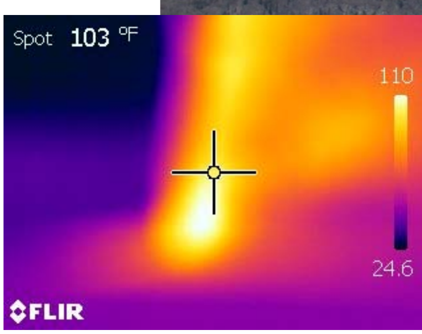
# Yellowstone National Park Facilities Energy Management Audit and Recommendations





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# Executive Summary

Yellowstone National Park has a difficult challenge ahead in dealing with rising energy costs and concerns of carbon emissions. To deal with this challenge, Yellowstone has tasked itself with reducing its energy consumption by 15%, fossil fuel consumption by 18%, and greenhouse gas emissions by 30% below 2003 levels. The University of Michigan team spent 18 months conducting a facility energy audit on 25 buildings within the park with the goal of adding the park's green team to achieve these goals. The goals also included providing building specific energy improvement recommendations that could be applied to similar buildings, and exploring policies hindering the development of renewable energy resources in the park.

To achieve these goals, data was collect about each building from several different sources. Two years of historical energy use data was gathered in the form of electricity bills and fuel invoices. Use and maintenance information was collected through interviews with key building and maintenance personnel. Each building was audited for building envelope characteristics, HVAC systems, lighting layout and design, and other industrial electronics. This was done by surveying the buildings in person and looking at building blueprints when available. The building surveys included an infrared camera audit which allowed the team to "see" issues areas in the building envelope and systems. Recommendations were developed by looking for improvements in equipment, building envelope, maintenance practices, building use and behavior, and lighting.

While each building was analyzed, several common park wide recommendations became apparent. These included lighting upgrades, weather stripping and caulking, maintenance, vending machine management, smart power strips, monitoring and benchmarking, and behavioral changes.

Lighting upgrade recommendations take advantage of recent reductions in LED, CFL, and T5 light prices. Upgrading to these lighting types reduces energy consumption and overall demand, while maintaining lighting intensity and quality. These upgrades may not be cost effective to perform in the near term, but it is important to consider these lighting technologies in any future renovations or new construction. Other lighting upgrades include installing occupancy sensors in common areas and installing photo sensors near windows to reduce artificial lighting when there is ample sunlight.

Maintaining weather-stripping and caulking is important to minimize the building leaks. The pictures taken with the infrared camera revealed that this maintenance was lacking in many of the buildings. Improving the maintenance schedule will greatly reduce the energy consumed by a building's HVAC system. Many of the vending machines in the park are old and run continuously. New vending machines have sensors that reduce the energy consumed when there are few or no people using the machine. Old vending machines can be upgraded with off-the-shelf-components to reduce their energy use. Similarly to the vending machine upgrades, smart power strips reduce the amount of energy consumed by "vampire" loads, or loads caused by electronics that are plugged in, but not turned on. These strips work by shutting down the outlets on the strip when specified equipment is turned off, like a workstation computer.

Current park practices of tracking electricity bills and fuel invoices do not accurately and sufficiently monitor how and where energy is being used. Current practices also do not allow for establishing a good baseline or benchmarking against other buildings of similar type. Using a program like Energy Star Portfolio Manager allows for quality benchmarking, as well as increasing the viability of energy use. Improving the systems that use energy in a building is only partially the solution. Changes in how the occupants use the building is just as important. To address this, the team recommends variety of techniques to better education the park staff on energy management programs and on how to include the park staff in future energy management improvements.

In addition to the park wide upgrades, it is recommended that the Gardiner Heritage Center establish a more extensive program to maintain the seals on the cold storage equipment in the building. Infrared pictures of the equipment indicated that some units where leaking more cold air than others. Similarly, upright freezers should be considered for upgrades to Energy Star rated chest freezers. This may not be cost effective for newer upright units, but should be considered for any future freezer purchases.

The lower Mammoth residences are currently being upgraded, but extra care should be taken to verify that wall insulation is present. It was observed in an infrared picture that a small strip of insulation was likely to be missing in #562. Appliances upgrades are also recommended for all residences.

The Mammoth Community Center is a prime example of how building uses change over time and how this creates a building which uses an excess of energy. Many electronic devices were found throughout the building and a thorough audit should be done to remove all unused and unnecessary electronics. Boiler pipes should be insulated as it was found with the infrared camera that much of the heat was emitted into the boiler room itself. From an overall building use perspective, the Community Center has much of its space unused, yet those spaces are still being heated. Considerations should be made on either modifying the builds systems to allow for these spaces to be shut down completely, or renovating the building to better suit its current uses.

The Mammoth Fleet Operations Garage is a large consumer of energy in comparison to the other buildings audited. This allows for a large impact when energy efficiency measures are implemented. Although, the nature of the work being performed in the garage bays makes major changes to the energy systems difficult. Current heating units in the work bays are hung from the rafters and attempt to heat the entire space. Upgrading these to allow for heating of the works would allow for a large reduction in energy consumption. Similarly to the Community Center, the boiler pipes supplying hot water to the building should be insulated.

The YCC facilities, both dorms and the mess hall, are buildings where use varies seasonally. Upgrading heating systems to radiant propane heating, replacing the electric baseboard heaters along with insulating hot water pipes, and reducing hot water heaters set points are all simple steps to reduce the energy consumption of these buildings. Other advanced upgrades to these buildings include occupancy and motion sensors on all common area lighting, and heat recovery from walk-in freezers and refrigerators.

While most of the buildings audited are older, the Old Faithful Visitor Center is a new, LEED Gold certified building, but there are still energy improvements that can be made. These improvements are centered on developing a better understanding of how the energy management systems in the building can be deployed.

The Canyon Visitor Education Center, while being recently renovated, has several opportunities to reduce its energy use. The lighting systems used on the education displays do not utilize many new bulb technologies, the lighting in the building is not considering the natural light in the building, and older HVAC and AHU components could be supplemented with variable frequency drives to improve their energy performance.

Being off the grid, the Lamar Buffalo Ranch already had many energy efficiency measures in place. However Lamar does not have an accurate understanding of how much energy it consumes and when it is using this energy. Currently, the amount of energy produced by the solar array must be back calculated based on generator run time and propane use is calculated from propane delivery invoices. These techniques only allow for the accuracy of energy use to be on a yearly time scale. Additional metering would allow for a large increase in accuracy, as well as better inform decisions about expanding renewable energy production and upgrades to the generator systems.

The park has a wide variety of water treatment facilities which all make use of large batteries of pumps performing various tasks. Pumps which are regularly throttled by valves, cycled on and off to control flow and output, or which are run intermittently for maintenance reasons could use less energy by installing variable frequency drive control. There are electronic units which control the electricity inputs to a pump and control the flow and output of the pump. When a pump does not have this control, while on, it uses the maximum amount of energy it is rated for. Variable frequency drives reduce the energy demands when pump demands are also reduced.

This project also considered how the park can institutionalize sustainable practices in order to improve its existing environmental management strategies. The park's sustainability efforts are currently led by the park's Green Team, which is a small interdisciplinary group based in the Mammoth administrative area. Although this group has done many things to improve sustainability in the park, there is still room for improvement. This group should include a wider coalition of park employees in order to make sustainability a park-wide priority and more achievable goal. The Green Team should consider working more closely with the departments in the park, and outside of the park, that plan, design, and maintain the built environment at the park. This includes the planning department, the Denver Service Center, interpretation and exhibit design, as well as maintenance and operations. Developing a broad interdepartmental strategy to improve sustainability at multiple scales will eliminate many of the problems between building design and function that the team noticed at the park.

While the primary purpose of this project was to reduce energy demand within the park, the team also developed a guide to help the park consider renewable energy options in order to increase the park's supply of electricity. Developing renewable energy in the park is a measure to both significantly mitigate and adapt to climate change. There are many limitations on developing renewable energy within the park, such as historic preservation areas and concerns about viewsheds. However, there are also many areas within the park that are zoned as administrative areas that the park should prioritize for these types of projects. Technology such as solar photovoltaics, solar hot water, small wind turbines, and hybrid systems would be appropriate for most administrative areas within the park. However, before moving forward with a renewable energy strategy, the park should either negotiate a better rate for net generation from the electric company or develop energy storage capabilities. While the National Park Service has prioritized off-grid areas for renewable energy development, because it is usually much cheaper than a grid connection, this is not the best strategy to reduce the park's carbon footprint. Because the local grid is very carbon intensive, in order to more meaningfully address climate change mitigation the park should prioritize renewable energy development in on-grid areas.

# Acknowledgements

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# Table of Contents

# List of Tables



# List of Photos

# List of Charts

# Abbreviations

AC – Alternating Current
AHU – Air Handler Unit
BTU – British Thermal Unit
CFL – Compact Fluorescent Lamp
$C0_2$ – Carbon Dioxide
DC – Direct Current
DOI - Department of the Interior
DSC – Denver Service Center
EPA – Environmental Protection Agency
GHG – Greenhouse Gas
HDD – Heating Degree Days
kW – Kilowatt
kWh – Kilowatt Hours
HVAC – Heating Ventilation Air Conditioning
LED – Light Emitting Diode
LEED – Leadership in Energy and Environmental Design
NEPA – National Environmental Policy Act
NPS – National Park Service
PV – Photovoltaic
SHW – Solar Hot Water
VEC – Visitor Education Center
VFD – Variable Frequency Drive
WECC – Western Electricity Coordinating Council
YA – Yellowstone Association
YCC – Youth Conservation Corps

# Introduction

Yellowstone National Park was established as the world's first national park in 1872. The national park was established under President Ulysses S. Grant to forever be preserved and "dedicated and set apart as a public park or pleasuring ground for the benefit and enjoyment of people."[1] Before that time, the region was home to many Native American tribes because of the rich hunting grounds, which include bear, gray wolf, bison, elk, moose, pronghorn and many additional species of mammals, birds, fish and plants. [2,3,4]

The park spans over 2,219,789 acres and is primarily located in the state of Wyoming, and also extends into Montana and Idaho. The park is situated over an active volcano and includes 10,000 thermal features and more than 300 geysers. The Yellowstone Lake, the largest high-altitude lake in the U.S., can also be found within the park's borders.

The National Park Service maintains 1,678 buildings within the park. These facilities service a variety of purposes including visitor education, rangers stations, hospitality, employee housing, administrative services and many more. Given that buildings consume 39% of all energy annually in the U.S., there is enormous potential to reduce Yellowstone's environmental footprint and generate savings by focusing on building energy improvements.[5] Currently, the parks facilities utilize a variety of energy sources including propane, diesel fuel, solar power, and hydro power for heating and electricity, although the majority of electrical power is being generated by a single NorthWest Energy power plant, which is located north of the park in Montana. Thus making the task of gathering data, analyzing the results, developing solutions, and executing the improvements a monumental task.

In October 2009, President Barak Obama signed Executive Order 13514, which requires all federal agencies, including the park, to measure and reduce their energy consumption:

> "It is therefore the policy of the United States that Federal agencies shall increase energy efficiency; measure, report, and reduce their greenhouse gas emissions from direct and indirect activities; conserve and protect water resources through efficiency, reuse, and storm water management; eliminate waste, recycle, and prevent pollution; leverage agency acquisitions to foster markets for sustainable technologies and environmentally preferable materials, products, and services; design, construct, maintain, and operate high performance sustainable buildings in sustainable locations; strengthen the vitality and livability of the communities in which Federal facilities are located; and inform Federal employees about and involve them in the achievement of these goals."

However, the park's interest in reducing its energy consumption stems not only from the Executive Order, but also from conservation groups, including the National Parks Conservation Association and Greening Yellowstone, who have identified the park as especially vulnerable to the negative effects of climate change. These negative effects include an increased risk of forest fire, extreme weather events, and regional electrical demand. The park is particularly vulnerable to these effects because it receives the bulk of its electricity from the single power plant. A forest fire in the region, extreme weather event, or a decrease in capacity of the plant will threaten the electric supply to the park and its functions.

Furthermore, Yellowstone has historically been a National Park Service leader in the environmental and cultural arenas. In 2008, Yellowstone developed a multi-year plan called the Yellowstone Environmental Stewardship (YES!) Initiative, which helps further leadership in land management and address the issues related to climate change. In line with these efforts, with the help of Ecos Consulting, the park set the following targets by 2016 using 2003 figures as the baseline[6]:

- Reduce greenhouse gas (GHG) emissions by 30%; and by 2025 achieve a 50% reduction in GHG emissions
- Reduce electricity consumption by 15%
- Reduce fossil fuel consumption by 18%
- Reduce water consumption by 15%
- Divert 100% of municipal solid waste from landfills

A team of five students from the School of Natural Resources and Environment at the University of Michigan, spent a year and a half working with Yellowstone National Park to identify opportunities to reduce facility energy usage from non-renewable sources. Energy audits were performed on each of the 25 buildings identified, located in four distinct areas of the park: Mammoth (Northwest), Canyon (Center), Old Faithful (Southwest), and Lamar (East). Data and information was collected through conference calls, spreadsheets, and an on-site visit over a ten-day period in May 2011. The purposes of this study are several:

- From the demand side, to provide reasonable building specific recommendations to improve the buildings' energy efficiency.
- From the supply side, to explore park service policies hinder the development of renewable energy projects within the park.
- To analyze and compare different technologies that will help the park reduce its overall energy consumption ranging from software management to renewable energy.

By having the School of Natural Resources and the Environment Team at the University of Michigan conduct a facility energy audit and investigate the possible implementation of renewable energy, the team is helping Yellowstone develop actions to achieve the 2016 targets.

The purpose of National Park areas is to preserve unique natural environments, and cultural and historic sites while also providing recreational and educational experiences for millions of visitors each year. Although these areas are often remote and far removed from urban centers, the park service must accommodate over 250 million visitors each year.[7] Park leaders must balance concerns about environmental conservation and historic preservation with the need to provide infrastructure and facilities for both visitors and employees. Additionally, planners and managers may also need to consider adjacent lands and regional concerns that may affect the park. In addition to the challenges that parks have traditionally faced, park leadership today must also consider the increasing impact of climate change on the region and the park. These concerns about climate change as well as increasing energy costs have increased the importance of improving energy efficiency and cultivating sustainable practices within the park. In order to reduce energy costs as well as to both mitigate and adapt to climate change, Yellowstone National Park should develop a holistic approach to sustainability and energy management and institutionalize sustainable practices park-wide.

This report also serves to guide the park planners and managers at Yellowstone to make better energy and sustainability decisions in order to both mitigate and adapt to climate change. Furthermore, the project seeks to guide the park in institutionalizing sustainability. By analyzing current DOI and NPS policies and practices regarding sustainability, this report can help park leaders make current environmental efforts be more robust and effective. While there have been policies enacted to support sustainability within YNP, there are still many challenges that keep sustainable practices and energy efficiency from being considered business as usual within Yellowstone and the NPS. Instead of becoming a part of park practices, these efforts are often considered to be isolated programs, or extra work, that employees are being asked to do. In addition, there are some Department of the Interior and National Park Service policies that do not support the goal of sustainability. It is essential that Yellowstone take an interdisciplinary and multi-scalar approach to sustainability in order to effectively change park policies and practices to both mitigate and adapt to climate change.

# Methods for Data Collection and Recommendations

## Data Collection

Yellowstone provided the team with a list of specific buildings to focus the analysis. These buildings represented a sample of the park's facilities, which would provide the basis for developing additional improvements for other buildings. Two years of electricity, propane, and diesel data was provided to the team by Yellowstone's Green Team. Additional reports and documents were made available to help the team understand park operations and previous environmental initiatives. The remainder of the data was collected on site during a 10-day site visit. With the exception of the Justice Center, whose high security measures prevented the team from investigating the majority of the building. The following information was collected for each building:

- Total occupancy
- Seasonal use
- Lighting
- Building envelope (including number and condition of doors, windows)
- Personal and industrial electronics
- Heating and cooling system
- Recent or planned maintenance

A Forward Looking Infrared (FLIR) camera was used during the audit to survey the thermal performance of the buildings. The camera uses digital technology that allows the user to "see" temperature differentials, which identify locations that are underperforming and are "leaking" hot or cold air into the building. These leaks can be located under doors and windows or on walls where there is poor insulation. (See Appendix A for more details on the use of thermal imaging for auditing building energy performance.) Finally, for each building, interviews with the park staff that use the space were conducted to better understand the occupancy and use patterns.

# Recommendation Development

The recommendations in the report were developed based on the data that the team collected. Chart 1 below shows the estimated energy consumption of U.S. commercial buildings.

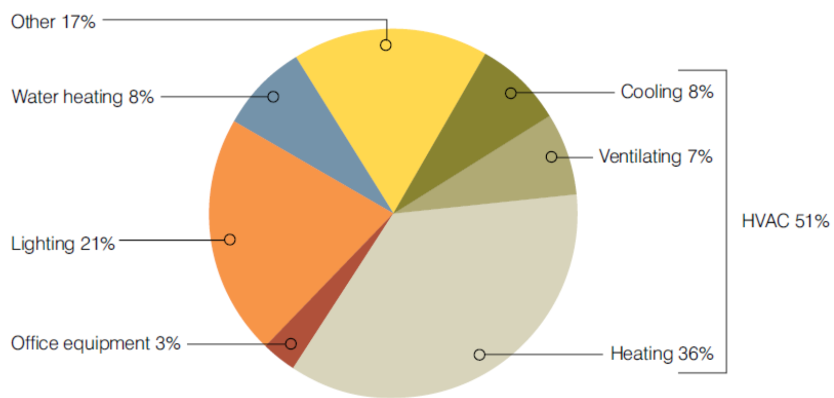



**Chart 1 – Estimated Consumption of U.S. Commercial Buildings in 2008**[8]

To touch on these items in at least one of the buildings, the team focused the recommendations around:

- Equipment – particularly large appliances that were left turned-on and drawing energy unnecessarily.
- Building Envelope and Maintenance – the use of the infrared camera was used to check window and door seals as well as exterior wall insulation properties.
- Behavior – ensuring that lights are turned off in well-lit rooms and that systems are not overridden by human behavior such as opening windows when the building is heating
- Lighting – upgrade lighting, especially since it is a relatively easy recommendation that can generate a large amount of savings. See Chart 2.

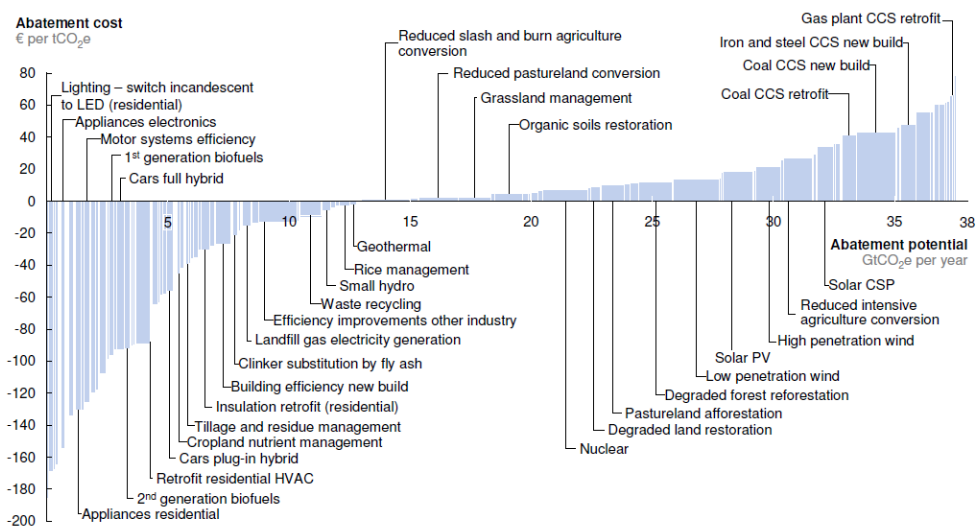



**Chart 2 – McKinsey Global Greenhouse Gas Abatement Cost Curve Beyond BAU - 2030**[9]

Energy management software was also surveyed in order to provide Yellowstone with an assessment of possible future options. Specifically, Tririga, an asset management software company, allowed the team to use its environmental software TREES to aid in the analysis. Building energy data was input into TREES as well as into Energy Star's Portfolio Manager. See Appendix B for a comparison of energy management software.

The buildings in the report are divided up into one of the following three categories:

- Priority 1: Buildings located in Mammoth as well as the two visitor centers and the Gardiner Heritage Center.
- Priority 2: Off-grid buildings located at the Lamar Buffalo Ranch.
- Priority 3: Treatment plants and lift stations; they are located in Canyon and Old Faithful areas.

Appendix C shows a map of the different locations.

One of the team's goals was to develop recommendations that could be applicable across a variety of building types throughout the park. The team therefore concentrated on Priority 1 buildings in this report, since those recommendations can be most easily applied to other buildings.

# Park Wide Recommendations

Regardless of function and use, there are a number of improvement options that can be implemented across all facilties. These opportunities can be explored not just at the facilities analyzed in this report, but should also be considered for all park facilites.

## Lighting

**Degree of Difficulty:** Medium

**Impact:** Low-Medium (varies by building)

**Potential Benefit:** Increased energy efficiency

Yellowstone National Park is currently upgrading facility lamps from T-12 to T-8. Such upgrades should continue to be pursued; however, it is recommended that in future renovations and facility upgrades, T-5 lamps be explored. Additionally, incandescent bulbs can be upgraded to LED bulbs. When replacing light bulbs, careful consideration should be made as to whether the light bulb needs to emit the same light intensity or if it can be replaced with a bulb that emits less light. Appendix D provides a list of recommended light levels for different uses (i.e. hallway, desk work, etc.). On the basis of our analysis, the following changes can be made for the respective light bulbs:

- T-8 to T-5 or Phillips Eco. T-8 or LED
- Incandescent bulb to CFL or LED
- Metal Halide (MH) to High Pressure Sodium (HPS)[10] or High Bay LED[11,12]

Table 1 quantifies the possible energy and cost savings that can be accrued by the respective buildings, by making any of the above mentioned changes. The calculations are based on the following assumptions:

- Average lighting demand is 10 hours/day, and Building usage is 300 days/year, implying a total usage of 3000 hours/year.
- Average cost of electricity is $0.10/kWh.
- Average Demand cost charged by the utility is $7/kW/month.

The savings are calculated as follows:

Annual Energy Cost Savings = [(Wattage of old bulb – Wattage of replacement)/1000] x No. of bulbs x Annual usage hours x Cost of electricity.  Annual Demand Cost Saving = [(Wattage of old bulb – Wattage of replacement)/1000] x No. of bulbs x Demand cost

Total Annual Savings = Annual Energy Cost Savings + Annual Demand Cost Savings

| Building Name | Current Bulb Type | No. of Bulbs | Replacement | Fixture Change | Total Load Reduction (kW) | Annual Demand Cost Saving ($/year) | Usage Hours | Electrical Energy Savings (kWh/ year) | Annual Energy Cost Savings ($/year) | Total Annual Savings ($/year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Heritage Center | F32 T8 | 2025 | F28 T5 | Y | 8.1 | 680.4 | 3000 | 24300 | 2430 | 3110.4 |
| | | 2025 | Phil. Eco T8 | N | 14.175 | 1190.7 | 3000 | 42525 | 4252.5 | 5443.2 |
| | | 2025 | 18 W LED | N | 28.35 | 2381.4 | 3000 | 85050 | 8505 | 10886.4 |
| Justice Center | F32 T8 | 154 | F28 T5 | Y | 0.616 | 51.744 | 3000 | 1848 | 184.8 | 236.544 |
| | | 154 | Phil. Eco T8 | N | 1.078 | 90.552 | 3000 | 3234 | 323.4 | 413.952 |
| | | 154 | 18 W LED | N | 2.156 | 181.104 | 3000 | 6468 | 646.8 | 827.904 |
| Residences | 75 W INC | 18 | 28 W CFL | N | 0.846 | 71.064 | 3000 | 2538 | 253.8 | 324.864 |
| | | 18 | 12.5 W LED | N | 1.125 | 94.5 | 3000 | 3375 | 337.5 | 432 |
| Community Center | F32 T8 | 266 | F28 T5 | Y | 1.064 | 89.376 | 3000 | 3192 | 319.2 | 408.576 |
| | | 266 | Phil. Eco T8 | N | 1.862 | 156.408 | 3000 | 5586 | 558.6 | 715.008 |
| | | 266 | 18 W LED | N | 3.724 | 312.816 | 3000 | 11172 | 1117.2 | 1430.016 |
| | 250 W - MH | 24 | 150 W HPS | Y | 2.64 | 221.76 | 3000 | 7920 | 792 | 1013.76 |
| | | 24 | 80 W High Bay LED | Y | 4.08 | 342.72 | 3000 | 12240 | 1224 | 1566.72 |
| | 100 W - INC | 5 | 26 W CFL | N | 0.37 | 31.08 | 3000 | 1110 | 111 | 142.08 |

| Building Name | Current Bulb Type | No. of Bulbs | Replacement | Fixture Change | Total Load Reduction (kW) | Annual Demand Cost Saving ($/year) | Usage Hours | Electrical Energy Savings (kWh/ year) | Annual Energy Cost Savings ($/year) | Total Annual Savings ($/year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Operations Fleet Garage | F32 T8 | 383 | F28 T5 | Y | 1.532 | 128.688 | 3000 | 4596 | 459.6 | 588.288 |
| | | 383 | Phil. Eco T8 | N | 2.681 | 225.204 | 3000 | 8043 | 804.3 | 1029.504 |
| | | 383 | 18 W LED | N | 5.362 | 450.408 | 3000 | 16086 | 1608.6 | 2059.008 |
| | 400 W - MH | 47 | 4 lamp T5 | Y | 12.408 | 1042.272 | 3000 | 37224 | 3722.4 | 4764.672 |
| | | 47 | 150 W High Bay LED | Y | 11.75 | 987 | 3000 | 35250 | 3525 | 4512 |
| | 250 W - MH | 14 | 150 W HPS | Y | 1.54 | 129.36 | 3000 | 4620 | 462 | 591.36 |
| | | 14 | 80 W High Bay LED | Y | 2.38 | 199.92 | 3000 | 7140 | 714 | 913.92 |
| YCC Dorms | F32 T8 | 302 | F28 T5 | Y | 1.208 | 101.472 | 3000 | 3624 | 362.4 | 463.872 |
| | | 302 | Phil. Eco T8 | N | 2.114 | 177.576 | 3000 | 6342 | 634.2 | 811.776 |
| | | 302 | 18 W LED | N | 4.228 | 355.152 | 3000 | 12684 | 1268.4 | 1623.552 |
| Old Faithful VEC | F32 T8 | 299 | F28 T5 | Y | 1.196 | 100.464 | 3000 | 3588 | 358.8 | 459.264 |
| | | 299 | Phil. Eco T8 | N | 2.093 | 175.812 | 3000 | 6279 | 627.9 | 803.712 |
| | | 299 | 18 W LED | N | 4.186 | 351.624 | 3000 | 12558 | 1255.8 | 1607.424 |

| Building Name | Current Bulb Type | No. of Bulbs | Replacement | Fixture Change | Total Load Reduction (kW) | Annual Demand Cost Saving ($/year) | Usage Hours | Electrical Energy Savings (kWh/ year) | Annual Energy Cost Savings ($/year) | Total Annual Savings ($/year) |
|---|---|---|---|---|---|---|---|---|---|---|
| Canyon VEC | F32 T8 | 125 | F28 T5 | Y | 0.5 | 42 | 3000 | 1500 | 150 | 192 |
| | | 125 | Phil. Eco T8 | N | 0.875 | 73.5 | 3000 | 2625 | 262.5 | 336 |
| | | 125 | 18 W LED | N | 1.75 | 147 | 3000 | 5250 | 525 | 672 |
| YCC Kitchen | F32 T8 | 196 | F28 T5 | Y | 0.784 | 65.856 | 3000 | 2352 | 235.2 | 301.056 |
| | | 196 | Phil. Eco T8 | N | 1.372 | 115.248 | 3000 | 4116 | 411.6 | 526.848 |
| | | 196 | 18 W LED | N | 2.744 | 230.496 | 3000 | 8232 | 823.2 | 1053.696 |
| | 400 W - MH | 1 | 4 lamp T5 | Y | 0.264 | 22.176 | 3000 | 792 | 79.2 | 101.376 |
| | | 1 | 150 W High Bay LED | Y | 0.25 | 21 | 3000 | 750 | 75 | 96 |
| | 100 W - INC | 27 | 26 W CFL | N | 1.998 | 167.832 | 3000 | 5994 | 599.4 | 767.232 |

Table 1 - Lighting Upgrades

Other than making these lighting upgrades, the park can also install dimmers, timers, and daylight or occupancy sensors to further cut energy costs towards lighting. These devices have to be connected to the electrical breaker box of the building to integrate them with the lighting circuit. These recommendations are further discussed in building specific recommendations. A brief description of these opportunities is given below:

Photosensor - These are electronic control units that automatically detect ambient light and automatically adjust the output level of artificial lights using a dimming ballast. Energy savings can vary widely depending on natural light availability.

Dimmer - A device that varies the voltage running to a lamp in order to reduce or increase lighting intensity. These can be manual (controlled by occupants) or electronic (controlled by a photosensor).

Occupancy/Motion Sensor – These are used in indoor spaces to control electric lighting, and turn lights off when no motion is detected for a pre-set period of time, and turn them on when motion is detected. These sensors can save significant amounts of energy in buildings that have spaces that are often unoccupied or where occupancy varies frequently through the day. However, they must be positioned correctly to respond to movement anywhere in the spaces they serve. It is also important to maintain the ability to override the automatic controls if necessary.

Timer – These automatically turn off lights, appliances, and irrigation systems and usually come with a switch that has a button or a knob that turns on the respective device for a preset amount of time.

# Maintenance

## Weather-stripping/Caulking for Exterior Doors and Windows

**Degree of Difficulty:** Medium

**Impact:** Medium

**Potential Benefit:** Reduce energy consumption

Decreasing air infiltration at exits and windows reduces energy costs. Ideally, a blower test would be conducted to get an accurate estimate of air infiltration (see Appendix A for more information on blower tests). Even without accurate estimates, the team was able to find air leakages with the infrared camera, therefore it is recommended to install weather stripping/caulking at exits and windows. This recommendation applies to all buildings, but it was particularly observed through infrared in the Canyon VEC and the YCC buildings.

This is a relatively inexpensive upgrade; however, typical payback period for the cost incurred for installing the weather-stripping can be estimated at approximately one year.[13] This can be expected to lead to the energy savings of 15% of total heating energy and 4% of cooling energy.[14]

The U.S. Department of Energy provides a concise table comparing different weather-stripping types. The table includes the best uses for each, their advantages and disadvantages, and their average cost. The information can be found at the following website: www.energysavers.gov/your_home/insulation_airsealing/index.cfm/mytopic=11280.

# Equipment

## Removing / Upgrading Vending Machines

**Degree of Difficulty:** Low

**Impact:** Medium

**Potential Benefit:** Reduce vampire energy

Vending machines have to be plugged in 24 hours a day in order to provide a service instantly if desired. However, they are only used for a few seconds each time. A vending machine, if left on all the time, can cost up to $380 per year.[15] Many utilities offer rebates for buying VendingMisers. Unfortunately, there are no rebates available in Montana or Wyoming. Idaho's Avista utilities offer a $90 rebate per miser and Rocky Mountain Power offers $75 per miser.[16] By installing a motion sensor, you can save up to 30-50% of the cost.[17] The cost of a VendingMiser is about $170, although it varies depending on the specific type needed for the machines in the building.[18]

A vending miser consists of a motion sensor and the miser itself (see Photo 1 below). The vending machine and the motion sensor are plugged into the VendingMiser, which is attached to a wall and plugged in to a power outlet. No physical changes are needed for the vending machine apart from drilling a hole near the top of the vending machine to fit the motion sensor.[19]


Photo 1 – VendingMiser

This device cuts power to the vending machine when the area is unoccupied, and hence stops the compressor and turns off the lights. It also monitors room conditions and allows the machine to operate as required. Usually, the sensor cuts power to the vending machine after the area has been vacant for 15 minutes. Generally, the device is designed so that a machine located in a 70ºF room will be shut down for up to two hours if no one walks by. Afterwards, the machine is turned back on to run a compressor cycle, after which it turns back off if the occupancy sensor indicates that the area is still vacant. This allows the beverages to stay cool even if no one walks by the vending machine for several hours. When someone approaches the machine, the sensor sends a signal to turn the lights and other electronic components back on, and the compressor runs a cooling cycle if needed. The controller ensures that after the machine is re-powered, the compressor is allowed to run a complete cooling cycle before it is powered down again. A sensor also determines whether the compressor is running and prevents the machine from shutting down until the cycle has been completed. Both of these features ensure that a high-pressure start, which would strain the compressor, does not occur.[20]

There are three vending machines in use throughout the Fleet Operations Garage. If it is determined that the machines are not often utilized, it is recommended that they be removed or they be condensed into one machine.

The YCC Kitchen has a vending machine as well. On certain days, the building is only used at meal times. This is the ideal situation for the vending machines to be replaced with a machine that utilizes a motion sensor to reduce the time the compressor is running.

The National Park Service has tested the VendingMiser at the Whitman Mission National Historic Site on a small Cavalier, six amp soda machine. The power consumption was recorded over a week and the vending machine averaged 2.43 kWh/day. Once the VendingMiser was installed, the energy consumption was reduced to 1.29 kWh/day, a 47% reduction, "with no effect to the temperature of the soda product."[21]

The situation becomes more complex in that the vending machines are owned by the concessionaires, not the park. If the park wants to reduce its overall energy conception, getting the concessioners on-board and including them in the dialogue, will be most beneficial for all parties.

## Smart Power Strips

**Degree of Difficulty:** Low

**Impact:** Medium

**Potential Benefit:** Reduce vampire energy

Offices and homes are the ideal locations to use smart power strips. These power strips are particularly helpful when a piece of equipment (such as a computer) has several related accessories (such as a printer, speakers, etc.). High-technology sensors know when the main piece of equipment (plugged into the control outlet) is no longer running and automatically switch off the peripherals instead of leaving them in “stand by” mode. The accessory equipment will automatically turn back on when the main equipment is running again. In the case of the Smart Strip brand, sensitivity of the strip can be adjusted and work with the computer’s “sleep mode.” There are also outlets on the power strip (constant hot outlets) that allow equipment to receive constant power and will not be turned off. These strips, which are also surge protectors, cost between $25-$45 each.


Photo 2 – A 10-Outlet LCG3 Smart Strip

## Monitoring and Benchmarking

**Degree of Difficulty:** Low

**Impact:** High

**Potential Benefit:** Increase understanding of energy use patterns, identify opportunities for further improvements

Energy monitoring throughout the park is inconsisent. Electricty data is taken from the utility bills. These bills are based on the reading of the electicty meters, which is not done consistantly. Many of the building meters are difficult to access during the winter months so they are not read and the park is billed on an estimate of energy consumed. In the spring, the meters are read and the billing is adjusted based on actual useage. Similarly, propane and heating fuel usage is taken from the tank trucks’ invoices. The tank trucks come on irregular intervals and tanks are filled when they are below a certain level. This also makes for inaccurate usage data since it is not certain how full the tank was filled or how empty the tank was before. Additionally, some buildings share fuel tanks and electricty meters.

It is difficult to manage what you don't measure. Consequently, installing electrical energy and gas meters at each building would provide the opportunity for improved monitoring and understanding. However, to be effective, a schedule for reading the analog meters must be initiated. Once full energy consumption data for both heat and electric are available, potential savings can be identified, capital expenditures can be justified, increased consumption can be detected, and billing errors can be identified. See Appendix E for details on metering equipment options.

Energy benchmarking is imperative to understand how a building is performing from one year to the next. Energy Star Portfolio Manager is one possibility to manage energy. It will generate a score automatically; however, it requires 12 months of consecutive data as well as a base year, to compare the data to. The score is based out of 100 points and the higher the score, the better the building is performing. A score of 75, for example, indicates that the building is performing better than 75% of similarly designed buildings. Another tool that can be used for energy benchmarking is the energy use index, which is calculated by dividing the kWh by the square footage of the building. This allows buildings of different sizes and uses to be compared to one another. The EUI does not have an upper range for the score, but the lower the score, the better the building is performing.

The following table shows the EUI and Energy Star Portfolio Manager scores. It is important to note that the scores in the following table cannot be taken for face value since certain buildings are missing months of data. A more detailed description of Energy Star Portfolio Manager can be found in Appendix A.

| | Energy Use Index (kWh/sq. feet) | Energy Star Portfolio Manager Score |
|---|---|---|
| **MA Fleet Operations** | 6* | N/A |
| **MA Mess Hall** | 29 | N/A |
| **MA Community Center** | 4 | 75 |
| **MA Residences 562** | 1* | N/A |
| **MA Justice Center** | 8 | 73 |
| **MA YCC North Dorm** | 8 | 94 |
| **MA YCC South Dorm** | 12 | 79 |
| **MA Heritage Center** | 12 | 53 |
| **OF VEC** | 6* | N/A |
| **Canyon VEC** | 2* | 85 |

* Buildings that have at least one missing month of data between April 2010 and March 2011

**Table 2 - Energy Use Index and Energy Star Portfolio Manager Score Comparison**

The chart below plots the various buildings on a EUI-energy consumption graph. An EUI energy plot tries to depict the fact how certain buildings can have a high EUI despite having low energy consumption, or vice-versa. This plot helps identify the best candidates for performing a detailed energy audit, and prioritizing our buildings. The buildings that lie in the top right quadrant of the graph should be the high priority buildings, since they would have a high EUI and also have high overall energy consumption (MA Mess Hall in this case). Whereas buildings which lie towards the bottom end of the bottom right quadrant, can be given a relatively lower priority since although their overall consumption is high, their EUI is low, and hence they are likely to have a smaller scope for improvement, and accordingly, a smaller return on energy saving investments made towards them. However, we must keep in mind that the scale of this graph is as per the limited sample of buildings that we are evaluating. Adding new buildings to this plot can change our reference points, and accordingly our analyses.

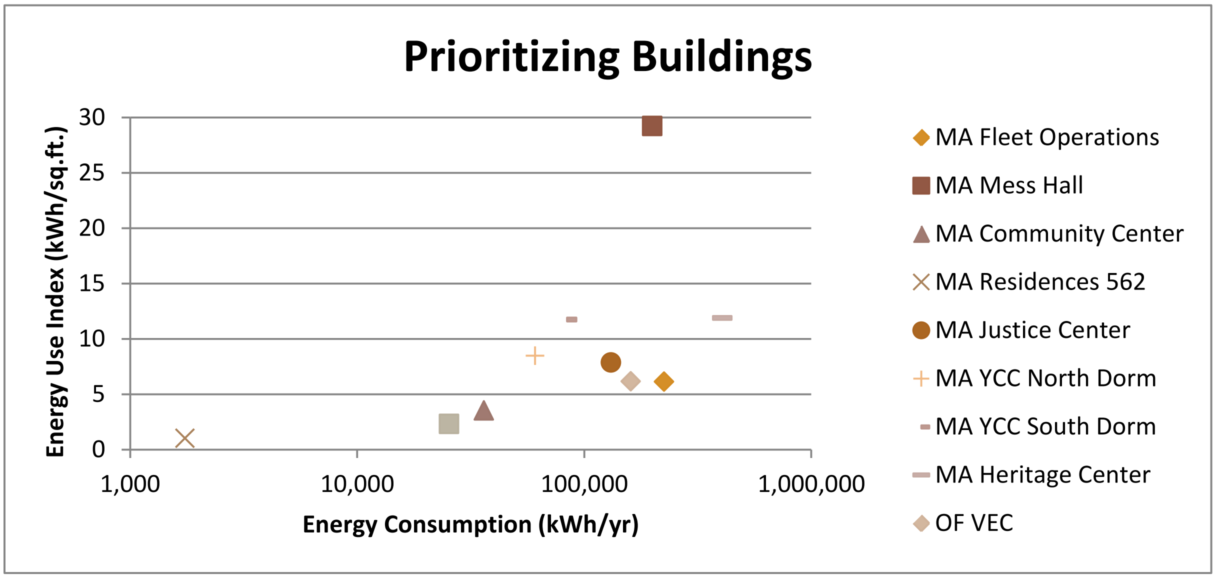



**Chart 3 - Prioritizing Buildings**

A final item to keep in mind when doing energy accounting in Yellowstone are the heating degree days (HDD). "A HDD is a measure of how much (in degrees), and for how long (in days), outside air temperature was lower than a specific "base temperature."[22] Looking at HDD allows the user to identify whether the building might be using more or less energy than the previous year because of the weather or due to changes in its use. See Appendix F for the degree-day weather correction calculation.

## Behavior

**Degree of Difficulty**: Low

**Impact**: High

**Potential Benefit**: Increase energy efficiency awareness, reduce energy consumption

An energy management program will be the most successful if it includes the following:

- Management support- Management should support and set the tone for the program. By emphasizing the importance of the program by communicating to employees its purpose and the desired results, this can motivate employees to participate. Management has the power to make energy conservation a priority in all departments and can also require necessary inter-departmental coordination to overcome barriers.
- Program branding – Branding will give the program a long-term value and be more successful. For example, ENERGY STAR is a well-known logo.
- Outreach – Mammoth, the Canyons, Lamar, and Old Faithful are dispersed, but there should be constant communication between the locations. Currently, energy education programs are being implemented in Lamar and should be expanded to other areas of the park as well.
- Employee participation – The Green Team is already formed, but all of the park's employees, staff, and residents should participate in energy reduction. In particular, each employee should be responsible for the following energy saving strategies:
    - Turning off lights when they are the last person to leave a room
    - Unplugging unused electronic equipment to reduce vampire electricity
    - Shutting off the computer monitor when not in use, even for 15 minutes
    - Utilizing task lighting rather than full room lighting when appropriate
- Maintenance issues reported - Any maintenance issues such as burnt out lamps, broken or cracked windows, faucet leaks, broken appliances and air leaks around doors and windows, etc. should be reported.
- Reward system in place– Giving a reward to the person/team for the greatest amount of energy conservation and/or most creative idea that reduces energy use. Rewards incentivize energy conservation habits by providing a clear signal about positive behavior. Rewards do not need to be monetary and could include an organization or city-wide recognition for achievement.

Potential communication and education avenues include:

- Employee training events and workshops- During yearly or on-boarding training, employees can be introduced to the program and taught about reduction strategies.
- Signage- Signage at specific locations including community boards, common areas such as break rooms and conference rooms, and near doorways to remind staff to turn off lights and equipment after use. Example signage is included in Appendix G.
- Feedback - Any initiative to conserve energy cannot succeed unless the employees are made aware of how much energy is being used and the progress that is made through their behavior changes. Feedback about energy use for employees in each building is critical to making behavior changes. Better metering and reporting about energy use will make employees aware of how much energy they consume each year. This information could be

used to create energy conservation competition between different park areas, buildings, or floors within a building to further drive reductions in energy use.

- Suggestion boxes – Encouraging employees to use the suggestion box could be a way to get creative solutions to decrease energy consumption. It would involve other employees besides the Green Team ones and could be anonymous. It might also help with reporting maintenance issues.
- Continued announcements in team meetings and emails that include behavior project introductions, feedback, project progress reports, and green tips.

Initiatives like these involve minimal costs and would also successfully increase the existing HVAC system's performance.[23] A Carbon Trust case concluded that such behavioral changes lead to a minimum 5% savings in energy usage, though other studies place this estimate at a much higher percentage of up to 25-30%.[24]

**Photo 3 – Coffee Pot Plugged in at Old Faithful**

# Building Specific Recommendations

## Gardiner Heritage Center

The park has a long historic past which has been documented in archeological findings. The Heritage Center was built in 2005 as a storage and research facility for these artifacts. It includes research labs, cold storage facilities, an archive, and office space. Twelve park employees work there year round, but seasonal staff adds 12 more during the summer months. The building is 34,100 square feet and is located outside of the park in Gardiner, Montana near the park's northern entrance.

Photo 4 – Gardiner Heritage Center[25]

## Equipment

### Opportunity 1 – Cold Storage Maintenance

**Degree of Difficulty**: Low

**Impact:** Low-Medium (based on regular maintenance)

**Potential Benefit:** Increase energy efficiency

Establish maintenance procedures to keep all cold storage freezers and refrigerators working at peak performance and maximum efficiency. These procedures include:

- Scheduled inspection and replacement of seals and seats on all units
- Quarterly consolidation of freezer items in order to shut down unused and underused equipment
- Scheduled annual defrost of manual defrost units

It is estimated that inspections will take about 15 minutes per unit, and that the replacement of seals will take about 60 minutes and cost approximately $110 per seal set replacement.[26]

## Opportunity 2 – Upgrade Storage Freezers

**Degree of Difficulty**: Medium

**Impact:** Low

**Potential Benefit:** Reduce electrical energy consumption

Replacing upright freezers with manual defrost chest freezers will reduce building energy usage and electrical costs by approximately $100 per year. However, this upgrade will require a capital investment of $1,500 resulting in a payback period of 15 years, assuming the freezer runs for 360 days a year and a price of electricity of $0.10 per kWh, which extends beyond the expected life of the freezer (10 years).[27] This makes upgrade not cost effective, but when considering the addition or replacement of freezers, manual defrost chest freezers should be strongly considered.

# Gardiner Heritage Center Photos

Photo 5 - Lights on Near Windows in Gardiner Heritage Center Lobby

Photo 6 - Library Entrance

Photo 7 - Exterior Hallway

Photo 8 - Pipes

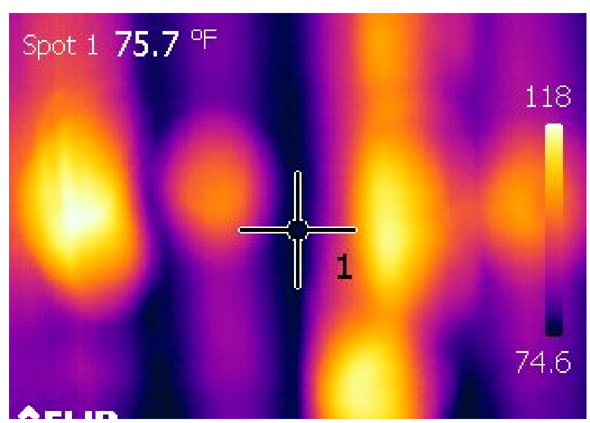



Photo 9 - Thermal Image of Photo 8

Photo 10 – Pipes

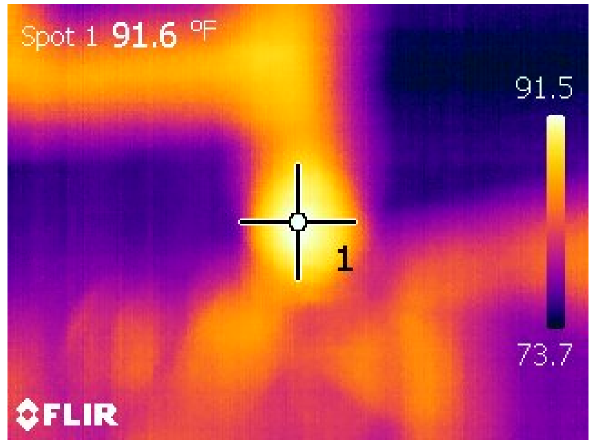



Photo 11 – Thermal Image of Photo 10

Photo 12 – Storage Refrigerator

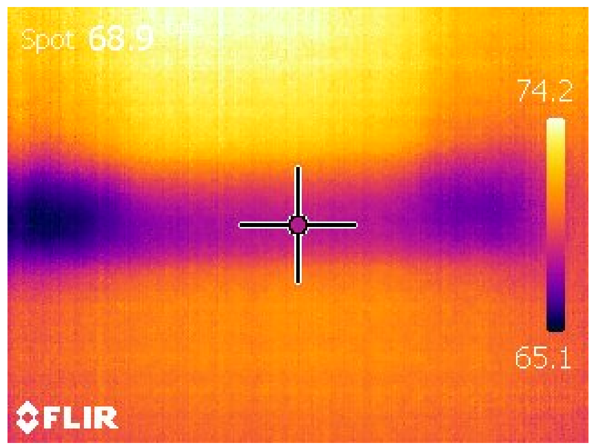



Photo 13 – Thermal Image of Photo 12

## Mammoth Justice Center

The Justice Center in Mammoth serves as the seat for a federal judge. The building was replaced in 2008 to update the building for post 9/11 security measures, which include metal detectors, baggage x-ray scanners, and bullet proof walls. These are some of the largest users of energy in the building in addition to the elevator located in the building. The building is 16,700 square feet and contains the judge's chambers, a courtroom, and offices for the federal marshals, which are the security force. The building is located in Mammoth at the historic fort Yellowstone and is used throughout the week and on some weekends year round.

**Photo 14 – Mammoth Justice Center**[28]

The recent construction and the limited access have restricted the recommendations to those identified under Park Wide Recommendations. These include replacing T-8 lamps with T-5 lamps, installing meters to monitor propane usage, and educating employees and staff on energy saving behaviors.

# Lower Mammoth Residences (551 & 562)

The park staff residences in lower Mammoth were built in 1963, but have recently been going through a series of upgrades and remodels. The single family homes all have a similar design and layout with each being 1700 square feet, three bedrooms, 1.5 bathrooms, and have about eight foot ceilings. They are equipped as a typical household with a washer, dryer, dishwasher, in window A/C units, and a central hot water heater. They are located in the Mammoth area just east of the historic fort.

The team looked at two of the residences. Residence 551 is currently going under renovation. Residence 562 was recently renovated and has new front and rear doors, new insulation in the front rooms, right side, and partially in the back.

Photo 15 - Lower Mammoth Residence

## Maintenance

### Opportunity 1 – Verify That Wall Insulation is Present and Suitable

**Degree of Difficulty:** High

**Impact:** Low-Medium

**Potential Benefit:** Reduce heat loss

Based on an infrared image, there is missing insulation on a narrow strip of the wall between the window and the cupboard in Residence 562. However keeping in mind that Residence 562 has recently been renovated, it is probably not worth it to add in the insulation at this time, since opening up the wall would require labor, be expensive, and be cumbersome. However, it is recommended that Yellowstone should remember to insulate well on small surfaces (i.e. between windows and cabinets) in new construction or when undertaking renovations in any other future buildings.

## Equipment

### Opportunity 2 – Appliances

**Degree of Difficulty:** Medium

**Impact:** Medium

**Potential Benefit:** Reduce electrical energy consumption

Since Residence 562 has recently been renovated and all the appliances that have been installed therein, like the heating unit, dryer and water tank already carry an Energy Star rating and are energy efficient, therefore it is not recommend to replace any of the appliances in the near future. It is recommended that all other residences, including Residence 551, have similarly efficient appliances.

## Lower Mammoth Residence Photos

Photo 16 - Front, Exterior of Residence

Photo 17 - Back, Exterior of Residence

Photo 18 -Missing Insulation Strip Between Window and Cabinet

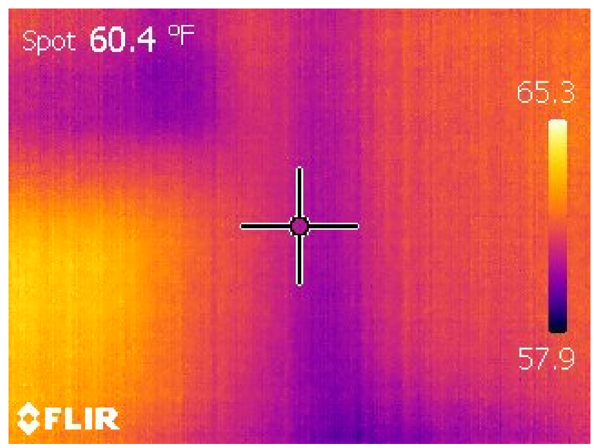



Photo 19 - Thermal Image of Photo 18

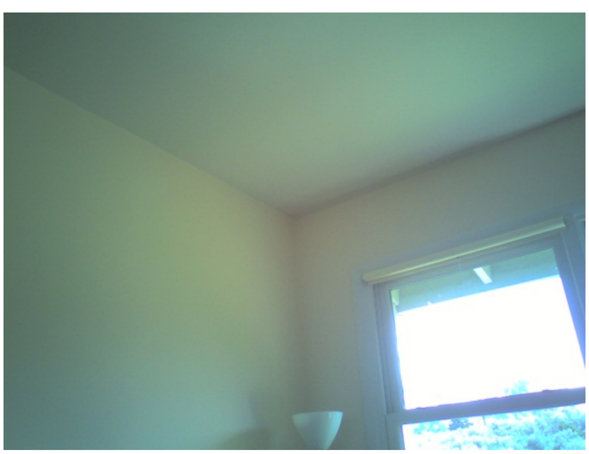


Photo 20 - Corner of Residence

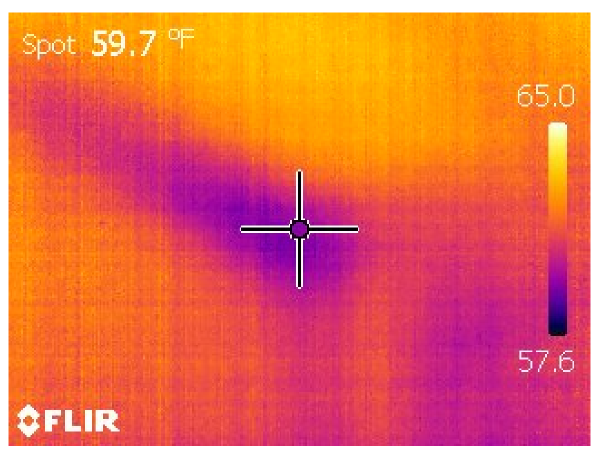



Photo 21 - Thermal Image of Photo 20

# Mammoth Community Center

Built originally as a school in 1963, the Mammoth Community Center is now used for church, community events, and staff training sessions. The building is 10,200 square feet including a full size basketball court, a workout room including exercise equipment, a small library, and five classrooms. The majority of the classrooms are used for storage. The building utilizes a heating fuel boiler for heating the building. The building is located in Mammoth next to the lower Mammoth Residences.

Photo 22 - Mammoth Community Center

## Equipment

### Opportunity 1 – Remove Unused Electronics

**Degree of Difficulty:** Low

**Impact:** Low

**Potential Benefit:** Reduce vampire energy

A number of electronics were observed throughout the facility including an electric stove with hood, a refrigerator, and microwave in the kitchen as well as a computer and copier in the library. It is recommended that the Yellowstone Energy Team inventory the electronic equipment in the Community Centers and monitor the usage of this equipment by asking visitors to track usage on a sheet provided. Once the usage data is collected, any unused and rarely used equipment should be removed and disposed of properly in an e-waste recycling program. This will reduce overall electricity usage by removing vampire electricity. At a minimum, rarely used equipment should be unplugged when not in use or smart power strips utilized.

### Opportunity 2 – Insulate HVAC pipes

**Degree of Difficulty:** Low

**Impact:** Low-Medium

**Potential Benefit:** Reduce heat loss

Thermal imaging in the boiler room revealed heat loss in excess of 25ºF from boiler outflow pipes. Insulating these pipes will result in a reduction of heat loss and maximize boiler efficiency.

# Building Envelope

## Opportunity 3 – Renovation

**Degree of Difficulty:** High

**Impact:** High

**Potential Benefit:** Reduce energy consumption

Of the five classrooms in the building, only two classrooms are utilized on a regular basis. Each classroom is about 32 feet by 32 feet (1024 square feet). This means that a large portion of the building, which still has equipment and requires heating, is rarely used (approximately 3000 square feet). Consideration should be taken to permanently shut down this unused portion of the building to significantly reduce energy usage and maintenance costs. A shut down would include installing valves to all water supply lines running to the unused rooms, so the line can be drained to remove danger of freezing. Also, all electrical circuits running to the unused rooms should be rewired so that they can be shut down at the main breaker box. Finally, the heating system would need to be reconfigured so that the unused space no longer receives heat from the boiler. These modifications do allow for the rooms to be reopened, if in the future there is a need for the space.

Alternatively, consideration should also be taken in demolishing and building a new facility more appropriate for the current usage as a community center. A new energy efficient facility should be designed with the specific use as a community center with meeting, recreation, and kitchen space.

# Mammoth Community Center Photos


Photo 23 – Pipes

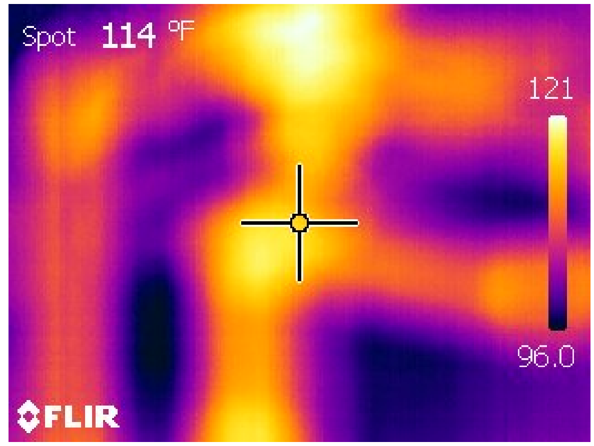



Photo 24 – Thermal Image of Photo 23


Photo 25 – Exterior Door in Gymnasium

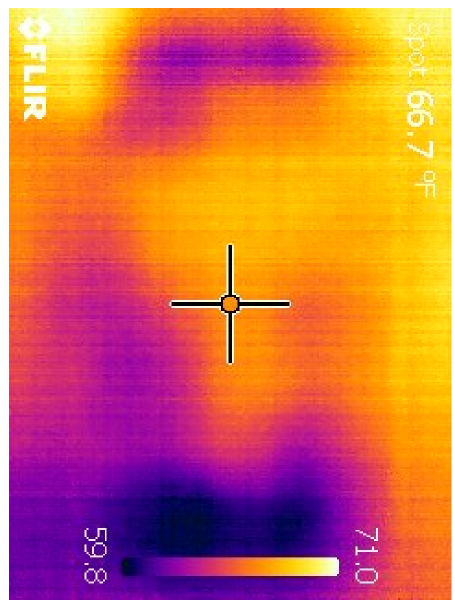



Photo 26 – Thermal Image of Photo 25

## Mammoth Fleet Operations Garage

Built in 1986, the Mammoth Fleet Operations building serves as the workshop for servicing and maintaining the park's vehicles. The building consists of two workshop bays on either side of an upstairs office space. The building is over 36,700 square feet with high bay ceilings and has large overhead doors for moving the equipment and vehicles in and out of the service bays. The major energy users in the building are heavy equipment used to service the vehicles. The building is used year round to a varying number of mechanics and office staff. The building is located in the Mammoth area near the YCC facilities.

Chart 4 shows the monthly electricity usage between April 2009 and March 2011. It is important to note the large increase in electricity usage after May 2010. At this point the electricity usage of the building more than tripled and has continued to increase steadily. Upon questioning, the Yellowstone Green Team was unable to verify why this had occurred. Energy monitoring and asking questions are the first steps in understanding how to decrease energy consumption.

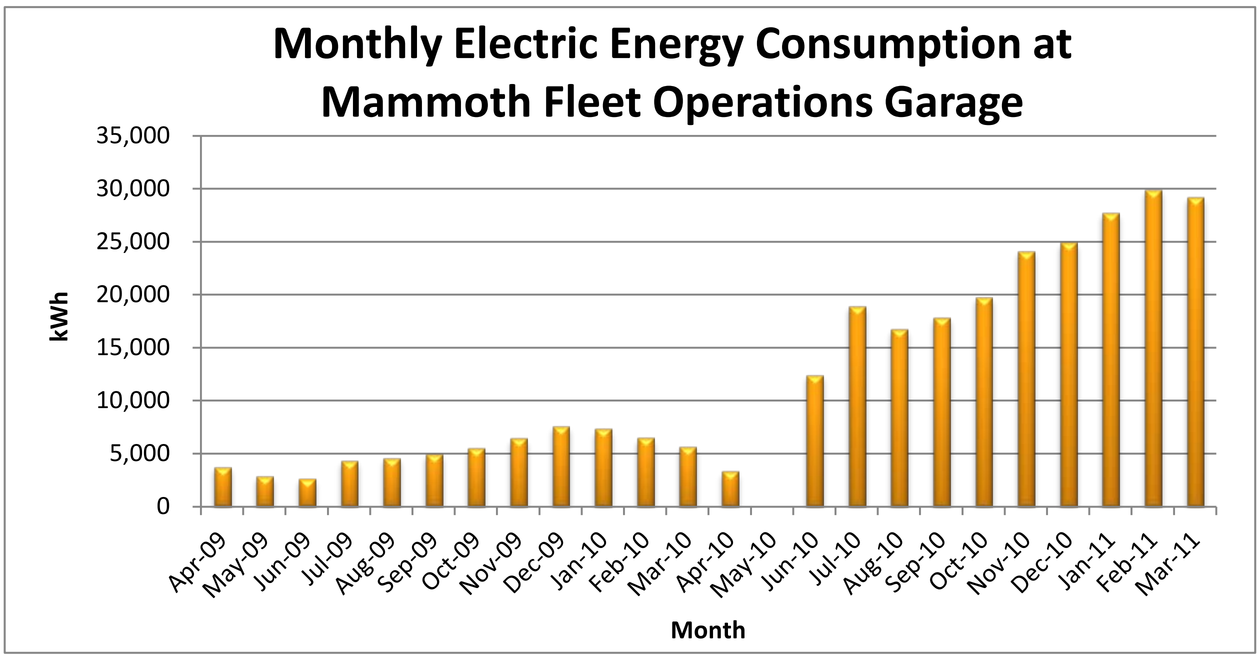



Chart 4- Electricity Consumption at Mammoth Fleet Operations Garage

# Equipment

## Opportunity 1 – Upgrade Heating System in Bays

**Degree of Difficulty:** Medium- High

**Impact:** Medium-High

**Potential Benefit:** Increase energy efficiency, reduce energy consumption

The current open flame heating system, which is hung from the rafters, is inefficient since a majority of the heat emitted from these units will rise to the ceiling and be lost from the roof. A gas-fired, low-intensity, infrared heating system could reduce energy consumption by 50% or more.[29] However, replacing a system before it has reached its end of life use is rather expensive and the payback low. As an alternative, industrial warehouse fans can be hung to force hot air downwards. By setting the fan to a clockwise rotation, it will push air near the ceiling where it is being heated, down toward the floor where it is needed. This will distribute heat more evenly throughout the bay and reduce the overall amount of propane that is needed to heat the space.

## Opportunity 2 – Insulate HVAC Pipes

**Degree of Difficulty:** Low

**Impact:** Low-Medium

**Potential Benefit:** Reduce heat loss

During the initial site walk-through of the facility, it was observed that the copper boiler outflow pipes were not insulated. Thermal imaging revealed the heat loss from these boiler pipes to be in excess of 35ºF (see Photos 34 & 35). These pipes should be insulated to reduce heat loss and maximize boiler efficiency.

## Mammoth Fleet Operations Garage Photos

Photo 27 – Upper Interior High Bay Garage Door

Photo 28 – Lower Interior High Bay Garage Door

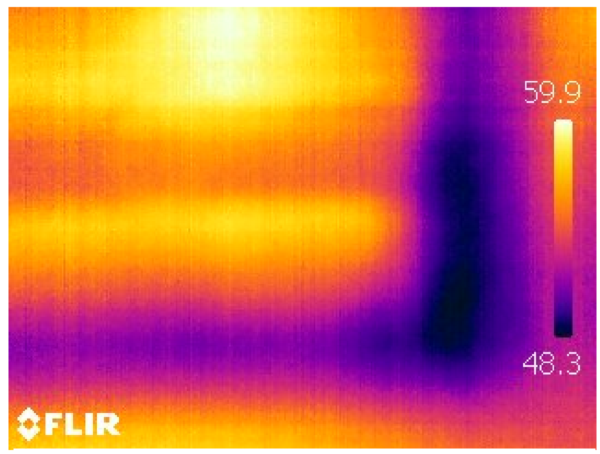



Photo 29 – Thermal Image of Photo 28

Photo 30 – Exterior Door

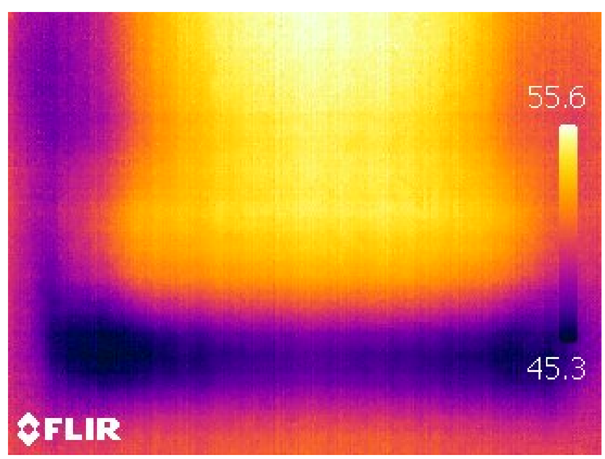



Photo 31 – Thermal Image of Photo 30

Photo 32 - Floor Near Water Fountain

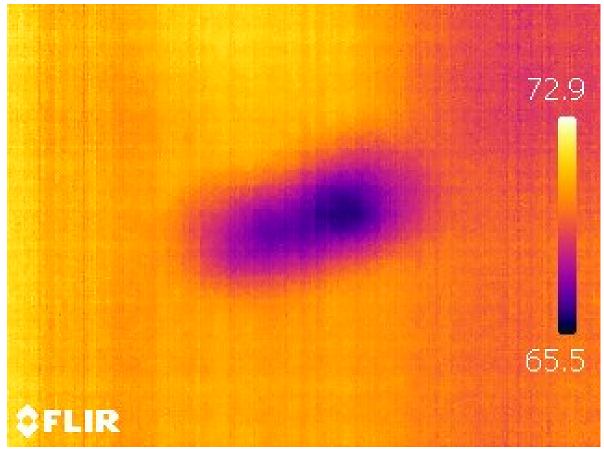



Photo 33 - Thermal Image of Photo 32 Reveals Water Spot

Photo 34 - Pipes

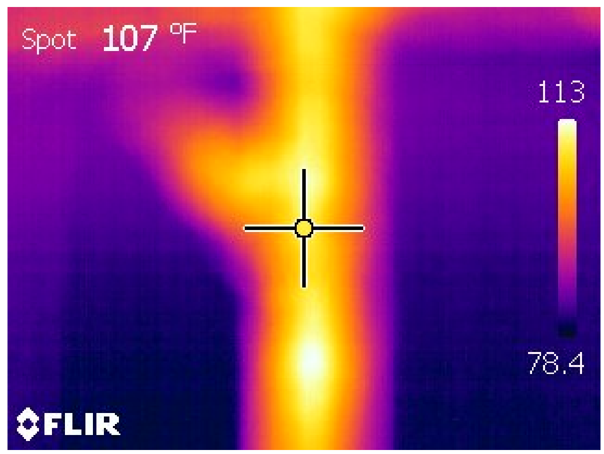



Photo 35 - Thermal Image of Photo 34

Photo 36 - Corner of Building Near Ceiling

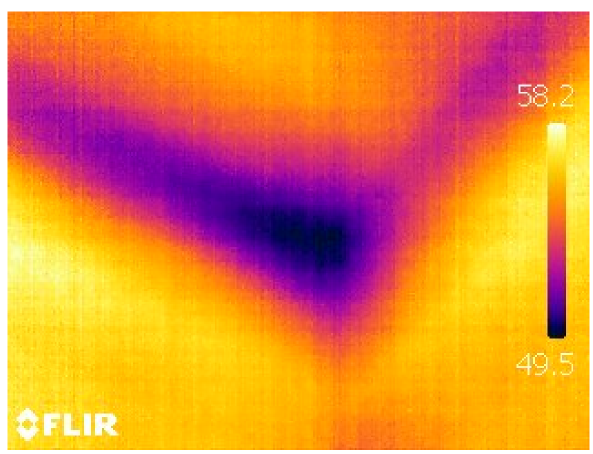



Photo 37 - Thermal Image of Photo 36

# Mammoth Youth Conservation Corps (YCC) Facility Kitchen

The YCC Facility Kitchen is used by the YCC to prepare and serve meals to the YCC guests and other park staff that may stay at the YCC dorms. Built in 1978, the building has an area of 6,800 square feet with a large open area used for seating and an industrial kitchen including a walk-in freezer, a walk-in refrigerator, and multiple ovens and ranges. The building is used year round, but only by a small staff that works in the one office. Throughout the spring and summer, it is used by 40 YCC volunteers and a full time cook. The building is located in the Mammoth area in the northwest corner of the park.

## Equipment

### Opportunity 1 - Use Radiant Heating and Propane

**Degree of Difficulty:** High

**Impact:** High

**Potential Benefit:** Reduce energy consumption

The YCC Facility Kitchen currently uses electric resistance heating to heat the facility. Because this is among the most expensive ways to heat a building,[30] a radiant heating system would be more efficient. There will be a logistical challenge to shift from resistance heating to radiant heating, as this would require laying hot water tubing, possibly through the building's floor, in baseboard radiators. This recommendation could also be a relatively expensive investment but is arguably an effective method to make the facility more energy efficient. Similarly to other buildings, propane should be used to heat water in the boiler, which could be then pumped through the tubes.[31] The cost-effectiveness of using propane or electricity as a heating source would depend on the relative costs of the two in the area.

Notwithstanding the cost, carbon dioxide ($CO_2$) emissions associated with propane in comparison to those associated with the electric grid for the same heat output are substantially lower. To elucidate, one gallon of propane[32] releases 12.17 pounds of $CO_2$ emissions and 27 kWh of usable energy.[33] At an assumed efficiency of 90% for a propane boiler,[34] emissions could be 0.50 pounds of $CO_2$ per kWh of heat energy from propane.[35] In comparison, electric heaters convert nearly 100% of electricity to heat[36] and the associated $CO_2$ emissions in the Western Electricity Coordinating Council (WECC) are 1.31 pounds of $CO_2$ per kWh.[37] Since, the $CO_2$ emissions associated with the grid are higher, from an overall perspective, propane would be a better option for heating, both in terms of cost as well as $CO_2$ emissions.

## Opportunity 2 - Insulate Hot Water Pipes and Heater

**Degree of Difficulty:** Low

**Impact:** Low- Medium

**Potential Benefit:** Reduce heat loss

It was observed that the hot water tank was not insulated. Insulating the hot water tank would be relatively easy to do and decrease the overall energy use of the building.

## Opportunity 3 - Lower Water Heating Temperature

**Degree of Difficulty:** Low

**Impact:** Medium

**Potential Benefit:** Reduce energy consumption

Since the dishwasher generates its own hot water, there is no reason to store a large supply of very hot water in the building only to wash hands. For each 10ºF reduction in water temperature, it is possible to save between 3%–5% in energy costs.[38] It is therefore highly recommended to bring about a change in usage and behavior of people using the water. This can be achieved by education and promoting awareness, and then reducing the water heating temperature.

| | TEMPERATURE | |
|---|---|---|
| Use | °F | °C |
| Hand washing | 105 | 40 |
| Showers and tubs | 110 | 43 |
| Commercial and institutional laundry | Up to 180 | Up to 82 |
| Residential type dish washing and laundry | 140 | 60 |
| Commercial spray type dishwashing—wash | 150 minimum | 65 minimum |
| Commercial spray type dishwashing—final rinse | 180–195 | 82–90 |

Table 3 - Hot Water Temperatures Required for Given Activities[39]

## Opportunity 4 – Recover Heat from Refrigerator Compressor

**Degree of Difficulty:** High

**Impact:** Medium-High

**Potential Benefit:** Increase energy efficiency

Heat could be recovered from the walk-in refrigerator compressor and be used for space heating or water heating. Most refrigerators run on a vapor compression refrigeration cycle, which is comprised of a compressor and a condenser, where the condenser is used to cool the refrigerant vapor. The heat absorbed in the condenser can be released into the room (in the case of an air cooled refrigerator) and hence used for space heating, or into a water cooling system (in the case of a water-cooled system) and recaptured using a heat recovery system to heat/pre-heat water to be used in the kitchen. A heat recovery system is comprised of three main components: 1) a heat exchanger (to transfer the heat from the condenser cooling water to the kitchen water), 2) pumps (to circulate water through the system at the appropriate flow level), and 3) safety controls (to ensure that the refrigeration equipment operates within the manufacturer's recommended temperature range).[40] Depending on the match between hot water use and condenser heat availability, the refrigeration system can replace about 25-40% of the water-heating energy.[41]

## Mammoth YCC Facility Kitchen Photos

Photo 38 – Refrigerator Exterior Door in Kitchen of YCC Facility

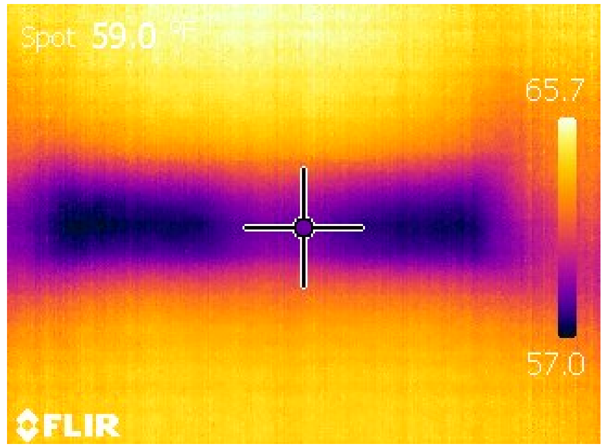



Photo 39 – Thermal Image of Photo 38

Photo 40 – Exterior Door Facing Dorms

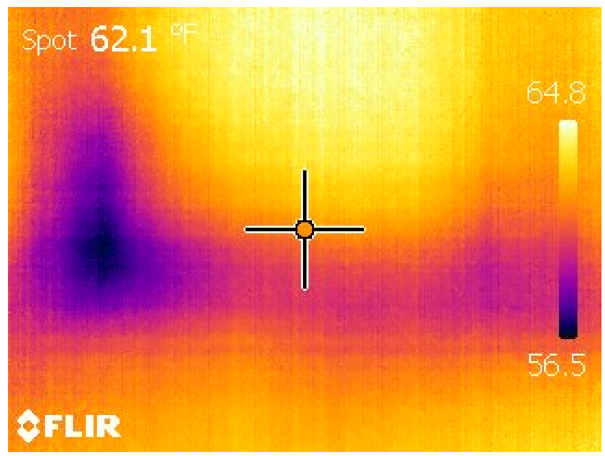



Photo 41 – Thermal Image of Photo 40


Photo 42 – Plugged in Vending Machine Without Mizer

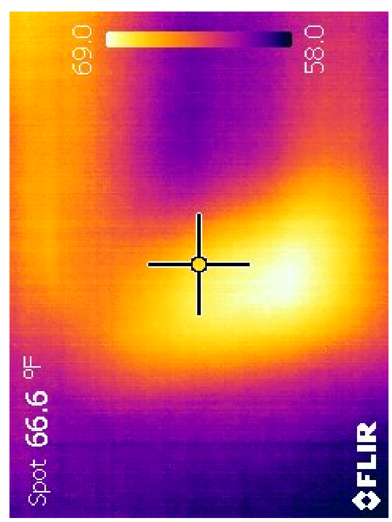



Photo 43 – Thermal Image of Photo 42

## Mammoth YCC Dorms

The YCC dorms are two 7,200 square foot buildings oriented north-south near the YCC Facility Kitchen. They are used to house temporary park staff throughout the year and the YCC volunteers during the summer. The buildings are the exact same footprint, but the internal layout is different. Combined, the dorms can house approximately 40 people. The northern building has multiple clothes washer and dryers, while the southern dorm has a kitchen with several refrigerators and other appliances. Both were built in 1978 and are located in the Mammoth area.

**Photo 44 – Mammoth YCC Dorms**

Chart 5 below shows the monthly electricity consumption of the Mammoth YCC Dorms between April 2009 and March 2011. It is important to note the seasonal variability of consumption. During the winter months, the electricity usage is significantly higher, even though there are much fewer people utilizing the facility.

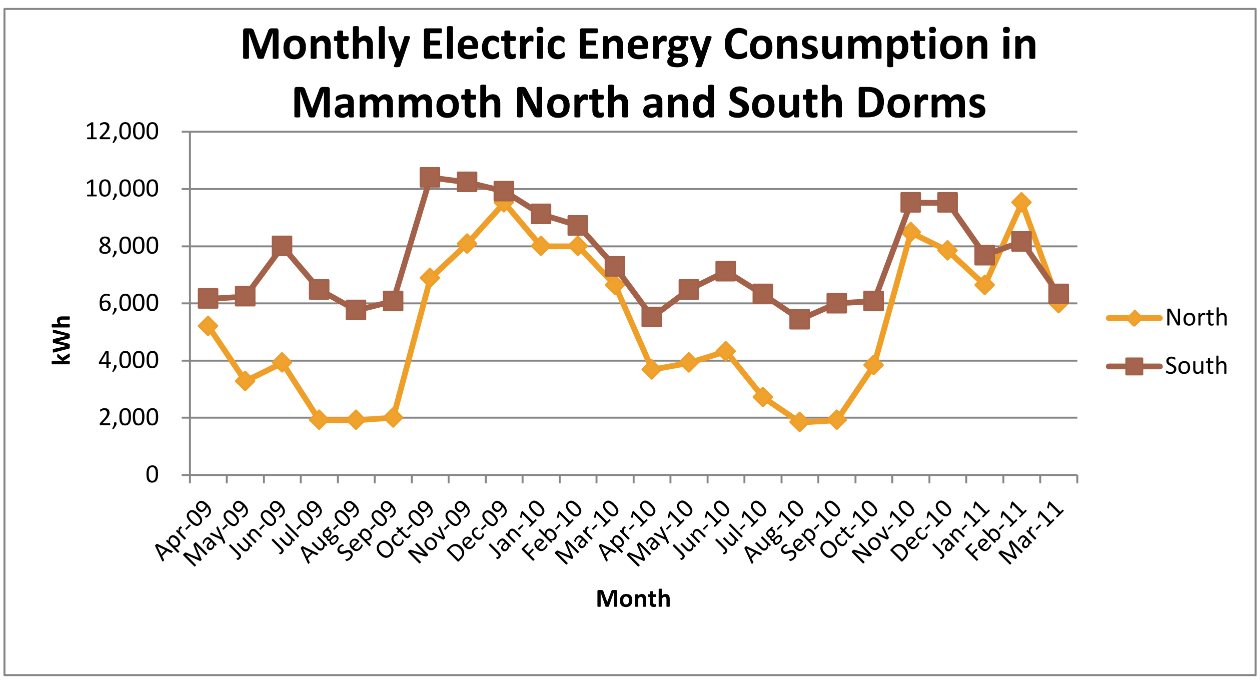



**Chart 5 - Electricity Consumption at Mammoth YCC Dorms**

# Lighting

## Opportunity 1 - Motion/Occupancy Sensors

**Degree of Difficulty:** Low

**Impact:** Medium

**Potential Benefit:** Reduce electrical energy consumption

Both dorms have common rooms and hallways that stay illuminated almost 24 hours a day. It was observed that some lights in the dorms cannot be turned off manually. Installing occupancy sensors would allow the lights to turn off automatically when no one is using the space. According to the State of California's Green California initiative, the typical payback period for occupancy sensors (before rebates) is two to three years, and can lead to 30% to 80% energy savings when installed in common areas like corridors.[42]

Typical costs of such sensors are in the range of less than $30 to $130 depending on whether the sensors are wireless or wired. Installing the wired sensors would require an electrician with experience in residential and commercial wiring practices. In comparison, some self-powered wireless sensors do not require additional wiring and are thus easy to install and even combine occupancy sensing technology with self-powered solar cells and wireless technologies.[43]

# Equipment

## Opportunity 2 – Repair Bathroom Heater-Fans

**Degree of Difficulty:** Low

**Impact:** Low

**Potential Benefit:** Reduce electrical energy consumption

The switches of the heater-fans in the south dorm were broken, and therefore extremely hard to turn on or off. Fixing these switches would incentivize people to switch them off after use and hence prevent its wasteful use and save electricity. An occupancy sensor with a separate main switch could also be potentially installed here, so that the fans can be switched-off in the summer months, when they are not required.

### Opportunity 3 – Rationalize the Heating

**Degree of Difficulty:** High

**Impact:** High

**Potential Benefit:** Reduce energy consumption

The heating is electric. Propane heating could be considered for the Dorms similarly to the YCC Facility Kitchen. This will not only save energy, but also reduce $CO_2$ emissions.

### Opportunity 4 – Lower Water Heating Temperature

**Degree of Difficulty:** Low

**Impact:** Medium

**Potential Benefit:** Reduce energy consumption

Similarly to the YCC Facility Kitchen, the water heating temperature should be lowered as much as possible in the YCC Dorms (see Table 3 for more detail on recommended hot water temperatures for given activities).[44] We observed uninsulated pipes and these should be should also be insulated in order to increase efficiency.

## Monitoring

### Opportunity 5 – Understand Energy Use Disparity Between the Dorms

**Degree of Difficulty:** Low

**Impact:** Medium

**Potential Benefit:** Understand energy consumption

As shown in Chart 5 above, the north dorm uses less electricity than the south dorm. In the 2009-2010 and 2010-2011 billing years, the south dorm used 44% and 39% more electricity respectively than the north dorm. This could have been due to two reasons. Firstly, more appliances might have been plugged in and used in the south dorm's kitchen. The south dorm had a CRT television set, eight refrigerators (out of which just two were unplugged), two smaller refrigerators (both of which were unplugged at the time of survey), five stoves, two microwaves and two toaster ovens, while the north dorm had two washers and dryers each. Secondly, the south dorm might have had a higher occupancy than the north dorm.

The north dorm however uses about 71% of its annual electricity in the six winter months (October through March) as compared to the south dorm, which uses about 58% during that same period. It is possible to conclude that the north dorm uses more electricity for heating than the south dorm.

It is recommended that if the north dorm has lower occupancy in the winter months, Yellowstone should try to use only the south dorm, and completely switch off the heating in the north dorm. This will lead to an efficient use of resources, space, and energy.

Also in the south dorm kitchen, all the refrigerators were not being used to their full capacity. It is recommended that the refrigerators should be used in proportion to occupancy and actual need. The remaining refrigerators should be unplugged, and only plugged back in when required for use. An inspection schedule should be organized to check the contents of the refrigerators in order to consolidate items to as few refrigerators as is reasonable and unplug those which are empty.

This analysis indicates that the park can monitor the occupancy of these buildings more closely to better understand this energy consumption disparity. The conditional statements above are predicated on facts that would be generated by this understanding.

## Mammoth YCC Dorm Photos

Photo 45 - Exterior Door

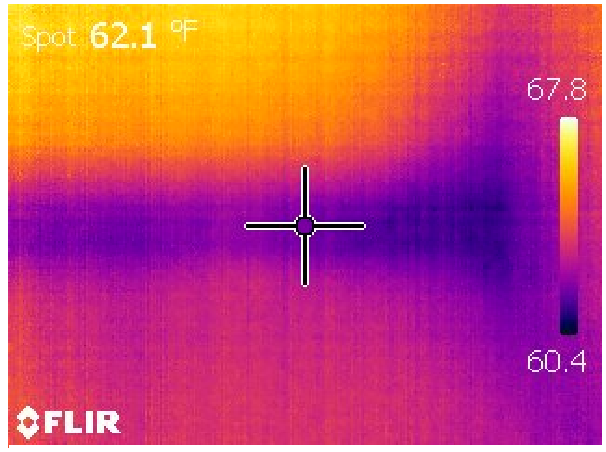



Photo 46 - Thermal Image of Photo 45

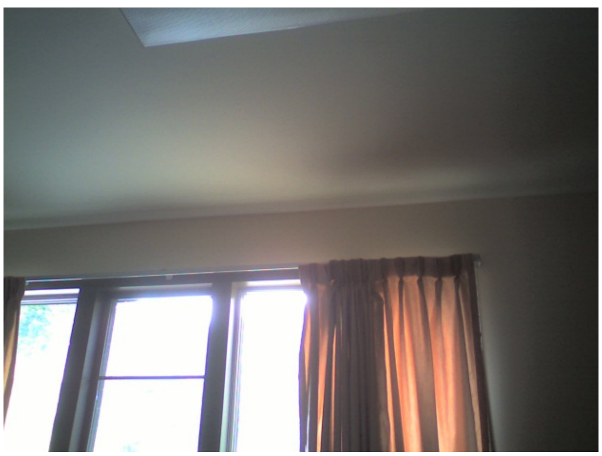


Photo 47 - Ceiling and Siding Joint by Windows

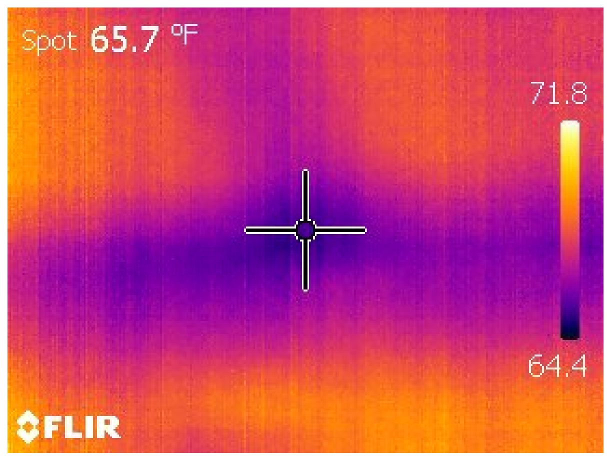



Photo 48 - Thermal Image of Photo 47

# Old Faithful Visitor Education Center (VEC)

The Old Faithful Visitor Education Center was constructed in 2010, and replaced an old visitor's center located at this site. It is located at a major point of attraction in the park, the Old Faithful Geyser, and sees about 1.1 million park visitors each year.[45] The building is 26,000 square feet and houses offices for staff, a theater, multiple educational displays, and a gift shop. The building was designed to have a minimal impact on the environment, and be energy efficient, and as a result achieved a LEED Gold certification. The building earned LEED points in areas including construction waste reduction, creating a sustainable site, as well as energy efficiency measures. The building is only open seasonally from April 15th through-November 6th and from December 15th through March 15th.

Photo 49 - Old Faithful Visitor Education Center

## Lighting

### Opportunity 1 – Install Dimmers

**Degree of Difficulty:** Low

**Impact:** Low

**Potential Benefit:** Reduce electrical energy consumption

The atrium in the building receives ample natural light. However, when we visited the building, there were also many lights on in this space. On sunny days, lighting in the atrium could be provided primarily by natural light. Installing dimmers that respond to the amount of light in the room would reduce the amount of energy needed to light this area. This is a relatively inexpensive option that would cost about $400 for sensor and dimming ballast.[46]

## Equipment

### Opportunity 2 – Building Commissioning

**Degree of Difficulty:** Low

**Impact:** Low-Medium

**Potential Benefit:** Maximize the performance of existing equipment

The building commissioning process would maximize the performance of the building's existing systems. When the team visited this building, employees mentioned how difficult it has been to get the building's energy and lighting systems working properly. Building commissioning would bring in a building systems expert to calibrate the HVAC and lighting to ensure that they are working at their maximum efficiency. Other systems that could be commissioned include plumbing, fire protection, elevators, telecommunications and data processing, building envelope, etc.

This process has a reasonable average cost of $0.30 to $1.16 per square foot; this can improve energy performance by 16%, giving a median payback period of 1.1 years.[47] The cost per square foot for building commissioning is lower for existing buildings than for new construction.[48] One survey found that only 3% of buildings commissioned were operating properly before being commissioned.[49]

### Opportunity 3 – Energy Management Systems

**Degree of Difficulty:** Unknown

**Impact:** Medium

**Potential Benefit:** Utilize installed computer software to better manage energy use

The Old Faithful VEC building already has a computer controlled energy management system, but was not being used as of May 2011. The purpose of the system is to maximize the performance of the building's heating and cooling systems. However, the system, that can also be operated remotely, is not being used due to logistical difficulties. Non-federal employees are restricted from using federal networks, and this limits the ability of outside technicians to remotely optimize the building energy systems.

# Old Faithful VEC Photos


Photo 50 – Old Faithful VEC Displays

Photo 51 – Visitor Displays

Photo 52 - Display Lighting

Photo 53 - Lighting Around the Main Area

Photo 54 - Display Lighting

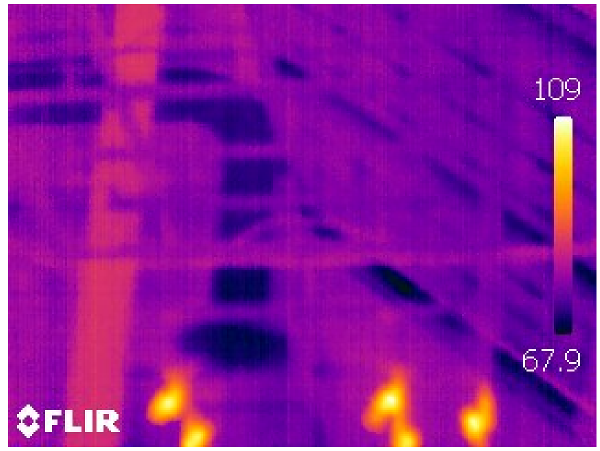



Photo 55 - Thermal Image of Photo 54

Photo 56 - Main Exterior Doors

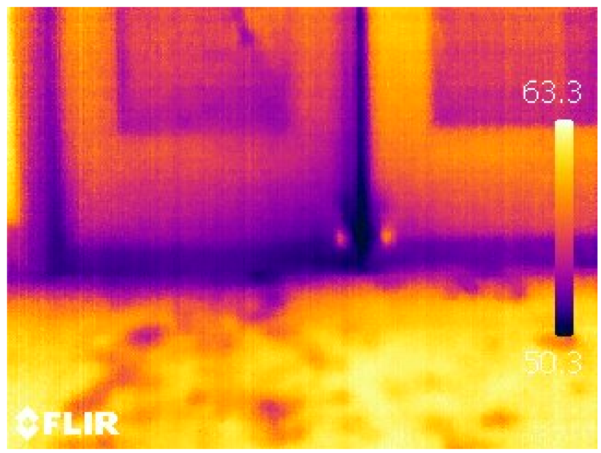



Photo 57 - Thermal Image of Photo 56

Photo 58 - Corner of Room

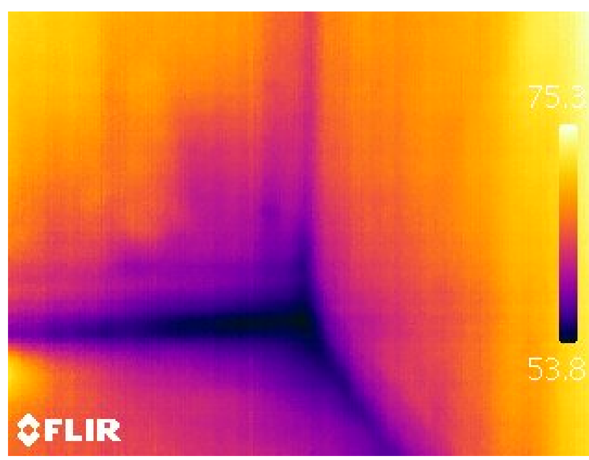



Photo 59 - Thermal Image of Photo 58

# Canyon Visitor Education Center

Photo 60 - Canyon VEC

The Canyon Visitor Education Center was built in 1958, but was renovated 2003-2004. It is a 10,900 square foot building and hosts educational displays about volcanism and houses the backcountry office that provides information about trail conditions in the Canyon area. The majority of the energy used by the building is for the educational displays. This visitor center is located near the center of the park, close to one of the park's major attractions, the Grand Canyon of Yellowstone, and sees over 400,000 visitors each year.[50] The center is in use seasonally, from May 8th through October 16th, and is also used as a warming center from December 15th until March 15th.

## Lighting

### Opportunity 1 – Upgrade Display Lighting

**Degree of Difficulty:** Low-Medium

**Impact:** Medium

**Potential Benefit:** Reduce energy consumption

The exhibits that are in the building were not designed with energy efficiency in mind. While it is important that these areas have ample light, it is possible to achieve this in a less energy intensive way. The first step in this process should be engaging the interpretation department to help identify appropriate options for lighting upgrades. The common lighting types used in NPS exhibit areas include reflector lamps, spotlights, and floodlights. These are typically very energy intensive and therefore a significant amount of energy could be saved by retrofitting lamps or redesigning exhibit areas. These common lamp types can be replaced with CFL reflector lamps or tungsten infrared lamps without needing to change the fixture.[51] However, for greater energy savings exhibit areas could be redesigned to not only incorporate energy efficient lamps, but also energy efficient fixtures and displays. For example, the existing track lighting could be replaced with CFL track lamps. In addition to reducing energy costs, CFL lamps reduce life-cycle costs because they require less maintenance than traditional incandescent.

### Opportunity 2 – Dimmers

**Degree of Difficulty:** Low

**Impact:** Low

**Potential Benefit:** Reduce electrical energy consumption

There are many windows on the south facing façade of the building that provide ample light to the spaces inside. Lighting in areas, such as the main lobby, could be provided primarily by natural light. Installing dimmers that respond to the amount of light in the room would reduce the amount of energy needed to light this area. Installing a dimmer, at least in the main lobby area, would be an easy way to save energy in the building. This is a relatively inexpensive option that would cost about $400 for sensor and dimming ballast.[52]

## Equipment

### Opportunity 3 – Variable Frequency Drive (VFD) for Boiler and Air Handler Units (AHUs)

**Degree of Difficulty:** High

**Impact:** Medium-High

**Potential Benefit:** Increase energy efficiency

Since the occupancy of the Canyon VEC varies greatly throughout the year, it is recommended to install VFD for boiler and AHUs. They could be programmed to work with the existing computer system in the building. This recommendation is relatively expensive to install, however, since the building occupancy is highly variable throughout the year and also varies by the time of day, this would be a cost effective way to reduce costs.[53] A HVAC engineer would need to be consulted for the integration of the VFD to determine the change in the requirements for the boiler and AHUs.

The installation of VFD and AHUs can lead to an estimated savings ranging anywhere between 30-40%.[54] In addition, they can reduce maintenance costs because of reduced wear of the mechanical system.[55] At a cost of around $5000 per item, the VFD/AHUs can be estimated to have a payback of anywhere between six months to two years.

## Opportunity 4 – Motion Sensor Controls on Bathroom Fixtures

**Degree of Difficulty:** Low

**Impact:** Low

**Potential Benefit:** Increase energy efficiency

During the winter, the building is open 24 hours as a warming hut. Additionally, the visitors have intermittent access to vending machines and restrooms. Due to the sporadic use by visitors, energy is wasted if machines and lights are kept on 24 hours per day (see Overall Building Recommendation on vending machines for more detail). As for the sensors in the bathrooms, these would cost approximately $30. However, the savings will depend on the number and type of light in each of the bathrooms.[56]

## Opportunity 5 – Building Commissioning

**Degree of Difficulty:** Low

**Impact:** Low-Medium

**Potential Benefit:** Maximize the performance of existing equipment

Similarly to the Old Faithful VEC, calibrating the building's energy systems in the Canyon VEC would help the park ensure that building's HVAC and other systems are running up to their design specifications (see Old Faithful VEC Opportunity 2 for more detail).

# Canyon VEC Photos


Photo 61 – Display at Canyon VEC

Photo 62 – Light Turned on Near Windows

Photo 63 - Lighting in the Exhibit Area

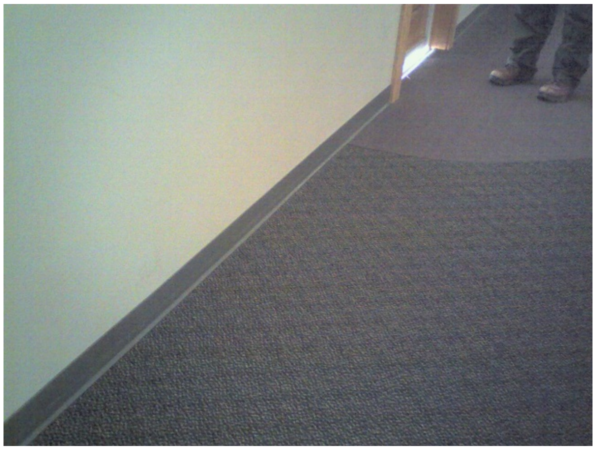


Photo 64 – Administrative Hallway

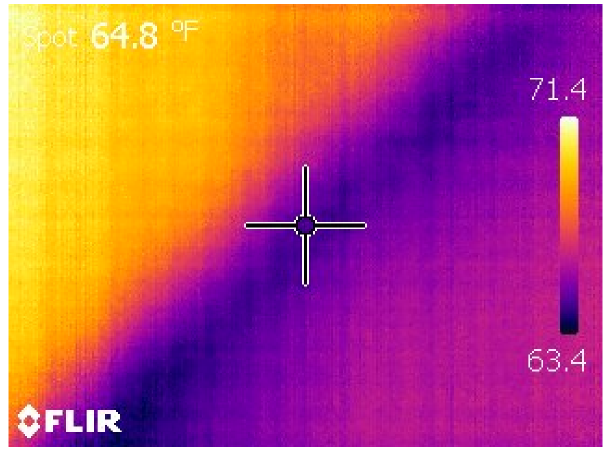



Photo 65 – Thermal Image of Photo 64


Photo 66 – Emergency Exit Door

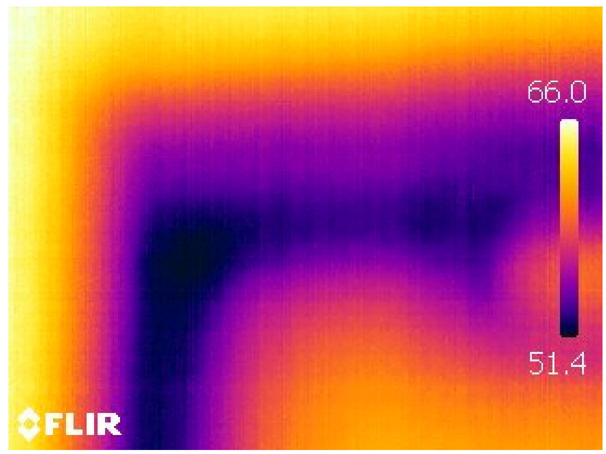



Photo 67 – Thermal Image of Photo 66

## Lamar Buffalo Ranch

The Lamar Buffalo Ranch is used by the Yellowstone Association (YA) as a learning center and by the park to house rangers near the north eastern edge of the park. Originally, the ranch was used to protect the last remaining bison in the park when they were nearly extinct. The ranch produces all of its own power through a solar array and a pair of propane generators. Extra solar energy is stored in a 9600 amp-hour battery pack at 24 volts.[57] The ranch consists of 22 buildings, which include:

Photo 68 - YA Cabins at Lamar Buffalo Ranch

- The 1,200 square foot Buffalo Keeper's House, which was built in 1922, home to a park ranger.
- The 850 square foot Soda Butte Ranger's Station, which was built in 1937 at Soda Butte, but was relocated to the ranch when it was decided that a ranger at Soda Butte was no longer necessary.
- The remaining buildings are used by the YA and include a 1,900 square foot bunkhouse, the 740 square foot YA Director's cabin, a 750 square foot bathhouse, and seventeen 170 square foot cabins.

Chart 6 illustrates the erratic refilling schedule of the upper and lower propane tanks at Lamar, both on a month to month and a year to year basis.

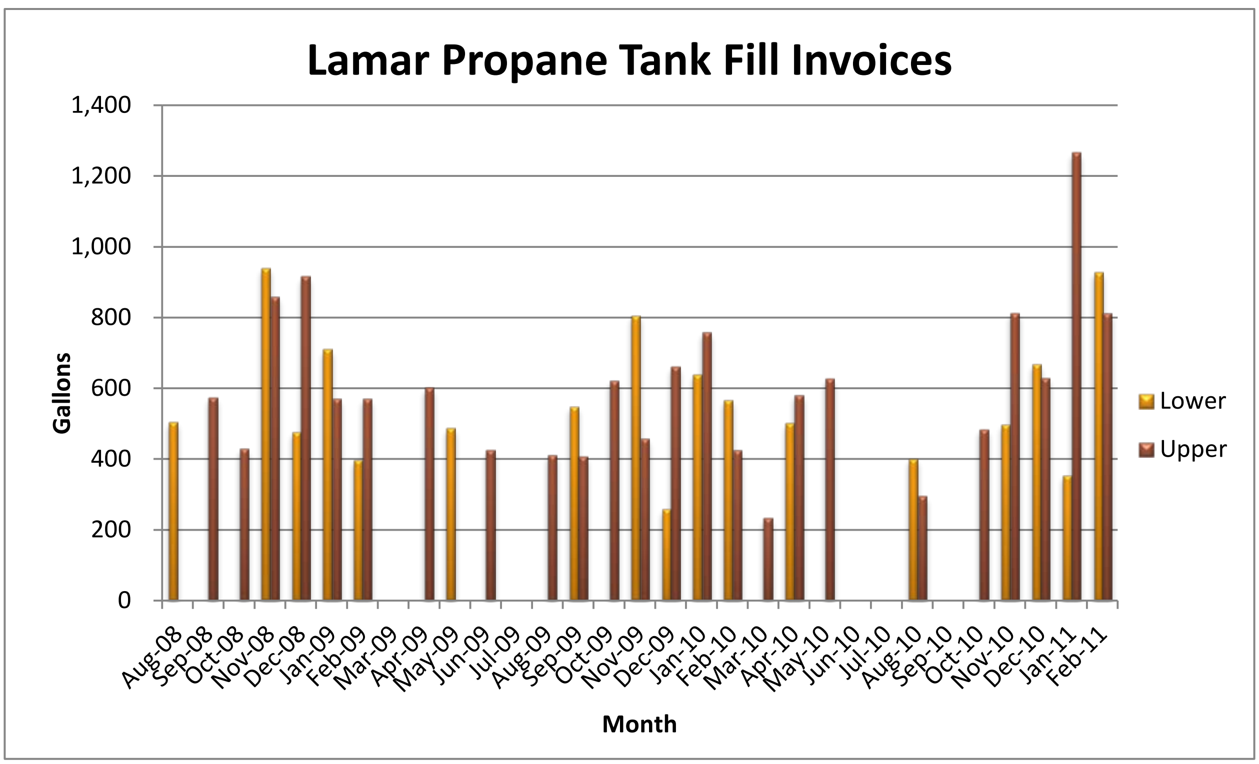



Chart 6 - Propane Refills at Lamar in Gallons

Chart 7 below graphs an average of the number of hours the combined Lamar generators run for a few days.

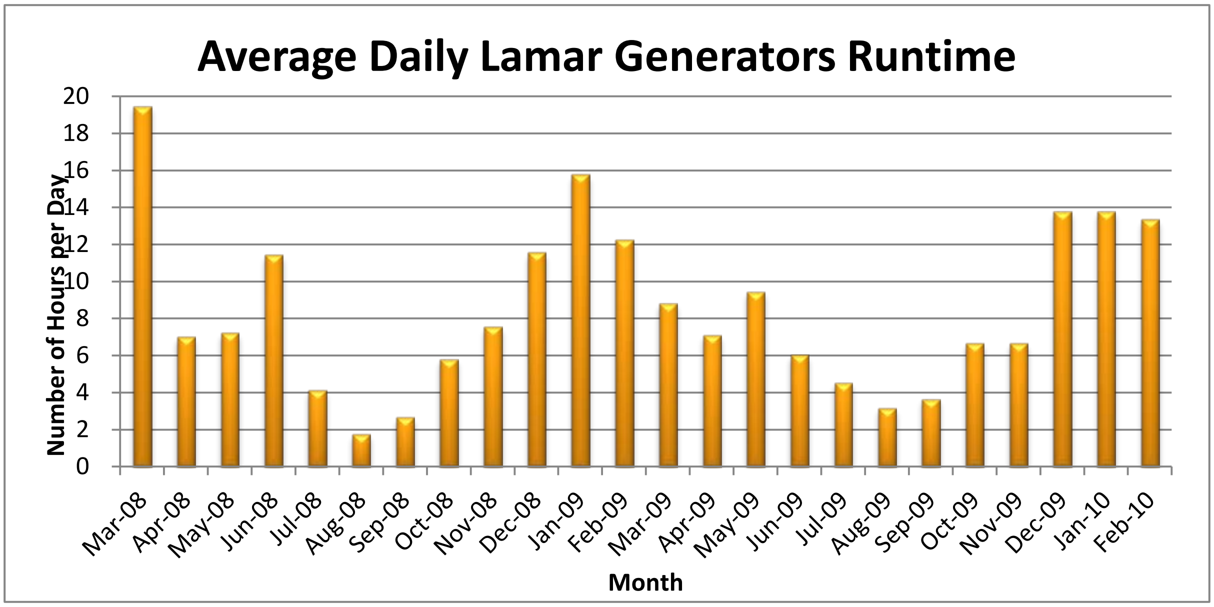



Chart 7 - Average Daily Hours of Lamar Generators Operation

## Monitoring

### Opportunity 1 – Propane Metering

**Degree of Difficulty**: Medium

**Impact:** Medium

**Potential Benefit:** Understand propane usage

Currently, a single meter is being utilized to monitor propane usage for the generator, Soda Butte Ranger Station, Lamar Bunkhouse, and Buffalo Keeper's House. Installing a propane meter on the upper tank will allow monitoring of the generators' propane usage, while installing meters on the lower tank will allow monitoring of the split between the three buildings' consumption.

Based on industry guidelines, it is estimated that installing the meters will take two days of work and cost approximately $200 per meter.[58] It is important to note that during the installation, the propane tank must be completely disconnected, meaning the Soda Butte Ranger Station, Lamar Bunkhouse and Buffalo Keeper's House will have no heat and the entire area will rely solely on solar electricity generation.

## Opportunity 2 – Solar Metering

**Degree of Difficulty**: Medium

**Impact:** Medium

**Potential Benefit:** Understand solar array electricity generation

Currently the propane generators make up the energy demand difference. Based on the propane delivered to the generator tank in 2009 and 2010 and the number of operating hours, the generators consume approximately 5,200 gallons of propane and produced approximately 25 MWh of electricity annually. The percentage of energy Lamar consumes that comes from the solar array is unknown. A meter that continuously records and stores data for download should be installed to better understand the efficiency of the array and the requirements for future expansion of the system. This data will also improve understanding of future generator requirements and needs for expansion of the solar array.

It is estimated that two meters will be required to monitor the energy at Lamar, costing approximately $350 each and a housing unit costing an additional $50.[59] The meters should be located on the battery storage shed since all of Lamar's electrical energy passes through that building (see Appendix E).

# Further Research

## Opportunity 3 – Additional Renewable Electricity Source

Approximately 27 MWh are output by the propane generator each year, but could be reduced with additional renewable electricity. Possible renewable systems include:

- Additional Solar Panels - Concentrated photovoltaic (PV) cells are the recommended cell type. Since space is limited and the cells are required to be hidden from certain sight lines, concentrated PV cells supply a high output per area, but are relatively expensive compared to other solar cell types.

- Pumped Storage Micro Hydro - This system would pump water from a downhill storage tank to an uphill storage tank at times when there is excess PV energy. The water would then be released to the downhill storage tank, turning a microturbine at the bottom, when the energy was required. This system could take advantage of the steep incline behind the ranch and could be completely or partially buried. Additionally, it would substitute the need for additional battery storage. The system could be a closed loop, so that it would not consume any water. Due to the cold temperatures, the water in the system would likely need an anti-freeze agent.

## Lamar Buffalo Ranch Photos

Photo 69 – Lamar Bunkhouse

Photo 70 – Lamar Bunkhouse Kitchen

Photo 71 – Classroom of Lamar Bunkhouse

Photo 72 – Bottom of a YA Cabin

Photo 73 – Interior of YA Director's Cabin

Photo 74 – Morgane with Solar Array at Lamar

# Lift Stations, Water and Sewer Treatment Buildings

Several of the park's mechanical facilities were surveyed. These included the water treatment plants at Canyon and Old Faithful, the sewage treatment plants at Canyon and Old Faithful, and the water lift stations at Old Faithful. The lift stations are small facilities with pumps that lift water from rivers to the larger water treatment plants where the water is treated so that it is potable. Similarly, waste water is sent to the sewage treatment plants where it is treated and then put back into the rivers. These facilities are simple and built to house the pumps, holding tanks, and equipment needed to supply water to the park's other facilities.

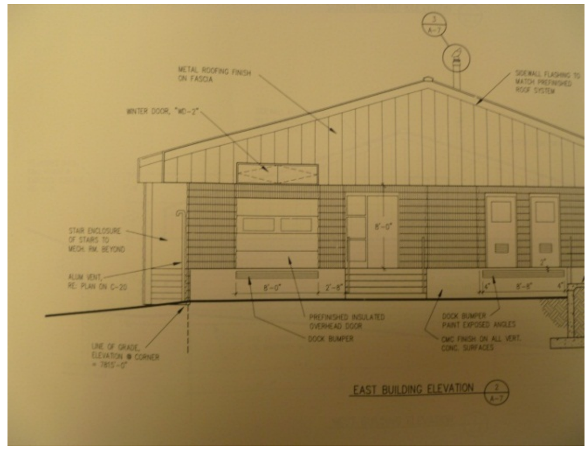



Photo 75 - Canyon Water Treatment Plant

## Equipment

### Opportunity 1 – Variable Frequency Drive Control

**Degree of Difficulty**: High

**Impact:** Medium-High

**Potential Benefit:** Increase energy efficiency

Currently, pump motors at these buildings run as either off or on. To control the output, the pumps must be controlled by value restriction or by turning the pump on and off. Variable frequency drive control (VFD) allows for pumps to be throttled electronically to a desired level of output. Valve control of pump output does not reduce the energy consumed by the pump, therefore the pump is operating inefficiently since it is still consuming the maximum energy. VFD allows for a reduction in energy use when a reduction in pump capacity is desired. Additionally, VFD allows for more precise control of the facilities. The following should be considered for VFD installation:

- Pumps which are regularly throttled by valving.
- Pumps which are cycled on and off to control flow.
- Pumps which are run intermittently for maintenance reasons.

The VFD equipment cost is estimated to be approximately $200 per pump.[60] Installation is likely to require electrical work. Personnel will need additional training to use the controls. It is difficult to determine the full energy and dollar savings from VFD; more detailed and accurate information about the conditions listed above is needed in order to calculate the savings from VFD. Full functionality of the VFD will require integration into a computer controlled system, which would dramatically increase the cost due to the age of these buildings and their equipment.

# Lift Stations, Water and Sewer Treatment Building Photos

Photo 76 - Old Faithful Inn Lift Station

Photo 77 - Old Faithful Main Lift Station

Photo 78 - Old Faithful Water Treatment Plant

Photo 79 - Old Faithful Water Treatment Plant

Photo 80 - Open Window with Heat Running

Photo 81 – Canyon Waste Water Treatment Plant

Photo 82 – Canyon Waste Water Treatment Plant

# Institutionalizing Sustainability and Planning for Renewable Energy

## Planning in National Parks

The idea of a National Park is relatively new, with Yellowstone being the world's first national park. Since the creation of YNP, areas of special environmental and cultural importance have been set aside around the world, and today there more than 6,500 national parks in existence.[61] In the United States, the NPS was established in 1916 by the congress with the passage of the National Park Service Organic Act. Since the inception of the park service the management goals and park planning philosophy have varied significantly. Initially the NPS sought to protect the pristine environment, then to provide solely for the public's enjoyment, and it currently seeks to balance these both of values. The NPS manages roughly 75 million acres of land at locations across the continent.[62] Although preserving natural resources while providing public enjoyment establishes a framework for park management, the variety of land uses and resources at specific parks means there is no single value that governs NPS decision-making.

Although Yellowstone is designated as a National Park and is a single jurisdictional unit within the DOI, its immense size, confluence of land uses, infrastructure systems, and multitude of developed areas make its planning and management a unique challenge. Park management must not only consider the park and the developed areas within it, but also the surrounding areas, including other federal lands as well as rangelands and residential areas. The park is larger than Rhode Island and Delaware combined, but remains 99% undeveloped.[63]

## Current Park Building and Planning Practices and Policies

Planning within National Parks is guided by a hierarchy of laws, executive orders, regulations, and policies established by Secretary of the Interior.[64] NPS planners must be aware of all of these rules, in addition to the specific programming needs and environmental and cultural values present at each site. The policies that govern planning decision-making in the parks comes from this framework of laws and is developed through a consensus building process comprising NPS managers, stakeholders, and the general public.

The goal of NPS planning is to "[…] define the set of resource conditions, visitor experiences, and management actions that, taken as a whole, will best achieve the mandate to preserve resources unimpaired for the enjoyment of present and future generations. NPS planning processes will flow from broad-scale general management planning through progressively more specific strategic planning, implementation planning, and annual performance planning and reporting, all of which will be grounded in foundation statements."[65] The department is primarily responsible for preparing comprehensive plans for each of the developed park areas, and for also preparing management plans, Environmental Impact Statements, Environmental Assessments, and Records of Decisions regarding parks developments. In addition, the planning department is responsible for scoping new developments within the park. In compliance with federal regulations, the planning department posts plans online so that the public may comment and review plans in development.

Yellowstone is unique within the National Park system because it has its own in-park planning office. Other National Parks receive planning services from the Denver Service Center (DSC). The DSC oversees planning, design, and construction management services for the entire NPS.[66] Although the park has its own in-house planning capabilities, the broad range of duties that the park planners are responsible for keep them from being proactive about planning future park developments. Instead, the planning department reacts to proposed developments, which holds the department back from tackling long-range planning problems. For example, although the park is responsible for developing comprehensive plans for each area of the park, these plans are currently in the process of being updated for the first time since the 1970s.[67] Comprehensive plans provide a framework for how and where future development may occur within park areas.

The plans for each of the developed areas identify important structures and landscapes that are to be preserved. Buildings and landscapes are often under strict preservation guidelines for both historic and environmental reasons. Because Yellowstone represents the Old West to many Americans, there are numerous areas in the park that are protected under historic preservation guidelines and that may not be altered in any significant way. Projects to retrofit the historic buildings in the park have occurred without changing the aesthetic character of the building exterior. Concerns about the environment also limit development in the park. Park planners consider the possible effects of development on plants, wildlife, viewsheds, and soundscapes. Development in the park happens slowly and conservatively in order to minimize any potential negative impact.

## Developing a Holistic Approach to Built Environment Sustainability

In order for the park to institutionalize sustainable building practices and energy conservation behavior, the park should develop a more holistic approach to building design and operations. Because planning, architectural design, maintenance, and operations all factor into the ultimate building sustainability, it is important that these different departments work together to create better buildings and energy management at the park. Although the DOI and the Park have adopted polices to promote sustainability, there are still barriers and gaps that remain between policies, practice, and sustainability.

The NPS, as well as the DOI and other federal agencies, established policies and programs to support better energy management and sustainability within parks. This includes the Executive Order 12902, the Advisory Council on Historic Preservation, and the New Technology Demonstration Program, which is a Department of Energy initiative. In addition to these government led initiatives, there is also a private-public partnership with the Yellowstone Park Foundation called the Yellowstone Environment Stewardship Initiative. These initiatives, as well as steps taken by YNP leadership, have resulted in improved practices regarding the environment within the park.

These efforts include the implementation of a park wide plastic, aluminum, and propane fuel canister recycling program as well as an administrative battery and cartridge recycling program. These efforts have made the park a leader regarding sustainable practices within the NPS.


Photo 83 - Recycling Batteries in VEC office

Since the DOI and NPS are institutions segmented into specific sectors, the multiple goals fundamental to sustainability projects pose organizational challenges. The process of developing a plan to institutionalize sustainability should be considered as important as the outcome of the project itself.[68] If successful, planning projects can be transformational.[69] For this reason, projects implemented incrementally, beginning with the low hanging fruit, can lead to significant structural changes.[70] This requires collaborative leadership, one that transcends specific expertise and institutional structures, along with action oriented purpose.[71] It is this emphasis on process, one devoted to appreciating and unweaving the complexities of sustainability on the ground that gradually breaks down the barriers between different departments and broadens communication streams.[72] While the park has begun to address this through the creation of the Yellowstone Green Team, the park should consider including a broader membership in the group in order to make sustainability efforts stronger park-wide.

There are still many challenges that keep sustainable practices and energy efficiency from being considered business as usual within Yellowstone and the NPS. Instead of becoming a part of park practices, these efforts are often considered to be isolated programs, or extra work that employees are being asked to do. In addition, there are technical and logistical challenges to improving energy management practices and sustainability. Furthermore, not all DOI and NPS policies support the goal of sustainability.

The section below describes different challenges and opportunities present in different park departments regarding the built environment. We recommend that the Green Team work more closely with these departments in order to institutionalize sustainable practices park-wide.

## Planning

Including the planning department in the park's sustainability efforts is critical as planners develop the foundation for the built environment in the park. Planning for sustainability is a challenge because it confronts conflicting values and agendas. It requires balancing three critical dimensions of sustainability known as the "planner's triangle," the intersection of environmental protection, economic development, and social equity.[73] Within National Parks, planners face the challenge of balancing environmental goals, with cultural and recreational values, as well as concerns about costs. Planners must also be cognizant of the multiple scales, spatial, temporal, and jurisdictional that may impact park development. Local scale projects that are incremental and iterative must also be designed with awareness of how they influence and are influenced by broader environmental and management goals. (See Appendix H)

National Park planning documents require that planners seek out public and private partnerships to ensure that plans are well-informed. NPS planners consider the stakeholders in the parks to be the American public and they must post plans online to allow the public to review and comment on plans in development. While this can make it difficult to balance competing concerns over park management, it does allow for park planners to engage with private businesses to develop energy in the park. For example, the park has a positive relationship with the Yellowstone Park Foundation, a non-profit organization, which helps the park with environmental and fundraising efforts.

## Designing and Siting New Construction Projects

There are policies and procedures that limit sustainable practices within in the park. While Yellowstone does develop its own area plans, it does not generate plans for buildings or oversee construction. Architectural designs and implementation comes from the DSC. While centralizing design services has some advantages, such as uniform park-wide design standards and streamlined decision-making, there are also challenges to this type of organizational structure. The lack of coordination between planners, architects, and building staff in the building design process has resulted in buildings that are not well suited to their sites, or to staff needs. The development of new buildings should involve employee stakeholders, including office workers as well as maintenance employees, in order to develop a building that is suited to its site as well as its function. The team noticed that this was a common problem at the park, even in new buildings. Yellowstone's buildings are designed for the summer tourist season, when the greatest number of employees are at the park. However, the rest of the year, buildings are underutilized. This variable occupancy of the buildings should be considered in the design process.

Another example is the Heritage Center, a new building at the park, which was designed with many windows that face south, and the spaces on this side of the building are well lit by natural light. However, these areas have many lights installed in the hallways and spaces on the south side of the building. Installing these lights was unnecessary because of the abundance of sunlight, and the fact that the building is primarily used from 9:00am – 5:00pm. As a result, once the building was completed, park electricians disconnected the circuits that powered these lights so that they could not be turned on. However, if building users were better considered in the design process, or if the architects had thought more about how the building was situated towards the sun, this problem could have been avoided.

Buildings that are designed and sited without regard for the location of the sun require large amounts of energy use to operate. New building construction and major remodeling projects should be designed to maximize passive solar gain and reduce lighting loads. Whenever possible, buildings should be situated to take advantage of the low winter sun. Buildings that are blocked from winter sun between 9:00am and 3:00pm cannot take advantage of sunlight for heating.[74] In addition, buildings should be shaped so that the east-west axis is elongated so as to maximize the surface area of the south façade. Interior spaces that require the most heat and light should be located along this south façade. Minimally used spaces, such as storage and utility rooms, should be located on the north side of the building. However, since the park is located in a cool climate, the overall amount of elongation should be low in order to keep the total amount of building surface area exposed to the elements to a minimum. By working closely with the DSC, the park will ensure that buildings are more suited to their sites and more efficient to operate.

## Building Operation and Maintenance

As noted previously, the buildings at YNP are major energy users and contribute a great deal to the park's carbon footprint. Building operations and maintenance staff are critical to improving energy management at the park. Buildings operations employees should be instructed to seek continuous improvements in building energy management. While implementing an energy metering and monitoring program will help energy management, another component is adopting better operations and management practices to drive better building performance. LEED O+M is an example of a maintenance standard that the park could adopt to drive continuous energy efficiency improvements in its buildings. The park could utilize LEED O+M guidelines without the extra cost of applying for LEED certification. The standard addresses building operation processes in regards to water and energy use as well as waste. An example of this checklist can be found in Appendix I.

## Interpretation and Exhibit Design

Within VECs, specialty, high intensity lights are used to illuminate educational displays. In addition, some exhibits use energy intensive displays to communicate information. For example, in the Canyon VEC, there is a large granite ball that rotates in water, and also lights up, to show visitors the locations of volcanic features on earth. This exhibit is extremely energy intensive as it has its own engine and water pump. An illuminated map of volcanoes could convey this same information without needing its own mechanical system. Future exhibits should be designed with energy efficiency in mind so that expensive and energy intensive features are not installed. Exhibit designers choose certain types of lights for their ability to render colors and brightly illuminate displays. However, there are also energy efficient choices available for this purpose. While low-wattage LED display and exhibit lights have a higher upfront cost than typical lights, they also have a much longer lifespan. Exhibit designers must be instructed and enabled to make better energy choices so that these spaces do not become expensive for the park to operate. If the current contractor that is charged with developing exhibits is unfamiliar with LED lighting possibilities, the park should seek a contractor that is more familiar with energy efficient exhibit options.

Photo 84 - Granite Display at the Canyon VEC

## Renewable Energy and Climate Adaptation at Yellowstone

As previously mentioned, Yellowstone National Park has been identified by conservation groups as especially vulnerable to the negative effects of climate change.[75] This project seeks to help the park both mitigate and adapt to climate change by increasing the efficiency of building energy use and helping the park plan for renewable energy. By examining both energy demand and supply within Yellowstone, this section of the project will help the park make better energy management decisions. Reducing energy demand and increasing supply will help YNP decrease its reliance on the existing fossil fuel powered grid. This is important as the Environmental Protection Agency (EPA) predicts that electric infrastructure will be under excessive demand as a result of increasing temperatures.[76] Additionally, because Yellowstone receives its electricity primarily from one source, any fire, extreme weather event, or excessive demand in the region could easily disrupt power in the park. Installing renewable energy will create redundancy in the electric supply, therefore, helping the park to reduce its carbon footprint and its risk of disrupted electricity.

Furthermore, although renewable energy technologies have a high upfront capital cost, once installed, these systems will reduce the park's energy bills. The price of energy is expected to greatly increase in the future because of aging infrastructure and the difficulty in obtaining fossil fuels.[77] Installing renewable energy will buffer the park against these higher costs.

There has already been an effort to develop renewable energy in the park. The DOI promotes the development of renewable energy in National Parks through the Green Energy Parks Initiative, which is a joint program with the DOE. In addition, part of the Yellowstone Environmental Stewardship Initiative directs the park to evaluating potential sites for implementation of renewable energy projects, particularly for solar photovoltaic power generation. This effort has resulted in a solar PV installation at the Lamar Buffalo Ranch, and the development of a micro-hydro system in the Mammoth area. The park has also engaged with Georgia Institute of Technology to help them reduce carbon emissions within the park.[78] However, each of these efforts has resulted in one-time projects without a clear long term vision and goals related to renewable energy have not been included in the park planning process. The purpose of this section is to provide a guide for the park's Green Team, as well as the park's planning department, that can help them make decisions related to renewable energy development.

## Barriers and Limitations

The parks are protected areas that are subject to rules and regulations that seek to preserve historic structures and landscapes as well as protect the visitor experience. It is for these reasons that renewable energy installations in National Parks have been extremely limited. The sensitive and unique environments present in National Parks severely limit any changes and developments. Other concerns about installing renewable energy in the park include the cost, the extreme winter weather conditions, and the impact on wildlife. Yellowstone could overcome these limitations, at least in part, by prioritizing renewable energy projects in park administrative zones. Choosing appropriate technology and having a plan for winter maintenance will also help renewable energy installations be cost-effective and successful.

Within Yellowstone, there are specific barriers and obstacles to renewable energy development. First, in order to avoid disturbing the pristine views of the park, installing new energy resources would be prohibited in many locations. Concerns about views might also require transmission wires to be installed underground. Installing these wires underground is both extremely expensive and also unfeasible in some areas where the geothermal resource is close to the surface of the earth. Second, although the park sits on the world's largest geothermal resource, utilizing its energy is prohibited by law. The DOI regulates the development of energy on federal lands and it has completely barred the development of geothermal leasing within all National Parks.[79]

In addition, because of strict DOI rules regarding the preservation of historic buildings and landscapes, the potential for installing renewable energy at historic sites is limited. Energy development at these sites is a challenge because new construction must not interfere with the historic character of the property and must maintain important viewsheds. Although some alterations are not possible, there is a resource within the park to provide support with this issue. The NPS's Technical Preservation Service provides assistance and expertise to parks that want to improve the energy efficiency of historic structures.[80]

Another major obstacle to developing renewable energy within the park is the high initial cost of renewable energy technology and the lack of strong financial incentives available in the area. The amount paid for net generation varies by state and by electricity company. NorthWestern Energy, the park's primary electricity provider, provides incentives that encourage small scale energy development.[81] However, the incentives are limited, so any large project would not see the benefit of the incentive program. NorthWestern Energy does not provide an incentive for projects that produce more than 1 MW of electricity. In addition, the park would need to work with NorthWestern Energy from the earliest stages of a project to submit a proposal for renewable energy funding to the company. Problems negotiating the price of energy produced by the park have held up the operation of the previously mentioned micro-hydro project that was installed in the Mammoth area in early 2011. The state of Wyoming only mandates net metering for up to 25 kW, so the park may consider energy storage options in order to maximize the benefit of the energy produced within the park.[82] Although some parks in California have been able to install renewable energy projects, many others in the state have been held up by negotiations about grid connection with Southern California Edison.[83] Working with the power company in order to arrange payment for a grid connection should begin at the earliest phase of project development in order to allow time to establish an agreeable arrangement. In addition, because of the Yellowstone's high profile and its status as a vacation destination for millions, the park may be able to develop a partnership with a renewable energy company in order to develop projects.

## Types of Renewable Energy Systems and Applications

### Photovoltaic (PV)

This type of system converts energy from the sun into direct current (DC) using panels of semiconducting materials. Depending on where a PV system is installed and its intended use, it will also require several other components in addition to the panels themselves in order to convert, control, store, and distribute the electricity produced. At an on-grid location, such as Mammoth, the PV panels require an inverter to convert the DC power produced by the panel into usable alternating current (AC) power. At an off-grid location, such as Lamar, a PV system will also require a battery bank to store electricity so that the system will continue to supply power even during times of low insolation.

PV systems have features that hold some advantages for being used at the park. First, a solar PV system could help the park supply some of its own electricity needs especially during summer months. In addition, PV systems are quiet, and have no moving parts, which would minimize their impact on visitors and wildlife. Furthermore, there is a precedence of these types of systems being used successfully at Yellowstone and other National Parks. These types of systems can be installed in a variety of locations as long as they receive an adequate amount of solar energy. For example, at the Lamar Buffalo Ranch, several PV panels have been installed in a field. At other parks, PV panels have been installed on south facing rooftops and parking lot canopies.

There are also challenges to utilizing this type of technology at the park. First, although PV prices have fallen recently, these types of systems have a high upfront cost. The price of purchasing and installing a PV system varies by geographic location and system chosen. In 2010, it is estimated that PV systems that generated less than 10 kW cost from $6.30 per watt to $8.40 per watt.[84] However, PV costs per watt can decrease significantly with larger installations. PV panels that are properly maintained generally have a useful life of 25 years.[85]

Second, PV systems are best utilized where there is a high amount of solar radiation. Although the EPA has determined Wyoming to be a good to excellent area for solar energy generation, the high amount of snowfall in the park may pose a problem for some areas.[86, 87] During a light snowfall, the warmth of the panel will melt the snow off of it. However, during heavy snows, the panels would need to be cleaned off in order to maintain the function of the panel. This can be done with a snow rake, which would allow park employees to reach about 20 feet high onto roof or panels to clear snow.[88]

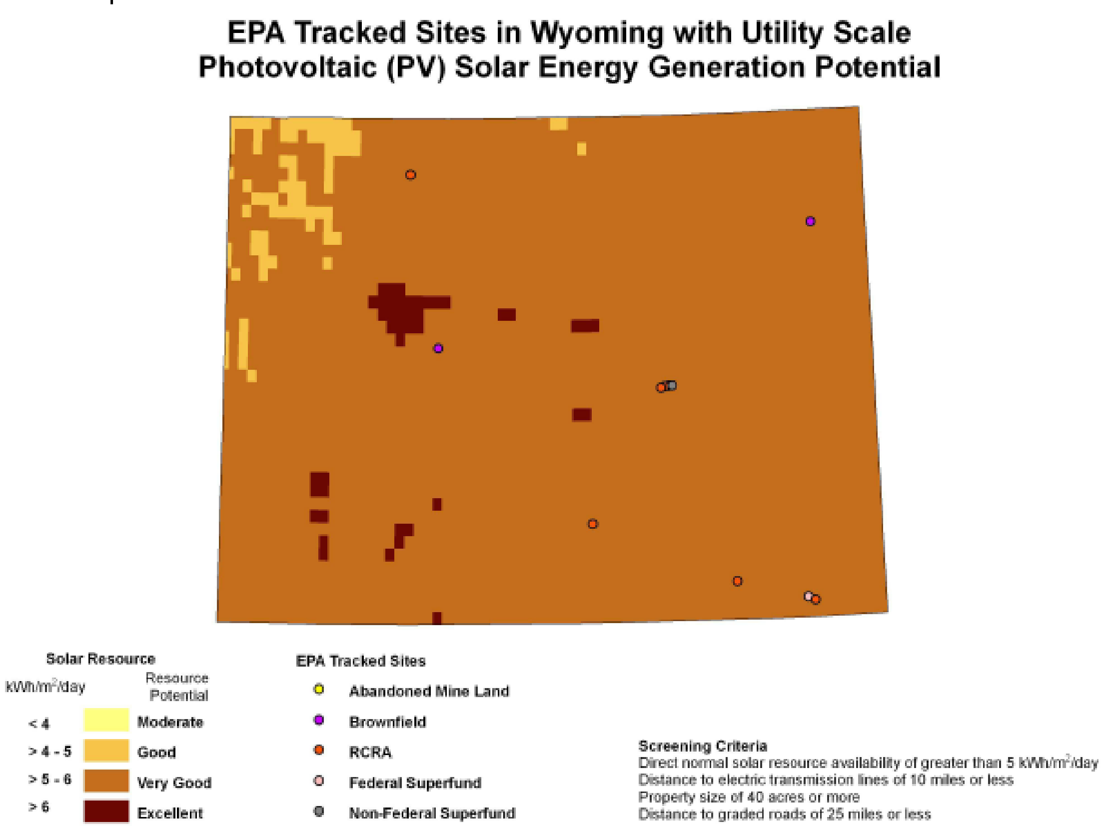



Photo 85 - Solar Resources in Wyoming[89]

## Solar Hot Water (SHW)

A SHW system heats water directly with solar energy and can be used in conjunction with a central building heating system, or to supply hot water. The system consists of a collector on a south facing wall or roof that collects solar energy, and a hot water storage tank. The system uses a heat transfer fluid, which contains an anti-freeze and a corrosion inhibitor, to exchange heat between the collector and the water storage tank. There are several system features to consider when selecting a SHP for use in the park, depending on the specific building location and hot water needs. A passive system uses natural convection to circulate the fluid between the collector and the storage tank, while an active system includes an electric pump to do this. Passive systems are generally less expensive, but are less efficient than active systems. In a passive system, the storage tank is typically on the roof with the collector. In an active system, the hot water storage tank can be located below the collector, inside the building, so that it is hidden from view.

Converting solar energy to hot water is very efficient. These systems are cost-effective and have been shown to reduce heating bills by 50%-80% and have a payback period of roughly three to four years.[90] The best location for a solar hot water system would be for a building that utilizes a boiler to heat water as part of its heating system. The SHW system could be integrated into the heating system in order to reduce the amount of electricity or fuel used to heat the boilers. The SHW system could offset a significant amount of the building's energy use that had been used to heat water because using electricity to heat water directly is very inefficient. Another option for a SHW is at a building where a large amount of hot water is used such as dorms or residences. There is already a precedence of this type of system being used in the park, as there are obsolete SHW systems installed in the lower Mammoth residences. These could be replaced with new equipment in order to improve the energy efficiency of these homes.

## Wind

Although the large turbines that are usually used for commercial electricity generation would not be appropriate for any place in the park, there are smaller options that the park should consider. Smaller wind turbines have a lower capacity to generate electricity, but they do not come with the impact on viewsheds that larger turbines would have. Yellowstone could utilize horizontal axis turbines or small vertical axis turbines in administrative areas that have large open spaces such as the field adjacent to the Canyon Water Treatment plant or the Old Faithful Waste Water Treatment Plant. In addition, the park could consider installing a small turbine in a public area, as the Golden Gate National Recreation Area has done, in order to educate visitors about wind power and renewable energy. However, before installing a wind turbine, a fine resolution map of wind resources at the park would need to be created in order to determine the locations of the best wind resources.

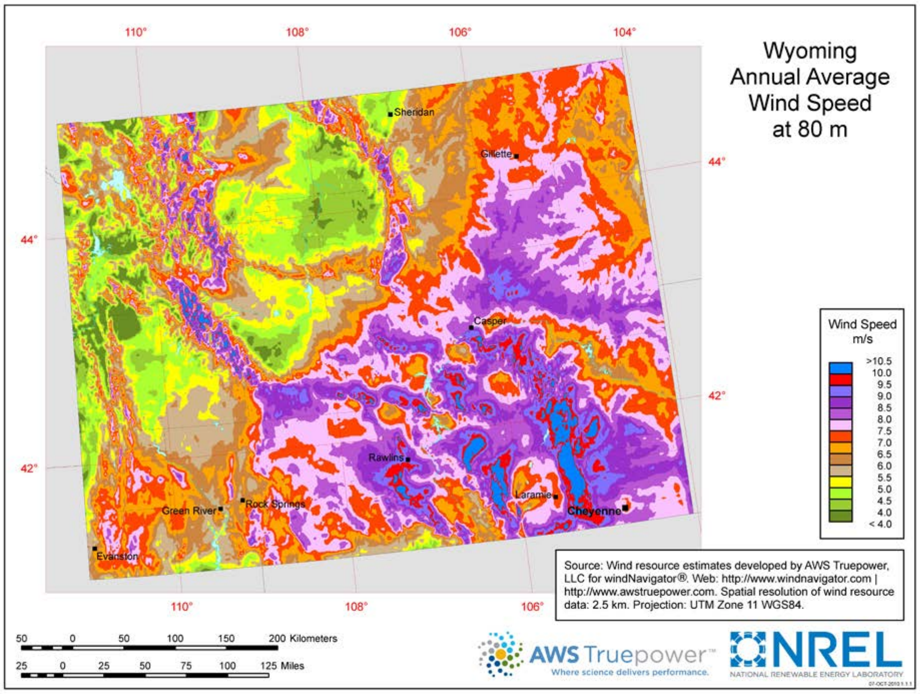



**Photo 86 - Wind Resources in Wyoming, at 2.5 km Resolution[91]**

Vertical and horizontal axis turbines capture the kinetic energy from wind and convert it into mechanical energy through a generator. Small horizontal axis turbines are commonly used by farmers or by rural landowners to generate wind. They generally produce less than 100 kw and come in a range of sizes. The turbines installed at the Golden Gate Recreation Area are 30-feet tall, however, those installed at the Channel Islands National Park are 91 feet tall. Vertical axis turbines are usually not used for commercial electricity because they are less efficient than vertical axis models. Although there is lower efficiency, these models can be used where there is a high amount variability in wind direction. Further research would need to be undertaken in order to determine the most appropriate technology for the park. Small turbines generally produce DC power and require an inverter to convert the power into AC.

## Hybrid Systems

Because solar and wind systems rely on inconstant energy sources in order to create electricity, combining them into a hybrid system has the benefit of reducing variability and creating a more reliable renewable energy source. In hybrid systems sunlight provides energy during the daytime, especially during the summer months. By also incorporating a small wind turbine into the system, it is possible to generate electricity at night and consistently through winter months. In addition there are also hybrid systems that combine propane or diesel generators with wind or solar to create a stable off-grid energy supply.

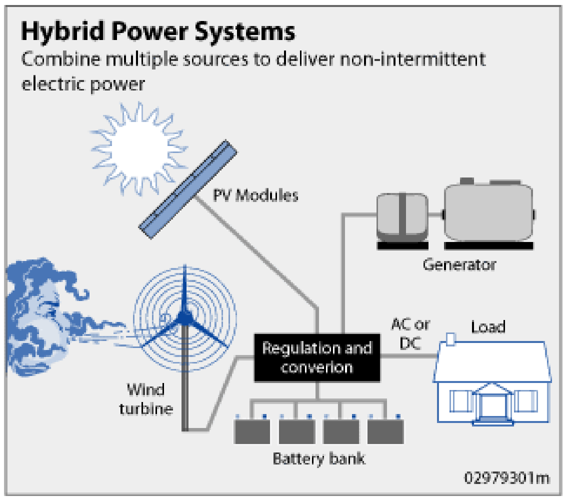



Photo 87 - Diagram of a Hybrid System[92]

These types of systems come in a wide variety of configurations in order to respond to the specific resources and requirements at sites where they are installed. However, system complexity can be reduced by using a model that incorporates a solar array and a wind turbine into a single unit.

## Co-Generation at Waste Water Treatment Facilities

Co-generation captures the anaerobic gas that is produced during the waste treatment process and reuses it to power cogeneration engines or generators that could power the treatment facility and other park buildings.[93, 94] A drawback of utilizing this type of technology in Yellowstone is that the waste treatment facilities are only in use for about half of the year, during the spring and summer months when the highest number of visitors are at the park. Although this technology has not been used within the NPS, it has been used in a National Park in Australia as well as in many utilities and municipalities across the United States. Retrofitting a facility in order to capture the energy that would otherwise be lost is expensive, but results in significant energy savings.[95]

## Micro-Hydro

Micro-hydro systems are a type of hydroelectric system that works with the natural flow of water to generate electricity. These systems can work on their own or in combination with other types of renewable energy systems to provide power to remote locations. Micro-hydro systems are also able to be tied to the grid and they generally use a pelton wheel to capture the potential energy of water to power a generator that creates electricity. These systems can be built in locations where there is a natural flow of water and a steep slope. The design and construction of these systems is dependent on the specific location where it is to be installed. In 2011, a micro-hydro system was installed near the Mammoth area in Yellowstone. While it has yet to come online because of financial difficulties, this is still a good way to generate electricity that also has a minimal impact on the environment. Yellowstone will be the first National Park to use this technology, but Denali National Park is in the process of developing a micro-hydro project. Once Yellowstone has their first micro-hydro system in operation, they should make use of the lessons learned from this experience to develop similar projects in the park.

# Case Studies

The purpose of the following case studies is to illustrate to the Yellowstone Green Team as well, as the planning department, the potential for renewable energy development within National Parks and other federally managed lands. In addition, the case studies serve to demonstrate the types of environments where the previously mentioned systems can be located.

## Grid Connected Solar in Yosemite

In 2011 Yosemite National Park became home to the largest solar panel installation in the NPS.[96] With the help of Recovery Act funding, the park was able to install a 672 kW system that consists of 2,800 panels and produces and estimated 800 kWh each year.[97] The system cost about $5.8 million dollars to install, but will receive $700,000 rebate from Pacific Gas and Energy, and save the park $50,000 per year by reducing purchased electricity costs by 12%.[98] The panels were installed on the roof of an existing administrative and warehouse buildings, as well as on the roof of parking lot canopies. The installation has a minimal impact on viewsheds as it is integrated into other park structures. An additional benefit to installing this system is that Pacific Gas and Electric, the park's energy supplier, pays the park for the net energy produced.

**Photo 88 - Parking Lot Canopies at Yosemite Equipped With Solar Arrays[99]**

## Solar Hot Water at the Great Smoky Mountains

The Great Smoky Mountains National Park installed a solar hot water heating system in 1996. The park was able to identify a location that used a significant amount of hot water where the system would be most beneficial. The park closely monitored the system's performance from 1996 to 2000 under four different configurations to determine the best one for the park. The system was able to supply up to 60% of the hot water demand for a restroom facility and a janitorial closet.[100] The system was used in conjunction with energy efficient faucets and fixtures in order to get the greatest benefit from the system. The Great Smoky Mountains National Park found the system to be very durable and reliable, as a solar hot water system does not require all the additional components that a solar PV system needs.

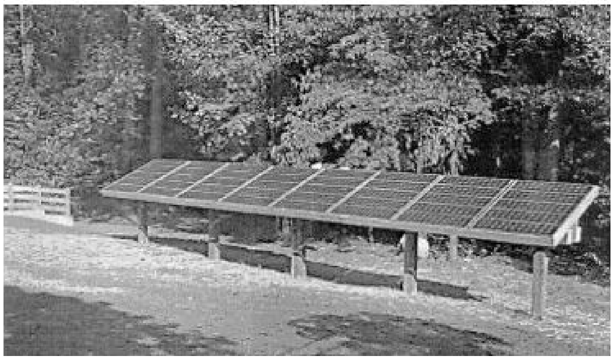


Photo 89 - PV Module at Great Smoky Mountains

Photo 90 - Hot Water Storage Tank[101]

## Off-Grid Hybrid Systems

Channel Islands National Park is an ideal site for renewable energy applications. It is located off of the Californian coast, where it is expensive to supply this remote park with fuel and electricity. In addition, the area has both ample wind and solar resources. As a result, the park is home to 63 renewable energy installations, most significantly, a hybrid wind and solar panel system equipped with a battery bank.[102] This system supplies electricity to the ranger station and other park facilities and replaced a 35W diesel generator and eliminated the need for 17,500 gallons of fuel each year. The NPS has used similar systems in other remote parks where establishing a grid-connection is cost-prohibitive.

Photo 91 - Channel Island Ranger Station[103]

## Wind Turbines as an Educational Tool

The Golden Gate National Recreation Area is home to five 30-foot tall wind turbines to generate electricity for a field center and an electric vehicle charging station.[104] The turbines are part of the Recreation Area's broad approach to sustainability. The park also features a new LEED certified facility as well as an electric vehicle charging station. The 5.4 kW installation features vertical axis turbines, as well as horizontal axis models that are designed to be bird-friendly.[105] The park service was able to do this project after negotiating an agreement with Southern California Edison. In addition, the Presidio Trust, the NPS, and the recreational area worked closely with the manufacturer, LuminaIt, to develop the project.

This installation is unique because unlike many renewable energy installations, these turbines are in a very visible, public location, at the entrance to the field center. Part of the purpose of this highly visible installation was to serve as an example to help educate the public about wind technology and demonstrate the park's commitment to sustainability. The installation of the turbines was featured on the local news and the park's website has a webcam that allows vistors to view the project in real-time.

**Photo 92 - Wind Turbine Installation at Crissy Field[106]**

| Technology | Solar PV | Solar Hot Water | Small Wind Turbines | Hybrid Wind/Solar System | Co-generation | Micro-Hydro |
|---|---|---|---|---|---|---|
| **Description & Requirements** | Panels which can be affixed to a south facing roof, or installed as a stand-alone array in a sunny field. Also requires an inverter | Panels which can be affixed to a south facing roof, or wall. This system also requires a hot water storage tank. | Vertical or horizontal axis turbines that about 1/6 the height of a typical commercial sized turbine. Should be installed in an open area. | Integrated solar and wind unit that can generate electricity under a wider variety of weather conditions | Anaerobic digester gas is captured and repurposed to power cogeneration engines to power the plant or other park buildings | Utilizes the natural flow of water to produce electricity through a small impoundment dam, a pelton wheel, and a generator. System details are site specific. |
| **DOI/NPS Precedence** | Yellowstone, Yosemite, Channel Islands, Alcatraz Island, Sleeping Bear Dunes, many others | Chickasaw, Redwood, Denali, Zion, Great Smoky Mountains, Yosemite, and others | Golden Gate, Channel Islands, many national parks in the UK | Channel Islands, Badlands, Dry Tortugas | None in the NPS. Cape Cod NS transports waste to an off-site co-generation facility, | Yellowstone, Denali, national parks in the UK and Australia |

| Technology | Solar PV | Solar Hot Water | Small Wind Turbines | Hybrid Wind/Solar System | Co-generation | Micro-Hydro |
|---|---|---|---|---|---|---|
| **Challenges & Limitations** | High upfront costs, Winter maintenance. Off-gird locations require a battery bank, on-grid location makes most sense when the park can get paid for energy put back onto the grid | Upfront cost, winter maintenance | Potential impact on viewsheds, can be noisy | Upfront costs and ongoing maintenance. Off grid locations would also require a battery banks | Since waste treatment facilities are not operated year round, retrofitting facilities for this technology may not be economical | Upfront costs, negotiating net generation coasts and grid connection fees with the power company |
| **Most Suitable Locations** | Off grid locations, locations with a high summer electricity demand | Buildings that utilize boilers for hot water heating, locations that have a high amount of domestic hot water use | Administrative zones that have a large amount of open space, such as the fields around the Canyon and Old Faithful Water Treatment Plants | Off grid locations, locations with a high summer electricity demand, open spaces in administrative zones | Waste treatment plants | Lamar Buffalo Ranch, anywere |

Table 4 - Sustainability Matrix of Renewable Energy Technologies

## Lessons Learned

National Park areas in remote areas such as islands or other off-grid areas have proven to be cost-effective locations for renewable energy development. The reason being that generator systems are replaced where establishing a grid connection would be cost-prohibitive. However, burning a kilogram (kg) of coal results in emitting 2.31 kg of carbon dioxide, while burning a kg of propane only results in the emission of 1.98 kg of carbon dioxide.[107] Therefore, since the grid at Yellowstone is supplied by a coal plant, and off-grid areas in the park are powered primarily through propane powered generators, prioritizing renewable energy developments in off-grid area is not the best way to reduce the park's carbon footprint.

## Recommendation

In order to reach the goal of 40% in-park renewable energy generation by 2020 that is stated in the park's Strategic Plan for Sustainability, Yellowstone should prioritize renewable energy development in its administrative areas.[108] The park should also prioritize on-grid areas in order to more significantly reduce its carbon footprint. Although this is a financial challenge, the park should work with the energy provider to try and negotiate better terms. In addition, Yellowstone's managers should engage with other park leaders from National Parks in California to learn how they negotiated contracts with their electric company.

# Conclusion

This report provides a guide for the park to improve energy management, both in the short and long term. In order for Yellowstone to remain a leader within the NPS in regards to sustainable practices, the park should begin to implement some of the easier recommendations while also developing strategies to tackle more difficult and long term projects. Yellowstone should change its management practices in regards to the environment and energy in order to institutionalize sustainability. This project has also identified options for the park to plan for, and develop, renewable energy within the park. Although additional research will need to be done to understand the feasibility of these suggestions, this could be the direction of a future Master's Project. Lastly, improving energy efficiency practices at the park, and developing renewable energy sources, provides an opportunity to educate the public about what the park is doing to address climate change mitigation and adaptation.

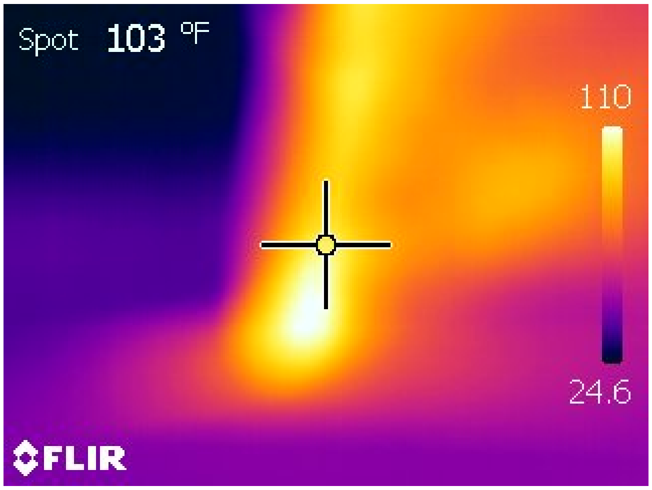
# Appendices

## Appendix A - Infrared Camera Audits

The decreasing prices of infrared cameras have allowed energy and building auditors to deploy these cameras to help “see” where energy is leaking out of a building. The team rented a FLIR camera to survey the buildings at Yellowstone for such leaks.

### How the camera works

Infrared light is outside of the visible light spectrum for humans. Thermal radiation of objects near room temperature is emitted as infrared light. Infrared cameras capture pictures of this infrared light and converts it into a scaled color picture so auditors can “see” the thermal radiation. These pictures show the difference in temperature of surfaces of the building. The photo below is an infrared photo of Old Faithful.

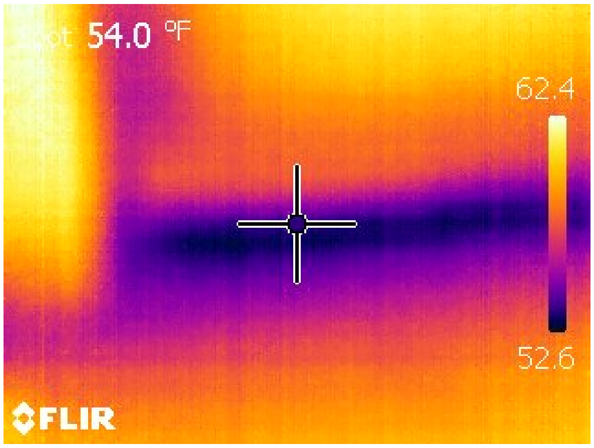



### How a full audit is performed

An infrared camera should be used when the temperature difference between the outside and indoor air is the most extreme. Consequently, doing an energy audit in the morning or the evening, when the sun is not affecting the materials’ surface temperature, will yield the best result. Similarly, using the camera in winter when the heating is turned on in the building is another good instance.

For a full infrared audit to be performed, the heat (or cold) leaking from the building needs to be exaggerated. Since infrared cameras “see” leaks, artificially increasing the amount of heat leaking from the building will increase the ability of the camera to detect the leaks. To do this, blower doors are installed. These doors use fans to pump air into the building increasing the pressure inside. This pressure increase exaggerates the leaks in the building making the temperature differential that the infrared camera detects greater and the leaks easier to spot on the camera’s pictures. Once the blower door is installed, the auditor surveys the building wall by wall with the infrared camera.

## How to interpret an infrared photo




The first observation is the scale on the right of the infrared photo, which indicates the range of temperatures displayed by in the picture. In Photo 85, the temperatures range from 62.4ºF to 52.6ºF with the scale varying between light yellow to deep purple. The exact temperature of a particular location can be measured by placing the crosshairs over a location and then can be read in the upper left corner of the image; in this case, it is 54ºF. This temperature differential indicates that cold air is leaking into the building (in this case under a door). If a photo is taken without a large variance in temperature, then it is unlikely that there is a problem in that location.

With the cold area identified by the infrared photo, the next step is to reference the standard photo of the same location. When interpreting the image, it is important to keep in mind that sometimes the infrared image is slightly more zoomed in than the real photo, which is the case in the two photos above. By comparing the images, possible culprits of the leak can be located and solutions for stopping the leak can be developed. In the case of these two photos, it is likely that the seal between the door and the kick is worn and needs to be replaced. Certain areas are more likely to have leaks and are targeted in infrared cameras audits. These areas include windows, doors, floor joists, ceiling joists, and the insulation bays in exterior walls.

# Appendix B - Software Analysis- Tririga and Energy Star Portfolio Manager

## Software Description

### TREES

One of IBM Tririga's main functions is to monitor and manage workplace assets and operations. The Tririga Real Estate Environmental Sustainability (TREES) software is part of the larger asset management software. TREES helps drive lower energy consumption and emissions by measuring environmental impacts of buildings.

### Energy Star Portfolio Manager

The Energy Star Portfolio Manager is developed by the Environmental Protection Agency (EPA). The free interactive management tool available on the internet focuses on tracking energy, water, and waste data in order to decrease energy consumption and greenhouse gas emissions.

## Software Pros

### TREES

1. Carbon footprint calculator using the Greenhouse Gas Protocol.
2. Data can be uploaded into the software through an offline Excel spreadsheet form (there are five different forms).
3. Connectivity with Energy Star – the information remains in the Tririga software but can receive an Energy Star rating and compare its facilities against other buildings of similar characteristics and use.
4. Reporting – the environmental reports produce nice and clear graphs including any of the data that is in the software. There are many to choose from.
5. Charts, graphs, and data can be exported to Excel.
6. Software customization – TREES has typical information that can be entered into the software, but additional fields can be created. For example, for this Master's Project, we added a seasonal use field and textboxes for appliances and the exterior shell of the building.
7. Additional features – additional features such as GIS mapping is also included in the software, but we did not use this feature.

### Energy Star Portfolio Manager

1. Easy and straightforward to use without any training.
2. Automated carbon footprint calculator for each building and overall use.
3. Data can be uploaded into the software through an offline Excel spreadsheet form (the form can only be uploaded if there is a minimum of 10 buildings being entered at once).[1]
4. Charts, graphs, and data can be exported to Excel

[1] We did not try the offline uploading feature through Energy Star Portfolio Manager, however, because we did not want to upload that many buildings at once. We are not sure how well this feature works, but it seems convenient.

5. Ratings are building type dependent – Portfolio Manager recognizes that some buildings use more energy than others, which is why it has this distinction.
6. Information desired – despite its simplicity, Portfolio Manager allows including some detailed information such as the number of computers, the number of people per floor, the percentage of building heated and cooled, etc.
7. Different uses for a building – it is possible to say that a building is used in two different ways (i.e. office and something else) and specify what percentage of the building is used under each type. If separate energy data is gathered for each type, it can be entered into Portfolio Manager independently.
8. Certification – if the building meets the Energy Star eligibility requirements, the building can receive a certification. The requirements revolved around building designation, operating characteristics, and energy data.

## Software Cons

### TREES

1. Price – not free.
2. Information location - the location of the information is not intuitive. There are many tabs and adding/editing the data is not straightforward.
3. Training – the training to learn how to use the software will take at least ten hours. Follow up trainings or phone calls will be probably be necessary in order to make sure that the users understand where to access all the information and that they are using the software to its full potential.
4. The carbon calculator
    a. It requires more work to set it up (need to input grams of carbon per gallon for example)
    b. Carbon calculations are only available on a monthly basis (because our data was entered in on a monthly basis). If emissions for an entire year are desired, then the calculation needs to be run 12 times.
    c. Every time the carbon calculation runs, the buildings that need to be included in the calculation need to be re-selected (checking a checkbox on each building tab).
5. Reporting - Tririga has a list of over 9,000 graphs and charts that can be automatically generated (most of them are irrelevant such as the “customer service satisfaction” or the “aggregate accident reports by status) that make it complicated and not as straightforward to graph the desired environmental information.

### Energy Star Portfolio Manager

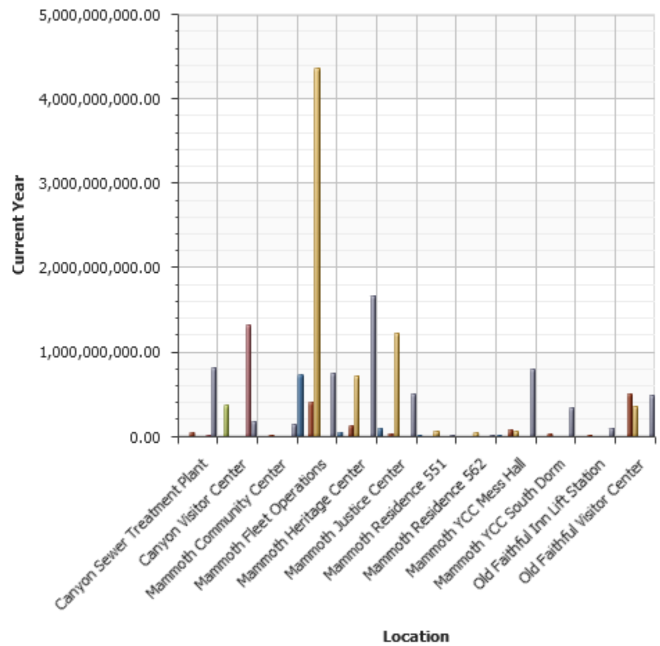
1. Building ratings – buildings that do not fit the specific building type such as “office” or “dorm” are titled “other” and do not receive a Portfolio Manager rating.
2. Building comparison – a rating can change significantly depending on the space designation. Because some of the buildings at Yellowstone have multiple uses, it is sometimes hard to associate a building type to it. Therefore, it is difficult to compare the ratings across buildings, since there are many assumptions built into the software according to the building type.
3. The carbon calculator can only calculate emissions for a building if it has 12 months of data.

4. Reporting – the graphing capabilities are somewhat helpful. They are not very esthetically pleasing and more importantly, they are generated based on the building rating. Therefore, if the rating is N/A (because the building was defined as an "other" type, for example), then a graph cannot be generated.

## Graph and Chart Comparison

### TREES

Output 1:




Output 2:

| | | | | 2009 | | | 2010 | | | Base Year (2009) | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Site | | | Gross SF | Quantity | Cost | Cost/ Quantity | Quantity | Cost | Cost/ Quantity | Quantity | Cost | Cost/ Quantity |
| **Country: United States of America** | | | | | | | | | | | | |
| **State: Yellowstone National Park** | | | | | | | | | | | | |
| Canyon Sewer Treatment Plant | | | 0.00 | | | | | | | | | |
| | | **Energy Log** | | | | | | | | | | |
| | (kilojoules) | Diesel | | 19,780,200.00 | $71.00 | $0.00 | 6,593,400.00 | $24.00 | $0.00 | 19,780,200.00 | $71.00 | $0.00 |
| | (kilojoules) | Electricity | | 566,496,000.00 | $22,942.00 | $0.00 | 772,992,000.00 | $33,672.00 | $0.00 | 566,496,000.00 | $22,942.00 | $0.00 |
| | | Total Energy Log | | 586,276,200.00 | $23,013.00 | $0.00 | 779,585,400.00 | $33,696.00 | $0.00 | 586,276,200.00 | $23,013.00 | $0.00 |
| Canyon Visitor Center | | | 0.00 | | | | | | | | | |
| | | **Energy Log** | | | | | | | | | | |
| | (kilojoules) | Diesel | | 880,731,720.00 | $16,444.00 | $0.00 | 1,319,998,680.00 | $29,253.00 | $0.00 | 880,731,720.00 | $16,444.00 | $0.00 |
| | (kilojoules) | Electricity | | 422,208,000.00 | $17,123.00 | $0.00 | 268,992,000.00 | $10,960.00 | $0.00 | 422,208,000.00 | $17,123.00 | $0.00 |
| | | Total Energy Log | | 1,302,939,720.00 | $33,566.00 | $0.00 | 1,588,990,680.00 | $40,213.00 | $0.00 | 1,302,939,720.00 | $33,566.00 | $0.00 |
| Mammoth Community Center | | | 0.00 | | | | | | | | | |
| | | **Energy Log** | | | | | | | | | | |
| | (kilojoules) | Electricity | | 62,496,000.00 | $2,002.00 | $0.00 | 121,824,000.00 | $3,806.00 | $0.00 | 62,496,000.00 | $2,002.00 | $0.00 |
| | | Total Energy Log | | 62,496,000.00 | $2,002.00 | $0.00 | 121,824,000.00 | $3,806.00 | $0.00 | 62,496,000.00 | $2,002.00 | $0.00 |
| Mammoth Fleet Operations | | | 0.00 | | | | | | | | | |
| | | **Energy Log** | | | | | | | | | | |
| | (kilojoules) | Electricity | | 126,576,000.00 | $4,964.00 | $0.00 | 505,440,000.00 | $14,614.00 | $0.00 | 126,576,000.00 | $4,964.00 | $0.00 |
| | (kilojoules) | Propane | | 1,536,256,028.91 | $0.00 | $0.00 | 3,728,791,908.23 | $0.00 | $0.00 | 1,536,256,028.91 | $0.00 | $0.00 |
| | | Total Energy Log | | 1,662,832,028.91 | $4,964.00 | $0.00 | 4,234,231,908.23 | $14,614.00 | $0.00 | 1,662,832,028.91 | $4,964.00 | $0.00 |
| Mammoth Heritage Center | | | 0.00 | | | | | | | | | |
| | | **Energy Log** | | | | | | | | | | |
| | (kilojoules) | Electricity | | 802,080,000.00 | $18,435.00 | $0.00 | 1,429,632,000.00 | $33,653.00 | $0.00 | 802,080,000.00 | $18,435.00 | $0.00 |
| | (kilojoules) | Propane | | 211,873,688.20 | $0.00 | $0.00 | 536,943,427.11 | $0.00 | $0.00 | 211,873,688.20 | $0.00 | $0.00 |

Output 3:

Most of the spreadsheet has 0's, because the data was not included, but this table shows the possible information that be included in the report.

TRIRIGA

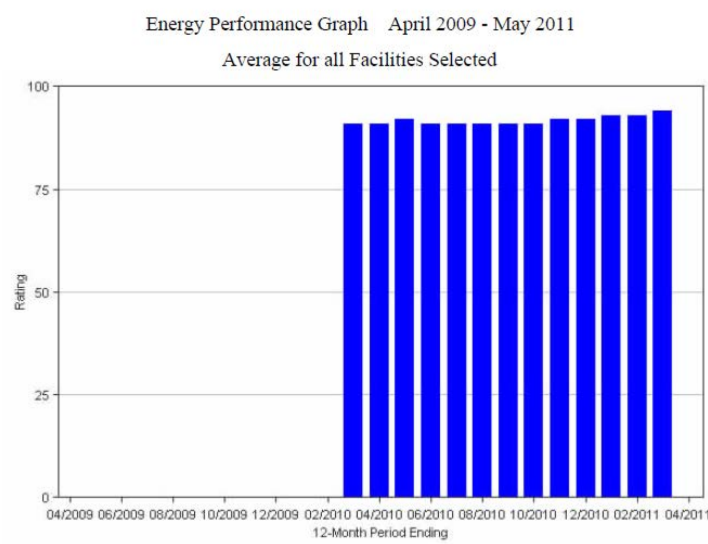
Environmental Impact Report

| | | 2009 | 2010 | Base Year (2009) | Delta |
|---|---|---|---|---|---|
| **Energy Summary** | | | | | |
| Total Energy Consumption | (kilojoules) | 6,341,866,166.17 | 11,776,898,181.49 | 6,341,866,166.17 | 5,435,032,015.33 |
| Total Energy Consumption/SF | (kilojoules) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Energy Consumption/Occupant | (kilojoules) | 0.00 | 0.00 | 0.00 | 0.00 |
| **Emission Summary** | | | | | |
| Total Co2 Emissions (Energy) | (US Tons Co2) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Co2 Emissions (Energy)/SF | (US Tons Co2) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Co2 Emissions (Energy)/Occupant | (US Tons Co2) | 0.00 | 0.00 | 0.00 | 0.00 |
| **Travel Summary** | | | | | |
| Total Co2 Emissions (Travel) | (US Tons Co2) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Co2 Emissions (Travel)/SF | (US Tons Co2) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Co2 Emissions (Travel)/Occupant | (US Tons Co2) | 0.00 | 0.00 | 0.00 | 0.00 |
| **Water Summary** | | | | | |
| Total Water Consumption | (CCF (Hundred Cubic feet)) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Water Consumption/SF | (CCF (Hundred Cubic feet)) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Water Consumption/Occupant | (CCF (Hundred Cubic feet)) | 0.00 | 0.00 | 0.00 | 0.00 |
| **Waste Summary** | | | | | |
| Total Office Paper Recycled | (tons (US)) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Office Paper Recycled/SF | (tons (US)) | 0.00 | 0.00 | 0.00 | 0.00 |
| Total Office Paper Recycled/Occupant | (tons (US)) | 0.00 | 0.00 | 0.00 | 0.00 |

## Energy Star Portfolio Manager

Output 4:

The following graph shows the Mammoth North Dorm rating output. The first year does not have a rating because it is the base year. The higher the rating, the more energy efficient the building.



## Carbon Calculation Comparison

| | Tririga TREES | | Energy Star Portfolio Manager | |
|---|---|---|---|---|
| | April 2009-March 2010 | April 2010-March 2011 | April 2009-March 2010 | April 2010-March 2011 |
| **MA Community Center** | 2086.75 | 2630.82 | 61.19 | 68.11 |
| **MA Justice Center** | 1154.61 | 1812.95 | 74.02 | 120.31 |
| **Canyon VEC** | 2616.73 | 4897.62 | N/A | 101.85 |

*Unit: $MtCO_2e$*

The carbon emissions from TREES and Energy Star Portfolio Manager produce very different results. Portfolio Manager should have a higher $MtCO_2$ equivalent since it includes all greenhouse gas emissions, but TREES only includes carbon emissions. It is possible to include additional emissions besides carbon within TREES, but all the information needs to be input manually. For TREES' carbon calculation, we assumed the carbon intensity of each fuel used and that all electricity was generated within the WECC. Portfolio Manager, on the other hand, generates the information automatically. Its assumptions are that the electric emissions rate (kg $CO_2e$/MBtu) is 114.8. The emissions are based on the NorthWestern Corporation electric distribution utility.

## Software Recommendation for Yellowstone

After extensively using both TREES and Energy Star Portfolio Manager, we suggest that Yellowstone use EPA's Energy Star software to monitor the energy use in the park. Since various people will want to use it, Portfolio Manager is simple enough to grasp in a short amount of time given that it is relatively intuitive. Buildings can be created quickly and drop-down menus allow for easy navigation on the site. TREES has a lot more tabs and subfields, which are not as intuitive.

Portfolio Manager requires some detailed information, which means that it can produce significant results and output carbon emissions through the automatic carbon calculator. Portfolio Manager monitors energy, water, and waste and their associated costs if desired. The software allows Yellowstone to set energy targets if wanted.

A building sometimes has trouble fitting into a particular building type, but this problem also exists in TREES. Regardless of building type, the change from the baseline for each individual building is accurate and is the most valuable information for Yellowstone to have for monitoring energy consumption in the park. Because not all buildings will have a rating, it is possible to assign them a different type of building, in order to get a rating, if the rating is desired.

TREES has more aesthetically pleasing graphs, but are more difficult to generate because there are so many. Portfolio Manager supposedly allows the user to make custom graphs, but we were only able to generate rating based graphs. We were not impressed with either TREES or Portfolio Manager's graphing capabilities. We recommend that when Yellowstone wants to graphically see a building's energy consumption, for example, the park should use an Excel template that allows the user to enter in the energy consumed for each building per designated time-period and automatically generate a graph. Generating graphs in Excel was our team's preferred method for this write-up.

Overall, Portfolio Manager seems like the better alternative because monitoring energy use is what the software is designed for and it is free. Tririga offers more options and would best be used if wanting to monitor all of the park's assets, not just energy.

We suggest using Portfolio Manager over TREES. However, we did some research and found some other software/energy benchmarking possibilities that would probably be good to look into as well.

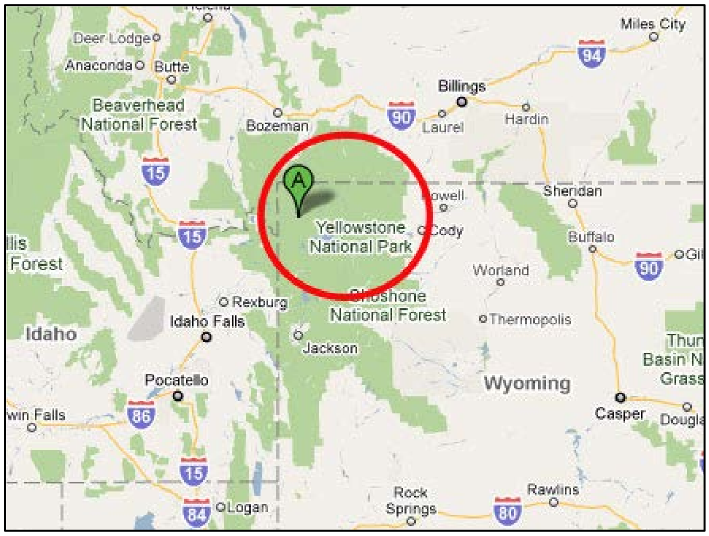
## Additional Energy Management Software

There are over 200 energy management software on the market with a variety of strengths and weaknesses in reporting, bill management, submetering, sustainability and more. Based on the current infrastructure and needs of Yellowstone, the following software has been identified as possibly meeting the data management needs of the park.

| **Vendor** | **Software Product** | **Features** |
|---|---|---|
| CA Technologies | ecoGovernance | • Centralized system manages carbon, water and waste<br>• Automated data collection, reporting, analysis, actions and integration<br>• Real-time dashboard<br>• Supplier, facility, employee and product assessments |
| Credit 360 | Energy and Carbon | • Estimation methodologies can compensate for missing data<br>• Monitor, review and manage energy usage to calculate scope 1, 2 and 3 emissions<br>• Report in line with GHG Protocol, CRC, EES, CDP, GRI, ISO 14064, NGERS and Climate Registry |
| Enablon | Energy & Carbon Management Suite | • Suite includes: GHG Emissions Accounting, Air Quality System, Cap & Trade Management, Sustainability Projects, Utility Data Management and Forecast & Scenario<br>• Identify personalized inventory |

In addition, Groom Energy has conducted a review of available software. The full report, which was released in March 2012, can be obtained at a cost from their website. (http://www.groomenergy.com/enterprise_smart_grid_research.html)

# Appendix C - Map of Yellowstone





Source: mapquest.com, Yellowstonenationalpark.com/maps.htm

# Appendix D - Recommended Light levels

**Experts made this list to make sure all areas have the correct illumination**

1.Go to different areas and record the Footcandles displayed

2.Record if each area needs **MORE** or **LESS** light(if it's okay, give it a "√" mark).

| AREA | RECOMMENDED FOOTCANDLES | MEASURED FOOTCANDLES | CHANGE NEEDED? |
|---|---|---|---|
| Classrooms (reading & writing) | 40-50 | | |
| Computer labs | 10-25 | | |
| Labs (general) | 30-40 | | |
| Labs (demonstrations/experiments) | 100 | | |
| Auditorium (seated activities) | 10 | | |
| Auditorium (reading activities) | 40-50 | | |
| Kitchens | 50 | | |
| Dining Areas | 20 | | |
| Hallways / Stairwells | 5-10 | | |
| Gymnasiums (exercise & rec.) | 20 | | |
| Gymnasiums (basketball games) | 75 | | |
| Locker rooms | 10 | | |
| Libraries & media centers | 40-50 | | |
| Shops (rough to medium work) | 30-40 | | |
| Shops (fine or detailed work) | 50-75 | | |
| Offices (reading tasks) | 50 | | |
| Offices (non-reading tasks) | 30 | | |
| Teacher's lounge | 20 | | |
| Bathrooms (by sink & mirror) | 30 | | |
| Bathrooms (lavatories) | 15 | | |
| Maintenance rooms | 30 | | |
| Parking lots / outdoor lighting | 1-5 | | |

**Adapted by Maine Energy Education Program, Summer 2009.**
**Sources: The NEED Project and Illuminating Engineering Society**

# Appendix E - Electricity and Propane Metering Options

Due to the difficulty of access to many of the buildings in Yellowstone National Park, the utility company is not able to read the electricity meters on a regular schedule. This makes using utility bills inaccurate for determining electricity consumption on a monthly time scale. Similarly, propane is delivered on an irregular schedule and tanks are filled from varying levels of empty. This makes using the filling truck invoices inaccurate to determine how much propane is being used on any time scale shorter than a year.

Below is a sampling of the metering options for both electricity and propane that fit needs of the park that will allow for a more accurate assessment of the park's energy consumption.

## Electricity Metering Options

The park operates on the three phase system. This limits the available metering and monitoring options as many off the shelf equipment options cannot be connected to a three phase system.

### OWL[109]

OWL is a U.K. based company, which supplies a verity of equipment for monitoring home energy use. Installation requires attaching sensors to the circuit leads inside the breaker panel. In the case of a 3 phase system, one sensor is required for each phase. The unit sends its data wirelessly to a computer where it can be stored and analyzed. The units also include a real time display. The units are currently only sold in the UK, but they can be configured for international use. Cost of equipment is approximately $80.

### TED 5000[110]

The TED 5000 is distributed by The Energy Detectives (TED). The unit is installed in the breaker panel and uses sensors attached to any of the leads inside the panel, including the main. The unit requires a breaker for itself within the panel. The unit can store data in itself or it can connect to a wireless network to transmit the data to a computer. Real time monitors are also available. These plug into any outlet in the circuit being monitored and display real time electricity use data. Unfortunately, at this time, TED only works on single phase circuits. They are working on a model that works for 3 phase, but a date for its release has not been set. The single phase system cost $200-$500 depending on the amount of supplementary displays and sensors for monitoring additional circuits.

### Wattmetrics[111]

Wattmertics adapt the GE kW2c smart meter to allow wireless monitoring. These meters replace or supplement utility meters and are installed in a similar fashion. They have a USB lead installed on the meter, which connects to a network agent, and sends the information to a computer. The meter records and transmits watts, volts and amps of the circuit being monitored. Some installing restrictions include the placement of the network agent which must be installed inside and within range of a wireless network or a wired connection to a computer. The meter USB lead cannot exceed 16 feet and therefore must be within 16 feet of the network agent. Costs of the system are estimated on a case by case basis.

## Data Loggers

### HOBO U12 External Data Logger[112]

The HOBO U12 is a multipurpose data logger, which can be connected to a kilowatt sensor for logging electricity use. The unit is programmable to log data at various intervals and stores up to 43,000 measurements. The unit connects to a computer via a USB for data off load. Due to the manual off load of data, there is no need to worry about locating the unit near a computer or in a wireless network, therefore making this unit ideal for moving between different locations. The cost of the unit is $108.

## Propane Metering Options[113]

Propane metering can be accomplished by most gas metering equipment. Meters just need to be sized for the piping and flow rate of the system. Units which have a built-in pulser can be more easily integrated into a monitoring system. Options include 200 CFH American Gas Meter, 250 CFH American Gas Meter and 250 CFH Itron Acraris Metris Gas Meter. These units range in cost from $160-$250. To be digitally monitored and have data stored, these meters should be integrated with one of the below digital monitors.

## Digital Monitoring Options

### AcquiSuite[114]

The AcquiSuite acts as a server that can collect data from any meter that has digital or analog outputs. These can be propane, natural gas, diesel or electricity meters. The data is stored on unit and can be downloaded manually or the unit can be connected to a network via wireless or wire. The AcquiSuite can also be upgraded to transmit its data via a cell phone network. The output is CSV files that can be integrated into excel spreadsheets, websites or secure databases. The cost of the base model is $1,900, but cost can increase by $700 - $1,400 when considering extending the range of the device or additional input modules.

### AcquiLite[115]

The AcquiLite acts as a modem or an Ethernet port to send collected data to a computer or online data base. The unit can collect data from up to four inputs from meters with popular signals. Data is also stored on the device and can be uploaded on a preset interval. The output is CSV files that can be integrated into spreadsheets, websites or secure databases. The cost of the unit is $700, but additional equipment to extend the range can increase the price by $700.

## Appendix F - Degree-Day Weather Correction Calculation

Degree days can be found at: http://www.degreedays.net

To adjust for weather effects on energy usage for heating, perform the following calculations:

Sum the annual heating energy use for the base year. In this case, the example is a school in the Puget Sound area for the year 1995. We then sum the monthly degree-day data for that same year.
You can develop your own degree-day data from monthly average daily temperatures. For our example, the degree-days for '95 is 6,500 degree-days.

<u>1995</u>

115,800 Therms / 6,500 Heating Degree-days = 17.8 Therms per DD

<u>1996</u>

The heating degree-day total for 1996 at this location is 6,800. The year was a little cooler than 1995. So what was the impact on the energy usage?

17.8 Therms /~~DD~~ x 6,800 ~~DD~~ = 121,040 Therms

The difference from 1995 to 1996 that can be attributed to the weather is 5,240 therms. If the building energy use is equal to or slightly less than 121,040 therms, then weather is the likely reason for the increased usage.

If the usage in the facility is significantly greater than 121,040 therms, then the building operator or manager should be looking for changes in building use or system efficiency.

If the usage is significantly less than the "degree-day" estimate, then the difference is likely due to decreased usage which may be attributed to conservation measures, heating system changes or changes in use and occupancy.

Source: Building Operator Certification 102: Energy Conservation Techniques – Student Handbook. 4th edition. Northwest Energy Efficiency Council, 2009.

# Appendix G - Behavior Signage

The following is an example of signage that could be posted in staff common area such as break rooms and team bulletin boards to remind employees about the ways they can help Yellowstone achieve their energy saving initiatives.

## Help Yellowstone Stay Green

**The Yellowstone Energy Team needs your help to reduce the park's energy consumption and carbon footprint. Here are a few tips for maintaining an energy efficient work space:**

- Don't forget to **turn off the lights** when you leave a room. We have all heard this a million times, but it is the easiest and most effective way you can help reduce our energy consumption. Don't be afraid to turn off lights in common areas such as lunch rooms when empty or in hallways when they are unnecessary such as during daylight hours.

- Did you know that a coffee maker will continue to use energy even when it is not in use, as long as it is plugged in? It is referred to as vampire electricity and can very simply be eliminated. Please be sure to **unplug electronics** such as coffee makers, cell phone chargers, toasters and radios when not in use.

- For those electronics that are not easy to unplug such as computers, printers and copiers, utilize **smart power stripes**. The smart power strip will detect when electronics have been shut off, then after a certain period of time, it will cut off the flow of electricity, thereby further reducing vampire energy.

- When working in the office, try to utilize **task lighting**, rather than the overhead office lights. Since the office lighting is connected to a larger system, it will use more energy than need based task lighting.

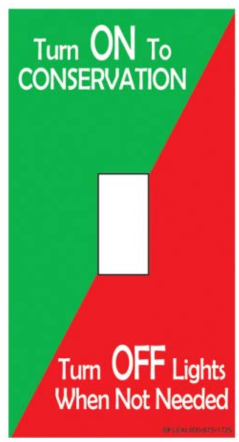
- **Please report** any of the following issues to maintenance as soon as possible so they can be quickly addressed:

  - Water faucet leaks
  - Broken or cracked windows
  - Burnt out lamps
  - Broken appliances
  - Air leaks around doors or windows

The following are additional signage which could be strategically placed near light switches, doors, and equipment throughout the facilities to remind employees to shut off or unplug idle and unused equipment or close doors behind them. The decals shown here can be obtained from awareness IDEAS (http://www.awarenessideas.com/Energy-Decals-s/10.htm).

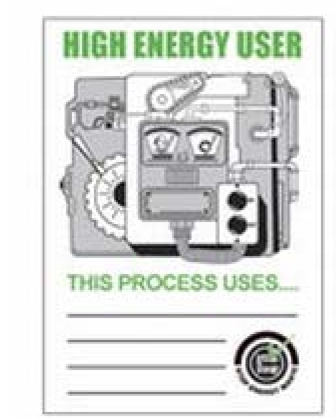




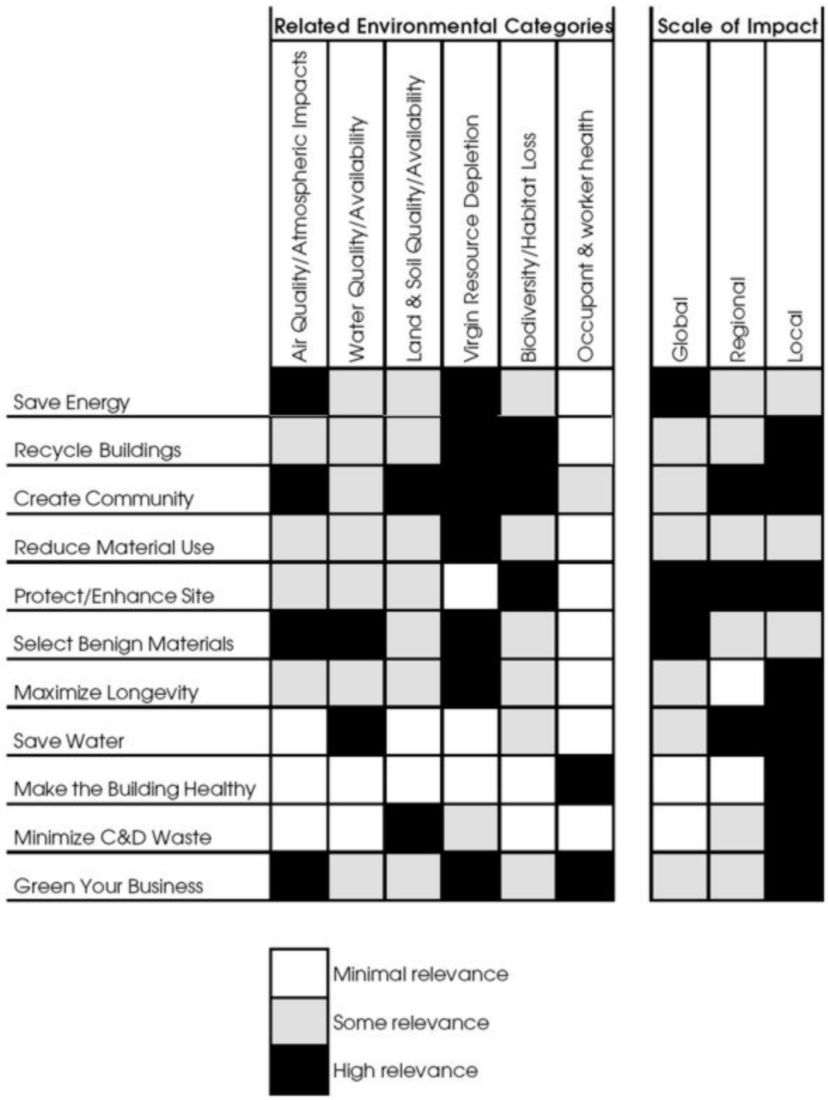








# Appendix H - Establishing Priorities in Buildings




Wilson, A. (1995) “Establishing Priorities with Green Building,” Environmental Building News, September/October

# Appendix I – LEED O + M Checklist

**LEED 2009 for Existing Buildings: Operations & Maintenance**

Project Checklist

Project Name

Date

| Y | ? | N | | Sustainable Sites | Possible Points: 26 |
|---|---|---|---|---|---|
| | | | Credit 1 | LEED Certified Design and Construction | 4 |
| | | | Credit 2 | Building Exterior and Hardscape Management Plan | 1 |
| | | | Credit 3 | Integrated Pest Mgmt, Erosion Control, and Landscape Mgmt Plan | 1 |
| | | | Credit 4 | Alternative Commuting Transportation | 3 to 15 |
| | | | Credit 5 | Site Development—Protect or Restore Open Habitat | 1 |
| | | | Credit 6 | Stormwater Quantity Control | 1 |
| | | | Credit 7.1 | Heat Island Reduction—Non-Roof | 1 |
| | | | Credit 7.2 | Heat Island Reduction—Roof | 1 |
| | | | Credit 8 | Light Pollution Reduction | 1 |

| Y | ? | N | | Water Efficiency | Possible Points: 14 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Minimum Indoor Plumbing Fixture and Fitting Efficiency | |
| | | | Credit 1 | Water Performance Measurement | 1 to 2 |
| | | | Credit 2 | Additional Indoor Plumbing Fixture and Fitting Efficiency | 1 to 5 |
| | | | Credit 3 | Water Efficient Landscaping | 1 to 5 |
| | | | Credit 4 | Cooling Tower Water Management | 1 to 2 |

| Y | ? | N | | Energy and Atmosphere | Possible Points: 35 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Energy Efficiency Best Management Practices | |
| Y | | | Prereq 2 | Minimum Energy Efficiency Performance | |
| Y | | | Prereq 3 | Fundamental Refrigerant Management | |
| | | | Credit 1 | Optimize Energy Efficiency Performance | 1 to 18 |
| | | | Credit 2.1 | Existing Building Commissioning—Investigation and Analysis | 2 |
| | | | Credit 2.2 | Existing Building Commissioning—Implementation | 2 |
| | | | Credit 2.3 | Existing Building Commissioning—Ongoing Commissioning | 2 |
| | | | Credit 3.1 | Performance Measurement—Building Automation System | 1 |
| | | | Credit 3.2 | Performance Measurement—System-Level Metering | 1 to 2 |
| | | | Credit 4 | On-site and Off-site Renewable Energy | 1 to 6 |
| | | | Credit 5 | Enhanced Refrigerant Management | 1 |
| | | | Credit 6 | Emissions Reduction Reporting | 1 |

| Y | ? | N | | Materials and Resources | Possible Points: 10 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Sustainable Purchasing Policy | |
| Y | | | Prereq 2 | Solid Waste Management Policy | |
| | | | Credit 1 | Sustainable Purchasing—Ongoing Consumables | 1 |
| | | | Credit 2.1 | Sustainable Purchasing—Electric-Powered Equipment | 1 |
| | | | Credit 2.2 | Sustainable Purchasing—Furniture | 1 |
| | | | Credit 3 | Sustainable Purchasing—Facility Alterations and Additions | 1 |
| | | | Credit 4 | Sustainable Purchasing—Reduced Mercury in Lamps | 1 |
| | | | Credit 5 | Sustainable Purchasing—Food | 1 |

| Y | ? | N | | Materials and Resources, Continued | |
|---|---|---|---|---|---|
| | | | Credit 6 | Solid Waste Management—Waste Stream Audit | 1 |
| | | | Credit 7 | Solid Waste Management—Ongoing Consumables | 1 |
| | | | Credit 8 | Solid Waste Management—Durable Goods | 1 |
| | | | Credit 9 | Solid Waste Management—Facility Alterations and Additions | 1 |

| Y | ? | N | | Indoor Environmental Quality | Possible Points: 15 |
|---|---|---|---|---|---|
| Y | | | Prereq 1 | Minimum IAQ Performance | |
| Y | | | Prereq 2 | Environmental Tobacco Smoke (ETS) Control | |
| Y | | | Prereq 3 | Green Cleaning Policy | |
| | | | Credit 1.1 | IAQ Best Mgmt Practices—IAQ Management Program | 1 |
| | | | Credit 1.2 | IAQ Best Mgmt Practices—Outdoor Air | 1 |
| | | | Credit 1.3 | IAQ Best Mgmt Practices—Increased Ventilation | 1 |
| | | | Credit 1.4 | IAQ Best Mgmt Practices—Reduce Particulates in Air Distribution | 1 |
| | | | Credit 1.5 | IAQ Mgmt Plan—IAQ Mgmt for Facility Alterations and Additions | 1 |
| | | | Credit 2.1 | Occupant Comfort—Occupant Survey | 1 |
| | | | Credit 2.2 | Controllability of Systems—Lighting | 1 |
| | | | Credit 2.3 | Occupant Comfort—Thermal Comfort Monitoring | 1 |
| | | | Credit 2.4 | Daylight and Views | 1 |
| | | | Credit 3.1 | Green Cleaning—High Performance Cleaning Program | 1 |
| | | | Credit 3.2 | Green Cleaning—Custodial Effectiveness Assessment | 1 |
| | | | Credit 3.3 | Green Cleaning—Sustainable Cleaning Products, Materials Purchases | 1 |
| | | | Credit 3.4 | Green Cleaning—Sustainable Cleaning Equipment | 1 |
| | | | Credit 3.5 | Green Cleaning—Indoor Chemical and Pollutant Source Control | 1 |
| | | | Credit 3.6 | Green Cleaning—Indoor Integrated Pest Management | 1 |

| Y | ? | N | | Innovation in Operations | Possible Points: 6 |
|---|---|---|---|---|---|
| | | | Credit 1.1 | Innovation in Operations: Specific Title | 1 |
| | | | Credit 1.2 | Innovation in Operations: Specific Title | 1 |
| | | | Credit 1.3 | Innovation in Operations: Specific Title | 1 |
| | | | Credit 1.4 | Innovation in Operations: Specific Title | 1 |
| | | | Credit 2 | LEED Accredited Professional | 1 |
| | | | Credit 3 | Documenting Sustainable Building Cost Impacts | 1 |

| Y | ? | N | | Regional Priority Credits | Possible Points: 4 |
|---|---|---|---|---|---|
| | | | Credit 1.1 | Regional Priority: Specific Credit | 1 |
| | | | Credit 1.2 | Regional Priority: Specific Credit | 1 |
| | | | Credit 1.3 | Regional Priority: Specific Credit | 1 |
| | | | Credit 1.4 | Regional Priority: Specific Credit | 1 |

| Y | ? | N | | Total | Possible Points: 110 |
|---|---|---|---|---|---|

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110

USGBC. 2009. LEED 2009 for Existing Buildings: Operations & Maintenance Checklist. 15 April 2012. <http:/www.usgbc.org/DisplayPage.aspx?CMSPageID=2195>.

[1] National Park Service- U.S. Department of the Interior. 2012. Windows into Wonderland: Yellowstone History. 27 March 2012. <www.windowsintowonderland.org/history/index.htm>.

[2] National Park Service – U.S. Department of the Interior. 2012. History and Culture. 2 February 2012. <http://www.nps.gov/yell/historyculture/index.htm>.

[3] YellowstoneNationalPark.com. 2011. Main. 2 February 2012. <www.yellowstonenationalpark.com>.

[4] National Park Service – U.S. Department of the Interior. 2012. Yellowstone Fact Sheet. 2 February 2012. <http://www.nps.gov/yell/planyourvisit/factsheet.htm>.

[5] Andy Hoffman. Green Construction and Design PowerPoint. 10 January 2012.

[6] Yellowstone Park Foundation. 2010. YES! Yellowstone Environmental Stewardship Initiative. 15 January 2012. <http://www.ypf.org/site/PageServer?pagename=WHAT_greenest_YES_home>.

[7]National Park Service. 2011. Annual Summary Report for 2011. 15 April 2012. <http://www.nature.nps.gov/stats/viewReport.cfm>

[8] U.S. Energy Information Administration. 2008. Commercial Buildings Energy Consumption Survey (CBECS) Detailed Tables. 25 March 2012. <www.eia.gov/emeu/cbecs/cbecs2003/detailed_tables_ 2003/detailed_tables_2003.html>.

[9] McKinsey & Company. 2012. Greenhouse Gas Abatement Cost Curves. 1 March 2012. <http://www.mckinsey.com/Client_Service/Sustainability/Latest_thinking/Costcurves>.

[10] Building Operator Certification Efficient Lighting Fundamentals – Student Handbook. 5th edition. Northwest Energy Efficiency Council.

[11] Yaham LED High Bay Light. 2012. 400W metal halide led replacement. 4 March 2012. <http://www.ledhibaylight.com/400w-metal-halide-led-replacement-61.html>.

[12] Alibaba.com. 2012. LED 80w high bay replacement of 250w metal halide lamp. 4 March 2012. <http://www.alibaba.com/product-gs/361405005/LED_80w_high_bay_replacement_of.html>.

[13] U.S. Department of Energy. 2012. Energy Savers. 1 April 2012. <energysavers.gov>.

[14] Emerich, S. and A. Persily. 1998. Energy Impacts of Infiltration and ventilation in US Office Buildings Using Multizone Airflow Simulation. 15 January 2012. <http://fire.nist.gov/bfrlpubs/ build99/PDF/b99093.pdf>.

[15] Tufts climate Initiative. 2010. Vending Misters: Facts and Issues. 4 April 2012. <http://sustainability.tufts.edu/downloads/VendingMiserHandout-updated020310.pdf>.

[16] EnergyMisers. 2012. Rebates. 19 March 2012. <http://www.vendingmiser.com/rebates.php>.

[17] Tufts climate Initiative. 2010. Vending Misters: Facts and Issues. 4 April 2012. <http://sustainability.tufts.edu/downloads/VendingMiserHandout-updated020310.pdf>.

[18] VendingMiserStore.com. 2009. Vending Miser Energy Savings Products. 25 March 2012. <http://www.vendingmiserstore.com/>.

[19] Tufts Climate Initiative. Vending Misers: Facts and Issues. 20 March 2012. <http://sustainability .tufts.edu/downloads/VendingMiserHandout-updated020310.pdf>.

[20] Michigan Department of Labor & Economic Growth. Vending Machine Energy Savings. 20 March 2012. <http://www.michigan.gov/documents/CIS_EO_Vending_Machine_05-0042_155715_7.pdf>.

[21] EnergyMisers. 2012. Testimonials. 19 March 2012. <www.vendingmiser.com/testimonials.php>.

[22] Degree Days.net. 2012. Custom Degree Day Data. 5 March 2012. <http://www.degreedays.net/>.

[23] Carbon Trust. 2012. Energy Awareness Campaigns – Loughborough University. 5 March 2012. <http://www.carbontrust.co.uk/cut-carbon-reduce-costs/products-services/technology-advice/employee-awareness/pages/energy-awareness-loughborough-university.aspx>.

[24] Ehrhrdt-Martinez, Karen, Laitner, John and Kenneth Keating. California Public Utilities Commission. 2009. Pursuing Energy-Efficient Behavior in a Regulatory Environment: Motivating Policymakers, Program Adminstrators, and Program Implementers. 6 March 2012. <http://uc-ciee.org/downloads/Motivating_Policymakers_rev.pdf>.

[25] Yellowstone Conference to Focus on Science and Decision Making. 31 March 2012. <www.yellowstonegate.com/2012/03/yellowstone-conference-focus-on-science-decision-making>.

[26] Appliance Parts Pros. 12 December 2011. <http://www.appliancepartspros.com>.

[27] US Department of Energy. 2 February 2012. Life Cycle Cost Estimate for Energy Star Residential Freezer(s).

[28] US District Court of Wyoming. Courthouse Location Information. 31 March 2012. <www.wyd.uscourts.gov/htmlpages/courtinfo.html>.

[29] Roberts- Gordon LLC. 2010. CoRayVac Brochure. 25 March 2012. <http://corayvac.com/pdf/CRV_Brochure_2009_lo.pdf>.

[30] US Department of Energy. 9 February 2011. Heating Systems. 8 January 2012. <http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12480>.

[31] Summers, Birney. 1 August 2011. When should I switch from Propane to Electric Heat. 7 January 2012. <http://www.energyboomer.typepad.com/energyboomer/save_on_heating_with_propane/>.

[32] US Environmental Protection Agency. 15 April 2011. Household Emissions Calculator Assumptions and References. 8 January 2012. **<**www.epa.gov/climatechange/emissions/ind_assumptions.html>.

[33] Propane 101. Propane vs Electricity. 7 January 2012. <www.propane101.com/propanevselectricity.htm>.

[34] Propane Education and Research Council. Propane Boiler. 7 January 2012. <www.usepropane.com/propane-boilers>.

[35] US Department of Energy. 9 February 2011. Furnaces and Boilers. 8 January 2012. <http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12530>.

[36] US Department of Energy. 9 February 2011. Furnaces and Boilers. 8 January 2012. <http://www.energysavers.gov/your_home/space_heating_cooling/index.cfm/mytopic=12520>.

[37] US Environmental Protection Agency. 7 January 2012. eGrid, GHG Annual Output Emissions Rates. 8 January 2012. <http://cfpub.epa.gov/egridweb/ghg.cfm>.

[38] US Department of Energy. 9 February 2011. Lower Water Heating Temperature for Energy Savings. 8 January 2012. <www.energysavers.gov/your_home/water_heating/index.cfm/mytopic=13090>.

[39] Stein, Benjamin and Reynolds, John. 2000. Water Supply. *Mechanical and Electrical Equipment for Buildings*: 599.

[40] Natural Resources Canada. 22 April 2009. Heat Recovery from Kitchen Refrigeration. 8 January 2012. <http://oee.nrcan.gc.ca/publications/commercial/15826>.

[41] Natural Resources Canada. 15 April 2009. Walk-in Commercial Refrigeration. 8 January 2012. <http://oee.nrcan.gc.ca/industrial/equipment/commercial-refrigeration/17005>.

[42] Environmental Defense Fund. 6 May 2010. EDF Climate Corps Handbook: 19. 8 January 2012.

[43] Home Controls. Leviton Occupancy Sensors. 8 January 2012. <http://www.homecontrols.com/manufacturers_list/LevitonOccupancySensors>.

[44] Environmental Defense Fund. 6 May 2010. EDF Climate Corps Handbook: 39. 8 January 2012.

[45] Lloyd Krueger. Email communication. 29 February 2012.

[46] Grainger, Inc. 2012. Infrared Motion Sensors. 12 January 2012. <www.grainger.com/Grainger/WATT-STOPPER-Photosensor-2HTG9?cm_sp=IO-_-IDP-_-BTM_BTB05209020&cm_vc=IDPBBZ2>.

[47] U.S. Department of Energy Federal Energy Management Program and Enviro-Management & Research, Inc. 2008. Commissioning for Federal Facilities. <http://www1.eere.energy.gov/femp/pdfs/commissioning_fed_facilities.pdf>.

[48] Ivanovich, M. 2005. Owners Perspective Magazine. What Owners Need to Know About Commissioning Buildings. <www.coaa.org/Portals/0/documents/owners_perspective/COAAFall05Final.pdf>.

[49] CEC/PIER. 2009. Building Commissioning: A Golden Opportunity for Reducing Energy Costs & Greenhouse Gas Emissions. 12 January 2012. <http://cx.lbl.gov/2009-assessment.html>.

[50] Lloyd Krueger. Email communication. 29 February 2012.

[51]Lawrence Berkley National Laboratory. 2001. Lighting Retrofit Workbook. 4 April 2012. <http://www.nps.gov/sustainability/documents/Energy/NPS_lighting_guidebook.pdf>.

[52] Grainger, Inc. 2012. Infrared Motion Sensors. 12 January 2012. <www.grainger.com/Grainger/WATT-STOPPER-Photosensor-2HTG9?cm_sp=IO-_-IDP-_-BTM_BTB05209020&cm_vc=IDPBBZ2>.

[53] James Piper. 2009. The Benefit of Using VFDs in HVAC Systems. 10 January 2012. <http://www.facilitiesnet.com/hvac/article/The-Benefits-of-VFDs-In-HVAC-Systems--11278#>.

[54] James Piper. 2009. The Benefit of Using VFDs in HVAC Systems. 10 January 2012. <http://www.facilitiesnet.com/hvac/article/The-Benefits-of-VFDs-In-HVAC-Systems--11278#>.

[55] Yaskawa America, Inc. 2012. Lower Your Operating Costs with Variable Frequency Drives. 10 January 2012. <http://www.yaskawa.com/site/AboutYEA.nsf/about/Energy-Efficiency.html>.

[56] Synergy Lighting. 2010. Occupancy Sensors Save Electricity. <http://synergylightingusa.com/occupancy-sensors-save-electricity-leviton-energy-savings/>.

[57] Lloyd Krueger. Email communication. 23 February 2012.

[58] Esubmeter.com. 2012. Residential Natural Gas and Propane Meters. 12 December 2011. <http://esubmeter.com/index.php?cPath=23_26>.

[59] Wattmetrics.com. 2012. Power Meters. 12 December 2011. <http://www.wattmetrics.com/_products/powermeters.aspx>.

[60] Automation Direct. 12 January 2012. <http://www.automationdirect.com/adc/Overview/Catalog/Drives?source=google&keyword=variable%20frequency%20motor%20drives&type=search&gclid=CJbx8IjI1a0CFULAKgod3DzkIA>.

[61] International Union for the Conservation of Nature. 2012. Setting gold standards for conservation. 8 March 2012. <http://www.iucn.org/>.

[62] Platt, Rutherford. 2004. Land Use and Society: Geography, Law, and Public Policy. Island Press: Washington.

[63] Federal Energy Management Program. 2002. Federal Greening Toolkit. 16 October 2011. <http://infohouse.p2ric.org/ref/20/19635.htm>.

[64] National Park Service. 2006. Management Policies 2006: The Guide to Managing the National Parks. 1 March 2012. <http://www.nps.gov/policy/mp/policies.html>.

[65] National Park Service. 2006. Management Policies 2006: The Guide to Managing the National Parks. 1 March 2012. <http://www.nps.gov/policy/mp/policies.html>.

[66] National Park Service. 2012. Design and Construction. 15 January 2012. <http://www.nps.gov/dsc/designconstruction.htm>.

[67] Interview with Lynn Chan. February 2012.

[68] Meppem, T. 2008. The discursive community: evolving institutional structures for planning sustainability. *Ecological Economics,* 34**,** 47-61.

[69] Kemp, R., Parto, S. and Gibson, R.B. 2005. Governance for sustainable development: moving from theory to practice. *Int. J. Sustainable Development*, 8(1/2),12–30.

[70] Conroy, M.M. and Beatley, T. 2007. Getting it done: an exploration of US sustainability efforts in practice. *Planning Practice and Research,* 22, 25–40.

[71] Laws, D., Scholz, R.W., Shiroyama, H., Susskind, L., Suzuki, T., and Weber, O. 2004. Expert views on sustainability and technology implementation. *International Journal of Sustainable Development and World Ecology*, 11, 247-261.

[72] Meppem, T. 2008. The discursive community: evolving institutional structures for planning sustainability. *Ecological Economics*, 34**,** 47-61.

[73] Campbell, S. 1996. Green cities, growing cities, just cities? Urban planning and the contradiction of sustainable development. *Journal of the American Planning Association,* 62, 296-312.

[74] Mazria, Edward. 1979. The Passive Solar Energy Book: A Complete Guide to Passive Solar Home Greenhouse and Building Design. Rodale Press: Pennsylvania.

[75] Hill, Joshua. 2011. Climate Change to Dramatically Alter Yellowstone Fire Cycle. 18 February 2012. <http://planetsave.com/2011/07/26/climate-change-to-dramatically-alter-yellowstone-fire-cycle/>.

[76]US Environmental Protection Agency. 2012. Adaptation. 1 May 2011. <http://www.epa.gov/climatechange/effects/adaptation.html>.

[77] Cauchon, Dennis. 2012. Household electricity bills skyrocket. 14 January 2012. <http://www.usatoday.com/money/industries/energy/story/2011-12-13/electric-bills/51840042/1>.

[78] Georgia Tech Research Institute. Undated. Case Study: Emissions Initiatives Makes Yellowstone More Environmentally Friendly. 12 March 2012. <http://www.gtri.gatech.edu/casestudy/emissions-initiative-yellowstone-environmentally>.

[79] National Park Service Geologic Resources Division. 2003. Geothermal Energy Development: Regulatory Overview. 15 January 2012. <http://www.nature.nps.gov/geology/adjacent_minerals/EnergySummit/Geothermal/geothermal%20regs.pdf>.

[80] US Environmental Protection Agency. 2012. Smart Growth and Sustainable Preservation of Existing and Historic Buildings. 1 March 2012. <www.epa.gov/smartgrowth/topics/historic_pres.htm>.

[81]NorthWestern Energy. 2009. Green Sense. 4 April 2012. <http://www.northwesternenergy.com/documents/E+Programs/E+RenewableEnergy.pdf>.

[82] US Department of Energy. 2012. Database of State Incentives for Renewables & Efficiency. 4 April 2012. <www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=WY01R&re=1&ee=1>.

[83] Cart, Julie. 2012. Renewable energy projects in California go unused. 13 March 2012. <http://articles.latimes.com/2012/jan/09/local/la-me-parks-solar-20120109>.

[84] Science Daily. 2011. Installed Cost of Solar Photovoltaic System in US Declined Significantly in 20120 and 2011. 28 February 2012. <http://www.sciencedaily.com/releases/2011/09/110915163959.htm>.

[85] Agriculture and Agri-Foods Canada. 2012. Solar-Powered Dugout Aeration. 14 March 2012. <http://www4.agr.gc.ca/AAFC-AAC/display-afficher.do?id=1187620075153&lang=eng>.

[86] US Environmental Protection Agency. 2008. EPA Tracked Sites in Wyoming with Utility Scale Photovoltaic (PV) Solar Energy Generation Potential. 14 March 2012. <http://www.epa.gov/oswercpa/maps/pdfs/utility_pv_wy.pdf>.

[87] National Renewable Energy Laboratory. 2012. Solar Maps. 14 March 2012. <http://www.nrel .gov/gis/solar.html>.

[88] LaMonica, Martin. 2009. A Tale of Solar Panels, Snow, and Roof Rakes. 13 March 2012. <http://news.cnet.com/8301-11128_3-10156471-54.html?tag=mncol;txt>.

[89] US Environmental Protection Agency. 2008. EPA Tracked Sites in Wyoming with Utility Scale Photovoltaic (PV) Solar Energy Generation Potential. 13 March 2012. <http://www.epa.gov/oswercpa/maps/pdfs/utility_pv_wy.pdf>.

[90] House-Energy. Undated. Solar Energy Costs and Payback. 13 March 2012. <http://www.house-energy.com/Solar/Costs-Payback-Solar.htm>.

[91] National Renewable Energy Laboratory. 2010. Wyoming Annual Average Wind Speed at 80m. 15 March 2012. <http://www.windpoweringamerica.gov/images/windmaps/wy_80m.jpg>.

[92] US Department of Energy. 2011. Small Hybrid Solar and Wind Electric Systems. 1 March 2012. <http://www.energysavers.gov/your_home/electricity/index.cfm/mytopic=11130?print>.

[93] Canadian Energy Commission. 2000. Cogeneration Optimization. 1 March 2012. <http://www.energy.ca.gov/process/pubs/cogen.pdf>.

[94] PennWell. 2011. Cogeneration & On-Site Power production. 25 March 2012. <http://www.cospp.com/cogeneration-chp.html>.

[95] Barry, Judith. 2007. Watergy: Energy and Water Efficiency in Municipal Water Supply and Wastewater Treatment. 13 March 2012. <http://www.aceee.org/sector/local-policy/toolkit/water>.

[96] Cichoski, D. 2011. Largest solar project in a national park, Yosemite, features Solar World solar panels in three formats. Solar World. 15 October 2012. < http://www.solarworld-usa.com/news-and-resources/news/yosemite-national-park-features-solarworld-solar-panels.aspx>.

[97] National Park Service. 2011. Yosemite National Park Unveils Largest Solar Energy System in the National Park Service. July 27, 2011. < ww.nps.gov/yose/parknews/epsolar11.htm>.

[98] National Park Service. 2011. Yosemite National Park Unveils Largest Solar Energy System in the National Park Service. July 27, 2011. < ww.nps.gov/yose/parknews/epsolar11.htm>.

[99] Dailey, Jessica. 2011. Yosemite Flips the Switch on the Largest Solar Array in a National Park.16 February 2012. <http://inhabitat.com/yosemite-flips-the-switch-on-the-largest-ever-solar-array-in-a-national-park/>.

[100] Fanney, A. Hunter, Dougherty, Brian, and John Richardson. 2002. Field Test of a Photovoltaic Water Heater. 25 March 2012. <http://fire.nist.gov/bfrlpubs/build02/PDF/b02012.pdf>.

[101] Fanney, A. Hunter, Dougherty, Brian, and John Richardson. 2002. Field Test of a Photovoltaic Water Heater. 25 March 2012. <http://fire.nist.gov/bfrlpubs/build02/PDF/b02012.pdf>.

[102] Federal Energy Management Program. 1997. Technical Assistance Case Study: Renewable Energy at Channel Islands National Park. 16 February 2012. <http://www1.eere.energy.gov/femp/pdfs/21237.pdf>.

[103] US Department of Energy. 2009. National Park Service – San Miguel. 16 February 2012. <http://www1.eere.energy.gov/femp/technologies/renewable_san_miquel.html>.

[104] Beckman, C. 2012. Crissy Field Harnesses Nature with Five New Wind Turbines. *Marina Times* 28(3). 15 March 2012. < http://www.marinatimes.com/1202/turbines.php>.

[105] Rosato, J. 2012. Crissy Field to Harness the Wind. NBC Bay Area. February 19, 2012. <http://www.nbcbayarea.com/news/local/Crissy-Field-to-Harness-the-Wind-139406758.html>.

[106] Beckman, C. 2012. Crissy Field Harnesses Nature with Five New Wind Turbines. *Marina Times* 28(3). 15 March 2012. < http://www.marinatimes.com/1202/turbines.php>.

[107] Low Impact Life Onboard. 2012. Carbon Footprint. 16 March 2012. <http://www.liloontheweb .org.uk/handbook/carbonfootprint#Coal>.

[108] Yellowstone National Park. 2011. Strategic Plan for Sustainability in Yellowstone Draft.

[109] The Owl.com. Wireless Electricity Monitors. 12 December 2011. <http://www.theowl.com/shop/index.php?target=products&product_id=45>.

[110] The Energy Detective.com. TED 5000. 12 December 2011. <www.theenergydetective.com/ted-5000>.

[111] Wattmetrics.com. 2012. Power Meters. 12 December 2011. <www.wattmetrics.com/_products/powermeters.aspx>.

[112] Onset.com. HOBO Data Loggers. 12 December 2011. <http://www.onsetcomp.com/products/data-loggers/U12-data-loggers>.

[113] Esubmeter.com. 2012. Residential Natural Gas and Propane Meters. 12 December 2011. <http://esubmeter.com/index.php?cPath=23_26>.

[114] Esubmeter.com. A8812 AcquiSuite DR™ Data Acquisition Server. 12 December 2011. <http://esubmeter.com/download/A8812_Datasheet.pdf>.

[115] Esubmeter.com. A7801-1 AcquiLite Data Acquisition Server. 12 December 2011. <http://esubmeter.com/download/A7801_Datasheet.pdf>.