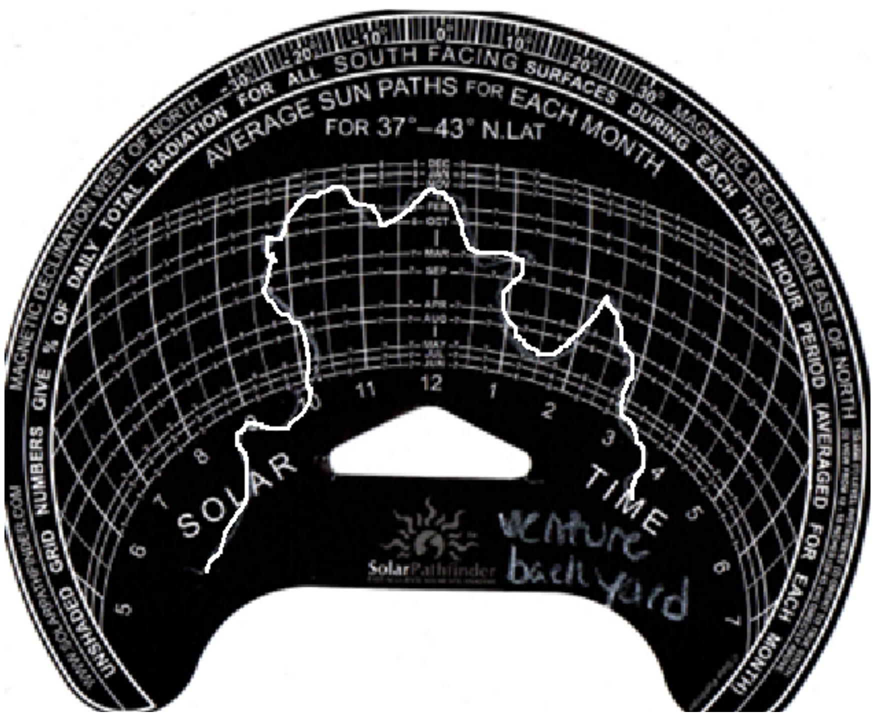

Figure 34: Sunpath Diagram for Venture Lodge (Back)

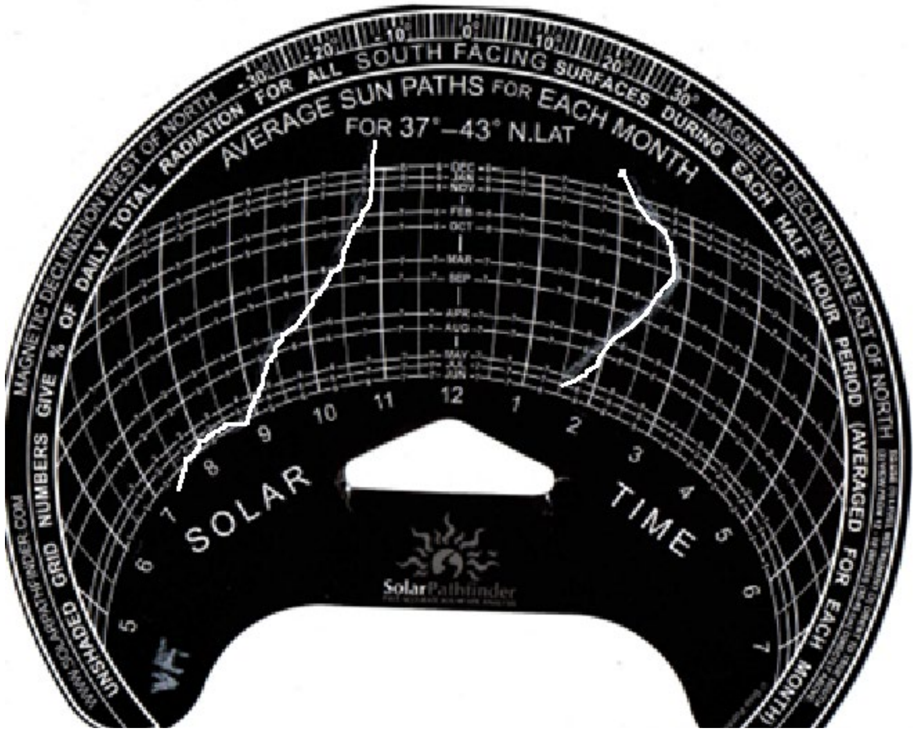

Figure 35: Sunpath Diagram for Venture Lodge (Front)

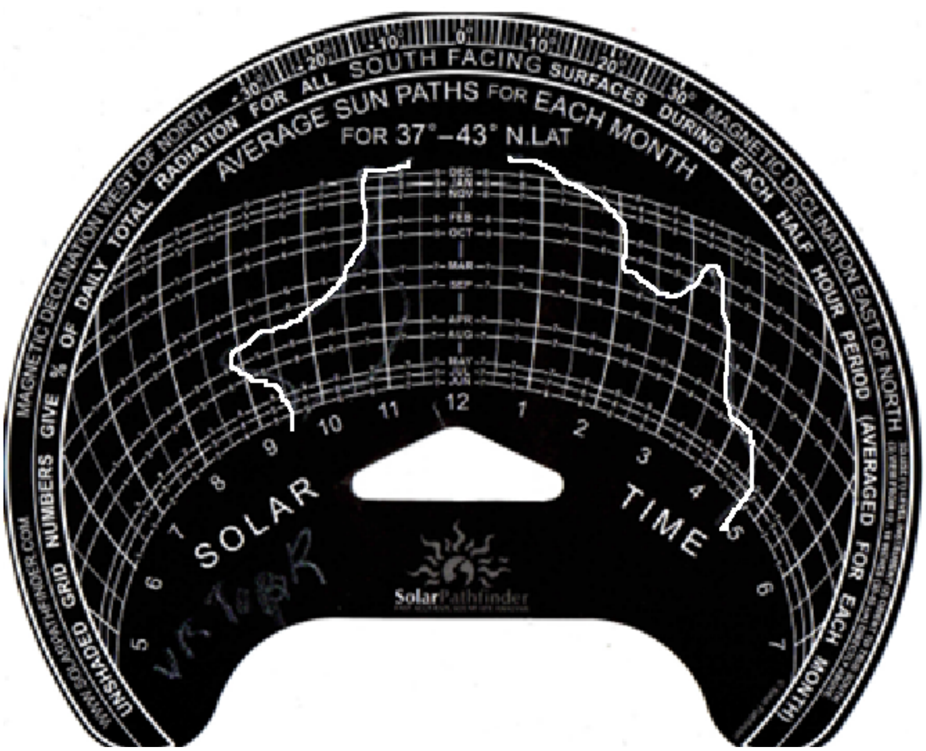

Figure 36: Sunpath Diagram for Venture Lodge Roof (Right)

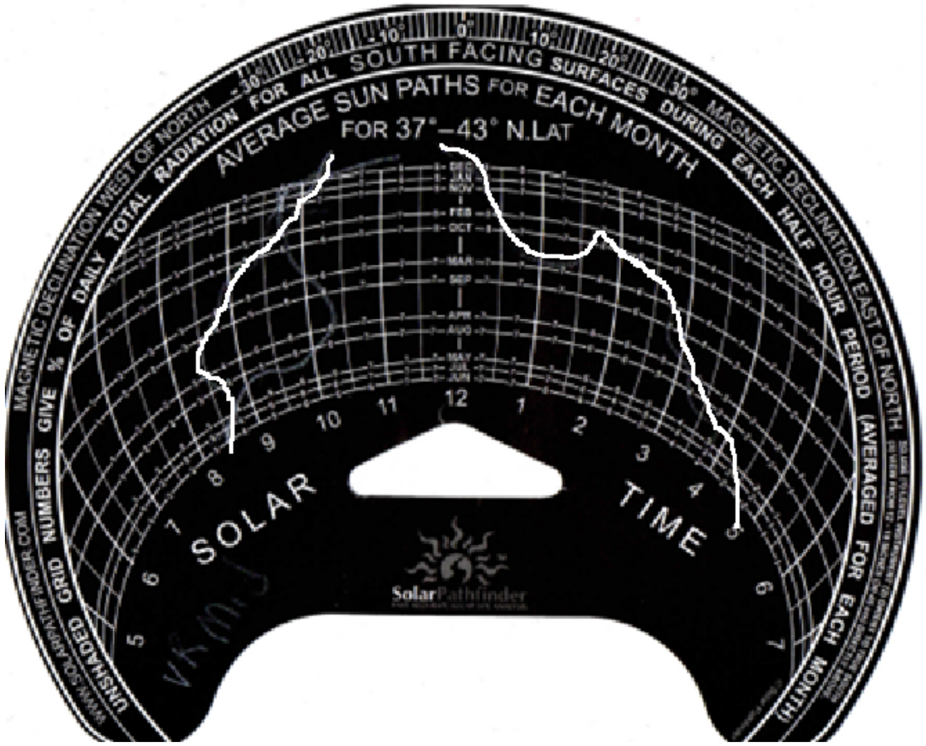

Figure 37: Sunpath Diagram for Venture Lodge Roof (Middle)

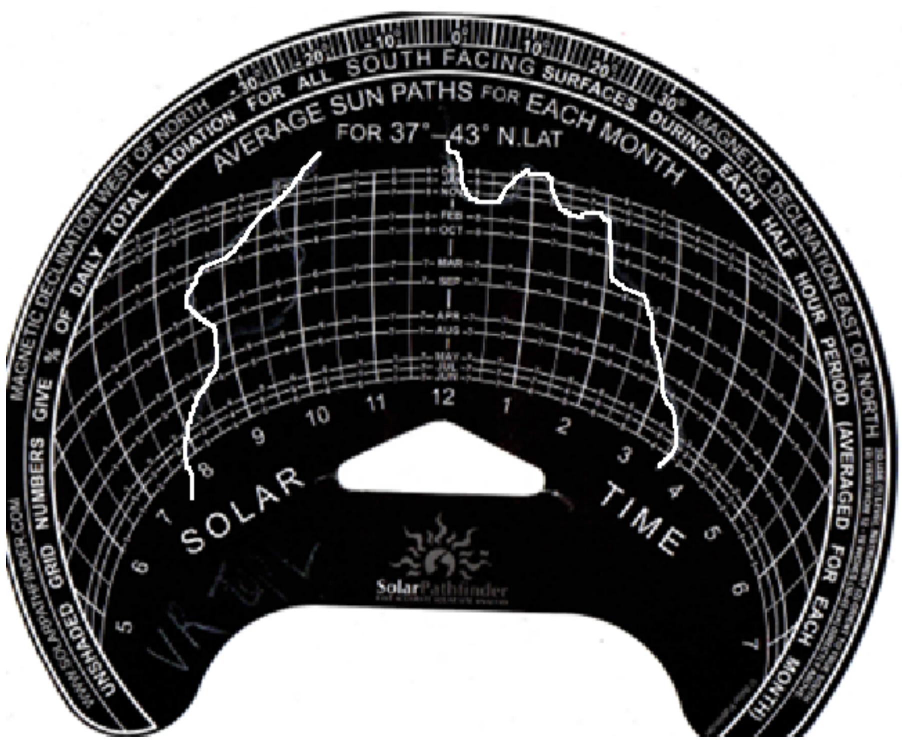

Figure 38: Sunpath Diagram for Venture Lodge Roof (Left)

APPENDIX E – CURRENT WEST CAMP HARDWARE REQUIREMENTS

Below are three tables outlining the hardware requirements of West Camp if it were to be converted to an off-grid system without any alterations or assumptions. Included are estimates on pricing for the calculated number of batteries, PV panels, and for the specifically sized charge controllers and inverters.

In calculating the number of panels and batteries needed for West Camp as it is, the number of kWh/day of energy use was multiplied by the number of 250W panels and 12V 100Ah batteries needed per kWh/day of energy use. For example, 28.3 kWh/day was multiplied by 0.7 batteries per kWh/day to find the requirement of twenty 250W panels for Columbus Lodge. The minimum inverter required is based upon the maximum load (Table 4). To calculate the number of Tesla Powerwalls required, the energy use per day was divided by 13.5 kWh (the usable capacity of a Tesla Powerwall) and rounded up. Refer to Appendix G for hardware pricing.

Table 20: Current Off-Grid Hardware Requirements

	kWh / Day (Upper Estimate)[29]	**PV Panel/(kWh/day) (250W)**	**Battery/(kWh/day) (12V 100Ah)**	**No. Panels (250W)**	**No. of 100 Ah Batteries (2-Day)**	**Charge Controller (A)**[30]	**Minimum Inverter Required (W)**
Columbus Lodge	28.3	0.7	5.6	20	159	100	5,000
Venture Lodge	91.9			65	513	600	29,000
West Lodge	80.5			57	451	500	22,000

[29] These daily energy values include a 15% factor of safety.

[30] Assumes all buildings on 48V batteries with one 100A charge controller for Columbus Lodge, six stacked 100A charge controllers for Venture Lodge, and five stacked 100A charge controllers for West Lodge.

Table 21: Current Off-Grid Hardware Costs (With Batteries)

	Cost per PV Panel (250W)	Cost per Battery (12V,100Ah)	Total PV Panel Cost	Total Battery Cost	Inverter Cost[31]	MPPT Charge Controller Cost	All Hardware
Columbus Lodge	$100	$200	$2,000	$31,800	$339	$395	$34,534
Venture Lodge			$6,500	$102,600	$2,034	$2,370	$111,134
West Lodge			$5,700	$90,200	$1,695	$1,975	$99,570
West Camp Total			$14,200	$224,600	$4,068	$4,740	$247,608

Table 22: Current Off-Grid Hardware Costs (With Powerwall)

	Total PV Panel Cost	Inverter Cost	No. of Tesla Wall[32]	Cost per Tesla Wall	Total Tesla Wall Cost	All Hardware
Columbus Lodge	$2,100	$678	5	$6,700	$33,500	$36,278
Venture Lodge	$6,500	$1,356	14		$93,800	$101,656
West Lodge	$5,600	$1,017	12		$80,400	$87,017
West Camp Total	$14,200	$3,051	31		$207,700	$224,951

[31] Assumes one 5kW inverter for Columbus Lodge, six stacked 5kW inverters for Venture Lodge, and five stacked 5kW inverters for West Lodge.
[32] Assumes 13.5 kWh usable per Powerwall. It is important to note that a maximum of 10 Tesla Powerwalls may be connected at once.

APPENDIX F – SAMPLE CALCULATIONS

1. PV Panel / (kWh/day)

The calculation below equates the number of 250W PV panels required per 1 kWh/day of energy use. This was done by dividing the number of W/(kWh/day) by the power of each panel (250W/panel). The value for watts per kilowatt hour per day was derived from a known value of 30 kWh/day with 5 kW of PV panels (Fred Looft).

$$\frac{167\left(\frac{W}{\frac{kWh}{day}}\right)}{250\frac{W}{panel}} = 0.668 \text{ [250W PV Panel / (kWh/day)]}$$

2. 12V 100Ah SLA battery / (kWh/day)

The calculation below shows the number of 12V 100Ah sealed lead-acid batteries required per 1kWh/day of energy use. This accounts for only 30% battery depletion (10/3 multiplier) and 2 days of energy storage per industry standard.

$$\frac{1000Wh}{12V} \times \frac{10}{3} \times \frac{1battery}{100Ah} \times 2\ days = 5.56 \text{ [12V 100Ah SLA battery / (kWh/day)]}$$

3. 240A charge controller requirement for West Lodge [A]

The calculation below demonstrates the sizing of the charge controller for West Lodge. This assumes the stacking of charge controllers to obtain the correct current. In this case 224A was rounded up to 240V in order to stack four 60A charge controllers.

$$\frac{Max\ PWR\ Surge\ (W)}{Battery\ Voltage\ (V)} + 8A\ (PV\ Panel) = \frac{10366.0W}{48V} + 8A = 224A \sim 240A$$

APPENDIX G – HARDWARE RECOMMENDATIONS AND LINKS

Solar Hardware Recommendations

- 250W Solar Panel
- 12V 100Ah SLA Battery
- 3kW Gas Generator
- 500W Inverter
- 1.5kW Inverter
- 5kW Inverter
- 10kW Inverter
- 30A Charge Controller
- 60/100A Charge Controllers

Columbus Lodge Recommendations

- 10W Floodlight
- 9W LED
- 5W LED
- 12V Ceiling Fan
- 3 cu ft Upright Freezer

Venture Lodge Recommendations

- 18W 3' LED
- 9W LED
- Gas Stove
- 18 cu ft Fridge/Freezer
- Microwave

West Lodge Recommendations

- 6.2W Outdoor Light
- 9W LED
- 18W 3' LED
- 5W LED
- 18 cu ft Fridge/Freezer
- 3 cu ft Upright Freezer
- Microwave

APPENDIX H – SUMMARY TABLES

Columbus Lodge

Action (A) refers to using SLA batteries for an off-grid storage system
Action (B) refers to using the Tesla Powerwall for an off-grid storage system
Unspecified actions should be followed regardless

Actions	Cost
1. Shut off ridge fan breaker	X
2. (A) Remove freezer and refrigerator; replace with ice coolers	X
3. (B) Remove refrigerator, replace freezer w/ Energy Star appliance	$200
4. (B) Use one slushy machine 2 hours/day maximum	X
5. Replace indoor lights with LED lights	$100
6. Replace outdoor lights with LED lights	$100
7. (A) Remove outlets (only 12V system implementation, not 120V)	X
8. (B) Keep outlets, building runs on 120V	X
9. Change out all smoke and fire detectors to battery operated, 10 year units	$100
10. *(Optional)* Change indoor light switches to 60 minute mechanical timers	$50
11. *(Optional)* Change outdoor lights to dusk to dawn sensors	$50
TOTAL:	$600

	Before Conversion	After Conversion
Peak Power (kW)	4.4	0.16 (A) 3.7 (B)[33]
kWh (peak, 1-day)	24.6	1.9 (A) 5.7 (B)

TOTAL ENERGY/POWER REDUCTIONS

Peak power reduction	4,240 Watts (A)
	700 Watts (B)
Peak energy reduction (1-day, worst case)	22.7 kWh (A)
	19.0 kWh (B)

Solar System Design for Columbus Lodge

NOTE: Calculations for hardware below were determined based on adherence to the previously listed recommendations and a two-day energy storage requirement for Columbus Lodge of 4.4 kWh (A) or 13.0 kWh (B) (with a 15% factor of safety). Both SLA batteries and the Tesla Powerwall requirements are listed below.

[33] This peak load assumes the surge startup of the slushy machine and freezer, which are optional. The peak load could be as low as in case (A).

ITEM / UNIT (Option)	No. of ITEM	COST ($)
PV Panels (250W nominal) (A) PV Panels (250W nominal) (B)	2 4	200 400
Batteries (SLA, 12V, 100Ah, 30% discharge) (A)	13	2,600
Tesla Powerwall (120V, 13.5kWh) (B)	1	9,000
Inverter (500W, 12V) (A) Inverter (1.5kW, 120V) (B)	1 1	90 229
Charge Controller (30 Amps) (A)	1	80
		TOTAL (A): $2,970 **TOTAL (B): $9,629**

<u>Venture Lodge</u>

Actions	**Cost**
1. Replace electric stove with gas stove	$2,000
2. Replace microwave	$60
3. Replace AC Unit	$125
4. Replace Whirlpool fridge with Energy Star Appliance	$1,150
5. Replace indoor 3ft fluorescent lights with 18W LED	$720
6. Replace outdoor lights with 10W LED	$15
7. Change out all smoke and fire detectors to battery operated, 10 year units	$180
8. *(Optional)* Change indoor light switches to 60 minute mechanical timers	$50
9. *(Optional)* Change outdoor lights to dusk to dawn sensors	$50
TOTAL:	$4,350

	Before Conversion	After Conversion
Peak Power (kW)	28.0	8.6
kWh (peak, 1-day)	79.9	19.4

TOTAL ENERGY/POWER REDUCTIONS

Peak power reduction	19,400 Watts
Peak energy reduction (1-day, worst case)	60.5 kWh

Solar System Design for Venture Lodge

NOTE: Calculations for hardware below were determined based on adherence to the previously listed recommendations and a <u>two-day</u> energy storage requirement for West Lodge, 44.6 kWh (with a 15% factor of safety). Due to this, only a Tesla Powerwall solution is recommended and provided.

ITEM / UNIT	No. of ITEM	COST ($)
PV Panels (250W nominal)	16	1,600
Tesla Powerwall	4	36,000
Inverter (5kW, 120V)	1	339
		TOTAL: $37,939

West Lodge

Actions	**Cost**
1. Replace Freezer	$200
2. Replace full-size microwave	$60
3. Replace Coffee Pot	$20
4. Replace Hot Point refrigerator with Energy Star Appliance	$1,150
5. Remove Polar refrigerator	X
6. Remove Coffee Machine	X
7. Replace indoor 3ft fluorescent lights with LEDs	$650
8. Replace indoor incandescent lights with LEDs	$20
9. Replace outdoor lights with LEDs	$30
10. Change out all smoke and fire detectors to battery operated, 10 year units	$100
11. *(Optional)* Change indoor light switches to 60 minute mechanical timers	$50
12. *(Optional)* Change outdoor lights to dusk to dawn sensors	$50
TOTAL:	$2,330

	Before Conversion	After Conversion
Peak Power (kW)	21.5	10.4
kWh (peak, 1-day)	70.0	40.2

TOTAL ENERGY/POWER REDUCTIONS

Peak power reduction	11,100 Watts
Peak energy reduction (1-day, worst case)	29.8 kWh

Solar System Design for West Lodge

NOTE: Calculations for hardware below were determined based on adherence to the previously listed recommendations and a two-day energy storage requirement for West Lodge, 92.4 kWh (with a 15% factor of safety). Due to this, only a Tesla Powerwall solution is provided.

ITEM / UNIT	**No. of ITEM**	**COST ($)**
PV Panels (250W nominal)	33	3,400
Tesla Powerwall	7	63,000
Inverter (5kW, 120V)	2	678
		TOTAL: $67,078

APPENDIX I – PROJECT CONTACT LIST

Below is a list of key actors and contacts for our IQP:

2. Fred J. Looft - Project advisor, WPI ECE Professor, and instigator, installer, and maintainer for most of the individual solar systems currently installed at TVSR in East Camp, also subject matter expert (SME) on non-grid-tied smaller solar systems

   Email: fjlooft@wpi.edu C/T Phone: (508) 454-4996

3. Derren Rosbach - Project co-advisor, WPI Civil and Environmental Engineering Professor

   Email: drosbach@wpi.edu Phone: (508) 831-5826

4. Mike McQuaid - Chair, TVSR Facilities and Maintenance Committee

   Email: mfm3981@comcast.net

5. Mike Prifti - Campmaster

   Email: mikeprifti@gmail.com

6. Tom Chamberland - VP Program chair on Executive Board, liaison between WPI and TVSR

   Email: tchamberland301@gmail.com

7. James Dunn - WPI alumnus, retired electrical engineer, SME specialist in technology and solar systems, both grid- and non-grid-tied, as well as battery and other back-up systems

   Email: jpdunn1@charter.net

8. Matt McLaughlin - Camp Ranger

   Email: matt.mclaughlin@scouting.org

9. Suzanne LePage - WPI Sustainability Project Center Director

   Email: slepage@wpi.edu Phone: (508) 831-5598; (508) 831-5294

10. Paul Sweeney- TVSR Electrician, former MBTA electrician, Friends of Treasure Valley

    Email: type5guy@hotmail.com Phone: (508) 688-4970

APPENDIX J – CAMP USAGE DATA

Below is yearly and monthly electrical usage data for West Camp of TVSR in units of kilowatt-hours (kWh). The information was provided courtesy of Michael McQuaid, TVSR Maintenance and Facilities Chairman (2019).

Table 23: West Camp Electrical Usage by Month and Year (kWh)

Year	2009	2010	2011	2012	2013	2014	2015
January	2,000	1,400	1,200	1,400	1,400	1,400	1,400
February	1,800	1,200	1,400	1,200	1,600	2,000	1,460
March	1,400	1,800	1,400	1,200	1,000	1,000	
April	1,400	800	1,200	1,200	1,400	1,400	
May	1,000	1,000	1,000	1,000	1,600	1,000	
June	1,200	600	800	2,800	3,400	3,800	
July	2,600	3,000	2,400	3,400	3,600	3,400	
August	2,400	2,400	2,400	2,200	2,200	2,200	
September	1,400	2,200	600	600	600	200	
October	1,200	800	1,400	1,200	1,200	1,000	
November	1,000	1,000	600	1,400	200	1,600	
December	1,000	1,400	1,200	1,400	1,400	1,400	
Total	18,400	17,600	15,600	19,000	19,600	20,400	2,860
						AVERAGE	**18,433**

APPENDIX K – WEST CAMP RENTAL INFORMATION AND PRICING

Below is rental information organized by weekend from 09-03-2018 to 06-10-2019 for Venture Lodge and West Lodge in West Camp of TVSR. Building rental information in West Camp is only provided for Venture Lodge and West Lodge, as Columbus Lodge is not rentable. The information was provided courtesy of Michael McQuaid, TVSR Maintenance and Facilities Chairman (2019).

Table 24: Rental Information by Weekend for Venture Lodge and West Lodge

Weekend Date	Venture Lodge (# of Rentals)	West Lodge (# of Rentals)
2018-09-03	0	0
2018-09-10	0	0
2018-09-17	2	2
2018-09-24	2	2
2018-10-01	3	3
2018-10-08	3	3
2018-10-15	3	2
2018-10-22	3	3
2018-10-29	3	2
2018-11-05	2	2
2018-11-12	2	2
2018-11-19	0	0
2018-11-26	0	0
2018-12-03	3	3
2018-12-10	2	3
2018-12-17	0	0
2018-12-24	0	0
2018-12-31	2	3
2019-01-07	2	3
2019-01-14	2	2
2019-01-21	3	3
2019-01-28	2	2
2019-02-04	2	2
2019-02-11	3	2
2019-02-18	3	4
2019-02-25	2	2
2019-03-04	2	2
2019-03-11	2	2
2019-03-18	2	2
2019-03-25	2	2
2019-04-01	0	2
2019-04-08	2	0
2019-04-15	0	0
2019-04-22	2	2
2019-04-29	0	0
2019-05-06	3	3
2019-05-13	2	2
2019-05-20	0	0

Table 14 (cont.)

Weekend Date	Venture Lodge (# of Rentals)	West Lodge (# of Rentals)
2019-05-27	2	0
2019-06-03	0	0
2019-06-10	0	0
TOTAL	**68**	**67**

Below is information on the number of participants in West Camp including staff and various programs for the Summer of 2018. The information was provided courtesy of Michael McQuaid, TVSR Maintenance and Facilities Chairman (2019).

Table 25: West Camp Summer Participants

Camp Name	Number of Participants	Number of Weeks
Staff	25	5
Family Camp	30	1
Webelos Overnight Camp	140	4
Day Camp	300	4
TOTAL	**470 + 125 Staff**	**5**

Below are tables summarizing the pricing for rentals in West Camp (Table 19) as well as pricing for the Cub Scout Adventure Camp (CSAC, Table 20). The pricing varies based on the group type and length of stay for building rentals, and varies based on camp type, number of adults and youths, and length of camp for CSAC. From this pricing a high estimate and minimum estimate for yearly revenue in West Camp were determined.

Table 26: West Camp Building Rental Pricing

Building	Group Type	1 Day ($)	Weekend ($)
West Lodge	HNE Council Unit	150	300
	Out of Council Unit	150	300
	Non-BSA Group	200	400
	Council Group	0	0
Venture Lodge	HNE Council Unit	150	300
	Out of Council Unit	150	300
	Non-BSA Group	200	400
	Council Group	0	0

Table 27: Cub Scout Adventure Camp Pricing

	Family Camp ($)	Webelos ($)	Day Camp ($)
Scout + Adult Pair	200		
Add. Youth	75		
Add. Adult	75		
Full Week		350	
1/2 Week		300	
Adult		75	
Cub Scout Youth			250

The data provided by TVSR outlining rental information for both West and Venture Lodges from September 2018 to June 2019 is shown above in Table 17. During these months, Venture Lodge is scheduled for sixty-eight rental nights while West Lodge is scheduled for sixty-seven. Additionally, the two buildings operate daily for approximately five summer weeks to accommodate the following camps – Family Camp, Webelos Overnight Camp, and Cub Scout Day Camp.

The annual gross revenue of TVSR was determined based on the Cub Scout of Adventure Camp (CSAC, outlined in Table 18), which includes the Family Camp, Webelos Camp, and the Day Camp, and the weekend rentals throughout the year (Table 17). The cost of each building is published on the TVSR website [58]. While the rate to attend the 5-week CSAC Camp is a flat rate, the rental rate for non-CSAC camps vary as it is determined based on four criteria – lodge, group type, day(s), and weekend (Table 19). Based upon this, the gross yearly revenue of TVSR was estimated to be between $147,000 (minimum) and $178,000 (high). From this, it is evident that the year-round operations of TVSR West Camp is a significant portion of the TVSR revenue stream.

APPENDIX L – WEST CAMP PROPOSED INVENTORY

Below is an updated inventory of all power-requiring appliances in West Camp according to recommendations and assumptions made in our analysis. Like the original inventory, this includes all appliances, run times, total energy usage, average power, and 1-day as well as 2-day energy usages. Bolded appliances denote an updated, more efficient appliances found in Appendix G. These appliances are adjusted based upon lower and more efficient power values

Table 28: Columbus Lodge Proposed Inventory[34]

Lighting												
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**
Flood Lights	2	10.0	Y	N	N	12	0	0	8.4	0	0	8.4
Outdoor Lights	5	10.0	Y	N	N	12	0	0	21	0	0	21
Indoor Lights	15	5.0	Y	N	N	12	0	0	31.5	0	0	31.5
Ceiling Fan	1	12.0	Y	N	N	12	0	0	5.0	0	0	5.0

Power			
Avg CSAC PWR (W)	**Avg WKND PWR (W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
10.0	0	1.0	20.0
25	0	2.4	50.0
37.5	0	3.6	75.0
6	0	0.6	12.0

Sum (kWh)	65.9	0	0	65.9
Percent Yearly	100.0	0	0	

Sum (W)	78.5	0	7.5	157.0
1-Day Energy (kWh)	1.9	0	0.2	3.8
2-Day Energy (kWh)	3.8	0	0.4	7.5

[34] Christmas lights, ceiling fan, emergency detectors, ridge fan, slushy machines, fridge, and freezer are removed from the building, and, subsequently, this proposed inventory.

Table 29: Venture Lodge Proposed Inventory[35]

Lighting													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Bedroom Lights	16	18.0	Y	Y	N	4	4	0	40.3	108.3	0	148.6	48.0	48.0	17.0	288.0
Hallway/Other Lights	46	18.0	Y	Y	N	10	10	0	289.8	778.3	0	1068.1	345.0	345.0	121.9	828.0
Bathroom Lights	10	18.0	Y	Y	N	4	4	0	25.2	67.7	0	92.9	30.0	30.0	10.6	180.0
Ceiling Light w/ Vent	1	100.0	Y	Y	N	4	4	0	14.0	37.6	0	51.6	16.7	16.7	5.9	100.0
Outdoor Lighting	3	10.0	Y	Y	N	12	12	0	12.6	33.8	0	46.4	15.0	15.0	5.3	30.0

Other													Power			
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**	**Avg CSAC PWR (W)**	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Pest Control	3	1.9	Y	Y	Y	24	24	24	4.8	12.9	49.9	49.9	5.7	5.7	22.1	5.7
Water Boiler Monitor	1	2-168.0	Y	Y	N	4	2	0	5.6	7.5	0	13.1	6.7	3.3	1.5	168.0
Heating System	1	0.2 - 0.5 HP	N	Y (minus summ)	Y (minus summ)	0	10 (7 months)	8 (7 months)	0	225.0	684.0	684.0	0	156.3	133.9	375.0

[35] Well pump, emergency detectors, electric stove, and the projector are removed from the building, and, subsequently, this proposed inventory.

Table 23 (cont.)

Appliances												
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**
Refrigerator	1	16-710.0	Y	Y	Y	24	24	24	21.5	57.7	224.1	224.1
Microwave	1	700.0	Y	Y	N	1	1	0	25.4	68.2	0	93.6
Air Conditioner	1	35-520.0	Y	N	N	24	0	0	240.9	0	0	240.9

Power			
Avg CSAC PWR (W)	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
25.6	25.6	25.6	710.0
30.2	30.2	10.7	700.0
286.8	0	27.5	520.0

Sum (kWh)	680.1	1397.0	958	2713.3
Percent Yearly	25.1	51.5	35.3	

Sum (W)	809.6	675.8	381.9	3904.7
1-Day Energy (kWh)	19.4	16.2	9.2	93.7
2-Day Energy (kWh)	38.9	32.4	18.3	187.4

Table 30: West Lodge Proposed Inventory[36]

Items	No.	Wattage (ea)	CSAC (5 weeks)	WKNDs (YR Round)	YR Round	Run Time CSAC (hr/day)	Run Time WKND YR Round (hr/day)	Run Time YR Round (hr/day)	Total Energy CSAC (kWh)	Total Energy WKND (kWh)	Total Energy YR Round (kWh)	Yearly Use (kWh)	Avg CSAC PWR (W)	Avg WKND PWR(W)	Avg Yearly PWR (W)	Max PWR Non Surge (W)
Lighting													**Power**			
Entrance Light	1	10.0	Y	Y	N	4	2	0	1.4	1.9	0	3.3	1.7	0.8	0.4	10.0
Porch Lights	3	10.0	Y	Y	N	12	12	0	12.6	33.8	0	46.4	15.0	15.0	5.3	30.0
Outdoor Light	2	10.0	Y	Y	N	12	12	0	8.4	22.6	0	31.0	10.0	10.0	3.5	20.0
Back Outdoor Light	1	10.0	Y	Y	N	12	12	0	4.2	11.3	0	15.5	5.0	5.0	1.8	10.0
Hallway Lights	8	18.0	Y	Y	N	18	12	0	90.7	162.4	0	253.2	108.0	72.0	28.9	144.0
Kitchen Lights	14	18.0	Y	Y	N	12	2	0	105.8	47.4	0	153.2	126.0	21.0	17.5	252.0
Bedroom Lights	8	18.0	Y	Y	N	14	14	0	70.6	189.5	0	260.1	84.0	84.0	29.7	144.0
Male Bathroom Lights	4	18.0	Y	Y	N	12	10	0	30.2	67.7	0	97.9	36.0	30.0	11.2	72.0
Female Bathroom Light	1	18.0	Y	Y	N	12	10	0	7.6	16.9	0	24.5	9.0	7.5	2.8	18.0
Ceiling Lights (steady)	10	14.5	Y	Y	N	18	12	0	91.4	163.6	0	254.9	108.8	72.5	29.1	145.0
Ceiling Lights (variable)	4	14.0	Y	Y	N	18	12	0	35.3	63.2	0	98.4	42.0	28.0	11.2	56.0
SpotLights	3	8.0	Y	Y	N	18	12	0	15.1	27.1	0	42.2	18.0	12.0	4.8	24.0
Storage Closet Light Bulb	1	5.0	Y	N	N	1	0	0	0.2	0	0	0.2	0.2	0.0	0.0	5.0
Basement Fluor. Lights	28	18.0	Y	Y	N	10	10	0	176.4	473.8	0	650.2	210.0	210.0	74.2	504.0
Basement Lights (Dirt Foor)	6	5.0	N	N	N	0	0	0	0	0	0	0	0	0	0	0

[36] Emergency detectors, projector, air-conditioning units, fridge, large microwave, coffee pot, dish washer, and storage coffee machine are removed from the building, and, subsequently, this proposed inventory.

Table 24 (cont.)

Other												
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**
Thermostat	2	1.0	Y	Y	Y	24	24	24	1.7	4.5	17.5	17.5
Loudspeaker	4	50.0	Y	N	N	0.5	0	0	3.5	0	0	3.5
Basement Heating System	1	0.2 - 0.5 HP	N	Y (minus summ)	Y (minus summ)	0	10 (7 months)	6 (7 months)	0	225.0	569.3	569.3
Upstairs Heating System	1	0.2 - 0.5 HP	N	Y (minus summ)	Y (minus summ)	0	10 (7 months)	8 (7 months)	0	225.0	684.0	684.0

Items	Power			
	Avg CSAC PWR (W)	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Thermostat	2.0	2.0	2.0	2.0
Loudspeaker	4.2	0	0.4	200.0
Basement Heating System	0	156.3	111.4	375.0
Upstairs Heating System	0	156.3	133.9	375.0

Appliances												
Items	**No.**	**Wattage (ea)**	**CSAC (5 weeks)**	**WKNDs (YR Round)**	**YR Round**	**Run Time CSAC (hr/day)**	**Run Time WKND YR Round (hr/day)**	**Run Time YR Round (hr/day)**	**Total Energy CSAC (kWh)**	**Total Energy WKND (kWh)**	**Total Energy YR Round (kWh)**	**Yearly Use (kWh)**
Hot Point Fridge	1	200-500.0	Y	Y	Y	24	24	24	34.8	93.5	363.1	363.1
Mini Freezer	1	10-450.0	Y	Y	Y	24	24	24	23.0	61.8	240.0	240.0
Toaster	1	680.0	Y	Y	N	0.5	0.5	0	10.9	29.3	0	40.2
Storage Coffee Pot	1	750.0	Y	Y	N	0.5	0.5	0	15.1	40.6	0	55.7
Food Warmer	1	1500.0	Y	N	N	12	0	0	646.6	0	0	646.6
Storage Microwave	1	700.0	Y	Y	N	1	1	0	22.7	61.0	0	83.7

Items	Power			
	Avg CSAC PWR (W)	**Avg WKND PWR(W)**	**Avg Yearly PWR (W)**	**Max PWR Non Surge (W)**
Hot Point Fridge	41.4	41.4	41.4	500.0
Mini Freezer	27.4	27.4	27.4	450.0
Toaster	13.0	13.0	4.6	680.0
Storage Coffee Pot	18.0	18.0	6.4	750.0
Food Warmer	769.7	0	73.8	1500.0
Storage Microwave	27.0	27.0	9.6	700.0

Sum (kWh)	1408.2	2021.7	1874	4634.4
Percent Yearly	30.4	43.6	40.4	

Sum (W)	1676.4	1009.2	631.2	6966.0
1-Day Energy (kWh)	40.2	24.2	15.1	167.2
2-Day Energy (kWh)	80.5	48.4	30.3	334.4