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"GREEN-FRIENDLY" BEST MANAGEMENT PRACTICES (BMPs) FOR INTERSTATE REST AREAS PHASE II

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A report of the findings of
ICT-R27-103
"Green-Friendly" Best Management Practices (BMPs) for Interstate Rest Areas

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16. Abstract

Interstate rest area buildings in Illinois range in age from 10 to nearly 50 years old and are on display and used 365 days a year by nearly 40 million people annually. The rest area sites comprise 53 buildings that provide restroom facilities, vending machines, and 11 welcome centers. These facilities are presently being maintained within the allowable budgets; however, they are in need of upgrades to improve their environmental and economic performance in supporting recent sustainability initiatives in Illinois. The main goal of this project was to investigate, determine, and recommend a list of green-friendly best management practices (BMPs) for the six interstate rest areas that have the highest energy consumption in Illinois. These six rest areas are Willow Creek, Coalfield, Great Sauk Trail, Mackinaw Dells, Cumberland Road, and Turtle Creek, which account for 32% of IDOT's rest area energy bills. The main results and findings of this study include (1) an online survey of state departments of transportation (DOTs) conducted to gather information on their experiences in implementing green-friendly measures in rest areas, welcome centers, office buildings, and related buildings; (2) an investigation of installing temporary or permanent sub-metering systems to measure, monitor, and analyze the actual energy consumption of devices and fixtures in the six rest areas; (3) on-site assessments and field measurements of the six rest areas; (4) an identification of energy and water-saving alternatives that can be implemented in the six rest areas, including: LED and induction lighting; motion sensors for interior lighting, vending machines, and exhaust fans; grid-connected photovoltaic systems; solar water heaters; solar tube lighting; double-pane glass, vestibule entrances; Energy Star–rated HVAC systems; geothermal heat pumps; and water-saving plumbing fixtures; (5) an energy audit analysis for the six selected rest areas, using eQuest energy simulation software to analyze the impact of implementing various energy-saving alternatives; (6) an economic analysis of the identified energy-saving alternatives for the selected rest areas in terms of their required upgrade costs, life-cycle cost, and payback periods; and (7) a practical and user-friendly decision support tool that is capable of identifying optimal upgrade measures for public buildings in Illinois to achieve a specified Leadership in Energy and Environmental Design (LEED) certification with the minimum upgrade costs or achieve the highest LEED points within a given upgrade budget.

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EXECUTIVE SUMMARY

This report presents the findings of a research project funded by the Illinois Center for Transportation to investigate, determine, and provide a list of "green-friendly" best management practices for the six interstate rest areas that have the highest energy consumption in Illinois. The six rest areas are Coalfield, Cumberland Road, Turtle Creek, Great Sauk Trail, Willow Creek, and Mackinaw Dells; and they account for 32% of the energy costs for IDOT rest areas.

The objectives of this project were to (1) conduct an online survey of state departments of transportation (DOTs) to gather information on their experiences in implementing green-friendly measures in their rest areas, welcome centers, office buildings, and related buildings; (2) investigate the feasibility and cost effectiveness of installing temporary or permanent sub-metering systems to measure, monitor, and analyze the actual energy consumption of devices and fixtures in the selected rest areas; (3) conduct on-site assessments and field measurements of the six selected rest areas; (4) explore and identify energy- and water-saving alternatives that can be implemented in the selected rest areas, including LED and induction lighting, motion sensors for interior lighting, vending machines, and exhaust fans; grid-connected photovoltaic systems; solar water heaters; double-pane glass; vestibule entrances; Energy Star–rated HVAC systems; geothermal heat pumps; and water-saving plumbing fixtures; (5) perform an energy audit analysis for the selected rest areas using the U.S. Department of Energy's eQuest energy simulation software (http://www.doe2.com/equest) to analyze the impact of implementing energy-saving alternatives; (6) evaluate the economic feasibility of the identified energy-saving alternatives for the selected rest areas in terms of their required upgrade costs, life-cycle cost, and payback periods; (7) develop a decision support tool to identify optimal upgrade measures for public buildings to provide the highest number of LEED points and certification level for any given upgrade budget or to identify the least possible cost to achieve a specified level of LEED certification, such as silver, gold, or platinum; and (8) provide recommendations for green-friendly best management practices at the six rest areas, along with cost estimates for full implementation, including payback periods. To achieve these objectives, the research team carried out six major tasks.

The research work in the first task focused on investigating the feasibility of installing sub-metering systems for energy and water consumption of the major fixtures and devices in the six rest areas. The research team evaluated the major components of sub-metering systems and benefits that could potentially be achieved by installing sub-metering systems in rest area buildings. These systems could be used to measure and monitor the energy and water consumption of various building components and systems, including interior lighting, exterior lighting, vending machines, HVAC systems (heating, ventilating, and air-conditioning systems), water heaters, hand dryers, and water fixtures. Furthermore, the researchers investigated the use of automatic people-counting systems to measure the actual number of visitors in the rest areas, the peak times of use, visitation profiles, and average number of visitors. Also in this task, a survey was conducted to gather information from state departments of transportation (DOTs) about their experiences in implementing green building measures in their public buildings and the performance of those measures in terms of user satisfaction, ease of maintenance, problems encountered, repair costs, energy or water savings, and payback periods.

For the second task, the project team conducted on-site assessments for the six rest areas selected. The on-site assessments were designed to study (1) the types of services provided by each of the six rest areas, (2) the conditions and characteristics of appliances and fixtures, and (3) the potential savings and energy-efficiency practices. On-site assessments were essential in understanding the conditions of and potential improvements for these six rest areas.

In the third task, the research team explored and identified potential and promising green-friendly measures for the six rest areas. The green building measures investigated in this task were LED and induction lighting; motion sensors for interior lighting, vending machines, and exhaust fans; grid-connected photovoltaic systems; solar water heaters; solar tube lighting; double-pane glass; vestibule entrances; Energy Star–rated HVAC systems; geothermal heat pumps; and water-saving plumbing fixtures. To evaluate the performance of green building measures in these rest areas, the researchers created six simulation models to identify the major contributors of energy consumption in buildings of each of the six rest areas and to analyze the feasibility of replacing the existing devices and equipment with more energy-efficient units.

For the fourth task, the research team analyzed the economic and environmental impacts of potential green-friendly measures identified in the previous task. A life-cycle cost analysis (LCCA) and carbon footprint assessment were conducted to identify promising green-friendly measures and their upgrade costs, annual savings, payback periods, and reduced CO_2 emissions.

In the fifth task, a decision support tool was developed to optimize the selection of green building measures to achieve a specified Leadership in Energy and Environmental Design (LEED) certification level with the minimum upgrade cost or to achieve the highest number of LEED points within a specified upgrade budget. The decision support tool developed was designed to analyze green-friendly measures, including interior light bulbs and fixtures, exterior light bulbs and fixtures, hand dryers, vending machines, motion sensors for interior lighting, HVAC systems, water heaters, solar photovoltaic systems, metering and sub-metering systems, and water fixtures. To ensure practicality, the tool was designed to minimize the required input data by using database systems for the building equipment and fixtures. Furthermore, user-friendly graphical interfaces were developed to facilitate the input and output of data in the decision support tool.

In the sixth task of this project, the research team developed recommendations for upgrading the six selected rest areas. These recommendations identified specific promising upgrade measures for each of the selected rest areas and the expected annual savings.

CONTENTS

FIGURES

TABLES

CHAPTER 1 INTRODUCTION

1.1 PROBLEM STATEMENT

Interstate rest area buildings in Illinois are among the most visible traveler amenities in the state. These facilities range in age from 10 to nearly 50 years old and are on display and used 365 days a year by nearly 40 million people annually. The rest area sites comprise 53 buildings that provide restroom facilities, vending machines, and 11 welcome centers offering tourism information for the traveling public. The facilities are presently being maintained as well as budgets allow; but these facilities are in need of upgrading, especially to improve their environmental and economic performance in support of recent initiatives by the State of Illinois to be more “green friendly.” These initiatives include the development of *Green Building Guidelines for State Construction*, by the Capital Development Board’s Green Building Advisory Council, as required in Public Act 094-0573 (Illinois CDB 2007). These guidelines were used as a basis for the Green Building Act (P.A. 096-0773), which requires all construction and major renovations of IDOT and any state-owned facilities to satisfy Leadership in Energy and Environmental Design (LEED), Green Globes or equivalent certification requirements. This Act also states that all construction and major renovation projects, regardless of size, must achieve the highest level of LEED, Green Globes or equivalent certification practicable within the project budget (Illinois General Assembly 2009).

The pressing need to upgrade IDOT rest areas, coupled with the requirements of the *Green Buildings Act,* presents a unique opportunity to implement cost-effective upgrade measures for these highly visible and frequently used facilities. To accomplish this goal, decision makers need to identify and implement an optimal set of upgrade measures that (1) maximize the green performance of IDOT rest areas, (2) reduce energy and water consumption, and (3) comply with limited upgrade budgets.

1.2 RESEARCH OBJECTIVES AND METHODOLOGY

The main goal of the research in this phase was to investigate, determine, and provide a list of green-friendly best management practices (BMPs) for the six interstate rest areas that have the highest energy consumption in Illinois. These six rest areas are Willow Creek, Coalfield, Great Sauk Trail, Mackinaw Dells, Cumberland Road, and Turtle Creek, which account for 32% of the IDOT rest areas’ energy bills. Improvements in energy consumption of these six facilities can provide significant annual savings in energy bills for IDOT. To accomplish this goal, the objectives of this research were as follows:

1. Conduct an online survey of state departments of transportation (DOTs) to gather information on their experiences in implementing green-friendly measures in their rest areas, welcome centers, office buildings, and other state buildings.
2. Investigate the feasibility and cost effectiveness of installing temporary or permanent sub-metering systems to measure, monitor, and analyze the actual energy consumption of devices and fixtures in the selected rest areas.
3. Conduct on-site assessments and field measurements of the six rest areas that have the highest energy bills and highest energy consumption per square footage (i.e., Willow Creek, Coalfield, Great Sauk Trail, Mackinaw Dells, Cumberland Road, and Turtle Creek).

4. Explore and identify energy- and water-saving alternatives that can be implemented in the selected rest areas, including LED and induction lighting; motion sensors for interior lighting, vending machines, and exhaust fans; grid-connected photovoltaic systems; solar water heaters; solar tube lighting; double-pane glass; vestibule entrances; Energy Star–rated HVAC systems; geothermal heat pumps; and water-saving plumbing fixtures.
5. Perform energy audit analysis for the selected rest areas using eQuest energy simulation software to analyze the impact of implementing the energy-saving alternatives identified in the previous task.
6. Evaluate the economic feasibility of the identified energy-saving alternatives for the selected rest areas in terms of their required upgrade costs, life-cycle cost (LCC), and payback periods.
7. Develop a decision support tool (DST) to identify optimal upgrade measures for public buildings to provide the highest number of LEED points and certification level for any given upgrade budget or to identify the smallest possible budget to achieve a specified level of LEED certification, such as silver, gold, or platinum.
8. Prepare recommendations for the six rest areas detailing the green-friendly BMPs to use, along with cost estimates for full implementation, including payback periods.

These research tasks and their deliverables are described in more detail in the following chapters, as shown in Figure 1.

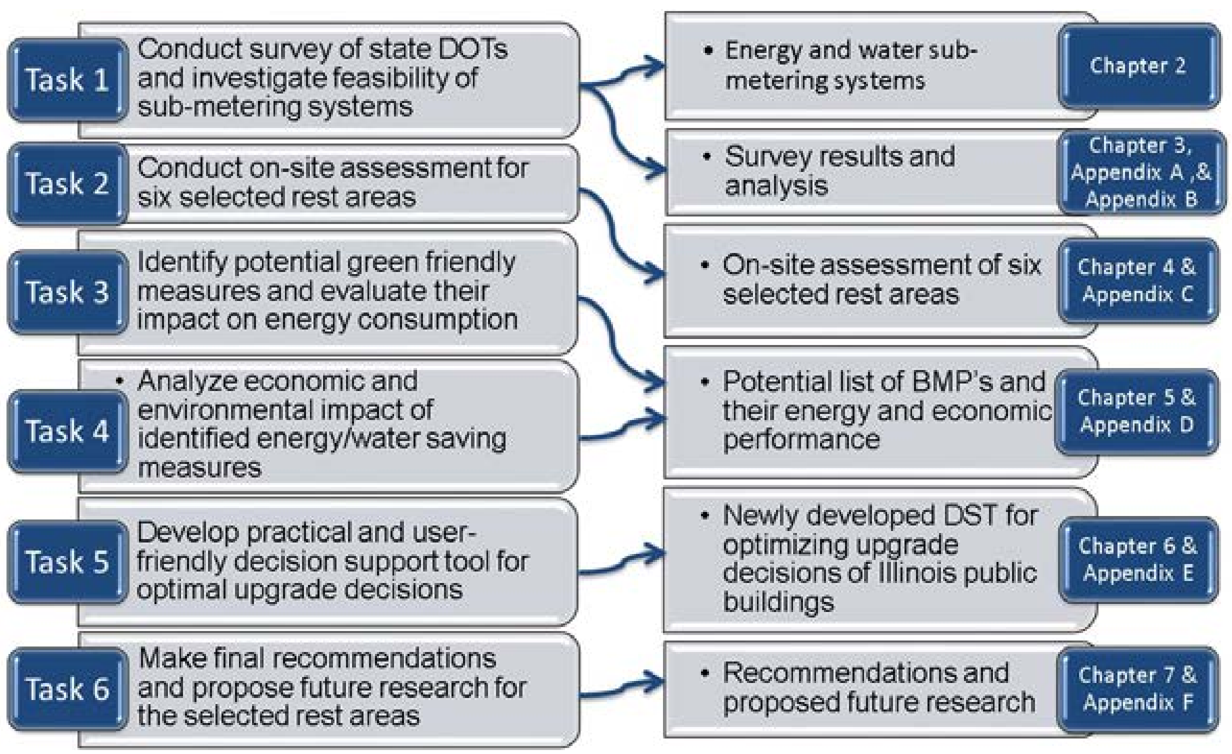


Figure 1. Project tasks and research deliverables.

CHAPTER 2 ENERGY AND WATER SUB-METERING SYSTEMS

Monitoring systems can be used to improve the efficiency of energy and water consumption in buildings. These systems include sub-metering systems to measure energy consumption, including electricity and natural gas, as well as water consumption (Pecko et al. 2011). Although metering systems can be used to measure the entire amount of energy/water consumption of a facility or a building, sub-metering systems can measure the energy/water consumption of individual units or specific systems in a building or facility. In the rest area buildings, these categories of energy/water consumption include HVAC systems, vending machines, exterior and interior lighting, water heaters, faucets, urinals, and toilets. An electricity meter, for example, can measure and register the continuous power consumption of one or more units that consume energy in the building. It typically consists of two parts: a transducer that converts power into a mechanical or electrical signal, and a counter that integrates and displays the value of the total energy that has been passed through the meter (MeterToCash 2013). Similarly, gas and water meters can be used to measure the consumption of natural gas and water in buildings. As shown in Figure 2, sub-metering systems often consist of three main components: (1) energy-metering units to measure electricity, natural gas, and/or water consumption; (2) a data collection and transmission system to collect and transmit data to various data repositories; and (3) a system that graphically displays the data received or generates data reports.

In addition to providing energy-use data and costs, sub-metering systems are capable of gathering interval data for load profiling. Information from the sub-meters can be read manually or gathered by automated meter-reading systems and can be presented and analyzed through various software tools, which are either installed on a personal computer (PC) or accessed via the Internet. These systems can also be programmed to highlight potential problem areas and alert operators when energy use strays outside the normal levels (Santee Cooper Power 2002). These systems can also be used to compare electricity consumption for a specific day in two successive years, as shown in Figure 3.

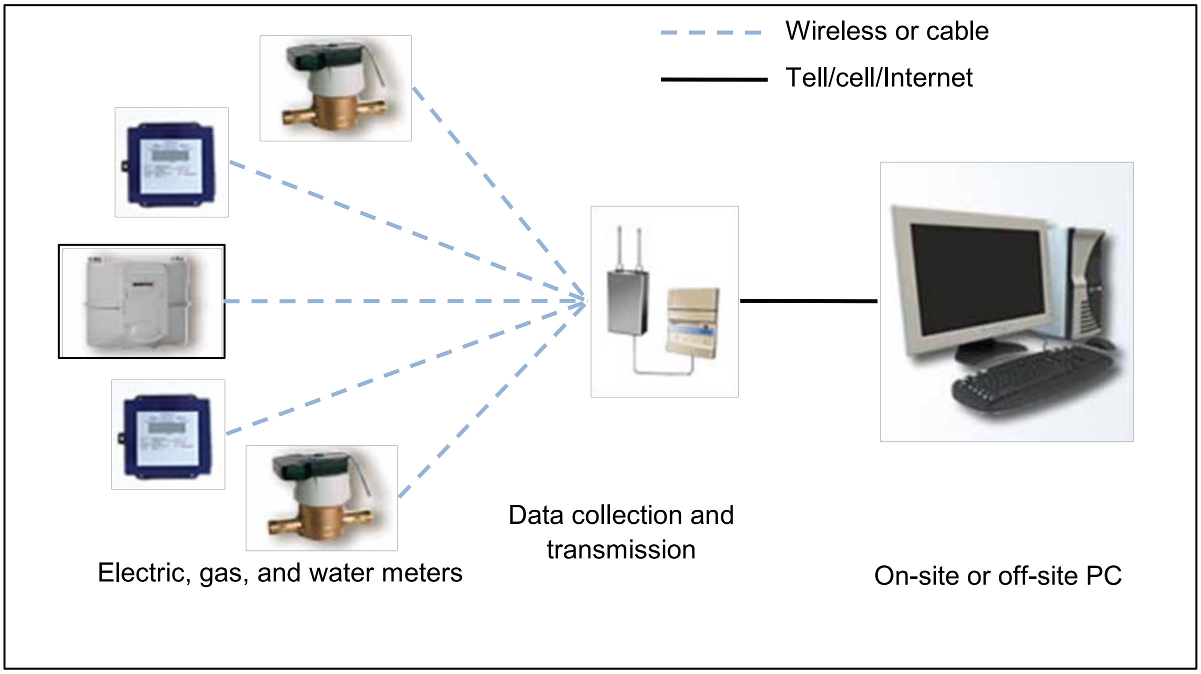


Figure 2. Sub-metering system (Byram Laboratories 2011).

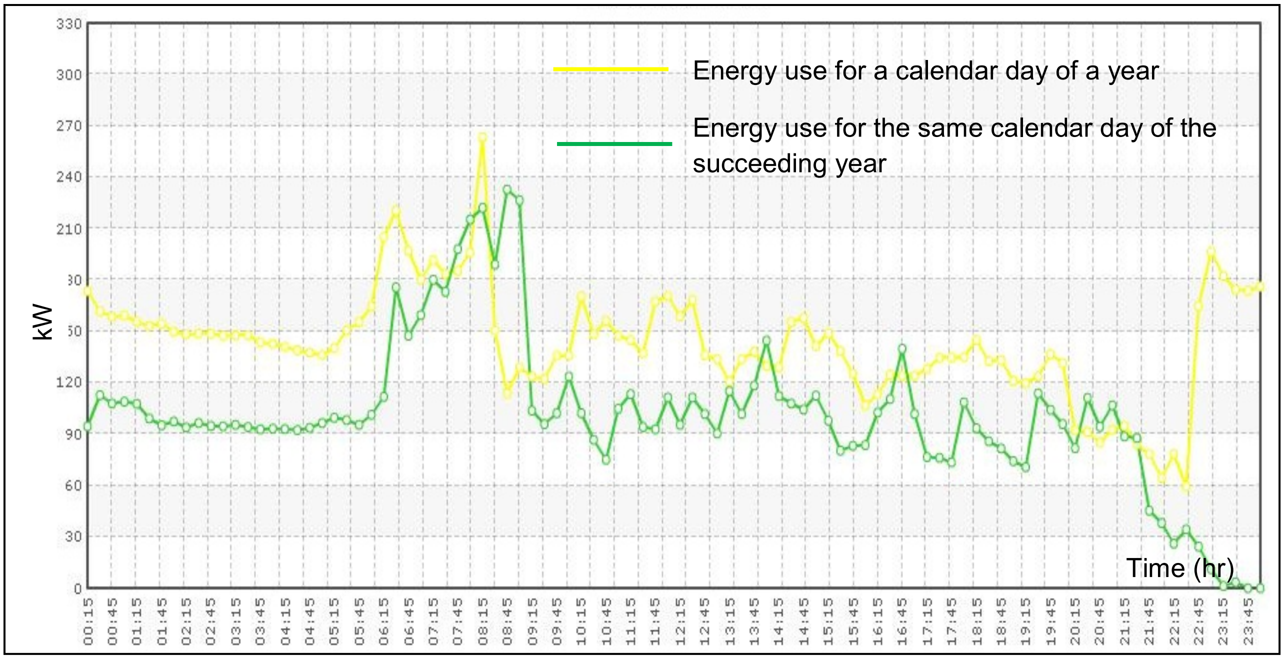


Figure 3. An example of a daily comparison report for electricity consumption.

In addition to energy and water sub-metering systems, electronic people-counters can be used in rest areas to identify the number of visitors, which is essential in analyzing the efficiency of the energy and water consumption. Currently, the Illinois Department of Transportation (IDOT) generates estimates for the average number of visitors to interstate rest areas in Illinois based on the number of vehicles passing by the rest areas, the vehicles' use rate of rest areas, and the vehicles' occupancy. The number of visitors in rest areas can be measured with better accuracy by using electronic people-counting systems. These systems can be installed at entrances and exits of the rest areas, along with a collecting device that can collect and store the count data. The collecting device can provide data about the total number of visitors that are using a facility and interval visitation data that range from half an hour to monthly visitation rate.

2.1 TYPES OF ENERGY/WATER SUB-METERS

Three types of meters are commonly used to measure energy and water consumption in buildings: electricity meter, natural gas meter, and water meter. These meters typically consist of two parts: a transducer to convert the energy/water into a mechanical or electrical signal, and a counter to integrate and display the value of total energy/water consumption that has passed through the meter. Unlike utility billing, which mostly requires once-a-month reporting to develop consumption bills, frequent reporting has a value in providing a better understanding of the energy/water consumption and opportunities for reducing energy and water consumption (EnergyTracking 2009).

Electric meters continuously operate to measure the instantaneous voltage and current and calculate the product, to measure the electrical power. There are two types of electric meter categories: the electromechanical and the solid-state meters. The electromechanical meter operates by counting the number of revolutions of an aluminum disk, which rotates at a speed proportional to the power supplied. Therefore, the number of revolutions is proportional to the energy use. The meter consumes a small amount of energy, typically around 2W.

Solid-state meters typically use a current transformer to measure the current. The main current-carrying conductors do not need to pass through the meter itself, and so the meter can be located remotely from the main current-carrying conductors, which is an advantage particularly in large-power installations. Solid-state meters display the power used on an LCD screen. In addition to measuring the amount of electricity used, the solid-state meters can also record other parameters of the load and supply, such as the maximum demand, power factor, and reactive power used. Advanced solid-state meters can also include an electronic clock mechanism to compute a value rather than an amount of electricity consumed, which accounts for varying electricity rates by the time of the day, day of the week, or seasonally.

Gas meters are devices that measure the quantity or rate of flow of a gas. There are typically two types of gas meters: the diaphragm meter and the rotary meter. The diaphragm meter is the most common gas meter in residential buildings; and gas flow in these meters is controlled by two internal valves, which alternatively fill the meter's two diaphragms. One diaphragm takes gas, while the other expels it. Levers attached to the diaphragms power an odometer that measures the frequency at which gas is expelled from the meter. The rotary meter is usually used in industrial sites, where a high volume of gas is consumed; and it can measure gas use more accurately. (R.R. Flowmeters 2012 Schwarz 2011).

Water meters are used to measure water consumption in gallons or cubic feet; and they are available in two main types: positive-displacement meters and velocity meters. In the positive-displacement meters, a known volume of liquid in a compartment moves with the flow of water. Positive-displacement meters operate by filling and empting these compartments, and the flow rate is calculated by the number of times these compartments were filled and emptied. The movement of a disk records the volume of liquid exiting the meter. In the velocity meters, water passing through a known cross-section area with a measured velocity can be used to calculate the flow volume. These meters are typically used for high-flow applications (Satterfield and Bhardwa 2004).

Smart meters are available on the market for electrical, gas, and water consumption; and they record energy/water consumption in intervals of an hour or less and communicate that information at least daily for monitoring and reporting purposes. Smart meters enable two-way communication between a meter and a central system. Unlike traditional energy/water monitors, smart meters can gather data for remote reporting.

2.2 BENEFITS OF SUB-METERING SYSTEMS

Detailed data on the facility's energy and water use creates a solid foundation for developing a successful ongoing energy-management program aimed at reducing energy costs. It is difficult to measure and track electricity, gas, or water use if the best available tool at the facility is the regular utility meter. To build a measurable profile of energy and water use, as a basis for improved efficiency, sub-meters for each building or category of energy/water consumption should be installed (Santee Cooper Power 2002). Several benefits could be achieved from sub-metering systems in rest areas, including (1) achieving better management of total energy use; (2) providing details about energy use and its timing, which enables adjustments and savings in energy consumption; (3) identifying major contributors of energy/water consumption and areas that need urgent renovations; (4) identifying and implementing operational strategies to control the load factor and peak-load requirements to reduce energy waste; (5) measuring and verifying actual energy savings achieved by implementing energy-efficiency measures and technologies; (6) identifying and assessing, on a real-time basis, the fiscal impact of energy consumption; (7) helping to evaluate performance and identify malfunction of equipment, based on energy consumption, assuming the sub-meters are linked to an energy-management system (EMS); (8) fulfilling one of the requirements for LEED certification of existing buildings; and (9) allowing the comparison of actual energy consumption of sub-metering systems and estimates that could be generated from energy simulation models (ECW 2000; EnergyTracking 2009).

Limited studies have been conducted to report the effectiveness of using sub-metering systems in buildings and how they can help in providing a better understanding of energy/water consumption and in reducing energy costs. The Santee Cooper Power company reported a case study of 25 buildings at the Boeing Auburn facility in the Puget Sound region, where each building is essentially a separate manufacturing organization and responsible for its own energy use. A total of 138 sub-meters have been installed, which allow the collection of load profile data, as well as energy use. The data from these sub-meters are communicated through the Internet, where the energy data can be accessed by PCs. After installing these sub-meters, building managers were able to improve the management of energy use. The sub-metering system allowed building managers to see when the shop is in production and when the lights, air-handling equipment, machines, and auxiliary system can be turned off, which resulted in significant energy savings. According to the improved awareness of energy use (2000 to 2002), the Boeing Auburn facility was able to decrease its energy consumption by 22% through turning off equipment not in use, adjusting settings, maintaining stream traps, and fixing leaks in compressed-air lines (Santee Cooper Power 2002).

Another study was conducted by the U.S. Environmental Protection Agency (EPA) to analyze the benefits of energy and water sub-metering at colleges and universities, using two case studies. The first case study analyzed the performance of sub-metering of electricity, steam, and chilled water use in a large research university for over a decade to improve energy efficiency and reduce costs. This university metered all energy sources for many buildings and has reported several benefits from the data collected, including (1) reducing the cost of demand by 10% in all 30 buildings of the university, through conjunctive metering, which reduces the chance that all buildings have peak demand at the same time; (2) optimizing the sizes of new steam and chilled-water piping and fittings in new buildings to lower the construction costs; (3) verifying the accuracy of utility meters; and (4) optimizing the future electrical load. The second case study analyzed the performance of installing sub-metering systems on a university campus for more than 15 years, to reduce overall expenses. The university used sub-metered data as part of a successful three-phase energy-reduction effort. Phase I of the plan was an energy-awareness program, which relied on the sub-metered data to reduce electricity consumption and was able to produce a 10% reduction in energy use. Additional savings were achieved through additional energy-retrofit capital projects, in Phase II, and negotiation for lower electricity rates, in Phase III (U.S. EPA 2002).

Similarly, the use of people-counter systems in rest areas can provide several benefits, including a better understanding of energy and water consumption in rest areas. Detailed measurements of the number of visitors can also be used to develop visitation profiles, which can show periods of peak visitation rates. These details can be helpful in studying the effectiveness of a number of green technologies in the rest areas, such as motion-activated lighting, efficient lightings, and vestibule entrances.

2.3 INITIAL AND MAINTENANCE COSTS OF SUB-METERING SYSTEMS

Several companies provide electricity-, gas-, and water-metering products and services. The cost of electricity sub-metering is mainly a function of the product type, services, and data that can be provided by the meter, current transducers (CT) needed for each meter, and the number of sub-meters that need to be installed at a given site. The number and size of the current transducers depend on voltage, amps, and whether the meter supports one phase or three phases of electricity. By contrast, the cost of gas and water sub-meters depends on the product type and the size of the pipe whose flow will be metered. A sub-metering system also requires a collector to gather data from the different meters and transmit the data to a local PC or through the Internet/cellular network to a website. A local PC or a website on the Internet can be used to store consumption data and generate analysis and consumption reports. Tables 1 through 3 provide cost estimates for electricity, gas, and water meters, respectively; while Table 4 provides estimates for other components of sub-metering systems, including converters, an interval data recorder, software, a connector, and adopters.

Table 1. Electricity Meters That Can Be Used for the Selected Rest Areas

Meter Description	Meter Wattage	Unit Cost	Meter Features
EKM-OmniMeter I v.3 	200A~800A (can meter up to 5000A with higher CT)	$160 + CT ($40~$120 each)	- Single-phase or 3-phase - Supports CT 100A to 5000A - Fast communication speed for remote reading - Does not need a power cut to be installed - The meter provides data for maximum demand (kW); and after setting, it can calculate the maximum demand for the following time periods: 15, 30, and 60 min.
E-Mon D-Mon class 1000 	25A~200A	$371~$406	- Utility-grade metering accuracy - Supports single-phase (2 wires) or 2-phase (3 wires) - Nonvolatile memory - Remote mounting of the current sensors up to 2,000 feet from the meter without power interruption
E-Mon D-Mon class 2000 	100A~3200A	$662~$1,352	- Utility-grade metering accuracy - Supports 3-phase and 2-phase - Nonvolatile memory - Remote mounting of current sensors up to 2,000 feet from the meter without power interruption

Table 2. Gas Meters That Can Be Used for the Selected Rest Areas

Meter Description	Meter Pipe Size	Unit Cost	Meter Features
EKM gas meter 	3/4″	$90	- Used with the EKM-25EDSP-N v.2, 3x pulse input kWh meter to count and store the gas meter pulses ($160) - Can be read remotely using the free EKM Reader software - Maximum flow rate: 6 m^3/hr - Minimum flow rate: 0.04 m^3/hr
E-Mon D-Mon GDP250 series 	3/4″ and 1″	$298	- Equipped with pulse output for interfacing with interval data recorders - Used with loads ranging from 200 to 250 ft^3/hr

Table 3. Water Meters That Can Be Used for the Selected Rest Areas

Meter Description	Meter Pipe Size	Unit Cost	Meter Features
H13034 hot water meter 	3/4″	$141	- Used for hot water - Can be connected to a pulser transmitter to transmit consumption to a data collector
E-Mon D-Mon C700 C70010 	1″	$225	- Can be connected to a pulser transmitter to transmit consumption to a data collector - Positive-displacement meter
H190 (MTH) high-temp/multijet (inferential) impeller meter 	1.5″	$478	- Hot water meter - High-temp/multijet (inferential) impeller meter - Can be connected to a pulser transmitter to transmit consumption to a data collector
E-Mon D-Mon C700 C70020 	2″	$650	- Positive-displacement meter - Cold-water meters with pulse output - Can be connected to a pulser transmitter to transmit consumption to a data collector
Hot water meters with pulse output H43004 	4″	$2,096	- Can be used for hot water - Woltman horizontal impeller (inferential) meter - Can be connected to a pulser transmitter to transmit consumption to a data collector

Table 4. Other Sub-Metering System Components
That Can Be Used for the Selected Rest Areas

Meter description	Type	Unit Cost	Meter Features
EKM iSerial V.2 	TCP/IP to serial converter	$65	- Supports 4- and 2-wire (RS-232 and RS-422/485) with AUTO-SEND™ and built-in terminator - No on-site computer necessary if the Internet is available - Can support multiple meters (unlimited)
E-Mon energy software 	Energy software	$5,513 (1~50 meters)	- Creates load profiles and charts of energy-use data - Monitors all of the utilities, including electricity, gas, water, and steam, with a single software package - Finds out if the facility is functioning at peak performance and identifies inefficiencies quickly - Divides utility costs based on the actual energy use - Avoids estimations and collects accurate backup records
E-Mon D-Mon interval data recorder (IDR16E) 	Interval data recorder	$2,460	- Reads kWh and kW in 5-, 15-, 30-, or 60-min intervals - Reads water, gas, and electric meters, which provide pulse output or E-Mon D-Mon meters - Reads and records data from up to 8 or 16 meters
E-Mon EKM-T external communication key with modem for telephone access	Connects AMR system to host a computer with modem	$753	- Converts RS-485 to RS-232 for input into a computer serial port - Includes built-in telephone modem for easy connection to a telephone line - Three RS-485 inputs (RJ-11 modular jack) from AMR system
E-Mon D-Mon PCA 	Pulse contact adapter	$85	- Allows standard electromechanical style kWh meters to interface to the E-Mon energy automatic meter-reading system - Allows interface with the E-Mon Energy™ Software system - Models of the PCA are available for some types of gas meters to allow an interface with the E-Mon energy software system
E-Mon D-Mon ECA-2	External contact adapter	$48	- Monitors the utility electric meter with the E-Mon energy software - Sends energy information via the ECA-2 to the IDR data accumulator - Connects utility meters with pulse contacts to the E-Mon Energy system through the IDR interface unit - ECA-2 can be used with water, gas, and BTU meters with contact (pulse) output

Calibration and maintenance of sub-meters depend mainly on the type of meter. Electricity meters are typically calibrated every 3 to 5 years. The calibration cost of electricity meters is not high because the current and voltage can be verified with an instantaneous demand meter. IDOT technicians can perform this calibration every 3 to 5 years. Calibration of water meters should be performed annually or more frequently if meter data stray beyond the expected ranges (U.S. EPA 2002).

2.4 COSTS OF SUB-METERING SYSTEMS IN THE SELECTED REST AREAS

To estimate the cost of installing a sub-metering system in the rest areas, electric and plumbing drawings need to be analyzed in conjunction with the site visits conducted for the six selected rest areas. Electric and plumbing drawings were provided for four of the selected rest areas: Turtle Creek, Cumberland Road, Coalfield, and Willow Creek. The existing electric metering system in the selected rest areas is limited to measuring the total electricity consumption of the rest area buildings. Table 5 lists the types and numbers of electricity meters in the six selected rest areas. Two cost estimates were developed for installing sub-metering systems in each of the selected rest areas. These two estimates were developed based on system components that were provided in Tables 1 through 4. The first cost estimate was developed for each rest area, based on electric meters, gas meters, and collectors from the EKM Metering, Inc. and water meters from the ElectricSubmeter Company, as shown in Table 6. EKM provides free software, which can remotely read total kWh, power (W), maximum demand, instantaneous voltage, instantaneous amperage, power factor, and pulse counts. This system can provide maximum demand for three time periods (15, 30, and 60 min); however, it cannot provide interval consumption data for electricity or water use. It should be noted that the estimated costs in Table 6 were provided for sub-metering system components only; shipping cost was not considered in the estimates. This cost estimate also assumes that these sub-metering systems will be installed by IDOT technicians, to reduce costs. The complexity of installing these sub-metering systems depends on the distribution panel and water networks in each rest area, system components, and any need for bypassing the electric cables or water pipes to be measured through the electricity/water meters.

The second cost estimate was developed for each rest area, as shown in Table 7. These sub-metering systems require an energy software package for cost allocation and graphing of energy use. This software package requires only one software license for all rest areas and is available from the ElectricSubmeter Company for $5,513. The sub-metering systems provided in Table 7 are capable of reading kW/demand and kW peak every 15 or 30 min, and it can collect information from meters every 5, 15, 30, or 60 min. Interval data collection can be used in generating graphs and charts to analyze when and where use takes place, to identify potential energy-saving opportunities in the rest areas. This arrangement will lead to better management for the building equipment and adjust the timing of energy loads to reduce overall energy use. Similar to the first estimate for sub-metering systems, shipping cost was not considered; and installation was assumed to be performed by IDOT technicians, to reduce initial costs.

Table 5. Existing Electricity Meters in the Selected Interstate Rest Areas in Illinois

Rest Area	Existing Electricity Meters
Coalfield	One digital electricity meter for each side of the rest area
Cumberland Road	One analog electricity meter in one bound and a digital electricity meter in the other bound
Turtle Creek	One digital electricity meter
Willow Creek	One digital meter for each bound of the rest area
Great Sauk Trail	One analog electrical meter for each bound of the rest area
Mackinaw Dells	One analog electricity meter

Table 6. Estimated Cost for Sub-Metering Systems for the Selected Rest Areas, Based on Information from EKM and the ElectricSubmeter Companies

Rest Area	Meter Type	System Components	Estimated Cost ($)		Total Cost ($)
Coalfield (each bound)	Electricity	7 EKM-OmniMeters, 13 200A CTs	1,640		3,326
	Water	Building water meter (E-Mon C70020, 2"), and hot water meter (E-Mon H13034, 3/4"), and 2 EKM-25EDSP-N v.2.	1,111		
	Collector	EKM iSerial V.2, RS-232 serial to RS-485 converter, and a PC.	575		
Cumberland Road (each bound)	Electricity	7 EKM-OmniMeters, 11 200A CTs,	1,560		3,547
	Water	Building water meter (E-Mon C70020, 2"), 2 hot water meters (E-Mon H13034, 3/4"), and 3 EKM-25EDSP-N v.2.	1,412		
	Collector	EKM iSerial V.2, RS-232 serial to RS-485 converter, and a PC.	575		
Turtle Creek	Electricity	7 EKM-OmniMeters, 15 200A CTs, 2 400A CTs, 2 EKM gas meters, 2 EKM-25EDSP-N v.2.	2,360		5,737
	Water	Building water meter (E-Mon H43003, 3"), and hot water meter (E-Mon H13034, 1"), and 2 EKM-25EDSP-N v.2.	2,802		
	Collector	EKM iSerial V.2, RS-232 serial to RS-485 converter, and a PC.	575		
Willow Creek (both bounds)	Electricity—Southbound	7 EKM-OmniMeters, 12 200A CTs, 3 400A CTs, 2 800A CTs, 2 EKM gas meters, and 2 EKM-25EDSP-N v.2	2,550		11,698
	Electricity—Northbound	7 EKM-OmniMeters, 13 200A CTs, 1 400A CTs, 2 EKM gas meters, 2 EKM-25EDSP-N v.2	2,210		
	Water (each bound)	Building water meter (E-Mon H43004, 4"), hot water meter (E-Mon H15015, 1.5"), and 2 EKM-25EDSP-N v.2.	2,894		
	Collector (each bound)	EKM iSerial V.2, RS-232 serial to RS-485 converter, and a PC.	575		
Great Sauk Trail (each bound)	Electricity	7 EKM-OmniMeters, 12 200A CTs, EKM gas meter, and EKM-25EDSP-N v.2	1,850		3,536
	Water	Building water meter (E-Mon C70020, 2"), hot water meter (E-Mon H13034, 3/4"), and 2 EKM-25EDSP-N v.2.	1,111		
	Collector	EKM iSerial V.2, RS-232 serial to RS-485 converter, and a PC.	575		
Mackinaw Dells (no drawing available)	Electricity	7 EKM-OmniMeters, 13 200A CTs,	1,640		3,326
	Water	Building water meter (E-Mon C70020, 2"), and hot water meter (E-Mon H13034, 3/4"), and 2 EKM-25EDSP-N v.2.	1,111		
	Collector	EKM iSerial V.2, RS-232 serial to RS-485 converter, PC.	575		

Table 7. Estimated Cost for Sub-Metering Systems for the Selected Rest Areas, Based on Information from the ElectricSubmeter Company

Rest Area	Meter Type	System Components	Estimated Cost ($)	Total Cost ($)
Coalfield (each bound)	Electricity	4 E-Mon D-Mon class 1000 (100A) and 3 E-Mon D-Mon class 1000 (200A).	2,842	7,442
	Water	Building water meter (E-Mon C70020) and hot water meter (E-Mon H13034).	791	
	Collector	E-Mon D-Mon IDR interval data recorder (16 meters), E-Mon EKM-T external communication key with modem for Internet/telephone access, 2 E-Mon D-Mon external contact adapter, and a PC.	3,809	
Cumberland Road (each bound)	Electricity	3 E-Mon D-Mon class 1000 (100A) and 4 E-Mon D-Mon class 1000 (200A).	2,842	7,631
	Water	Building water meter (E-Mon C70020) and 2 hot water meters (E-Mon H13034).	932	
	Collector	E-Mon D-Mon IDR interval data recorder (16 meters), E-Mon EKM-T external communication key with modem for Internet/telephone access, 3 E-Mon D-Mon external contact adapter, and a PC.	3,857	
Turtle Creek	Electricity	1 E-Mon D-Mon class 1000 (100A), 1 E-Mon D-Mon class 1000 (200A), 2 E-Mon D-Mon class 2000 (100A), 2 E-Mon D-Mon class 2000 (200A), 1 E-Mon D-Mon class 2000 (400A), and E-Mon D-Mon GDP250 series (gas meters).	4,420	10,759
	Water	Building water meter (E-Mon H43003, 3") and hot water meter (E-Mon H13034, 1").	2,482	
	Collector	E-Mon D-Mon IDR interval data recorder (16 meters), E-Mon EKM-T external communication key with modem for Internet/telephone access, 3 E-Mon D-Mon external contact adapter for water and gas meters, and a PC.	3,857	
Willow Creek (both bounds)	Electricity—Southbound	1 E-Mon D-Mon class 1000 (100A), 2 E-Mon D-Mon class 1000 (200A), 1 E-Mon D-Mon class 2000 (100A), 3 E-Mon D-Mon class 2000 (200A), and 2 E-Mon D-Mon GDP250 Series gas meters.	4,462	22,288
	Electricity—Northbound	2 E-Mon D-Mon class 1000 (100A), 2 E-Mon D-Mon class 1000 (200A), 2 E-Mon D-Mon Class 2000 (100A), 1 E-Mon D-Mon Class 2000 (200A), and 2 E-Mon D-Mon GDP250 Series gas meters.	4,868	
	Water (each bound)	Building water meter (E-Mon H43004) and hot water meter (E-Mon H15015).	2,574	
	Collector (each bound)	E-Mon D-Mon IDR interval data recorder (16 meters), E-Mon EKM-T external communication key with modem for Internet/telephone access, 4 E-Mon D-Mon external contact adapters for gas and water meters, and a PC.	3,857	
Great Sauk Trail (each bound)	Electricity	3 E-Mon D-Mon class 1000 (100A), 4 E-Mon D-Mon class 1000 (200A), and E-Mon D-Mon GDP250 Series gas meter.	3,140	7,788
	Water	Building water meter (E-Mon C70020) and hot water meter (E-Mon H13034).	791	
	Collector	E-Mon D-Mon IDR interval data recorder (16 meters), E-Mon EKM-T external communication key with modem for Internet/telephone access, 3 E-Mon D-Mon external contact adapters for the gas and water meters, and a PC.	3,857	
Mackinaw Dells (no drawing available)	Electricity	3 E-Mon D-Mon class 1000 (100A) and 4 E-Mon D-Mon class 1000 (200A).	2,842	6,442
	Water	Building water meter (E-Mon C70020), and hot water meter (E-Mon H13034).	791	
	Collector	E-Mon D-Mon IDR interval data recorder (16 meters), E-Mon EKM-T external communication key with Modem for Internet/Telephone Access, 2 E-Mon D-Mon external contact adapter, and a PC.	3,809	

Digital clamp-on power meters can also be used as an alternative for installing the aforementioned electric sub-metering systems in the rest areas. Clamp meters are temporary meters that can be hocked to electric cables and measure electricity consumption. The clamp-on power HiTESTER (model 3169-20 or 21) (Figure 4) can be used in rest areas to measure electricity consumption and provide detailed information of energy use. It can simultaneously measure voltage, current, power (active, reactive, and apparent), integrated power, power factor, and frequency. This power meter supports several types of clamp-on current sensors to enable measurement of a variety of items that range from 0.5A to 5000A. One single unit of clamp-on power HiTESTER can measure four circuits (single-phase, 2 wires), two circuits (3-phase, 3 wires), or one circuit (3-phase, 4 wires). This capability can decrease the number of meters required to measure different categories of energy use in the rest areas. It can store valuable measurement data on PC cards up to 1GB, which provides a convenient way to store data for long periods. The data stored on PC cards can be transmitted to a PC, where data can be analyzed. Clamp-on power meters are easily installed in rest areas, and they provide the flexibility of data being transmitted to other buildings to monitor and measure energy consumption for energy audit of other buildings. By contrast, installing clamp-on power meters cannot identify a malfunction of the building equipment because it cannot be monitored through the Internet or linked to an energy-management system (EMS). To measure the major categorizes of energy consumption in each building of a rest area, three to six clamp-on power meters will be required. The number of clamp meters depends on capacity (amps) and the type of power (single or three-phase) in major categories of energy consumption in each rest area. Each clamp meter costs $2,678, and therefore the estimated cost of sub-metering electricity consumption using clamp meter in a single rest area building will range from $8,034 to $16,068.

Figure 4. HiTESTER clamp-on power meter (Hioki).

More details of energy consumption for the current electricity meters in the rest areas can be provided by installing Wattvision monitoring systems. Wattvision consists of a gateway and a sensor. Sensors can be installed on the current meters in the rest areas and monitor energy consumption using short time intervals (15 seconds). The gateway is wired to the sensor, where interval data consumption can be uploaded to wattvision.com through a wireless network. Wattvision can provide a live view of energy consumption in the rest areas, and the consumption data can be downloaded and analyzed through MS Excel or other analytic tools; and alerts can be received for energy spikes, as shown in Figure 5. The Wattvision sensor and gateway costs $249; however, this system requires the availability of wireless Internet in the rest area buildings.

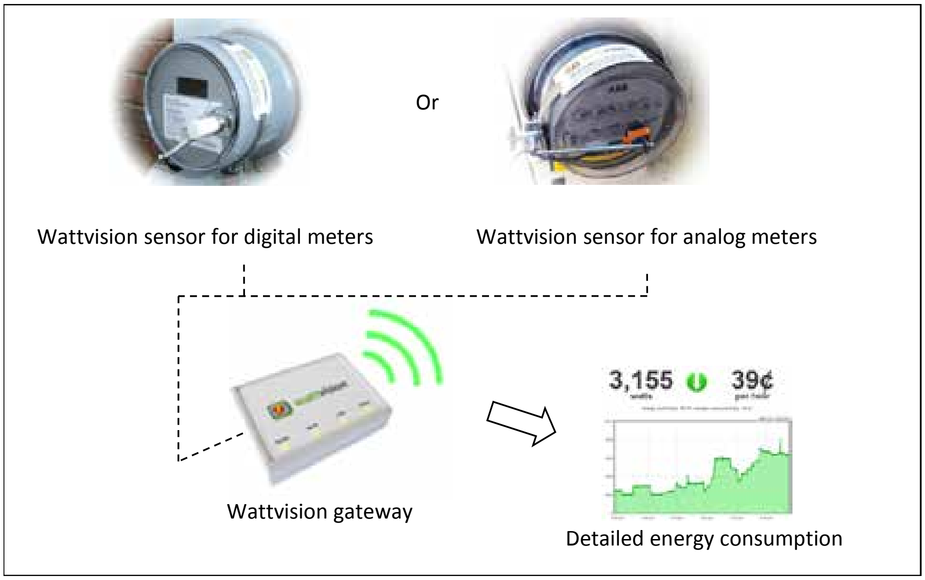


Figure 5. Wattvision for monitoring energy consumption in rest areas.

Based on the investigation conducted on installing sub-metering systems in the six selected interstate rest areas, the research team recommends that IDOT install sub-metering systems that are capable of collecting energy- and water-consumption data at 5-, 15-, 30-, or 60-min intervals, similar to the systems shown in Table 7. This type of interval data collection can be used to (1) achieve better management of total energy use; (2) provide details about energy use and its timing, which allows adjustments to be made and reduces energy consumption; (3) identify major contributors of energy/water consumption and areas that need urgent renovations; (4) identify operational strategies to control the load factor and peak-load requirements to reduce energy waste; (5) measure and verify actual energy savings that can be achieved by implementing energy-efficiency measures and technologies; and (6) help in evaluating performance and identifying any equipment malfunctions based on energy consumption, assuming the sub-meters are linked to an energy-management system. Furthermore, installing these sub-metering systems will allow the rest area buildings to earn up to four LEED points when applying for a certification level of the LEED rating system for existing buildings.

The cost of installing an electronic people-counter depends mainly on the number of counters that will be mounted on the entrances and exits of the rest area buildings and whether the counter will be mounted on the wall or the doorframe. Table 8 lists the costs for integrating an electronic people-counter in the selected rest areas. This cost estimate does not account for installation costs because it requires a simple installation procedure. The people-counter can be mounted easily on the wall or doorframe; and it can be connected wirelessly to the collection device, which can be placed within a reasonable distance from the people-counter.

Table 8. Costs of Electronic People-Counter in the Selected Rest Areas

Rest area	Number of counters	Installation Cost
Coalfield (each bound)	2	$2,500
Cumberland Road (each bound)	2	$2,500
Turtle Creek	2	$2,500
Willow Creek (each bound)	4	$4,000
Great Sauk Trail (each bound)	3	$3,250
Mackinaw Dells (each bound)	2	$2,500

CHAPTER 3 SURVEY RESULTS AND ANALYSIS

This chapter presents the findings of a survey of state DOTs to gather information on their experiences in implementing green-friendly measures in their rest areas, welcome centers, office buildings, and other related buildings. The survey was designed to identify green-friendly measures that were implemented by different state DOTs and to evaluate their performance in terms of user satisfaction, ease of maintenance, problems encountered, repair costs, estimated savings, and payback periods.

The survey was conducted using an online tool (SurveyGizmo, http://www.surveygizmo.com) to facilitate its distribution to and completion by state DOT officials. An e-mail with a link to the survey website was sent to the members of the subcommittee on design of the American Association of State Highway and Transportation Officials (AASHTO). A total of 31 responses were received from 30 officials in state DOTs and one in the Ontario Ministry of Transportation in Canada. Responses were received from DOT officials in 26 states: a response from one official in Michigan, Indiana, Iowa, Pennsylvania, California, New York, Massachusetts, Florida, Texas, Arizona, Mississippi, North Dakota, South Dakota, Alabama, Utah, North Carolina, South Carolina, Louisiana, Idaho, Arkansas, Kentucky, and Wyoming; and responses from two officials in Washington, Colorado, New Mexico, and Minnesota. The affiliations of the survey respondents are maintenance analyst, facilities manager, roadside environmental engineer, roadside development program manager, manager of sustainable transportation, two principal landscape architects, associate landscape architect, rest area administrator, two capital facilities operations and inventory managers, capital improvements manager, facility project planner, project management architect, two maintenance and operations branch managers, chief landscape architect, roadside program administrator, facilities management section head, facilities engineer, maintenance engineer, consultant management engineer, architect, regional manager, business manager, chief of facilities management division, division director, architecture and highway standards engineer, safety rest area program manager, and maintenance officer from the Ontario Ministry of Transportation.

The survey was developed following the guidelines of the American Association for Public Opinion Research (AAPOR 2013). The survey consists of five sections (see Appendix A). The first section requires the state DOT officials to select green building measures that were implemented in their facilities and identify the types of the buildings where these green measures were implemented. The second section asks them to report their user satisfaction for each measure selected in the previous section. User satisfaction is identified for each selected measure based on a scale of five categories: “very satisfied,” “satisfied,” “neutral,” “dissatisfied,” and “very dissatisfied.” The third section requires them to indicate the ease of maintenance for each green measure selected. Ease of maintenance is identified for each selected measure using a scale that consists of three levels: “easy to maintain,” “moderate,” and “difficult to maintain.” The fourth section asks them to list problems encountered and the estimated repair cost for each green measure selected. The last section asks state DOT officials to report the average reduction experienced in electricity/water use and the expected payback period for each green measure. The following sections in this chapter provide detailed analysis of the survey responses in these five sections. Additional tables and figures that provide detailed analysis of the responses to the survey questions are presented in Appendix B.

3.1 IMPLEMENTED GREEN TECHNOLOGIES

The survey respondents were asked to identify green-friendly measures implemented in their buildings, using a list based on the findings of the first phase of this project and the recommendations of the project Technical Review Panel (TRP). This list is organized in four categories of green measures: (1) energy-efficient lighting, which includes LED lighting, induction lighting, and energy-efficient fluorescent lighting; (2) renewable energy, which includes solar panels, solar water-heating systems, solar daylight tubes, geothermal heat pumps, and wind-power technology; (3) energy-efficient measures, which include motion-activated lighting, double-pane glass windows, energy-efficient hand dryers, exhaust-heat recovery, and airtight entrances; and (4) water-efficient measures, which include water-conserving toilets, water-conserving urinals, water-conserving faucets, rain gardens, and gray water systems. In addition, the survey was designed to enable respondents to list up to three additional measures that they adopted if those are not included in the list provided. Table 9 summarizes the green measures implemented in various state DOT buildings. The survey results show that LED lighting; energy-efficient fluorescent lighting; geothermal heat pumps; motion-activated lighting; double-pane glass windows; and water-conservative toilets, urinals, and faucets are the most commonly used green technologies, which were reported by at least 14 respondents, representing 45.2% of the survey respondents. Other green measures implemented less frequently include induction lighting, solar water heaters, solar daylight tubes, wind-power technology, rain gardens, and gray water systems, each of which were reported by six respondents at most, representing 19.4% of the survey respondents. The additional green measures that were not included in the survey list but were reported by the respondents are summarized in Table 10. The survey respondents were also asked in this section to indicate the type of building where these green measures were implemented, as shown in Table 11.

Table 9. Green Measures Implemented in State DOT Buildings

Measures Category	Green Measures Implemented	Number of Respondents	Percentage of Responses
Energy-efficient lighting	LED lighting	14	45.2%
	Induction lighting	4	12.9%
	Energy-efficient fluorescent lighting	28	90.3%
Renewable energy	Solar panels	11	35.5%
	Solar water heaters	3	9.7%
	Solar daylight tubes	6	19.4%
	Geothermal heat pumps	14	45.2%
	Wind-power technology	3	9.7%
Energy-efficient measures	Motion-activated lighting	18	58.1%
	Double-pane glass windows	25	80.6%
	Energy-efficient hand dryers	11	35.5%
	Exhaust-heat recovery	10	32.3%
	Airtight entrances	9	29.0%
Water-efficient measures	Water-conserving toilets	22	71.0%
	Water-conserving urinals	21	67.7%
	Water-conserving faucets	22	71.0%
	Rain gardens	6	19.4%
	Gray water systems	3	9.7%

Table 10. Green Measures Not Listed in the Survey but Added by Respondents

Measure #	Added Green Measure	Number of Respondents
1	Passive solar siting	3
2	Recycling	2
3	Using recycled materials	2
4	Native vegetation requiring no water other than naturally available	2
5	HVAC controls and temperature management	2
6	Cistern for flushing toilets	1
7	Cistern for watering landscaping	1
8	Waterless urinals	1
9	Radiant floor heating	1
10	Designed, constructed, and maintained to LEED Silver	1
11	LEED design	1
12	Switch-activated heaters	1
13	Installing T-12 lighting	1
14	Energy audits	1
15	Equipment upgrades/replacements	1
16	All new construction LEED certified	1
17	Evaporative cooling in desert rest areas	1
18	Hot water boilers	1
19	Building automation and controls	1
20	Local materials	1
21	Low/no VOC paints	1

Table 11. Types of Buildings with Green Measures

Rest Areas/Welcome Centers	Office Buildings	Other*
28	14	8

* Other reported buildings include a district complex, salt storage building, truck station, transit buildings, airport facilities, freeway lighting demo, and three maintenance facilities

3.2 USER SATISFACTION

Survey respondents reported the level of user satisfaction for the green measures implemented, using a five-point scale: “very satisfied,” “satisfied,” “neutral,” “dissatisfied,” or “very dissatisfied.” To identify an average user satisfaction for each green measure, these five levels are represented numerically, using a scale that ranges from 1.0 to 5.0, where 1.0 represents “very dissatisfied” and 5.0 represents “very satisfied”. These green building measures are ranked based on their average user satisfaction, as shown in Figure 6. The survey results show that seven green measures provided average satisfaction levels higher than 4.0, which is equivalent to “satisfied,” as shown in Figure 6. These seven satisfactory measures can be ranked based on their reported averages: double-pane glass windows, energy-efficient fluorescent lighting, exhaust-heat recovery, solar daylight tubes, geothermal heat pumps, motion-activated lighting, and water-conserving faucets. The remaining building measures received average user satisfaction levels that ranged from 3.3 to 4.0, with the exception of wind-power technology, which received an average user satisfaction of 2.0, equivalent to “dissatisfied,” as shown in Figure 6.

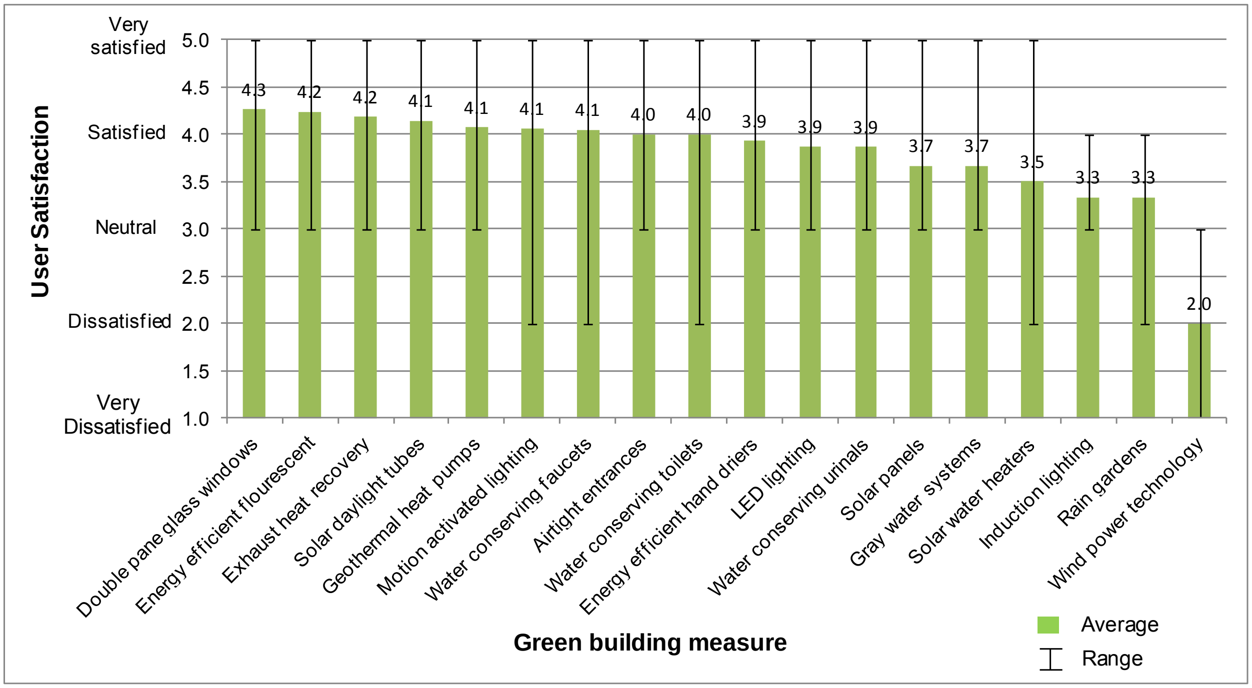


Figure 6. Ranking of green building measures, based on their user satisfaction.

3.3 EASE OF MAINTENANCE

Survey respondents reported the ease of maintenance for their implemented green measures using a 3-point scale that offers three alternative selections: “easy to maintain,” “moderate,” and “difficult to maintain.” To identify an average ease of maintenance for each green measure, these three levels are represented numerically using a scale that ranges from 1.0 to 3.0, where 1.0 represents “difficult to maintain” and 3.0 represents “easy to maintain”. These green building measures are ranked based on their average ease of maintenance, as shown in Figure 7. The survey results show that 14 green measures provided average ease of maintenance levels higher than 2.0, which is equivalent to “moderate,” as shown in Figure 7. These 14 easy-to-maintain measures can be ranked based on their reported averages: LED lighting, energy-efficient fluorescent lighting, induction lighting, double-pane glass windows, motion-activated lighting, solar daylight tubes, exhaust-heat recovery, water-conserving toilets, water-conserving faucets, airtight entrances, energy-efficient hand dryers, water-conserving urinals, geothermal heat pumps, and solar panels. The remaining building measures received average ease of maintenance levels that ranged from 1.7 to 2.0, as shown in Figure 7.

3.4 OPERATION PROBLEMS AND REPAIR COSTS

Survey respondents were asked to list the problems encountered and the associated repair costs, if available, for the green measures implemented in their buildings. The problems reported by the survey respondents are listed and summarized in Tables 12 through 15 for each of the four identified categories of green building measures (i.e., energy-efficient lighting, renewable energy, energy-efficient measures, and water-efficient measures). The green building measures are ranked based on the percentage of respondents reporting problems, as shown in Figure 8. The survey results show that six green measures had no reported problems: LED lighting, energy-efficient fluorescent lighting, solar daylight tubes, double-pane glass windows, rain gardens, and gray water systems, as shown in Figure 8. The remaining building measures received varying numbers of reported problems that range from 1 to 5, as shown in Tables 12 through Table 15. The percentage of respondents reporting problems ranges from 9.1% to 66.7%, as shown in Figure 8.

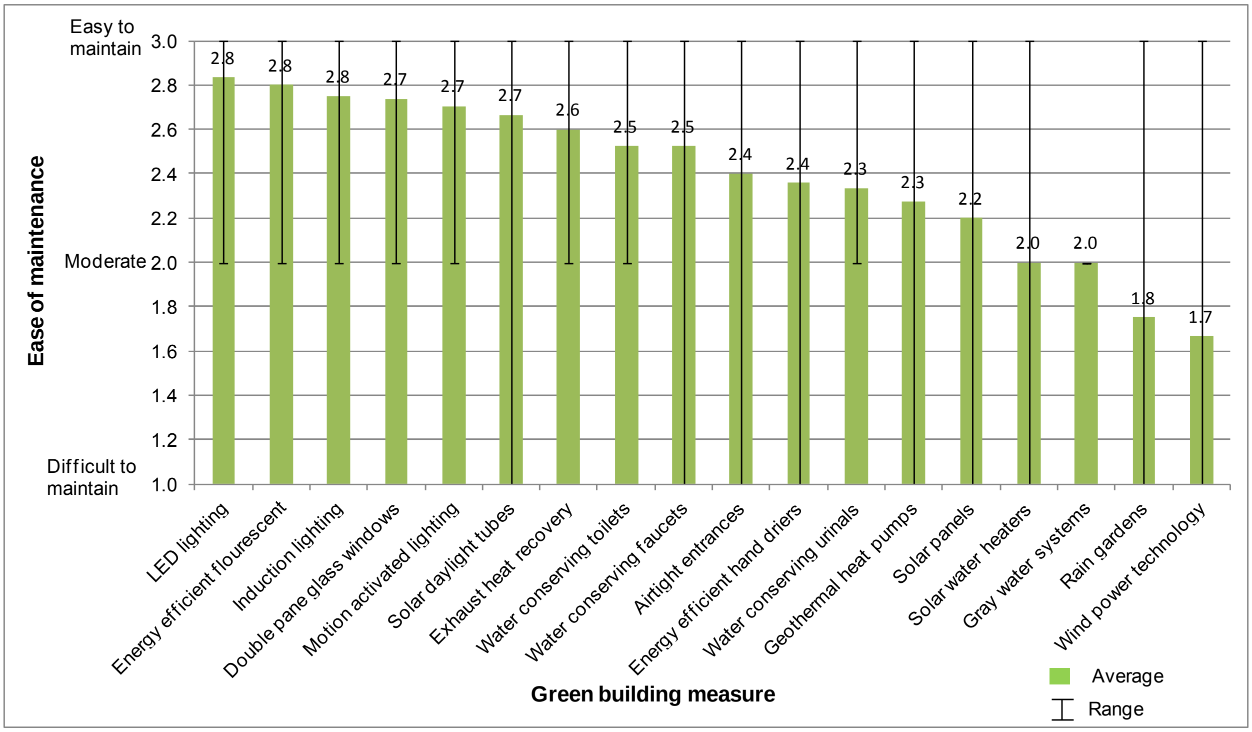


Figure 7. Ranking of green-friendly measures, based on their ease of maintenance.

Table 12. Operation Problems and Repair Costs for Energy-Efficient Lighting

Energy-Efficient Lighting	Problems Encountered	Number of Respondents	Percentage of Respondents Reporting Problems*		Repair Cost	Number of Respondents	Percentage of Respondents Reporting Repair Cost*	
			All Problems	Sub-Problem			All Repair Costs	Sub-Repair Cost
LED lighting	None	0	0.0%	0.0%	None	0	0.0%	0.0%
Induction lighting	Problems with initial fixtures	1	25.0%	25.0%	Repaired under warranty	1	25.0%	25.0%
Energy-efficient fluorescent	None	0	0.0%	0.0%	None	0	0.0%	0.0%

*Percentage of respondents reporting problems or repair cost = $\frac{\text{Number of respondents reporting problems or repair cost for green measure (e.g., LED lighting)}}{\text{Number of respondents implementing this green measure (e.g., LED lighting)}}$

Table 13. Operation Problems and Repair Costs for Renewable Energy

Renewable Energy	Problems Encountered	Number of Respondents	Percentage of Respondents Reporting Problems*		Repair Cost	Number of Respondents	Percentage of Respondents Reporting Repair Cost*	
			All Problems	Sub-Problem			All Repair Costs	Sub-Repair Cost
Solar panels	Vandalism/theft	3	27.3%	27.3%	$6,900, total replacement	2	18.2%	18.2%
Solar water heaters	Unavailability of parts for an old system	1	33.3%	33.3%	None	0	0.0%	0.0%
Solar daylight tubes	None	0	0.0%	0.0%	None	0	0.0%	0.0%
Geothermal heat pumps	Pump replacement	2	21.4%	14.3%	$250	1	14.3%	7.1%
	Problem during installation	1		7.1%	Repaired under warranty	1		7.1%
Wind-power technology	Maintenance costs were more than energy savings.	1	66.7%	33.3%	Maintenance costs, $1,200 annually	1	66.7%	33.3%
	Problem with initial units supplied	1		33.3%	Repaired under warranty	1		33.3%

*Percentage of respondents reporting problems or repair cost = $\frac{\text{Number of respondents reporting problems or repair cost for green measure (e.g., solar panels)}}{\text{Number of respondents implementing this green measure (e.g., solar panels)}}$

Table 14. Operation Problems and Repair Costs for Energy-Efficient Measures

Energy-Efficient Measures	Problems Encountered	Number of Respondents	Percentage of Respondents Reporting Problems*		Repair Cost	Number of Respondents	Percentage of Respondents Reporting Repair Cost*	
			All Problems	Sub-Problem			All Repair Costs	Sub-Repair Cost
Motion-activated lighting	Sensor failure	1	22.2%	5.6%	None	0	0.0%	0.0%
	Training personnel	1		5.6%	None	0		0.0%
	Getting light sensors properly located, having them function as designed	2		11.1%	None	0		0.0%
Double-pane glass windows	None	0	0.0%	0.0%	None	0	0.0%	0.0%
Energy-efficient hand dryers	Increased noise level the closer that hands are held near the exhaust	1	36.4%	9.1%	None	1	18.2%	9.1%
	Part replacement	1		9.1%	None	0		0.0%
	Unacceptable decibel level on certain models	1		9.1%	None	0		0.0%
	Equipment problems with two new units	1		9.1%	Repaired under warranty	1		9.1%
Exhaust-heat recovery	Can be large and hard to get into the space initially	1	20.0%	10.0%	None	1	20.0%	10.0%
	Shortened unit life because of missing filters	1		10.0%	None	1		10.0%
Airtight entrances	Automatic doors need frequent adjustment	1	33.3%	11.1%	At least $200 each time a repair-worker comes out	1	22.2%	11.1%
	Gaskets and seals	1		11.1%	$500	$1		11.1%
	Ongoing repair of weather stripping, ice buildup causing doors to stick open.	1		11.1%	None	0		0.0%

*Percentage of respondents reporting problems or repair cost = $\frac{\text{Number of respondents reporting problems or repair cost for green measure}}{\text{Number of respondents implementing this green measure}}$

Table 15. Operation Problems and Repair Costs for Water-Efficient Measures

Water-Efficient Measures	Problems Encountered	Number of Respondents	Percentage of Respondents Reporting Problems*		Repair Cost	Number of Respondents	Percentage of Respondents Reporting Repair Cost*	
			All Problems	Sub-Problem			All Repair Costs	Sub-Repair Cost
Water-conserving toilets	Increases solids	1	18.2%	4.5%	Adjustments needed, $0	1	12.5%	6.3%
	Lower flows contribute to plugging and increased solids at rest areas.	1		4.5%	Extra maintenance/time/ effort to keep operational	1		6.3%
	Effectiveness	1		4.5%	None	0		0.0%
	Incomplete flush	1		4.5%	None	0		0.0%
Water-conserving urinals	Electronic controls	1	23.8%	4.8%	$250/unit	1	5.6%	5.6%
	Odor problem	1		4.8%	None	0		0.0%
	Odor and increased maintenance frequency	1		4.8%	None	0		0.0%
	Cartridge replacement	1		4.8%	None	0		0.0%
	Increases solids	1		4.8%	None	0		0.0%
Water-conserving faucets	Electronic controls	1	9.1%	4.5%	None	0	6.3%	0.0%
	Initial adjustments	1		4.5%	By contractor	1		6.3%
Rain gardens	None	0	0.0%	0.0%	None	0	0.0%	0.0%
Gray water systems	None	0	0.0%	0.0%	None	0	0.0%	0.0%

*Percentage of respondents reporting problems or repair cost = $\frac{\text{Number of respondents reporting problems or repair cost for green measure}}{\text{Number of respondents implementing this green measure}}$

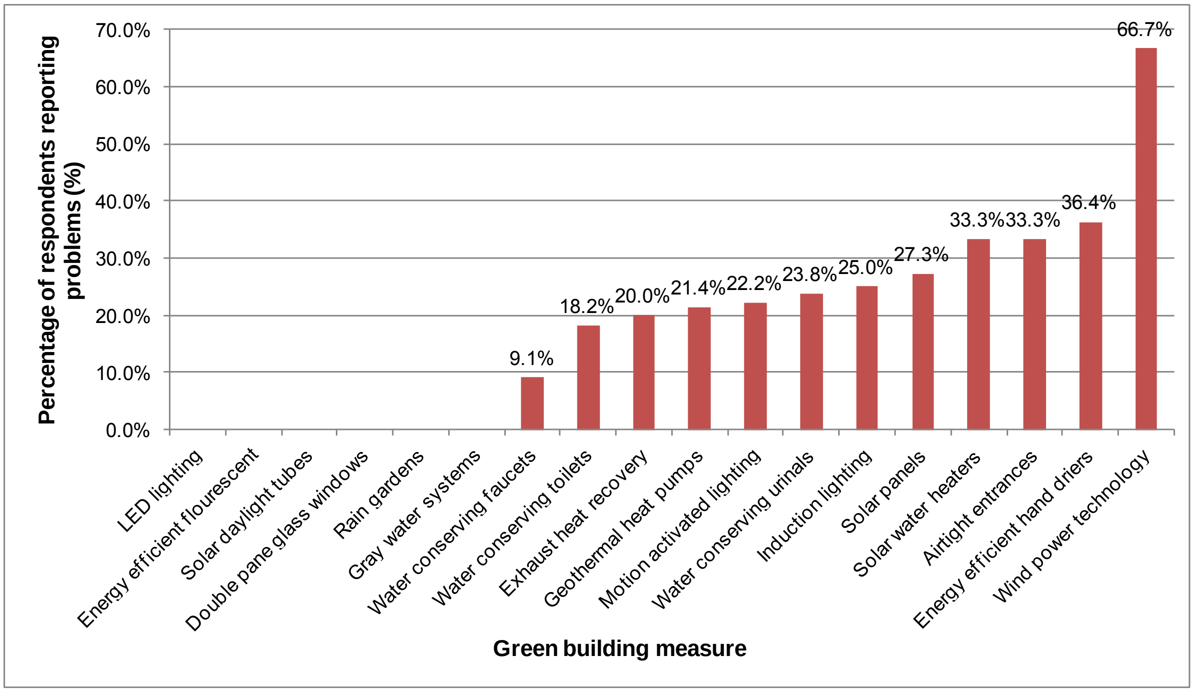


Figure 8. Ranking of green building measures based, on percentage of respondents reporting problems.

3.5 ENERGY SAVINGS AND PAYBACK PERIODS

Survey respondents were asked to indicate the energy/water savings and payback periods for the green measures implemented, if available. These green building measures are ranked based on their average energy/water savings, as shown in Figure 9. The survey results show that eight green measures provided energy/water savings that range from 10% to 60%, as shown in Figure 9. These eight green measures can be ranked based on their average energy/water savings: LED lighting; geothermal heat pumps; water-conserving urinals, toilets, and faucets; energy-efficient fluorescent lighting; motion-activated lighting; and exhaust-heat recovery. Four green building measures have average energy savings of less than or equal to 10%, as shown in Figure 9. These four green building measures can be ranked based on their energy savings: solar panels, energy-efficient hand dryers, airtight entrances, and double-pane glass windows. The survey respondents did not report savings for the remaining six building measures (induction lighting, solar water heaters, solar daylight tubes, wind-power technology, rain gardens, and gray water systems).

The green building measures are also ranked based on their average expected payback periods, as shown in Figure 10. The survey results show that ten green measures have a reasonable payback period of less than or equal to 10 years, as shown in Figure 10. These 10 green measures can be ranked based on their payback periods: energy-efficient hand dryers, energy-efficient fluorescent lighting, water-conserving faucets, toilets, and urinals; motion-activated lighting; exhaust-heat recovery; solar water heaters; solar daylight tubes; and airtight entrances. Five building measures have payback periods that range from 10.67 to 36 years, as shown in Figure 10. These five green building measures can be ranked based on their payback periods: geothermal heat pumps, double-pane glass windows, LED lighting, solar panels, and wind-power technology. The survey respondents did not report expected payback periods for the remaining three measures: induction lighting, rain gardens, and gray water systems.

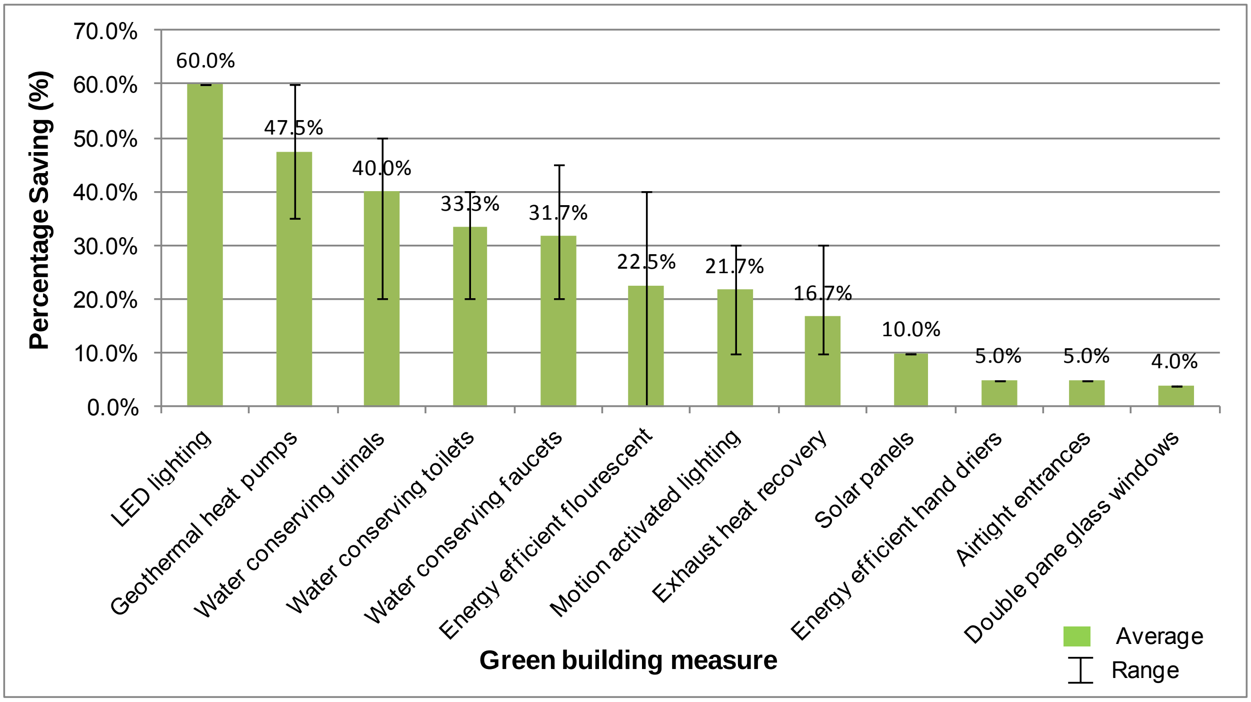


Figure 9. Ranking of green-friendly measures, based on reported energy/water savings.

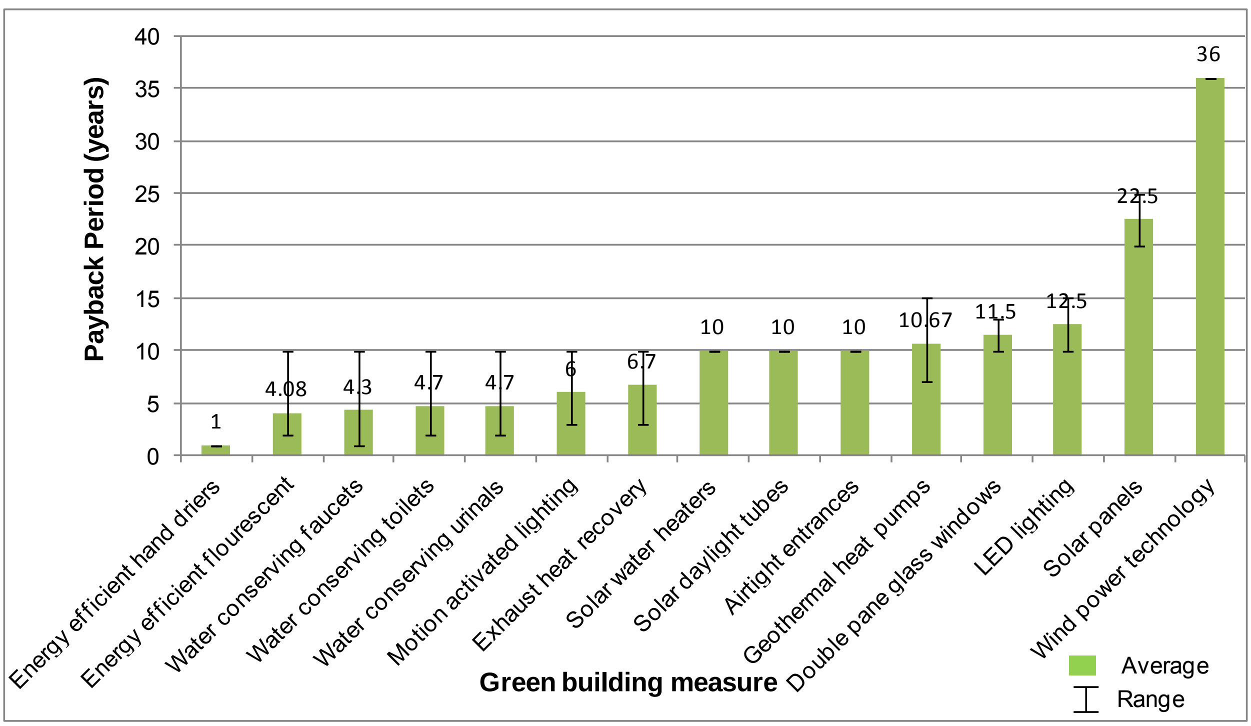


Figure 10. Ranking of green-friendly measures, based on reported payback periods.

CHAPTER 4 ON-SITE ASSESSMENT FOR SELECTED REST AREAS

A series of site visits and on-site assessments was conducted for the six selected rest areas to provide a better understanding of their current conditions and the potential for improving the performance of these facilities. The site visits and assessments for these six rest areas were conducted on April 6, 11, 13, and 29, 2011. The site visit and assessment team included the research team members, the chair of the Technical Review Panel, members of the panel, and Illinois Department of Transportation (IDOT) maintenance personnel. The main objectives of these site visits and on-site assessments were to study (1) the types of services provided by each rest area; (2) the conditions and characteristics of its appliances and fixtures; and (3) potential savings and energy-efficiency measures. These six rest areas were selected in this phase of the project for on-site assessment based on the highest annual energy cost and/or annual energy cost per square footage, as shown in Figures 11 and 12, respectively. These six high-potential rest areas were Willow Creek, Coalfield, Great Sauk Trail, Mackinaw Dells, Cumberland Road, and Turtle Creek; and they account for 32% of IDOT rest areas' energy bills, as shown in Figure 13 (El-Rayes et al. 2010). This chapter presents the findings of the on-site assessment for the Willow Creek rest area. The findings of the on-site assessments for the remaining five rest areas are presented in Appendix C.

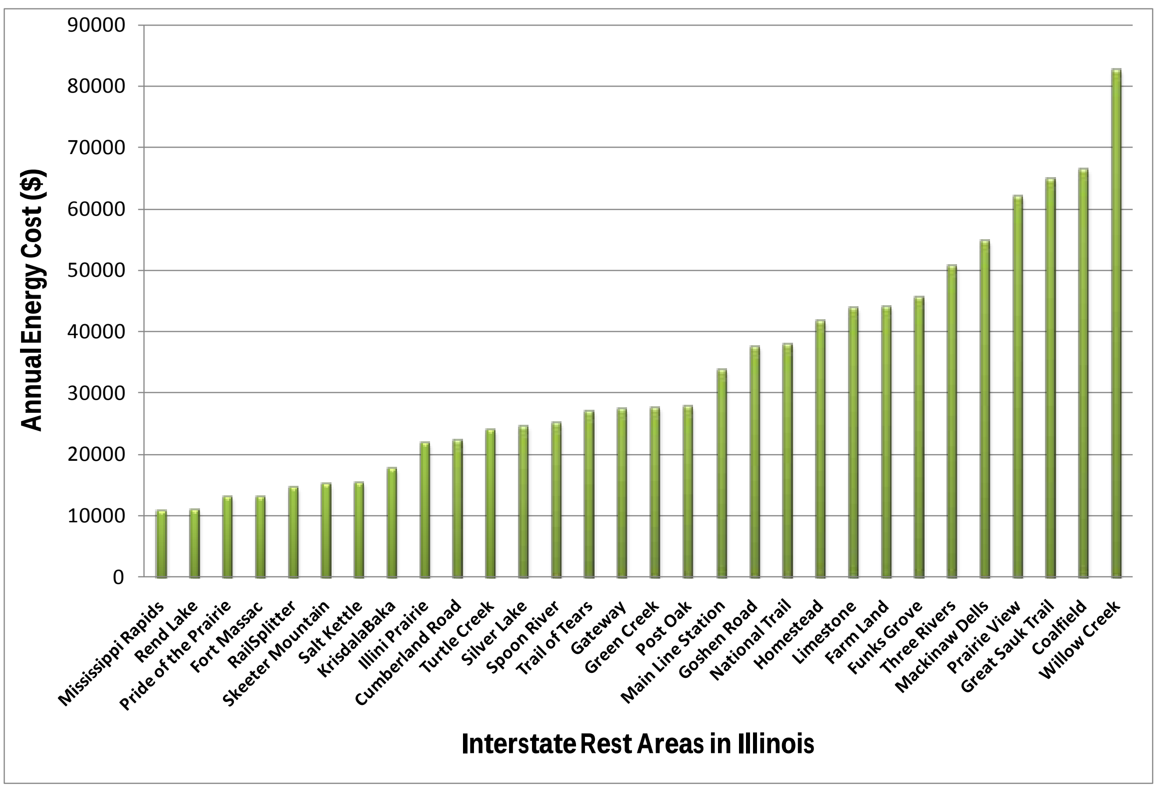


Figure 11. Annual energy consumption for interstate rest areas in Illinois (El-Rayes et al. 2010).

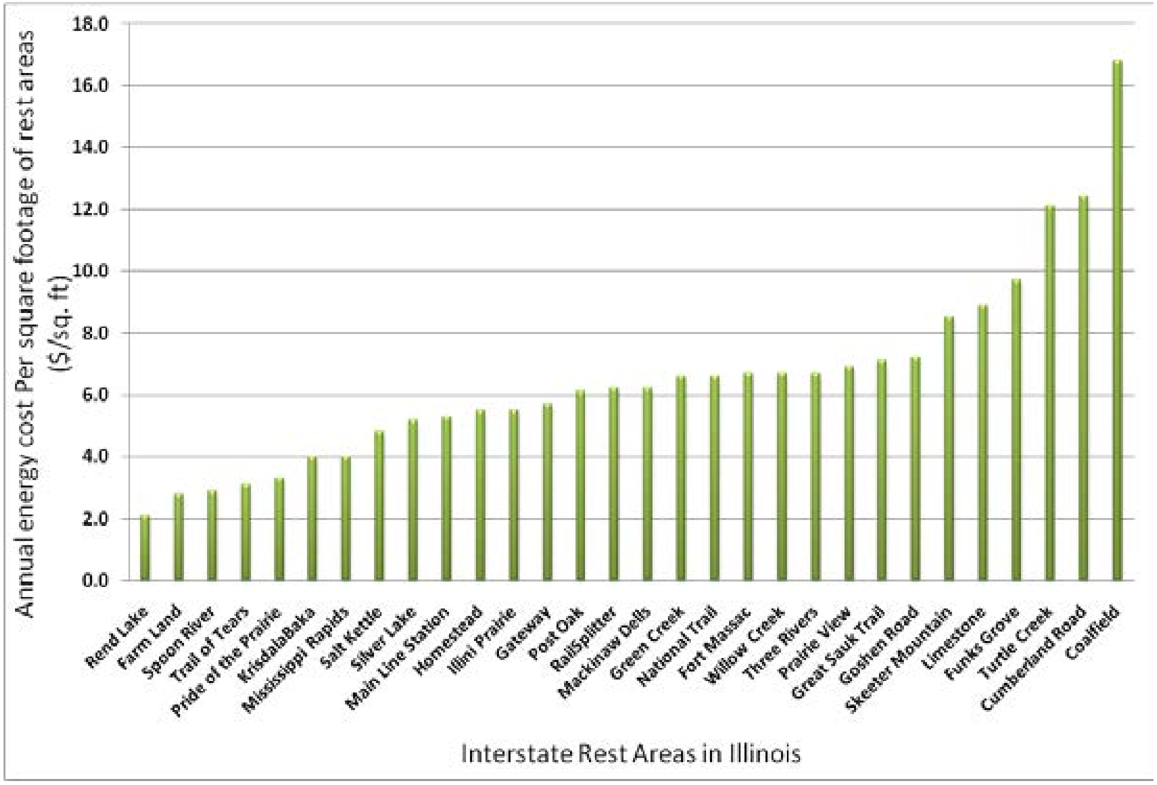


Figure 12. Annual energy consumption per square footage for interstate rest areas in Illinois (El-Rayes 2010).

Figure 13. Selected rest areas.

4.1 WILLOW CREEK REST AREA

Willow Creek rest area has approximately 1.1 million annual visitors, based on 2009 statistics, with a 0.49% annual increase in the visitation rate. It was built in 1993 and comprises two buildings that serve the north- and southbound lanes of I-39 at mile marker 85. The southbound portion of the rest area consists of one building with two floors to serve cars and trucks heading south on Interstate 39, while the northbound portion consists of one building with one floor to serve both cars and trucks heading north on Interstate 39. These buildings provide several services for visitors, including weather information, travel information and guides, restrooms, vending machines, and outdoor picnic areas; see Figure 14.

Southbound rest area

Northbound rest area

Figure 14. Willow Creek rest area.

The components of energy consumption in the northbound and southbound sides of the Willow Creek rest area include exterior lighting, interior lighting, space heating, air-conditioning, water heating, water treatment, vending machines, surveillance cameras, weather information, hand dryers, water coolers, and a pump station. The exterior lighting include light poles for the road between I-39 and the rest area parking lots, light poles for the parking lot, and outdoor lighting fixtures for the rest area building. The interior lighting includes light fixtures for the lobbies, men‘s restrooms, women‘s restrooms, mechanical room, water-treatment room, mechanical storage room, and vending storage room. The interior and exterior light fixtures in this rest area are summarized in Tables 16 and 17. Some lighting fixtures at the Willow Creek rest area are shown in Figure 15.

Table 16. Interior Lighting for the Willow Creek Rest Area

Location		Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Southbound	Lobby	square fluorescent fixture	32	2	U-shape Sylvania Supersaver 34W
		recessed light fixture, type 1	6	1	high-pressure sodium (HPS) (Philips) 70W
		recessed light fixture, type 2	13	1	MH compact 400W
		spotlight fixture	2	2	N.A.
		exit signs	7	1	fluorescent 5W
	Men's restrooms	square fluorescent fixture	8	2	U-shape Sylvania Supersaver 34W
		rectangular fixture, type 1	12	4	fluorescent 4' GE F34 CW/FS/WM/ECO
		rectangular fixture, type 2	12	2	fluorescent 4' GE F34 CW/FS/WM/ECO
		recessed light fixture	6	1	HPS (Philips) 70W
	Women's restrooms	square fluorescent fixture	8	2	U-shape Sylvania Supersaver 34W
		rectangular fixture, type 1	12	4	fluorescent GE F34 CW/FS/WM/ECO
		rectangular fixture, type 2	12	2	fluorescent 4' GE F34 CW/FS/WM/FRO
		recessed light fixture	6	1	HPS (Philips) 70W
	Family restroom	square fluorescent fixture	2	1	U-shape Sylvania Supersaver 34W
	Mechanical rooms	surface light fixture	36	1	HPS (Philips) 70W
	Storage rooms	surface light fixture	10	1	HPS (Philips) 70W
Northbound	Lobby	recessed light fixture, type 1	6	1	U-shape Sylvania Supersaver 34W
		recessed light fixture, type 2	11	1	MH compact 400W
		exit signs	4	1	fluorescent 5W
	Men's restrooms	square fluorescent fixture	6	2	U-shape Sylvania Supersaver 34W
		rectangular fixture, type 1	8	4	fluorescent 4' GE F34 CW/FS/WM/ECO
		rectangular fixture, type 2	8	2	fluorescent 4' GE F34 CW/FS/WM/ECO
		recessed light fixture	3	1	HPS (Philips) 70W
	Women's restrooms	square fluorescent fixture	6	2	U-shape Sylvania Supersaver 34W
		rectangular fixture, type 1	8	4	fluorescent 4’ GE F34 CW/FS/WM/ECO
		rectangular fixture, type 2	8	2	fluorescent 4' GE F34 CW/FS/WM/ECO
		recessed light fixture	3	1	HPS (Philips) 70W
	Family restroom	square fluorescent fixture	1	1	U-shape Sylvania Supersaver 34W
	Mechanical rooms	surface light fixture	15	1	HPS (Philips) 70W
	Storage rooms	surface light fixture	11	1	HPS (Philips) 70W

Table 17. Exterior Lighting for the Willow Creek Rest Area

Location		Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Southbound	Entrances and exits	lighting pole 1	9	1	N.A.
		lighting pole 2	10	1	N.A.
		lighting pole 3	1	2	N.A.
	Building	dusk–dawn fixture	10	1	HPS 50W
	Car parking	lighting tower 1	1	4	N.A.
	Truck parking	lighting tower 1	2	4	N.A.
		lighting tower 2	1	6	N.A.
Northbound	Entrances and exits	lighting pole 1	18	1	N.A.
		lighting pole 2	10	1	N.A.
		lighting pole 3	1	2	N.A.
	Building	Dusk-dawn fixture	10	1	HPS 50W
	Car parking	lighting tower 1	1	4	N.A.
		lighting tower 2	1	2	N.A.
	Truck parking	lighting tower 2	2	4	N.A.
		lighting tower 3	1	6	N.A.

Figure 15. Lighting fixtures at the Willow Creek rest area.

The building of the southbound Willow Creek rest area is heated and air-conditioned using two rooftop units, which use natural gas for heating and electricity for cooling. Each unit has a CFM supply of 5,250, heat output of 142 MBh, and efficiency of 81%. Similarly, the building of the northbound Willow Creek rest area is heated and air-conditioned using two units, which use natural gas for heating and electricity for cooling. Each unit has a CFM supply of 2,790, heat output of 79 MBh, and efficiency of 79%. All four units were manufactured in 1994. One natural gas water heater is used for each building to heat water, with a capacity of 82 gallons. One of the HVAC units and a water heater are shown in Figure 16.

Rooftop unit Water heater

Figure 16. Rooftop unit and water heater in southbound Willow Creek rest area.

One well is used in each bound of the rest area to supply water, and a water-treatment system is used in each bound of the rest area to treat well water. Each system includes a pressure tank, hydro-pneumatic control panel, air compressor, water softener, and brine tank. Figure 17 shows some of the equipment used in the rest area building. The southbound rest area has four vending machines on the first floor and another four vending machines on the second floor. These vending machines include two vending machines for drinks, four for snacks, one for coffee, and one for ice cream. The northbound side of this rest area contains six vending machines: three for cold drinks, two for snacks, and one for coffee, as shown in Figure 18.

Pressure tank Air pump Hydro-pneumatic panel

Figure 17. Water-treatment system components in the southbound Willow Creek rest area.

Figure 18. Vending machines in the Willow Creek rest area.

Twelve surveillance cameras are used in the southbound side of the rest area and six in the northbound to maintain safety for visitors, and these cameras need interior lighting all the time to increase the clarity of video recording. The weather information service is provided using a television on the first and second floors of the southbound rest area and in the lobby of the northbound rest area. Four Code Blue emergency phones are available in the southbound rest area: one on each floor and one in each parking lot. Three Code Blue emergency phones are also available in the northbound rest area: one in the lobby and one in each parking lot. The southbound building also includes one computer for surveillance cameras, a refrigerator, and two ceiling fans.

The men‘s and women‘s restrooms of the southbound rest area include 18 hand dryers while the men’s and women’s restrooms of the northbound rest area include nine hand dryers. Each of these hand dryer units has 2,300W electrical capacity. Eight water coolers are available in the lobbies of the southbound rest area and four in the lobby of the northbound rest area to provide cold drinking water for visitors. Hand dryers and water coolers in the Willow Creek rest area are shown in Figure 19. Other water-consumption fixtures in the Willow Creek rest area include faucets, urinals, and toilets. The quantities and characteristics of these water fixtures in this rest area are shown in Table 18.

Figure 19. Hand dryers and water coolers in the Willow Creek rest area.

Table 18. Water Fixtures in the Willow Creek Rest Area

Location		Type of Water Fixture	Quantity	Characteristics
Southbound	Men's restrooms	Faucets	8	Electronic faucets (Sloan)
		Toilets	8	Electronic 1.6 gal/flush
		Urinals	8	Electronic 4 units, 1.6 gal/flush; 4 units, 1.0 gal/flush
	Women's restrooms	Faucets	8	Electronic faucets (Sloan)
		Toilets	12	Electronic 1.6 gal/flush
	Family restrooms	Faucets	2	Electronic faucets (Sloan)
		Toilets	2	Electronic 1.6 gal/flush
Northbound	Men's restrooms	Faucets	6	Electronic faucets (Sloan)
		Toilets	4	Electronic 1.6 gal/flush
		Urinals	6	Electronic 2 units, 1.6 gal/flush; 4 units, 1.0 gal/flush
	Women's restrooms	Faucets	6	Electronic faucets (Sloan)
		Toilets	8	Electronic 1.6 gal/flush
	Family restroom	Faucets	1	Electronic faucets (Sloan)
		Toilets	1	Electronic 1.6 gal/flush

CHAPTER 5 POTENTIAL LISTS OF BMPS AND THEIR ENERGY AND ECONOMIC PERFORMANCE

This chapter presents the findings of a detailed analysis of (1) the energy consumption of the six selected rest areas and (2) the potential green building measures that can be implemented in Coalfield rest area. The findings of the detailed analysis for the remaining five rest areas (Willow Creek, Great Sauk Trail, Mackinaw Dells, Cumberland Road, and Turtle Creek) are presented in Appendix D. The green building measures analyzed were energy-efficient lighting, such as fluorescent T8 bulbs, LED lighting, and induction lighting; occupancy controls for interior lighting, exhaust fans, and vending machines; efficient HVAC systems, including geothermal heat pumps and high-efficiency air-source heat pumps; double-pane glass for windows and doors; vestibule entrances; high-velocity hand dryers; solar daylight tubes, photovoltaic systems, and solar water heater; and water-conserving plumbing fixtures. Furthermore, a life-cycle cost (LCC) analysis was conducted to evaluate the cost effectiveness of implementing these green building measures in the rest areas. LCC analysis is suitable for evaluating building upgrades and design alternatives that satisfy the same requirements of performance, including occupant comfort, engineering standards, system reliability, and aesthetics considerations, however, being different in one or more elements of cost (Fuller and Petersen 1995). Elements of the cost include the initial cost, operating cost, maintenance cost, time value of money, and increase in electricity rates. The findings from these analyses can be used by IDOT decision makers to identify promising green building measures for each of the selected rest areas, based on their cost effectiveness. Moreover, the impact of these green building measures on the environment was analyzed based on their potential reduction of CO_2 emission. The following sections describe the energy consumption analysis conducted for the Coalfield rest areas and a list of BMPs that can be implemented in it.

5.1 COALFIELD REST AREA

The Coalfield rest area is located 25 miles from Springfield at mile marker 64 of I-55, and it comprises two buildings to serve the north- and southbound lanes of I-55. It has approximately 1.8 million visitors, with an annual increase in visitation rate of 1.07%, based on 2009 statistics. The rest area was built in 1985 and had major renovations in 1991, when new vending areas were added to both buildings. The major sources of energy consumption in the rest area are the interior and exterior lighting, space heating and cooling, vending machines, hand dryers, pump station, and water heater. The next sections discuss the energy consumption analysis for the rest area building, as well as an LCC analysis for implementing different green building measures, including interior and exterior energy-saving light bulbs, motion-activated lighting, vending occupancy controls, motion exhaust sensors, geothermal heat pumps, an Energy Star air-source heat pump, double-pane glass windows, vestibule entrance, energy-efficient hand dryers, photovoltaic systems, solar water heater, solar daylight tubes, and water-saving plumbing fixtures.

5.1.1 Energy Audit and Analysis

The Coalfield rest area has one utility meter to measure energy consumption in each building of the rest area. The two utility meters can be used to measure the monthly energy consumption of each building; however, they cannot provide a measure of the energy consumed by each device or piece of equipment in the rest area. To identify major sources of energy consumption in the rest area buildings and their costs, an energy simulation model was developed using the eQuest energy simulation software environment. The eQuest software can be used to simulate the energy performance of a building, including its construction materials, weather, space heating and cooling, air ventilation, air infiltration and exhaust, temperature control, interior and exterior lighting, water use, windows and doors, skylights, operation schedule and occupancy, building activities, and equipment loads. Furthermore, eQuest can account for different scenarios for replacing any of the current equipment or devices in buildings and calculate the energy consumption accordingly. This capability of measuring a building's energy consumption based on different scenarios of implementing various green building measures and equipment was used to analyze and identify a list of promising BMPs for the Coalfield rest area.

The Coalfield rest area was modeled by first setting its geographical location to Springfield, Illinois, which is the nearest major U.S. city that is available in the database of the eQuest software. The next modeling step was to define the analysis year, seasonal schedule of the rest area, and utility rates. This step was followed by defining the size and shape of the rest area building using the eQuest wizard forms to specify its square footage and architecture shape based on its plan dimensions, as shown in Figure 20. Building zones were also defined in the model to represent the interior design of the building and to assign different activities, as well as heating and cooling system(s), to the model created. The eQuest software was also used to define the building envelope, including its roof surface, above-grade walls, ground floor construction and interior finishing, ceiling finishing and insulation, air infiltration, and type of vertical walls, as shown in Figure 21. The model also defined the building's doors and windows, including their surface areas and types, and overhangs, based on the building's geometry and the surrounding trees. The building operation schedule was also defined in the model to specify that the rest area building operates 24 hr a day and 7 days a week. The model also defined the building's activity area allocation by assigning percentages for various activities in the building, such as lobby, restrooms, mechanical and electrical, and storage. These percentages were determined based on the square footage of these areas with respect to the total square footage of the facility, as shown in Figure 22. Building occupancies were also assigned for these allocated areas because the eQuest software model considers the number of occupants throughout the operation of the building.

To model the occupancy for the rest areas in eQuest, we assumed that visitors spent an average of 5 min in the rest area building. The occupancy for the mechanical and storage rooms was assumed to be 0.5 person per mechanical room and 0.5 person per storage room to account for non-occupancy times in the rest area building. Ventilation and Infiltration were also defined by assigning rates for each occupied area. Infiltration rates were estimated based on the exhaust rates in the restroom areas, which were measured during the site visits.

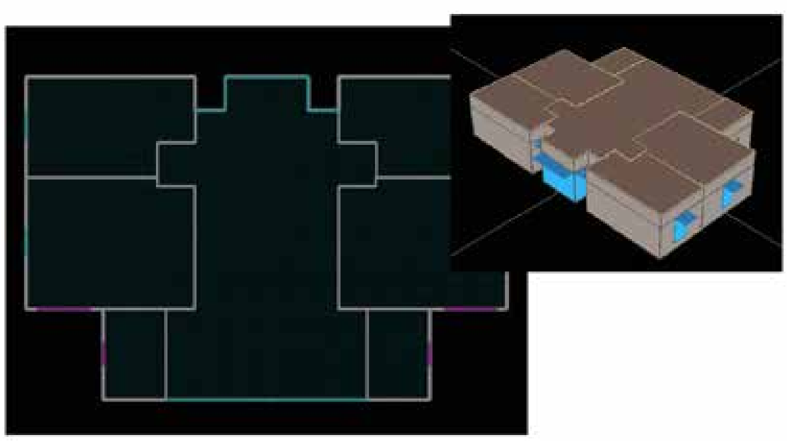


Figure 20. Architectural layout and shape of the Coalfield rest area buildings.

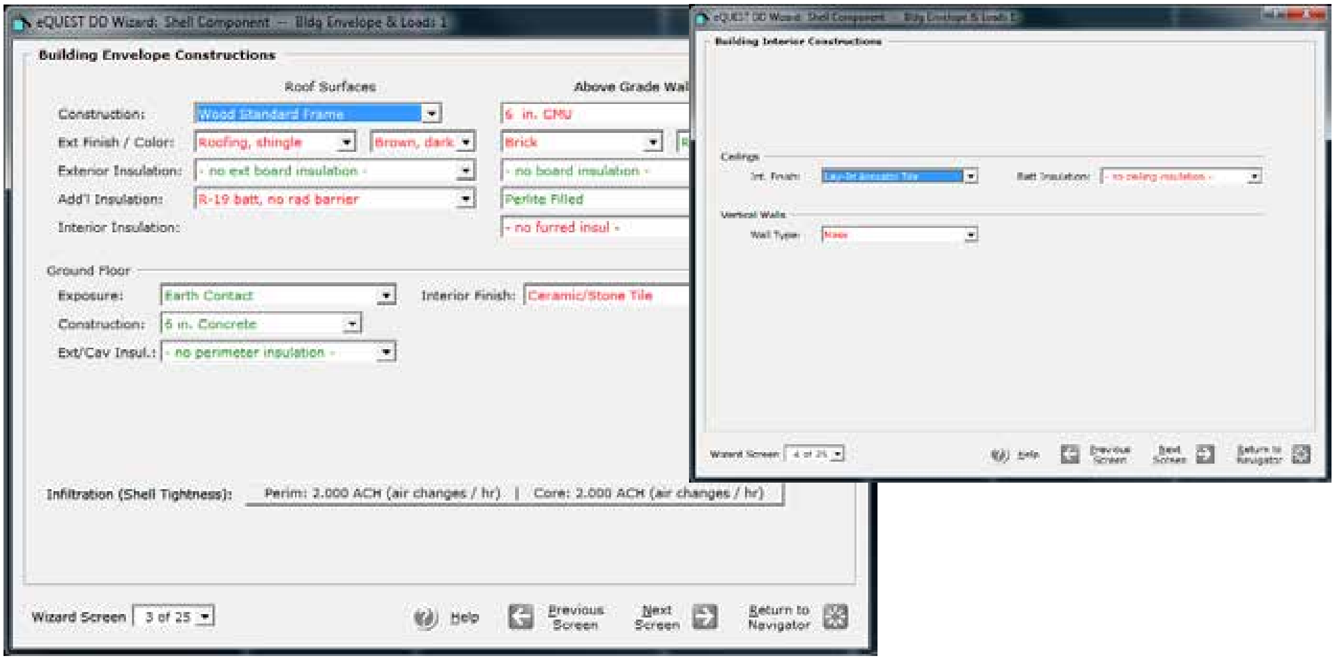


Figure 21. Building envelope in eQuest for the Coalfield rest area.

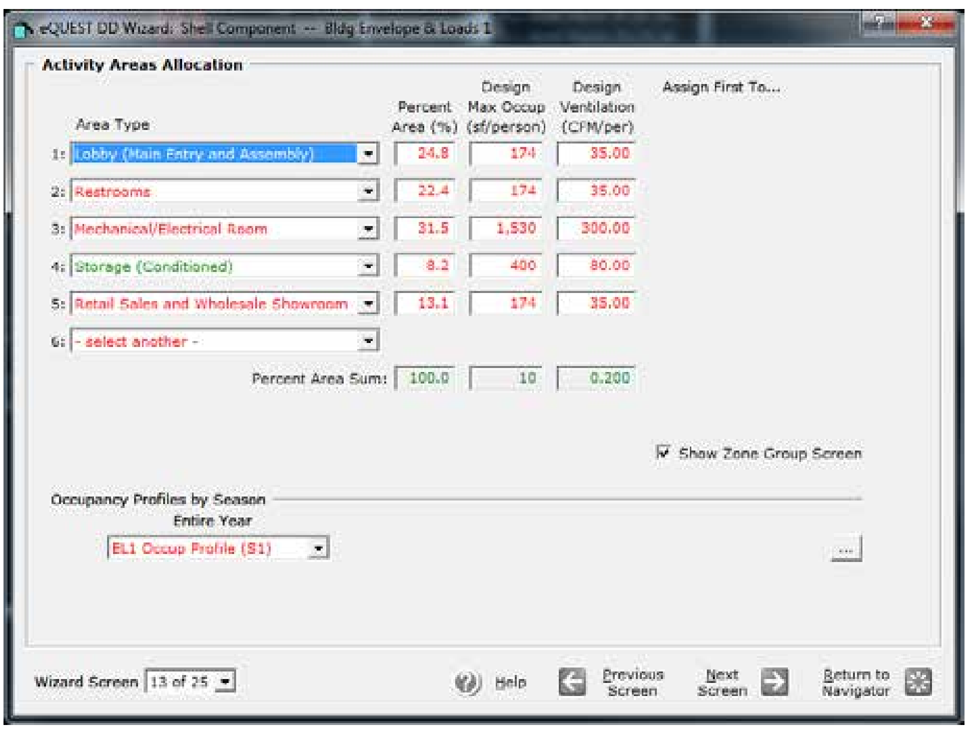


Figure 22. Activity areas' allocation and occupancy for the Coalfield rest area.

HVAC systems were then assigned to defined zones, as well as exhaust flow, as shown in Figure 23. During the site visit to the Coalfield rest area, exhaust flows were measured for the men's and women's restrooms as 77CFL and 76CFL, respectively. These values were used to assign exhaust for the simulation model. Interior lighting and miscellaneous equipment loads were also assigned to the model, where lighting loads were calculated by dividing the watt use of the building by its square footage, as shown in Figure 24. Similarly, equipment and device loads were assigned by dividing their watt use over the square footage of the allocated area. The energy use of water and wastewater pumps were estimated and assigned to the simulation model based on the working hours of pumps, pump rates, and square footage of the mechanical room. The energy use for water pumps, surveillance cameras, and a personal computer were assigned to the mechanical room load. An industry average watt use was assumed for a few pieces of equipment and devices in the rest area, such as vending machines, water coolers, weather station, fridges, and other small devices, owing to the inability to measure accurately their actual electricity consumption during the site visit. Energy consumption for hand dryers was estimated based on the assumption that half of the rest area visitors use the dryers for an average duration of 30 seconds each. Pump-station energy consumption was estimated based on water use in the rest area, which was reasonably assumed based on the number of rest area visitors and the water use of toilets, urinals, and faucets. An hourly profile for the interior lighting, devices, and equipment are set to full load to represent the full use of the interior lighting and other device such as vending machines. The watt use of other equipment or devices that do not operate 24 hr/day, such as the hand dryers and the interior lighting for the mechanical room and the storage rooms, was reduced, based on their estimated operation time. Miscellaneous equipment and devices were assigned to the model by dividing their total watt use by the building square footage, as shown in Figure 25.

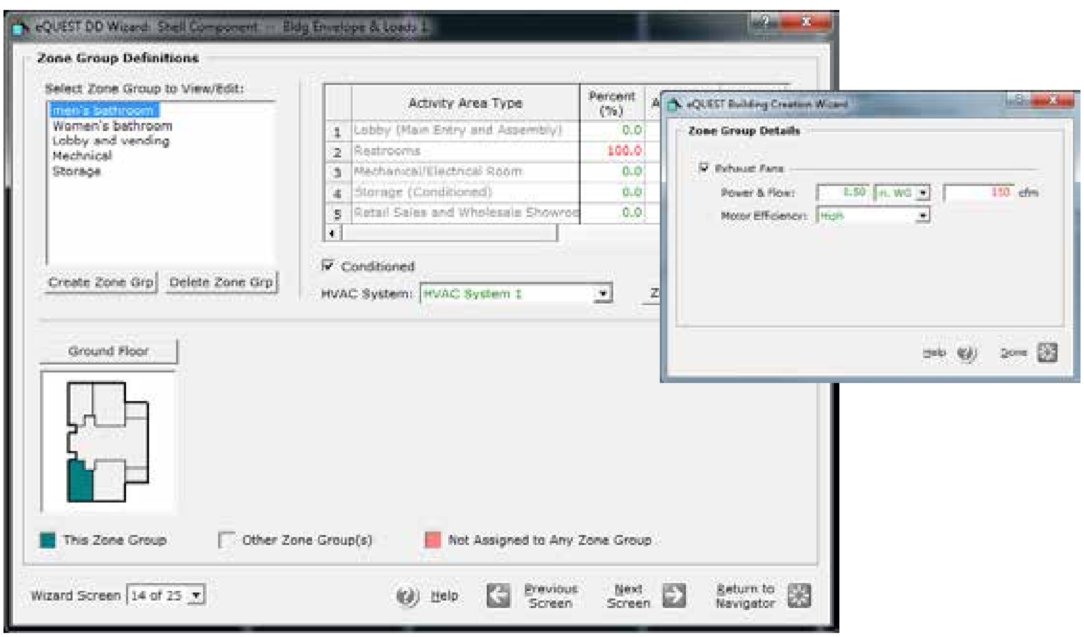


Figure 23. HVAC system zones and exhaust flow.

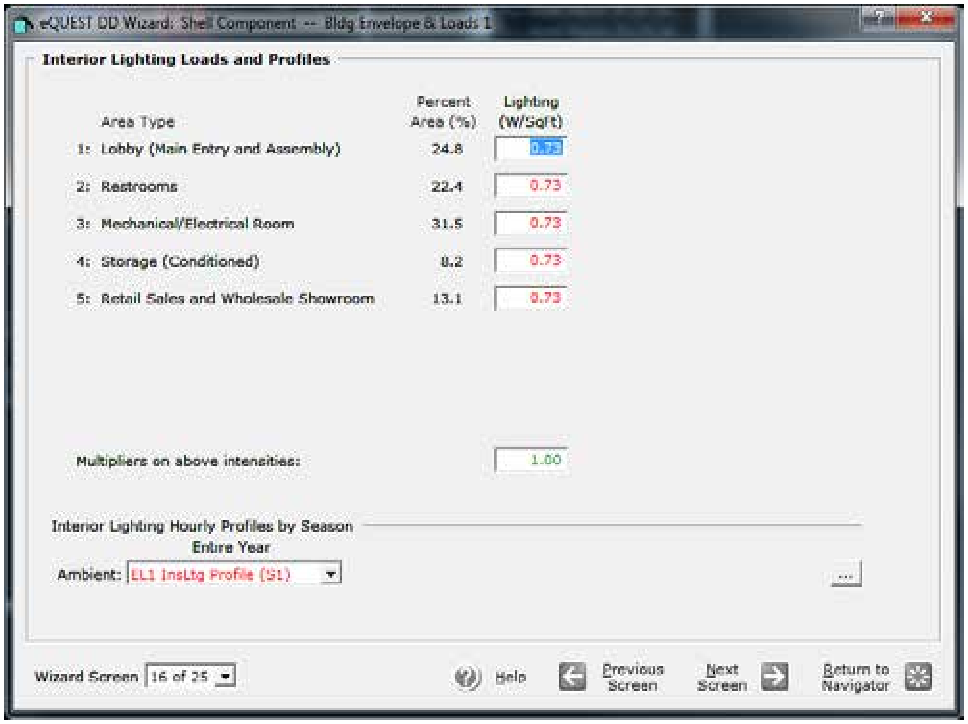


Figure 24. Interior lighting loads.

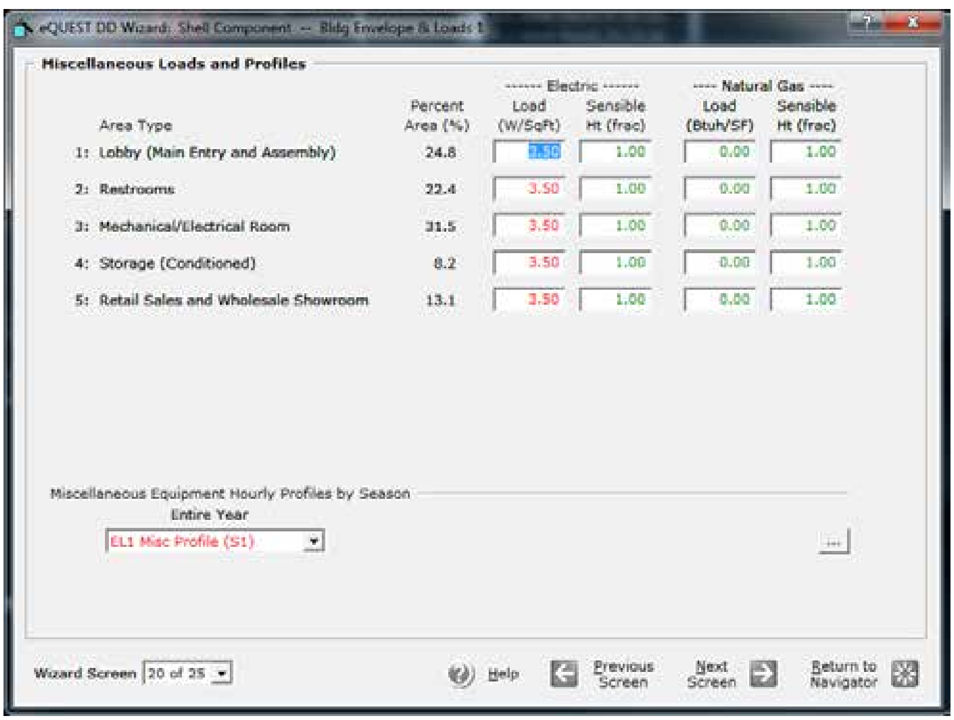


Figure 25. Equipment and devices loads for the Coalfield rest area.

The required input data for the exterior lighting load in the eQuest software is expressed in watt/ft^2 (see Figure 26); and accordingly, it was calculated in the developed simulation model by dividing the total wattage of the exterior lighting by the square footage of the building. The eQuest software accounts for the operating hours of the exterior lighting based on the location of the modeled building, which accounts for its seasonal hourly profiles. The HVAC system in the Coalfield rest area consists of two split-system air-conditioners with electric resistance duct heaters. The system has a total cooling capacity of 7.5 tons, and the heating system has a capacity of 35kW. Ducts of the HVAC system are routed through an unconditioned attic space where they were not insulated. The HVAC system for the Coalfield rest area was modeled in eQuest with an assumed energy-efficiency ratio (EER) of 8.9 for cooling and an auto-size capacity for heating. Seasonal thermostat set points were set in the model to 70^{o}F for cooling in summer and 74^{o}F for heating in winter. The water heater was modeled in eQuest based on the estimated daily water use per occupant; the supply water temperature was set to 94^{o}F, as it was reported during the site visit.

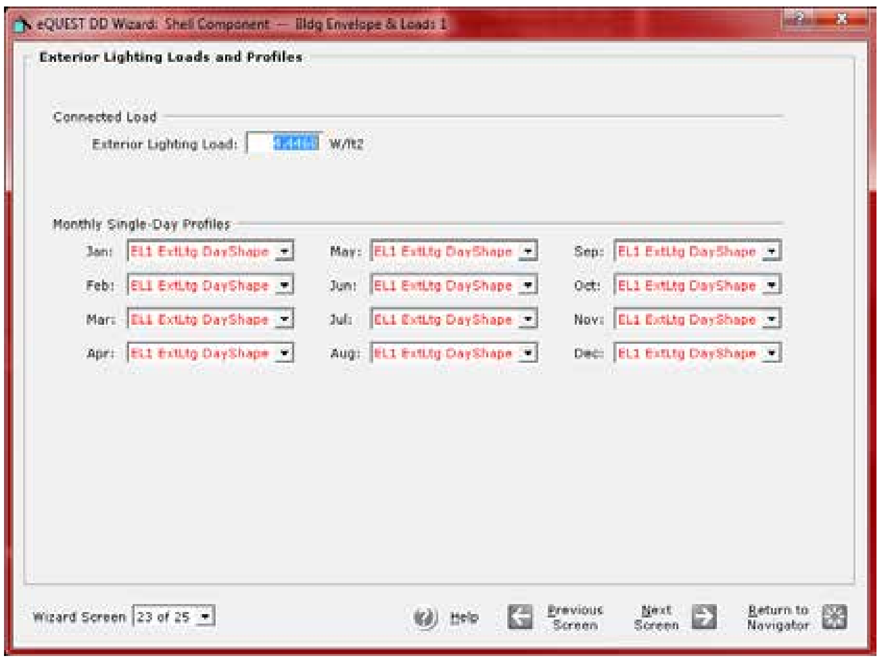


Figure 26. Exterior lighting loads and profiles for the Coalfield rest area buildings.

After modeling the rest area building in eQuest, the simulation model was run to simulate the building performance with respect to weather conditions throughout the year and calculate monthly and total energy consumption categories of the building. Because of the difficulty of measuring the air-infiltration rates for the entry doors during the site visit, several runs of the simulation model were conducted with varying reasonable rates of infiltration and ventilation to minimize the differences between simulated and actual energy consumption reported in the building's energy bills. The parameters of infiltration were eventually set in the model to 35 CFM/person for the restrooms, lobby, and vending area; 300 CFM/person for the mechanical room; and 80 CFM/person for the storage room.

Figure 27 compares the simulated monthly energy consumption of the building based on the model developed in eQuest to the actual energy consumption reported in the utility bills of the Coalfield rest area buildings in 2009. Based on the results in Figure 27, the average absolute difference between the energy consumption for the simulation model developed and the actual bills is 11.5%; and the maximum and minimum differences between the energy consumption for the simulation model developed and the actual bills were 20.3% in September and 2.2 % in March. The results also show that the Coalfield rest area has an average consumption of 239,332 kWh for each building.

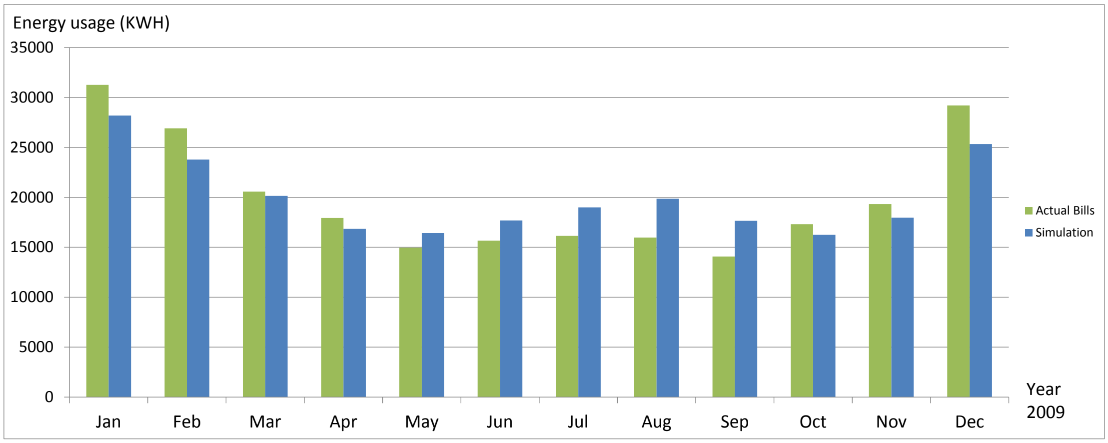


Figure 27. Simulated and actual electricity consumption of the Coalfield rest area buildings in 2009.

The square footage of the Coalfield rest area is 2,444 ft^2; and its annual number of visitors is 880,000 per building, which leads to electricity consumption rates of 97.93 $kWh/ft^2/yr$, $13.71/$ft^2$/yr, and 0.27 kWh/visitor/yr. The breakdown of the electricity cost for the Coalfield rest area buildings for its main sources of consumption is shown in Figure 28. Space heaters account for 23% of the total energy consumption of the rest area building and represent the highest energy consumption. The lowest energy consumption is from hand dryers and water coolers, which account for 4% and 2%, respectively, of total energy consumption. This breakdown of energy costs will help in prioritizing energy-improvement efforts. The “other” category includes small equipment and devices such as vacuum cleaners, coffee machines, microwaves, and personnel laptops that are occasionally used in the rest area building and that were not considered in the simulation model.

The greatest use of energy for heating purposes (approximately 10% of total energy consumption) is for heating the space envelope of the rest area building. Additionally, 7% of the total energy cost is for heating infiltrated air that leaks into the building, primarily because of frequent opening and closing of the building doors (infiltration was modeled in eQuest model by 1.2 average air changes per hour).

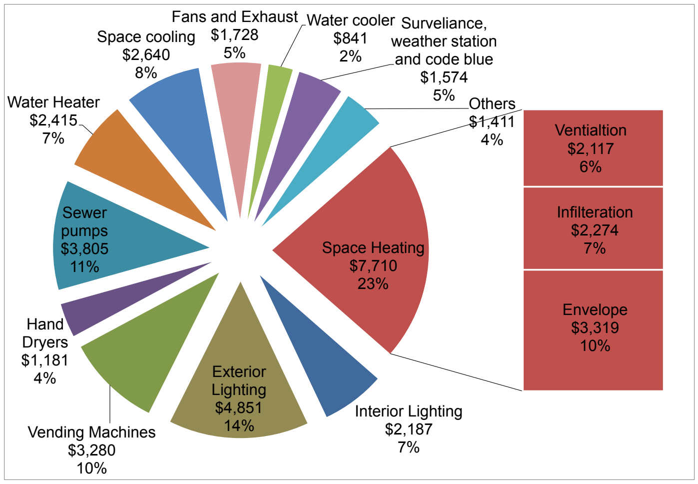


Figure 28. Energy cost breakdown of the Coalfield rest area.

5.1.2 Lighting

Lighting in the Coalfield rest area represents approximately 21% of the total energy consumption, with an annual cost of $6,616. The following two subsections analyze the feasibility of replacing the current interior and exterior lighting with more-efficient and energy-saving bulbs. The economic analysis of light replacement in these two sections follows the same procedures discussed in the first phase of this project and assumes an annual interest rate of 2% and escalation in utility rate of 5%.

Given the diversity of light characteristics, shapes, and fixtures, as well as the aesthetic requirements of each building, a spreadsheet was developed to (1) analyze the feasibility of using new lighting technologies such as LED or induction lighting in rest areas and (2) provide IDOT decision makers with the flexibility to analyze the impact of varying the LCCA assumptions on the net potential savings and payback periods of these new lighting technologies. The spreadsheet takes into consideration LCC components, including utility cost, annual increases in utility cost, discount rate, incentives, and a study period of 30 years. This spreadsheet was used to conduct an LCCA, as presented in the following sections.

5.1.2.1 Interior Lighting

Interior lighting in the Coalfield rest area consists of linear and U-shape fluorescent T12 bulbs. These bulbs can be replaced with linear and U-shaped fluorescent T8 bulbs to provide similar luminance level, less energy consumption, and longer life expectancy. Tables 19 and 20 summarize the impact of replacing current T12 with T8 fluorescent light bulbs for the Coalfield rest area. These lighting replacements can provide annual savings of $464 and reduce total energy consumption by 1.4%. The LCC analysis conducted for replacing all current T12 lighting with T8 bulbs is shown in Figure 29. The average payback period for all light replacement is 0.85 years, which represents a green building measure with a promising return on investment.

Table 19. Replacing U-Shape Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in the Lobby and Restrooms of the Coalfield Rest Area Buildings

Lighting Characteristics, Costs, and Savings	**Existing Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	Sylvania (FB34/CW/6/SS/ECO	Sylvania 22305 (FBO28/841/XP/SS/ECO
Number of bulbs	32	32
Mean lumens (lumen)	2,279	2,265
Kelvin temperature (K)	4,200	4,100
Color rendering index (CRI)	62	75
Lifetime (hr)	18,000	26,000
Consumption per bulb (watt)	34	28
Lamp cost ($/each)	9.99	15.79
Change in lumens output levels (%)	N.A.	-0.6
Reduction in energy consumption (%)	N.A.	17.6
Annual savings in energy consumption—first year ($)	N.A.	236
Payback period (yr)	N.A.	0.8

Table 20. Replacing Linear Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in the Lobby, Restrooms, Maintenance Rooms, and Storage Rooms of the Coalfield Rest Area Buildings

Lighting Characteristics, Costs, and Savings	**Existing Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	34CW/RS/WM/ECO	Sylvania 22234 (FO32/25W/841/XP/SS/ECO)
Number of bulbs	36	36
Mean lumens (lumen)	2,280	2,327
Kelvin temperature (K)	4,100	4,100
Color rendering index (CRI)	60	85
Lifetime (hr)	20,000	36,000
Consumption per bulb (watt)	34	25
Lamp cost ($/each)	1.8	7.39
Change in lumens output levels (%)	N.A.	+2.1
Reduction in energy consumption (%)	N.A.	17.6
Annual savings in energy consumption—first year ($)	N.A.	227
Payback period (yr)	N.A.	0.51, 1.53, 5.77,*

* Payback period for lobby and restrooms, maintenance room, and storage rooms, respectively

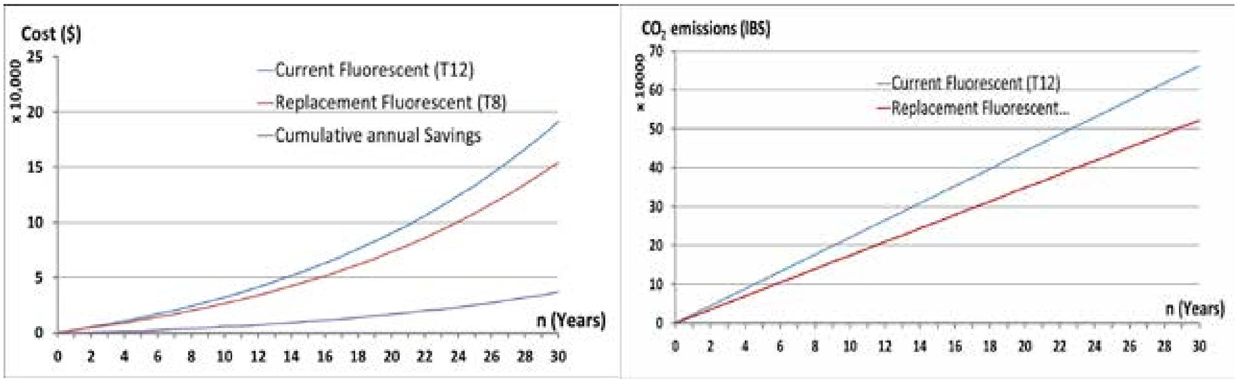


Figure 29. Cumulative costs, savings, and CO_2 emissions for the current and replacement lighting of the Coalfield rest area buildings.

5.1.2.2 Exterior Lighting

This section analyzes the impact of replacing the current exterior lighting of the Coalfield rest area with LED and induction lighting. The average lighting operating hours was determined based on the eQuest simulation model, which accounts for the location of the rest area building and its seasonal operational hours. The average lighting hours of the exterior lighting was calculated to be 8.72 hr. The current exterior lighting of the Coalfield rest area consists of (1) ten recessed lighting fixtures with 70W HPS bulbs in each; (2) six light poles at the entrance and exit of the rest area with 250W HPS bulbs in each; and (3) three lighting towers with a total of eighteen 400W HPS bulbs. Because of the unavailability of the exact brand and luminance characteristics of the current exterior lighting, reasonable assumptions were made for their luminance levels, given the fact that the luminance characteristics of the lighting do not significantly differ among brand names.

An LCC analysis was conducted to examine the feasibility of implementing a one-for-one replacement of the current exterior lighting for the rest area building and its parking lot, as well as LED and induction lighting at its entrance and exit. The analysis considered the possible lighting fixtures and bulbs shown in Table 21, as recommended by manufacturers. It should be noted that the LCC was conducted for one-for-one replacement to reduce initial costs. This one-for-one replacement is expected to reduce the current total lighting output (lumen) of light poles by 47% and 54% for LED and induction lighting replacements, respectively. Similarly, this one-for-one replacement will reduce the current total lighting output (lumen) of (1) light towers by 60% and 64% for LED and induction lighting replacements, respectively; and (2) recessed fixtures by 42% and 46% for LED and induction lighting replacements, respectively. The results of the analysis of this one-for-one replacement are summarized in Tables 22 through 24 for all the lighting fixtures/bulbs of the rest area. The potential cumulative cost and savings, as well as the carbon footprint and the reductions in CO_2 emissions for replacing the exterior lighting of the Coalfield rest area, are shown in Figure 30. The analysis shows that these potential lighting replacements can provide an annual savings of $2,622 or 7.8% of the total energy consumption for LED lighting replacements; and $2,565, or 7.7% of the total energy consumption for induction lighting replacements. This figure leads to a payback period of 14.2 years for LED light replacements and 4.8 years for induction lighting replacements. Although this one-for-one replacement is recommended by manufacturers, it might not be feasible to implement in rest areas that cannot permit the aforementioned reductions in exterior lighting levels; accordingly, this potential replacement was not included in the recommendation sections.

Another analysis was conducted to examine the feasibility of exterior lighting replacements that maintain existing lumens output levels. To maintain the same light lumens, existing exterior HPS light bulbs can be replaced by LED luminaires that provide similar lumen output, such as HMLED14. This luminaire (HMLED14) has an initial cost of $2,400, energy consumption of 551 watts, and initial lumens of 41,934. Although this LED luminaire can provide one-for-one replacement of existing HPS 400-watt bulbs at comparable lumen levels, this potential replacement has a higher cost and consumes more energy than existing HPS 400W bulbs that consume 481W and have an initial cost of $54 each. Accordingly, based on current costs, this potential light replacement is not economically feasible. It should be noted, however, that the outcome of this economic feasibility analysis is expected to change because of the forecasted reduction in the initial cost of LED luminaries over time that are expected to be brought about by advancements in technology and increased competitiveness among manufacturers and vendors of LED luminaires.

Table 21. Characteristics of the Current and Replacement Lighting for the Exterior of the Coalfield Rest Area Buildings

Light Characteristic items	Current lighting		Replacement (LED lighting)		Replacement (Induction light)	
	Type	Characteristics	Type	Characteristics	Type	Characteristics
Mean Lumens (lumen)	HPS 70w	5200	LED Lamp	3000	Induction Lamp	2800
Color temperature (Kelvin)		3000		3000-5000		2700-6500
Color rendering index (CRI)		75		80		83
Life time (hours)		10000		50000		100000
Consumption (w)		70		40		40
Lamp cost ($)		33		335		215
Lamp and fixture cost ($)		-		-		-
Initial Lumens (lumen)	HPS 250w	28500	LED Steet Light	15000	Induction Steet Light	13200
Color temperature (Kelvin)		2000		2700-8000		5000
Color rendering index (CRI)		25		75		83
Life time (hours)		30000		50000		75000
Consumption (w)		250		168		165
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1274		486
Initial Lumens (lumen)	HPS 400w	50000	LED Steet Light	20000	Induction Steet Light	18000
Color temperature (Kelvin)		2100		2700-8000		5000
Color rendering index (CRI)		20		75		83
Life time (hours)		24000		50000		75000
Consumption (w)		400		224		225
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1493		538

Table 22. Replacing HPS 400W Bulbs with Energy-Efficient LED and Induction Light Bulbs in the Coalfield Rest Area Buildings

Lighting Characteristics, Costs, and Savings	**Existing Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	HPS	LED	Induction
Number of bulbs	18	18	18
Initial lumens (lumens)	50,000	20,000	18,000
Kelvin temperature (K)	2100	2,700–8,000	5,000
Color rendering index (CRI)	20	75	83
Life time (hr)	24,000	50,000	75,000
Consumption per bulb, including ballast (watt)	481	224	230
Bulb cost ($)	54	1,493	538
Installation cost ($)	102	102	102
Reduction in lumens output levels (%)	N.A.	60	64
Reduction in energy consumption (%)	N.A.	53	52
Annual savings in energy—first year ($/yr)	N.A.	2,064	2,016
Payback period (yr)	N.A.	12.1	4.2

Table 23. Replacing HPS 250W Bulbs with Energy-Efficient LED and Induction Light Bulbs in the Coalfield Rest Area Buildings

Lighting Characteristics, Costs, and Savings	**Existing Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	HPS	LED	Induction
Number of bulbs	6	6	6
Initial lumens (lumens)	28,500	15,000	13,200
Kelvin temperature (K)	2,000	4,900	5,000
Color Rendering Index (CRI)	25	75	83
Life time (hr)	30,000	50,000	75,000
Consumption per bulb, including ballast (watt)	315	168	168
Bulb cost ($)	54	1,320	486
Installation cost ($)	102	102	102
Reduction in lumens output levels (%)	N.A.	47	54
Reduction in energy consumption (%)	N.A.	47	47
Annual savings in energy—first year ($/yr)	N.A.	394	394
Payback period (yr)	N.A.	22.4	6.2

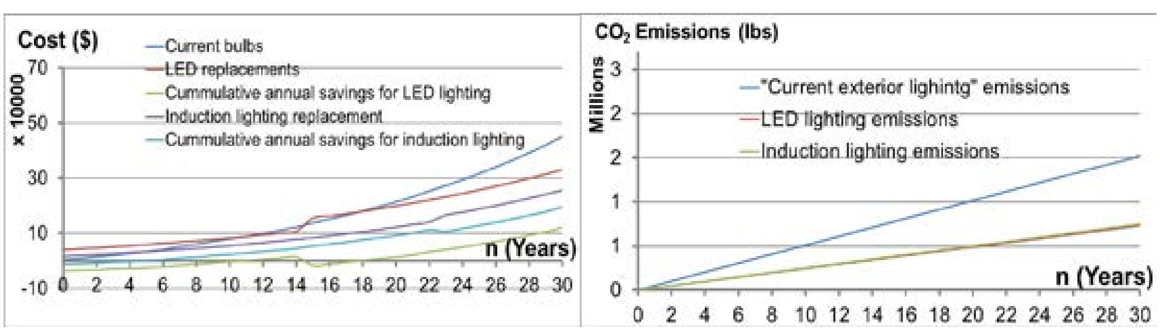


Figure 30. Cumulative costs, savings, and CO_2 emissions for LED and induction lighting replacements for the Coalfield rest area buildings.

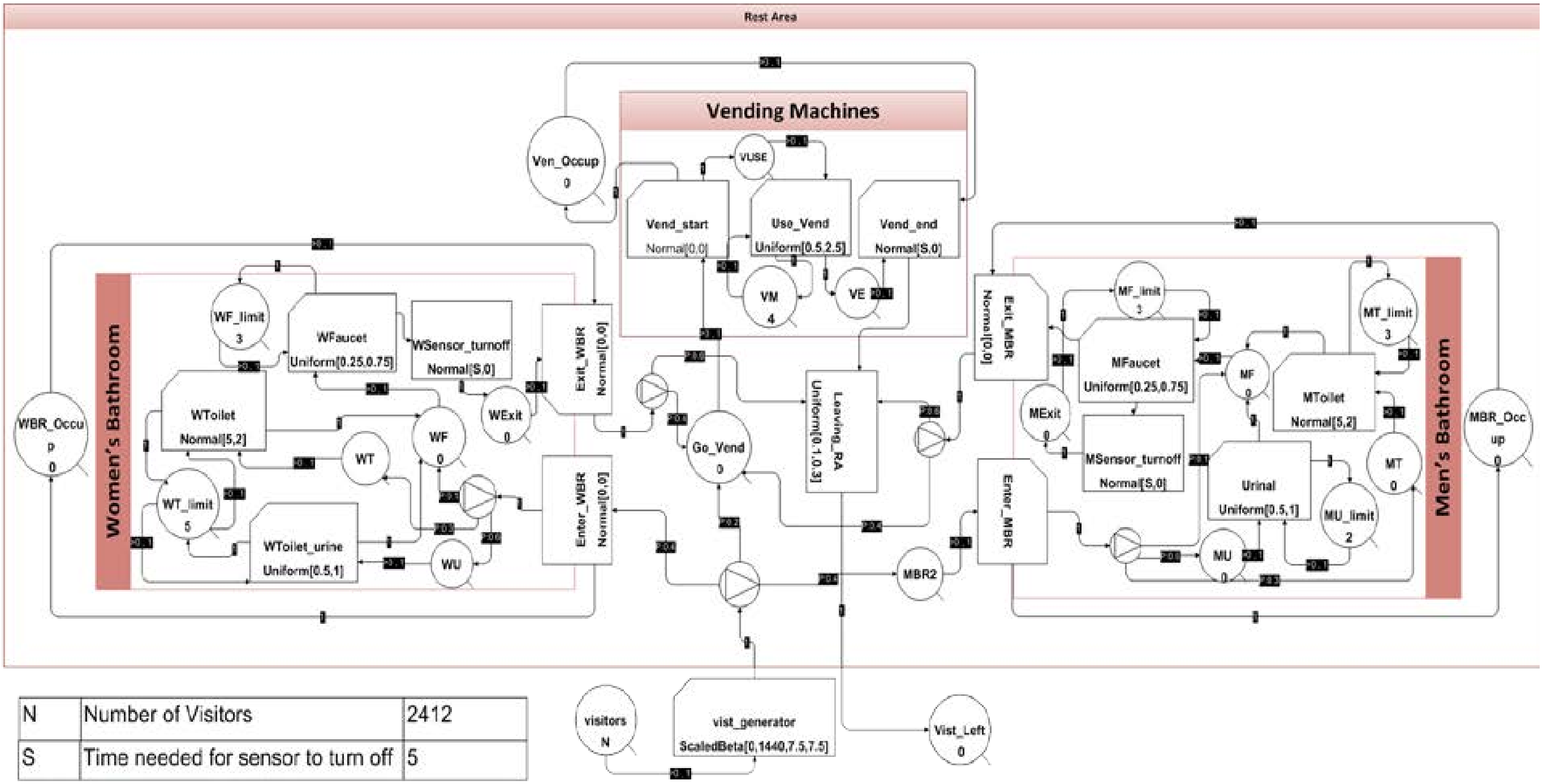
Table 24. Replacing HPS 70W Bulbs with Energy-Efficient LED and Induction Light Bulbs in the Coalfield Rest Area Buildings

Lighting Characteristics, Costs, and Savings	Existing fixtures/bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	Cobra head LED Luminaire	Induction
Number of bulbs	10	10	10
Initial lumens (lumens)	5,200	3,000	2,800
Kelvin temperature (K)	3,000	3,000–5,000	2,700–6,500
Color rendering index (CRI)	75	80	83
Lifetime (hr)	10,000	50,000	10,0000
Consumption per bulb, including ballast (W)	77	40	42
Bulb cost ($)	$33	355	215
Reduction in lumens output levels (%)	N.A.	42	46
Reduction in energy consumption (%)	N.A.	48	36
Annual savings in energy—first year ($/yr)	N.A.	165	156
Payback period (yr)	N.A.	5	2.3

5.1.3 Motion Sensors

Rest areas have a different operational schedule than most business and commercial buildings, and they have to operate 24 hr a day with few or no occupants during low visitation periods at night. This makes motion sensors a promising technology for rest area buildings. This section analyzes the implementation of motion sensors to control the lighting of restrooms and vending machine areas. Motion sensors also can be used to reduce space heating and cooling by reducing the use of exhaust fans at night, when there are few or no occupants in the restrooms.

To estimate the energy savings in lighting and exhaust fans, the research team developed a separate simulation model using EZstrobe simulation language (Martinez 2006) to analyze and simulate the use of the restrooms and vending machines, based on the number and frequency of rest area visitors. The simulation model was developed to mimic the utilization of the rest area facilities by its visitors. The model was created to generate the number of visitors to the rest area using a beta distribution function to represent a high frequency of visitors during the morning, noon, and afternoon hours and a low frequency during the night and early morning hours. The model also assumes that the percentages of visitors that use the men's restroom, women's restroom, and vending machines are 40%, 40%, and 20%, respectively. Similarly, the probabilities that restroom visitors use urinals, toilets and only faucets were assumed to be 30%, 60%, and 10%, respectively, with reasonable random durations for each of these restroom tasks, as shown in Figure 31. It should be noted that the model assumes that each visitor using the toilet or urinal also uses the faucet afterwards. The model developed accounts for an amount of time for sensors to keep the light on after a visitor leaves a restroom. After a visitor leaves the restroom, the model assumes a 60% probability that the visitor leaves the rest area and a 40% probability that the visitor uses the vending machines. The model developed can estimate how long the lighting in the restrooms of the rest area will be turned off if motion-activated lighting were implemented in the restrooms. Similarly, the amount of time that vending machine lights and exhaust fans are turned/switched off can be calculated by the simulation model developed. Figure 32 shows the number of rest area visitors in the men's restroom throughout a simulation day. Table 25 summarizes the percentages of occupancy for the restrooms and vending machines of the Coalfield rest area, assuming that the lights or fans remain turned on for 5 min after the departure of the last visitor. The following subsections use the developed simulation model to estimate potential savings for using motion sensors in the rest area building and their expected payback periods. The economic analysis of the motion sensors accounts for an annual interest rate of 2% and an annual escalation in utility rates of 5% in calculating the payback period of implementing this technology.



N	Number of Visitors	2412
S	Time needed for sensor to turn off	5

Figure 31. Motion-sensor simulation model for the Coalfield rest area buildings.

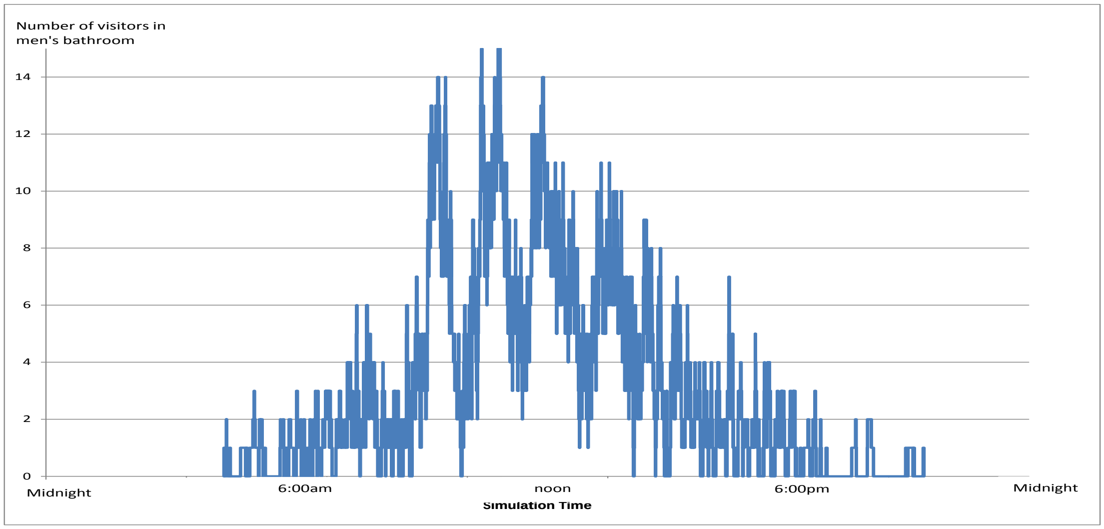


Figure 32. Number of visitors in the men's restroom throughout a simulation day for the Coalfield rest area buildings.

Table 25. Percentage Occupancy for Restrooms and Vending Areas of the Coalfield Rest Area Buildings

Percentage of Occupancy in Men's Restroom	Percentage Occupancy in Women's Restroom	Percentage Average Occupancy in Restrooms	Percentage Occupancy in Vending Machines Area
60.9%	61.2%	61.1%	47.5%

5.1.3.1 Motion-Activated Lighting

Motion-activated lighting can be installed in restrooms to turn off lights automatically when the rooms are not occupied. As discussed in the previous section, restrooms in the Coalfield rest area have an average approximate occupancy of 61.1%, including 5 min for the occupancy sensors to turn off after detecting motion. This figure leads to an average of 38.9% savings in the lighting of restrooms. Table 26 shows the results of the LCC analysis for implementing motion-activated lighting in the restrooms of the Coalfield rest area. The analysis shows that the motion-activated lighting can provide approximate savings of $324, or 1.0% of total energy consumption of the Coalfield rest area buildings, which represents a payback period of 2.7 years for this green building measure. Furthermore, motion-activated lighting in restrooms can eliminate 3,267 lb of CO_2 emissions annually.

Implementing motion-activated lighting in the lobby will not be feasible because of security requirements that the lights to be turned on at all times to ensure the proper operation of the surveillance cameras. Moreover, implementing motion-activated lighting in the maintenance rooms will not provide much savings, and the payback period will be long because the maintenance staff often turns off the light before leaving the mechanical rooms of the rest area.

Table 26. Analysis of Motion-Activated Lighting for the Restrooms of the Coalfield Rest Area Buildings

Savings and Cost Items	Amount/Savings
Total load of lighting fixtures (W)	680
Electricity cost ($/kWh)	0.14
Occupancy sensor cost ($)	288
Labor cost for installation ($)	583
Total Initial cost ($)	871
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	834
Annual lighting energy savings ($)	324
Payback period (yr)	2.7
Amount of eliminated CO_2 (lb)	3,267
Savings in total energy consumption of the building (%)	1.0

5.1.3.2 Vending Occupancy Controls

Similar to motion-activated lighting, occupancy controls can be installed for vending machines to turn off their lighting when the vending area is not occupied. Based on the simulation model developed for motion sensors, the lights of a vending machine are expected to be on for approximately 47.5% of the hours during the day, assuming a duration of 5 min for the sensor to remain on after detecting the last motion in the vending area. This figure leads to a 52.5% lighting savings in the vending machine area. Table 27 shows the economic analysis of installing occupancy controls for the vending machine areas in the Coalfield rest area. The analysis shows that these occupancy controls can provide an approximate annual savings of $386, or 1.2% of the total energy consumption of the Coalfield rest area buildings, which leads to a payback period of 0.9 year. This measure can also eliminate 3,891 lb of CO_2 emissions annually because of the reduction in energy consumption.

Table 27. Analysis of Occupancy Controls for the Vending Machine Areas in the Coalfield Rest Area Buildings

Savings and Cost Items	Amount
Total load of vending machines lighting (W)	600
Electricity cost ($/kWh)	0.14
Occupancy sensor cost ($)	120
Labor cost for installation ($)	219
Total initial cost ($)	339
Lighting operation time (hr)	24
Annual lighting energy cost for vending machines ($)	736
Annual lighting energy savings ($)	386
Payback period (yr)	0.89
Amount of eliminated CO_2 (lb)	3,891
Savings in total energy consumption of the building (%)	1.2

5.1.3.3 Motion Sensors for Exhaust

Similar to motion-activated lighting, exhaust fans can operate only during the times visitors are present. This arrangement will allow exhaust fans to be switched off automatically when there are no visitors, which will decrease the amount of outside air that needs to be heated or cooled. The eQuest software does not provide a direct method to account for the use of exhaust fan sensors; however, this feature can be modeled by decreasing the exhaust rate by a value that reflects the switching off of exhaust fans when there are no occupants. Accordingly, exhaust fan flow can be decreased with the average non-occupancy percentage of restrooms (38.9%). Table 28 summarizes the economic analysis results for implementing motion sensors for exhaust fans in the rest area building. The analysis shows that motion sensors for exhaust fans can provide approximate annual savings of $966, or 2.9% of total energy consumption of the Coalfield rest area buildings, which leads to a payback period of 0.6 year. This measure can also eliminate 9,729 lb of CO_2 emissions annually because of reduction in energy consumption of heating and cooling.

Table 28. Results of an LCC Analysis for Implementing Exhaust Fan Motion Sensors in the Coalfield Rest Area Buildings

Savings and Cost Items	**Amount/Savings**
Electricity cost ($/kWh)	0.14
Fan(s) and sensors cost ($)	433
Labor cost for installation ($)	109
Total initial cost ($)	542
Annual energy savings ($)	966
Payback period (yr)	0.57
Amount of eliminated CO_2 (lb)	9,729
Savings in total energy consumption of the building (%)	2.9

5.1.4 More-Efficient HVAC Systems

The current HVAC system in the Coalfield rest area consists of two split-air conditioner systems with electric resistance duct heaters. The system has a cooling capacity of about 7.5 tons, and the heating system has a capacity of 35kW. The current HVAC system can be replaced with a more energy-efficient system that reduces the consumption of heating and cooling energy. The following three subsections analyze the replacement of the current HVAC system with more-efficient units and setting back the temperature at night.

5.1.4.1 Geothermal Heat Pump

The existing HVAC system in the Coalfield rest area buildings operates continuously year round, and its consumption represents 36% of the building total. Ground-source heat pumps can be more efficient than air-source heat pumps because they use the nearly constant temperature of the earth (55°F) to heat and cool buildings. The eQuest simulation environment can be used to model the use of a geothermal HVAC system for the Coalfield rest area buildings. The system was modeled to have a heating coefficient performance (COP) of 4.0 and a cooling efficiency of 18 EER. This system was also modeled to operate in an economizer mode, which brings fresh air when the outside air temperature is sufficient to condition the space. After running the eQuest model with a geothermal heat pump, the model provides savings of 23% of total energy consumption.

The geothermal heat pump costs approximately $2,500 per ton of capacity (California Energy Commission 2008). The geothermal loop varies in cost according to the loop system and the type of soil. The horizontal loop system has a lower initial cost; however, it needs a large area to place the pipes, and the surface landscape needs to be restored after construction. By contrast, the vertical loop system has a higher initial cost; and it needs very limited outdoors area to be placed. The horizontal loop system cost ranges from $800 to $1,500 per ton of capacity, with an average cost of $1,150 per ton of capacity. The vertical loop system cost ranges from $1,200 to $2,000 per ton of capacity, with an average cost of $1,600 per ton of capacity (Geothermal Design Associates 2012; Kozlowski 2007). It should be noted that the construction of the horizontal/vertical loop system varies significantly with the soil type. The geothermal loop has a very long lifetime, and the piping materials usually have a long warranty period of up to 55 years. With high-quality products and proper installation, the geothermal loop has a life expectancy of over 100 years. The loop length varies based on the loop system used in construction, where the horizontal system needs 100 to 150 ft of trench per ton of heat exchange, with an average of 125 ft of trench per ton, and the trench width is specified to be 2 ft to account for four longitudinal pipes. The vertical system needs 130 to 300 ft of depth per ton of heat exchange with an average of 215 ft of depth per ton; and each well includes two pipes connecting at the bottom to form a U shape (Ground Loop 2013 Geothermal Design Associates 2012). The analysis conducted accounted only for a vertical system because its installation requires limited space; and accordingly, it does not require surface restoration in the rest area site.

The maintenance cost of geothermal systems can be estimated as annual expenses per square footage of the building. Based on a study conducted by Bloomquist in 2001, the annual average maintenance cost of geothermal HVAC systems is $0.13/ft^2/yr (Bloomquist 2001). The operating cost can be estimated to account for the potential savings that were calculated from the eQuest energy simulation model. The geothermal heat pump will need to be replaced after 20 years, with the same installation cost of $2,500 per ton of capacity. Table 29 summarizes the LCC components of replacing the current HVAC system with a geothermal heat pump.

Table 29. LCC Components for Replacing the Current HVAC System with a Geothermal Heat Pump in the Coalfield Rest Area Buildings

LCC Components	**Cost**
Capital cost—horizontal system*($)	31,570
Annual maintenance cost ($)	318
Annual operating cost ($)	4,365
Periodic cost ($)	19,570
Life (yr)	20

* Installation cost may vary as a result of soil conditions and resizing of the HVAC equipment

To compare the cost effectiveness and payback periods of replacing the current HVAC systems in rest areas with geothermal systems, the initial, maintenance, operating and replacement costs of the current HVAC systems need to be identified. The initial cost to replace the current heating and cooling equipment in rest areas can be estimated using the 2012 RSMeans Building Construction Cost Data. This analysis assumed air-source heat pumps as reasonable replacements of the current systems in rest areas. The air-source heat pumps and the current capacity of the units in the rest areas were used to calculate the cost. The maintenance cost can be calculated based on the aforementioned study conducted to compare the maintenance cost of different HVAC systems. Air-source heat pumps have an average annual maintenance cost of 0.28 $/ft^2/yr (Bloomquist 2001). The life of conventional HVAC systems ranges from 15 to 20 years. In this cost analysis, air-source heat pumps are assumed to have a useful life of 17 years. Table 30 summarizes the LCC components for the current HVAC system for the Coalfield rest area buildings.

Table 30. LCC Components for the Current HVAC System in the Coalfield Rest Area Buildings

LCC Components	Cost
Capital cost ($)	13,020
Annual maintenance cost ($)	684
Annual operating cost ($)	10,388
Periodic cost ($)	13,020
Life (yr)	17
Manufacture year	2008
Replacement year	2025

An LCC analysis was conducted to compare the potential replacement of the current HVAC system with a geothermal heat pump, based on an annual interest rate of 2%, escalation in utility rate of 5%, and annual increase of maintenance cost of 2%. Table 31 summarizes the LCC analysis results for replacing the current HVAC with a geothermal heat pump. The analysis shows that replacing the current HVAC system with a vertical loop geothermal heat pump has a payback period of 3.8 years. The cumulative costs for the current HVAC system, a vertical loop geothermal system, and savings are shown in Figure 33. The geothermal heat pump can also be installed along with a desuperheater to heat water in the cooling season. The desuperheater uses heat that is removed from the building space to heat domestic hot water. This unit can provide free hot water in the summer or when the system is in cooling mode. It can provide an annual savings of $530, or 1.6% of the total energy consumption. The payback period of the desuperheater is 3 years, and it can eliminate 5,340 lb of CO_2 emissions.

Table 31. Results of the LCC Analysis for Replacing the Current HVAC System with a Geothermal Heat Pump in the Coalfield Rest Area Buildings

Savings	Amount
Annual savings (kWh)	55,090
Annual energy savings—first year ($)	7,713
Annual eliminated CO_2 emissions (lb)	77,677
Payback period—vertical system (yr)	3.8

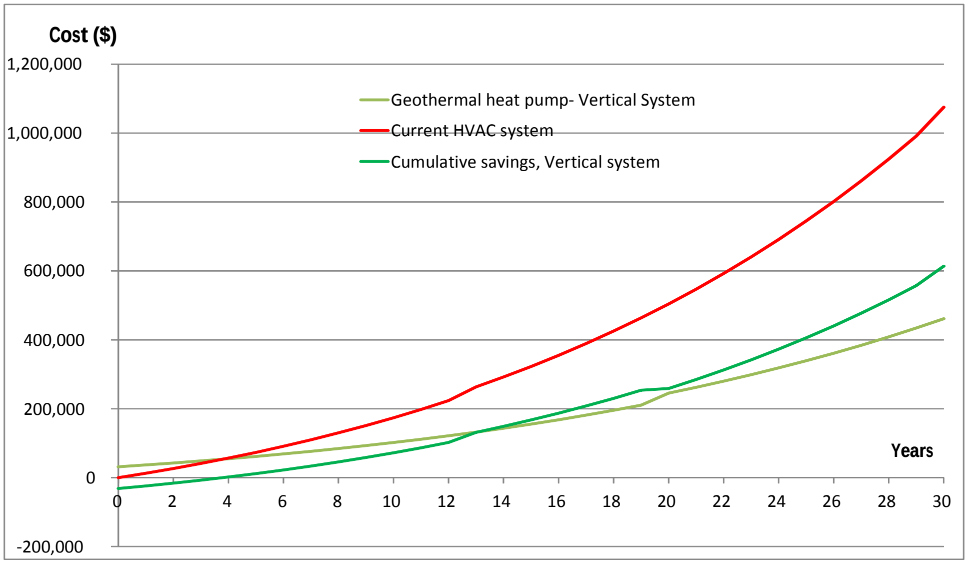


Figure 33. Cumulative costs of a horizontal loop geothermal system, a vertical loop geothermal system, the current HVAC system, and savings for the Coalfield rest area buildings.

5.1.4.2 High-Efficiency Air-Source Heat Pump

Another alternative for the current HVAC system in the Coalfield rest area is for it to be replaced with a more-efficient Energy Star–rated air-source heat pump to reduce heating and cooling expenses. An air-source heat pump was modeled in eQuest to meet Energy Star recommendations, with a cooling efficiency of 12 EER and a heating performance rating of 8.2 HSPR (Energy Star 2003). Table 32 summarizes the results of the LCC for replacing the current HVAC system with an Energy Star–rated air-source heat pump. The analysis shows that a more energy-efficient and Energy Star–rated HVAC system can provide annual savings of $3,778, or 11.3% of the total energy consumption of the rest area building. This model leads to a payback period of 3.6 years, based on an annual interest rate of 2% and an escalation in the utility rate of 5%. This replacement can eliminate CO_2 emissions of 38,056 lb annually.

Table 32. Results of the Analysis for Replacing the Current HVAC System with an Energy-Efficient Air-Source Heat Pump in the Coalfield Rest Area Buildings

Savings and Cost Items	**Amount/Savings**
Electricity cost ($/kWh)	0.14
Total initial cost for air-source heat pump ($)	13,800
Annual energy savings ($)	3,778.60
Payback period (yr)	3.58
Amount of eliminated CO_2 (lb)	38,056
Savings in total energy consumption of the building (%)	11.3

5.1.4.3 Setting Back the HVAC System at Night

Another method to reduce energy consumption for space heating and cooling of the rest area is to set back the temperature of the HVAC system at night. The number of visitors using the rest area at night is very limited; and accordingly, setting back the temperature at night can reduce the energy consumption of heating and cooling. The temperature can be set at night to 68°F in the winter and 76°F in the summer. This measure can be modeled in eQuest by editing the temperature set points in the simulation model to a temperature that reflects the set points at night using interpolation. The eQuest model developed showed that setting back the temperature at night can provide annual savings of $140, or 0.4% reduction in total energy consumption. The Coalfield rest area buildings have programmable thermostats, which make this measure easy to be implemented in the rest area facility without any additional costs.

5.1.5 Double-Pane Glass for Windows and Doors

Double-pane glass is a green building measure that can be added to the rest area building to reduce space cooling and heating energy consumption. This measure requires replacing all glazing, as well as doors, in the rest area building with double-pane glass. This measure can be modeled in eQuest by replacing current single-glass glazing and doors with double-pane glass. The analysis of implementing this measure provided annual savings of $1,106, or 3.3% of total energy consumption, as shown in Table 33. The payback period for this measure is more than 30 years because it requires a major renovation for the rest area building, with high initial cost. This measure can eliminate 11,139 lb of CO_2 annually.

Table 33. Results of an LCC Analysis for Replacing the Current Glazing and Doors with Double-Pane Glass

Savings and Cost Items	Amount/Savings
Electricity cost ($/kWh)	0.14
Total initial cost for adding another door ($)	51,571
Annual energy savings (kWh)	7900
Annual energy savings ($)	1,106
Payback period (yr)	More than 30
Amount of eliminated CO_2 (lb)	11,139
Savings in total energy consumption of building (%)	3.3

5.1.6 Vestibule Entrance

Another measure to reduce energy consumption in the Coalfield rest area buildings is to add a vestibule entrance to reduce air infiltration and provide better insulation in the lobby area. This measure can be modeled in eQuest by reducing air infiltration approximately from 2.0 to 1.6 air changes per hour (ACH) (i.e., a 20% reduction). Figure 34 shows the addition of a second door for the Coalfield rest area entrance to create a vestibule. Table 34 summarizes the results of the LCC analysis for adding a second door in the rest area entrance. This measure can provide annual savings of $623, or 1.9% of the total energy consumption of the rest area building. The analysis shows that this measure can pay back its installation cost in 5.2 years, based on an annual interest rate of 2% and an escalation in utility rate of 5%. This door replacement can eliminate 6,275 lb of CO_2 emissions annually by reducing energy consumption.

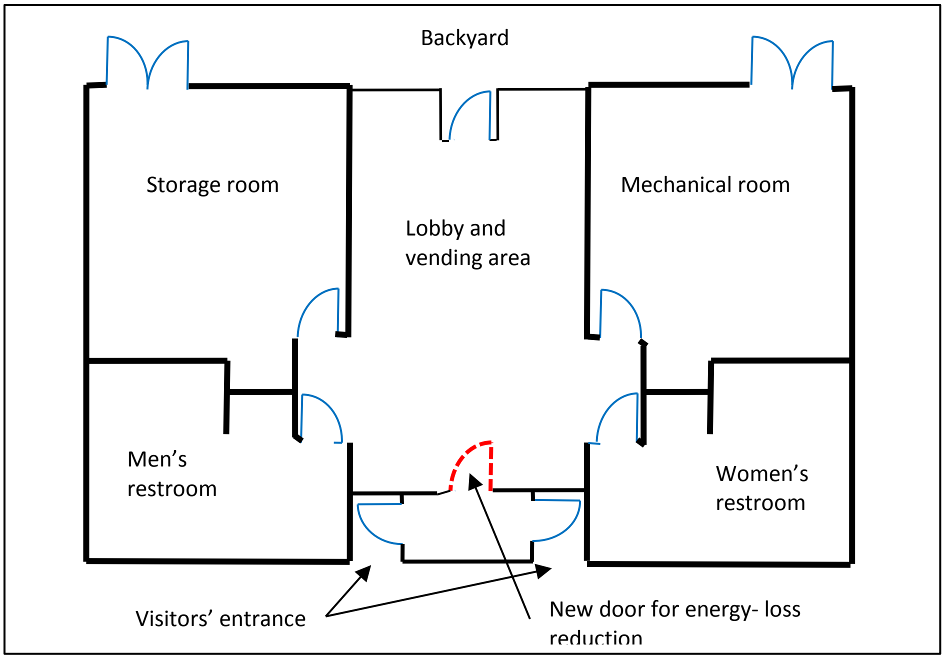


Figure 34. Layout for adding a second door in
the Coalfield rest area to create a vestibule entrance.

Table 34. Results of an LCC Analysis for Adding a Vestibule
Entrance in the Coalfield Rest Area Buildings

Savings And Cost Items	Amount/Savings
Electricity cost ($/kWh)	0.14
Total initial cost for adding vestibule entrance ($)	3,404
Annual energy savings (kWh)	4450
Annual energy savings ($)	623
Payback period (yr)	5.23
Amount of eliminated CO_2 (Ib)	6,275
Savings in total energy consumption of the building (%)	1.9

5.1.7 Energy-Efficient Hand Dryers

Energy-efficient hand dryers are one of the green building measures that can be implemented in the Coalfield rest area buildings to reduce their energy consumption. The energy consumption of hand dryers was estimated based on a 50% use by rest area visitors each for 30 seconds, according to manufacturer's use recommendations. Although the current hand dryers account for only approximately 3% of the total energy consumption, they are one of the most visible devices to the rest area visitors. Moreover, slow velocity or inefficient hand dryers may discourage people from using them. This analysis considers the impact of installing three different models of energy-efficient hand dryers in the Coalfield rest area buildings to reduce their energy consumption, as shown in Table 35. The analysis shows that replacing the current hand dryers may result in annual savings of $873 to $955, or 2.6% to 2.9% of the total energy consumption in the rest area building, based on three different models of energy-efficient hand dryers. These savings can provide a payback period of 1.2 to 6.9 years for the three different models, based on an annual interest rate of 2% and an escalation in the utility rate of 5%. This measure can eliminate up to 9,620 lb of CO_2 of the Coalfield rest area buildings.

Table 35. Results of an LCC Analysis for Replacing the Current Hand Dryers with Energy-Efficient Units in the Coalfield Rest Area Buildings

LCC Items/Savings	Current Hand Dryer, World Dryer	1- World Dryer Airforce, J Series Hand Dryers	2- Xlerator Series Hand Dryers	3- Dyson Airblade Series Hand Dryers
Number of hand dryers	4			
Hand dryer consumption (W)	2,300	1,100	1,100	1,500
Drying time (s)	30	12	15	12
Initial cost ($)	N.A.	1,092*	1,600*	6,400*
Annual visitors—2009	880,380			
Savings over current hand dryers (%)	N.A.	81	76	74
Utility cost ($/kWh)	0.14			
Annual operating cost, based on 50% use by visitors ($)	1,181	226	282	308
Annual savings ($)	N.A.	955	899	873
Annual operating cost, based on 50% use by visitors (%)	N.A.	2.9	2.7	2.6
Eliminated CO_2 emissions (lb)	N.A.	9,620	9,051	8,793
Payback period (yr)	N.A.	1.2	1.8	6.9

* Restroom Direct 2013

5.1.8 Solar Measures

Several solar measures can be used to reduce energy consumption in the rest area buildings. These measures include solar daylight tubes, photovoltaic systems, and solar water heaters. These measures can reduce the energy consumption for internal lighting and heating water, as well as generating renewable and clean electricity. The next subsections discuss the installation of these systems in the Coalfield rest area buildings.

5.1.8.1 Solar Tube Lighting

Solar daylight tubes are one of the green building measures that can provide light for the building during daylight hours. The technology requires solar tubes to penetrate the building roof to the ceiling, where they transmit sunlight during the daytime. These lights can be installed in the restrooms and the lobby to decrease lighting use during daylight hours. They can be installed in the attic of the rest area building, along with controls that dim interior lighting during the day. The energy savings were calculated based on reducing daily lighting use by 5 hr. The analysis for solar daylight tubes is summarized in Table 36. Cumulative costs and savings for implementing solar daylight tubes in the restrooms and the lobby of the rest area are shown in Figures 35 and 36. The analysis shows that this measure can provide savings of $382 annually, or 1.14% of the total energy consumption, with a payback period of 24.92 years for restrooms and 18.25 years for the lobby. Correct installation of these lights is crucial in terms of the amount of savings they can provide. Incorrect installation of solar daylight tubes or installation of solar daylight tubes with low insulation (low U value) can lead to a high dissipation of energy and increase the cooling and heating costs. By contrast, proper installation and use of sufficient U-value, Energy Star–rated solar daylight tubes could bring only slightly increased heating and cooling costs. The results from modeling solar tubes in eQuest with similar skylight areas showed an increase in energy cost $105 annually. Consequently, the expected savings achieved by this measure could be reduced to $277 annually.

Table 36. Results of an LCC Analysis for Installing Solar Daylight Tubes in the Restrooms and Lobby of the Coalfield Rest Area Buildings

Savings and Cost Items	**Restrooms**	**Lobby**
Total load of lighting fixtures (W)	680	816
Electricity cost ($/kWh)	0.14	
Number of solar daylight tubes (10” diameter)	5	0
Number of solar daylight tubes (18″ diameter)	2	4
Total Initial cost ($)	4,165	3,300
Solar tubes’ operation time (hr)	5	5
Annual lighting energy cost ($)	834	1,001
Annual lighting energy savings ($)	174	208
Payback period (yr)	24.92	18.25
Amount of eliminated CO_2 (lb)	1,750	2,100
Savings in total energy consumption of the building (%)	0.52	0.62

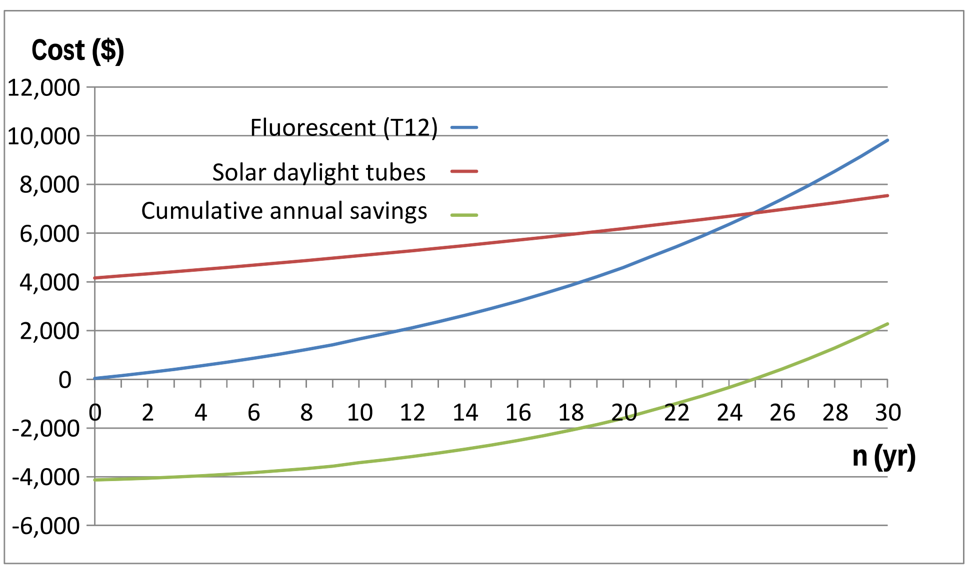


Figure 35. Cumulative costs and savings for implementing solar daylight tubes in the restrooms of the Coalfield rest area buildings.

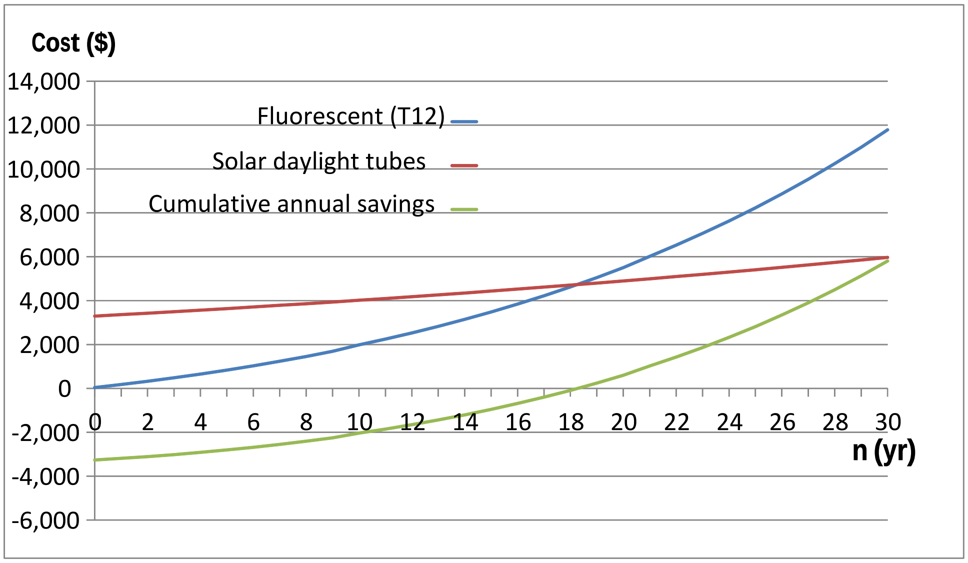


Figure 36. Cumulative costs and savings for implementing solar daylight tubes in the lobby of the Coalfield rest area buildings.

5.1.8.2 Grid-Connected Photovoltaic Systems

Photovoltaic systems are one of the renewable energy measures that can generate electricity for the Coalfield rest area buildings. Performing an LCC for the use of photovoltaic systems in the rest area requires the system design take into consideration the number and type of system parts. Several factors affect the design of grid-connected systems, including average daily peak sun hours, capacity of solar panels, capacity of inverters, and mounting of solar panels. The average daily peak sun hours for the rest areas is considered 4.4 hr/day, based on the annual average daily peak sun hours data in United States compiled by the Department of Energy (U.S. DOE 1997).

The design of the grid-connected system was carried out to provide a reduction in total annual energy consumption of 5%. The number of solar panels is determined based on the amount of power needed to be generated per day. The required number of solar panels in the photovoltaic system is determined based on the average daily consumption of electricity, the average daily sun hours in Illinois, and the solar panel capacity. The capacity of the required inverter is determined based on 110% of the total capacity of the solar panels to allow for safe and efficient operation (Texas State Energy Conservation Office 2006). The initial cost of the system can be calculated by summing up all equipment and labor costs required to install the system. An additional 20% of the hardware costs was added to account for wiring, switches, fuses, connectors, meters, and other miscellaneous parts. The labor cost is calculated using a rate of $1.75/W (Texas State Energy Conservation Office 2006; Affordable Solar 2013). The maintenance cost is considered 0.5% of the total hardware costs. The replacement cost is calculated using the required parts and labor installation cost.

Table 37 summarizes the cost components for installing a grid-connected photovoltaic system in the Coalfield rest area buildings. The LCC analysis was conducted to determine annual savings, payback period, amount of eliminated CO_2 emissions, and required area of the system, while accounting for an annual interest rate of 2%, an escalation in utility rate of 5%, and an annual increase of maintenance cost of 2%, as shown in Table 38. The analysis shows that incorporating a grid-connected photovoltaic system in the Coalfield rest area has a payback period of 18.1 years. The system requires 33 solar panels to be installed; 10 can be mounted on the south part of the roof and 23 on the ground near the rest area building. The required area for solar panels on the ground is 270 ft^2. These calculations accounted for a 51° tilt angle for the solar panels and prevention of any shading that might occur as a result of the layout of the solar panels in winter and summer. Figure 37 shows the cumulative savings of installing a grid-connected system in the rest area building.

Table 37. Cost Components for Installing a Grid-Connected Photovoltaic System in the Coalfield Rest Area Buildings

Cost Components	**Amount/Savings**
Total number of solar panels	33
Number of inverters	1
System capacity (kW)	7.8
Utility cost ($/kWh)	0.140
Initial cost ($)	33,466
Annual maintenance cost ($)	101
Solar panels periodic cost ($)	11,453
Inverter periodic cost ($)	4,110
Annual savings ($)	1,675
Annual savings (kWh)	11,967
Cost per watt ($/W)	4.44

Table 38. Results of an LCC Analysis for Incorporating a Grid-Connected Photovoltaic System in the Coalfield Rest Area Buildings

LCC Items/Savings	**Amount/Savings**
Annual CO_2 emissions eliminated (lb)	16,873
Number of solar panels on roof	10
Number of solar panels on the ground	23
Required area for solar panels (SF)	270
Tilt angle of solar panels (degree)	51
Payback period (yr)	18.1

The stand-alone photovoltaic system was not considered in this analysis because the payback period identified in the first phase of this project was determined to be infeasible because of the high initial and periodic costs of battery systems.

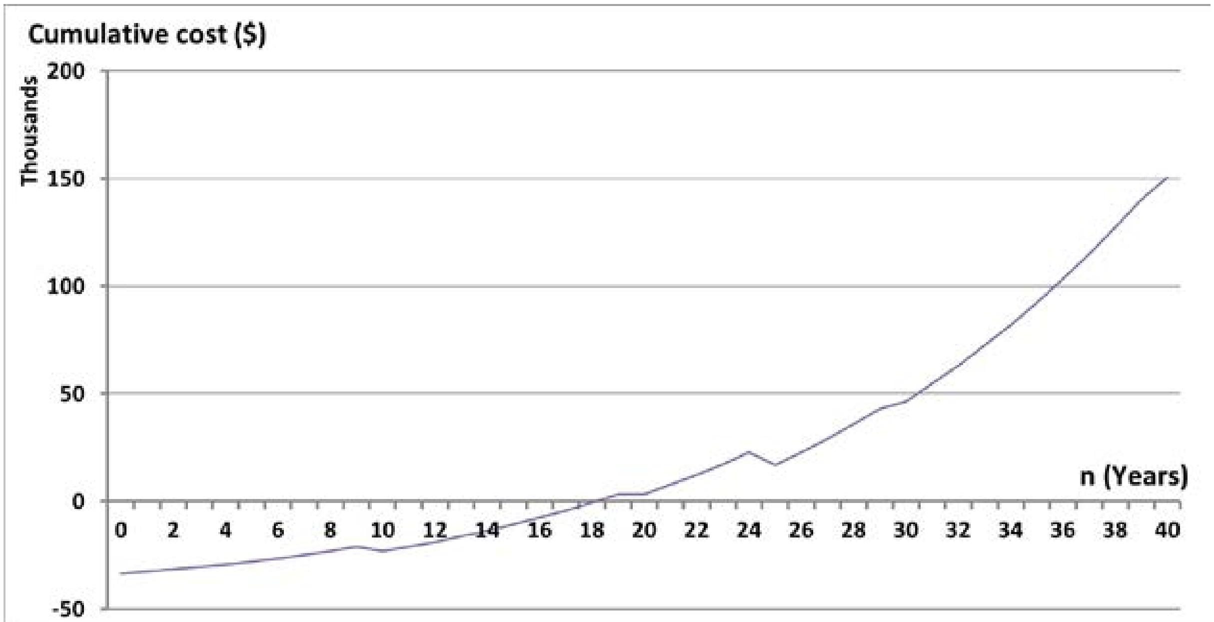


Figure 37. Cumulative cost of incorporating a grid-connected system in the Coalfield rest area building.

5.1.8.3 Solar Water-Heating Systems

Solar water heating is another technology that can reduce energy consumption in the rest area buildings. This technology can be installed with the current water heaters in the rest area to mitigate the cost of replacing the current water heaters and to serve as a backup when sunlight is unavailable or insufficient to heat water to the desired temperature. The components of this system include solar collector(s) and mountings, heat exchanger, circulator, antifreeze (glycol), water storage tank(s), controller, fittings, pipes, and insulation. The initial capital cost of the system was calculated for Coalfield rest area buildings, using the RSMeans Building Construction Cost Data (RSMeans Building Construction Cost Data 2012). The annual maintenance cost is assumed to be 1% of the initial cost, with an annual increase of 2%. The replacement cost of this system depends on its parts and expected useful life. The water tank and heat exchanger usually have a useful life that ranges from 12 to 20 years and is assumed to be 16 years in this analysis. System circulators usually have a useful life of more than 5 years and are assumed to have a life of 5 years in this analysis (Radiantec, no date). Table 39 summarizes the LCC components for incorporating solar water heaters in the Coalfield rest area buildings. An LCC analysis was conducted based on an annual interest rate of 2%, an escalation in the utility rate by 5%, and 2% annual increase in maintenance costs, as shown in Table 40. The analysis shows that installing solar water heaters in the Coalfield rest area buildings has a payback period that ranges from 3.6 to 12.6 years based on 70% and 20% energy savings in heating water, and it can reduce CO_2 emissions by 4,830 to 16,905 lb annually.

Solar collector(s) can be installed on the roof with clamps/straps or on the ground using a rack to hold the collector(s). Installing solar collectors on the roof might not be feasible, however, because the building roof of the rest area was not designed to carry an extra load such as this. Consequently, solar collectors should be mounted on the ground.

Table 39. LCC Components for Installing a Solar Water Heater in the Coalfield Rest Area Buildings

LCC Components	Amount/Savings
Capital cost (ground mount) ($)	5,960
Annual maintenance cost (ground rack)	60
Utility cost ($/kWh)	0.14
Conventional water-heater consumption (kWh)	16,800
Annual operating cost for conventional water heater ($)	2,352
Annual savings (20% to 70% savings) ($)	483 to 1,691
Periodic cost for pump after 5 yr ($)	250
Periodic cost for water tank after 16 yr ($)	1,600
Circulating pump life (yr)	5
Tank life (yr)	16

Table 40. Results of an LCC Analysis for Installing a Solar Water Heater in the Coalfield Rest Area Buildings

Savings	Amount/Savings
Annual kWh saved (20% savings) (kWh)	3,450
Annual kWh saved (70% savings) (kWh)	12,075
Annual CO_2 emissions eliminated, 20% savings (lb)	4,830
Annual CO_2 emissions eliminated, 70% savings (lb)	16,905
Payback period, 20% savings (yr)	12.64
Payback period, 70% savings (yr)	3.58

5.1.9 Water-Saving Plumbing Fixtures

Rest areas have a high rate of water consumption because of the large number of visitors that use their restrooms. Using water-conserving fixtures in these rest areas will provide significant savings in water consumption. A number of feasible water-saving technologies can be used to minimize water consumption in the rest areas, including efficient faucets, aerators, toilets, and urinals. Currently, the Coalfield rest area buildings have low-flow faucets, which make them suitable for conserving water use in the facility. The flushing rates for urinals and toilets were difficult to be determined during the site visit; however, the research team made reasonable assumptions to estimate flushing rates based on other rates reported in other rest area buildings. An LCC analysis was conducted to estimate the feasibility of installing the conserving fixtures in the rest area buildings. Table 41 summarizes the LCC analysis of replacing current plumbing fixtures with water-conserving ones. As it was difficult to calculate precisely the number of visitors using urinals or toilets, the analysis assumes that 24% of the visitors use the urinals and 48% of the visitors use the men's and women's toilets. The replacement of the current plumbing fixtures can provide savings of 87.5% of the water consumption by urinals and 46.7% of the water consumption by toilets. This change could result in a total water savings of 970,619 gal annually. Furthermore, this reduction in water consumption can provide energy savings because of decreased use of the pump station. This reduction in energy use can be estimated as $278 annually, or 0.83% savings of total energy consumption. The payback period for replacing the current urinals and toilets with water-conserving fixtures is 1.7 and 1.5 years, respectively.

Table 41. LCC Analysis for Replacing the Current Urinals and Toilets with Water-Conserving Fixtures in the Coalfield Rest Area Buildings

Saving / cost items	Urinals	Toilets
Current fixture rate (gallons per flush, gpf)	1.0*	3.0*
Number of fixtures	3	8
Type	Wall mount	Wall mount
Water-conserving rate (gpf)	0.125	1.6
Initial replacement cost ($)	1,985**	5,640**
Savings per flush (gal)	0.875	1.4
Percentage savings (%)	87.5	46.7
Annual visitors 2009	880,380	
Annual savings for 24% visitors using urinals and 48% using toilets (gal)	140,431	449,380
Annual water savings ($)	1,212	3,879
Payback period (yr)	1.7	1.5

* Assumed rate, data was not available during the site visit.

** (RSMeans 2012; Lowe's 2012)

5.1.10 Summary of All Promising Green Building Measures

This section summarizes all green building measures that can be used in the Coalfield rest area buildings to reduce its energy consumption. All promising green building measures were added in the eQuest model to analyze the impact of their collective use and potential interactions on the overall energy consumption of the building. Table 42 summarizes all LCC components, savings, and payback periods for all promising green building measures that were analyzed in the previous sections. The eQuest simulation model and energy analysis shows that the Coalfield rest area buildings can achieve a total of 43.5% reduction in energy costs by implementing the following energy-efficient measures: fluorescent T8 bulbs, induction lighting fixtures for exterior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, a geothermal heat pump along with desuperheater, vestibule entrance, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 7.8KW capacity, setting back HVAC at night, and water-conserving fixtures.

Table 42. All Promising Green Building Measures in the Coalfield Rest Area Buildings

Green Building Measure	Estimated Initial Cost	Maintenance Cost, If Applicable	Annual Energy/ Water Savings	Annual CO_2 Emissions Eliminated (lb)	Reduction In Energy Consumption	Payback Period (yr)
Interior lighting—Fluorescent T8	$771	N.A.	$464	4,669	1.4%	0.8
Exterior lighting—induction lighting	$17,198	N.A.	$2,565	25,834	7.7%	4.1
Motion-activated lighting	$871	N.A.	$324	3,267	1.0%	2.7
Vending occupancy controls	$339	N.A.	$386	3,891	1.2%	0.9
Motion-sensor exhaust fans	$542	N.A.	$966	9,729	2.9%	0.6
Geothermal heat pump	$31,570	$318	$7,713	77,677	23.0%	3.8
Desuperheater	$1,600	N.A.	$530	5,340	1.6%	3.0
Vestibule entrance	$3,404	N.A.	$623	6,275	1.9%	5.2
Energy-efficient hand dryers	$1,092	N.A.	$955	9,620	2.9%	1.2
Photovoltaic system	$33,466	$101	$1,675	16,873	5.0%	18.1
Solar daylight tubes	$7,465	N.A.	$254	2,557	0.8%	21.6
Setting back the HVAC at night	$0	N.A.	$140	1,410	0.4%	Immediate
Water-conserving fixtures	$7,625	N.A.	$5,091	N.A.	N.A.	N.A.
All promising green building measures together (eQuest model)	$106,243	$419	$19,311	194,696	43.5%	6.8

CHAPTER 6 DECISION SUPPORT TOOL DEVELOPED FOR OPTIMIZING UPGRADE DECISIONS OF ILLINOIS PUBLIC BUILDINGS

6.1 DECISION SUPPORT TOOL DESIGN AND CAPABILITIES

The decision support tool (DST) developed for this project was designed to optimize the upgrade decisions for IDOT rest areas and other buildings according to their conditions and potential for improvements. The two main objectives of the optimization tool were to minimize the total required upgrade costs and to maximize the sustainability of the interstate rest areas and other IDOT buildings. Accordingly, the DST was designed to identify a set of upgrade decisions that achieves an optimal tradeoff between sustainability (represented by the number of LEED points earned) and the required upgrade cost, as shown in Figure 38.

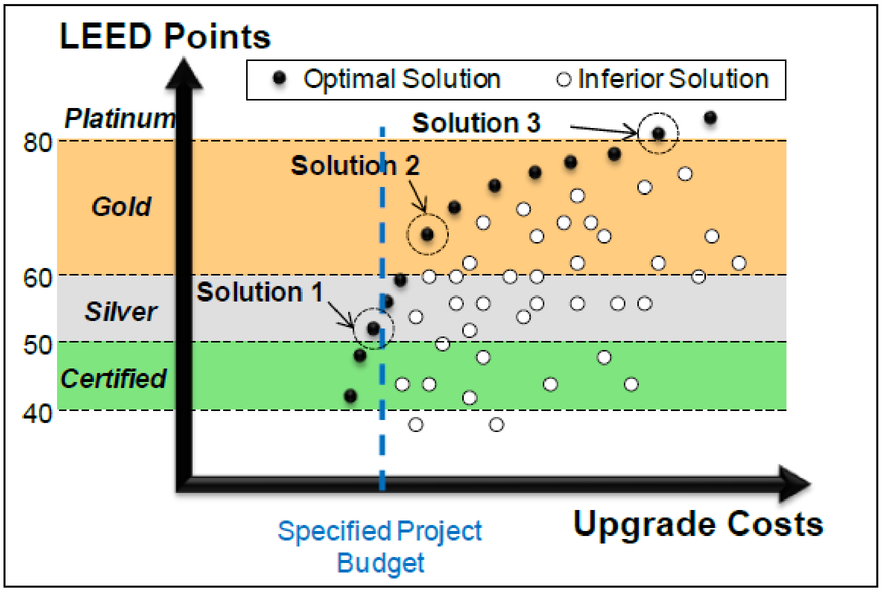


Figure 38. Optimal upgrade decisions for rest area buildings.

In this phase of the project, the DST was upgraded to (1) facilitate its use by IDOT decision makers by integrating the analysis of green-friendly measures into the tool developed; (2) improve the practicality of the DST by minimizing the amount of input data required by incorporating databases that contain updated data on the latest green products and technologies on the market; (3) facilitate its input and output data by incorporating user-friendly graphical user interfaces (GUIs) to maximize the tool's use and adoption by IDOT decision makers; and (4) study and implement various optimization techniques to improve the efficiency and effectiveness of the optimization process and to enable development of additional capabilities and features.

The following section describes in detail how the DST was upgraded to account for new capabilities and features. The new methodologies for optimizing LEED upgrade decisions are then described in the subsequent section of this chapter.

6.2 DECISION SUPPORT TOOL UPGRADE

The DST developed was upgraded to optimize the selection of (1) building measures, including interior and exterior lighting, hand dryers, vending machines, grid-connected photovoltaic systems, other devices (e.g., PCs and surveillance cameras), HVAC systems, water heaters, and water fixtures; and (2) energy- and water-metering systems, including electricity, gas, and water sub-meters and whole-building meters. To implement all these building measures and metering systems, the DST developed is required to gather more building data to model buildings and monitor their performance accordingly. The implementation of these measures and metering systems in the DST developed is presented in Appendix E, along with the system design, databases, and graphical user interfaces (GUIs) that were implemented to improve the practicality of the tool developed and facilitate its use by IDOT decisions makers.

6.3 OPTIMIZING UPGRADE DECISIONS OF THE LEED RATING SYSTEM FOR EXISTING BUILDINGS

The DST is designed to identify optimal sets of upgrade decisions to qualify each of the analyzed IDOT buildings for LEED certification by earning the required number of LEED points while minimizing the required upgrade costs. The LEED rating system for existing buildings provides four certification levels: (a) certified level, which requires 40–49 points; (b) silver level, 50–59 points; (c) gold level, 60–79 points; and (d) platinum level, 80 points or more. Each of these levels requires a minimum number of LEED points, which can be earned by satisfying a set of requirements under seven credit areas for existing buildings: (1) sustainable sites; (2) water efficiency; (3) energy and atmosphere; (4) materials and resources; (5) indoor environmental quality; (6) innovation in operations; and (7) regional priority. Each of these credit levels can have prerequisites as well as credits that can potentially provide LEED points if certain measures are added to the building. As a result, there is a significantly large number of alternative upgrade measures, which need to be evaluated for each of the buildings analyzed; therefore, it is impractical to conduct all the evaluations to identify an optimal list of upgrade measures. To address this challenge, the DST developed uses a robust optimization technique that is capable searching and identifying an optimal set of upgrade measures for each of the buildings analyzed (U.S. GBC 2012).

The DST uses a genetic algorithm (GA) to optimize LEED upgrade decisions for public buildings because of its capabilities to optimize problems that include nonlinear and step changes among their inputs and outputs. The GA can provide better modeling for some LEED credits, such as performance of indoor water consumption, performance of outdoor water consumption, performance of building energy consumption, and on-site and off-site renewable energy. By contrast, the GA can be time-consuming when used to optimize large problems. The GA optimization model developed is integrated in an MS Excel spreadsheet because of Excel's widespread use and practicality. The spreadsheet integrates an add-in, named EVOLVER, to perform GA computations in an Excel spreadsheet. This commercially available add-in can be purchased through Palisade Corporation (Palisade 2012). The following two optimization models were developed in the DST to optimize upgrade decisions for existing IDOT buildings to (1) minimize the total upgrade cost to accomplish a desired level of Leadership in Energy and Environmental Design for existing buildings (LEED-EB certification); and (2) maximize the number of accredited LEED-EB points for a specified budget.

6.3.1 Optimization Model 1: Minimize Upgrade Cost To Achieve a Specified LEED Certification Level

The first optimization model minimizes the total upgrade costs that are required to accomplish a specified LEED certification level such as silver or gold. The objective function of minimizing the upgrade cost of this model is illustrated in Equation 1, and its constraints are listed in Equations 2 through 12. The decision variable for each credit area is represented with an integer number that identifies which alternative should be selected during the optimization process; a value of zero indicates that no alternative is selected for this credit area, while a value of 1, 2, or more represents the alternative selected within the credit area. The decision variables for building energy and water performance credits, as well as energy- and water-metering systems, are represented with integer variables. These integer variables represent the selected products that can be implemented in the analyzed building to improve its energy or water performance or the selected meter/sub-meter to measure energy or water consumption. For example, an integer variable for interior lighting can select a product of energy-efficient light bulb that can improve the building energy performance by reducing its energy consumption.

The model constraints address the requirements for the LEED certification and the type of the decision variables, along with their minimum and maximum values; and building performance requirements, such as required lighting levels. The required number of LEED-EB points to achieve a certain LEED certificate is expressed in Equation 2. The decision variables of the optimization tool are defined as integer variables, as shown in Equations 3 through 5. According to the first required credit of the Material and Resources division, one credit should be achieved for credits MRc2 to MRc4, which is achieved in Equation 6. The number of achieved LEED points for the first credit of the Innovation in Operation division is limited to four points, as shown in Equation 7. The number of achieved LEED points for the credit of Regional Priority division is limited to four points, as shown in Equation 8. The minimum values for all decision variables are defined in Equation 9. The integer variables for energy and water measures are bounded by the total number of devices or fixtures available in the databases, as shown in Equation 10. The integer variables for energy and water meters/sub-meters are limited to the total number of meters/sub-meters available in the databases, as shown in Equation 11. Lighting levels are maintained similarly to the existing lighting, or a predefined reduction can be allowed, as shown in Equation 12.

$$\mathbf{T.C.} = \sum_{i=1}^{I} \mathbf{CC_i}(\mathbf{X_i}) + \sum_{k=1}^{K} \sum_{r=1}^{R} \mathbf{CG_{kr}}(\mathbf{Y_{kr}}) + \sum_{m=1}^{M} \mathbf{CM_m}(\mathbf{Z_m})$$ Equation 1

Subject to

$$\sum_{i=1}^{I} P_i(X_i) \geq a$$ Equation 2

$$\sum_{i=1}^{I} X_i \quad \rightarrow \text{ integer variables}$$ Equation 3

$$\sum_{k=1}^{K} \sum_{r=1}^{R} Y_{Krj} \rightarrow \text{ integer variables}$$ Equation 4

$$\sum_{m=1}^{M} Z_m \quad \rightarrow \text{ integer variables}$$ Equation 5

$$\sum P_i(X_i) \geq 1 \; ; \; i = MR_{c2}, MR_{c3}, \text{and } MR_{c4}$$ Equation 6

$$X_i, Y_{ij}, Z_m \geq 0$$ Equation 7

$$P_i(X_i) \leq 4 \; ; \; i = IO_{c1}, RP_{c1}$$ Equation 8

$$X_i, Y_{ij}, Z_m \geq 0$$ Equation 9

$$Y_{kr} \leq Y_k \; ; \; k = 1 \text{ to } K; \; r = 1 \text{ to } R$$ Equation 10

$$Z_m \leq Z \; ; \; m = 1 \text{ to } M$$ Equation 11

$$L_r \leq A_r ; r = 1 \text{ to } R$$ Equation 12

Where

T.C.	Total upgrade cost for achieving a certain LEED-EB certificate
CC_i	Cost of implementing alternative X in a LEED-EB credit area i
X_i	An integer decision variable to decide which alternative, if any, can be implemented in an LEED-EB credit area (i), including sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, and innovation in operation
$CG_{kr}(Y_{kr})$	Cost of implementing a green alternative Y of an energy or water building measure (k) in a location (r). Energy and water measures including interior lighting fixtures, interior light bulbs, exterior lighting fixtures, exterior light bulbs, vending machines, hand dryers, HVAC systems, water heaters, other devices, water faucets, urinals, and toilets; locations include rooms, building exterior, parking lot, and landscape
Y_{kr}	An integer decision variable to specify which energy or water building measure (k) is selected from the database in a location (r); locations include rooms, building exterior, parking lot, and landscape
$CM_m(Z_m)$	Cost of installing a meter Z to measures a category of energy or water consumption (m), including building electricity consumption, building gas consumption, building water consumption, interior-lighting electricity consumption, exterior-lighting electricity consumption, vending-machines electricity consumption, hand dryer electricity consumption, HVAC system electricity/gas consumption, water-heater electricity/gas consumption, faucet water consumption, water consumption by urinals, and/or water consumption by toilets
Z_m	An integer decisions variable to specify which energy or water meter is selected from the database to measure energy or water consumption
I	Total number of LEED-EB rating systems credits
K	Total number of energy and water building measures
R	Total number of energy and water measures' locations
M	Total number of metering systems categories

$P_i(X)$	Possible LEED points that can be earned by implementing green alternative X in LEED-EB credit area i
a	Number of required LEED-EB points for achieving a certain LEED certificate (certified, silver, gold, or platinum)
Y_k	Number of green alternatives available in the database for an energy or water building measure (k)
Z	Number of meters available in the database for measuring electricity, gas, or water consumption
L_r	[1 – Existing light intensity in a location (r) /light intensity after a bulb replacement in a location (r)]
A_r	Allowable reduction of light intensity in a location (r)

6.3.2 Optimization Model 2: Maximizing Accredited LEED Points Within a Certain Budget

The second model maximizes the number of accredited LEED-EB points that can be earned. The objective function of maximizing LEED-EB points in this model is illustrated in Equation 13. The constraints of the second scenario optimization problem are listed in Equations 14 through 24. The decision variables that are used in this model are similar to those in model 1.

The constraints of model 2 address the available budget; the requirements for the LEED certification; the type of decision variables, along with their minimum and maximum values; and building performance requirements such as required lighting levels. The available budget for upgrading a certain building according to the LEED-EB rating system is represented in Equation 14. The decision variables of the optimization tool are defined as integer variables, as shown in Equations 15 through 17. According to the first required credit of the Material and Resources division, one credit should be achieved for credits MRc2 to MRc4, which is achieved in Equation 18. The number of LEED points achieved for the first credit of the Innovation in Operation division is limited to four points, as shown in Equation 19. The number of achievable LEED points for the credit of Regional Priority division is limited to four points, as shown in Equation 20. The minimum values for all decision variables are defined in Equation 21. The integer variables for the energy and water measures are bounded by the total number of devices or fixtures available in the databases, as shown in Equation 22. The integer variables for energy and water meters are limited to the total number of meters available in the databases, as shown in Equation 23. Lighting levels are maintained similarly to the existing lighting, or a predefined reduction can be allowed, as shown in Equation 24.

$$\text{T.A.L.P.} = \sum_{i=1}^{I} P_i(X_i) \qquad \text{Equation 13}$$

Subject to

$$\sum_{i=1}^{I} CC_i(X_i) + \sum_{k=1}^{K} \sum_{r=1}^{R} CG_{kr}(Y_{kr}) + \sum_{m=1}^{M} CM_m(Z_m) \le b \qquad \text{Equation 14}$$

$$\sum_{i=1}^{I} X_i \quad \rightarrow \text{ integer variables}$$ Equation 15

$$\sum_{k=1}^{K} \sum_{r=1}^{R} Y_{Krj} \rightarrow \text{ integer variables}$$ Equation 16

$$\sum_{m=1}^{M} Z_m \quad \rightarrow \text{ integer variables}$$ Equation 17

$\sum P_i(X_i) \geq 1$; $i = MR_{c2}, MR_{c3}$, and MR_{c4} Equation 18

$X_i , Y_{ij}, Z_m \geq 0$ Equation 19

$P_i(X_i) \leq 4$; $i = IO_{c1}, RP_{c1}$ Equation 20

$X_i , Y_{ij}, Z_m \geq 0$ Equation 21

$Y_{kr} \leq Y_k$; $k = 1$ to K ; $r = 1$ to R Equation 22

$Z_m \leq Z$; $m = 1$ to M Equation 23

$L_r \leq A_r$; $r = 1$ to r Equation 24

Where

T. A. L. P.	Total Accredited LEED-EB Points (TALP)
$P_i(X)$	Possible LEED points that can be earned by implementing green alternative X in LEED-EB credit area i
I:	Total number of LEED-EB rating systems credits
b:	Available budget for upgrading a certain building
CC_i:	Cost of implementing alternative X in a LEED-EB credit area i
X_i:	An integer decision variable to decide which alternative, if any, can be implemented in an LEED-EB credit area (i), including sustainable sites, water efficiency, energy and atmosphere, material and resources, indoor environmental quality, and innovation in operation
$CG_{kr}(Y_{kr})$:	Cost of implementing a green alternative Y of an energy or water building measure (k) in a location (r). Energy and water measures include interior lighting fixtures, interior light bulbs, exterior lighting fixtures, exterior light bulbs, vending machines, hand dryers, HVAC systems, water heaters, other devices, water faucets, urinals, and toilets; locations include rooms, building exterior, parking lot, and landscape
Y_{kr}:	An integer decision variable to specify which energy or water building measure (K) is selected from the database in a location (r); locations include rooms, building exterior, parking lot, and landscape

K: Total number of energy and water building measures

R: Total number of building locations for energy and water measures

$CM_m(Z_m)$: Cost of installing a meter Z to measure energy or water consumption(m), including building electricity consumption, building gas consumption, building water consumption, interior-lighting electricity consumption, exterior-lighting electricity consumption, vending-machine electricity consumption, hand dryer electricity consumption, HVAC system electricity/gas consumption, water-heater electricity/gas consumption, faucet water consumption, water consumption by urinals, and/or water consumption by toilets

Z_m: An integer decisions variable to specify which energy or water meter is selected to measure energy or water consumption

M: Total number of metering systems categories

Y_k : Number of green alternatives available in the database for an energy or water building measure (k)

Z : Number of meters available in the database for measuring electricity, gas, or water consumption

L_r [1 - Existing light intensity in a location (r) /light intensity after a bulb replacement in a location (r)]

A_r: Allowable reduction of light intensity in a location (r)

CHAPTER 7 RECOMMENDATIONS AND FUTURE RESEARCH

7.1 RECOMMENDATIONS FOR SELECTED REST AREAS

This section provides a list of recommended upgrade measures for the selected rest areas based on the findings of this research study. These recommended green-friendly upgrade measures are summarized in the following section for each of the six selected rest areas. It should be noted that, these recommendations are developed based on the data gathered for the selected rest areas during the site visits in March 2011.

7.1.1 Coalfield Rest Area

The Coalfield rest area was analyzed to investigate the feasibility of implementing various green building measures to reduce its energy and water consumption, as well as to reduce its environmental impacts. This study of green building measures accounted for energy-efficient lighting, such as energy-efficient fluorescent bulbs, LED, and induction lighting; energy-efficient HVAC systems, such as geothermal heat pumps and high-efficiency air-source heat pumps; motion sensors for interior lighting, vending machines, and exhaust fans; energy-efficient hand dryers; solar practices such as solar daylight tubes, grid-connected photovoltaic systems, and solar water heaters; vestibule entrances; double-pane glass for windows and doors; and water-efficient faucets, toilets, and urinals. The results of this analysis provide a list of promising best management practices (BMPs) for the Coalfield rest area that includes fluorescent T8 bulbs for interior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, a geothermal heat pump along with desuperheater, vestibule entrance, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 7.8KW capacity, setting back the HVAC at night, and water-conserving fixtures. The Coalfield rest area consists of two identical buildings to serve the north- and southbound sides of I-55. The recommendations for implementing this list of BMPs are listed in Tables 43 and 44; this list of recommendations can be implemented for each bound of the Coalfield rest area buildings. The implementation of this list of BMPs can reduce the total energy consumption of the rest area building by up to 35.8%.

Table 43. Recommendations for Interior and Exterior Lighting in the Coalfield Rest Area Buildings

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Interior lighting	Replace existing T12 lamps with energy-efficient T8 bulbs (28W and 25W) while maintaining the same lumens output levels, as discussed in Chapter 5. This light replacement will reduce electricity consumption of the interior lighting.	$771	1.4%	0.8
Motion sensors	Install motion sensors for lighting in the men's and women's restrooms. These motion sensors will reduce electricity consumption of the interior lighting.	$871	1.0%	2.7
Solar daylight tubes	Study the feasibility of installing solar daylight tubes in the restrooms and lobby to provide lighting during the daytime. This change can provide savings in electricity consumption; however, it can cause dissipation of energy for space heating and cooling, which leads to a long payback period. A detailed analysis of this potential replacement was discussed in Chapter 5.	$7,465	0.8%	21.6

Table 44. Recommendations for Vending Machines, Exhaust Fans, Hand Dryers, HVAC System, Water Heater, PV System, and Water Fixtures in the Coalfield Rest Area Buildings

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Vending area	Install motion sensors for lighting in the vending area and lighting of vending machines. These sensors will reduce the electricity consumption of lighting the vending area and vending machines.	$339	1.2%	0.9
Exhaust fans	Install motion sensors for exhaust fans in the men's and women's restrooms. These motion sensors will allow the exhaust fans to operate only when the restrooms are occupied, which will reduce the unnecessary dissipation of energy for space heating and cooling when the restrooms are unoccupied.	$542	2.9%	0.6
Hand dryers	Replace the existing hand dryers in the women‘s and men‘s restrooms with more energy-efficient units such as Blast hand dryers.	$1,092	2.9%	1.2
HVAC system	Consider the feasibility of replacing the existing HVAC system with a geothermal heat pump. The rest area building is used 24/7; and accordingly, it can benefit from the use of an energy-efficient HVAC system, such as a geothermal heat pump, to reduce the energy consumption for space heating and cooling.	$31,570	23.0%	3.8
Water heater	Install desuperheater along with the geothermal heat pump to provide hot water during the summer and reduce the energy consumption of water heaters.	$1,600	1.6%	3.0
HVAC settings	Adjust the settings of the HVAC thermostat to allow the HVAC system to be set back at night during the low visitation periods.	$0	0.4%	Immediate
Vestibule entrance	Add a vestibule entrance to the rest area building by installing a second door at the building entrance, as described in Chapter 5. This measure will reduce air infiltration and provide better insulation in the lobby of the rest area building.	$3,404	1.9%	5.2
Water fixtures	Replace existing water fixtures (toilets and urinals) with water-efficient units. A detailed analysis of this potential replacement is provided in Chapter 5.	$7,625	N.A.	N.A.
PV system	Consider the possibility of installing a grid-connected photovoltaic system with a capacity of 7.8KW to generate 5% of the total electricity consumed at the rest area site. It should be noted that PV systems can generate renewable electricity on-site for the rest area; however, the payback period for this system is relatively long.	$33,466	5.0%	18.1
Code blue emergency phone	Consider the possibility of replacing existing bulbs in the Code Blue emergency phones with LED lights to reduce the electricity consumption, while considering the impact of this replacement on their visibility at night.	$300	%1.0	1.0
All measures	**All the above energy measures were modeled in the energy simulation software to consider all interactions among the measures and to estimate the overall reduction in energy consumption.**	**$89,045**	**35.8%**	**6.9**

The research team also developed a practical decision support tool (DST) that can be used to optimize the upgrade decisions for Illinois public buildings with two primary objectives: to (1) minimize the total upgrade cost to accomplish a desired level of LEED-EB certification and (2) maximize the number of accredited LEED-EB points for a specified budget. IDOT decision makers can use the DST to investigate the potential for achieving a specified LEED certification level (e.g., silver or gold) with the lowest possible upgrade cost or earning the maximum number of LEED credit points within a specified budget.

7.2 FUTURE RESEARCH

During the course of this study, the research team identified a number of promising research areas that need further in-depth analysis and investigation in a follow-up phase. Phase II of this completed project focused on six rest areas (Coalfield, Cumberland Road, Turtle Creek, Great Sauk Trail, Willow Creek, and Mackinaw Dells) that were selected based on their annual energy consumption and annual energy consumption per square foot. Building on the accomplishments in Phases I and II, the research team foresees an opportunity to continue in a Phase III research effort to (1) install sub-metering systems in three selected rest area buildings to measure and compare their energy and/or water consumption before and after the implementation of the recommended green building measures; (2) develop three showcases of green rest areas in Illinois by creating dynamic and interactive websites to provide real-time monitoring and reporting of the energy savings and positive environmental impacts that are realized from implementing green measures in these rest areas; (3) implement, monitor, and improve the effectiveness of the recommended green building measures in this project based on the readings of the installed sub-meters and the findings of the analyses of the previous phases; (4) investigate, determine, and provide a list of green-friendly best management practices (BMPs) for five additional rest areas that have the highest energy consumption rate in Illinois and account for account for 22% of IDOT rest areas' energy bills; and (5) expand the capabilities of the DST developed in Phase II to enable the optimization model to minimize the operational cost of IDOT buildings while complying with the available upgrade budgets. To accomplish these five main goals, the objectives of the proposed Phase III research, subject to modifications in scope to adjust to the needs of IDOT, are to

1. Install sub-metering systems for three selected rest area buildings where electricity, natural gas, and the number of visitors can be measured in real time to generate load profiles. These three rest areas will be selected based on the feedback and recommendations of the TRP.
2. Develop showcases of green rest areas in Illinois for the aforementioned three selected rest areas. This task will be accomplished by creating dynamic and interactive websites to provide real-time monitoring and reporting of the energy savings and the positive environmental impacts that are realized from implementing green measures in each of these three rest areas. These interactive websites can be displayed in each rest area using touch-screen monitors/tablets to inform and educate the visitors of these rest areas of the energy and cost savings realized, the improvements in operational performance, the impact of the renewable energy generated, and the reduction in carbon emissions over time. Furthermore, these websites will also be available on the Internet for the public at large, illustrating IDOT's commitment to support the recent initiatives in the State of Illinois to be more green friendly.

3. Implement, monitor, and improve the effectiveness of the green building measures recommended in the previous phases of the project based on the readings of the installed sub-meters. This task will be accomplished in the same three rest area buildings that were selected in the aforementioned two objectives.
4. Develop a comparison between the analysis developed of the selected rest area buildings and their actual energy savings achieved after the implementation of green building measures.
5. Conduct on-site assessment and field measurements of five additional rest areas that have the next-highest energy consumption rates in Illinois and account for 22% of IDOT rest areas' energy bills.
6. Explore and identify energy-saving measures that can be implemented in the five additional rest areas, such as energy-efficient lighting, motion-activated lighting, solar practices, double-pane glass, energy-efficient hand dryers, geothermal heat pumps, and water-saving plumbing fixtures.
7. Perform an energy audit analysis for the five additional rest areas using energy simulation tools such as eQuest and Ecotect to analyze the impact of implementing the energy-saving alternatives identified in the previous task.
8. Evaluate the economic feasibility of the identified energy-saving alternatives for the five additional rest areas in terms of their required upgrade costs, life-cycle costs (LCC), and payback periods.
9. Expand the capabilities of the DST developed in Phase II to enable the optimization model to minimize the operational cost of IDOT buildings while complying with the available upgrade budgets.
10. Prepare a plan/report with recommendations detailing (1) the recommended green-friendly BMPs to use with cost estimates for full implementation, including payback periods for the five additional rest areas; (2) instructions for using the expanded DST to identify optimal upgrade decisions for Illinois public buildings; and (3) a review of the green building measures implemented in the selected rest area building and their correlation with the analysis conducted.

This proposed future research is designed to support IDOT and the State of Illinois in their ongoing efforts to maximize the sustainability and green performance of their facilities. The expected deliverables of the proposed research include (1) monitoring of energy consumption, performance, and visitation rates in three selected rest areas, as well as measuring and calculating energy savings after implementing the green building measures recommended in Phases I and II; (2) conducting a detailed comparison between the energy simulation analysis results and the actual savings realized in these three selected rest area buildings; (3) developing three showcases for the three selected rest area buildings where green measures are implemented; (4) developing a comprehensive energy audit and analysis of five additional rest areas that have the second-highest energy consumption in Illinois; (5) identifying best management practices and specific recommendations to enable IDOT to identify the most economical and optimal building upgrade measures to achieve the highest possible energy savings and LEED certification for the five additional rest areas; (6) developing an expanded and practical DST that can identify optimal upgrade energy and water measures available on the market for minimizing operation cost of buildings while maintaining the upgrade cost within a specified budget; (7) achieving significant savings in IDOT rest areas' energy consumption and bills; (8) achieving environmental benefits such as improving air and water quality; (9) achieving social benefits such as enhancing visitors' comfort and health. These deliverables will ensure that IDOT's limited budgets for upgrading its buildings are spent in the most cost-effective manner. The proposed DST will also enable IDOT to monitor the performance of their buildings and implement the most cost-effective products on the market, which can reduce the operational cost of its buildings. The proposed research effort will also ensure IDOT's leadership in preserving the environment and in sustainability and green construction.

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APPENDIX A SURVEY FORM

Evaluating Performance of Green Measures

Introduction and Contact Information

Introduction:

The Illinois Department of Transportation is sponsoring an ongoing research project that aims to study green-friendly Best Managements Practices (BMP) for Illinois interstate rest areas. This survey is designed to evaluate performance of green-friendly and sustainability measures in interstate rest areas, welcome centers, and DOT-owned facilities. Your valuable feedback is needed to complete this online survey that is designed to take **less than 15 minutes**. We would appreciate it if you can complete the survey by **October 28th, 2011**.

The research team will be glad to share with you the findings of this survey upon completion.

If you have any questions or comments, please contact the Proposed Investigator (PI) of this project: Khaled El-Rayes, Associate Professor, Department of Civil and Environmental Engineering, University of Illinois at Urbana-Champaign, Tel: (217) 265-0557, e-mail: elrayes@ad.uiuc.edu.

Thank you in advance for your time.

Your Contact Information:

Name:: __________________________

Title: __________________________

State:: __________________________

Phone:: __________________________

E-mail: __________________________

Fax: __________________________

1. Use of Green Building Measures

Please, indicate which **green measure(s)** is/are **currently used** in your State Department of Transportation (DOT) buildings.

Energy-Efficient Lighting

[ ] LED lighting

[ ] Induction lighting

[ ] Energy-efficient fluorescent (T8)

[ ] None

Renewable Energy

[ ] Solar panels

[ ] Solar water-heating systems

[ ] Solar daylight tubes

[ ] Geothermal heat pumps

[ ] Wind-power technology

[ ] None

Energy-Efficient Measures

[ ] Motion-activated lighting

[ ] Double-pane glass windows

[ ] Energy-efficient hand dryers

[ ] Exhaust-heat recovery

[ ] Airtight entrances

[ ] None

Water-Efficient Measures

[ ] Water-conserving toilets

[ ] Water-conserving urinals

[ ] Water-conserving faucets

[ ] Rain gardens

[ ] Gray water systems

[ ] None

Other Green Measures (please state)

Measure # 1: __________________________

Measure # 2: __________________________

Measure # 3: __________________________

To what buildings have you implemented these green measures?

[ ] Rest areas/welcome centers

[ ] Office buildings

[ ] Other

Please list other buildings, if any.

____

2. User Satisfaction

Please, indicate average user satisfaction of each green measure.

Energy-Efficient Lighting

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
LED lighting					
Induction lighting					
Energy-efficient fluorescent (T8)					

Renewable Energy

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Solar panels					
Solar water-heating systems					
Solar daylight tubes					
Geothermal heat pumps					
Wind-power technology					

Energy-Efficient Measures

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Motion-activated lighting					
Double-pane glass windows					
Energy-efficient hand dryers					
Exhaust-heat recovery					
Airtight entrances					

Water-Efficient Measures

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Water-conserving toilets					
Water-conserving urinals					
Water-conserving faucets					
Rain gardens					
Gray water systems					

Other Green Measures Listed on Page 2, If Any

	Very Satisfied	Satisfied	Neutral	Dissatisfied	Very Dissatisfied
Measure # 1					
Measure # 2					
Measure # 3					

3. Ease of Maintenance

Please, indicate ease of maintenance for each green measure.

Energy-Efficient Lighting

	Easy to Maintain	Moderate	Difficult to Maintain
LED lighting			
Induction lighting			
Energy-efficient fluorescent (T8)			

Renewable Energy

	Easy to Maintain	Moderate	Difficult to Maintain
Solar panels			
Solar water-heating systems			
Solar daylight tubes			
Geothermal heat pumps			
Wind-power technology			

Energy-Efficient Measures

	Easy to Maintain	Moderate	Difficult to Maintain
Motion-activated lighting			
Double-pane glass windows			
Energy-efficient hand dryers			
Exhaust-heat recovery			
Airtight entrances			

Water-Efficient Measures

	Easy to Maintain	Moderate	Difficult to Maintain
Water-conserving toilets			
Water-conserving urinals			
Water-conserving faucets			
Rain gardens			
Gray water systems			

Other Green Measures Listed on Page 2, If Any

	Easy to Maintain	Moderate	Difficult to Maintain
Measure # 1			
Measure # 2			
Measure # 3			

4. Encountered Operational Problems and Repair Cost

Please, list encountered problems and actual/estimated repair costs for each green measure, if available.

Energy-Efficient Lighting

	Encountered Problems	**Repair Costs ($)**
LED lighting		
Induction lighting		
Energy-efficient fluorescent (T8)		

Renewable Energy

	Encountered Problems	**Repair Costs ($)**
Solar panels		
Solar water-heating systems		
Solar daylight tubes		
Geothermal heat pumps		
Wind-power technology		

Energy-Efficient Measures

	Encountered Problems	**Repair Costs ($)**
Motion-activated lighting		
Double-pane glass windows		
Energy-efficient hand dryers		
Exhaust-heat recovery		
Airtight entrances		

Water-Efficient Measures

	Encountered Problems	**Repair Costs ($)**
Water-conserving toilets		
Water-conserving urinals		
Water-conserving faucets		
Rain gardens		
Gray water systems		

Other Green Measures Listed on Page 2, If Any

	Encountered Problems	**Repair Costs ($)**
Measure # 1		
Measure # 2		
Measure # 3		

5. Energy Savings

Please input the average reduction in electricity/water use and expected payback period for each green measure, if known.

Energy-Efficient Lighting

	Reduction in Electricity Use (%)	Expected Payback Period (yr)
LED lighting		
Induction lighting		
Energy-efficient fluorescent (T8)		

Renewable Energy

	Reduction in Electricity Use (%)	Expected Payback Period (yr)
Solar panels		
Solar water-heating systems		
Solar daylight tubes		
Geothermal heat pumps		
Wind-power technology		

Energy-Efficient Measures

	Reduction in Electricity Use (%)	Expected Payback Period (yr)
Motion-activated lighting		
Double-pane glass windows		
Energy-efficient hand dryers		
Exhaust-heat recovery		
Airtight entrances		

Water-Efficient Measures

	Reduction in Water Use (%)	Expected Payback Period (yr)
Water-conserving toilets		
Water-conserving urinals		
Water-conserving faucets		
Rain gardens		
Gray water systems		

Other Green Measures Listed on Page 2, If Any

	Reduction in Electricity/Water Use (%)	Expected Payback Period
Measure # 1		
Measure # 2		
Measure # 3		

6. Sharing Information and Results

1) Are you willing to provide more information, if needed?

( ) Yes

( ) No

2) Are you interested to receive the main findings of this survey upon completion?

( ) Yes

( ) No

7. Thank You!

Thank you for taking our survey. Your response is very important to us.

APPENDIX B TABLES AND FIGURES ILLUSTRATING DETAILED ANALYSIS OF SURVEY RESPONSES

B.1 IMPLEMENTED GREEN TECHNOLOGIES

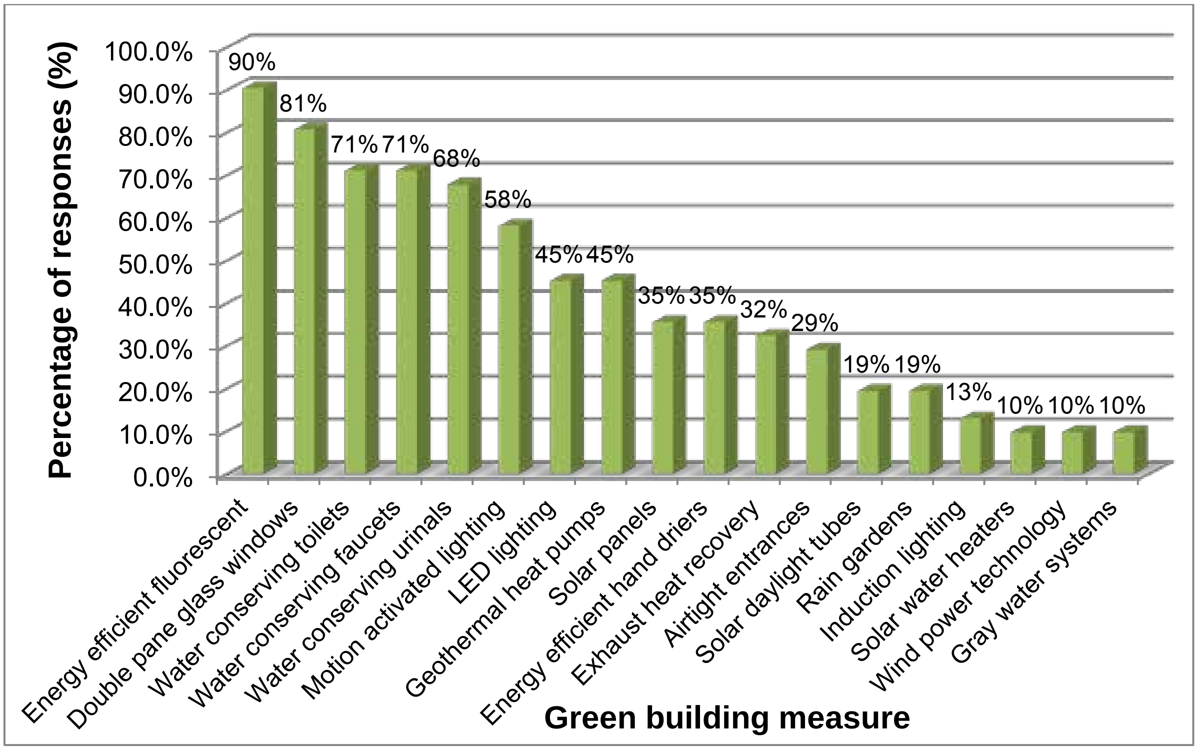

Figure 39. Percentage of responses implementing various green measures.

B.2 USER SATISFACTION

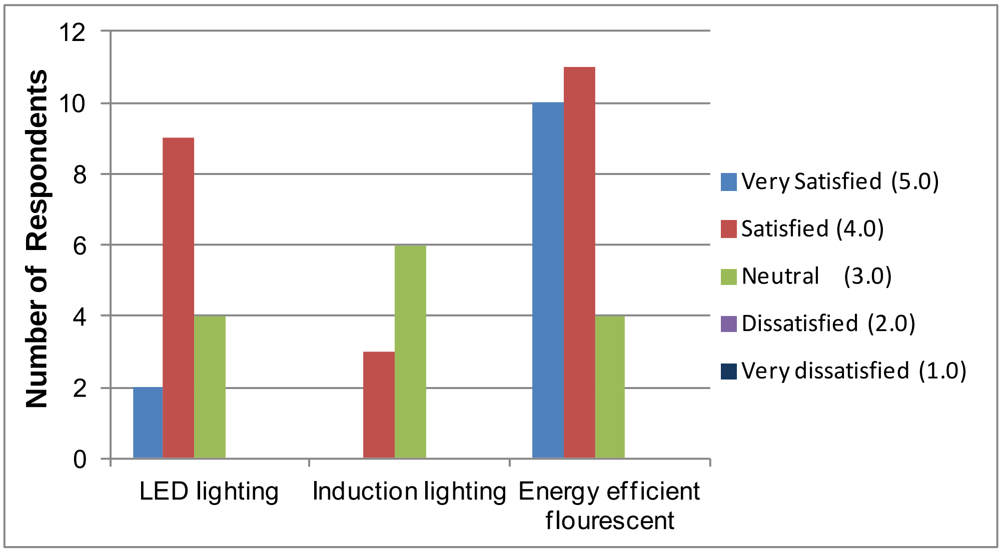

Figure 40. User satisfaction results for energy-efficient lighting measures.

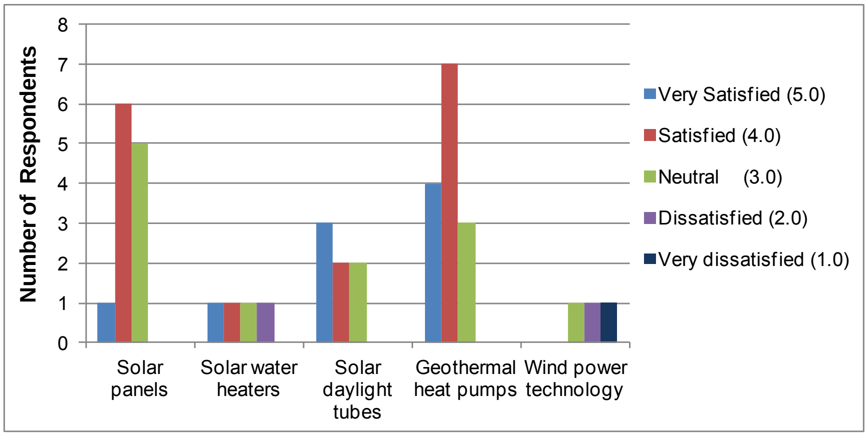

Figure 41. User satisfaction results for renewable energy.

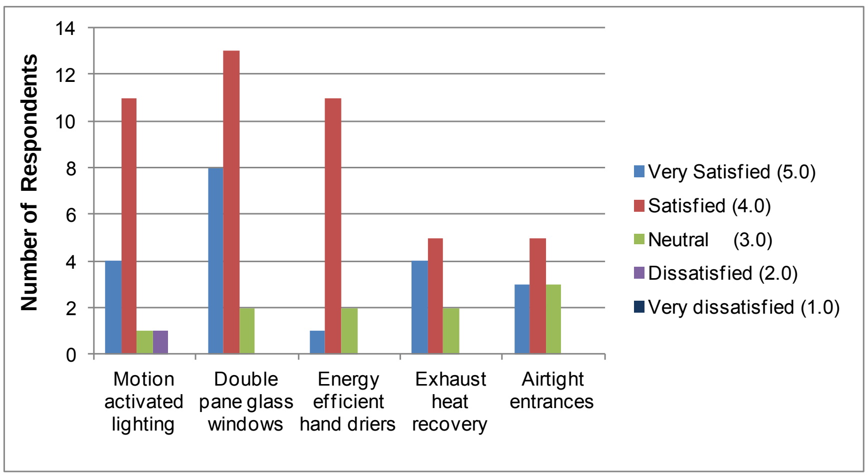

Figure 42 User satisfaction results for energy-efficient measures.

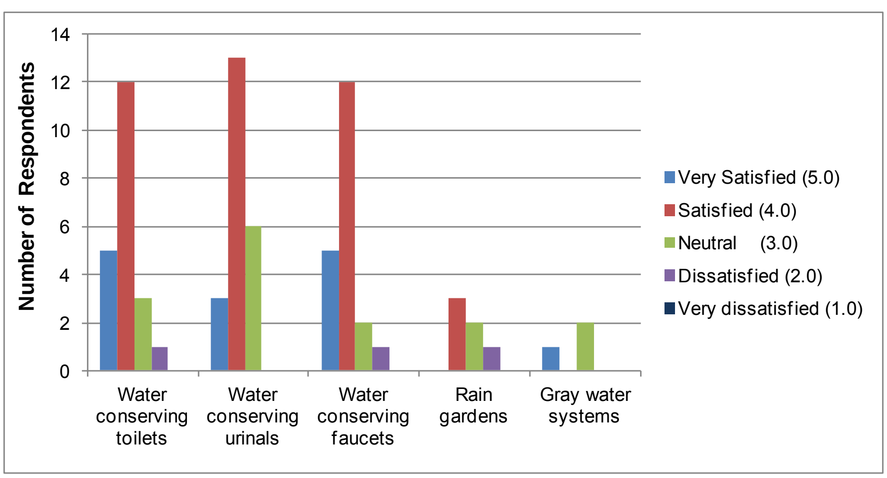

Figure 43. User satisfaction results for water-efficient measures.

Table 45. User Satisfaction Results for Added Green Measures

#	Added Green Measures	User Satisfaction
1	Passive solar sitting	Satisfied
2	Recycling	Very satisfied, Satisfied
3	Using recycled materials	Satisfied, Neutral
4	Native vegetation requiring no water other than naturally available	Very satisfied
5	Cistern for flushing toilets	Satisfied
6	Cistern for watering landscaping	Satisfied
7	Waterless urinals	Very satisfied
8	Radiant floor heating	Very satisfied
9	Designed, constructed and maintained to LEED Silver	Very satisfied
10	LEED design	Satisfied
11	Switch-activated heaters	N.R.*
12	Installing T-12 lighting	Satisfied
13	Energy audits	Satisfied
14	HVAC controls and temperature management	Satisfied
15	Equipment upgrades/replacements	Satisfied
16	All new construction LEED certified	Satisfied
17	Evaporative cooling in desert rest areas	Very satisfied
18	Hot water boilers	Very satisfied
19	Building automation and controls	Very satisfied
20	Local materials	N.R.*
21	Low/no-VOC paints	N.R.*

*N.R.: Not Reported

Table 46. User Satisfaction Results for Green-Friendly Measures and Technologies

Measures category	Energy-Efficient Lighting	Very Satisfied (5.0)	Satisfied (4.0)	Neutral (3.0)	Dissatisfied (2.0)	Very Dissatisfied (1.0)	Number of Responses	Average Satisfaction (1.0 To 5.0)
Energy-efficient lighting	LED lighting	13%	60%	27%	0%	0%	15	3.9
	Induction lighting	0%	33%	67%	0%	0%	9	3.3
	Energy-efficient fluorescent	40%	44%	16%	0%	0%	25	4.2
Renewable energy	Solar panels	8%	50%	42%	0%	0%	12	3.7
	Solar water heaters	25%	25%	25%	25%	0%	4	3.5
	Solar daylight tubes	43%	29%	29%	0%	0%	7	4.1
	Geothermal heat pumps	29%	50%	21%	0%	0%	14	4.1
	Wind-power technology	0%	0%	33%	33%	33%	3	2.0
Energy-efficient measures	Motion-activated lighting	24%	65%	6%	6%	0%	17	4.1
	Double-pane glass windows	35%	57%	9%	0%	0%	23	4.3
	Energy-efficient hand dryers	7%	79%	14%	0%	0%	14	3.9
	Exhaust-heat recovery	36%	45%	18%	0%	0%	11	4.2
	Airtight entrances	27%	45%	27%	0%	0%	11	4.0
Water-efficient measures	Water-conserving toilets	24%	57%	14%	5%	0%	21	4.0
	Water-conserving urinals	14%	59%	27%	0%	0%	22	3.9
	Water-conserving faucets	25%	60%	10%	5%	0%	20	4.1
	Rain gardens	0%	50%	33%	17%	0%	6	3.3
	Gray water systems	33%	0%	67%	0%	0%	3	3.7

B.3 EASE OF MAINTENANCE

Table 47. Ease-of-Maintenance Results for Green-Friendly Measures and Technologies

Measures Category	Green Measure	Easy to Maintain (3.0)	Moderate (2.0)	Difficult to Maintain (1.0)	Number of Responses	Average Ease of Maintenance (1.0 to 3.0)
Energy-efficient lighting	LED lighting	83%	17%	0%	12	2.8
	Induction lighting	75%	25%	0%	4	2.8
	Energy-efficient fluorescent	80%	20%	0%	25	2.8
Renewable energy	Solar panels	30%	60%	10%	10	2.2
	Solar water heaters	33%	33%	33%	3	2.0
	Solar daylight tubes	83%	0%	17%	6	2.7
	Geothermal heat pumps	36%	55%	9%	11	2.3
	Wind-power technology	33%	0%	67%	3	1.7
Energy-efficient measures	Motion-activated lighting	71%	29%	0%	17	2.7
	Double-pane glass windows	74%	26%	0%	23	2.7
	Energy-efficient hand dryers	43%	50%	7%	14	2.4
	Exhaust-heat recovery	60%	40%	0%	10	2.6
	Airtight entrances	60%	20%	20%	10	2.4
Water-efficient measures	Water-conserving toilets	52%	48%	0%	21	2.5
	Water-conserving urinals	33%	67%	0%	21	2.3
	Water-conserving faucets	57%	38%	5%	21	2.5
	Rain gardens	25%	25%	50%	4	1.8
	Gray water systems	0%	100%	0%	1	2.0

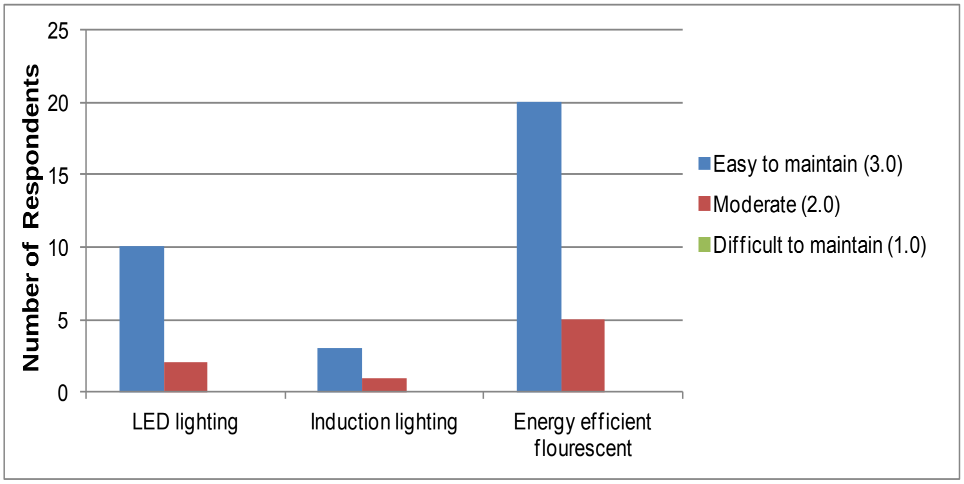

Figure 44. Ease-of-maintenance results for energy-efficient lighting.

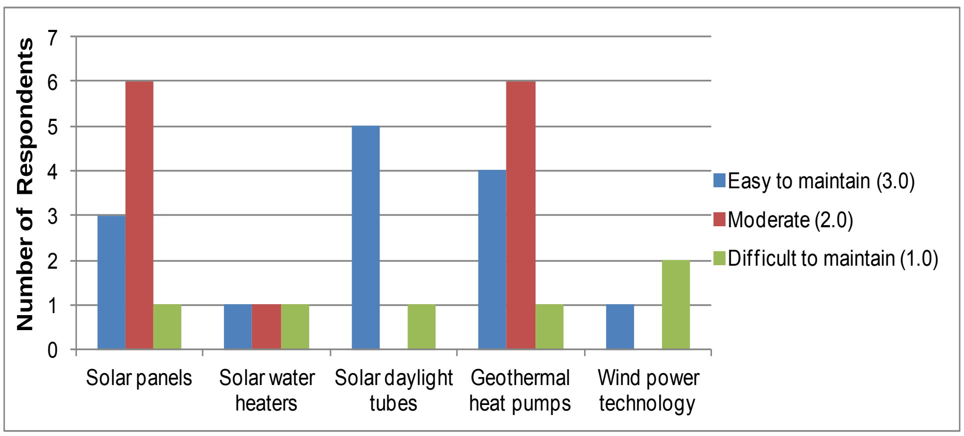

Figure 45. Ease-of-maintenance results for technologies of renewable energy.

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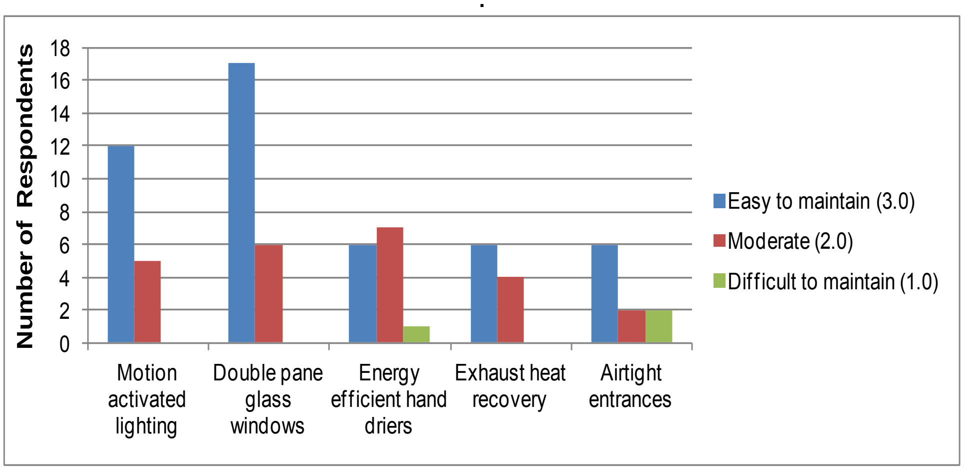


Figure 46. Ease-of-maintenance results for energy-efficient measures.

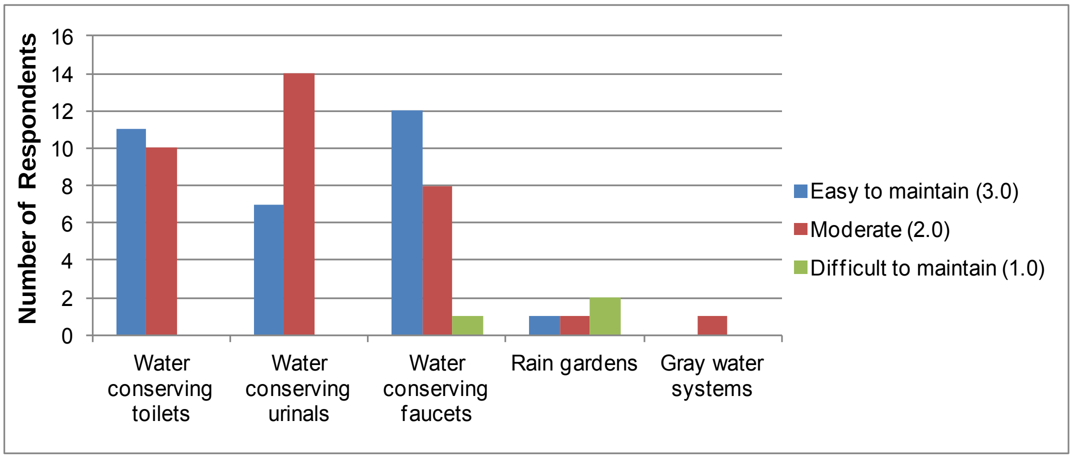


Figure 47. Ease-of-maintenance results for water-efficient measures.

Table 48. Ease-of-Maintenance Results for Added Measures

#	Added Green Measures	Ease-of-Maintenance Level
1	Passive solar sitting	Easy to maintain
2	Recycling	Easy to maintain
3	Using recycled materials	Easy to maintain
4	Native vegetation requiring no water other than naturally available	Easy to maintain
5	Cistern for flushing toilets	Moderate
6	Cistern for watering landscaping	Moderate
7	Waterless urinals	Moderate
8	Radiant floor heating	Moderate
9	Designed, constructed and maintained to LEED Silver	Moderate
10	LEED design	Moderate
11	Switch-activated heaters	N.R.*
12	Installing T-12 lighting	Easy to maintain
13	Energy audits	Moderate
14	HVAC controls and temperature management	Easy to maintain, moderate
15	Equipment upgrades/replacements	Moderate
16	All new construction LEED certified	Easy to maintain
17	Evaporative cooling in desert rest areas	Easy to maintain
18	Hot water boilers	Easy to maintain
19	Building automation and controls	Easy to maintain
20	Local materials	N.R.*
21	Low/no VOC paints	N.R.*

*N.R.: Not Reported

B.4 OPERATIONAL PROBLEMS AND REPAIR COSTS

Table 49. Operation Problems and Repair Costs for Added Measures

#	Added Green Measure	Encountered Problems	Repair Cost ($)
1	Passive solar sitting	Unable to purchase solar louvers.	N.R.*
2	Recycling	None	N.R.*
3	Using recycled materials	None	N.R.*
4	Native vegetation requiring no water other than naturally available	None	N.R.*
5	Cistern for flushing toilets	Pump system that has been hit by lighting	N.R.*
6	Cistern for watering landscaping	No meter on this system to know amount of water collected.	N.R.*
7	Waterless urinals	Cartridge must be changed after certain number of uses, and waste piping must be flushed out on a regular basis to avoid build up.	N.R.*
8	Radiant floor heating	None	N.R.*
9	Designed, constructed and maintained to LEED Silver	None	N.R.*
10	LEED design	Added cost and effort during design and construction	N.R.*
11	Switch-activated heaters	None	N.R.*
12	Installing T-12 lighting	None	N.R.*
13	Energy audits	None	N.R.*
14	HVAC controls and temperature management	None	N.R.*
15	Equipment upgrades/replacements	None	N.R.*
16	All new construction LEED certified	None	N.R.*
17	Evaporative cooling in desert rest areas	Regular maintenance	N.R.*
18	Hot water boilers	No problems	N.R.*
19	Building automation and controls	Operator error	N.R.*
20	Local materials	None	N.R.*
21	Low/no VOC paints	None	N.R.*

*N.R.: Not Reported

B.5 ENERGY SAVINGS AND PAYBACK PERIODS

Table 50. Energy Savings and Payback Periods for Green-Friendly Measures

Measures category	Energy-Efficient Lighting	Average Energy/Water Saving (%)	Number of Respondents	Average Expected Payback Period (yr)	Number of Respondents
Energy-efficient lighting	LED lighting	60.00%	1	12.5	2
	Induction lighting	None	0	None	0
	Energy-efficient fluorescent	22.50%	4	4.08	6
Renewable energy	Solar panels	10.00%	1	22.5	2
	Solar water heaters	None	0	10	2
	Solar daylight tubes	None	0	10	1
	Geothermal heat pumps	47.50%	2	10.67	3
	Wind-power technology	None	0	36	1
Energy-efficient measures	Motion-activated lighting	21.70%	3	6	3
	Double-pane glass windows	4.00%	1	11.5	2
	Energy-efficient hand dryers	5.00%	1	1	1
	Exhaust-heat recovery	16.70%	3	6.7	3
	Airtight entrances	5.00%	2	10	2
Water-efficient measures	Water-conserving toilets	33.30%	3	4.7	3
	Water-conserving urinals	40.00%	3	4.7	3
	Water-conserving faucets	31.70%	3	4.3	3
	Rain gardens	None	0	None	0
	Gray water systems	None	0	None	0

Table 51. Energy Savings and Payback Periods for Added Measures

#	Added Green Measure	Energy/Water Savings (%)	Payback Period (yr)
1	Passive solar sitting	N.R.*	N.R.*
2	Recycling	N.R.*	N.R.*
3	Using recycled materials	N.R.*	N.R.*
4	Native vegetation requiring no water other than naturally available	N.R.*	N.R.*
5	Cistern for flushing toilets	N.R.*	N.R.*
6	Cistern for watering landscaping	N.R.*	N.R.*
7	Waterless urinals	N.R.*	N.R.*
8	Radiant floor heating	N.R.*	N.R.*
9	Designed, constructed and maintained to LEED Silver	N.R.*	N.R.*
10	LEED design	N.R.*	N.R.*
11	Switch-activated heaters	N.R.*	N.R.*
12	Installing T-12 lighting	N.R.*	N.R.*
13	Energy audits	20%	10
14	HVAC controls and temperature management	N.R.*	N.R.*
15	Equipment upgrades/replacements	N.R.*	N.R.*
16	All new construction LEED certified	N.R.*	N.R.*
17	Evaporative cooling in desert rest areas	N.R.*	N.R.*
18	Hot water boilers	35%	3
19	Building automation and controls	25%	5
20	Local materials	N.R.*	N.R.*
21	Low/no VOC paints	N.R.*	N.R.*

*N.R.: Not Reported

APPENDIX C ON-SITE ASSESSMENT FOR THE SELECTED REST AREAS OF COALFIELD, GREAT SAUK TRAIL, MACKINAW DELLS, CUMBERLAND ROAD, AND TURTLE CREEK

C.1 COALFIELD REST AREA

Coalfield rest area has approximately 1.8 million annual visitors based on 2009 statistics with 1.07% annual increase in visitation rate. It was built in 1985 and renovated in 1991 when a new vending area was added to the building. The rest area comprises of two buildings that serve the north and south bounds of I-55 at mile marker 64, 25 miles of Springfield. The Coalfield site visit and data collection was conducted in the southbound rest area building since the two rest area buildings on the north and south bounds are identical. This rest area provides several services for visitors including: weather information, travel information and guides, restrooms, vending machines, and outdoor picnic areas, see Figure 48.

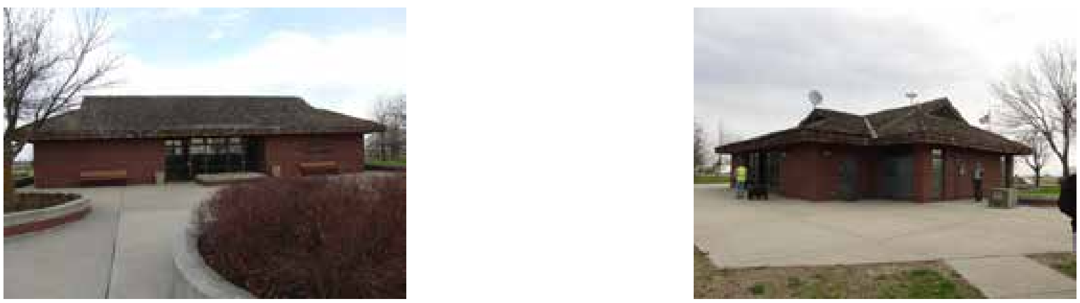


Figure 48. Southbound Coalfield rest area.

The components of energy consumption in the southbound Coalfield rest area include exterior lighting, interior lighting, space heating, air conditioning, water heating, water treatment, vending machines, surveillance cameras, weather information, hand dryers, water coolers, and water-treatment system and well pump. The exterior lighting include lighting poles for the road between I-55 and the rest area parking lots, lighting poles for the parking lot, and outdoor lighting fixtures for the rest area building. The interior lighting includes lighting fixtures for lobbies, men's restrooms, women's restrooms, mechanical room, and storage rooms. The interior and exterior lighting fixtures in the southbound rest area are summarized in Table 52 and Table 53. Some of the lighting fixtures in southbound rest area are shown in Figure 49.

Table 52. Interior Lighting in Coalfield Rest Area

Location		Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Southbound	Lobby	square fluorescent fixture	12	2	U-shape fluorescent lamp
		rectangular fluorescent fixture	2	2	4' GE F34 CW-RS-WM ECO
	Men's restrooms	square fluorescent fixture	2	2	U-shape fluorescent lamp
		rectangular fluorescent fixture	2	2	4' GE F34 CW-RS-WM ECO
	Women's restrooms	square fluorescent fixture	2	2	U-shape fluorescent lamp
		rectangular fluorescent fixture	4	2	4' GE F34 CW-RS-WM ECO
	Mechanical rooms	rectangular fluorescent fixture	6	2	4' (2 GE F40 CW-RS-WM 34W and 10 F34 CW-RS-WM-ECO)
	Storage rooms	rectangular fluorescent fixture	4	2	4' GE F34 CW-RS-WM ECO, vendors come once per day for 2 hours
	Well room	light fixture	6	1	100 watt light bulb, 15~20 min. per day

Table 53. Exterior Lighting in Coalfield Rest Area

Location		Type of Lighting Fixture	Quantity	Lamp(s) Per Fixture	Characteristics
Southbound	Entrance and exit	wall light fixture	6	1	HPS 400 watts
	Building	recessed light fixture	10	1	HPS 70 watts
	Parking lot	lighting tower 1	2	8	HPS 400 watts
		lighting tower 2	1	2	HPS 400 watts

Figure 49. Lighting fixtures in southbound Coalfield rest area.

The southbound Coalfield rest area is heated and air-conditioned using two furnaces and two air-cooled condensing units, which use electricity. One furnace and air-condensing unit are used for heating and cooling the vending area of the southbound building while the other furnace and air-cooled condensing unit are used for the rest of the building. Both furnaces have a capacity of 119.4 MBH and both air-cooled condensing units have a capacity of 7.5 tons. An electrical water heater is used for each bound of the rest area to heat water with a capacity of 40 gallons. Air-conditioning units and water heater are shown in Figure 50.

Furnace | Air-cooled condensing units | Water heater

Figure 50. Air-conditioning units and water heater in Coalfield rest area.

The southbound rest area has six vending machines: three for drinks, two for snacks, and one for coffee, as shown in Figure 51. Seven Surveillance cameras are used in the southbound rest area to maintain safety for visitors, and interior lighting is needed all the time for these cameras to ensure the clarity of video recording. The weather information is provided using a television in the lobby. Three Code Blue emergency phones are available in southbound of the rest areas: one in the lobby, one in the cars parking lot, and one in the trucks parking lot. The southbound building also includes a refrigerator, a vacuum cleaner, a computer for surveillance cameras, and two fans in the maintenance room.

Figure 51. Vending machines in Coalfield rest area.

The men's and women's restrooms of the southbound include four hand dryers, where each has 2200 watt electrical capacity. Two water coolers are available in the lobby of the southbound rest area to provide cold drinking water for visitors. Hand dryers and water coolers are shown in Figure 52. Other water consumption fixtures in the southbound Coalfield rest area include faucets, urinals and toilets, as shown in Figure 53. The quantities and characteristics of water fixtures in the southbound rest area are shown in Table 54.

Figure 52. Hand dryers and water coolers in southbound Coalfield rest area.

Table 54. Water Fixtures in Coalfield Rest Area

Location		Type of Water Fixture	Quantity	Characteristics
Southbound	Men's restrooms	Faucets	2	Electronic faucets
		Toilets	3	aqua flush, ZURN
		Urinals	2	Manual flush
	Women's restrooms	Faucets	2	Electronic faucets
		Toilets	5	aqua flush, ZURN

Figure 53. Water fixtures in Coalfield rest area.

C.2 GREAT SAUK TRAIL REST AREA

Great Sauk Trail rest area has approximately 980 thousand annual visitors based on 2009 statistics, and it was built in 1969 and renovated in 1989. The rest area comprises of two buildings that serve the east and west bounds of I-80 at mile marker 51, 5 miles west of Princeton. The Great Sauk Trail site visit and data collection was conducted in the westbound rest area building since the two rest area buildings on the east and west bounds are identical. This rest area provides several services for visitors including: weather information, travel information and guides, restrooms, vending machines, and outdoor picnic areas, see Figure 54.

Figure 54. Westbound Great Sauk Trail rest area.

The components of energy consumption in the westbound Great Sauk Trail rest area include exterior lighting, interior lighting, space heating, air conditioning, water heater, vending machines, surveillance cameras, weather information, hand dryers, water coolers, and water-treatment system and well pump. The exterior lighting include lighting poles for the road between I-80 and the rest area parking lots, lighting poles for the parking lot, and outdoor lighting fixtures for the rest area building. The interior lighting includes lighting fixtures for lobbies, men‘s restrooms, women‘s restrooms, mechanical room, and storage rooms. The interior and exterior lighting fixtures in the westbound rest area are summarized in Table 55 and Table 56. Some lighting fixtures for westbound rest area are shown in Figure 55.

Table 55. Interior Lighting for Great Sauk Trail Rest Area

Location		**Type of Lighting Fixture**	**Quantity**	**Lamp(s) per Fixture**	**Characteristics**
Westbound	Lobby	recessed fixture	24	1	50 watt light bulb
		rectangular fluorescent fixture	6	2	4' Philips F32T8/TL741 32 watts
	Men's restroom	rectangular fluorescent fixture	11	2	4' Philips F32T8/TL741 32 watts
	Women's restroom	rectangular fluorescent fixture	11	2	4' Philips F32T8/TL741 32 watts
	Restroom storage	surface light fixture	2	1	Energy-saving bulb 23 watts
	Mechanical room	rectangular fluorescent fixture	5	2	4' Philips F32T8/TL741 32 watts
		Surface light fixture	7	1	Energy-saving bulb 23 watts
	Vending storage	rectangular fluorescent fixture	4	2	4' Philips F32T8/TL741 32 watts
		surface light fixture	4	1	75 watt light bulb

Table 56. Exterior Lighting for Great Sauk Trail Rest Area

Location		Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Westbound	Entrance and exit	lighting pole 1	16	1	250 watt light bulb
		lighting pole 2	1	2	250 watt light bulb
	Building	recessed light fixture	4	1	50 watt light bulb
	parking lot	lighting tower 1	2	8	HPS 400 watts
		lighting tower 2	3	4	HPS 400 watts

Figure 55. Lighting fixtures in westbound Great Sauk Trail rest area.

The westbound Great Sauk Trail rest area is heated and air-conditioned using an air-handling unit and air-cooled condensing unit. The air-handling unit is located in the underground floor while the air-cooled condensing unit is placed outside the rest area building. The air-handling unit has a sensible coil capacity of 110,056 BTU/h and the air-cooled condensing unit has a nominal cooling capacity of 15 tons. An electrical water heater (State water heater) is used for each bound of the rest area to heat water. Air-conditioning units and water heater are shown in Figure 56.

Air-cooled condensing unit | Furnace | Water heater

Figure 56. Air-conditioning units and water heater in Great Sauk Trail rest area.

One well is used in each bound of the rest area to supply water, and a water-treatment system is used in each bound of the rest area to treat well water. Each system includes hydro-pneumatic tank with a capacity of 1000 gallons, hydro-pneumatic control panel, air compressor, two iron filter tanks, back wash tank, chemical feed tanks, a brine tank, and a sump pump, as shown in Figure 57. The westbound rest area has contains six vending machines; three for drinks, two for snacks, and one for hot drinks, as shown in Figure 58. Seven Surveillance cameras are used in the westbound rest area to maintain safety for visitors, and interior lighting is needed all the time for these cameras in order to ensure clarity of video recording. The weather information is provided using a television in the lobby. Four Code Blue emergency phones are available in westbound of the rest areas: one in the lobby, and three in the parking lot of the rest area building. The westbound building also includes a small refrigerator, microwave, humidifier, toaster, and a computer for surveillance cameras in the maintenance room. The vending storage includes a refrigerator and an electric heater unit.


Pressure tank


Air pump


Iron filter tanks


Well sump

Figure 57. Water-treatment system components in Great Sauk Trail rest area.

Figure 58. Vending machines in Great Sauk Trail rest area.

The men's and women's restrooms of the southbound include eight hand dryers, where each has 2300 watt electrical capacity. Two water coolers are available in the lobby of the westbound rest area to provide cold drinking water for visitors. Hand dryers and water coolers are shown in Figure 59. Other water consumption fixtures in the westbound Great Sauk Trail rest area include faucets, urinals and toilets, as shown in Figure 60. The quantities and characteristics of water fixtures in the westbound rest area are shown in Table 57.

Figure 59. Hand dryers and water coolers in westbound Great Sauk Trail rest area.

Table 57. Water Fixtures in Great Sauk Trail Rest Area

Location		Type of Water Fixture	Quantity	Characteristics
Westbound	Men's restrooms	Faucets	4	Electronic low-flow faucet
		Toilets	4	American standard 3.5 gpf
		Urinals	3	American standard 1 gpf
	Women's restrooms	Faucets	4	Electronic low-flow faucet
		Toilets	6	American standard 3.5 gpf

Figure 60. Water fixtures in Great Sauk Trail rest area.

C.3 MACKINAW DELLS REST AREA

Mackinaw Dells rest area has approximately 1.54 million annual visitors based on 2009 statistics with annual increase of 0.18%. The rest area comprises of two buildings that serve the south and north bounds of I-74 at mile marker 114, 14 miles west of Bloomington. The Mackinaw Dells site visit and data collection was conducted in the southbound rest area building since the two rest area buildings on the north and south bounds are identical. This rest area provides several services for visitors including: travel information, restrooms, vending machines, and outdoor picnic areas, see Figure 61.

Figure 61. Southbound Mackinaw Dells rest area.

The components of energy consumption in the southbound Mackinaw Dells rest area include exterior lighting, interior lighting, space heating, air conditioning, water heater, vending machines, surveillance cameras, hand dryers, water coolers, and water-treatment system and well pump. The exterior lighting include lighting poles for the road between I-74 and the rest area parking lots, lighting poles for the parking lot, and outdoor lighting fixtures for the rest area building. The interior lighting includes lighting fixtures for lobbies, men‘s restrooms, women‘s restrooms, mechanical room, maintenance room and storage rooms. The interior and exterior lighting fixtures in the southbound rest area are summarized in Table 58 and Table 59. Some lighting fixtures of southbound Mackinaw Dells rest area are shown in Figure 62.

The southbound Mackinaw Dells rest area is heated and air-conditioned using an air handling unit, two water boilers, and two air-cooled condensing units. The air-handling unit and water boilers are located in the underground floor while the air-cooled condensing units are placed outside the rest area building. An electrical water heater (A.O. Smith) is used for each bound of the rest area to heat water with a capacity of 119 gallons. Air-conditioning units and water heater are shown in Figure 63.

Table 58. Interior Lighting for Mackinaw Dells Rest Area

Location		Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Southbound	Lobby	square recessed fixture	14	1	N.A.
		rectangular fluorescent fixture	4	1	4' GE F-32T8-SP35-ECO 32 watts
		square fluorescent fixture	4	3	4' GE F-32T8-SP35-ECO 32 watts
	Vending area	rectangular fluorescent fixture	2	2	4' GE F-32T8-SP35-ECO 32 watts
	Men's restroom	rectangular fluorescent fixture	9	2	4' GE F-32T8-SP35-ECO 32 watts
	Women's restroom	rectangular fluorescent fixture	9	2	4' GE F-32T8-SP35-ECO 32 watts
	Maintenance room	rectangular fluorescent fixture	4	2	4' Sylvania F34 CW/SS/ECO 34 watts
	Mechanical room	rectangular fluorescent fixture 1	4	2	4' Sylvania F34 CW/SS/ECO 34 watts
		rectangular fluorescent fixture 2	2	2	4' Philips F40 LW-RS-EW 34 watts
	Vending storage	rectangular fluorescent fixture	7	2	4' Sylvania F34 CW/SS/ECO 34 watts

Table 59. Exterior Lighting for Mackinaw Dells Rest Area

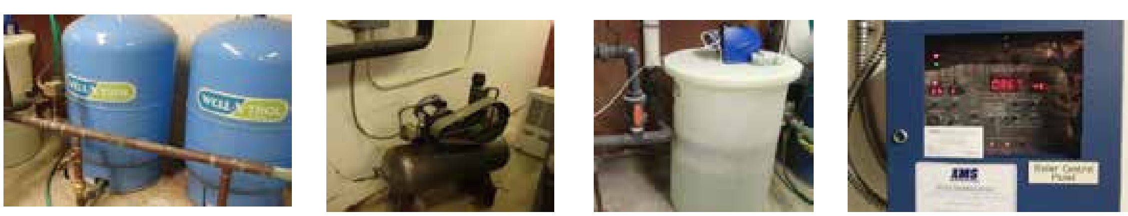
Location		Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Southbound	Entrance and exit	light pole	8	1	N.A.
		wall light fixture	1	1	N.A.
	Building	square recessed fixture	7	1	Philips 100w, 1480 average lumens
		floodlight fixture	4	1	250 watt light bulb
	parking lot	lighting tower 1	1	8	N.A.
		lighting tower 2	1	2	N.A.
		light pole	3	1	N.A.

Figure 62. Lighting fixtures in Mackinaw Dells rest area.

Furnace | Air-cooled condensing unit | Water heater

Figure 63. Air-conditioning units and water heater in Mackinaw Dells rest area.

One well is used in each bound of the rest area to supply water, and a water-treatment system is used in each bound of the rest area to treat well water. Each system includes pressure tank, hydro-pneumatic control panel, air compressor, filter tanks, chemical tank, and a sump pump, as shown in Figure 64. The southbound rest area has six vending machines: three for drinks, two for snacks, and one for hot drinks, as shown in Figure 65. Six Surveillance cameras are used in the southbound rest area to maintain safety for visitors, and interior lighting is needed all the time for these cameras in order to ensure clarity of video recording. Three Code Blue emergency phones are available in southbound of the rest areas: one in the lobby, and two in the parking lot of the rest area building. The southbound building also includes two ceiling fans, two electric heater units, a small refrigerator, microwave, and a computer for surveillance cameras in the maintenance room.



Filter tanks | Air pump | Chemical tank | Hydro-pneumatic panel

Figure 64. Water-treatment system components for Mackinaw Dells rest area.

Figure 65. Vending machines in Mackinaw Dells rest area.

The men's and women's restrooms of the southbound include six hand dryers, where each has 2300 watt electrical capacity. A water cooler is available in the lobby of the southbound rest area to provide cold drinking water for visitors. Hand dryers and water coolers are shown in Figure 66. Other water consumption fixtures in the southbound Mackinaw Dells rest area include faucets, urinals and toilets, as shown in Figure 67. The quantities and characteristics of water fixtures in the southbound rest area are shown in Table 60.

Figure 66. Hand dryers and water coolers in Mackinaw Dells rest area.

Table 60. Water Fixture in Mackinaw Dells Rest Area

Location		Type of Water Fixture	Quantity	Characteristics
Southbound	Men's restrooms	Faucets	4	Electronic low-flow faucet
		Toilets	3	American standard 1.6 gpf
		Urinals	2	Aqua flush
	Women's restrooms	Faucets	4	Electronic low-flow faucet
		Toilets	5	American standard 1.6 gpf

Figure 67. Water fixtures in Mackinaw Dells rest area.

C.4 CUMBERLAND ROAD REST AREA

Cumberland Road rest area has approximately 608 thousand annual visitors based on 2009 statistics with annual decrease of 1.53%. It was built in 1989 and renovated in 1992. The rest area comprises of one building that serves the south and north bounds of I-70 at mile marker 149, 7 miles west of Indiana line (boarder). This rest area provides several services for visitors including: weather information, travel information and guides, restrooms, vending machines, and outdoor picnic areas, see Figure 68.

Figure 68. Cumberland Road rest area.

The components of energy consumption in Cumberland Road rest area include exterior lighting, interior lighting, space heating, air conditioning, water heater, vending machines, surveillance cameras, weather information, hand dryers, water coolers, and water-treatment system and well pump. The exterior lighting include lighting poles for the road between I-70 and the rest area parking lot, lighting towers for the parking lot, and outdoor lighting fixtures for the rest area building. The interior lighting includes lighting fixtures for lobbies, men‘s restrooms, women‘s restrooms, information room, garage, attic, mechanical room, and storage room. The interior and exterior lighting fixtures in this rest area are summarized in Table 61 and Table 62. Some lighting fixtures for Cumberland Road rest area are shown in Figure 69.

The Cumberland Road rest area is heated and air-conditioned using a furnace, two air-cooled condensing units, and two exhaust fans. The furnace is located in the storage room while the two air-cooled condensing units are placed outside the rest area building. Two electrical water heaters (Bradford White cooperation, PHCC) are used for the rest area building to heat water with capacities of 30 gallons and 40 gallons. Furnace, air-cooled conditioning units and one water heater are shown in Figure 70.

Table 61. Interior Lighting for Cumberland Road Rest Area

Location	Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Lobby	square fluorescent fixture	8	2	U-shape GE F35CW-U-6-WM-ECO 35 watts
Information room	square fluorescent fixture	2	2	U-shape GE F35CW-U-6-WM-ECO 35 watts
	rectangular fluorescent fixture 1	3	2	4' F34 CW-RS-WU-ECO 34 watts
	rectangular fluorescent fixture 2	1	1	4' F34 CW-RS-WU-ECO 34 watts
Men's restroom	square fluorescent fixture	3	2	U-shape GE F35CW-U-6-WM-ECO 35 watts
	rectangular fluorescent fixture	6	1	4' F34 CW-RS-WU-ECO 34 watts
Women's restroom	rectangular fluorescent fixture	3	2	U-shape GE F35CW-U-6-WM-ECO 35 watts
	rectangular fluorescent fixture	6	1	4' F34 CW-RS-WU-ECO 34 watts
Garage	rectangular fluorescent fixture	3	2	4' Philips F40CW/RS/EW 34 watts, not used frequently
Mechanical room	rectangular fluorescent fixture	4	2	4' Philips F40CW/RS/EW 34 watts
Attic	Surface fixture	4	2	Philips F40CW 40 watts, turned on 20 min. per day
Vending storage	rectangular fluorescent fixture	2	2	4' F34 CW-RS-WU-ECO 34 watts

Table 62. Exterior Lighting for Cumberland Road Rest Area

Location	Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Entrance and exit	light pole	25	1	N.A.
Building	recessed fixture	10	1	MH M140/M90/E MHC 100/O/M/4K
parking lot	lighting tower	2	8	HPS

Figure 69. Lighting fixture in Cumberland Road rest area.

Figure 70. Air-conditioning units and water heater in Cumberland Road rest area.

The rest area has six vending machines: three for cold drinks, two for snacks, and one for hot drinks, as shown in Figure 71. Nineteen Surveillance cameras are used inside and outside the rest area building to maintain safety for visitors, and interior lighting is needed all the time for these cameras while exterior lighting is need during the night time in order to ensure clarity of video recording. The weather information is provided using a television in the lobby. Six Code Blue emergency phones are available in the rest area building: one in the building lobby and five in the parking lot. The rest area building also includes a refrigerator, a microwave, a humidifier, a coffee maker, a fan, two vacuum cleaners, an air-conditioning unit, and two computers for surveillance cameras (inside and outside cameras) in the maintenance room.

Figure 71. Vending machines in Cumberland Road rest area.

The men‘s and women‘s restrooms of the southbound include four hand dryers, where each has 2300 watt electrical capacity. Five water coolers are available in the rest area to provide cold drinking water for visitors: two water coolers are available in the lobby of the rest area building and three water coolers are available outside the building. Hand dryers and water coolers in Cumberland Road rest area are shown in Figure 72. Other water consumption fixtures in the Cumberland Road rest area include faucets, urinals and toilets, as shown in Figure 73. The quantities and characteristics of water fixtures in this rest area are shown in Table 63.

Figure 72. Hand dryers and water coolers in Cumberland Road rest area.

Table 63. Water Fixture in Cumberland Road Rest Area

Location	Type of Water Fixture	Quantity	Characteristics
Men's restrooms	Faucets	3	Electronic low-flow faucet
	Toilets	3	Electronic 3.5 GPF
	Urinals	2	Electronic 1.6 GPF
Women's restrooms	Faucets	3	Electronic low-flow faucet
	Toilets	5	Electronic 3.5 GPF

Figure 73. Water fixtures in Cumberland Road rest area.

C.5 TURTLE CREEK REST AREA

Turtle Creek rest area has approximately 839 thousand annual visitors based on 2009 statistics with estimated annual decrease of 1.05%. This rest area was built in 1980 and it comprises of one building that serve the east and west bounds of I-90 at mile marker 2, 2 miles south of Wisconsin line (boarder). This rest area provides several services for visitors including: weather information, travel information and guides, restrooms, vending machines, and outdoor picnic areas, see Figure 74.

Figure 74. Turtle Creek rest area.

The components of energy consumption on the westbound of Turtle Creek rest area include exterior lighting, interior lighting, space heating, air conditioning, water heater, vending machines, surveillance cameras, weather information, hand dryers, water coolers, and water-treatment system and well pump. The exterior lighting include lighting poles for the road between I-90 and the rest area parking lot (both ways), lighting towers for the parking lot, and outdoor lighting fixtures for the rest area building. The interior lighting includes lighting fixtures for lobbies, men‘s restrooms, women‘s restrooms, Handicap toilet, mechanical room, and storage rooms. The interior and exterior lighting fixtures in this rest area are summarized in Table 64 and Table 65. Some lighting fixtures in Turtle Creek rest area are shown in Figure 75.

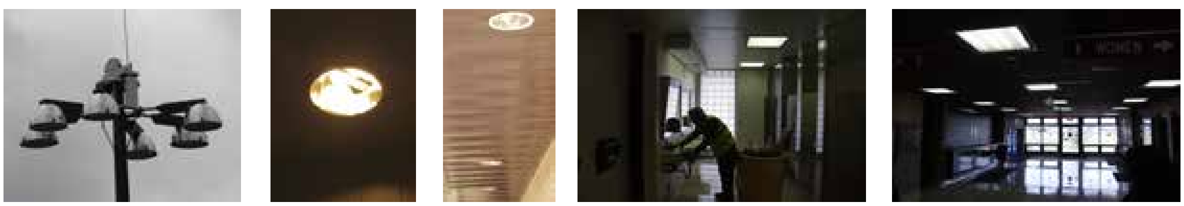


Figure 75. Lighting fixtures in Turtle Creek rest area.

Table 64. Interior Lighting for Turtle Creek Rest Area

Location	Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Lobby	square fluorescent fixture	18	2	U-shape Sylvania Supersaver H018 34 watts
Tourism office	rectangular fluorescent fixture	5	2	4' Philips F30T12/CW/RS/EW-II 25 watts
	square fluorescent fixture	2	2	U-shape Sylvania F20T12/CW 20 watts
Men's restroom	square fluorescent fixture	6	2	U-shape Sylvania Supersaver H018 34 watts
	rectangular fluorescent fixture	4	4	4' Sylvania F34 CW/SS/ECO 34 watts
Women's restroom	square fluorescent fixture	6	2	U-shape Sylvania Supersaver H018 34 watts
	rectangular fluorescent fixture	4	4	4' Sylvania F34 CW/SS/ECO 34 watts
Handicap toilet	square fluorescent fixture	1	2	U-shape Sylvania Supersaver H018 34 watts
Storage room	rectangular fluorescent fixture	3	2	4' Sylvania F34 CW/SS/ECO 34 watts
Mechanical room	rectangular fluorescent fixture 1	4	2	4' Sylvania F34 CW/SS/ECO 34 watts and 4' GE F48 T12-CW-HO

Table 65. Exterior Lighting for Turtle Creek Rest Area

Location	Type of Lighting Fixture	Quantity	Lamp(s) per Fixture	Characteristics
Building	recessed fixture	15	1	MH ED17 PMH7100 100 watts
parking lot	lighting tower	2	6	N.A.

The Turtle Creek rest area building is heated and air-conditioned using two furnaces, two air-cooled condensing units, and an exhaust fan. The two furnaces are located in the attic of the building while the two air-cooled condensing units are placed outside the rest area building. Each furnace has a HTG coil capacity of 25 KW while each condensing unit has a capacity of 4 tons. A natural gas water heater (State water heater) is used in the rest area building to heat water with a capacity of 100 gallons. Air-conditioning units and water heater are shown in Figure 76.

Furnace

Air cooled condensing units

Water heater

Figure 76. Air-conditioning units and water heater in Turtle Creek rest area.

One well is used the rest area to supply water, and a water-treatment system is used to treat well water. The treatment system includes hydro-pneumatic tank, hydro-pneumatic control panel, air compressor, chemical feed tanks, and a sump pump, as shown in Figure 77. The rest area has six vending machines: three for cold drinks, two for snacks, and one for hot drinks, as shown in Figure 78. Seven Surveillance cameras are used in the rest area to maintain safety for visitors inside and outside the rest area building. Interior lighting is needed all the time for these cameras and exterior lighting is needed at night time in order to ensure clarity of video recording. The weather information is provided using a television in the lobby. Four Code Blue emergency phones are available in rest areas: one in the lobby and three in the parking lot of the rest area building. The rest area building also includes a microwave, a kettle, a coffee maker, a cassette, and a computer for surveillance cameras in the maintenance room.

Pressure tank

Air pump

Figure 77. Two components of water-treatment system at the Turtle Creek rest area.

Figure 78. Vending machines in Turtle Creek rest area.

The men's and women's restrooms on the southbound include eight hand dryers, where each has 2300 watt electrical capacity. Two water coolers are available in the lobby of the rest area building to provide cold drinking water for visitors. Hand dryers and water coolers in Turtle Creek rest area are shown in Figure 79. Other water consumption fixtures in the Turtle Creek rest area include faucets, urinals and toilets, as shown in Figure 80. The quantities and characteristics of water fixtures in this rest area are shown in Table 66.

Figure 79. Hand dryers and water coolers in Turtle Creek rest area.

Table 66. Water Fixtures in Turtle Creek Rest Area

Location	Type of Water Fixture	Quantity	Characteristics
Men's restrooms	Faucets	6	Electronic faucet
	Toilets	6	Electronic 3.5 GPF
	Urinals	4	Electronic 1.6 GPF
Women's restrooms	Faucets	6	Electronic faucet
	Toilets	10	Electronic 3.5 GPF

Figure 80. Water fixtures in Turtle Creek rest area.

APPENDIX D POTENTIAL BMPS AND THEIR ENERGY AND ECONOMIC PERFORMANCE FOR CUMBERLAND ROAD, TURTLE CREEK, GREAT SAUK TRAIL, WILLOW CREEK, AND MACKINAW DELLS REST AREAS

D.1 CUMBERLAND ROAD REST AREA

The Cumberland Road rest area is located at 7 miles west of the Indiana line (border), at mile marker 149 of I-70 and consists of one building that serves the north- and southbound lanes of I-70. It has approximately 608 thousands visitors with annual decrease of 1.53% in visitation rate based on 2009 statistics. The rest area was built in 1989 and renovated in 1992. The major sources of energy consumption in the rest area include the interior and exterior lighting, heating and cooling, vending machines, hand dryers, pump station, and water heater. The next sections discuss the energy consumption analysis for the rest area building as well as LCC analysis for implementing different green building measures including interior and exterior energy-saving light bulbs, motion-activated lighting, vending occupancy controls, motion exhaust sensors, geothermal heat pumps, Energy Star–rated air-source heat pump, thermal pane glass, vestibule entrance, energy-efficient hand dryers, photovoltaic systems, solar water heater, solar daylight tubes, and water-saving plumbing fixtures.

D.1.1 Energy Audit and Analysis

The Cumberland Road rest area has one utility meter to measure energy consumption in its building. The utility meter can be used to measure the monthly energy consumption of the rest area however they cannot provide energy consumed by each device or equipment in the rest area. In order to identify major sources of energy consumption in the rest area buildings and their costs, an energy simulation model was developed using the eQuest energy simulation software environment. The eQuest software can be used to simulate the energy performance of a building including its construction materials, weather, space heating and cooling, air ventilation, air infiltration and exhaust, temperature control, interior and exterior lighting, water use, windows and doors, skylights, operation schedule and occupancy, building activities, equipment loads. Furthermore, eQuest can account for different scenarios for replacing any of the current equipment or devices in buildings and calculate energy consumption accordingly. This capability of measuring building energy consumption based on different scenarios of implementing various green building measures and equipment will be used to analyze and identify a list of promising BMPs for Cumberland Road rest area.

The Cumberland Road rest area model was developed similar to the Coalfield rest area buildings. The model was developed based on the rest area's location, square footage, architectural shape, zones, building envelope construction, infiltration, building orientation, operation schedule, building activities, building occupancy, ventilation, HVAC system, temperature control, and water heater. All energy consumption data for the Cumberland Road rest area including lighting, HVAC system, hand dryers, vending machines, ventilation, infiltration, exhaust, occupancy, water pump and water heater were modeled using a similar procedure to the one described earlier for the Coalfield rest area buildings.

After modeling the rest area building in eQuest, the simulation model was run to simulate the building performance with respect to weather conditions throughout a year and calculate monthly and total energy consumption categories of the building. Due to the difficulty of measuring air-infiltration rates for entry doors during the site visit; several runs of the simulation model were conducted with varying reasonable rates of infiltration and ventilation in order to minimize the differences between simulated and actual energy consumption reported in the building's energy bills. The parameters of infiltration were eventually set in the model to 15 CFM/ person for restrooms, lobby, and vending area, and 85 CFM/person for mechanical and storage rooms, infiltration rate was set to 2.0 air change per hour in the model to account for single entry of the rest area and match with energy bills. Figure 81 compares the simulated monthly energy consumption of the building based on the developed model in eQuest to the actual energy consumption reported in the utility bills of the Cumberland Road rest area building in 2009. Based on the results in Figure 81, the average absolute difference between the energy consumption for the developed simulation model and actual bills is 5.7% and the maximum and minimum difference between the energy consumption for the developed simulation model and actual bills were 10.0% in March and 0.4% in December.

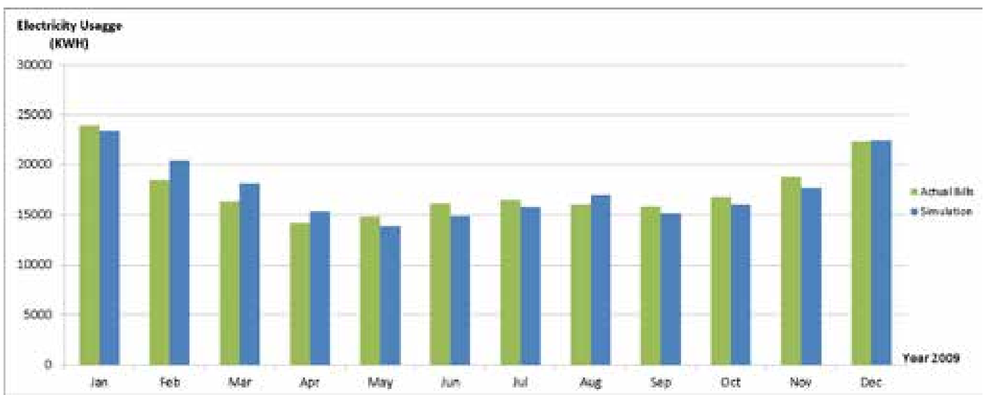


Figure 81. Simulated and actual electricity consumption of Cumberland Road rest area building in 2009.

It should be noted that the number of visitors per day was assumed to be constant throughout the year. Therefore, the difference in energy consumption between the eQuest simulation model and energy bills can be caused by the varying number of visitors per day which affects the building's heating and cooling energy consumption as well as its water use. In addition, the occasional and varying use of other small devices such as a microwave, laptop, small fan or heater unit that were observed during the site visits in the maintenance room can contribute to this difference between the simulation results and the energy bills.

The square footage of Cumberland Road rest area is 2410 SF and its annual number of visitors is 607,725 which leads to electricity consumption rate of 87.27 kwh/SF per year, 13.71 $/SF per year, and 0.35 kwh/visitor per year. The breakdown of electricity cost for the Cumberland Road rest area building among its main sources of consumption is shown in Figure 82. The eQuest energy simulation model shows that the highest source of energy consumption is exterior lighting that represents 26% of the total energy consumption of the building. On the other hand, the two sources that consume the lowest energy in the building are hand dryers and water pump that represent 3% and 1% of the building's total energy consumption, respectively. Space heating and cooling comprises 23% of total energy consumption of the building. The "other" category includes small equipment and devices such as vacuum cleaners, coffee machines, microwave, personnel laptop, etc., that are occasionally used in the rest area building and were not considered in the simulation model.

The greatest use of energy for heating purposes (approximately 7% of total energy consumption) is caused by air ventilation in the rest area building which represents the outside air that replaces exhausted air from the restroom fans in addition to the outside air that enters the HVAC cycle. Additionally, 2% of the total energy costs is caused by infiltration which requires heating infiltrated air that leaks into the building mainly due to the frequent opening and closing of the building entry and exit doors (infiltration was modeled in eQuest model by 1.2 average air changes per hour).

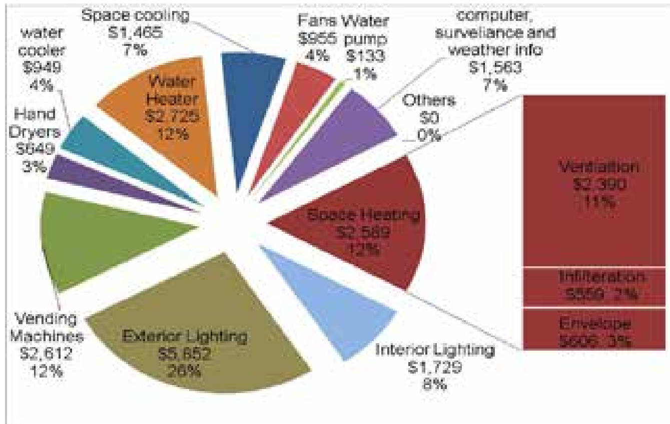


Figure 82. Energy cost breakdown of Cumberland Road rest area building.

D.1.2 Lighting

Lighting in the Cumberland Road rest area represents approximately 34% of total energy consumption with an annual cost of $7,554. The following two subsections analyze replacing current interior and exterior lighting with more-efficient and energy-saving bulbs. The economic analysis of light replacement in these two sections assumes an annual interest rate of 2% and escalation in utility rate of 5%.

D.1.2.1 Interior Lighting

Interior lighting in the Cumberland Road rest area consists of linear and U-shape fluorescent T12 bulbs. These bulbs can be replaced by linear and U-shaped fluorescent T8 to provide similar luminance level, less energy consumption and longer life expectancy. Table 67 through Table 69 summarizes the impact of replacing current T12 with T8 fluorescent light bulbs for the Cumberland Road rest area. These lighting replacements can provide annual saving of $393 and reduce total energy consumption by 2.8%. The conducted LCC analysis for replacing all current T12 lighting with T8 bulbs is shown in Figure 83. The average payback period for all light replacement is 0 years (immediate payback period) which represents a green building measure with promising return on investment.

Table 67. Replacing U-Shape Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in Lobby and Restrooms of Cumberland Road Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	GE (F35CW/U6/WM/ ECO/CVG-UPC)	Sylvania (FBO28/841/XP/SS/ECO)
Number of bulbs	32	32
Mean lumens (lumen)	2520	2585
Kelvin temperature (K)	4100	4100
Color Rendering Index (CRI)	60	75
Life time (hr)	18000	26000
Consumption per bulb (watt)	35	28
Lamp cost ($/each)	62.99	15.79
Change in lumens output levels (%)	N.A.	+2.6
Reduction in energy consumption (%)	N.A.	20
Annual savings in energy consumption - first year ($)	N.A.	$208
Payback period (yr)	N.A.	Immediate payback

Table 68. Replacing Linear Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in Lobby, Restrooms, Maintenance and Storage Rooms in Cumberland Road Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	GE 23010 (F34CW/RS/WM/ECO)	Sylvania 22234 (FO32/25W/841/ XP/SS/ECO)
Number of bulbs	31	31
Mean lumens (lumen)	2280	2327
Kelvin temperature (K)	4100	4100
Color Rendering Index (CRI)	60	85
Life time (hr)	20000	36000
Consumption per bulb (watt)	34	25
Lamp cost ($/each)	3.39	7.39
Change in lumens output levels (%)	N.A.	+2.1
Reduction in energy consumption (%)	N.A.	26.4
Annual savings in energy consumption - first year ($)	N.A.	183
Payback period (yr)	N.A.	0.48, 1.5, and 5.5*

* Payback period for lobby and restrooms, maintenance room, and storage rooms, respectively

Table 69. Replacing Fluorescent T12 bulbs with Energy-Efficient T8 Light Bulbs in Attic of Cumberland Road Rest Area Building

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement Fixtures/Bulbs
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	Philips (F40T12 CWX ALTO)	Sylvania 22234 (FO32/25W/841/ XP/SS/ECO)
Number of bulbs	8	8
Mean lumens (lumen)	1800	2327
Kelvin temperature (K)	4100	4100
Color Rendering Index (CRI)	89	85
Life time (hr)	20000	36000
Consumption per bulb (watt)	40	25
Lamp cost ($/each)	3.99	7.39
Change in lumens output levels (%)	N.A.	+29
Reduction in energy consumption (%)	N.A.	37.5
Annual savings in energy consumption - first year ($)	N.A.	2
Payback period (yr)	N.A.	19.8*

*Attic lighting is used approximately 20 minutes per day.

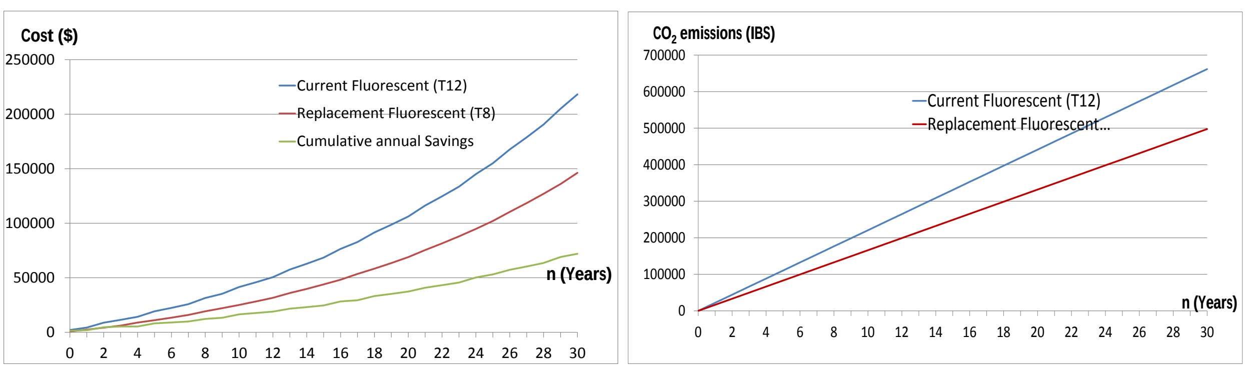


Figure 83. Cumulative costs, savings, and CO_2 emissions for current and replacement lighting in Cumberland Road rest area building.

D.1.2.2 Exterior Lighting

This section analyzes the impact of replacing current exterior lighting of Cumberland Road rest area with LED and induction lighting. The average lighting operating hours was determined based on eQuest simulation model, which accounts for the location of the rest area building and its seasonal operational hours. The average lighting hours of exterior lighting was calculated to be 9.07 hours. The current exterior lighting of Cumberland Road rest area consists of (1) ten recessed light fixtures with 100 MH in each; (2) twenty-five light poles at entrance and exit of the rest area with HPS 250 watts in each (assumed bulbs); and (3) two lighting towers with a total of sixteen 400 watt HPS bulbs. Due to the unavailability of the exact brand and luminance characteristics of current exterior lighting, reasonable assumptions were made for their luminance level giving the fact that the luminance characteristics are not significantly affected by the manufacturers. It should be noted that LCC was conducted for one-for-one replacement to reduce initial costs. This one-for-one replacement is expected to reduce the current total lighting output (lumen) of light poles by 47% and 54% for LED and induction lighting replacements respectively. Similarly, this one-for-one replacement will reduce the current total lighting output (lumen) of (1) light towers by 60% and 64% for LED and induction lighting replacements, respectively; and (2) recessed fixtures by 33% and 38% for LED and induction lighting replacements, respectively. It should be noted that despite the lower average luminance of LED and induction lighting compared to HPS lighting, LED and induction lighting provide higher Color Rendering Index (CRI) than HPS lighting. CRI measures the effect of a light source on the perceived color of object and surface. Having high value of CRI makes virtually all colors look natural and reduces glare (Light Sout Services 2010). Furthermore, HPS light bulbs have low color temperature that ranges from 1900 to 2700 degrees K which is referred to as “warm” light sources, while LED and induction lighting have higher color temperature that ranges from 2700 to 8000 degrees K which is referred to as “cool” light source. Receptors in the eye respond to light sources differently, which can affect mood and human health. In addition, mixing light sources is not desirable and should be avoided in the light replacement (McColl & Veitch 2001; U.S. DOE 2008).

A LCC analysis was conducted to examine the feasibility of replacing a one-for-one replacement of the current exterior lighting of the rest area building, its parking lot as well as entrance and exit with LED and induction lighting. The conducted analysis considered the possible lighting fixtures and bulbs shown in Table 78 as recommended by manufactures.

The components and results of the conducted analysis of one-for-one replacements are summarized in Table 71 through Table 73 for all lighting fixtures/bulbs of the rest area. The cumulative cost and savings as well as carbon footprint and reductions in CO_2 emissions for replacing exterior lighting of Cumberland Road rest area are shown in Figure 86. The analysis shows that these light replacements can provide annual savings of 2,989, or 13.4% of total energy consumption for LED lighting replacements and $2,947 or 13.2% of total energy consumption for induction lighting replacements. This leads to a payback period of 22.5 years for LED light replacements and 6.3 years for induction lighting replacements.

U.S. DOE “LED Application Series: Outdoor Area Lighting,“ U.S. Department of Energy, Energy Efficiency and Renewable Energy, 2008, http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/led-color-characteristics-factsheet.pdf, accessed June 8, 2013.
McColl, S.L. and Veitch, J.A. “Full-spectrum fluorescent lighting: a review of its effects on physiology and health,” National Research Council Canada, NRCC-43097, 2001.

Table 70. Characteristics of Current and Replacement Lighting for Exterior Lighting of Cumberland Road Rest Area Building

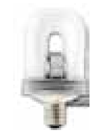
Light Characteristic items	Current lighting		Replacement (LED lighting)		Replacement (Induction light)	
	Type	Characteristics	Type	Characteristics	Type	Characteristics
Mean Lumens (lumen)	MH 100w	9000	LED Lamp	6000	Induction Lamp	5600
Color temperature (Kelvin)		4200		3000-5000		2700-6500
Color rendering index (CRI)		93		80		83
Life time (hours)		2400		50000		100000
Consumption (w)		100		80		80
Lamp cost ($)		80		405		248
Lamp and fixture cost ($)		-		-		-
Initial Lumens (lumen)	HPS 250w	28500	LED Steet Light	15000	Induction Steet Light	13200
Color temperature (Kelvin)		2000		2700-8000		5000
Color rendering index (CRI)		25		75		83
Life time (hours)		30000		50000		75000
Consumption (w)		250		168		165
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1274		486
Initial Lumens (lumen)	HPS 400w	50000	LED Steet Light	20000	Induction Steet Light	18000
Color temperature (Kelvin)		2100		2700-8000		5000
Color rendering index (CRI)		20		75		83
Life time (hours)		24000		50000		75000
Consumption (w)		400		224		225
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1493		538

Table 71. Replacing HPS 400W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Cumberland Road Rest Area Building

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	LED	Induction
Number of bulbs	16	16	16
Initial lumens (lumen)	45000	20000	18000
Kelvin temperature	2100	2700-8000	5000
Color Rendering Index (CRI)	20	75	83
Life time (hr)	24000	50000	75000
Consumption per bulb, including ballast (watt)	481	224	230
Bulb cost ($)	54	1493	538
Reduction in lumens output levels (%)	N.A.	60	64
Reduction in energy consumption (%)	N.A.	53	52
Annual savings in energy - first year ($/year)	N.A.	1,492	1,457
Payback period	N.A.	18.6	5.1

Table 72. Replacing HPS 250W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Cumberland Road Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	HPS	LED	Induction
Number of bulbs	25	25	25
Initial lumens (lumen)	28500	15000	13200
Kelvin temperature	2000	4900	5000
Color Rendering Index (CRI)	25	75	83
Life time (hr)	30000	50000	75000
Consumption per bulb, including ballast (watt)	315	168	168
Bulb cost ($)	54	1274	486
Reduction in lumens output levels (%)	N.A.	47	54
Reduction in energy consumption (%)	N.A.	47	47
Annual savings in energy - first year ($/year)	N.A.	1,334	1,334
Payback period (yr)	N.A.	27.2	7.2

Table 73. Replacing MH 100W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Cumberland Road Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	MH	Cobra head LED Luminaire	Induction
Number of bulbs	10	10	10
Initial lumens (lumen)	5200	3000	3500
Kelvin temperature	3000	3000-5000	5000
Color Rendering Index (CRI)	75	80	82
Life time (hr)	10000	50000	100000
Consumption per bulb, including ballast (watt)	110	80	82
Bulb cost ($)	33	405	248
Reduction in lumens output levels (%)	N.A.	33	38
Reduction in energy consumption (%)	N.A.	27	25
Annual savings in energy - first year ($/year)	N.A.	109	102
Payback period ($)	N.A.	20.9	6.8

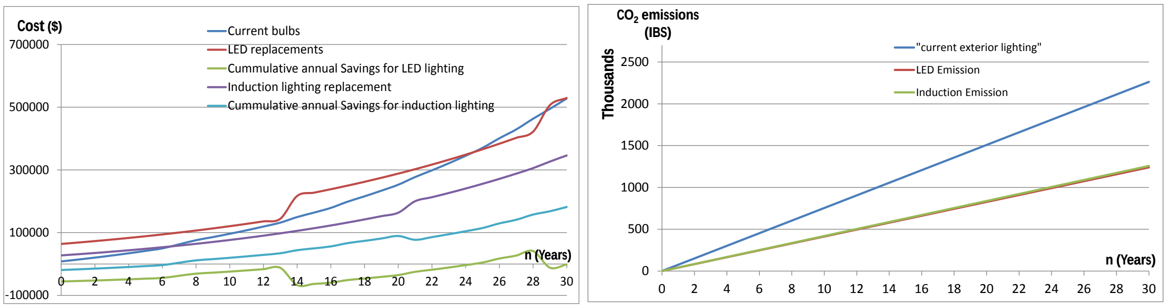
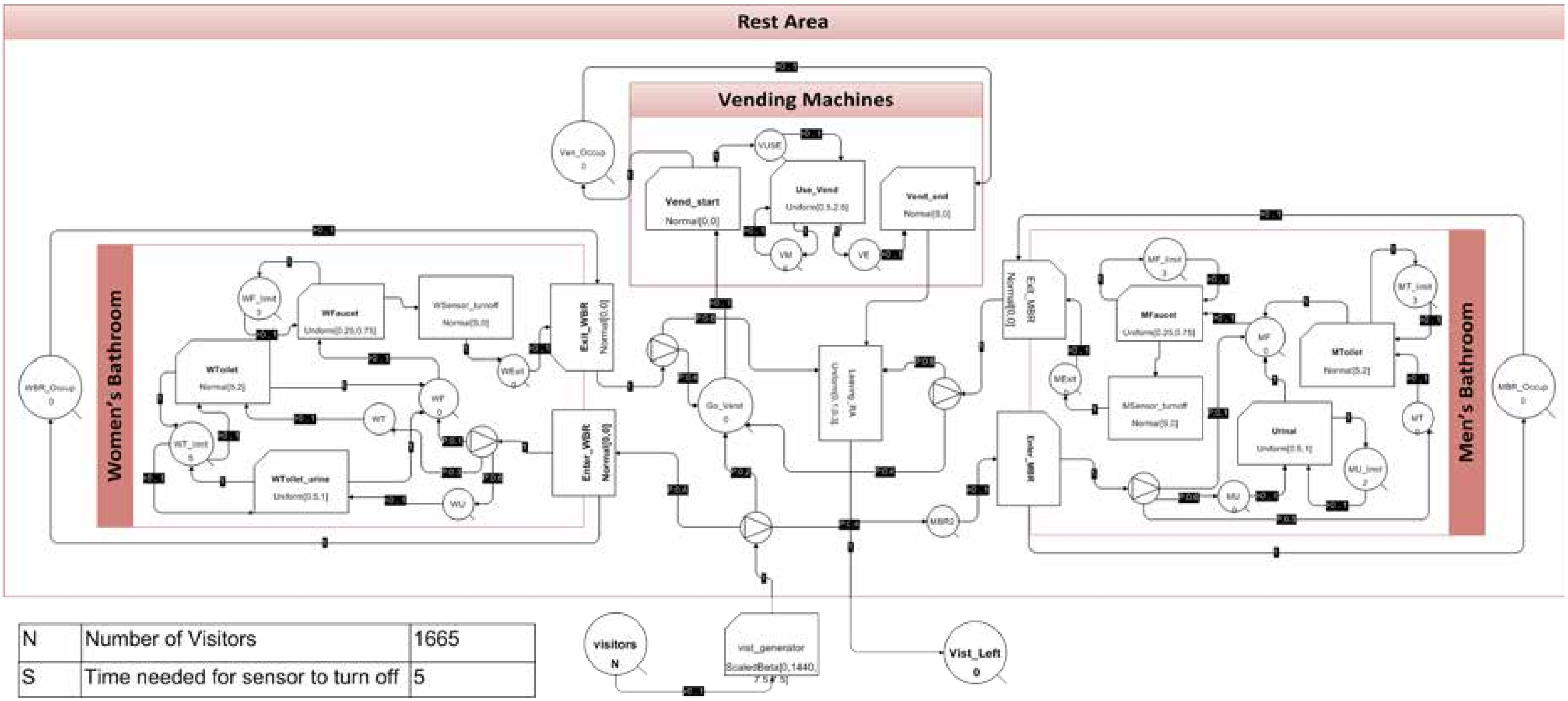


Figure 84. Cumulative costs, savings, and CO_2 emissions for LED and induction lighting replacements for Cumberland Road rest area building.

D.1.3 Motion Sensors

Rest areas have different operational schedule than business and commercial buildings and they have to operate 24 hours a day with few or no occupants during low visitation periods at night. This makes motion sensors a promising technology for rest area buildings. This section analyzes the implementation of motion sensors to control the lighting of restrooms and vending machine areas. Motion sensors also can be used to reduce space heating and cooling by reducing the use of exhaust fans at night when there are few or no occupants in the restrooms.

In order to estimate the energy savings in lighting and exhaust fans, the research team developed a separate simulation model using EZstrobe simulation language (Martinez 2006) to analyze and simulate the use of restrooms and vending machines based on the number and frequency of rest area visitors. The simulation model was developed to mimic the utilization of the rest area facilities by its visitors. The model was created to generate the number of visitors to the rest area using a beta distribution function to represent a high frequency of visitors during the morning, noon, and afternoon hours and low frequency during the night and early morning hours. The model also assumes that the percentages of visitors that will use the men's restroom, women's restroom and vending machines are 40%, 40%, and 20%, respectively. Similarly, the probabilities that restroom visitors will use urinals, toilets and only faucets were assumed to be 30%, 60%, and 10%, respectively with reasonable random durations for each of these restroom tasks, as shown in Figure 85. It should be noted that the model assumes that each visitor using the toilet or urinal will also use the faucet afterwards. The developed model accounts for an amount of time for sensors to keep the light on after a visitor leaves a restroom. After a visitor leaves the restroom, the model assumes that there is a probability of 60% that the visitor will leave the rest area and 40% will use vending machines. The developed model can estimate how long the lighting in restrooms of the rest area will be turned off if motion-activated lighting were implemented in the restrooms. Similarly, the amount of time that lighting in vending machines and exhaust fans being turned/switched off can be calculated by the developed simulation model. Figure 86 shows rest area visitors while being in the men's restroom throughout a simulation day. Table 74 summarizes the percentages of occupancy for restrooms and vending machines of the Cumberland Road rest area assuming that the lights or fans remain turned on for 5 minutes after the departure of the last visitor. The following subsections use the developed simulation model to estimate potential savings for using motion sensors in the rest area building and their expected payback periods. The economic analysis of motion sensors accounts for an annual interest rate of 2% and escalation in utility rate of 5% in calculating payback period of implementing this technology.



N	Number of Visitors	1665
S	Time needed for sensor to turn off	5

Figure 85. Motion-sensor simulation model for Cumberland Road rest area building.

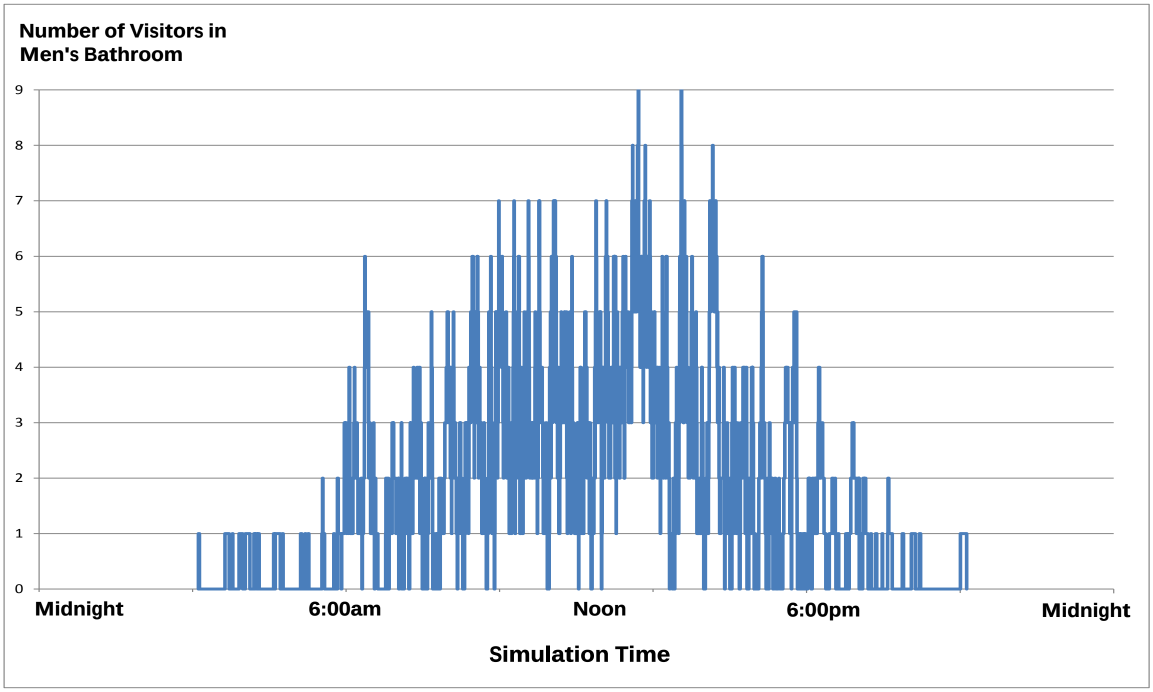


Figure 86. Number of visitors in men's restroom throughout a simulation day in Cumberland Road rest area building.

Table 74. Percentage Occupancy for Restrooms and Vending Area in Cumberland Road Rest Area Building

Percentage of Occupancy In Men's Restroom	Percentage Occupancy in Women's Restroom	Percentage Average Occupancy in Restrooms	Percentage Occupancy in Vending Machines Area
59.3%	57.4%	58.4%	39.9%

D.1.3.1 Motion-Activated Lighting

Motion-activated lighting can be installed in restrooms to turn off lights automatically when they are not occupied. As discussed in the previous section, restrooms in the Cumberland Road rest area have an average approximate occupancy of 58.4% including 5 minutes for the occupancy sensors remain in detection before turning off automatically. This leads to average 41.6% savings in lighting of restrooms. Table 75 shows the results of the LCC analysis for implementing motion-activated lighting in the restrooms of the Cumberland Road rest area. The analysis shows that the motion-activated lighting can provide approximate savings of $320 annually or 1.4% of total energy consumption of the Cumberland Road rest area building which represents a payback period of 2.7 years for this green building measure. Furthermore, motion-activated lighting in restrooms can eliminate annually 4,254 lb of CO_2 emissions.

Implementing motion-activated lighting in the lobby will not be feasible due to security requirements that require lights to be turned on at all times to ensure the proper operation of the surveillance cameras. Moreover, implementing motion-activated lighting in maintenance rooms will not provide much savings and the payback period will be long since the maintenance staff often turn off the light before leaving the mechanical rooms of the rest area.

Table 75. Motion-Activated Lighting Analysis for Restrooms of Cumberland Road Rest Area Building

Savings and Cost Items	Amount/Savings
Total load of lighting fixtures (watt)	828
Electricity cost ($/kwh)	0.106
Occupancy sensors cost ($)	288
Labor installation cost ($)	583
Total Initial cost ($)	871
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	769
Annual lighting energy savings ($)	320
Payback period (yr)	2.7
Amount of eliminated CO_2 (Ib)	4,254
Savings in total energy consumption of building (%)	1.4

D.1.3.2 Vending Occupancy Controls

Similar to motion-activated lighting, occupancy controls can be installed for vending machines to turn off their lighting when the vending area is not occupied. Based on the developed simulation model for motion sensors, lights of vending machines are expected to be on for approximately 39.9% of hours during the day assuming a duration of 5 minutes for the sensor to remain on after detecting the last motion in the vending area. This leads to 61.1% lighting savings of the vending machine area. Table 76 shows the economic analysis of installing occupancy controls for vending machines area in the Cumberland Road rest area. The analysis shows that these occupancy controls can provide approximate savings of $335 annually or 1.5% of total energy consumption of the Cumberland Road rest area building, which leads to a payback period of 1.03 years. This measure can also eliminate 4,454 Ib of CO_2 emissions annually due to the achieved reduction in energy consumption.

Table 76. Occupancy Controls Analysis for Vending Machines Area in Cumberland Road Rest Area Building

Motion-Activated Lighting Analysis	Amount/Savings
Total load of vending machines lighting (watt)	600
Electricity cost ($/kwh)	0.106
Occupancy sensors cost ($)	120
Labor installation cost ($)	219
Total Initial cost ($)	339
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	557
Annual lighting energy savings ($)	335
Payback period (yr)	1.03
Amount of eliminated CO_2 (Ib)	4,454
Savings in total energy consumption of building (%)	1.5

D.1.3.3 Motion Sensors for Exhaust

Similar to motion-activated lighting, exhaust fans can operate only during the occupancy times of visitors. This will allow exhaust fans to be switched off automatically when there are no visitors, which will decrease the amount of outside air that needs to be heated or cooled. eQuest software does not provide a direct method to account for the use of exhaust fan sensors; however, this can be modeled by decreasing the exhaust rate by a value which reflects the switching off of exhaust fans when there are no occupants. Accordingly, exhaust fan flow can be decreased with the average non-occupancy percentage of restrooms (41.6%). Table 77 summarizes the economic analysis results for implementing motion sensors for exhaust fans in rest area building. The analysis shows that motion sensors for exhaust fans can provide approximate annual savings of $915 annually or 4.1% of total energy consumption of Cumberland Road rest area building, which leads to a payback period of 0.6 years. This measure can also eliminate 12,168 Ib of CO_2 emissions annually due to the reduction in energy consumption of heating and cooling.

Table 77. Analysis Results for Implementing Motion-Sensor Exhaust Fans in Cumberland Road Rest Area Building

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.106
Fan(s) and sensors cost ($)	433
Labor installation cost ($)	109
Total Initial cost ($)	542
Annual energy savings ($)	915
Payback period (yr)	0.6
Amount of eliminated CO_2 (Ib)	12,168
Savings in total energy consumption of building (%)	4.1

D.1.4 More-Efficient HVAC Systems

The current HVAC system at the Cumberland Road rest area consists of a split system with two condensers and electric resistance duct heaters. The system has a cooling capacity of about 7.5 tons and unknown heating capacity. The current HVAC system can be replaced with a more energy-efficient system that reduces heating and cooling energy consumption. The following three subsections analyze the replacement of the current HVAC system with more-efficient units and setting back the temperature at night.

D.1.4.1 Geothermal Heat Pump

The existing HVAC system in the Cumberland Road rest area building operates continuously year round and its consumption represents 27% of the total building consumption. Ground-source heat pumps can be more efficient than air-source heat pump as it uses the nearly constant temperature of earth (55°F) to heat and cool buildings. The eQuest simulation environment can be used to model the use of a geothermal HVAC system for Cumberland Road rest area building. The system was modeled to have heating coefficient of performance (COP) of 4.0 and a cooling efficiency of 18 EER. After running the eQuest model with geothermal heat pump, the model provides savings of 11.7% of total energy consumption. The installation and maintenance costs of geothermal heat pump were calculated similar to Coalfield rest area buildings. Table 78 summarizes the LCC components of replacing the current HVAC system with a geothermal heat pump.

Table 78. LCC Components for Replacing Current HVAC System with Geothermal Heat Pump in Cumberland Road Rest Area Building

Rest Area/LCC Components	Cost/Life
Capital cost - vertical system* ($)	31,570
Annual maintenance cost ($)	325
Annual operating cost ($)	3,235
Periodic cost ($)	19,570
Life (yr)	20

* Installation cost may vary due to soil conditions and resizing of the HVAC equipment

In order to compare the cost effectiveness and payback periods of replacing the current HVAC systems in the rest area with geothermal systems, the initial, maintenance, operating and replacement costs of the current HVAC system need to be identified. These costs were estimated similar to the Coalfield rest area buildings in order to carry out the LCC analysis. Table 79 summarizes the LCC components for the current HVAC system of the Cumberland Road rest area building.

Table 79. LCC Components for Current HVAC System of Cumberland Road Rest Area Building

Rest Area/LCC Components	Cost/Life
Capital cost ($)	13,020
Annual maintenance cost ($)	700
Annual operating cost ($)	5,975
Periodic cost ($)	13,020
Life (yr)	17
Manufacture year	2008 (assumed)
Replacement year	2025

A LCC analysis was conducted to compare the potential replacement of the current HVAC system with a geothermal heat pump based on an annual interest rate of 2%, escalation in utility rate of 5%, and annual increase of maintenance cost of 2%. Table 80 summarizes the LCC analysis results for replacing current HVAC with geothermal heat pump. The analysis shows that replacing the current HVAC system with a vertical loop geothermal heat pump has a payback period of 9.5 years. The cumulative costs for the current HVAC system, a vertical loop geothermal system, and savings are shown in Figure 87. Geothermal heat pump can also be installed along with a desuperheater to heat water in the cooling season. The desuperheater uses heat that is removed from the building space to heat domestic hot water. This unit can provide free hot water in the summer or when the system is in cooling mode. It can provide annual savings of $705 or 3.2% of total energy consumption. The payback period of the desuperheater is 2.3 years and it can eliminate 9,384 Ib of CO_2 emissions.

Table 80. LCC Analysis Results for Replacing Current HVAC System with Geothermal Heat Pump in Cumberland Road Rest Area Building

Rest Area	**Savings**
Annual kwh saved	24,640
Annual energy savings - first year ($/yr)	2,612
Annual eliminated CO_2 emissions (lb)	34,742
Payback period - vertical system (yr)	9.5

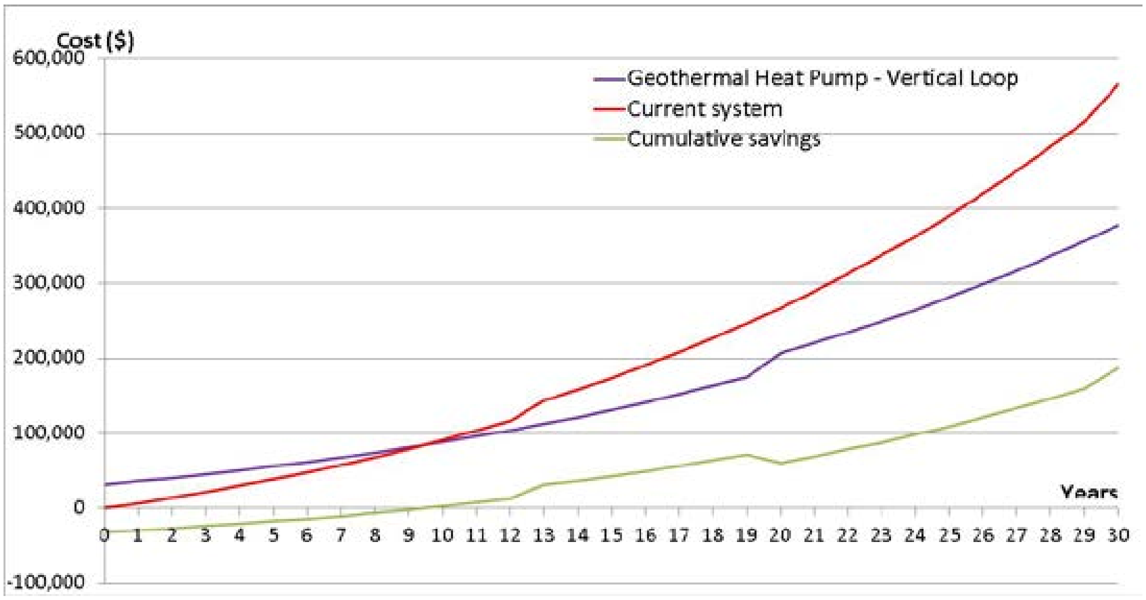


Figure 87. Cumulative costs of current HVAC system, vertical loop geothermal system, and savings for Cumberland Road rest area building.

D.1.4.2 High-Efficiency Air-Source Heat Pump

Another alternative for the current HVAC system at the Cumberland Road rest area is to replace it with a more-efficient Energy Star–rated air-source heat pump to reduce heating and cooling expenses. An air-source heat pump was modeled in eQuest to meet Energy Star recommendations with cooling efficiency of 12 EER and heating performance rating of 8.2 HSPR (Energy Star 2003). Table 81 summarizes the economic analysis results for replacing the current HVAC system with an Energy Star–rated air-source heat pump. The analysis shows that Energy Star–rated HVAC systems can provide annual savings of $1,401 annually or 7.9% of total energy consumption of the rest area building. This leads to a payback period of 7.3 years based on an annual interest rate of 2% and escalation in utility rate of 5%. This replacement can eliminate CO_2 emissions by 23,293 lb annually.

Table 81. Analysis Results for Replacing Current HVAC System With Energy Air-Source Heat Pump In Cumberland Road Rest Area Building

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.106
Total initial cost for air-source heat pump ($)	13,800
Annual energy savings ($)	1,751
Payback period (yr)	7.31
Amount of eliminated CO_2 (Ib)	23,293
Savings in total energy consumption of the rest area building (%)	7.9

D.1.4.3 Setting Back HVAC System at Night

Another method to reduce energy consumption for space heating and cooling of the rest area is to set back the temperature of the HVAC system at night. The number of visitors using the rest area at night is very limited and, accordingly, setting back the temperature at night can reduce the energy consumption of heating and cooling. Temperature can be set at night to 66°F in winter and 76°F in summer. This measure can be modeled in eQuest by editing the temperature set points in the simulation model to a temperature that reflects the set points at night using interpolation. The developed eQuest model showed that setting back the temperature at night can provide annual savings of $504 or 2.3% reduction in total energy consumption. The Cumberland Road rest area building may need programmable thermostats in order to setback the HVAC temperature at night. This measure can be implemented easily to the rest area with low initial cost.

D.1.5 Thermal Pane Glass for Windows and Doors

Thermal pane glass is a green building measure that can be added to the rest area building in order to reduce its cooling and heating energy consumption. This measure requires replacing all glazing as well as doors and windows in the rest area building with double-pane glass. This measure can be modeled in eQuest by replacing current single pane glass with double-pane glass. The analysis of implementing this measure provides annual savings of $575 or 2.6% of total energy consumption, as shown in Table 82. There is no expected payback period for this measure within 30 years as it requires major renovation for the rest area building with high initial cost. This measure can eliminate 7,642 Ib of CO_2 annually.

Table 82. LCC Analysis Results for Replacing Current Glazing and Doors with Double-Pane Glass in Cumberland Road Rest Area Building

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.106
Total initial cost ($)	40,024
Annual energy savings (kwh)	5420
Annual energy savings ($)	575
Payback period (yr)	More than 30
Amount of eliminated CO_2 (Ib)	7,642
Savings in total energy consumption of the rest area building (%)	2.6

D.1.6 Vestibule Entrance

Another measure to reduce energy consumption in the Cumberland Road rest area building is to add vestibule entrance to reduce air infiltration and provide better insulation in the lobby area. This measure can be modeled in eQuest by reducing air infiltration approximately from 1.2 ACH to 0.9 ACH (25% reduction). Table 83 summarizes the LCC analysis results for adding vestibule entrance in the rest area building. This measure can provide annual savings of $296 or 1.3% of the total energy consumption of the rest area building. The analysis shows that this measure can payback its installation cost in more than 30 years based on an annual interest rate of 2% and escalation in utility rate of 5%. This door replacement can eliminate 3,934 Ib of CO_2 emissions annually due to reduction in energy consumption.

Table 83. LCC Analysis Results for Adding Vestibule Entrance in Cumberland Road Rest Area Building

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.106
Total initial cost for adding another door ($)	19,878
Annual energy savings (kwh)	2790
Annual energy savings ($)	296
Payback period (yr)	More than 30 years
Amount of eliminated CO_2 (Ib)	3,934
Savings in total energy consumption of building (%)	1.3

D.1.7 Energy-Efficient Hand Dryers

Energy-efficient hand dryers are one of the green building measures that can be implemented in the Cumberland Road rest area building to reduce energy consumption of hand dryers was estimated based on a 50% use of rest area visitors each for 30 seconds according to manufacture use recommendations. Although, current hand dryers only consume approximately 2.2% of total energy consumption, they are one of the most visible devices for the rest area visitors. Moreover, slow velocity or inefficient hand dryers may discourage people to use them. This analysis considers the impact of installing three different models of energy-efficient hand dryers in the Cumberland Road rest area building to reduce their energy consumption, as shown in Table 84. The analysis shows that replacing current hand dryers may result in annual savings of $456 to $499 or 2.0% to 2.2% of total energy consumption in the rest area building based on three different models of energy-efficient hand dryers. These savings can provide a payback period of 2.2 years to 12.1 years for the three different models based on an annual interest rate of 2% and escalation in utility rate of 5%. This measure can eliminate up to 6,641 Ib of CO_2 emissions in Cumberland Road rest area building.

Table 84. LCC Analysis Results for Replacing Current Hand Dryers with Energy-Efficient Units for Cumberland Road Rest Area Building

LCC Items/Savings	Current Hand Dryer - World Dryer	1- World Dryer Airforce - J Series Hand Dryers	2- Xlerator Series Hand Dryers	3- Dyson Airblade Series Hand Dryers
Number of hand dryers	4			
Hand dryer consumption (watt)	2,300	1,100	1100	1500
Drying time (second)	30	12	15	12
Initial cost ($)	N.A.	1,092*	1,600*	6,400*
Annual visitors - 2009	607,725			
Savings over current hand dryers (%)	N.A.	81	76	74
Utility cost ($/kwh)	0.106			
Annual operating cost based on 50% use of visitors ($)	617	118	148	161
Annual savings (%)	N.A.	499	470	456
Annual savings of total energy consumption (%)	N.A.	2.2	2.1	2.0
Eliminated CO_2 emissions (lb)	N.A.	6,641	6,248	6,070
Payback period (yr)	N.A.	2.2	3.4	12.1

* (Restroom Direct 2012)

D.1.8 Solar Measures

Several solar measures can be used to reduce energy consumption in the Cumberland Road rest area building. These measures can include solar daylight tubes, photovoltaic systems, and solar water heaters. These measures can reduce energy consumption of interior lighting, heating water as well as generate renewable and clean electricity. The next subsections discuss the installation of these systems in the Cumberland Road rest area building.

D.1.8.1 Solar Tube Lighting

Solar daylight tubes are one of the green building measures that can be used to provide lighting for the building during the day light hours. The technology requires solar tubes to penetrate the building roof to the ceiling where they transmit the sunlight during the day time. This technology can be installed in restrooms and lobby to decrease the lighting use during the day light time. It can be installed in the attic of the rest area building while installing light controls in restrooms and lobby to control/dim interior lighting during the day. The energy savings that this technology can provide was calculated based on reducing daily lighting use by 5 hours. The analysis for adding solar daylight tubes in the rest area building is summarized in Table 85. Cumulative costs and savings for implementing solar daylight tubes in restrooms and lobby of the rest area are shown in Figure 88 and Figure 89. The analysis shows that this measure can provide saving of $341 annually or 1.53% of the total energy consumption. This can lead to a payback period of 20.8 years for restrooms and 15 years for lobby. It should be noted that, the installation of this measure is crucial in terms of the amount of savings that it can provide. Improper installation of solar daylight tubes with low insulation (low U value) can lead to high dissipation of energy and subsequently increase cooling and heating costs. On the other hand, proper installation of this measure with sufficient U value, Energy Star–rated tubes, can slightly increase heating and cooling. Based on modeling solar tubes in eQuest with similar skylight areas, this can lead to an increase in energy cost $156 annually. As a result the expected savings of this measure may reduce to $185 annually.

Table 85. LCC Analysis Results for Installing Solar Daylight Tubes in Restrooms and Lobby in Cumberland Road Rest Area Building

Savings and Cost Items	Restrooms	Lobby
Total load of lighting fixtures (watt)	828	938
Electricity cost ($/kwh)	0.106	
Number of Solar daylight tubes (10' diameter)	5	0
Number of Solar daylight tubes (18" diameter)	4	4
Total Initial cost ($)	$4,435	$3,300
Solar tubes operation time (hr)	5	5
Annual lighting energy cost ($)	$769	$871
Annual lighting energy savings (%)	$160	$181
Payback period (yr)	20.84	15.01
Amount of eliminated CO_2 (lb)	2,131	2,414
Savings in total energy consumption of building (%)	0.72	0.81

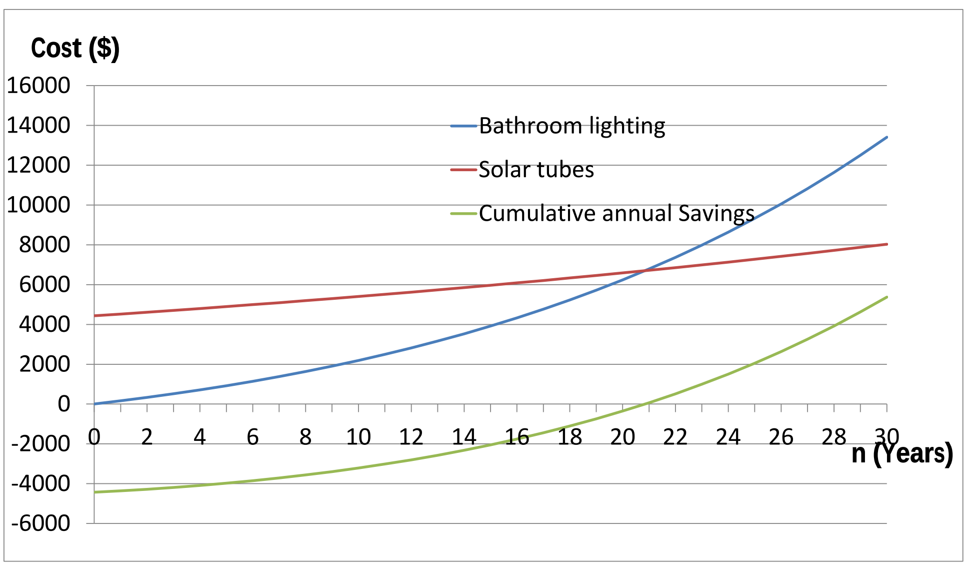


Figure 88. Cumulative costs and savingsfor implementing solar daylight tubes in restrooms of Cumberland Road rest area building.

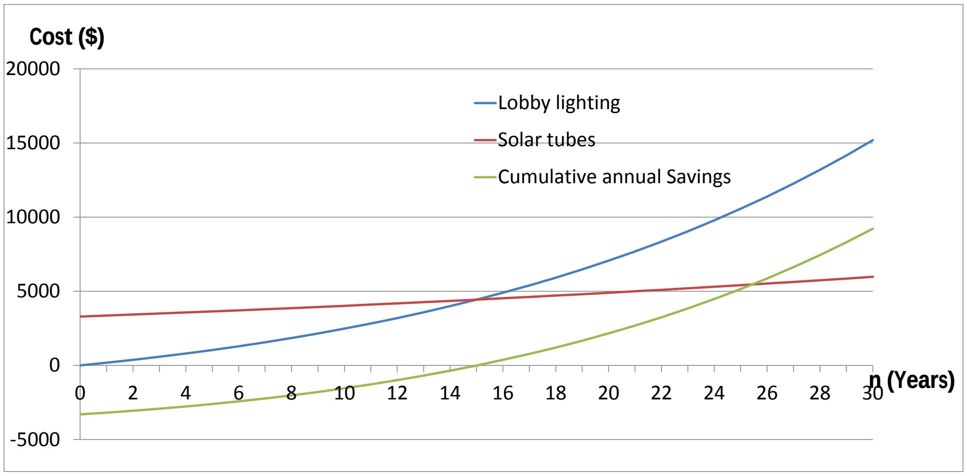


Figure 89. Cumulative costs and savings for implementing solar daylight tubes in lobby of Cumberland Road rest area building.

D.1.8.2 Grid-Connected Photovoltaic Systems

Photovoltaic systems are one of the renewable energy measures that generate electricity to the Cumberland Road rest area building. In order to perform LCC for installing photovoltaic systems in the rest area, this system needs to be designed to estimate the number and type of system parts. Several factors affect the design of grid-connected systems including average daily peak sun hours, capacity of solar panels, capacity of inverters, and mounting of solar panels. The design of photovoltaic system for the Cumberland Road rest area was conducted using a similar procedure to the one described earlier in the Coalfield rest area.

This measure was analyzed to generate 5% of Cumberland Road total energy consumption. Table 86 summarizes the cost components for installing grid-connected photovoltaic system in the Cumberland Road rest area building. The LCC analysis was conducted to determine annual savings, payback period, amount of eliminated CO_2 emissions, and required area of the system. The analysis accounted for an annual interest rate of 2%, escalation in utility rate of 5%, and an annual increase of maintenance cost by 2%, as shown in Table 87. The analysis shows that incorporating grid-connected photovoltaic system at the Cumberland Road rest area has a payback period of 25.9 years. The system requires 29 solar panels to be installed, 10 of which can be mounted on the south part of the roof and 19 solar panels on ground south of the rest area building. The required area for solar panels on the ground is 270 SF, these calculations accounted for 51^{o} tilt angle for the solar panels and preventing shading that might occur due to layout of solar panels in winter and summer. Figure 90 shows the cumulative savings of installing a grid-connected system in the rest area building.

Table 86. Cost Components for Installing Grid-Connected Photovoltaic System in the Cumberland Road Rest Area Building

Cost Components	Amount/Savings
Total number of solar panels	29
Number of inverters	1
System capacity (KW)	6.8
Utility cost ($/kwh)	0.140
Initial cost ($)	29,191
Annual maintenance cost ($)	88
Solar Panels periodic cost ($)	10,065
Inverter periodic cost ($)	3,550
Annual Savings ($)	1,115
Annual Savings (kwh)	10516
Cost per watt ($/w)	4.41

Table 87. LCC Analysis Results for Incorporating Grid-Connected Photovoltaic System in the Cumberland Road Rest Area Building

LCC Items/Savings	Amount/Savings
Annual eliminated CO_2 emissions (lb)	14,827
Number of solar panels on roof	10
Number of solar panels on the ground	19
Required area for solar panels (SF)	270
Tilt angle of solar panels	51
Payback period (yr)	25.9

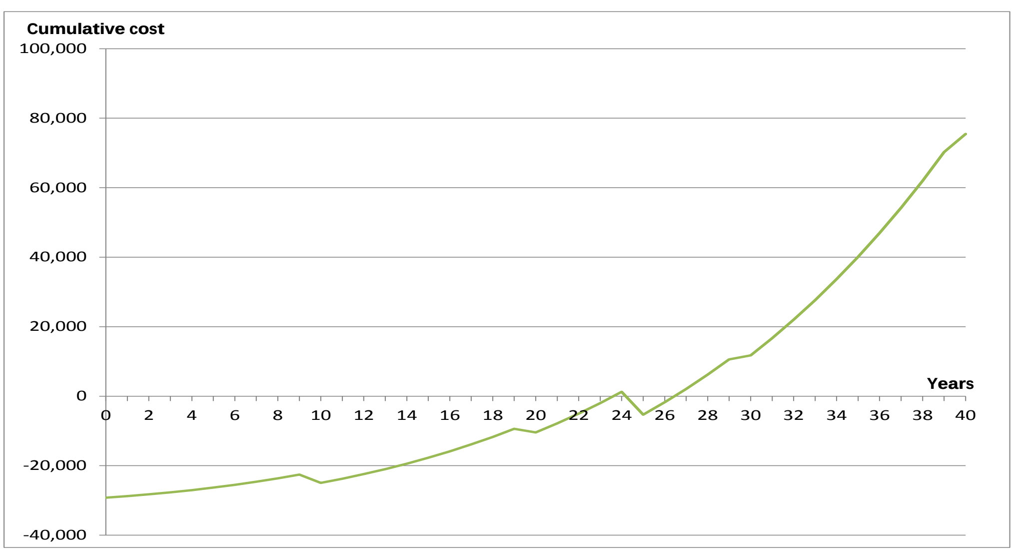


Figure 90. Cumulative cost of incorporating grid-connected system in the Cumberland Road rest area building.

It should be noted that the stand-alone photovoltaic system was not considered in this analysis because of its infeasible payback period that was identified in the first phase of this project due to its high initial and periodic costs of battery systems.

D.1.8.3 Solar Water-Heating Systems

Solar water heater is another technology that can reduce energy consumption for heating water in the rest area building. This technology can be installed with the current water heaters in the rest area in order to mitigate the cost of replacing current water heater. Moreover, current water heater can work as a backup when the sun rays are unavailable or insufficient to heat water to the desired temperature. The components of installing this system include solar collector(s), collector's mounting, heat exchanger, circulator, antifreeze (glycol), water storage tank(s), controller, fittings, pipes, and insulation. The initial capital cost of the system can be calculated for the three rest areas using the RSMeans Building Construction Cost Data (2012). Maintenance cost and life were calculated similar to Coalfield rest area buildings. Table 88 summarizes the LCC components for incorporating solar water heaters in the Cumberland Road rest area building. A LCC analysis was conducted based on an annual interest rate of 2%, escalation in utility rate by 5%, and an annual increase of maintenance cost by 2%, as shown in Table 89. The analysis shows that installing solar water heaters in Cumberland Road rest area building has a payback period that ranges from 3.2 to 11.3 years based on 70% and 20% energy savings heating water, and it can eliminate CO_2 emissions by 7,202 to 25,206 Ib annually.

It should be noted that solar collector(s) can be installed on the roof by clamps/straps or on the ground where a rack is used to hold the collector(s). Installing solar collectors on the roof might not be feasible as the building roof of the rest area was not designed to carry such extra load. Subsequently, solar collectors should be mounted on the ground.

Table 88. LCC Components for Installing Solar Water Heater in Cumberland Road Rest Area Building

LCC Components	Amount/Savings
Capital cost (Ground mount) ($)	5,960
Annual maintenance cost (Ground mount) ($/yr)	60
Utility Cost ($/kwh)	0.106
Conventional water heater consumption (kwh)	25,720
Annual operating cost for conventional water heater	2,726
Annual savings (20% to 70% savings) ($)	545 to 1,908
Periodic cost for pump @ 5 years ($)	250
Periodic cost for water tank @ 16 years ($)	1,600
Circulating pump life (yr)	5
Tank life (yr)	16

Table 89. LCC Analysis Results for Installing Solar Water Heater in Cumberland Road Rest Area Building

Savings	Amount/Savings
Annual kwh saved (20% savings)	5,144
Annual kwh saved (70% savings)	18,004
Annual eliminated CO_2 emissions - 20% savings (lb)	7,202
Annual eliminated CO_2 emissions - 70% savings (lb)	25,206
Payback period - 20% savings (yr)	11.30
Payback period - 70% savings (yr)	3.18

D.1.9 Water-Saving Plumbing Fixtures

Rest areas have a high rate of water consumption due to the large number of visitors that use their restrooms. Using water-conserving fixtures in these rest areas will provide significant savings in water consumption. A number of feasible water-saving technologies can be used to minimize water consumption in the rest areas including efficient faucets, aerators, toilets, and urinals. Currently the Cumberland Road rest area building has low-flow faucets, which make them suitable for conserving water use in the facility. An analysis was conducted to estimate the feasibility of installing conserving toilets and urinals in the rest area building. Table 90 summarizes the analysis of replacing current plumbing fixtures with water-conserving ones. As it was difficult to calculate precisely the number of visitors using urinals or toilets, the analysis assumed that 24% of visitors use urinals and 48% of visitors use men’s and women’s toilets. The replacement of current plumbing fixtures can provide savings of 92.5% of water consumption by urinals and 54.3% of water consumption by toilets. This could result in a total water savings of 768,380 gallons annually. The payback period for these fixtures could not be calculated as water unit cost could not be identified as the rest area uses ground water to supply its needs.

Table 90. LCC Analysis for Replacing Current Urinals and Toilets with Water-Conserving Fixtures in Cumberland Road Rest Area Building

Saving/Cost Items	Urinal	Toilets
Current fixture rate (GPF)	1.6	3.5
Number of fixtures	2	8
Type	Wall mount	Wall mount
Water-conserving rate (GPF)	0.125	1.6
Initial replacement Cost ($)	1,323*	5,640*
Savings per flush (G)	1.475	1.9
Percentage savings (%)	92.2%	54.3%
Annual visitors 2009	880,380	
Annual savings for 24% visitors using urinals and 48% using toilets (gallons)	215,135	554,245

* (RSMeans 2012; Lowe's 2012)

D.1.10 Summary of All Promising Green Building Measures

This section summarizes all green building measures that can be used at the Cumberland Road rest area building to reduce their energy consumption. All promising green building measures were added in the eQuest model in order to analyze the impact of their collective use and potential interactions on the overall energy consumption of the building. Table 91 summarizes all LCC components, savings and payback periods for all promising green building measures, which were analyzed in the previous sections. The eQuest simulation model and energy analysis shows that the Cumberland Road rest area building can achieve a total of 48.2% reduction in energy costs by implementing the following energy-efficient measures: fluorescent T8 bulbs, induction lighting fixtures for exterior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 6.8KW capacity, setting back HVAC at night, and water-conserving fixtures.

Table 91. All Promising Green Building Measures for Cumberland Road Rest Area Building

Green Building Measure	Initial Cost	Annual Maintenance Cost, If Applicable	Annual Energy Savings	Annual Eliminated CO_2 Emissions (lb)	Reduction in Energy Consumption	Payback Period (yr)
Interior lighting - Fluorescent T8	$793.5	N.A.	$393	5,233	1.8%	Immediate payback period
Exterior lighting - induction lighting	$27,420	N.A.	$2,947	39,202	13.2%	6.2
Motion-activated lighting	$871	N.A.	$320	4,254	1.4%	2.7
Vending occupancy controls	$339	N.A.	$335	4,454	1.5%	1.0
Motion-sensor exhaust fans	$542	N.A.	$473	12,168	4.1%	0.6
Geothermal heat pump	$31,570	$325	$1,815	34,742	11.7%	9.5
Desuperheater	$1,600	N.A.	$705	9,384	3.2%	2.3
Energy-efficient hand dryers	$1,092	N.A.	$499	6,641	2.2%	2.2
Photovoltaic system	$29,191	$88	$1,115	14,827	5.0%	25.9
Solar daylight tubes	$7,735	N.A.	$342	4,544	1.5%	17.9
Setting back HVAC at night	$200	N.A.	$442	6,698	2.3%	0.4
Water-conserving fixtures	$6,963	N.A.	N.A.	N.A.	N.A.	N.A.
All promising green building measures together (eQuest model)	$108,317	$413	$10,745	142,932	48.2%	7.1

D.2 TURTLE CREEK REST AREA

The Turtle Creek rest area is located at 2 miles south of Wisconsin border at mile marker 2 of I-90 and consists of one building that serves the east and west bounds of I-90. The rest area was built in 1980 and has approximately 839 thousand visitors with an annual decrease of 1.05% based on 2009 statistics. The major sources of energy consumption of the rest area include the interior and exterior lighting, heating and cooling, vending machines, hand dryers, pump station, and water heater. The next sections discuss the energy consumption analysis for the rest area building as well as LCC analysis for implementing different green building measures including interior and exterior energy-saving light bulbs, motion-activated lighting, vending occupancy controls, motion exhaust sensors, geothermal heat pumps, Energy Star air-source heat pump, thermal pane glass, energy-efficient hand dryers, photovoltaic systems, solar water heater, solar daylight tubes, and water-saving plumbing fixtures.

D.2.1 Energy Audit and Analysis

The Turtle Creek rest area has one utility meter to measure energy consumption in its building. The utility meters can be used to measure the monthly energy consumption of the rest area however they cannot provide energy consumed by each device or equipment in the rest area. In order to identify major sources of energy consumption in the rest area buildings and their costs, an energy simulation model was developed using the eQuest energy simulation software environment. The eQuest software can be used to simulate the energy performance of a building including its construction materials, weather, space heating and cooling, air ventilation, air infiltration and exhaust, temperature control, interior and exterior lighting, water use, windows and doors, skylights, operation schedule and occupancy, building activities, equipment loads. Furthermore, eQuest can account for different scenarios for replacing any of the current equipment or devices in buildings and calculate energy consumption accordingly. This capability of measuring building energy consumption based on different scenarios of implementing various green building measures and equipment will be used to analyze and identify a list of promising BMPs for Turtle Creek rest area.

The Turtle Creek rest area model was developed similar to the Coalfield rest area buildings. The model was developed based on the rest area's location, square footage, architectural shape, zones, building envelope construction, infiltration, building orientation, operation schedule, building activities, building occupancy, ventilation, HVAC system, temperature control, and water heater. All energy consumption data for the Turtle Creek rest area including lighting, HVAC system, hand dryers, vending machines, ventilation, infiltration, exhaust, occupancy, water pump and water heater were modeled using a similar procedure to the one described earlier for the Coalfield rest area buildings.

After modeling the rest area building in eQuest, the simulation model was run to simulate the building performance with respect to weather conditions throughout the year and calculate monthly and total energy consumption categories of the building. Due to the difficulty to measure air infiltration rates for entry doors during the site visit; several runs of simulation model were conducted with varying reasonable rates of infiltration and ventilation in order to minimize the differences between simulated and actual energy consumption reported in the building's energy bills. The parameters of infiltration were eventually set in the model to 93 CFM/ person for restrooms, lobby, and vending area, 490 CFM/person for mechanical room, and 442 CFM/person for storage room. Similarly, infiltration rates were set to 1.36 air change per hour to account for double doors entry of the rest area. Figure 91 and Figure 92 compare the simulated monthly electricity and gas consumption respectively of the building based on the developed model in eQuest to the actual energy consumption reported in the utility bills of the Turtle Creek rest area building in 2009. Based on the results in Figure 91 and Figure 92, the average absolute differences between the electricity and gas consumption for the developed simulation model and actual bills are 6% and 14.9% respectively. The maximum and minimum difference in electricity consumption between the developed simulation model and actual bills are 16.1% in December and 0.7% in January respectively. Similarly, the maximum and minimum difference in gas consumption between the developed simulation model and actual bills are 32.8% in November and 1.7% in September respectively.

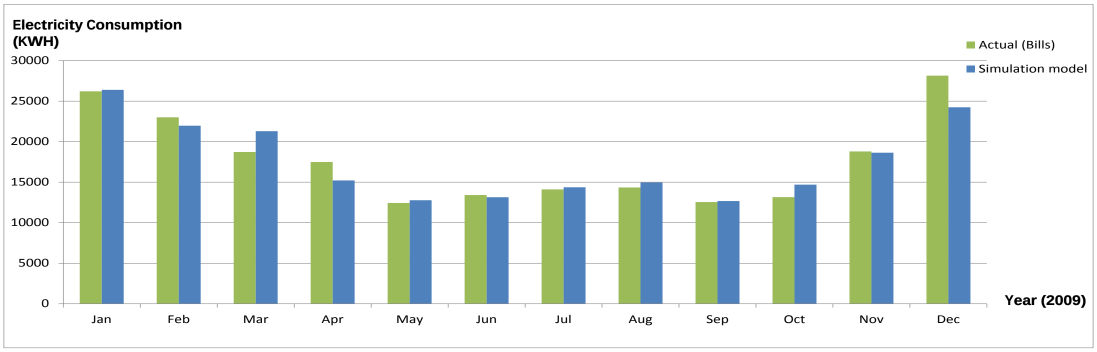


Figure 91. Simulated and actual electricity consumption of Turtle Creek rest area building in 2009.

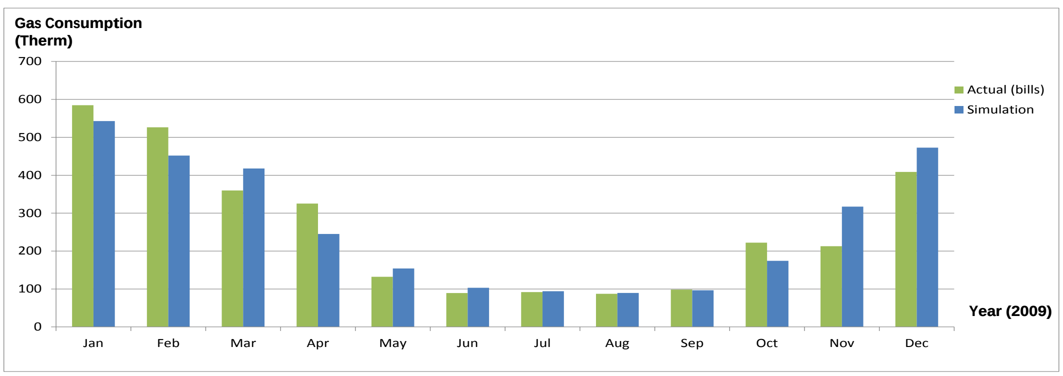


Figure 92. Simulated and actual gas consumption of Turtle Creek rest area building in 2009.

It should be noted that the number of visitors per day was assumed to be constant throughout the year. Therefore, the difference in energy consumption between the eQuest simulation model and energy bills can be caused by the varying number of visitors per day which affects the building's heating and cooling energy consumption as well as its water use. In addition, the occasional and varying use of other small devices such as a microwave, laptop, small fan or heater unit that were observed during the site visits in the maintenance room can contribute to this difference between the simulation results and the energy bills.

The square footage of Turtle Creek rest area building is 3575 SF and its annual number of visitors is 838,770 which leads energy consumption rates of 59.4kwh/SF per year plus 0.88 therm/SF per year, 6.76 $/SF per year, and 2.88 cents/visitor/yr. The breakdown of electricity cost for the Turtle Creek rest area building among its main sources of consumption is shown in

Figure 93. The eQuest energy simulation model shows that the highest energy consumption (35%) of the rest area building is represented in space heating while the lowest energy consumption of the building is represented in hand dryers, water pump, and water cooler

at 3%,3%, and 2% respectively. The “others” category includes small equipment and devices such as vacuum cleaners, coffee machines, microwave, personnel laptop, etc., that are occasionally used in the rest area building and were not considered in the simulation model. This breakdown of energy costs will helps in prioritizing energy-improvement efforts for the rest area building.

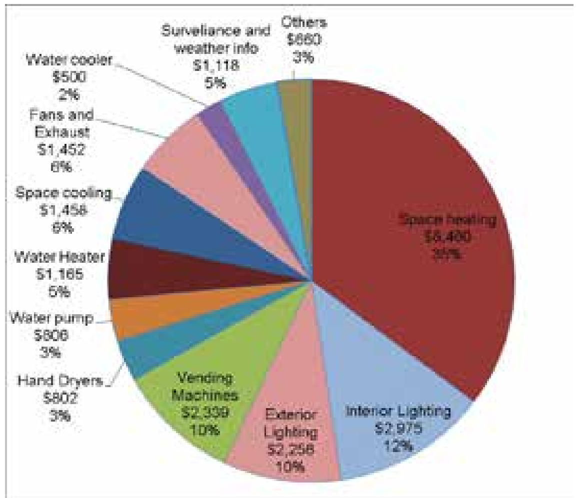


Figure 93. Energy cost breakdown for Turtle Creek rest area building.

D.2.2 Lighting

Lighting in the Turtle Creek rest area represents approximately 21% of total energy consumption with an annual cost of $5,233. The following two subsections analyze replacing current interior and exterior lighting with more-efficient and energy-saving bulbs. The economic analysis of light replacement in these two sections assumes an annual interest rate of 2% and escalation in utility rate of 5%.

D.2.2.1 Interior Lighting

Interior lighting in the Turtle Creek rest area consists of linear and U-shape fluorescent T12 bulbs. These bulbs can be replaced by linear and U-shaped fluorescent T8 to provide similar luminance level, less energy consumption and longer life expectancy. Table 92 through Table 95 summarizes the impact of replacing current T12 with T8 fluorescent light bulbs for the Turtle Creek rest area. These lighting replacements can provide annual saving of $617 and reduce total energy consumption by 2.5%. The conducted LCC analysis for replacing all current T12 lighting with T8 bulbs is shown in Figure 94. The average payback period for all light replacement is 1.75 years, which represents a green building measure with promising return on investment.

Table 92. Replacing U-Shape Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in Lobby and Restrooms of Turtle Creek Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	Sylvania (FB34/CW/6/SS/ECO)	Sylvania (FBO28/841/XP/SS/ECO)
Number of bulbs	62	62
Mean lumens (lumen)	2279	2265
Kelvin temperature (K)	4200	4100
Color Rendering Index (CRI)	62	75
Life time (hr)	18000	26000
Consumption per bulb (watt)	34	28
Lamp cost ($/each)	9.99	15.79
Change in lumens output levels (%)	N.A.	-0.6
Reduction in energy consumption (%)	N.A.	17.6
Annual savings in energy consumption - first year ($/yr)	N.A.	326
Payback period (yr)	N.A.	2.17

Table 93. Replacing Linear Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in Restrooms and Maintenance Room of Turtle Creek Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	(assumed)	Sylvania 22234 (FO32/25W/841/ XP/SS/ECO)
Number of bulbs	38	38
Mean lumens (lumen)	2279	2327
Kelvin temperature (K)	4200	4100
Color Rendering Index (CRI)	62	85
Life time (hr)	20000	36000
Consumption per bulb (watt)	34	25
Lamp cost ($/each)	1.73	8.99
Change in lumens output levels (%)	N.A.	+2.1
Reduction in energy consumption (%)	N.A.	26.4
Annual savings in energy consumption - first year ($/yr)	N.A.	268
Payback period (yr)	N.A.	0.94 and 2.74*

Payback period for restrooms and maintenance room.

Table 94. Replacing Fluorescent T12 (U-Shape) Bulbs with Energy-Efficient T8 Light Bulbs in Tourism Office of Turtle Creek Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12) 24"	Fluorescent (T8) 24"
	Sylvania Cool White F20T12/CW 20W	Sylvania 21770 (FO17/741/ECO)
Number of bulbs	4	4
Mean lumens (lumen)	1200	1325
Kelvin temperature (K)	4200	4100
Color Rendering Index (CRI)	62	75
Life time (hr)	18000	20000
Consumption per bulb (watt)	20	17
Lamp cost ($/each)	1.89	5.79
Change in lumens output levels (%)	N.A.	+10.4
Reduction in energy consumption (%)	N.A.	15
Annual savings in energy consumption - first year ($)	N.A.	4
Payback period (yr)	N.A.	5.84

*Tourism office lighting is used approximately 9 hr per day.

Table 95. Replacing Fluorescent T12 bulbs with Energy-Efficient T8 Light Bulbs in Tourism Office of Turtle Creek Rest Area Building

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	30T12/CW/RS/EW, ALTO (assumed)	Sylvania 22233 (FO32/25W/835/XP/SS/ECO)
Number of bulbs	10	8
Mean lumens (lumen)	1950	2475
Kelvin temperature (K)	4100	4100
Color Rendering Index (CRI)	62	75
Life time (hr)	18000	36000
Consumption per bulb (watt)	25	25
lamp cost ($/each)	3.5	7.99
Change in lumens output levels (%)	N.A.	+1.5
Reduction in energy consumption (%)	N.A.	20
Annual savings in energy consumption - first year ($)	N.A.	16
Payback period (yr)	N.A.	1.9*

*Tourism office lighting is used approximately 9 hr per day.

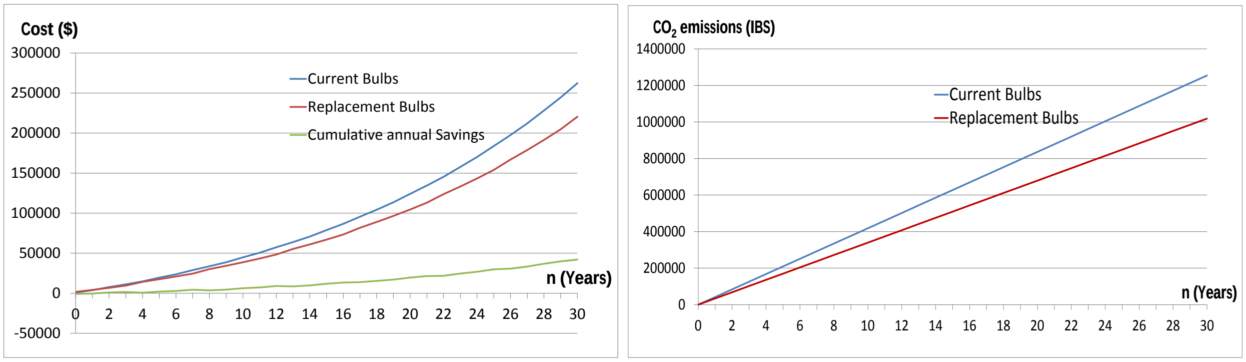


Figure 94. Cumulative costs, savings, and CO_2 emissions for current and replacement lighting in Turtle Creek rest area building.

D.2.2.2 Exterior Lighting

This section analyzes the impact of replacing current exterior lighting of Turtle Creek rest area with LED and induction lighting. The average lighting operating hours was determined based on eQuest simulation model which accounts for the location of the rest area building and its seasonal operational hours. The average lighting hours of exterior lighting was calculated to be 8.74 hours. The current exterior lighting of Turtle Creek rest area consists of (1) fifteen recessed lighting fixtures with 100 watt MH bulbs in each; and (2) two lighting towers with a total of sixteen 400 watt HPS bulbs. Due to the unavailability of the exact brand and luminance characteristics of current exterior lighting, reasonable assumptions were made for their luminance levels given the fact that the luminance characteristics are not significantly affected by the manufacturers.

A LCC analysis was conducted to examine the feasibility of implementing a one-for-one replacement of current exterior lighting of the rest area building, its parking lot, as well as entrance and exit with LED and induction lighting. The conducted analysis considered the possible lighting fixtures and bulbs shown in Table 96 as recommended by manufactures. It should be noted that LCC was conducted for one-for-one replacement to reduce initial costs. This one-for-one replacement is expected to reduce the current total lighting output (lumen) of light towers by 60% and 64% for LED and induction lighting replacements, respectively; and recessed fixtures by 33% and 38% for LED and induction lighting replacements, respectively. It should be noted that despite the lower average luminance of LED and induction lighting compared to HPS lighting, LED and induction lighting provide higher Color Rendering Index (CRI) than HPS lighting. CRI measures the effect of a light source on the perceived color of object and surface. Having high value of CRI makes virtually all colors look natural and reduces glare (Light Sout Services 2010).

The components and results of the conducted analysis of one-for-one replacements are summarized in Table 97 and Table 98 for all lighting fixtures/bulbs of the rest area. The cumulative cost and savings as well carbon footprint and reductions in CO_2 emissions for replacing exterior lighting of Turtle Creek rest area are shown in Figure 95. The analysis shows that these light replacements can provide annual savings of $1,199 or 4.96% of total energy consumption for LED lighting replacements and $1,167 or 4.83% of total energy consumption for induction lighting replacements. This leads to a payback period of 21.2 years for LED light replacements and 6.2 years for induction lighting replacements.

Table 96. Characteristics of Current and Replacement Lighting for Exterior Lighting of Turtle Creek Rest Area Building

Light Characteristic items	Current lighting		Replacement (LED lighting)		Replacement (Induction light)	
	Type	Characteristics	Type	Characteristics	Type	Characteristics
Mean Lumens (lumen)	MH 100w	9000	LED Lamp	6000	Induction Lamp	5600
Color temperature (Kelvin)		4200		3000-5000		2700-6500
Color rendering index (CRI)		93		80		83
Life time (hours)		2400		50000		100000
Consumption (w)		100		80		80
Lamp cost ($)		80		405		248
Lamp and fixture cost ($)		-		-		-
Initial Lumens (lumen)	HPS 400w	50000	LED Steet Light	20000	Induction Steet Light	18000
Color temperature (Kelvin)		2100		2700-8000		5000
Color rendering index (CRI)		20		75		83
Life time (hours)		24000		50000		75000
Consumption (w)		400		224		225
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1493		538

Table 97. Replacing HPS 400W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Turtle Creek Rest Area Building

Building Factors	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	LED	Induction
Number of bulbs	12	12	12
Initial lumens (lumen)	45000	20000	18000
Kelvin temperature	2100	2700-8000	5000
Color Rendering Index (CRI)	20	75	83
Life time (hr)	24000	50000	75000
Consumption per bulb, including ballast (watt)	481	224	230
Bulb cost ($)	54	1,493	538
Installation cost ($)	102	102	102
Reduction in lumens output levels (%)	N.A.	60%	64
Reduction in energy consumption (%)	N.A.	53%	52
Annual savings in energy - first year ($/year)	N.A.	984	961
Payback period	N.A.	20.7	5.7

Table 98. Replacing HPS 100W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Turtle Creek Rest Area Building

Building Factors	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	MH	LED	Induction
Number of bulbs	15	15	15
Initial lumens	5200	3000	3500
Kelvin temperature	3000	3000-5000	5000
Color Rendering Index (CRI)	75	80	82
Life time (jr)	10000	50000	100000
Consumption per bulb, including ballast (watt)	125	80	82
Bulb cost ($)	33	405	248
Reduction in lumens output levels (%)	N.A.	33	38
Reduction in energy consumption (%)	N.A.	36	34
Annual savings in energy - first year ($/year)	N.A.	215	206
Payback period	N.A.	22.7	7

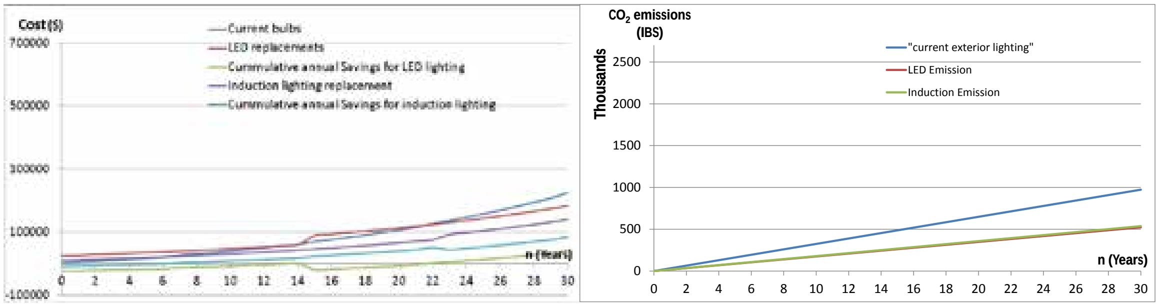
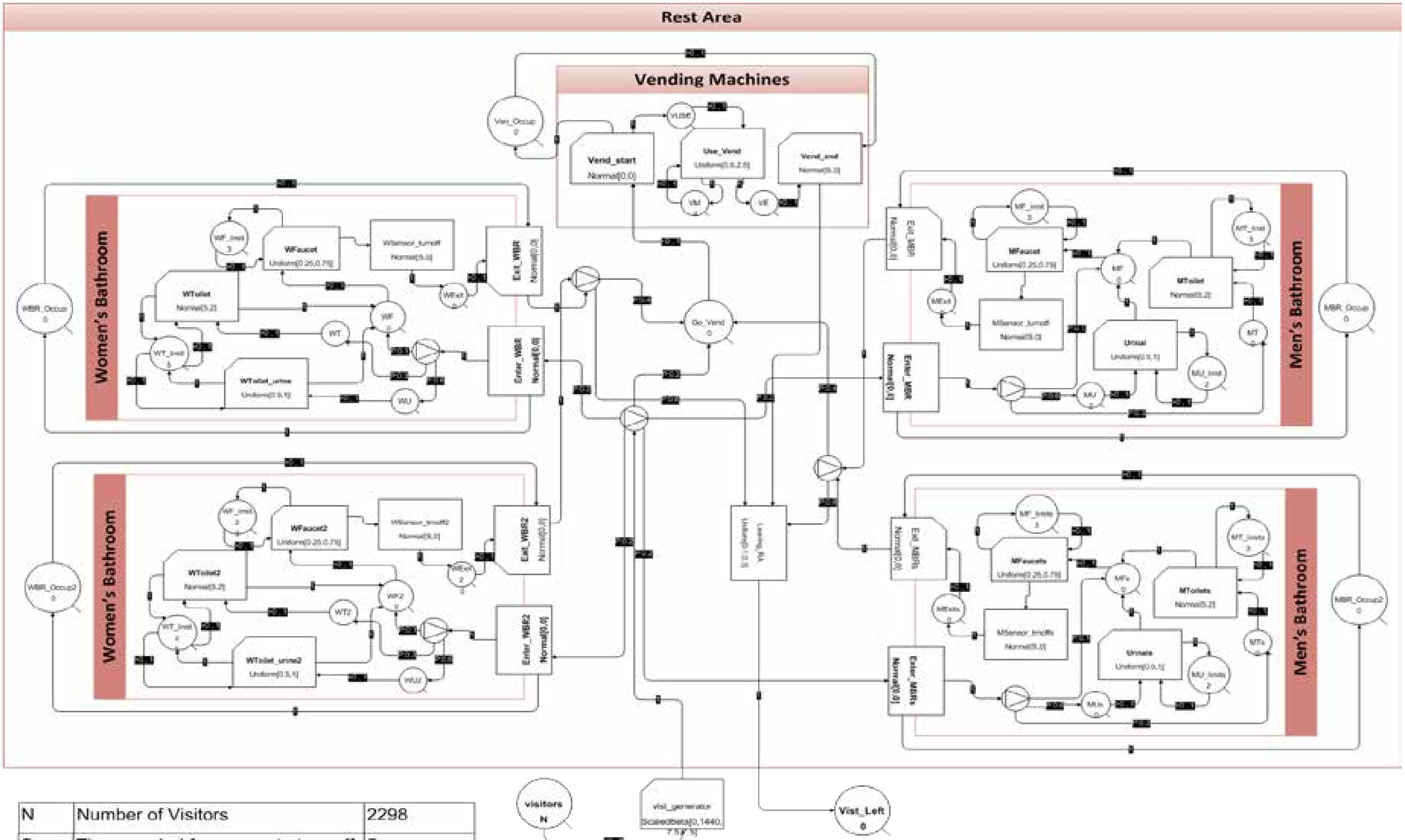


Figure 95. Cumulative costs, savings, and CO_2 emissions for LED and induction lighting replacements for Turtle Creek rest area building.

D.2.3 Motion Sensors

Rest areas have different operational schedule than business and commercial buildings and they have to operate 24 hours a day with few or no occupants during low visitation periods at night. This makes motion sensors a promising technology for rest area buildings. This section analyzes the implementation of motion sensors to control the lighting of restrooms and vending machine areas. Motion sensors also can be used to reduce space heating and cooling by reducing the use of exhaust fans at night when there are few or no occupants in the restrooms.

In order to estimate the energy savings in lighting and exhaust fans, the research team developed a separate simulation model using EZstrobe simulation language (Martinez 2006) to analyze and simulate the use of restrooms and vending machines based on the number and frequency of rest area visitors. The simulation model was developed to mimic the utilization of the rest area facilities by its visitors. The model was created to generate the number of visitors to the rest area using a beta distribution function to represent a high frequency of visitors during the morning, noon, and afternoon hours and low frequency during the night and early morning hours. The model also assumes that the percentages of visitors who will use the men's restroom, women's restroom, and vending machines are 40%, 40%, and 20%, respectively. Similarly, the probabilities that restroom visitors will use urinals, toilets and only faucets were assumed to be 30%, 60%, and 10%, respectively with reasonable random durations for each of these restroom tasks as, shown in Figure 96. It should be noted that the model assumes that each visitor using the toilet or urinal will also use the faucet afterwards. The developed model accounts for an amount of time for sensors to keep the light on after a visitor leaves a restroom. After a visitor leaves the restroom, the model assumes that there is a probability of 60% that the visitor will leave the rest area and 40% will use vending machines. The developed model can estimate how long the lighting in restrooms of the rest area will be turned off if motion-activated lighting were implemented in the restrooms. Similarly, the amount of time that lighting in vending machines and exhaust fans being turned/switched off can be calculated by the developed simulation model. Figure 97 shows rest area visitors while being in the men's restroom throughout a simulation day. Table 99 summarizes the percentages of occupancy for restrooms and vending machines of the Turtle Creek rest area assuming that the lights or fans remain turned on for 5 minutes after the departure of the last visitor. The following subsections use the developed simulation model to estimate potential savings for using motion sensors in the rest area building and their expected payback periods. The economic analysis of motion sensors accounts for an annual interest rate of 2% and escalation in utility rate of 5% in calculating payback period of implementing this technology.



N	Number of Visitors	2298
S	Time needed for sensor to turn off	5

Figure 96. Motion-sensor simulation model for Turtle Creek Road rest area building.

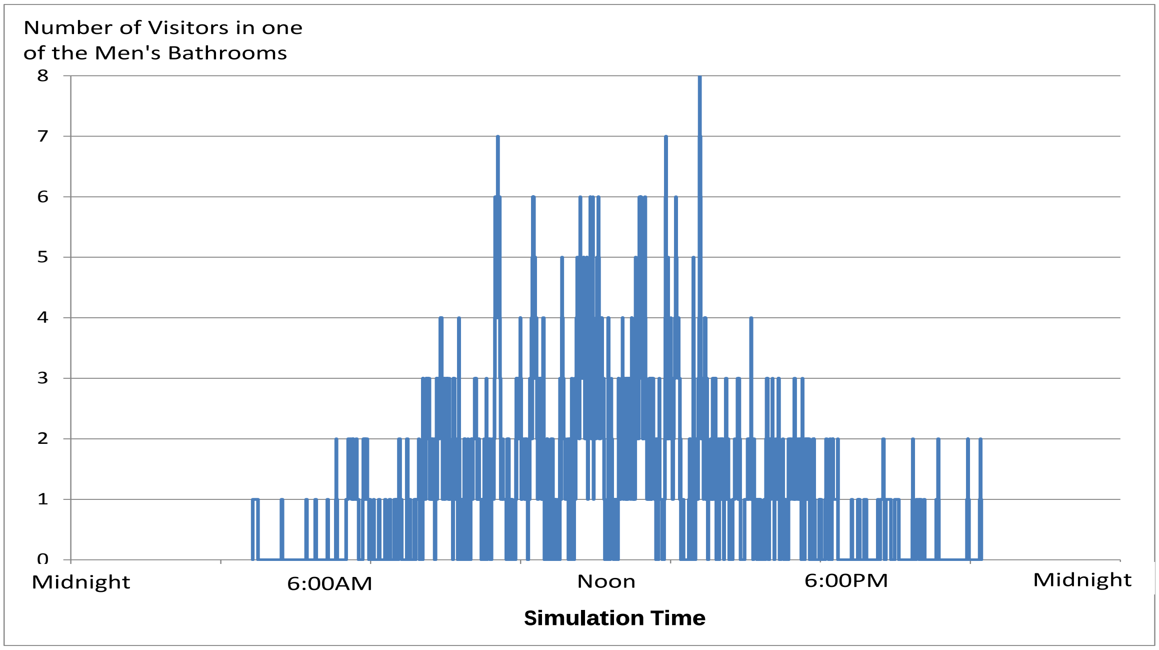


Figure 97. Number of visitors in men's restroom throughout a simulation day in Turtle Creek rest area Building.

Table 99. Percentage Occupancy for Restrooms and Vending Area in Turtle Creek Rest Area Building

Percentage of Occupancy In Men's Restrooms	**Percentage Occupancy In Women's Restrooms**	**Percentage Average Occupancy In All Restrooms**	**Percentage Occupancy In Vending Machines Area**
55.1%	53.9%	54.5%	47.4%

D.2.3.1 Motion-Activated Lighting

Motion-activated lighting can be installed in restrooms to turn off lights automatically when they are not occupied. As discussed in the previous section, restrooms in the Turtle Creek rest area have an average approximate occupancy of 54.5% including 5 minutes for the occupancy sensors remain in detection before turning off automatically. This leads to average 45.5 savings in lighting of restrooms. Table 100 shows the results of the LCC analysis for implementing motion-activated lighting in the restrooms of the Turtle Creek rest area. The analysis shows that the motion-activated lighting can provide approximate savings of $786 annually or 3.3% of total energy cost of the Turtle Creek rest area building which represents a payback period of 2 years. Furthermore, motion-activated lighting in restrooms can eliminate annually 11,083 Ib of CO_2 emissions.

Implementing motion-activated lighting in the lobby will not be feasible due to security requirements that require lights to be turned on at all times to ensure the proper operation of the surveillance cameras. Moreover, implementing motion-activated lighting in maintenance rooms will not provide much savings and the payback period will be long since the maintenance staff often turn off the light before leaving the mechanical rooms of the rest area.

Table 100. Motion-Activated Lighting Analysis for Restrooms of Turtle Creek Rest Area Building

Savings and Cost Items	Amount/Savings
Total load of lighting fixtures (watt)	1972
Electricity cost ($/kwh)	0.1
Occupancy sensors cost ($)	536
Labor installation cost ($)	1,020
Total Initial cost ($)	1,556
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	1,727
Annual lighting energy savings ($)	786.00
Payback period (yr)	1.99
Amount of eliminated CO_2 (lb)	11,083
Savings in total energy consumption of the rest area building (%)	3.3

D.2.3.2 Vending Occupancy Controls

Similar to motion-activated lighting, occupancy controls can be installed for vending machines to turn off their lighting when the vending area is not occupied. Based on the developed simulation model for motion sensors, lights of vending machine are expected to be on for approximately 47.4% of hours during the day assuming a duration of 5 minutes for the sensors to remain on after detecting the last motion in the vending area. This leads to 52.6% lighting savings of the vending machines area. Table 101 shows the economic analysis of installing occupancy controls for vending machines area in the Turtle Creek rest area. The analysis shows that these occupancy controls for vending machines can provide approximate savings of $276 annually or 1.1% of total energy cost of the Turtle Creek rest area building which leads to a payback period of 1.24 years. This measure can also eliminate 3,898 lb of CO_2 emissions annually due to the achieved reduction in energy consumption.

Table 101. Occupancy Controls Analysis for Vending Machine in Turtle Creek Rest Area Building

Motion-Activated Lighting Analysis	Amount/Savings
Total load of vending machines lighting (watt)	600
Electricity cost ($/kwh)	0.1
Occupancy sensors cost ($)	120
Labor installation cost ($)	219
Total Initial cost ($)	339
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	526
Annual lighting energy savings ($)	276
Payback period (yr)	1.24
Amount of eliminated CO_2 (lb)	3,898
Savings in total energy consumption of the rest area building (%)	1.1

D.2.3.3 Motion Sensors for Exhaust

Similar to motion-activated lighting, exhaust fans can operate only during the occupancy times of visitors. This will allow exhaust fans to be switched off automatically when there are no visitors, which will decrease the amount of outside air that needs to be heated or cooled. eQuest software does not provide a direct method to account for the use of exhaust fan sensors, however, this can be modeled by decreasing the exhaust rate by a value which reflects the switching off of exhaust fans when there are no occupants. Accordingly, exhaust fan flow can be decreased with the average non-occupancy percentage of restrooms (41.6%). Table 102 summarizes the economic analysis results for implementing motion sensors for exhaust fans in rest area building. The analysis shows that motion sensors for exhaust fans can provide approximate annual savings of $2,249 annually or 9.3% of total energy consumption of Turtle Creek rest area building, which leads to a payback period of 0.6 years. This measure can also eliminate 31,710 Ib of CO_2 emissions annually due to the reduction in energy consumption of heating and cooling.

Table 102. LCC Analysis Results for Implementing Motion-Sensor Exhaust Fans in Turtle Creek Rest Area Building

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.1
Gas cost ($/therm)	0.936
Fan(s) and sensors cost($)	866
Labor installation cost ($)	437
Total Initial cost ($)	1,303
Annual electricity savings (kwh)	22490
Annual gas savings (therm)	0
Annual energy savings ($)	2,249
Payback period (yr)	0.59
Amount eliminated CO_2 (Ib)	31,710
Savings in total energy consumption of the rest area building (%)	9.3

D.2.4 More-Efficient HVAC Systems

The current HVAC system at the Turtle Creek rest area consists of a split system with four condensers and three electric resistance duct heaters. The system has an assumed cooling capacity of about 15 tons and approximate total heating capacity of 75KW. The current HVAC system can be replaced with a more energy-efficient system that reduces heating and cooling energy consumption. The following three subsections analyze the replacement of the current HVAC system with more-efficient units and setting back the temperature at night.

D.2.4.1 Geothermal Heat Pump

The existing HVAC system in the Turtle Creek rest area building operates continuously all year round and its consumption represents 47% of the total rest area consumption. Ground-source heat pump can be more efficient than air-source heat pump as it uses the nearly constant temperature of earth (55°F) to heat and cool buildings. The eQuest simulation environment can be used to model the use of a geothermal HVAC system for the Turtle Creek rest area building. The system was modeled to have heating coefficient of performance (COP) of 4.0 and a cooling efficiency of 18 EER. This system was also modeled to operate in economizer mode, which brings fresh air when the outside air temperature is sufficient to condition the space. After running the eQuest model with geothermal heat pump, the model provides savings of 26% of total energy consumption. The installation and maintenance costs of geothermal heat pump were calculated similar to Coalfield rest area buildings. Table 103 summarizes the LCC components of replacing the current HVAC system with a geothermal heat pump.

Table 103. LCC Components for Replacing Current HVAC System with Geothermal Heat Pump in Turtle Creek Rest Area Building

LCC Components	Cost/Life
Capital cost - vertical system* ($)	62,320
Annual maintenance cost ($)	318
Annual operating cost ($)	5,089
Periodic cost ($)	38,320
Life (yr)	20

* Installation cost may vary due to soil conditions and resizing of the HVAC equipment

In order to compare the cost effectiveness and payback periods of replacing the current HVAC system at the rest area with a geothermal system, the initial, maintenance, operating and replacement costs of the current HVAC systems need to be identified. These costs were estimated similar to the Coalfield rest area buildings in order to carry out the LCC analysis. Table 104 summarizes the LCC components for the current HVAC system in the Turtle Creek rest area building.

Table 104. LCC Components for Current HVAC System in the Turtle Creek Rest Area Building

Rest Area/LCC Components	Cost/Life
Capital cost ($)	24,420
Annual maintenance cost ($)	684
Annual operating cost ($)	11,370
Periodic cost ($)	24,420
Life (yr)	17
Manufacture year	1992
Replacement year	2009

A LCC analysis was conducted to compare the potential replacement of the current HVAC system with a geothermal heat pump based on an annual interest rate of 2%, escalation in utility rate of 5%, and annual increase of maintenance cost by 2%. Table 105 summarizes the LCC analysis results for replacing current HVAC with geothermal heat pump. This analysis shows that, geothermal heat pump can provide savings of $6,281 annually or 26% of total energy cost. The analysis shows that replacing the current HVAC system with a vertical loop geothermal heat pump has a payback period of 5.5 years. The cumulative costs for a vertical loop geothermal system, current HVAC system, and savings are shown in Figure 98. The geothermal heat pump can also be installed along with a desuperheater to heat water in the cooling season. The desuperheater uses heat that is removed from the building space to heat domestic hot water. This unit can provide free hot water in the summer or when the system is in cooling mode. It can provide annual savings of $301 or 1.2% of the total energy consumption. The payback period of the desuperheater is 5.1 years and it can eliminate 4,251 Ib of CO_2 emissions.

Table 105. LCC Analysis Results for Replacing Current HVAC System with Geothermal Heat Pump at Turtle Creek Rest Area Building

Savings	Amount
Annual electricity saved (kwh)	44,890
Annual gas saved (Therm)	1,915
Annual energy savings - first year ($/yr)	6,281
Percentage of total energy saved (%)	26.0
Annual eliminated CO_2 emissions (Ib)	85,700
Payback period - vertical system (yr)	5.5

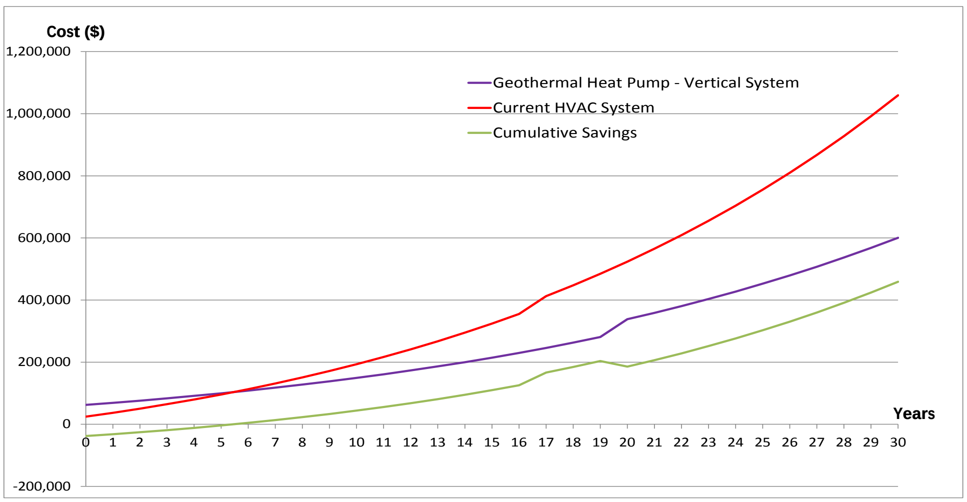


Figure 98. Cumulative costs of current HVAC system, vertical loop geothermal system, and savings for Turtle Creek rest area building.

D.2.4.2 High-Efficiency Air-Source Heat Pump

Another alternative for the current HVAC system in the Turtle Creek rest area is replace it with a more-efficient Energy Star–rated, air-source heat pump to reduce heating and cooling expenses. An air-source heat pump was modeled in eQuest to meet Energy Star recommendations with cooling efficiency of 12 EER and heating performance rating of 8.2 HSPR (Energy Star 2003). Table 106 summarizes the economic analysis results for replacing the current HVAC system with an Energy Star–rated air-source heat pump. The analysis shows that Energy Star–rated HVAC systems can provide annual savings of $1,809 annually or 7.5% of total energy consumption of the rest area building. This leads to a payback period of 12.3 years based on an annual interest rate of 2% and escalation in utility rate of 5%. This replacement can eliminate CO_2 emissions by 22,638 Ib annually.

Table 106. Analysis Results for Replacing Current HVAC System with Energy-Efficient Air-Source Heat Pump at Turtle Creek Rest Area Building

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.1
Gas cost ($/therm)	0.936
Total initial cost for air-source heat pump ($)	12,200
Annual energy savings ($)	1,809
Payback period (yr)	12.3
Amount of eliminated CO_2 (Ib)	22,638
Savings in total energy consumption of the rest area building (%)	7.5

D.2.4.3 Setting Back HVAC System at Night

Another method to reduce energy consumption for space heating and cooling of the rest area is to set back the temperature of the HVAC system at night. The number of visitors using the rest area at night is very limited; therefore, it might be worth it to set back the temperature at night to reduce some of the energy consumption for heating and cooling. Temperature can be set at night to 64^{o}F in winter and 72^{o}F in summer. This measure can be modeled in eQuest by editing the temperature set points in the simulation model to a temperature that reflects the set points at night using interpolation. The developed eQuest model showed that setting back the temperature at night can provide annual savings of $92 or 0.4% reduction in total energy consumption. Turtle Creek rest area building has already programmable thermostats, which make this measure easy to be implemented in the rest area facility without any additional costs.

D.2.5 Thermal Pane Glass for Windows and Doors

Thermal pane glass is a green building measure that can be added to the rest area building in order to reduce its cooling and heating energy consumption. This measure requires replacing all glazing as well as doors and windows in the rest area building with double-pane glass. This measure can be modeled in eQuest by replacing current single pane glass with double-pane glass. The analysis of implementing this measure provides annual savings of $596 or 2.5% of total energy consumption, as shown in Table 107. There is no expected payback period for this measure within 30 years as it requires major renovation in the rest area building with high initial cost. This measure can eliminate 8,118 Ib of CO_2 annually.

Table 107. LCC Analysis Results for Replacing Current Glazing and Doors with Double-Pane Glass in Turtle Creek Rest Area Building

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.1
Gas cost ($/therm)	0.936
Total initial cost for double-pane glass glazing and doors ($)	52,124
Annual electricity savings ($)	4140
Annual gas savings (therm)	195
Annual energy savings (kwh)	596
Payback period (yr)	More than 30 years
Amount of eliminated CO_2 (Ib)	8,118
Savings in total energy consumption of the rest area building (%)	2.5

D.2.6 Energy-Efficient Hand Dryers

Energy-efficient hand dryers are one of the green building measures that can be implemented in the Turtle Creek rest area building to reduce energy consumption. The energy consumption of hand dryers was estimated based on a 50% use of rest area visitors each for 30 seconds according to manufacture use recommendations. Although, current hand dryers only consume approximately 2.1% of total energy consumption, they are one of the most visible devices for the rest area visitors. Moreover, slow velocity or inefficient hand dryers may discourage people to use them. This analysis considers the impact installing three different models of energy-efficient hand dryers in the Turtle Creek rest area building to reduce their energy consumption, as shown in Table 108. The analysis shows that replacing current hand dryers may result in annual savings of $594 to $650 or 2.5% to 2.7% of total energy consumption in the rest area building based on three different models of energy-efficient hand dryers. These savings can provide a payback period of 3.3 years to 17.1 years for the three different models based on an annual interest rate of 2% and escalation in utility rate of 5%. This measure can eliminate up to 9,166 Ib of CO_2 emissions in Turtle Creek rest area building.

Table 108. LCC Analysis Results for Replacing Current Hand Dryers with Energy-Efficient Units for Turtle Creek Rest Area Building

LCC Items/Savings	Current Hand Dryer - World Dryer	1- World Dryer Airforce - J Series Hand Dryers	2- Xlerator Series Hand Dryers	3- Dyson Airblade Series Hand Dryers
Number of hand dryers	8			
Hand dryer consumption (watt)	2,300	1,100	1100	1500
Drying time (s)	30	12	15	12
Initial cost ($)	N.A.	2,184*	3,200*	12,800*
Annual visitors - 2009	838,770			
Percentages savings over the current hand dryers (%)	N.A.	71	64	61
Utility cost ($/kwh)	0.1			
Annual operating cost based on 50% use of visitors ($)	$804	154	192	210
Annual savings ($)	N.A.	650	612	594
Annual savings of total energy consumption (%)	N.A.	2.7	2.5	2.5
Eliminated CO_2 emissions (Ib)	N.A.	9,166	8,624	8,377
Payback period (yr)	N.A.	3.3	5.0	17.1

* (Restroom Direct 2012)

D.2.7 Solar Measures

Several solar measures can be used to reduce energy consumption in the Turtle Creek rest area building. These measures can include solar daylight tubes, photovoltaic systems, and solar water heaters. These measures can reduce energy consumption of interior lighting, heating water as well as generate renewable and clean electricity. The next subsections discuss the installation of these systems in the Turtle Creek rest area building.

D.2.7.1 Solar Tube Lighting

Solar daylight tubes are one of the green building measures that can be used to provide lighting for the building during the day light hours. The technology requires solar tubes to penetrate the building roof to the ceiling where they transmit the sunlight during the day time. This technology can be installed in restrooms to decrease the lighting use during the day light time. It can be installed in the roof of the rest area building while installing light controls in restrooms to control/dim interior lighting during the day. The energy savings that this technology can provide was calculated based on reducing daily lighting use by 5 hours. The analysis for adding solar daylight tubes in the rest area building is summarized in Table 109. Cumulative costs and savings for implementing solar daylight tubes in restrooms and lobby of the rest area are shown in Table 109. The analysis shows that this measure can provide saving of $347 annually or 1.44% of the total energy consumption. This can lead to a payback period of 13.4 years. It should be noted that, the installation of this measure is crucial in terms of the amount of savings that it can provide. Improper installation of solar daylight tubes with low insulation (low U value) can lead to high dissipation of energy and subsequently increase cooling and heating costs. On the other hand, proper installation of this measure with sufficient U value, Energy Star–rated tubes can slightly increase heating and cooling. Based on modeling solar tubes in eQuest with similar skylight areas, this can lead to an increase in energy cost $100 annually. As a result the expected savings of this measure may reduce to $247 annually.

Table 109. LCC analysis Results for Installing Solar Daylight Tubes in Restrooms and Lobby of Turtle Creek Rest Area Building

Savings and Cost Items	Amount
Total load of lighting fixtures (watt)	1904
Electricity cost ($/kwh)	0.1
Number of Solar daylight tubes (10' diameter)	4
Number of Solar daylight tubes (18" diameter)	8
Total Initial cost ($)	6,508
Solar tubes operation time (hr)	5
Annual lighting energy cost ($)	1,668
Annual lighting energy savings ($)	347
Payback period (yr)	13.36
Amount of eliminated CO_2 (Ib)	4,899
Savings in total energy consumption of the rest area building (%)	1.44

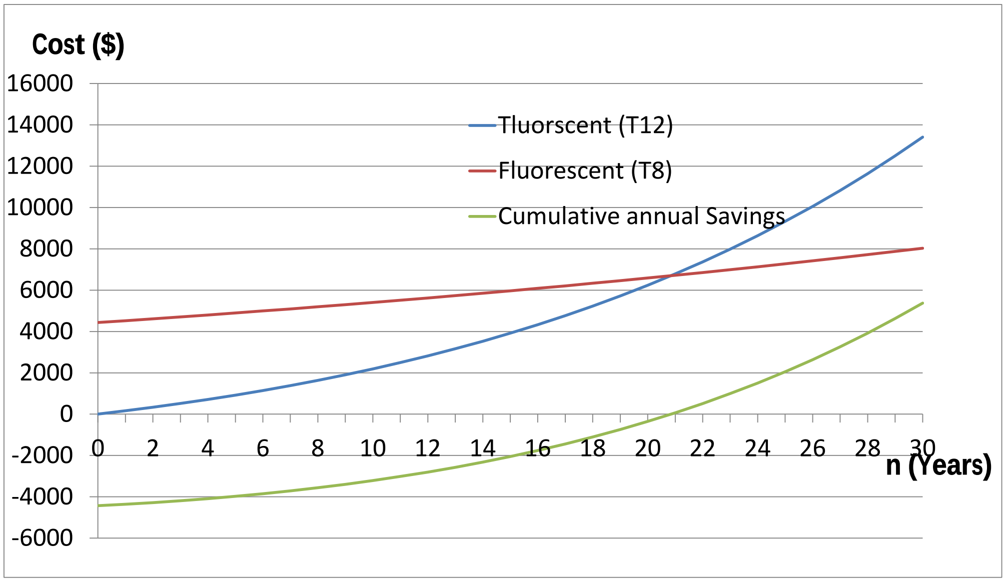


Figure 99. Cumulative costs and savings for implementing solar daylight tubes in restrooms of Turtle Creek rest area building.

D.2.7.2 Grid-Connected Photovoltaic Systems

Photovoltaic systems are one of the renewable energy measures that can generate electricity to the Turtle Creek rest area building. In order to perform LCC for installing photovoltaic systems in the rest area, this system needs to be designed to estimate the number and type of system parts. Several factors affect the design of grid-connected systems including average daily peak sun hours, capacity of solar panels, capacity of inverters, and mounting of solar panels. The design of photovoltaic system for the Turtle Creek rest area was conducted using a similar procedure to the one described earlier in the Coalfield rest area.

This measure was analyzed to generate 6% of Turtle Creek total energy consumption. Table 110 summarizes the cost components for installing grid-connected photovoltaic system in the Turtle Creek rest area building. The LCC analysis was conducted in order to determine annual savings, payback period, amount of eliminated CO_2 emissions, and required area of the system. The analysis accounted for an annual interest rate of 2%, escalation in utility rate of 5%, and an annual increase of maintenance cost by 2%, as shown in Table 111 The analysis shows that incorporating grid-connected photovoltaic system at the Turtle Creek rest area has a payback period of 26.6 years. The system requires 35 solar panels to be installed, 22 of which can be mounted on the south part of the roof and 13 on the ground south of the rest area building. The required area for solar panels on the ground is 270SF, these calculations accounted for 51^{o} tilt angle for the solar panels and preventing shading that might occur due to layout of solar panels in winter and summer. Figure 101 shows the cumulative savings of installing a grid-connected system in the rest area building.

Table 110. Cost Components for Installing Grid-Connected Photovoltaic System in the Turtle Creek Rest Area Building

Cost/Savings Components	Amount/Savings
Total number of solar panels	35
Number of inverters	1
System capacity (KW)	8.2
Utility cost ($/kwh)	0.140
Initial cost ($)	33,900
Annual maintenance cost ($)	99
Solar Panels periodic cost ($)	12,147
Inverter periodic cost ($)	4,110
Annual Savings ($)	1,274
Annual Savings (kwh)	12743
Cost per watt ($/w)	4.22

Table 111. LCC Analysis Results for Incorporating Grid-Connected Photovoltaic System in the Turtle Creek Rest Area Building

LCC Items/Savings	Amount/Savings
Annual eliminated CO_2 emissions (lb)	17,967
Number of solar panels on roof	22
Number of solar panels on the ground	13
Required area for solar panels (SF)	270
Tilt angle of solar panels	51
Payback period (yr)	26.6

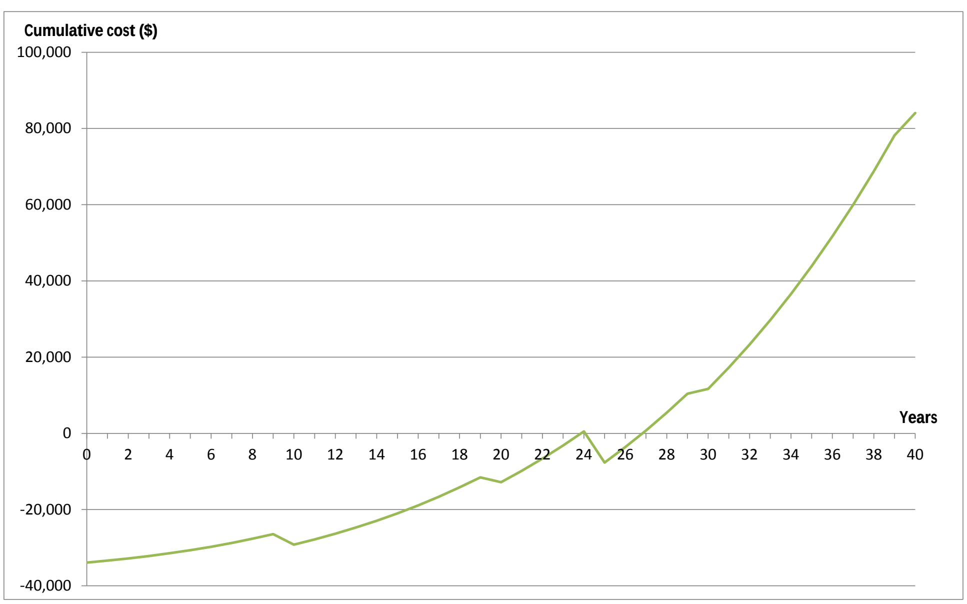


Figure 100. Cumulative cost of incorporating grid-connected system in the Turtle Creek rest area building.

It should be noted that the stand-alone photovoltaic system was not considered in this analysis because of its infeasible payback period that was identified in the first phase of this project due to its high initial and periodic costs of battery systems.

D.2.7.3 Solar Water-Heating Systems

Solar water heater is another technology that can reduce energy consumption for heating water in the rest area building. This technology can be installed with the current water heaters in the rest area in order to mitigate the cost of replacing current water heater. Moreover, current water heater can work as a backup when the sun rays are unavailable or insufficient to heat water to the desired temperature. The components of installing this system include solar collector(s), collector's mounting, heat exchanger, circulator, antifreeze (glycol), water storage tank(s), controller, fittings, pipes, and insulation. The initial capital cost of the system can be calculated for the three rest areas using the RSMeans Building Construction Cost Data (2012). Maintenance cost and life were calculated similar to Coalfield rest area buildings. Table 112 summarizes the LCC components for incorporating solar water heaters in the Turtle Creek rest area building. A LCC analysis was conducted based on an annual interest rate of 2%, escalation in utility rate by 5%, and an annual increase of maintenance cost by 2%, as shown in Table 113. The analysis shows that installing solar water heaters in Turtle Creek rest area building has a payback period of more than 10 years based on 20% energy savings of heating water, and it can eliminate CO_2 emissions by 2,912 to 10,192 Ib annually.

It should be noted that solar collector(s) can be installed on the roof by clamps/straps or on the ground where a rack is used to hold the collector(s). Installing solar collectors on the roof might not be feasible as the building roof of the rest area was not designed to carry such extra load. Subsequently, solar collectors should be mounted on the ground.

Table 112. LCC Components for Installing Solar Water Heater in Turtle Creek Rest Area Building

LCC Components	Amount/Savings	
Capital cost (Ground mount) ($)	8,135	
Annual maintenance cost (Ground rack) ($)	81	
Utility gas Cost ($/therm)	0.94	
Conventional water heater consumption (therm)	1,136	
Annual operating cost for conventional water heater ($)	1,063	
Annual savings (20% to 70% savings) ($)	223	815
Periodic cost for pump @ 5 years ($)	250	
Periodic cost for water tank @ 16 years ($)	1,600	
Circulating pump life (yr)	5	
Tank life (yr)	16	

Table 113. LCC Analysis Results for Installing Solar Water Heater in Turtle Creek Rest Area Building

LCC Items/Savings	Amount/Savings
Annual gas saved - 20% savings (therm)	249
Annual gas saved - 70% savings (therm)	871
Annual eliminated CO_2 emissions - 20% savings (Ib)	2,912
Annual eliminated CO_2 emissions - 70% savings (Ib)	10,192
Payback period - 20% savings (yr)	More than 30
Payback period - 70% savings (yr)	10.22

D.2.8 Water-Saving Plumbing Fixtures

Rest areas have a high rate of water consumption due to the large number of visitors that use their restrooms. Using water-conserving fixtures in these rest areas will provide significant savings in water consumption. A number of feasible water-saving technologies can be used to minimize water consumption in the rest areas including efficient faucets, aerators, toilets, and urinals. Currently the Turtle Creek rest area building has low-flow faucets which make them suitable for conserving water use in the facility. An analysis was conducted to estimate the feasibility of installing conserving toilets and urinals in the rest area building. Table 114 summarizes the analysis of replacing current plumbing fixtures with water-conserving ones. As it was difficult to calculate precisely the number of visitors using urinals or toilets, the analysis assumed that 24% of visitors use urinals and 48% of visitors use men's and women's toilets. The replacement of current plumbing fixtures can provide savings of 92.5% of water consumption by urinals and 54.3% of water consumption by toilets. This could result in a total water savings of 1,061,883 gallons annually. The payback period for these fixtures could not be calculated as water unit cost could not be identified as the rest area uses ground water to supply its needs.

Table 114. LCC Analysis for Replacing Current Urinals and Toilets with Water-Conserving Fixtures in Turtle Creek Rest Area Building

Saving/Cost Items	Urinal	Toilets
Current fixture rate (GPF)	1.6	3.5
Number of fixtures	4	16
Type	Wall mount	Wall mount
Water-conserving rate (GPF)	0.125	1.6
Initial replacement Cost ($)	2,647*	11,280*
Savings per flush (G)	1.475	1.9
Percentage savings (%)	92.2	54.3
Annual visitors 2009	838,770	
Annual savings for 24% visitors using urinals and 48% using toilets (G)	296,925	764,958
Annual energy savings due to reduction in water pump use (%)	0.17	0.45
Annual energy savings due to reduction in water pump use ($)	42	108

* (RSMeans 2012; Lowe's 2012)

D.2.9 Summary of All Promising Green Building Measures

This section summarizes all green building measures that can be used in the Turtle Creek rest area building to reduce its energy consumption. All promising green building measures were added in the eQuest model in order to analyze the impact of their collective use and potential interactions on the overall energy consumption of the building. Table 115 summarizes all LCC components, savings and payback periods for all promising green building measures, which were analyzed in the previous sections. The eQuest simulation model and energy analysis shows that the Turtle Creek rest area building can achieve a total of 51.8% reduction in energy costs by implementing the following energy-efficient measures: fluorescent

T8 bulbs, induction lighting fixtures for exterior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 8.2KW capacity, setting back HVAC at night, and water-conserving fixtures.

Table 115. All Promising Green Building Measures for Turtle Creek Rest Area Building

Green Building Measure	Initial Cost	Annual Maintenance Cost, If Applicable	Annual Energy Savings	Annual Eliminated CO_2 Emissions (lb)	Reduction in Energy Consumption	Payback Period (yr)
Interior lighting - Fluorescent T8	$1,637	N.A.	$617	8,701	2.6%	1.8
Exterior lighting - induction lighting	$11,400	N.A.	$1,167	16,449	4.8%	6.2
Motion-activated lighting	$1,556	N.A.	$786	11,083	3.3%	2.0
Vending occupancy controls	$339	N.A.	$276	3,898	1.1%	1.2
Motion-sensor exhaust fans	$1,303	N.A.	$2,249	31,710	9.3%	0.6
Geothermal heat pump	$62,320	$318	$6,281	88,568	26.0%	5.5
Desuperheater	$1,600	N.A.	$301	4,251	1.2%	5.1
Energy-efficient hand dryers	$2,184	N.A.	$650	9,166	2.7%	3.3
Photovoltaic system	$33,900	$99	$1,274	17,967	5.3%	26.6
Solar daylight tubes	$6,508	N.A.	$347	4,899	1.4%	13.4
Setting back HVAC at night	$0	N.A.	$92	1,291	0.4%	Immediate payback
Water-conserving fixtures	$13,927	N.A.	$150	2,120	0.6%	N.A.
All promising green building measures together (eQuest model)	$136,674	$417	$12,538	176,783	51.8%	9.8

D.3 GREAT SAUK TRAIL REST AREA

The Great Sauk Trail rest area is located at 5 miles west of Princeton, at mile marker 51 of I-80. It consists of two identical buildings that serve the north- and southbound lanes of I-80 and it has approximately 970 thousand visitors based on 2009 statistics. The rest area was built in 1969 and renovated in 1989. The major sources of energy consumption in the rest area include the interior and exterior lighting, heating and cooling, vending machines, hand dryers, pump station, and water heater. The next sections discuss the energy consumption analysis for the rest area buildings as well as LCC analysis for implementing different green building measures including interior and exterior energy-saving light bulbs, motion-activated lighting, vending occupancy controls, motion exhaust sensors, geothermal heat pumps, Energy Star air-source heat pump, thermal pane glass, energy-efficient hand dryers, photovoltaic systems, solar water heater, solar daylight tubes, and water-saving plumbing fixtures.

D.3.1 Energy Audit and Analysis

The Great Sauk Trail rest area has two utility meters to measure energy consumption in each building of the rest area. These two utility meters can be used to measure the monthly energy consumption of each building however they cannot provide energy consumed by each device or equipment in the rest area. In order to identify major sources of energy consumption in the rest area buildings and their costs, an energy simulation model was developed using the eQuest energy simulation software environment. The eQuest software can be used to simulate the energy performance of a building including its construction materials, weather, space heating and cooling, air ventilation, air infiltration and exhaust, temperature control, interior and exterior lighting, water use, windows and doors, skylights, operation schedule and occupancy, building activities, equipment loads. Furthermore, eQuest can account for different scenarios for replacing any of the current equipment or devices in buildings and calculate energy consumption accordingly. This capability of measuring building energy consumption based on different scenarios of implementing various green building measures and equipment will be used to analyze and identify a list of promising BMPs for Great Sauk Trail rest area.

The Great Sauk Trail rest area model was developed similar to the Coalfield rest area buildings. The model was developed based on the rest area's location, square footage, architectural shape, zones, building envelope construction, infiltration, building orientation, operation schedule, building activities, building occupancy, ventilation, HVAC system, temperature control, and water heater. All energy consumption data for the Great Sauk Trail rest area including lighting, HVAC system, hand dryers, vending machines, ventilation, infiltration, exhaust, occupancy, water pump and water heater were modeled using a similar procedure to the one described earlier for the Coalfield rest area buildings.

After modeling the rest area building in eQuest, the simulation model was run to simulate building performance with respect to weather conditions throughout the year and calculate monthly and total energy consumption categories of the building. Due to the difficulty of measuring air infiltration rates for entry doors during the site visit, several runs of simulation model were conducted with varying reasonable rates of infiltration and ventilation in order to minimize the differences between simulated and actual energy consumption reported in the building's energy bills. The parameters of infiltration were eventually set in the model to 93 CFM/ person for restrooms, lobby, and vending area and 545 CFM/person for mechanical and storage rooms. Similarly, infiltration rate was set to 1.2 air change per hour in the model to account for double doors entry of the rest area and match with energy bills.

Figure 101 compares the simulated monthly energy consumption of the building based on the developed model in eQuest to the actual energy consumption reported in the utility bills of the Coalfield rest area buildings in 2010. Based on the results in Figure 101, the average absolute difference between the energy consumption for the developed simulation model and actual bills is 12.5% and the maximum and minimum difference between the energy consumption for the developed simulation model and actual bills were 35.4% in October and 0.3% in March.

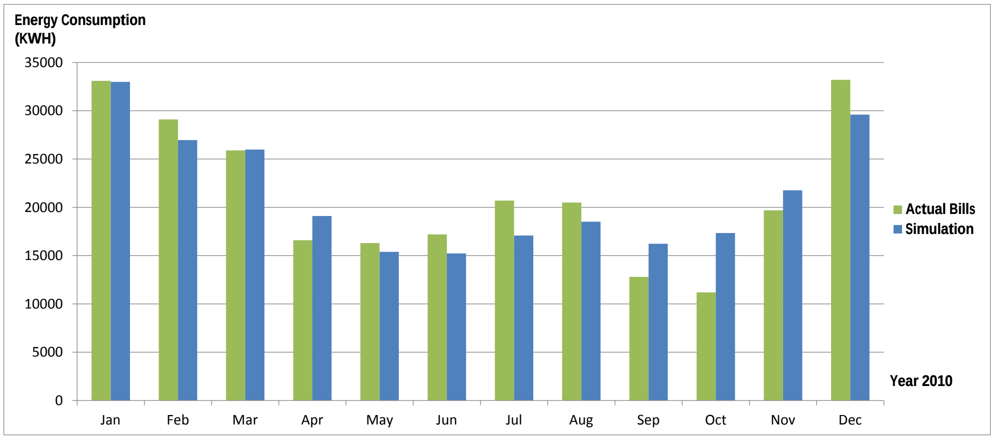


Figure 101. Simulated and actual electricity consumption of Great Sauk Trail rest area buildings in 2010.

It should be noted that the number of visitors per day was assumed to be constant throughout the year. Therefore, the difference in energy consumption between the eQuest simulation model and energy bills can be caused by the varying number of visitors per day which affects the building's heating and cooling energy consumption as well as its water use. In addition, the occasional and varying use of other small devices such as a microwave, laptop, small fan or heater unit that were observed during the site visits in the maintenance room can contribute to this difference between the simulation results and the energy bills. The "other" category includes small equipment and devices such as vacuum cleaners, coffee machines, microwave, personnel laptop, etc., that are occasionally used in the rest area building and were not considered in the simulation model.

The square footage of Great Sauk Trail rest area is 3722 SF per building and its annual number of visitors is 979,660 visitors for both bounds which leads to electricity consumption rate of 68.86 kwh/SF per year, 8.75 $/SF per year, and 0.52 kwh/visitor per year. The breakdown of electricity cost for the Great Sauk Trail rest area buildings for their main sources of consumption is shown in Figure 102. The eQuest energy simulation model shows that the highest source of energy consumption is space heating, which represents 27% of the total energy consumption of the building. On the other hand, the two sources that consume the least energy in the building are hand dryers and a water pump, which represent 2% and 1% of the building's total energy consumption, respectively. Space heating and cooling comprises 33% of total energy consumption of the building. This breakdown of energy costs will helps in prioritizing energy-improvement efforts. The "other" category includes small equipment and devices such as vacuum cleaners, coffee machines, microwave, personnel laptop, etc., that are occasionally used in the rest area building and were not considered in the simulation model.

The greatest use of energy for heating purposes (approximately 18% of total energy consumption) is caused by air ventilation in the rest area building which represents the outside air that replaces exhausted air from the restroom fans in addition to the outside air that enters the HVAC cycle. Additionally, 3% of the total energy costs is caused by infiltration which requires heating infiltrated air that leaks into the building mainly due to the frequent opening and closing of the building entry and exit doors (infiltration was modeled in eQuest model by 1.2 air change per hour).

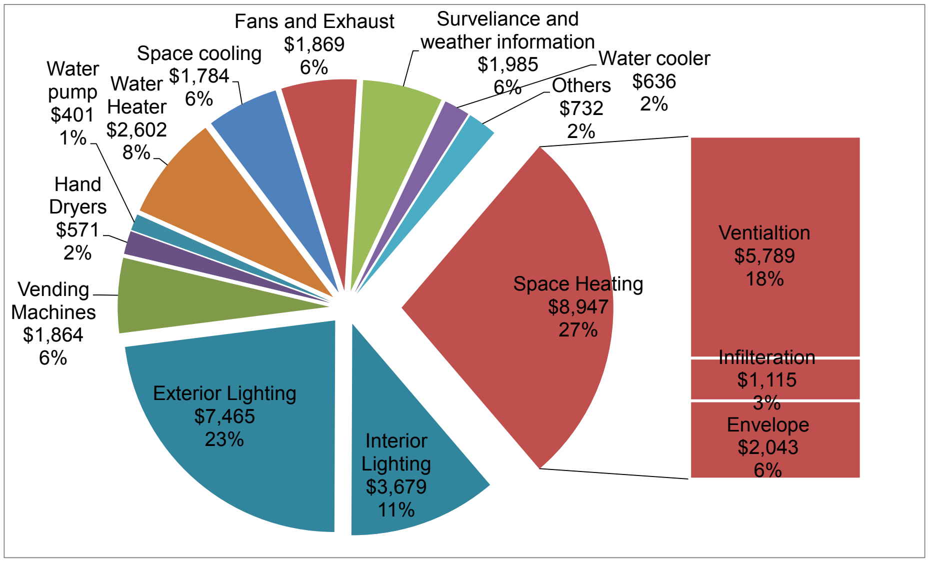


Figure 102. Energy cost breakdown of Great Sauk Trail rest area buildings.

D.3.2 Lighting

Lighting in the Great Sauk Trail rest area represents approximately 34% of total energy consumption with an annual cost of $11,144.The following two subsections analyzes replacing current interior and exterior lighting with more-efficient and energy-saving bulbs. The economic analysis of light replacement in these two subsections assumes an annual interest rate of 2% and escalation in utility rate of 5%.

D.3.2.1 Interior Lighting

Interior lighting in the Great Sauk Trail rest area consists of linear fluorescent T12 and T8 bulbs and assumed flood light bulbs. These bulbs can be replaced by more-efficient linear fluorescent T8 and CFL to provide similar luminance levels, less energy consumption and longer life expectancy. Table 116 through Table 118 summarize the impact of replacing current fluorescent T12 and flood with fluorescent T8 and CFL light bulbs for the Great Sauk Trail rest area. These lighting replacements can provide annual saving of $1,139 and reduce total energy consumption by 3.5%. The conducted LCC analysis for replacing all current T12 lighting with T8 bulbs is shown in Figure 103. The average payback period for all light replacement is calculated to be 0.48 years which represents a green building measure with promising return on investment.

Table 116. Replacing Linear Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in Lobby and Restrooms, Maintenance Rooms and Storage Rooms of Great Sauk Trail Rest Area.

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T8)	Fluorescent (T8)
	Philips 360131 (F32T8/TL741 PLUS/ALTO)	Sylvania 22179 (FO28/841/XP/SS/ECO)
Number of bulbs	77	77
Mean lumens (lumen)	2660	2562
Kelvin temperature (K)	4200	4100
Color Rendering Index (CRI)	62	85
Life time (hr)	42000	36000
Consumption per bulb (watt)	32	28
Lamp cost ($/each)	6.49	8.99
Change in lumens output levels (%)	N.A.	-3.7
Reduction in energy consumption (%)	N.A.	12.5
Annual savings in energy consumption - first year ($)	N.A.	281
Payback period (yr)	N.A.	0.57, 1.69, and 6.35*

* Payback period for lobby and restrooms, maintenance room, and storage rooms, respectively

Table 117. Replacing Current Halogen Flood Lighting with CFL Light Bulbs in Lobby of Great Sauk Trail Rest Area.

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Halogen Flood Light Bulb	CFL
	Sylvania *	Sylvania 20678 (CF18DD/841)
Number of bulbs	24	24
Mean lumens (lumen)	585	989
Kelvin temperature (K)	2200	2100
Color Rendering Index (CRI)	100	82
Life time (hr)	2500	12000
Consumption per bulb (watt)	50	18
Lamp cost ($/each)	8.49	4.99
Change in lumens output levels (%)	N.A.	+69
Reduction in energy consumption (%)	N.A.	64
Annual savings in energy consumption - first year ($)	N.A.	854
Payback period (yr)	N.A.	0.41

* Light bulb characteristics were assumed as these characteristics were not available during the site visit.

Table 118. Replacing Fluorescent T12 bulbs with Energy-Efficient T8 Light Bulbs in Attic of Great Sauk Trail Rest Area Buildings.

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	Philips 355669 (F60T12/CW/HO)	(F60T12/CW/HO/ALTO)
Number of bulbs	4	4
Mean lumens (lumen)	4500	4300
Kelvin temperature (K)	4100	5400
Color Rendering Index (CRI)	62	90
Life time (hr)	12000	20000
Consumption per bulb (watt)	75	58
Lamp cost ($/each)	12.49	24.99
Change in lumens output levels (%)	N.A.	+4.4
Reduction in energy consumption (%)	N.A.	22.7
Annual savings in energy consumption - first year ($)	N.A.	5
Payback period (yr)	N.A.	9.7*

*Storage lighting is assumed to be used 2 hours per day.

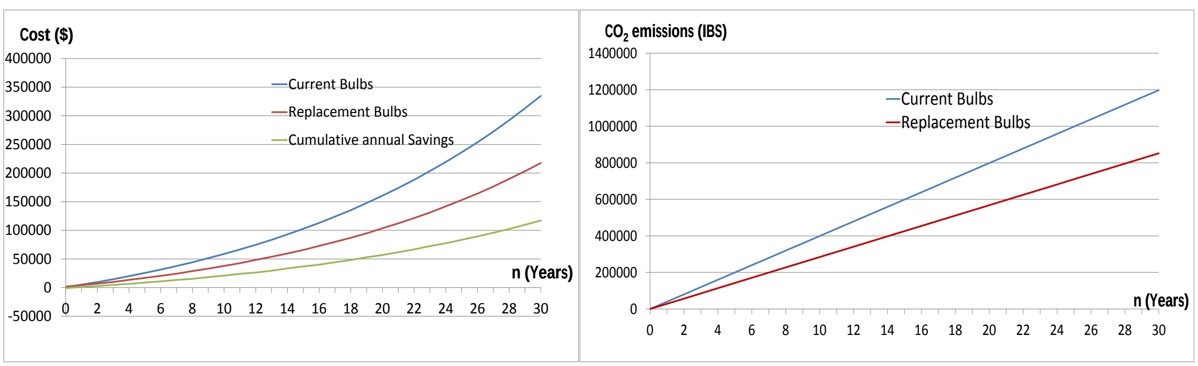


Figure 103. Cumulative costs, savings, and CO_2 emissions for current and replacement lighting in Great Sauk Trail rest area buildings.

D.3.2.2 Exterior Lighting

This section analyzes the impact of replacing current exterior lighting of Great Sauk Trail rest area with LED and induction lighting. The average lighting operating hours was determined based on eQuest simulation model which accounts for the location of the rest area building and its seasonal operational hours. The average lighting hours of exterior lighting was calculated to be 8.74 hours. The current exterior lighting of Great Sauk Trail rest area consists of (1) four recessed light fixtures with 50 watt HPS bulbs in each; (2) 17 light poles at entrance and exit of the rest area with a total of eighteen 250 watt HPS bulbs in each; and (3) five lighting towers with a total of twenty-eight 400 watt HPS bulbs. Due to the unavailability of the exact brand and luminance characteristics of current exterior lighting, reasonable assumptions were made for their luminance levels given the fact that the luminance characteristics are not significantly affected by the manufacturers.

A LCC analysis was conducted to examine the feasibility of implementing a one-for-one replacement of the current exterior lighting of the rest area building, its parking lot, as well as its entrance and exit with LED and induction lighting. The conducted analysis considered the possible lighting fixtures and bulbs shown in Table 119 as recommended by manufactures. It should be noted that LCC was conducted for one-for-one replacement to reduce initial costs. This one-for-one replacement is expected to reduce the current total lighting output (lumen) of light poles by 47% and 54% for LED and induction lighting replacements respectively. Similarly, this one-for-one replacement will reduce the current total lighting output (lumen) of (1) light towers by 60% and 64% for LED and induction lighting replacements, respectively; and (2) recessed fixtures by 38% and 48% for LED and induction lighting replacements, respectively. It should be noted that despite the lower average luminance of LED and induction lighting compared to HPS lighting, LED and induction lighting provide higher Color Rendering Index (CRI) than HPS lighting. CRI measures the effect of a light source on the perceived color of object and surface. Having high value of CRI makes virtually all colors look natural and reduces glare (Light Sout Services 2010).

The components and results of the conducted analysis are summarized in Table 120 through Table 122 for all lighting fixtures/bulbs of the rest area. The cumulative cost and savings as well carbon footprint and reductions in CO_2 emissions for replacing exterior lighting of Great Sauk Trail rest area are shown in Figure 104 The analysis shows that these light replacements can provide annual savings of $4,313 or 13.2% of total energy consumption for LED lighting replacements and $4,236 or 13.0% of total energy consumption for induction lighting replacements. This leads to a payback period of 16.9 years for LED light replacements and 4.9 years for induction lighting replacements.

Table 119. Characteristics of Current and Replacement Lighting for Great Sauk Trail Rest Area Buildings

Light Characteristic items	Current lighting		Replacement (LED lighting)		Replacement (Induction light)	
	Type	Characteristics	Type	Characteristics	Type	Characteristics
Initial Lumens (lumen)	HPS 50w	4000	LED Lamp	2500	Induction Lamp	2100
Color temperature (Kelvin)		3000		3000-5500		2700-6500
Color rendering index (CRI)		85		80		83
Life time (hours)		10000		50000		100000
Consumption (w)		50		30		30
Lamp cost ($)		40		206		206
Lamp and fixture cost ($)		-		-		-
Initial Lumens (lumen)	HPS 250w	28500	LED Steet Light	15000	Induction Steet	13200
Color temperature (Kelvin)		2000		2700-8000	Light	5000
Color rendering index (CRI)		25		75		83
Life time (hours)		30000		50000		75000
Consumption (w)		250		168		165
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1274		486
Initial Lumens (lumen)	HPS 400w	50000	LED Steet Light	20000	Induction Steet	18000
Color temperature (Kelvin)		2100		2700-8000	Light	5000
Color rendering index (CRI)		20		75		83
Life time (hours)		24000		50000		75000
Consumption (w)		400		224		225
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1493		538

Table 120. Replacing HPS 400W Bulbs with Energy-Efficient
LED and Induction Light Bulbs in Great Sauk Trail Rest Area Buildings

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	LED	Induction
Number of bulbs	28	28	28
Initial lumens (lumen)	50000	20000	18000
Kelvin temperature	2100	2700-8000	5000
Color Rendering Index (CRI)	20	75	83
Life time (hr)	24000	50000	75000
Consumption per bulb, including ballast (watt)	481	224	230
Bulb cost ($)	54	1,493	538
Reduction in lumens output levels (%)	N.A.	60	64
Reduction in energy consumption (%)	N.A.	53	52
Annual savings in energy - first year ($/year)	N.A.	3,119	2,791
Payback period (yr)	N.A.	14.1	4.3

Table 121. Replacing HPS 250W Bulbs with Energy-Efficient
LED and Induction Light Bulbs in Great Sauk Trail Rest Area Buildings

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	LED	Induction
Number of bulbs	18	18	18
Initial lumens (lumen)	28500	15000	13200
Kelvin temperature	2000	4900	5000
Color Rendering Index (CRI)	25	75	83
Life time (hr)	30000	50000	75000
Consumption per bulb, including ballast (watt)	315	168	168
Bulb cost	54	1320	486
Reduction in lumens output levels (%)	N.A.	47	54
Reduction in energy consumption (%)	N.A.	47	47
Annual savings in energy - first year ($/year)	N.A.	1,147	1,147
Payback period (yr)	N.A.	23.0	6.4

Table 122. Replacing HPS 50W Bulbs with Energy-Efficient
LED and Induction Light Bulbs in Great Sauk Trail Rest Area Buildings

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	LED	Induction
Number of bulbs	10	10	10
Initial lumens (lumen)	4000	2500	2100
Kelvin temperature	3000	5000	2700-6500
Color Rendering Index (CRI)	85	80	83
Life time (hr)	10000	50000	100000
Consumption per bulb, including ballast (watt)	57	30	32
Bulb cost	40	206	206
Reduction in lumens output levels (%)	N.A.	38	48
Reduction in energy consumption (%)	N.A.	47	44
Annual savings in energy - first year ($/year)	N.A.	47	43
Payback period (yr)	N.A.	7.1	7.2

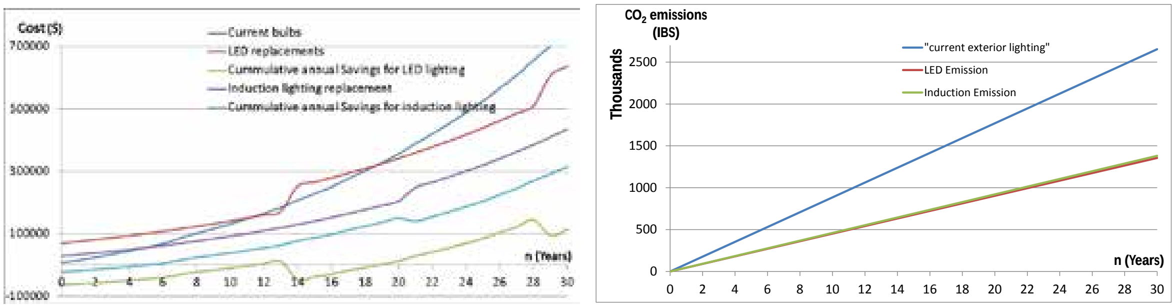
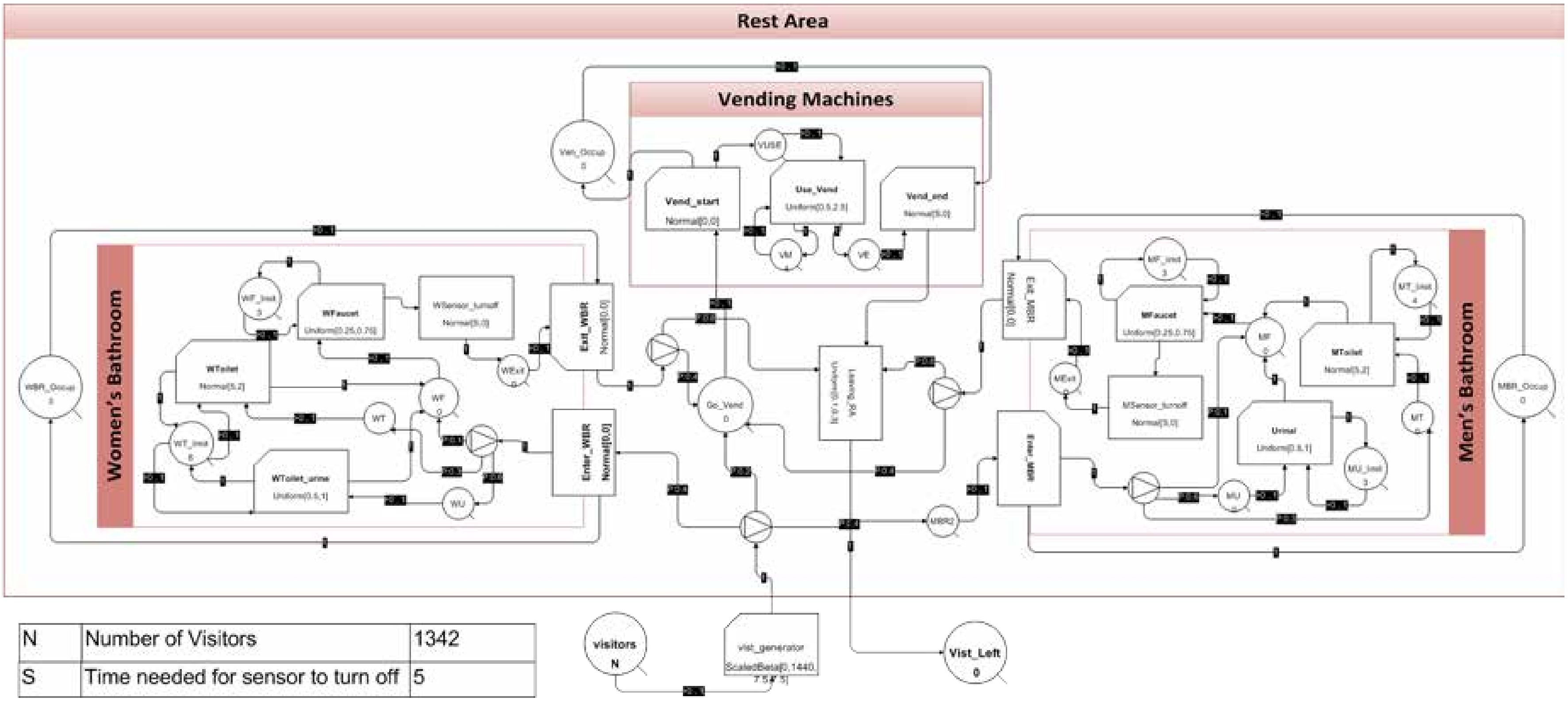


Figure 104. Cumulative costs, savings, and CO_2 emissions for LED and induction lighting replacements in Great Sauk Trail rest area buildings.

D.3.3 Motion Sensors

Rest areas have different operational schedule than business and commercial buildings and they have to operate 24 hours a day with few or no occupants during low visitation periods at night. This makes motion sensors a promising technology for rest area buildings. This section analyzes the implementation of motion sensors to control the lighting of restrooms and vending machine areas. Motion sensors also can be used to reduce space heating and cooling by reducing the use of exhaust fans at night when there are few or no occupants in the restrooms.

In order to estimate the energy savings in lighting and exhaust fans, the research team developed a separate simulation model using EZstrobe simulation language (Martinez 2006) to analyze and simulate the use of restrooms and vending machines based on the number and frequency of rest area visitors. The simulation model was developed to mimic the utilization of the rest area facilities by its visitors. The model was created to generate the number of visitors to the rest area using a beta distribution function to represent a high frequency of visitors during the morning, noon, and afternoon hours and low frequency during the night and early morning hours. The model also assumes that the percentages of visitors who will use the men’s restroom, women’s restroom, and vending machines are 40%, 40%, and 20%, respectively. Similarly, the probabilities that restroom visitors will use urinals, toilets and only faucets were assumed to be 30%, 60%, and 10%, respectively with reasonable random durations for each of these restroom tasks as, shown in Figure 105. It should be noted that the model assumes that each visitor using the toilet or urinal will also use the faucet afterwards. The developed model accounts for an amount of time for sensors to keep the light on after a visitor leaves a restroom. After a visitor leaves the restroom, the model assumes that there is a probability of 60% that the visitor will leave the rest area and 40% will use vending machines. The developed model can estimate how long the lighting in restrooms of the rest area will be turned off if motion-activated lighting were implemented in the restrooms. Similarly, the amount of time that lighting in vending machines and exhaust fans being turned/switched off can be calculated by the developed simulation model. Figure 106 shows rest area visitors while being in the men’s restroom throughout a simulation day. Table 123 summarizes the percentages of occupancy for restrooms and vending machines of the Great Sauk Trail rest area assuming that the lights or fans remain turned on for 5 minutes after the departure of the last visitor. The following subsections use the developed simulation model to estimate potential savings for using motion sensors in the rest area building and their expected payback periods. The economic analysis of motion sensors accounts for an annual interest rate of 2% and escalation in utility rate of 5% in calculating payback period of implementing this technology.



N	Number of Visitors	1342
S	Time needed for sensor to turn off	5

Figure 105. Motion-sensor simulation model for Great Sauk Trail Road rest area building.

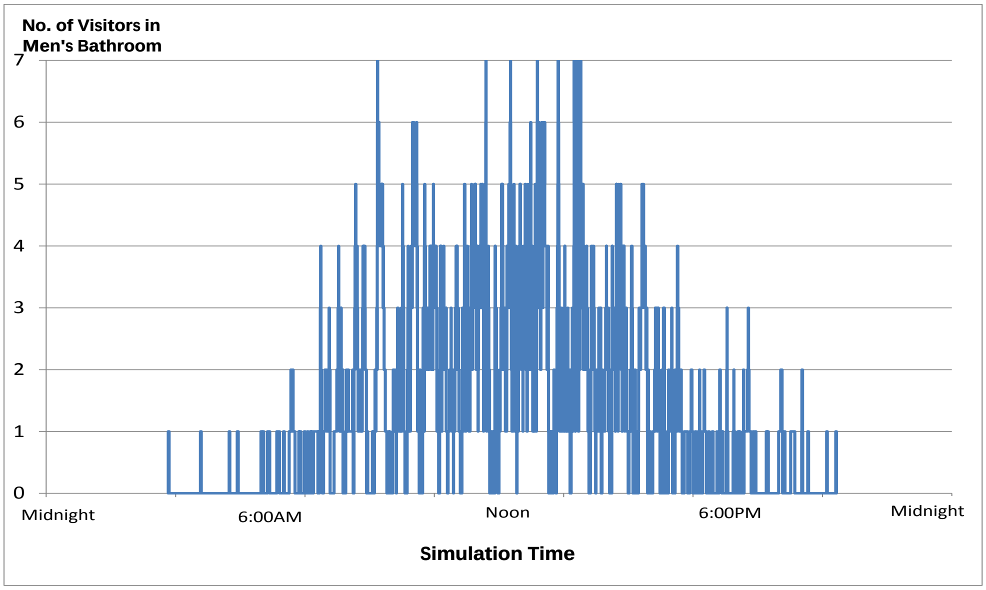


Figure 106. Number of visitors in men's restroom throughout a simulation day of Great Sauk Trail rest area buildings.

Table 123. Percentage Occupancy for Restrooms and Vending Area for Great Sauk Trail Rest Area Buildings

Percentage of Occupancy in Men's Restroom	Percentage Occupancy in Women's Restroom	Percentage Average Occupancy in Restrooms	Percentage Occupancy in Vending Machines Area
54.4%	56.0%	55.2%	37.2%

D.3.3.1 Motion-Activated Lighting

Motion-activated lighting can be installed in restrooms to turn off lights automatically when they are not occupied. As discussed in the previous section, restrooms in the Great Sauk Trail rest area have an average approximate occupancy of 55.2% including 5 minutes for the occupancy sensors remain in detection before turning off automatically. This leads to average 44.8% savings in lighting of restrooms. Table 124 shows the results of the LCC analysis for implementing motion-activated lighting in the restrooms of the Great Sauk Trail rest area. The analysis shows that the motion-activated lighting can provide approximate savings of $702 annually or 2.8% of total energy consumption of Great Sauk Trail rest area buildings, which represents a payback period of 1.8 years for this green building. Furthermore, motion-activated lighting in restrooms can eliminate annually 17,391 lb of CO_2 emissions.

Implementing motion-activated lighting in the lobby will not be feasible due to security requirements that require lights to be turned on at all times to ensure the proper operation of the surveillance cameras. Moreover, implementing motion-activated lighting in maintenance rooms will not provide much savings and the payback period will be long since the maintenance staff often turn off the light before leaving the mechanical rooms of the rest area.

Table 124. Motion-Activated Lighting Analysis for Restrooms of Great Sauk Trail Rest Area Buildings

Savings and Cost Items	Amount/Savings
Total load of lighting fixtures (watt)	1,408
Electricity cost ($/kwh)	0.127
Occupancy sensors cost ($)	368
Labor installation cost ($)	874
Total Initial cost ($)	1,242
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	1,566
Annual lighting energy savings ($)	702
Payback period (yr)	1.8
Amount of eliminated CO_2 (Ib)	17,391
Savings in total energy consumption of the rest area building (%)	2.8

D.3.3.2 Vending Occupancy Controls

Similar to motion-activated lighting, occupancy controls can be installed for vending machines to turn off their lighting when the vending area is not occupied. Based on the developed simulation model for motion sensors, lights of vending machine are expected to be on for approximately 37.2% of hours during the day assuming a duration of 5 minutes for sensors to remain on after detecting the last motion in the vending area. This leads to 59.8% lighting savings of the vending machine area. Table 125 shows the economic analysis of installing occupancy controls for vending machines area in the Great Sauk Trail rest area. The analysis shows that these occupancy controls can provide approximate savings of $419.2 annually or 1.3% of total energy consumption of the Great Sauk Trail rest area buildings, which lead to a payback period of 0.82 years. This measure can also eliminate 4,654 Ib of CO_2 emissions annually due to the achieved reduction in energy consumption.

Table 125. Occupancy Controls Analysis for Vending Machine in Great Sauk Trail Rest Area Buildings

Savings and Cost Items	Amount
Total load of lighting fixtures (watt)	600
Electricity cost ($/kwh)	0.127
Occupancy sensors cost ($)	120
Labor installation cost ($)	219
Total Initial cost ($)	339
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	668
Annual lighting energy savings ($)	419
Payback period (yr)	0.82
Amount of eliminated CO_2 (Ib)	4,654
Savings in total energy consumption of the rest area building (%)	1.3

D.3.3.3 Motion Sensors for Exhaust

Similar to motion-activated lighting, exhaust fans can operate only during the occupancy times of visitors. This will allow exhaust fans to be switched off automatically when there are no visitors which will decrease the amount of outside air that needs to be heated or cooled. eQuest software does not provide a direct method to account for the use of exhaust fan sensors however this can be modeled by decreasing the exhaust rate by a value which reflects the switching off of exhaust fans when there are no occupants. Accordingly, exhaust fan flow can be decreased with the average non-occupancy percentage of restrooms (44.8%). Table 126 summarizes the economic analysis results for implementing motion sensors for exhaust fans in rest area building. The analysis shows that motion sensors for exhaust fans can provide approximate annual savings of $1,097 annually or 3.4% of total energy consumption of Great Sauk Trail rest area buildings, which leads to a payback period of 0.8 years after implementing motion sensors for exhaust fans. This measure can also eliminate 12,182 lb of CO_2 emissions annually due to the reduction in energy consumption of heating and cooling.

Table 126. LCC Analysis Results for Implementing Exhaust Fan Motion Sensors in Great Sauk Trail Rest Area Buildings

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.127
Fan(s) and sensors cost($)	698
Labor installation cost ($)	146
Total Initial cost ($)	844
Annual energy savings ($)	1,097
Payback period (yr)	0.78
Amount of eliminated CO_2 (lb)	12,182
Savings in total energy consumption of building (%)	3.4

D.3.4 More-Efficient HVAC Systems

The current HVAC system at the Great Sauk Trail rest area consists of a split system with a condenser and electric resistance duct heaters. The system has a cooling capacity of about 15 tons and 110,056 BTU/H heating capacity. The current HVAC system can be replaced with a more energy-efficient system that reduces heating and cooling energy consumption. The following three subsections analyze the replacement of the current HVAC system with more-efficient units and setting back the temperature at night.

D.3.4.1 Geothermal Heat Pump

The existing HVAC system in the Great Sauk Trail rest area buildings operates continuously year round their consumption represents 39% of the total building consumption. Ground-source heat pumps can be more efficient than air-source heat pumps because they uses the nearly constant temperature of earth (55°F) to heat and cool buildings. The eQuest simulation environment can be used to model the use of a geothermal HVAC system for the Great Sauk Trail rest area buildings. The system was modeled to have heating coefficient of performance (COP) of 4.0 and a cooling efficiency of 18 EER. This system was also modeled to operate in economizer mode, which brings fresh air when the outside air temperature is sufficient to condition the space. After running eQuest model with geothermal heat pump, the model provides savings of 22% of total energy consumption. The installation and maintenance costs of geothermal heat pump were calculated similar to Coalfield rest area buildings. Table 127 summarizes the LCC components of replacing the current HVAC system with a geothermal heat pump.

Table 127. LCC Components for Replacing Current HVAC System with Geothermal Heat Pump at Great Sauk Trail Rest Area Buildings

LCC Components	Cost/Life
Capital cost - vertical system* ($)	62,320
Annual maintenance cost ($)	484
Annual operating cost ($)	5,453
Periodic cost ($)	38,320
Life (yr)	20

* Installation cost may vary due to soil conditions and resizing of the HVAC equipment

In order to compare the cost effectiveness and payback periods of replacing the current HVAC system at the rest area with a geothermal system, the initial, maintenance, operating and replacement costs of the current HVAC systems need to be identified. These costs were estimated similar to the Coalfield rest area buildings in order to carry out the LCC analysis. Table 128 summarizes the LCC components for the current HVAC system in the Great Sauk Trail rest area buildings.

Table 128. LCC Components for Current HVAC System in the Great Sauk Trail Rest Area Buildings

LCC Components	Cost/Life
Capital cost ($)	24,420
Annual maintenance cost ($)	1,042
Annual operating cost ($)	13,291
Periodic cost ($)	24,420
Life (yr)	17
Manufacture year	2010
Replacement year	2027

A LCC analysis was conducted to compare the potential replacement of the current HVAC system with a geothermal heat pump based on an annual interest rate of 2%, escalation in utility rate of 5%, and annual increase of maintenance cost of 2%. Table 129 summarizes the LCC analysis results for replacing current HVAC with geothermal heat pump. The analysis shows that replacing the current HVAC system with a vertical loop geothermal heat pump has a payback period of 7.5years. The cumulative costs for the horizontal loop geothermal system, vertical loop geothermal system, current HVAC system, and savings are shown in Figure 107. The geothermal heat pump can also be installed along with a desuperheater to heat water in the cooling season. The desuperheater uses heat that is removed from the building space to heat domestic hot water. This unit can provide free hot water in the summer or when the system is in cooling mode. It can provide annual savings of $548 or 1.7% of the total energy consumption. The payback period of the desuperheater is 2.9 years and it can eliminate 6,084 lb of CO_2 emissions.

Table 129. LCC Analysis Results for Replacing Current HVAC System with Geothermal Heat Pump at Great Sauk Trail Rest Area Buildings

Rest Area	Savings
Annual kwh saved	56,280
Annual energy savings - first year ($/yr)	7,148
Annual eliminated CO_2 emissions (lb)	79,355
Payback period - vertical system (yr)	7.5

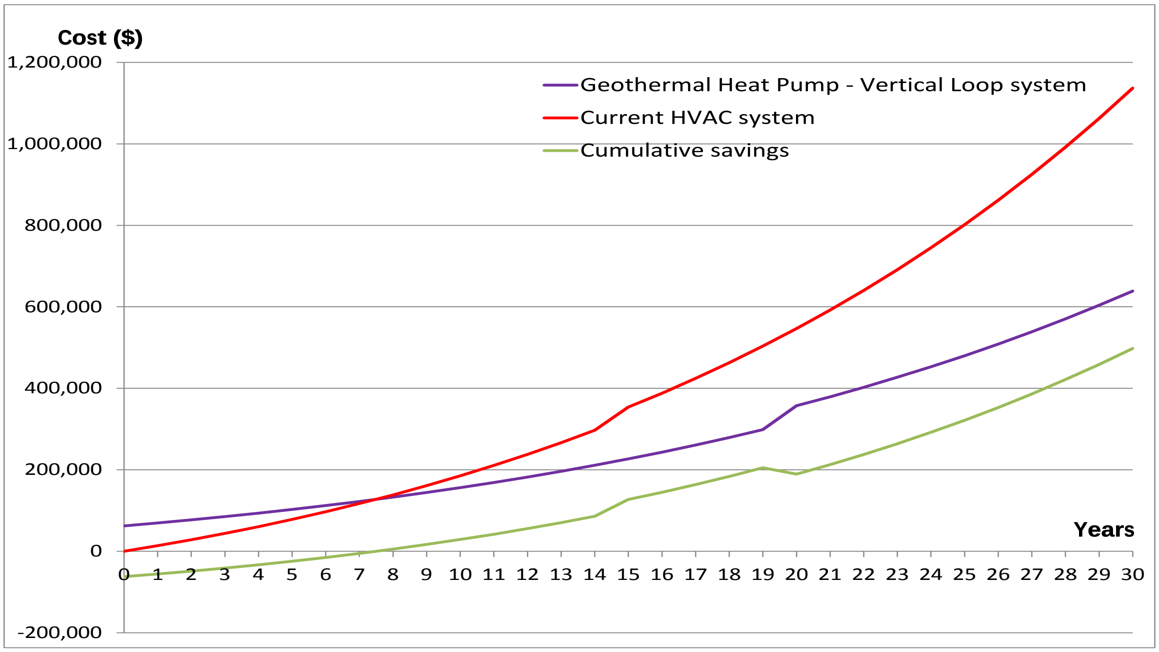


Figure 107. Cumulative costs of current HVAC system, vertical loop geothermal system, and savings for Great Sauk Trail rest area buildings.

D.3.4.2 High-Efficiency Air-Source Heat Pump

Another alternative for the current HVAC system at the Great Sauk Trail rest area is replacement with a more-efficient Energy Star–rated air-source heat pump to reduce heating and cooling expenses. An air-source heat pump was modeled in eQuest to meet Energy Star recommendations with a cooling efficiency of 12 EER and heating performance rating of 8.2 HSPR (Energy Star 2003). Table 130 summarizes the economic analysis results for replacing the current HVAC system with an Energy Star–rated air-source heat pump. The analysis shows that an Energy Star–rated HVAC system can provide annual savings of $3,858 annually or 11.9% of total energy consumption of the rest area building. This leads to a payback period of 6.3 years based on an annual interest rate of 2% and escalation in utility rate of 5%. This replacement can eliminate CO_2 emissions by 42,836 Ib annually.

Table 130. Analysis Results for Replacing Current HVAC System with Energy Star–Rated Air-Source Heat Pump at Great Sauk Trail Rest Area Buildings

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.127
Total initial cost for air-source heat pump	23,600
Annual energy savings ($)	3,858
Payback period (yr)	6.3
Amount eliminated CO_2 (Ib)	42,836
Savings in total energy consumption of building (%)	11.9

D.3.4.3 Setting Back HVAC System at Night

Another method to reduce energy consumption for space heating and cooling of the rest area is to set back the temperature of the HVAC system at night. The number of visitors using the rest area at night is very limited and, accordingly, setting back the temperature at night can reduce the energy consumption for heating and cooling. The temperature can be set at night to 68°F in winter and 70°F in summer. This measure can be modeled in eQuest by editing the temperature set points in the simulation model to a temperature that reflects the set points at night using interpolation. The developed eQuest model showed that setting back the temperature at night can provide annual savings of $136 or 0.4% reduction in total energy consumption. The Great Sauk Trail rest area buildings already have programmable thermostats that can be used to set back the HVAC temperature at night. This measure can be implemented easily to the rest area without additional costs.

D.3.5 Thermal Pane Glass for Windows And Doors

Thermal pane glass is a green building measure that can be added to the rest area building in order to reduce its cooling and heating energy consumption. This measure requires replacing all glazing as well as doors and windows in the rest area building with double-pane glass. This measure can be modeled in eQuest by replacing current single pane glass with double-pane glass. The analysis of implementing this measure provides annual savings of $692 or 2.1% of total energy consumption, as shown in Table 131. There is no expected payback period for this measure within 30 years as it requires major renovation for the rest area building with high initial cost. This measure can eliminate 7,685 Ib of CO_2 annually.

Table 131. LCC Analysis Results for Replacing Current Glazing and Doors with Double-Pane Glass in Great Sauk Trail Rest Area Buildings

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.127
Total initial cost for adding another door	51,206
Annual energy savings (kwh)	5450
Annual energy savings ($)	692
Payback period (yr)	More than 30 years
Amount of eliminated CO_2 (Ib)	7,685
Savings in total energy consumption of building (%)	2.1

D.3.6 Energy-Efficient Hand Dryers

Energy-efficient hand dryers are one of the green building measures that can be implemented in the Great Sauk Trail rest area buildings to reduce energy consumption of hand dryers, which was estimated based on a 50% use of rest area visitors each for 30 seconds according to manufacture use recommendations. Although, current hand dryers only consume approximately 1.3% of total energy consumption, they are one of the most visible devices for the rest area visitors. Moreover, slow velocity or inefficient hand dryers may discourage people to use them. This analysis considers the impact of installing three different models of energy-efficient hand dryers in the Great Sauk Trail rest area buildings to reduce their energy use, as shown in Table 132.The analysis shows that replacing current hand dryers may result in annual savings of $441 to $482 or 1.4% to 1.5% of total energy consumption in the rest area building based on three different models of energy-efficient hand dryers. These savings can provide a payback period of 3.9 years to 19.5 years for the three different models based on an annual interest rate of 2% and escalation in utility rate of 5%. This measure can eliminate up to 5,353 Ib of CO_2 emissions in Great Sauk Trail rest area buildings.

Table 132. LCC Analysis Results for Replacing Current Hand Dryers with Energy-Efficient Units for Great Sauk Trail Rest Area Buildings

LCC Items/Savings	Current Hand Dryer - World Dryer	1- World Dryer Airforce - J Series Hand Dryers	2- Xlerator Series Hand Dryers	3- Dyson Airblade Series Hand Dryers
Number of hand dryers	7			
Hand dryer consumption (w)	2,300	1,100	1100	1500
Drying time (s)	30	12	15	12
Initial cost ($)	N.A.	1,911*	2,800*	11,200*
Annual visitors - 2009	489,830			
Savings over the current hand dryers (%)	N.A.	81	76	74
Utility cost ($/kwh)	0.127			
Annual operating cost based on 50% use of visitors ($)	596	114	143	156
Annual savings ($)	N.A.	482	454	441
Annual savings of total energy consumption (%)	N.A.	1.5	1.4	1.4
Eliminated CO_2 emissions (Ib)	N.A.	5,353	5,036	4,892
Payback period (yr)	N.A.	3.9	5.9	19.5

* (Restroom Direct 2012)

D.3.7 Solar Measures

Several solar measures can be used to reduce energy consumption in the Great Sauk Trail rest area buildings. These measures can include solar daylight tubes, photovoltaic systems, and solar water heaters. These measures can reduce energy consumption of interior lighting, heating water as well as generate renewable and clean electricity. The next subsections discuss the installation of these systems in the Great Sauk Trail rest area buildings.

D.3.7.1 Solar Tube Lighting

Solar daylight tubes are one of the green building measures that can be used to provide lighting for the building during the day lighting hours. The technology requires solar tubes to penetrate the building roof to the ceiling where they transmit the sunlight during the day time. This technology can be installed in restrooms to decrease the interior lighting use during the day light time. It can be installed in the roof of the rest area building while installing light controls in restrooms to control/dim interior lighting during the day. The energy savings that this technology can provide was calculated based on reducing daily lighting use by 5 hours. The analysis for adding solar daylight tubes in the rest area building is summarized in Table 85. Cumulative costs and savings for implementing solar daylight tubes in restrooms of the rest area is shown in Table 133 The analysis shows that this measure can provide saving of $360 annually or 1.0% of the total energy consumption. This can lead to a payback period of 12.16 years. It should be noted that, the installation of this measure is crucial in terms of the amount of savings that it can provide. Improper installation of solar daylight tubes with low insulation (low U value) can lead to high dissipation of energy and subsequently increase cooling and heating costs. On the other hand, proper installation of this measure with sufficient U value, Energy Star–rated tubes can slightly increase heating and cooling. Based on modeling solar tubes in eQuest with similar skylight areas, this can lead to an increase in energy cost $99 annually. As a result the expected savings of this measure may reduce to $261 annually.

Table 133. LCC Analysis Results for Installing Solar Daylight Tubes in Restrooms and Lobby for Great Sauk Trail Rest Area Buildings

Savings and Cost Items	Restroom
Total load of lighting fixtures (watt)	1,408
Electricity cost ($/kwh)	0.127
Number of Solar daylight tubes (10' diameter)	4
Number of Solar daylight tubes (18" diameter)	6
Total Initial cost ($)	4,886
Solar tubes operation time (hr)	5
Annual lighting energy cost ($)	1,727
Annual lighting energy savings ($)	360
Payback period (yr)	12.16
Amount of eliminated CO2 (lb)	3,623
Savings in total energy consumption of the rest area building (%)	1.00

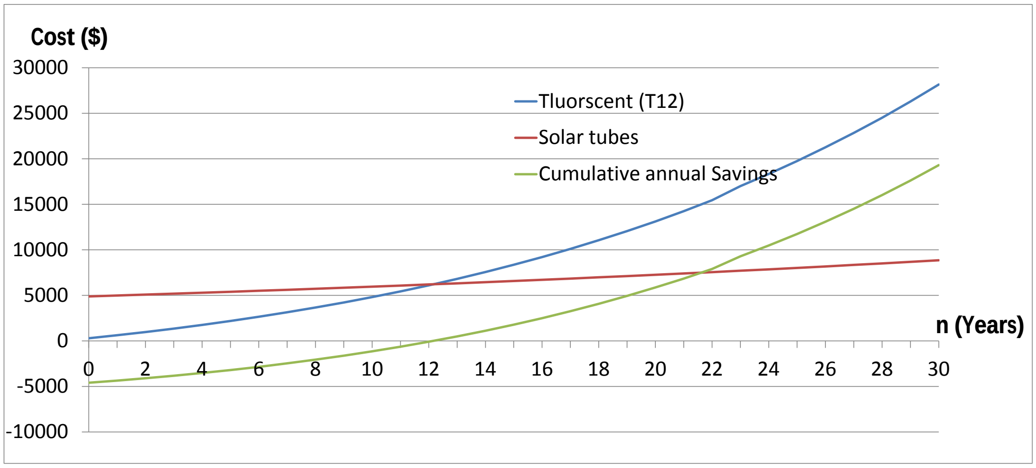


Figure 108. Cumulative costs and savings for implementing solar daylight tubes in restrooms of Great Sauk Trail rest area buildings.

D.3.7.2 Grid-Connected Photovoltaic Systems

Photovoltaic systems are one of the renewable energy measures that generate electricity to the Great Sauk Trail rest area buildings. In order to perform LCC for installing photovoltaic systems in the rest area, this system needs to be designed to estimate the number and type of system parts. Several factors affect the design of grid-connected systems including average daily peak sun hours, capacity of solar panels, capacity of inverters, and mounting of solar panels. The design of photovoltaic system for the Great Sauk Trail rest area was conducted using a similar procedure to the one described earlier in the Coalfield rest area.

This measure was analyzed to generate 5% of Great Sauk Trail total energy consumption. Table 134 summarizes the cost components for installing grid-connected photovoltaic system in the Great Sauk Trail rest area buildings. The LCC analysis was conducted in order to determine annual savings, payback period, amount of eliminated CO_2 emissions, and required area of the system. The analysis accounted for an annual interest rate of 2%, escalation in utility rate of 5%, and an annual increase of maintenance cost by 2%, as shown in Table 135. The analysis shows that incorporating grid-connected photovoltaic system at the Great Sauk Trail rest area has a payback period of 20.8 years. The system requires 35 solar panels to be installed and they can be placed on the roof of the restrooms. The required area for solar panels on the roof is 270 SF, these calculations accounted for 51^{o} tilt angle for the solar panels and preventing shading that might occur due to layout of solar panels in winter and summer. Figure 109 shows the cumulative savings of installing grid-connected system in the rest area building.

Table 134. Cost Components for Installing Grid-Connected Photovoltaic System in the Great Sauk Trail Rest Area Buildings

Cost Components	**Amount/Savings**
Total number of solar panels	35
Number of inverters	1
System capacity (KW)	8.2
Utility cost ($/kwh)	0.127
Initial cost ($)	36,590
Annual maintenance cost ($)	112
Solar Panels periodic cost ($)	12,147
Inverter periodic cost ($)	4,110
Annual Savings ($)	1,628
Annual Savings (kwh)	12815
Cost per watt ($/w)	4.53

Table 135. LCC Analysis Results for Incorporating Grid-Connected Photovoltaic System in the Great Sauk Trail Rest Area Buildings

LCC Items/Savings	**Amount/Savings**
Annual eliminated CO_2 emissions (lb)	18,069
Number of solar panels on roof	35
Number of solar panels on the ground	0
Required area for solar panels (SF)	270
Tilt angle of solar panels	51
Payback period (yr)	20.8

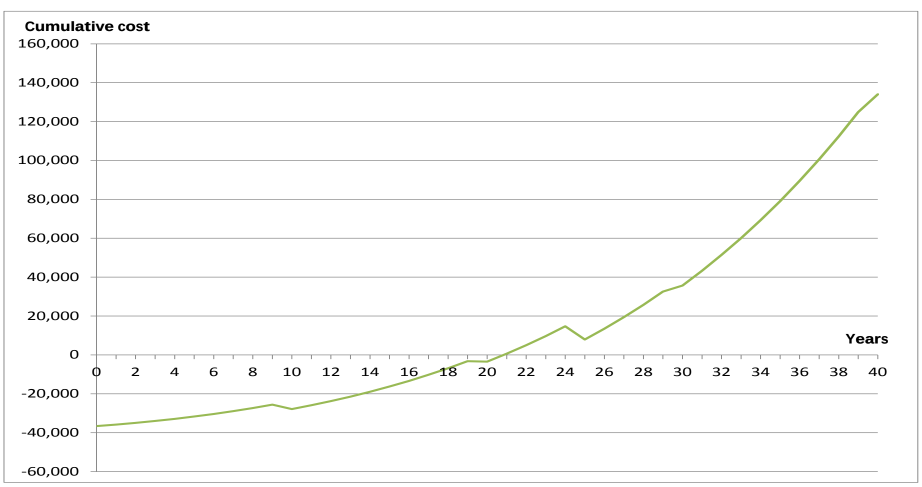


Figure 109. Cumulative cost of incorporating grid-connected system in the Great Sauk Trail rest area buildings.

It should be noted that the stand-alone photovoltaic system was not considered in this analysis because of its infeasible payback period that was identified in the first phase of this project due to its high initial and periodic costs of battery systems.

D.3.7.3 Solar Water-Heating Systems

Solar water heater is another technology that can reduce energy consumption for heating water in the rest area buildings. This technology can be installed with the current water heaters in the rest area in order to mitigate the cost of replacing current water heater. Moreover, current water heater can work as a backup when the sun rays are unavailable or insufficient to heat water to the desired temperature. The components of installing this system include solar collector(s), collector's mounting, heat exchanger, circulator, antifreeze (glycol), water storage tank(s), controller, fittings, pipes, and insulation. The initial capital cost of the system can be calculated for the three rest areas using the RSMeans Building Construction Cost Data (2012). Maintenance cost and life were calculated similar to Coalfield rest area buildings. Table 136 summarizes the LCC components for incorporating solar water heaters in the Great Sauk Trail rest area buildings. A LCC analysis was conducted based on an annual interest rate of 2%, escalation in utility rate by 5%, and an annual increase of maintenance cost by 2%, as shown in Table 137. The analysis shows that installing solar water heaters in Great Sauk Trail rest area buildings has a payback period that ranges from 4.3 to 16.7 years based on 70% and 20% energy savings heating water, and it can eliminate CO_2 emissions by 5,737 to 20,080 Ib annually.

It should be noted that solar collector(s) can be installed on the roof by clamps/straps or on the ground where a rack is used to hold the collector(s). Installing solar collectors on the roof might not be feasible as the building roof of the rest area was not designed to carry such extra load. Subsequently, solar collectors should be mounted on the ground.

Table 136. LCC Components for Installing Solar Water Heater in Great Sauk Trail Rest Area Buildings

LCC Components	Amount/Savings
Capital cost (Ground mount) ($)	7,735
Annual maintenance cost (Ground mount) ($/yr)	77
Utility Cost ($/kwh)	0.127
Conventional water heater consumption (kwh)	20,490
Annual operating cost for conventional water heater ($)	2,602
Annual savings (20% to 70% savings) ($)	520 to $,822
Periodic cost for pump @ 5 years ($)	250
Periodic cost for water tank @ 16 years ($)	1,600
Circulating pump life (yr)	5
Tank life (yr)	16

Table 137. LCC Analysis Results for Installing Solar Water Heater in Great Sauk Trail Rest Area Buildings

Savings	Amount
Annual kwh saved (20% savings)	4,098
Annual kwh saved (70% savings)	14,343
Annual eliminated CO_2 emissions - 20% savings (Ib)	5,737
Annual eliminated CO_2 emissions - 70% savings (Ib)	20,080
Payback period - 20% savings (yr)	16.65
Payback period - 70% savings (yr)	4.33

D.3.8 Water-Saving Plumbing Fixtures

Rest areas have a high rate of water consumption due to the large number of visitors that use their restrooms. Using water-conserving fixtures in these rest areas will provide significant savings in water consumption. A number of feasible water-saving technologies can be used to minimize water consumption in rest areas including efficient faucets, aerators, toilets, and urinals. Currently, the Great Sauk Trail rest area buildings have low-flow faucets, which make them suitable for conserving water use in the facility. An analysis was conducted to estimate the feasibility of installing conserving toilets and urinals in the rest area building. Table 138 summarizes the analysis of replacing current plumbing fixtures with water-conserving ones. As it was difficult to calculate precisely the number of visitors using urinals or toilets, the analysis assumed that 24% of visitors use urinals and 48% of visitors use men's and women's toilets. The replacement of current plumbing fixtures can provide savings of 87.5% of water consumption by urinals and 54.3% of water consumption by toilets. This could result in a total water savings of 549,589 gallons annually. The payback period for these fixtures could not be calculated because water unit cost could not be identified (the rest area uses ground water to supply its needs).

Table 138. LCC Analysis for Replacing Current Urinals and Toilets with Water-Conserving Fixtures in Great Sauk Trail Rest Area Buildings

Saving / Cost Items	Urinal	Toilets
Current fixture rate (GPF)	1	3.5
Number of fixtures	2	8
Type	Wall mount	Wall mount
Water-conserving rate (GPF)	0.125	1.6
Initial replacement Cost ($)	1,323*	5,640*
Savings per flush (G)	0.875	1.9
Percentage savings (%)	87.5	54.3
Annual visitors 2009	489,830	
Annual savings for 24% visitors using urinals and 48% using toilets (gallons)	102,864	446,725
Annual energy savings due to reduction in water pump use (%)	0.05	0.24
Annual energy savings due to reduction in water pump use ($)	18	78

* (RSMeans 2012; Lowe's 2012)

D.3.9 Summary of All Promising Green Building Measures

This section summarizes all green building measures that can be used in the Great Sauk Trail rest area buildings to reduce their energy consumption. All promising green building measures were added in the eQuest model in order to analyze the impact of their collective use and potential interactions on the overall energy consumption of the building. Table 139 summarizes all LCC components, savings and payback periods for all promising green building measures which were analyzed in the previous sections. The eQuest simulation model and energy analysis shows that the Great Sauk Trail rest area buildings can achieve a total of 52.3% reduction in energy costs by implementing the following energy-efficient measures: fluorescent T8 bulbs, induction lighting fixtures for exterior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 8.2KW capacity, setting back HVAC at night, and water-conserving fixtures.

Table 139. All Promising Green Building Measures for Great Sauk Trail Rest Area Buildings

Green Building Measure	Initial Cost	Annual Maintenance Cost, If Applicable	Annual Energy Savings	Annual Eliminated CO_2 Emissions (lb)	Reduction in Energy Consumption	Payback Period (yr)
Interior lighting	$1,632	N.A.	$1,139	12,650	3.5%	0.5
Exterior lighting - induction lighting	$29,328	N.A.	$4,236	42,923	13.0%	5.4
Motion-activated lighting	$1,242	N.A.	$702	7,791	2.2%	1.8
Vending occupancy controls	$339	N.A.	$419	4,654	1.3%	0.8
Motion-sensor exhaust fans	$844	N.A.	$1,097	12,182	3.4%	0.8
Geothermal heat pump	$62,320	$484	$7,148	79,355	22.0%	7.5
Desuperheater	$1,600	N.A.	$548	6,084	1.7%	2.9
Energy-efficient hand dryers	$1,911	N.A.	$482	5,353	1.5%	3.9
Photovoltaic system	$36,590	$112	$1,628	18,069	5.0%	20.8
Solar daylight tubes	$4,886	N.A.	$326	3,623	1.0%	12.2
Setting back HVAC at night	$0	N.A.	$136	1,509	0.4%	Immediate payback
Water-conserving fixtures	$6,963	N.A.	$95	1,059	0.3% of electricity	N.A.
All promising green building measures together (eQuest model)	$148,063	$596	$17,030	189,067	52.32%	8.0

D.4 WILLOW CREEK REST AREA

The Willow Creek rest area is located at mile marker 85 of I-39 and it comprises of two buildings that serve the north and south bounds of I-39. The rest area was built in 1993 and it has approximately 1.1 million annual visitors with annual increase of 0.49% in visitation rate based on 2009 statistics. The major sources of energy consumption in the rest area include the interior and exterior lighting, heating and cooling, vending machines, hand dryers, pump station, and water heater. The next sections discuss the energy consumption analysis for the rest area building as well as LCC analysis for implementing different green building measures including interior and exterior energy-saving light bulbs, motion-activated lighting, vending occupancy controls, motion exhaust sensors, geothermal heat pumps, Energy Star–rated air-source heat pump, thermal pane glass, energy-efficient hand dryers, photovoltaic systems, solar water heater, solar daylight tubes, and water-saving plumbing fixtures.

D.4.1 Energy Audit and Analysis

The Willow Creek rest area has one electricity meter and two gas meters to measure energy consumption in the two buildings, these three utility meters can be used to measure the monthly energy consumption of each building however they cannot provide energy consumed by each device or equipment in the rest area. In order to identify major sources of energy consumption in the rest area buildings and their costs, two energy simulation models were developed using the eQuest energy simulation software environment. Two simulation models were needed to mimic the performance of Willow Creek rest area buildings as one building consists of two floors to serve cars and trucks heading south on I-39 and the other building consists of one floor to serve cars and trucks heading north on I-39. The eQuest software can be used to simulate the energy performance of a building including its construction materials, weather, space heating and cooling, air ventilation, air infiltration and exhaust, temperature control, interior and exterior lighting, water use, windows and doors, skylights, operation schedule and occupancy, building activities, equipment loads. Furthermore, eQuest can account for different scenarios for replacing any of the current equipment or devices in buildings and calculate energy consumption accordingly. This capability of measuring building energy consumption based on different scenarios of implementing various green building measures and equipment will be used to analyze and identify a list of promising BMPs for Willow Creek rest area.

The Willow Creek rest area models were developed similar to the Coalfield rest area buildings. The models were developed based on the rest area's location, square footage, architectural shape, zones, building envelope construction, infiltration, building orientation, operation schedule, building activities, building occupancy, ventilation, HVAC system, temperature control, and water heater. All energy consumption data for the Willow Creek rest area including lighting, HVAC system, hand dryers, vending machines, ventilation, infiltration, exhaust, occupancy, water pump and water heater were modeled using a similar procedure to the one described earlier for the Coalfield rest area buildings.

After modeling the rest area buildings in eQuest, the simulation models were run to simulate the building performance with respect to weather conditions throughout the year and calculate monthly and total energy consumption categories of the buildings. Due to the difficulty of measuring air infiltration rates for entry doors during the site visit; several runs of simulation models were conducted with varying reasonable rates of infiltration and ventilation in order to minimize the differences between simulated and actual energy consumption reported in the building's energy bills. The parameters of infiltration were eventually set in the northbound model to 110 CFM/ person for restrooms, lobby, and vending area, 400 CFM/person for mechanical room and storage rooms. Infiltration rates were set to 0.4 air change per hour (ACH) in the model to account for vestibule entry of the rest area building. The parameters of infiltration were set in the southbound model to 296 CFM/person for restrooms, lobby, and vending area, and 810 CFM/person for mechanical and storage rooms. Infiltration rates were set to 0.3 air change per hour (ACH) in the model to account for vestibule entry of the rest area building.

Figure 110 compares the simulated monthly electricity consumption of the building to the actual energy consumption reported in the utility bills of the Willow Creek rest area buildings in 2010. Based on the results in Figure 110 the average absolute difference between the energy consumption for the developed simulation model and actual bills is 5.8% and the maximum and minimum difference in electricity consumption between the developed simulation model and actual bills are 12% in May and 0.5% in August. Similarly, Figure 111 and Figure 112 compare the simulated monthly gas consumption of the northbound and southbound buildings respectively based on the developed models in eQuest to the actual energy consumption reported in the utility bills of the Willow Creek rest area buildings in 2010. Based on the results in Figure 111 and Figure 112 the average absolute difference between the energy consumption for the developed simulation model and actual bills are 18.9% and 36.8% for northbound and southbound buildings respectively. The maximum and minimum difference in gas consumption between the developed simulation model and actual bills of northbound building are 46.8% in March and 1.1% in January. Similarly, the maximum and minimum difference in gas consumption between the developed simulation model and actual bills of southbound building are 160.6% in October and 0.9% in February. It should be noted that, gas consumption bills for northbound and southbound buildings were not available for May, June, and October, and their values were reasonably estimated based on similar rest areas and energy simulation models.

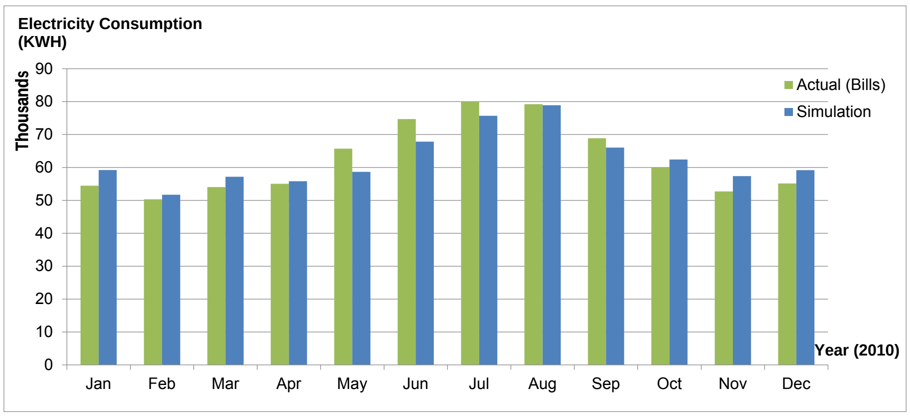


Figure 110. Simulated and actual electricity consumption of Willow Creek rest area buildings in 2010.

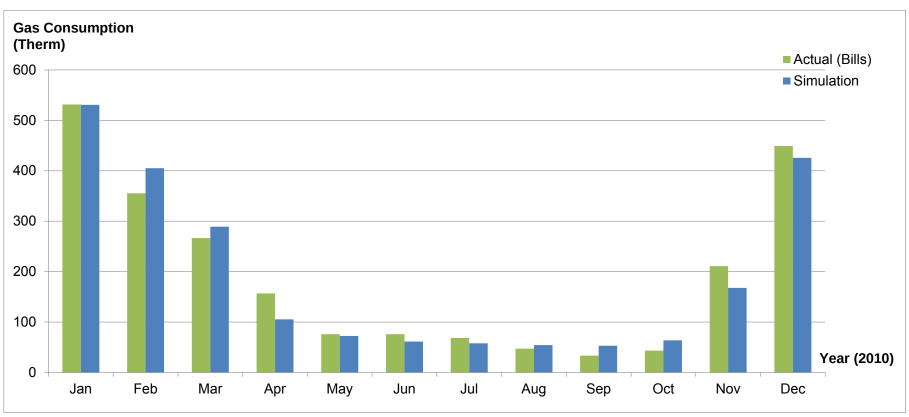


Figure 111. Simulated and actual gas consumption of Willow Creek rest area northbound building in 2010.

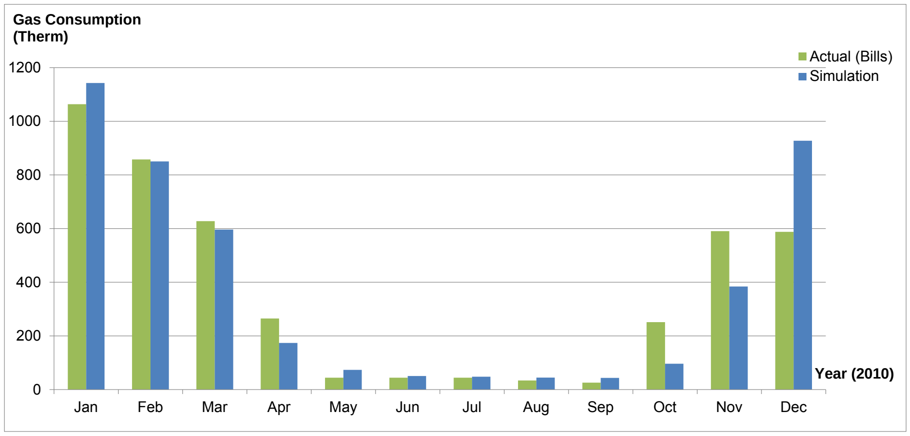


Figure 112. Simulated and actual gas consumption of Willow Creek rest area southbound building in 2010.

It should be noted that the number of visitors per day was assumed to be constant throughout the year. Therefore, the difference in energy consumption between the eQuest simulation model and energy bills can be caused by the varying number of visitors per day, which affects the building's heating and cooling energy consumption as well as its water use. In addition, the occasional and varying use of other small devices such as a microwave, laptop, small fan or heater unit that were observed during the site visits in the maintenance room can contribute to this difference between the simulation results and the energy bills. More importantly, the significant different between the developed energy simulation model of southbound building and actual reported bills of gas consumption (October through December) could result from improper reporting or measuring of gas consumption in the reported bills, malfunctioning of one of the furnaces equipment, or changes in settings of the HVAC system controls.

The square footage of Willow Creek rest area is 12,306 and its annual number of visitors is 1,117,265, which leads to energy consumption rate of 57.1 kwh/SF per year plus 0.75 Therm/SF per year, 6.69 $/SF per year, and 7.4 cents/visitor per year. The breakdown of energy cost for Willow Creek rest area buildings among their main sources of consumption are shown in Figure 113 and Figure 114 for northbound and southbound buildings respectively.

The eQuest energy simulation model shows that the highest source of energy consumption for northbound building is interior lighting that represents 32% of the total energy consumption. On the other hand, the two sources that consume the lowest energy in the northbound building are hand dryers and water pump that represent 2% and 1% of the building's total energy consumption, respectively. Similarly, the highest source of energy consumption for southbound building is interior lighting that represents 29% of the total energy consumption. On the other hand, the two sources that consume the lowest energy in the southbound building are hand dryers and water heater that represent 1% each of the building's total energy consumption.

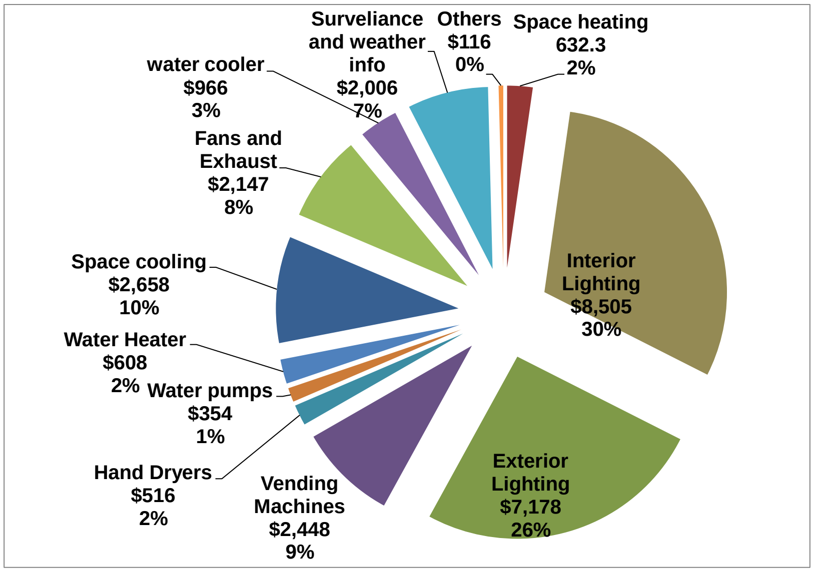


Figure 113. Energy cost breakdown for northbound building of Willow Creek rest area.

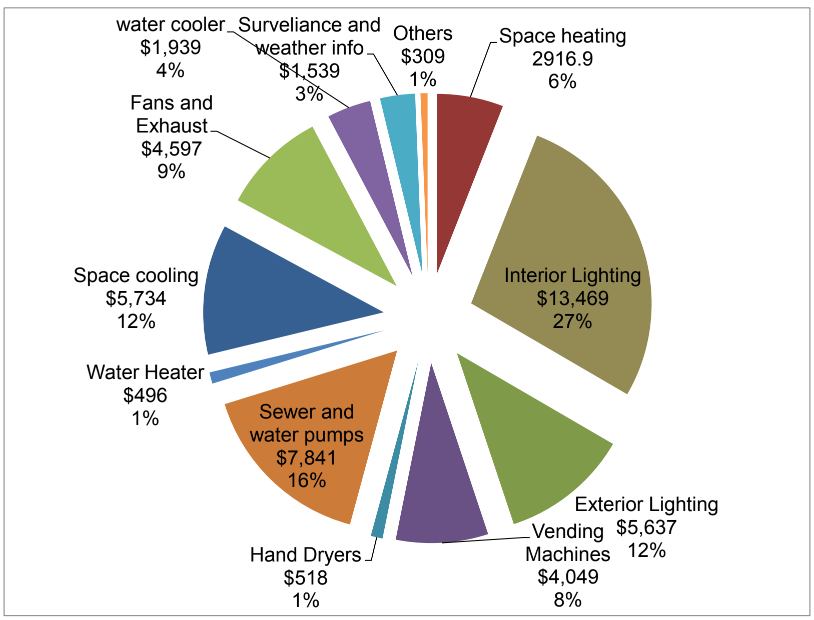


Figure 114. Energy cost breakdown for southbound building of Willow Creek rest area.

D.4.2 Lighting

Lighting in the Willow Creek rest area represents the highest energy consumption of the rest area buildings; it represents approximately 56% for northbound building and 39% for southbound building with total annual cost of $34,789. The next two subsections analyze replacing current interior and exterior lighting with more-efficient and energy-saving bulbs. The economic analysis of light replacement in these two subsections assumes an annual interest rate of 2% and escalation in utility rate of 5%.

D.4.2.1 Interior Lighting

Interior lighting in the Willow Creek rest area consists of linear and U-shape fluorescent T12 bulbs, 70w HPS bulbs and 400w MH bulbs. These bulbs can be replaced by linear and U-shaped fluorescent T8 to provide similar luminance level, less energy consumption and long life expectancy. Table 140 through Table 144 summarize the impact of replacing current fluorescent T12, HPS, and MH with fluorescent T8, CFL and induction light bulbs for the northbound building of the Willow Creek rest area. Similarly, Table 145 through Table 149 summarize the impact of replacing current fluorescent (T12), HPS, and MH with fluorescent (T8), CFL, and induction light bulbs for the southbound building of the Willow Creek rest area. It should be noted that replacing current HPS bulbs at the door entrances and corridors of the restrooms will reduce the lumens output levels by 44.6% and reduce the lumens output levels of current MH bulbs of the lobby by 31.4%. Despite the fact that CFL and induction lighting replacements have lower average lumens output levels however they provide higher Color Rendering Index (CRI) than HPS and MH. CRI measures the effect of a light source on the perceived color of object and surface. Having high value of CRI makes virtually all colors look natural and reduces glare (Light Sout Services 2010)

These lighting replacements can provide annual saving of $2,518 and reduce total energy consumption by 8.8% of the northbound building. Similarly, these lighting replacements can provide annual savings of $3,740 and reduce total energy cost by 7.6% of southbound building. The conducted LCC analysis for replacing all current T12, HPS, and MH lighting with T8, CFL, and induction light bulbs is shown in Figure 115 and Figure 116 for northbound and southbound buildings respectively. The average payback period for all light replacement is 3.7 years for northbound building and 3.2 years for southbound building. This represents a green building measure with promising return on investment.

Table 140. Replacing HPS Bulbs with Energy-Efficient CFL Light Bulbs for Restroom Corridors and Entrances in Northbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	HPS	CFL
	Philips 33192-6 - LU70 - HPS /cam light bulb	Philips 139485 (EL/DT 42W)
Number of bulbs	12	12
Mean lumens (lumen)	5050	2800
Kelvin temperature (K)	2100	4100
Color Rendering Index (CRI)	21	82
Life time (hr)	24000	8000
Consumption per bulb (watt)	70	42
lamp cost ($/each)	1.73	22.99
Change in lumens output levels (%)	N.A.	-44.6
Reduction in energy consumption (%)	N.A.	40
Annual savings in energy consumption - first year ($)	N.A.	284
Payback period (yr)	N.A.	5.5

Table 141. Replacing MH Bulbs with Induction Light Bulbs for Lobby in Northbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	MH	Induction lighting
	Sylvania 64488 (M400/U/BT28)	Sylvania 26152 (ICE150/835/ 2P/ECO)
Number of bulbs	11	22
Mean lumens (lumen)	26000	8915
Kelvin temperature (K)	4000	5000
Color Rendering Index (CRI)	65	83
Life time (hr)	20000	100000
Consumption per bulb (watt)	455	161
Total consumption (watt)	5,005	3,542
lamp cost ($/each)	$31.99	380
Change in lumens output levels (%)	N.A.	-31.4
Reduction in energy consumption (%)	N.A.	29
Annual savings in energy consumption - first year ($)	N.A.	1,238
Payback period (yr)	N.A.	5.5

Table 142. Replacing Fluorescent T12 (U-Shape) Bulbs with Energy-Efficient T8 Light Bulbs for Restrooms in Northbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	Sylvania (FB34/CW/6/SS/ECO	Sylvania 22305 (FBO28/841/XP/SS/ECO
Number of bulbs	24	24
Mean lumens (lumen)	2279	2265
Kelvin temperature (K)	4200	4100
Color Rendering Index (CRI)	62	75
Life time (hr)	18000	26000
Consumption per bulb (watt)	34	28
lamp cost ($/each)	9.99	15.79
Change in lumens output levels (%)	N.A.	+0.6
Reduction in energy consumption (%)	N.A.	17.6
Annual savings in energy consumption - first year ($)	N.A.	122
Payback period (yr)	N.A.	2.2

Table 143. Replacing Linear Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs for Restrooms in Northbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	34CW/RS/WM/ECO	Sylvania 22234 (FO32/25W/841/ XP/SS/ECO)
Number of bulbs	96	96
Mean lumens (lumen)	2280	2327
Kelvin temperature (K)	4100	4100
Color Rendering Index (CRI)	60	85
Life time (hr)	20000	36000
Consumption per bulb (watt)	34	25
lamp cost ($/each)	1.8	7.39
Change in lumens output levels (%)	N.A.	+2.1
Reduction in energy consumption (%)	N.A.	26.5
Annual savings in energy consumption - first year ($)	N.A.	731
Payback period (yr)	N.A.	0.74

Table 144. Replacing Light Bulbs of Maintenance and Storage Rooms with CFL Light Bulbs in Northbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Incandescent (assumed)	CFL
	Philips 213561 (50T60/HEA/WH)	Philips 137158 (EL/MDT 27W)
Number of bulbs	26	26
Mean lumens (lumen)	1600	1750
Kelvin temperature (K)	2900	2700
Color Rendering Index (CRI)	100	82
Life time (hr)	10000	10000
Consumption per bulb (watt)	70	27
lamp cost ($/each)	11.49	9.99
Change in lumens output levels (%)	N.A.	+9.4
Reduction in energy consumption (%)	N.A.	61
Annual savings in energy consumption - first year ($)	N.A.	142
Payback period (yr)	N.A.	Immediate return

Table 145. Replacing HPS Bulbs with Energy-Efficient CFL Light Bulbs for Restroom Corridors and Entrances in Southbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	HPS	CFL
	Philips 33192-6 - LU70 - HPS /cam light bulb	Philips 139485 (EL/DT 42W)
Number of bulbs	18	18
Mean lumens (lumen)	5050	2800
Kelvin temperature (K)	2100	4100
Color Rendering Index (CRI)	21	82
Life time (hr)	24000	8000
Consumption per bulb (watt)	70	42
lamp cost ($/each)	1.73	22.99
Change in lumens output levels (%)	N.A.	-44.6
Reduction in energy consumption (%)	N.A.	40
Annual savings in energy consumption - first year ($)	N.A.	426
Payback period (yr)	N.A.	5.5

Table 146. Replacing MH Bulbs with Induction Light Bulbs for Upper Lobby in Southbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	MH	Induction lighting
	Sylvania 64488 (M400/U/BT28)	Sylvania 26152 (ICE150/835/2P/ECO)
Number of bulbs	13	26
Mean lumens per bulb (lumen)	26000	8915
Kelvin temperature (K)	4000	5000
Color Rendering Index (CRI)	65	83
Life time (hr)	20000	100000
Consumption per bulb (watt)	455	161
Total consumption (watt)	5,915	4,186
lamp cost ($/each)	$31.99	$380
Change in lumens output levels (%)	N.A.	-31.4
Reduction in energy consumption (%)	N.A.	29.2
Annual savings in energy consumption - first year ($)	N.A.	1,463
Payback period (yr)	N.A.	5.5

Table 147. Replacing Fluorescent T12 (U-Shape) Bulbs with Energy-Efficient T8 Light Bulbs for Lobby and Restrooms in Southbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	Sylvania (FB34/CW/6/SS/ECO	Sylvania 22305 (FBO28/841/XP/SS/ECO
Number of bulbs	100	100
Mean lumens (lumen)	2279	2265
Kelvin temperature (K)	4200	4100
Color Rendering Index (CRI)	62	75
Life time (hr)	18000	26000
Consumption per bulb (watt)	34	28
lamp cost ($/each)	9.99	15.79
Change in lumens output levels (%)	N.A.	-0.6
Reduction in energy consumption (%)	N.A.	17.6
Annual savings in energy consumption - first year ($)	N.A.	508
Payback period (yr)	N.A.	2.2

Table 148. Replacing Linear Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs for Restrooms in Southbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	**Current Fixtures/Bulbs**	**Replacement Fixtures/Bulbs**
Type of bulb	Fluorescent (T12)	Fluorescent (T8)
	34CW/RS/WM/ECO	Sylvania 22234 (FO32/25W/841/ XP/SS/ECO)
Number of bulbs	144	144
Mean lumens (lumen)	2280	2327
Kelvin temperature (K)	4100	4100
Color Rendering Index (CRI)	60	85
Life time (hr)	20000	36000
Consumption per bulb (watt)	34	25
lamp cost ($/each)	1.8	7.39
Change in lumens output levels (%)	N.A.	+2.1
Reduction in energy consumption (%)	N.A.	26.4
Annual savings in energy consumption - first year ($)	N.A.	1097
Payback period (yr)	N.A.	0.74

Table 149. Replacing Light Bulbs of Maintenance and Storage Rooms with CFL Light Bulbs in Southbound Building of Willow Creek Rest Area

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement Fixtures/Bulbs
Type of bulb	Incandescent (assumed)	CFL
	Philips 213561 (50T60/HEA/WH)	Philips 137158 (EL/MDT 27W)
Number of bulbs	45	45
Mean lumens (lumen)	1600	1750
Kelvin temperature (K)	2900	2700
Color Rendering Index (CRI)	100	82
Life time (hr)	10000	10000
Consumption per bulb (watt)	70	27
lamp cost ($/each)	11.49	9.99
Change in lumens output levels (%)	N.A.	+9.4
Reduction in energy consumption (%)	N.A.	61
Annual savings in energy consumption - first year ($)	N.A.	246
Payback period (yr)	N.A.	Immediate return

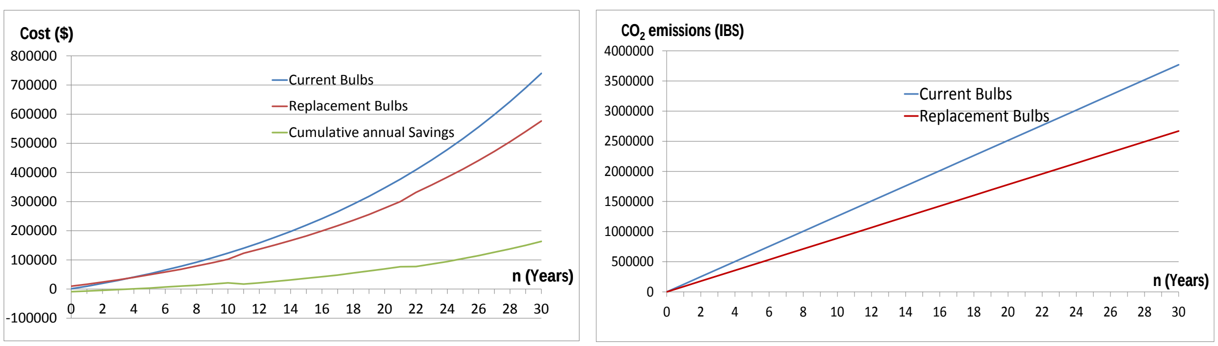


Figure 115. Cumulative costs, savings, and CO_2 emissions for current and replacement lighting in northbound building of Willow Creek rest area.

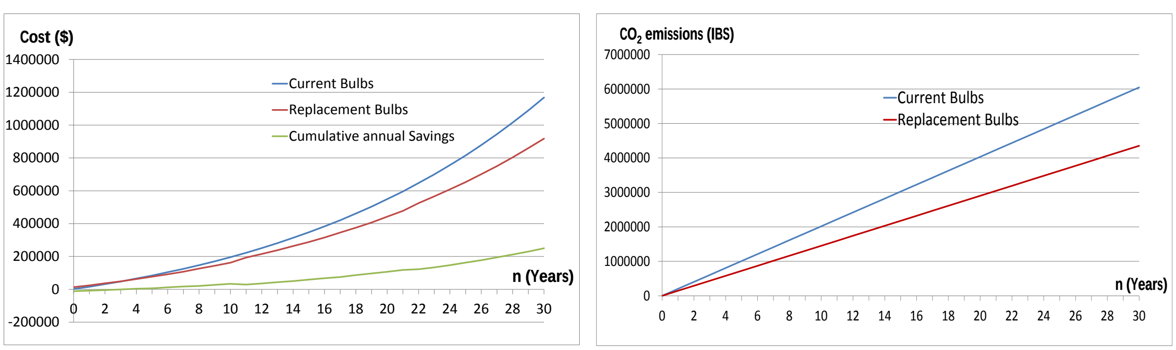


Figure 116. Cumulative costs, savings, and CO_2 emissions for current and replacement lighting in southbound building of Willow Creek rest area.

D.4.2.2 Exterior Lighting

This section analyzes the impact of replacing current exterior lighting of Willow Creek rest area with LED and induction lighting. The average lighting operating hours was determined based on eQuest simulation model, which accounts for the location of the rest area building and its seasonal operational hours. The average lighting hours of exterior lighting was calculated to be 8.73 hours. The current exterior lighting in northbound building of Willow Creek rest area consists of (1) 10 dusk-to-dawn light fixtures with 50 watt HPS bulbs in each; (2) 29 lighting poles with a total of thirty 250 watt HPS bulbs; and (3) five lighting towers with a total of twenty 400watt HPS bulbs. The current exterior lighting in southbound building of Willow Creek rest area consists of (1) ten dusk-to-dawn light fixtures with 50 watt HPS bulbs in each; (2) twenty lighting poles with a total of twenty-one 250 watt HPS bulbs; and (3) three lighting towers with eighteen 400 watt HPS bulbs. Due to the unavailability of the exact brand and luminance characteristics of current exterior lighting, reasonable assumptions were made for luminance level giving the fact that the luminance characteristics are not significantly affected by the manufacturers. Due to the unavailability of the exact brand and luminance characteristics of current exterior lighting, reasonable assumptions were made for their luminance level giving the fact that the luminance characteristics are not significantly affected by the manufacturers. It should be noted that LCC was conducted for one-for-one replacement to reduce initial costs. This one-for-one replacement is expected to reduce the current total lighting output (lumen) of light poles by 47% and 54% for LED and induction lighting replacements respectively. Similarly, this one-for-one replacement will reduce the current total lighting output (lumen) of (1) light towers by 60% and 64% for LED and induction lighting replacements, respectively; and (2) recessed fixtures by 38% and 48% for LED and induction lighting replacements, respectively. It should be noted that despite the lower average luminance of LED and induction lighting compared to HPS lighting, LED and induction lighting provide higher Color Rendering Index (CRI) than HPS lighting. CRI measures the effect of a light source on the perceived color of object and surface. Having high value of CRI makes virtually all colors look natural and reduces glare (Light Sout Services 2010).

A LCC analysis was conducted to examine the feasibility of a one-for-one replacement of the current exterior lighting of rest area buildings, their parking lots, as well as entrances and exits with LED and induction lighting replacements, the conducted analysis considered the possible lighting fixtures and bulbs shown in Table 150 as recommended by manufactures. The components and results of the conducted analysis of one-for-one replacements are summarized in Table 151 and Table 152 for all lighting fixtures/bulbs of northbound building, Table 153 and Table 154 for all lighting fixtures/bulbs of southbound building. The cumulative cost and savings as well as carbon footprint and reductions in CO_2 emissions for replacing exterior lighting of Willow Creek rest area are shown in Figure 117 and Figure 118 for northbound and southbound respectively. The analysis shows that these light replacements in northbound building can provide annual savings of $4,032 or 14.1% of total energy consumption for LED lighting replacements and $3,934 or 13.7% of total energy consumption for induction lighting replacements. Similarly, these light replacements in southbound building can provide annual savings of $3,162 or 6.5% of total energy consumption for LED lighting replacements and $3,084 or 6.3% of total energy consumption for induction lighting replacements. This leads to a payback period of 22.1 years for LED light replacements and 6.2 years for induction lighting replacements in northbound building and 22 years for LED lighting and 6.2 years for induction lighting in the southbound building.

Table 150. Characteristics of Current and Replacement Lighting for Exterior Lighting of Willow Creek Rest Area Buildings

Light Characteristic items	Current lighting		Replacement (LED lighting)		Replacement (Induction light)	
	Type	Characteristics	Type	Characteristics	Type	Characteristics
Initial Lumens (lumen)	HPS 50w	4000	LED Lamp	2500	Induction Lamp	2100
Color temperature (Kelvin)		3000		3000-5500		2700-6500
Color rendering index (CRI)		85		80		83
Life time (hours)		10000		50000		100000
Consumption (w)		50		30		30
Lamp cost ($)		40		206		206
Lamp and fixture cost ($)		-		-		-
Initial Lumens (lumen)	HPS 400w	50000	LED Steet Light	20000	Induction Steet Light	18000
Color temperature (Kelvin)		2100		2700-8000		5000
Color rendering index (CRI)		20		75		83
Life time (hours)		24000		50000		75000
Consumption (w)		400		224		225
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1493		538

Table 151. Replacing HPS 400W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Northbound Building of Willow Creek Rest Area

Building Factors	**Current Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	HPS	LED	Induction
Number of bulbs	50	50	50
Initial lumens (lumen)	50000	20000	18000
Kelvin temperature	2100	2700-8000	5000
Color Rendering Index (CRI)	20	75	83
Life time (hr)	24000	50000	75000
Consumption per bulb, including ballast (watt)	481	224	230
Bulb cost ($)	54	1,493	538
Reduction in lumens output levels (%)	N.A.	60	64
Reduction in energy consumption (%)	N.A.	53	52
Annual savings in energy - first year ($/year)	N.A.	3,955	3,863
Payback period	N.A.	21.9	6.1

Table 152. Replacing HPS 50W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Northbound Building of Willow Creek Rest Area

Building Factors	**Current Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	HPS	LED	Induction
Number of bulbs	10	10	10
Initial lumens (lumen)	4000	2500	2100
Kelvin temperature	2100	3000-5000	2700-6500
Color Rendering Index (CRI)	21	80	83
Life time (hr)	24000	50000	100000
Consumption per bulb, including ballast (watt)	55	30	32
Bulb cost	18	206	206
Reduction in lumens output levels (%)	N.A.	38	48
Reduction in energy consumption (%)	N.A.	45	42
Annual savings in energy - first year ($/year)	N.A.	86	79
Payback period	N.A.	26.7	17.8

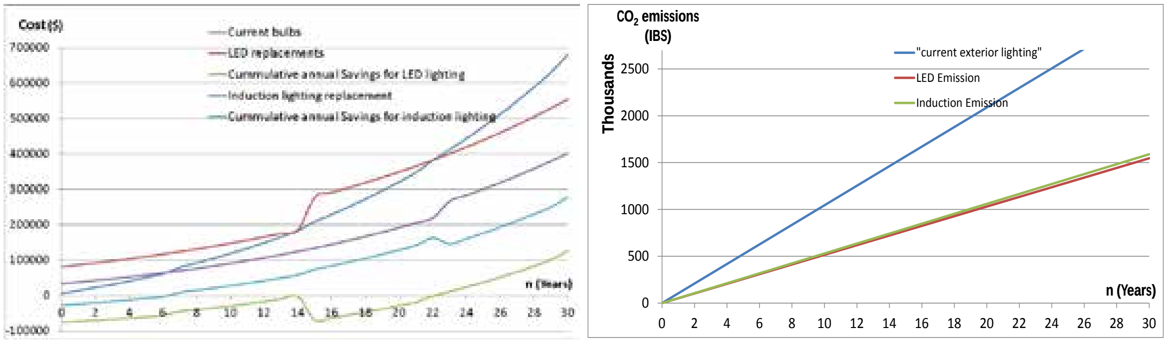


Figure 117. Cumulative costs, savings, and CO_2 emissions for LED and induction lighting replacements for northbound building of Willow Creek rest area.

Table 153. Replacing HPS 400W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Southbound Building of Willow Creek Rest Area

Building Factors	**Current Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	HPS	LED	Induction
Number of bulbs	39	39	39
Initial lumens (lumen)	50000	20000	18000
Kelvin temperature	2100	2700-8000	5000
Color Rendering Index (CRI)	20	75	83
Life time (hr)	24000	50000	75000
Consumption per bulb, including ballast (watt)	481	224	230
Bulb cost ($)	54	1,493	538
Reduction in lumens output levels (%)	N.A.	60	64
Reduction in energy consumption (%)	N.A.	53	52
Annual savings in energy - first year ($/year)	N.A.	3,085	3,013
Payback period	N.A.	21.9	6.1

Table 154. Replacing HPS 50W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Southbound Building of Willow Creek Rest Area

Building Factors	**Current Fixtures/Bulbs**	**Replacement 1**	**Replacement 2**
Type of bulb	HPS	LED	Induction
Number of bulbs	10	10	10
Initial lumens (lumen)	4000	2500	2700-6500
Kelvin temperature	2100	3000-5000	5000
Color Rendering Index (CRI)	21	80	83
Life time (hr)	24000	50000	100000
Consumption per bulb, including ballast (watt)	55	30	32
Bulb cost ($)	18	206	206
Reduction in lumens output levels (%)	N.A.	38	48
Reduction in energy consumption (%)	N.A.	45	42
Annual savings in energy - first year ($/year)	N.A.	77	71
Payback period	N.A.	26.7	17.8

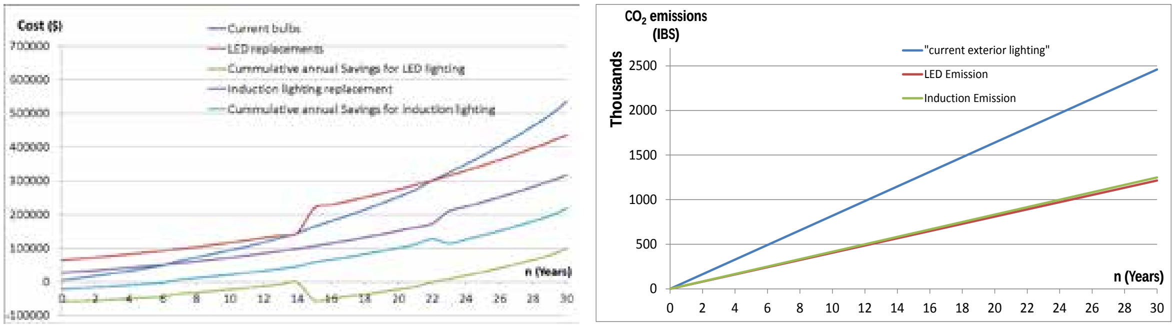
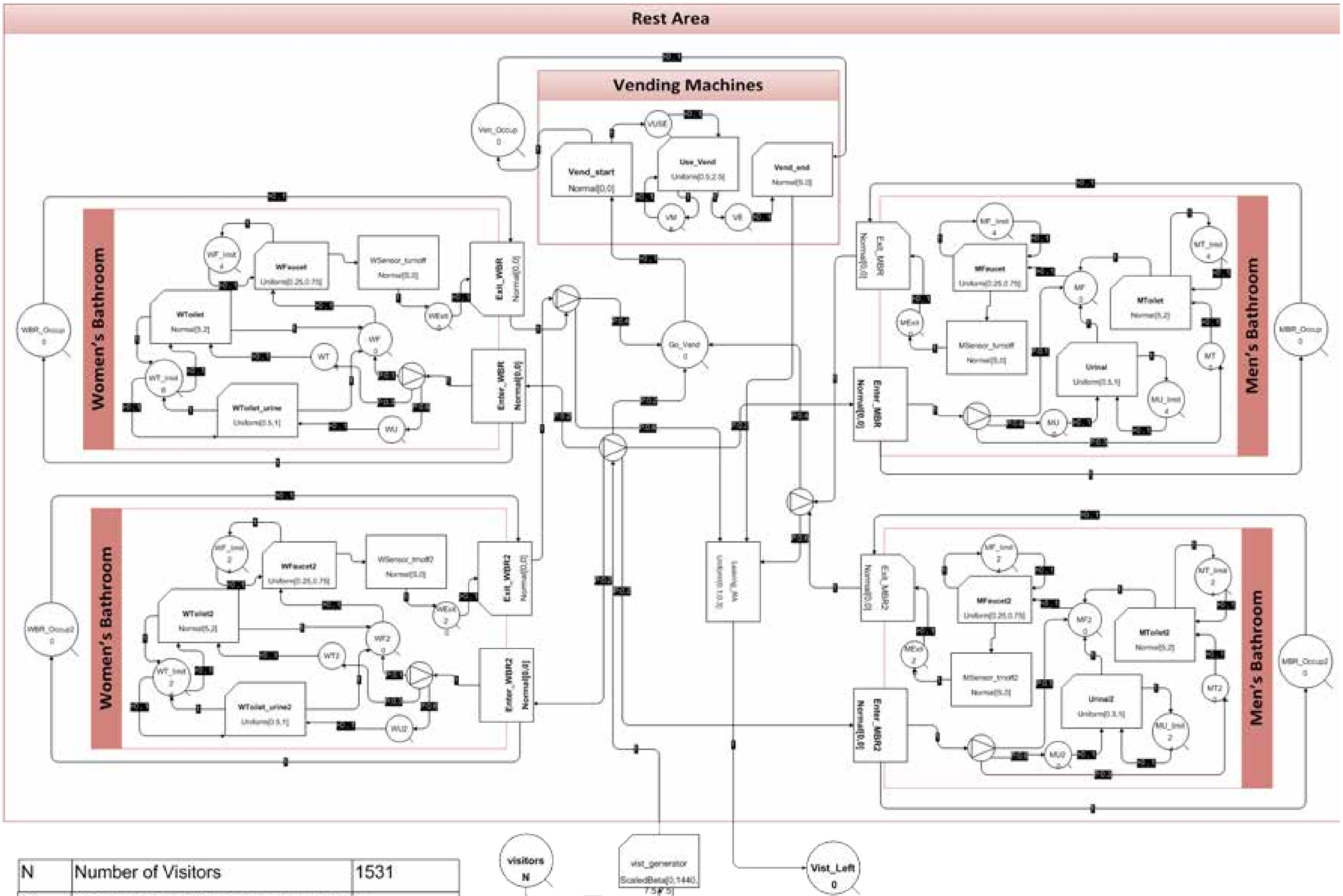


Figure 118. Cumulative costs, savings, and CO_2 emissions for LED and induction lighting replacements for northbound building of Willow Creek rest area.

D.4.3 Motion Sensors

Rest areas have different operational schedule than business and commercial buildings and they have to operate 24 hours a day with few or no occupants during low visitation periods at night. This makes motion sensors a promising technology for rest area buildings. This section analyzes the implementation of motion sensors to control the lighting of restrooms and vending machine areas. Motion sensors also can be used to reduce space heating and cooling by reducing the use of exhaust fans at night when there are few or no occupants in the restrooms.

In order to estimate the energy savings in lighting and exhaust fans, the research team developed a separate simulation model using EZstrobe simulation language (Martinez 2006) to analyze and simulate the use of restrooms and vending machines based on the number and frequency of rest area visitors. The simulation model was developed to mimic the utilization of the rest area facilities by its visitors. The model was created to generate the number of visitors to the rest area using a beta distribution function to represent a high frequency of visitors during the morning, noon, and afternoon hours and low frequency during the night and early morning hours. The model also assumes that the percentages of visitors that will use the men’s restroom, women’s restroom and vending machines are 40%, 40%, and 20%, respectively. Similarly, the probabilities that restroom visitors will use urinals, toilets and only faucets were assumed to be 30%, 60%, and 10%, respectively with reasonable random durations for each of these restroom tasks as, shown in Figure 119. It should be noted that the model assumes that each visitor using the toilet or urinal will also use the faucet afterwards. The developed model accounts for an amount of time for sensors to keep the light on after a visitor leaves a restroom. After a visitor leaves the restroom, the model assumes that there is a probability of 60% that the visitor will leave the rest area and 40% will use vending machines. The developed model can estimate how long the lighting in restrooms of the rest area will be turned off if motion-activated lighting were implemented in the restrooms. Similarly, the amount of time that lighting in vending machines and exhaust fans being turned/switched off can be calculated by the developed simulation model. Figure 120 shows rest area visitors while being in the men’s restroom throughout a simulation day. Table 155 summarizes the percentages of occupancy for restrooms and vending machines of the Willow Creek rest area assuming that the lights or fans remain turned on for 5 minutes after the departure of the last visitor. The following subsections use the developed simulation model to estimate potential savings for using motion sensors in the rest area building and their expected payback periods. The economic analysis of motion sensors accounts for an annual interest rate of 2% and escalation in utility rate of 5% in calculating payback period of implementing this technology.



N	Number of Visitors	1531
S	Time needed for sensor to turn off	5

Figure 119. Motion-sensor simulation model for Willow Creek rest area buildings.

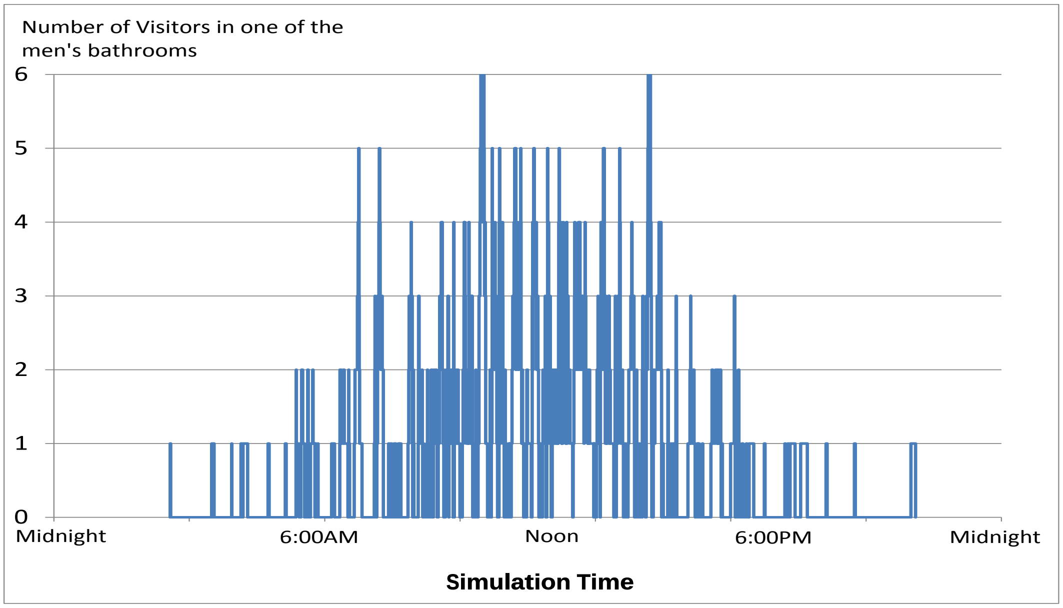


Figure 120. Number of visitors in men's restroom throughout a simulation day in Willow Creek rest area buildings.

Table 155. Average Percentage Occupancy for Restrooms and Vending Area of Willow Creek Rest Area Buildings

Percentage of Occupancy In Men's Restrooms	Percentage Occupancy in Women's Restrooms	Percentage Average Occupancy in All Restrooms	Percentage Occupancy in Vending Machines Area
49.5%	49.9%	49.7%	40.2%

D.4.3.1 Motion-Activated Lighting

Motion-activated lighting can be installed in restrooms to turn off lights automatically when they are not occupied. As discussed in the previous section, restrooms in the Willow Creek rest area have an average approximate occupancy of 49.7% including 5 minutes for the occupancy sensors remain in detection before turning off automatically. This leads to average 50.3% savings in lighting of restrooms. Table 156 shows the results of the LCC analysis for implementing motion-activated lighting in restrooms of Willow Creek rest area buildings. The analysis shows that motion-activated lighting can provide approximate savings of $1,915 annually for northbound building and $2,963 for southbound building or 6.7% of total energy cost for northbound building and 6% for southbound building. This represents a payback period of 0.83 years for northbound building and 1.07 years for southbound building. Furthermore, motion-activated lighting in restrooms can eliminate annually 71,199 Ib of CO_2 emissions for both buildings.

Implementing motion-activated lighting in the lobby will not be feasible due to security requirements that require lights to be turned on at all times to ensure the proper operation of the surveillance cameras. Moreover, implementing motion-activated lighting in maintenance rooms will not provide much savings and the payback period will be long since the maintenance staff often turn off the light before leaving the mechanical rooms of the rest area.

Table 156. Motion-Activated Lighting Analysis for
Restrooms of Willow Creek Rest Area Buildings

Savings and Cost Items	Northbound	Southbound
	Amount/Savings	Amount/Savings
Total load of lighting fixtures (watt)	4500	6960
Electricity cost ($/kwh)	0.0966	0.0966
Occupancy sensors cost ($)	536	1,072
Labor installation cost ($)	1,020	2,040
Total Initial cost ($)	1,556	3,112
Lighting operation time (hr)	24	24
Annual lighting energy cost for restrooms ($)	3,808	5,890
Annual lighting energy savings ($)	1,915	2,963
Payback period (yr)	0.83	1.07
Amount of eliminated CO_2 (lb)	27,958	43,241
Savings in total energy consumption of the rest area building (%)	6.7	6.0

D.4.3.2 Vending Occupancy Controls

Similar to motion-activated lighting, occupancy controls can be installed for vending machines to turn off their lighting when the vending area is not occupied. Based on the developed simulation model for motion sensors, lights of vending machine are expected to be on for approximately 40.2% of hours during the day assuming a duration of 5 minutes for the sensors to remain on after detecting the last motion in the vending area. This leads to 59.8% lighting savings of the vending machine area. Table 157 shows the economic analysis of installing occupancy controls for vending machines areas in the Willow Creek rest area. The analysis shows that these occupancy controls for vending machines can provide approximate savings of $708 annually or 1.0% of total energy cost of Willow Creek rest area buildings, which leads to average payback period of 1.3 years. This measure can also eliminate 10,341 lb of CO_2 emissions annually due to reduction in energy consumption.

Table 157. Occupancy Controls Analysis for Vending
Machine in Willow Creek Rest Area Buildings

Savings and Cost Items	Northbound	Southbound
	Amount/ Savings	Amount/Savings
Total load of vending lights (watt)	600	800
Electricity cost ($/kwh)	0.0966	0.0966
Occupancy sensors cost ($)	160	160
Labor installation cost ($)	291	291
Total Initial cost ($)	451	451
Vending operation time (hr)	24	24
Annual lighting energy cost ($)	508	677
Annual lighting energy savings ($)	304	405
Payback period (yr)	1.50	1.13
Amount of eliminated CO_2 (lb)	4,432	5,909
Savings in total energy consumption of building (%)	1.1	0.8

D.4.3.3 Motion Sensors for Exhaust

Similar to motion-activated lighting, exhaust fans can operate only during the occupancy times of visitors. This will allow exhaust fans to be switched off automatically when there are no visitors, which will decrease the amount of outside air that needs to be heated or cooled. eQuest software does not provide a direct method to account for the use of exhaust fan motion sensors however this can be modeled by decreasing the exhaust rate by a value, which reflects the switching off of exhaust fans when there are no occupants. Accordingly, exhaust fan flow can be decreased with the average non-occupancy percentage of restrooms (50.3%). Table 158 summarizes the economic analysis results for implementing motion sensors for exhaust fans in rest area buildings. The analysis shows that motion sensors for exhaust fans can provide approximate annual savings of $1,979 annually or 2.4% of total energy consumption of Willow Creek rest area buildings, which leads to an average payback period of 3 years. This measure can also eliminate 29,624 Ib of CO_2 emissions annually due to the reduction in energy consumption of heating and cooling.

Table 158. LCC Analysis Results for Implementing Exhaust Motion Sensors in Willow Creek Rest Area Buildings

Savings and Cost Items	Northbound	Southbound
	Amount/Savings	**Amount/ Savings**
Electricity cost ($/kwh)	0.0966	0.0966
Gas cost ($/therm)	0.77	0.77
Fan(s) and sensors cost ($)	1,732	1,732
Labor installation cost ($)	874	874
Total Initial cost ($)	2,606	2,606
Annual electricity savings (kwh)	3490	4320
Annual gas savings (therm)	397.0	1193.8
Annual energy savings ($)	643	1,337
Payback period (yr)	3.96	1.96
Amount eliminated CO_2 (Ib)	9,566	20,059
Savings in total energy consumption of building (%)	2.2	2.7

D.4.4 More-Efficient HVAC Systems

The current HVAC system at the Willow Creek rest area consists of two packaged rooftop units for northbound building and two packaged rooftop units for southbound building. The northbound HVAC system has a cooling capacity of 17 tons and an approximate total heating capacity of 79MBH; the southbound HVAC system has a cooling capacity of 27 tons and an approximate total heating capacity of 142MBH. The current HVAC systems can be replaced with more energy-efficient systems that reduce heating and cooling energy consumption. The next three subsections analyze the replacement of the current HVAC systems with more-efficient units and setting back the temperature at night.

D.4.4.1 Geothermal Heat Pump

The existing HVAC systems in the Willow Creek rest area building operate continuously year round and their consumption represents 20% of the total energy cost in the northbound building and 27% of total energy cost in the southbound building. Ground-source heat pumps use the nearly constant temperature of earth (55°F) to heat and cool buildings. The eQuest simulation environment can be used to model the use of geothermal HVAC systems for Willow Creek rest area buildings. These systems were modeled to have heating coefficient of performance (COP) of 4.0 and a cooling efficiency of 18 EER. This system was also modeled to operate in economizer mode, which brings fresh air when the outside air temperature is sufficient to condition the space. After running the eQuest model with geothermal heat pump, the developed models provide annual savings of 8.2% of total energy cost in northbound building and 9.2% of total energy cost in southbound building. The installation and maintenance costs of geothermal heat pump were calculated similar to Coalfield rest area buildings. Table 159 summarizes the LCC components of replacing the current HVAC systems with geothermal heat pumps.

Table 159. LCC Components for Replacing Current HVAC System with Geothermal Heat Pump at Willow Rest Area Buildings

LCC Components	**Northbound**	**Southbound**
	Costs/Life	**Costs/Life**
Capital cost - vertical system ($)	70,520	111,520
Annual maintenance cost ($)	533	533
Annual operating cost ($)	5,051	9,827
Periodic cost ($)	43,320	68,320
Life (yr)	20	20

* Installation cost may vary due to soil conditions and resizing of the HVAC equipment

In order to compare the cost effectiveness and payback periods of replacing the current HVAC systems in the rest area with geothermal systems, the initial, maintenance, operating and replacement costs of the current HVAC systems need to be identified. These costs were estimated similar to the Coalfield rest area buildings in order to carry out the LCC analysis. Table 160 summarizes the LCC components for current HVAC system of Willow Creek rest area buildings.

Table 160. LCC Components for Current HVAC System in Willow Rest Area Buildings

LCC Components	**Northbound**	**Southbound**
	Cost/Life	**Cost/Life**
Capital cost ($)	25,420	40,060
Annual maintenance cost ($/yr)	1,149	1,149
Annual operating cost ($/yr)	5,918	13,454
Periodic cost ($)	25,420	40,060
Life (yr)	17	17
Manufacture year	1995	1995
Replacement year	2012	2012

A LCC analysis was conducted to compare the potential replacement of the current HVAC system with a geothermal heat pump based on an annual interest rate of 2%, escalation in utility rate of 5%, and annual increase of maintenance cost of 2%. Table 161 summarizes the LCC analysis results for replacing current HVAC with geothermal heat pump. This analysis shows that a geothermal heat pump can provide savings of $2,349 in the northbound building and $4,530 annually in the southbound building. The analysis shows that replacing current HVAC systems with vertical loop geothermal heat pumps has a payback period of 13.4 years for the northbound building and 12.2 years for the southbound building. The cumulative costs for a vertical loop geothermal system, current HVAC systems, and savings are shown in Figure 121 and Figure 122 for the northbound and southbound buildings of Willow Creek rest area, respectively. The geothermal heat pump can also be installed along with a desuperheater to heat water in the cooling season. The desuperheater uses heat that is removed from the building space to heat domestic hot water. This unit can provide free hot water in the summer or when the system is in cooling mode. It can provide annual savings of $175 or 0.6% of the northbound building total energy consumption and annual savings of $140 or 0.3% of the southbound total energy consumption. The payback period of the desuperheater is 8.4 years for northbound building and 11.5 years for southbound building. These desuperheaters can eliminate 4,784 Ib of CO_2 emissions for northbound building and 6,084 for southbound building.

Table 161. LCC Analysis Results for Replacing Current HVAC System with Geothermal Heat Pump in Willow Rest Area Buildings

Savings	Northbound Amount	Southbound Amount
Annual electricity saved (kwh)	12,380	16,700
Annual gas saved (therm)	1,497	3,788
Annual energy savings - first year ($/yr)	2,349	4,530
Percentage of total energy saved (%)	8.2	9.2
Annual eliminated CO_2 emissions (lb)	34,971	67,869
Payback period - vertical system (yr)	13.4	12.2

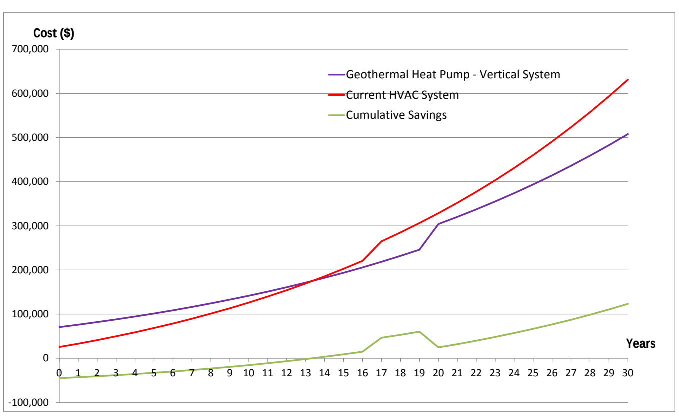


Figure 121. Cumulative costs of current HVAC system, vertical loop geothermal system, and savings for northbound building of Willow Creek rest area.

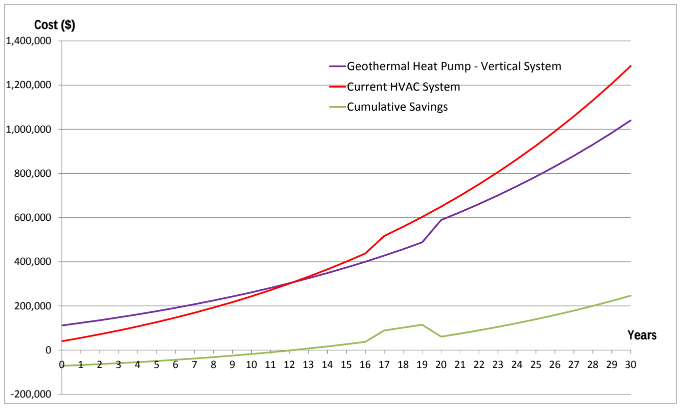


Figure 122. Cumulative costs of current HVAC system, vertical loop geothermal system, and savings for southbound building of Willow Creek rest area.

D.4.4.2 High-Efficiency Packaged Furnace

Another alternative for the current HVAC system at the Willow Creek rest area is to replace it with a more-efficient Energy Star–rated packaged furnace to study the feasibility of reducing heating and cooling expenses. A packaged furnace was modeled in eQuest to meet Energy Star recommendations with cooling efficiency of 12 EER and heating performance of 0.95 AFUE (Energy Star 2003). Table 162 summarizes the economic analysis results for replacing the current HVAC system with an Energy Star–rated air-source heat pump. The analysis shows that an Energy Star–rated furnace can provide annual savings of $1,325 for the northbound building and $2,898 for the southbound building, with a payback period of 20.8 years for the northbound building and 14.2 years for the southbound building. This replacement can also eliminate CO_2 emissions by 61,880 lb annually.

Table 162. Analysis Results for Replacing Current HVAC System with Energy-Efficient Air-Source Heat Pump at Willow Creek Rest Area Buildings

Savings and Cost Items	Northbound Amount/Savings	Southbound Amount/Savings
Electricity cost ($/kwh)	0.0966	0.0966
Gas cost ($/therm)	0.77	0.77
Estimated initial cost for packaged furnace ($)	36,450	49,275
Annual energy savings ($)	1,325	2,898
Payback period (yr)	20.8	14.2
Amount of eliminated CO_2 (lb)	19,402	42,478
Savings in total energy consumption of the rest area building (%)	4.6	5.9

D.4.4.3 Setting Back HVAC System at Night

Another method to reduce energy consumption for space heating and cooling of the rest area is to set back the temperature of the HVAC system at night. The number of visitors using the rest area at night is very limited and, accordingly, setting back the temperature at night can reduce the energy consumption for heating and cooling. The temperature can be set at night to 68°F in winter and 76°F in summer. This measure can be modeled in eQuest by editing the temperature set points in the simulation model to a temperature that reflects the set points at night using interpolation. The developed eQuest model showed that setting back the temperature at night can provide annual savings of $524 for northbound building and $403 for southbound building or 1.8% of total energy cost of northbound building and 0.8% of total energy cost of southbound building. Willow Creek rest area buildings have already programmable thermostats, which make this measure easy to be implemented in the rest area without additional cost.

D.4.5 Energy-Efficient Hand Dryers

Energy-efficient hand dryers are one of the green building measures that can be implemented in the Willow Creek rest area buildings to reduce energy consumption of hand dryers was estimated based on a 50% use of rest area visitors each for 30 seconds according to manufacture use recommendations. Although, current hand dryers only consume approximately 1.4% of total energy cost, they are one of the most visible devices for the rest area visitors. Moreover, slow velocity or inefficient hand dryers may discourage people to use them. This analysis considers the impact of installing three different models of energy-efficient hand dryers in Willow Creek rest area buildings to reduce their energy consumption, as shown in Table 163 and Table 164 for northbound and southbound buildings of Willow Creek rest area respectively. The analysis shows that replacing current hand dryers may result in annual savings of $382 to $418 or 1.3 % to 1.5% of total energy cost for northbound building and 0.8% to 0.9% of total energy cost for southbound building of the rest area based on the three different models of energy-efficient hand dryers. These savings can provide a payback period of more than 5.6 years based on an annual interest rate of 2% and escalation in utility rate of 5%. This measure can eliminate up to 12,208 lb of CO_2 emissions in Willow Creek rest area buildings.

Table 163. LCC Analysis Results for Replacing Current Hand Dryers with Energy-Efficient Units for Northbound Building of Willow Creek Rest Area

LCC Items/Savings	Current Hand Dryer - World Dryer	1- World Dryer Airforce - J Series Hand Dryers	2- Xlerator Series Hand Dryers	3- Dyson Airblade Series Hand Dryers
Number of hand dryers	9			
Hand dryer consumption (watt)	2,300	1,100	1100	1500
drying time (second)	30	12	15	12
Initial cost ($)	N.A.	2,457*	3,600*	14,400*
Annual visitors - 2009	558,633			
Savings over current hand dryers (%)	N.A.	81	76	74
Utility cost ($/kwh)	0.0966			
Annual operating cost based on 50% use of visitors ($)	517	99	124	135
Annual savings ($)	N.A.	418	393	382
Annual savings of total energy consumption (%)	N.A.	1.5	1.4	1.3
Eliminated CO_2 emissions (lb)	N.A.	6,104	5,743	5,579
Payback period (yr)	N.A.	5.6	8.4	26.1

* (Restroom Direct 2012)

Table 164. LCC Analysis Results for Replacing Current Hand Dryers with Energy-Efficient Units for Southbound Building of Willow Creek Rest Area

LCC Items/Savings	**Current Hand Dryer - World Dryer**	**1- World Dryer Airforce - J Series Hand Dryers**	**2- Xlerator Series Hand Dryers**	**3- Dyson Airblade Series Hand Dryers**
Number of hand dryers	18			
Hand dryer consumption (watt)	2,300	1,100	1100	1500
drying time (second)	30	12	15	12
Initial cost ($)	N.A.	4,914*	7,200*	28,800*
Annual visitors - 2009	558,633			
Savings over the current hand dryers (%)	N.A.	81	76	74
Utility cost ($/kwh)	0.0966			
Annual operating cost based on 50% use of visitors ($)	$517	99	124	135
Annual savings ($)	N.A.	418	393	382
Annual savings of total energy consumption (%)	N.A.	0.9	0.8	0.8
Eliminated CO_2 emissions (lb)	N.A.	6,104	5,743	5,579
Payback period (yr)	N.A.	10.4	15.1	More than 30 years

* (Restroom Direct 2012)

D.4.6 Solar Measures

Several solar measures can be used to reduce energy consumption in the Willow Creek rest area buildings. These measures can include solar daylight tubes, photovoltaic systems, and solar water heaters. These measures can reduce energy consumption of interior lighting, heating water as well as generating renewable and clean electricity. Solar daylight tubes were not analyzed for Willow Creek rest area buildings as they have metal roofs, which obstruct the penetration of solar tubes. Moreover, due to the inexistence of attic in the Willow Creek rest area, the installation of solar tubes could affect the insulation of the building roof and subsequently increase heating and cooling costs. The next subsections discuss the installation of photovoltaic systems and solar water heater in Willow Creek rest area buildings.

D.4.6.1 Grid-Connected Photovoltaic Systems

Photovoltaic systems are one of the renewable energy measures that generate electricity to the Willow Creek rest area buildings. In order to perform LCC for installing photovoltaic systems in the rest area, this system needs to be designed to the estimate number and type of system parts. Several factors affect the design of grid-connected systems including average daily peak sun hours, capacity of solar panels, capacity of inverters, and mounting of solar panels. The design of photovoltaic system for the Willow Creek rest area was conducted using a similar procedure to the one described earlier in the Coalfield rest area.

This measure was analyzed to generate 10% of annual electricity consumption in northbound building and 6% of annual electricity consumption in southbound building. Table 165 summarizes the cost components for installing grid-connected photovoltaic system in the Willow Creek rest area buildings. The LCC analysis was conducted to determine annual savings, payback period, amount of eliminated CO_2 emissions, and required area of the system. The analysis accounted for an annual interest rate of 2%, escalation in utility rate of 5%, and an annual increase of maintenance cost by 2%, as shown in Table 166 for northbound and southbound buildings respectively. The analysis shows that incorporating a grid-connected photovoltaic system at the Willow Creek rest area has a payback period of 27 years for the northbound building and 26.7 years for the southbound building. The northbound system requires 74 solar panels to be installed, 45 can be mounted on the south part of the roof and 29 solar panels can be placed on the ground south of the rest area building. Similarly, the southbound system requires 76 solar panels to be installed, 45 can be mounted on the south part of the roof and 31 solar panels can be placed on the ground south of the rest area building. The required area for solar panels on the ground is 270 SF in each bound, these calculations accounted for 51^{o} tilt angle for the solar panels and preventing shading that might occur due to layout of solar panels in winter and summer. Figure 123 and Figure 124 show the cumulative savings of installing a grid-connected system in the northbound and southbound buildings of the rest area.

Table 165. Cost Components for Installing Grid-Connected Photovoltaic System in Willow Creek Rest Area Buildings

Cost Components	**Northbound**	**Southbound**
	Amount/Savings	**Amount/Savings**
Total number of solar panels	74	76
Number of inverters	2	2
System capacity (KW)	17.4	17.9
Utility cost ($/kwh)	0.140	0.140
Initial cost ($)	71,977	73,836
Annual maintenance cost ($)	208	213
Solar Panels periodic cost ($)	25,682	26,376
Inverter periodic cost ($)	8,220	8,220
Annual Savings ($)	2,663	2,738
Annual Savings (kwh)	27565	28342
Cost per watt ($/w)	4.15	4.14

Table 166. LCC Analysis Results for Incorporating Grid-Connected Photovoltaic System in Willow Creek Rest Area Buildings

LCC Items / Savings	**Northbound**	**Southbound**
	Amount/Savings	**Amount/Savings**
Annual eliminated CO_2 emissions (Ib)	38,866	39,963
Number of solar panels on roof	45	45
Number of solar panels on the ground	29	31
Required area for solar panels (SF)	270	270
Tilt angle of solar panels	51	51
Payback period (yr)	27.0	26.7

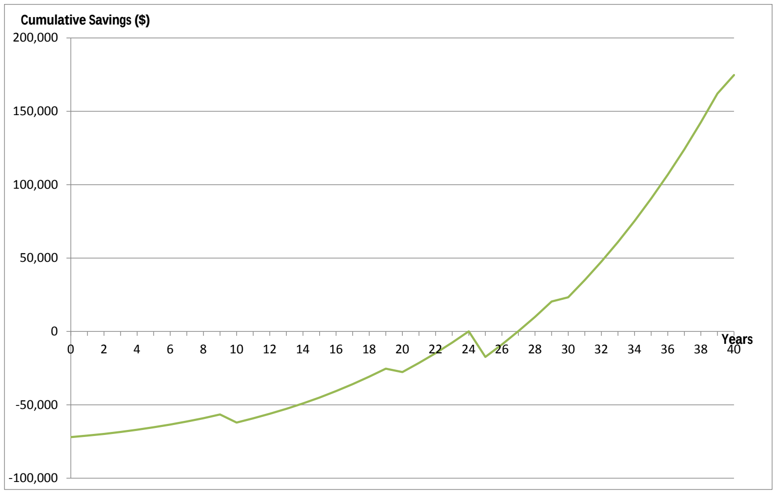


Figure 123. Cumulative cost of incorporating grid-connected system in the northbound building of Willow Creek rest area.

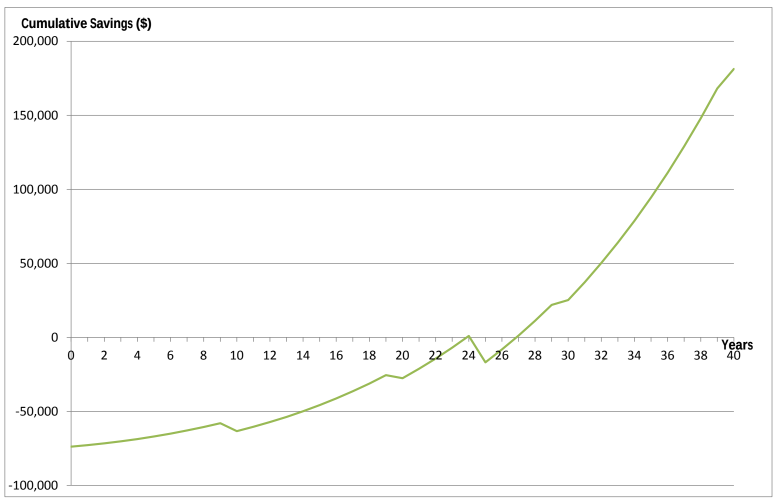


Figure 124. Cumulative cost of incorporating grid-connected system in the southbound building of Willow Creek rest area.

It should be noted that the stand-alone photovoltaic system was not considered in this analysis because of its infeasible payback period that was identified in the first phase of this project due to its high initial and periodic costs of battery systems.

D.4.6.2 Solar Water-Heating Systems

Solar water heater is another technology that can reduce energy consumption for heating water in the rest area building. This technology can be installed with the current water heaters in the rest area in order to mitigate the cost of replacing current water heater. Moreover, current water heater can work as a backup when the sun rays are unavailable or insufficient to heat water to the desired temperature. The components of installing this system include solar collector(s), collector's mounting, heat exchanger, circulator, antifreeze (glycol), water storage tank(s), controller, fittings, pipes, and insulation. The initial capital cost of the system can be calculated for the three rest areas using the RSMeans Building Construction Cost Data (2012). Maintenance cost and life were calculated similar to Coalfield rest area buildings. Table 167 summarizes the LCC components for incorporating solar water heaters in the Willow Creek rest area buildings. A LCC analysis was conducted based on an annual interest rate of 2%, escalation in utility rate by 5%, and an annual increase of maintenance cost by 2%, as shown in Table 168. The analysis shows that installing solar water heaters in the Willow Creek rest area buildings has a payback period more than 20.7 years based on 70% energy savings of water heater in northbound and southbound building. This measure can eliminate CO_2 emissions by 3,355 to 11,743 Ib annually for Willow Creek rest area buildings.

It should be noted that solar collector(s) can be installed on the roof by clamps/straps or on the ground where a rack is used to hold the collector(s). Installing solar collectors on the roof might not be feasible as the building roof of the rest area was not designed to carry such extra load. Subsequently, solar collectors should be mounted on the ground.

Table 167. LCC Components for Installing Solar Water Heater in Willow Creek Rest Area Buildings

LCC Components	Amount/ Savings	Amount/Savings
Capital cost (Ground mount)	8,135	8,135
Annual maintenance cost (Ground rack)	81	81
Utility gas cost ($/therm)	0.77	0.77
Conventional water heater consumption (therm)	790	644
Annual operating cost for conventional water heater ($)	608	496
Annual savings (20% to 70% savings) ($)	122 to 426	99 to 347
Periodic cost for pump @ 5 years ($)	250	250
Periodic cost for water tank @ 16 years ($)	1,600	1,600
Circulating pump life (yr)	5	5
Tank life (yr)	16	16

Table 168. LCC Analysis Results for Installing Solar Water Heater in Willow Creek Rest Area Buildings

Savings	Amount	Amount
Annual gas saved - 20% savings (therm)	158	129
Annual gas saved - 70% savings (therm)	553	451
Annual eliminated CO_2 emissions - 20% savings (lb)	1,848	1,507
Annual eliminated CO_2 emissions - 70% savings (lb)	6,468	5,275
Payback period - 20% savings (yr)	More than 30	More than 30
Payback period - 70% savings (yr)	20.65	24.41

D.4.7 Water-Saving Plumbing Fixtures

Rest areas have a high rate of water consumption due to the large number of visitors that use their restrooms. Using water-conserving fixtures in these rest areas will provide significant savings in water consumption. A number of feasible water-saving technologies can be used to minimize water consumption in the rest areas including efficient faucets, aerators, toilets, and urinals. Currently, the Willow Creek rest area buildings have low-flow faucets, which makes them suitable for conserving water use in the facility. Furthermore, the current toilets in the Willow Creek rest area buildings provide efficient use of water for flushing toilets as they have a flushing rate 1.6 GPF. An analysis was conducted to estimate the feasibility of installing conserving urinals in the rest area buildings. Table 169 summarizes the analysis of replacing current urinals with water-conserving ones. As it was difficult to calculate precisely the number of visitors using urinals, the analysis assumed that 24% of visitors use urinals. The replacement of current plumbing fixtures can provide savings of 87.5% to 92.5% of water consumption by urinals. This could result in a total water savings of 328,476 gallons annually. The payback period for these fixtures could not be calculated as water unit cost could not be identified as the rest area uses ground water to supply its needs.

Table 169. LCC Analysis for Replacing Current Urinals and Toilets with Water-Conserving Fixtures in Willow Creek Rest Area Buildings

Saving/Cost Items	Northbound		Southbound	
	Urinals (Type 1)	Urinals (Type 2)	Urinals (Type 1)	Urinals (Type 2)
Current fixture rate (GPF)	1	1.6	1	1.6
Number of fixtures	2	4	4	4
Type	Wall mount	Wall mount	Wall mount	Wall mount
Water-conserving rate (GPF)	0.125	0.125	0.125	0.125
Initial replacement Cost ($)	1,323	2,647	2,647	2,647
Savings per flush (G)	0.875	1.475	0.875	1.475
Percentage savings (%)	87.5	92.2	87.5	92.2
Annual visitors 2009	558,633		558,633	
Annual water savings for 24% of visitors use urinals (G)	39,104	131,837	58,656	98,878
Annual energy savings due to reduction in water pump use (%)	0.02	0.07	0.02	0.03
Annual energy savings due to reduction in water pump use ($)	6	21	9	16

D.4.8 Summary of All Promising Green Building Measures

This section summarizes all green building measures that can be used in the Willow Creek rest area buildings to reduce their energy consumption. All promising green building measures were added in the eQuest model in order to analyze the impact of their collective use and potential interactions on the overall energy consumption of the building. Table 170 and Table 171 summarize all LCC components, savings and payback periods for all promising green building measures that were analyzed in the previous sections for northbound building and southbound building respectively. The eQuest simulation model and energy analysis shows that the northbound building of Willow Creek rest area building can achieve a total of 52.8% reduction in energy costs by implementing the following energy-efficient measures: fluorescent T8 bulbs, CFL, and induction bulbs for interior lighting; induction lighting fixtures for exterior lighting; motion-activated lighting for restrooms; vending occupancy controls; motion sensors for exhaust fans; geothermal heat pump along with desuperheater; energy-efficient hand dryer; solar daylight tubes for restrooms; photovoltaic system with 17.4KW capacity, setting back HVAC at night, and water-conserving fixtures. Similarly, the eQuest simulation model and energy analysis shows that the southbound building of Willow Creek rest area building can achieve a total of 39.8% reduction in energy costs by implementing the following energy-efficient measures: fluorescent T8 bulbs, CFL, and induction bulbs for interior lighting; induction lighting fixtures for exterior lighting; motion-activated lighting for restrooms; vending occupancy controls; motion sensors for exhaust fans; geothermal heat pump along with desuperheater;

energy-efficient hand dryer; solar daylight tubes for restrooms; photovoltaic system with 17.9KW capacity, setting back HVAC at night, and water-conserving fixtures.

Table 170. All Analyzed Green Building Measures for Northbound Building of Willow Creek Rest Area

Green Building Measure	Initial Cost	Annual Maintenance Cost, If Applicable	Annual Energy Savings	Annual Eliminated CO_2 Emissions (lb)	Reduction in Energy Consumption	Payback Period (yr)
Interior lighting	$9,984	N.A.	$2,518	36,751	8.8%	3.7
Exterior lighting - induction lighting	$34,060	N.A.	$3,934	51,578	13.7%	6.2
Motion-activated lighting	$1,556	N.A.	$1,915	27,958	6.7%	0.8
Vending occupancy controls	$451	N.A.	$304	4,432	1.1%	1.5
Motion-sensor exhaust fans	$2,606	N.A.	$643	9,383	2.2%	4.0
Geothermal heat pump	$70,520	$533	$2,349	34,971	8.2%	13.4
Energy-efficient hand dryers	$2,457	N.A.	$418	6,104	1.5%	5.6
Photovoltaic system	$71,977	$208	$2,663	38,866	9.3%	27.0
Solar water heater	$8,135	$81	$274	3,994	1.0%	43.8
Setting back HVAC at night	$0	N.A.	$524	7,654	1.8%	Immediate payback
Desuperheater	$1,600	N.A.	$175	2,652	0.6%	8.4
Water-conserving fixtures	$3,970	N.A.	$27	401	0.1%	N.A.
All promising green building measures together (eQuest model)	$207,617	$823	$15,142	221,020	52.8%	11.9

Table 171. All Analyzed Green Building Measures for Southbound Building of Willow Creek Rest Area

Green Building Measure	Initial Cost	Annual Maintenance Cost, If Applicable	Annual Energy Savings	Annual Eliminated CO_2 Emissions (lb)	Reduction in Energy Consumption	Payback Period (yr)
Interior lighting	$13,387	N.A.	$3,740	54,585	7.6%	3.2
Exterior lighting - induction lighting	$27,020	N.A.	$3,084	43,241	6.3%	6.2
Motion-activated lighting	$3,112	N.A.	$2,963	43,241	6.0%	1.1
Vending occupancy controls	$451	N.A.	$405	5,909	0.8%	1.1
Motion-sensor exhaust fans	$2,606	N.A.	$1,337	19,508	2.7%	2.0
Geothermal heat pump	$111,520	$533	$4,530	67,869	9.2%	12.2
Energy-efficient hand dryers	$4,914	N.A.	$418	6,104	0.9%	10.4
Photovoltaic system	$73,836	$213	$2,738	39,963	5.6%	26.7
Solar water heater	$8,135	$81	$223	3,258	0.5%	53.2
Setting back HVAC at night	$0	N.A.	$403	5,885	0.8%	Immediate payback
Desuperheater	$1,850	N.A.	$140	2,131	0.3%	11.5
Water-conserving fixtures	$5,294	N.A.	$25	370	0.1%	N.A.
All promising green building measures together (eQuest model)	$252,125	$294	$8,069	117,782	39.75%	11.3

D.5 MACKINAW DELLS REST AREA

The Mackinaw Dells rest area is located at 14 miles west of Bloomington, at mile marker 114 of I-74. It consists of two buildings that serve the north- and southbound lanes of I-74. It has approximately 1.54 million visitors with annual increase of 0.18% in visitation rate based on 2009 statistics. The major sources of energy consumption in the rest area include the interior and exterior lighting, heating and cooling, vending machines, hand dryers, pump station, and water heater. The next sections discuss the energy consumption analysis for the rest area building as well as LCC analysis for implementing different green building measures including interior and exterior energy-saving light bulbs, motion-activated lighting, vending occupancy controls, motion exhaust sensors, geothermal heat pumps, Energy Star–rated air-source heat pump, thermal pane glass, energy-efficient hand dryers, photovoltaic systems, solar water heater, solar daylight tubes, and water-saving plumbing fixtures.

D.5.1 Energy Audit and Analysis

The Mackinaw Dells rest area has two utility meters to measure energy consumption in each building of the rest area. The two utility meters are used to measure the monthly energy consumption of each building however they cannot provide energy consumed by each device or equipment in the rest area. In order to identify major sources of energy consumption in the rest area building and its costs, an energy simulation model was developed using the eQuest energy simulation software environment. The eQuest software can be used to simulate the energy performance of a building including its construction materials, weather, space heating and cooling, air ventilation, air infiltration and exhaust, temperature control, interior and exterior lighting, water use, windows and doors, skylights, operation schedule and occupancy, building activities, equipment loads. Furthermore, eQuest can account for different scenarios for replacing any of the current equipment or devices in buildings and calculate energy consumption accordingly. This capability of measuring building energy consumption based on different scenarios of implementing various green building measures and equipment will be used to analyze and identify a list of promising BMPs for Mackinaw Dells rest area.

The Mackinaw Dells rest area model was developed similar to the Coalfield rest area buildings. The model was developed based on the rest area's location, square footage, architectural shape, zones, building envelope construction, infiltration, building orientation, operation schedule, building activities, building occupancy, ventilation, HVAC system, temperature control, and water heater. All energy consumption data for the Mackinaw Dells rest area including lighting, HVAC system, hand dryers, vending machines, ventilation, infiltration, exhaust, occupancy, water pump and water heater were modeled using a similar procedure to the one described earlier for the Coalfield rest area buildings.

After modeling the rest area building in eQuest, the simulation model was run to simulate building performance with respect to weather conditions throughout the year and calculate monthly and total energy consumption categories of the building. Due to the difficulty of measuring air infiltration rates for entry doors during the site visit, several runs of simulation model were conducted with varying reasonable rates of infiltration and ventilation in order to minimize the differences between simulated and actual energy consumption reported in the building's energy bills. The parameters of infiltration were eventually set in the model to 55 CFM/ person for restrooms, lobby, and vending area and 500 CFM/person for mechanical and storage rooms. Similarly, infiltration rate was set to 0.68 air change per hour in the model to account for single door entry of the rest area and match with energy bills.

Figure 101 compares the simulated monthly energy consumption of the building based on the developed model in eQuest to the actual energy consumption reported in the utility bills of the Mackinaw Dells rest area buildings in 2009. Based on the results in Figure 101, the average absolute difference between the energy consumption for the developed simulation model and actual bills is 5.5% and the maximum and minimum difference between the energy consumption for the developed simulation model and actual bills were 10.7% in December and 0.8% in April.

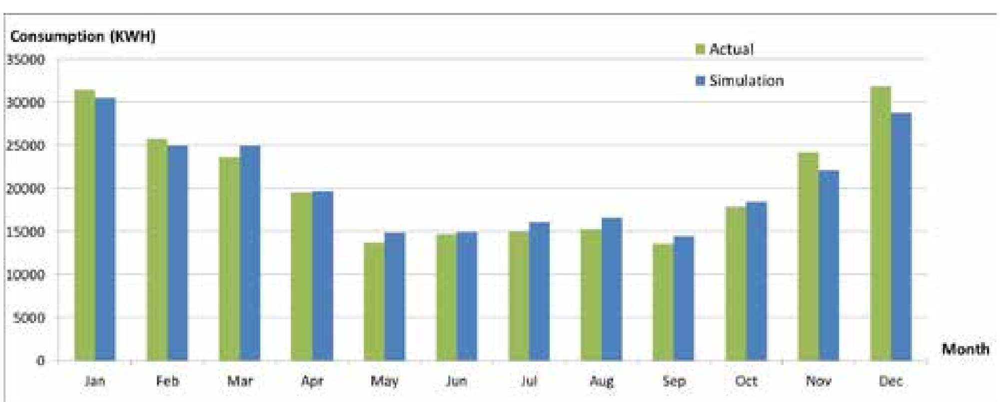


Figure 125. Simulated and actual electricity consumption of Mackinaw Dells rest area buildings in 2009.

It should be noted that the number of visitors per day was assumed to be constant throughout the year. Therefore, the difference in energy consumption between the eQuest simulation model and energy bills can be caused by the varying number of visitors per day, which affects the building's heating and cooling energy consumption as well as its water use. In addition, the occasional and varying use of other small devices such as a microwave, laptop, small fan or heater unit that were observed during the site visits in the maintenance room can contribute to this difference between the simulation results and the energy bills.

The square footage of Mackinaw Dells rest area is 3736 SF per building and its annual number of visitors is 767,960 visitors for each building of the rest area. The breakdown of electricity cost for the Mackinaw Dells rest area buildings among its main sources of consumption is shown in Figure 102. The eQuest energy for model shows that the highest source of energy consumption is space heating that represents 31% of the total energy consumption of the building. On the other hand, the two sources that consume the lowest energy in the building are hand dryers and water pump that represent 2% each of the building's total energy consumption. Space heating and cooling comprises 40% of total energy consumption of the building. This breakdown of energy costs will helps in prioritizing energy-improvement efforts. The "other" category includes small equipment and devices such as coffee machines, microwave, computer and surveillance cameras, personnel laptop, etc., that are used in the rest area building.

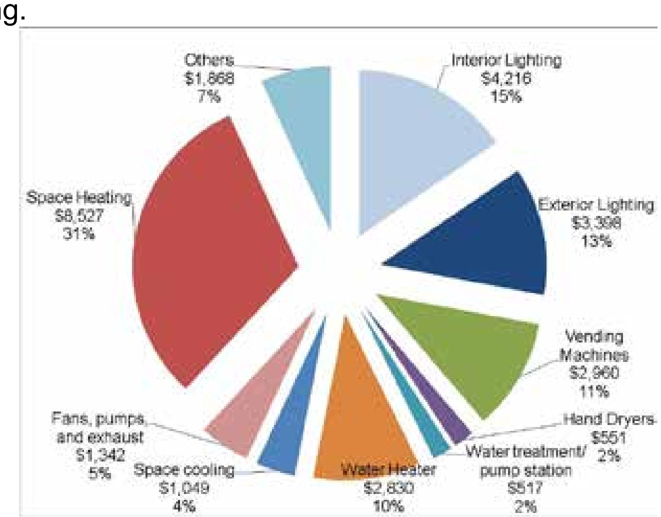


Figure 126. Energy cost breakdown of Mackinaw Dells rest area buildings.

D.5.2 Lighting

Lighting in the Mackinaw Dells rest area represents approximately 28% of total energy consumption with an annual cost of $7,612. The next two subsections analyze replacing current interior and exterior lighting with more-efficient and energy-saving bulbs. The economic analysis of light replacement in these two sections assumes an annual interest rate of 2% and escalation in utility rate of 5%.

D.5.2.1 Interior Lighting

Interior lighting in the Mackinaw Dells rest area consists of linear fluorescent T12 and T8 bulbs and incandescent (assumed) light bulbs. These bulbs can be replaced by more-efficient linear fluorescent T8 and CFL to provide similar luminance levels, less energy consumption and longer life expectancy. Table 172 through Table 174 summarize the impact of replacing current fluorescent (T12 and T8, and incandescent bulbs with fluorescent T8 and CFL for the Mackinaw Dells rest area. These lighting replacements can provide annual saving of $1224 and reduce energy consumption by 4.5%. The conducted LCC analysis for replacing all current T12 lighting with T8 bulbs is shown in Figure 127. The average payback period for all light replacement is 1.3 years, which represents a green building measure with promising return on investment.

Table 172. Replacing U-Shape Fluorescent T8 Bulbs with More Energy-Efficient T8 Light Bulbs in Lobby and Restrooms of Mackinaw Dells Rest Area Buildings

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement Fixtures/Bulbs
Type of bulb	Fluorescent T8	Fluorescent T8
	GE - F32T8/SP35/ECO	Sylvania - FO28/841/XP/SS/ ECO
Number of bulbs	56	56
Light output (lumen)	2660	2562
Kelvin temperature (K)	3500	4100
Color Rendering Index (CRI)	78	85
Life time (hr)	24000	36000
Consumption per bulb (watt)	32	28
Lamp cost ($/each)	2.57	8.99
Change in lumens output levels (%)	N.A.	-3.7
Reduction in energy consumption (%)	N.A.	12.5
Annual savings in energy consumption - first year ($)	N.A.	220
Payback period (yr)	N.A.	1.4

Table 173. Replacing Fluorescent T12 Bulbs with Energy-Efficient T8 Light Bulbs in Lobby of Mackinaw Dells Rest Area Buildings

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement Fixtures/Bulbs
Type of bulb	Incandescent (assumed)*	CFL
	Philips 374744	Sylvania (CF30EL/TWIST/2700K)
Number of bulbs	14	14
Light output (lumen)	1600	2000
Kelvin temperature (K)	4200	2700
Color Rendering Index (CRI)	62	82
Life time (hr)	750	10000
Consumption per bulb (watt)	100	30
Lamp cost ($/each)	0.99	10.89
Change in lumens output levels (%)	N.A.	+25
Reduction in energy consumption (%)	N.A.	70
Annual savings in energy consumption - first year ($)	N.A.	961
Payback period (yr)	N.A.	1.16

* Light bulb characteristics were assumed as these characteristics were not available during the site visit.

Table 174. Replacing Fluorescent T12 Bulbs with Energy-Efficient T8 Lighting Bulbs in Maintenance and Storage Rooms of Mackinaw Dells Rest Area Buildings

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement Fixtures/Bulbs
Type of bulb	Fluorescent T12	Fluorescent (T8)
	Sylvania (F34 CW/SS/ECO)	Sylvania 22234 (FO32/25W/841/ XP/SS/ECO)
Number of bulbs	28	28
Mean lumens (lumen)	2279	2327
Kelvin temperature (K)	4200	4100
Color Rendering Index (CRI)	62	85
Life time (hr)	20000	36000
Consumption per bulb (watt)	34	25
Lamp cost ($/each)	1.73	7.39
Change in lumens output levels (%)	N.A.	+2.1
Reduction in energy consumption (%)	N.A.	26.4
Annual savings in energy consumption - first year ($)	N.A.	42
Payback period (yr)	N.A.	1.93 and 7.16*

* Payback period for maintenance and storage rooms, respectively.

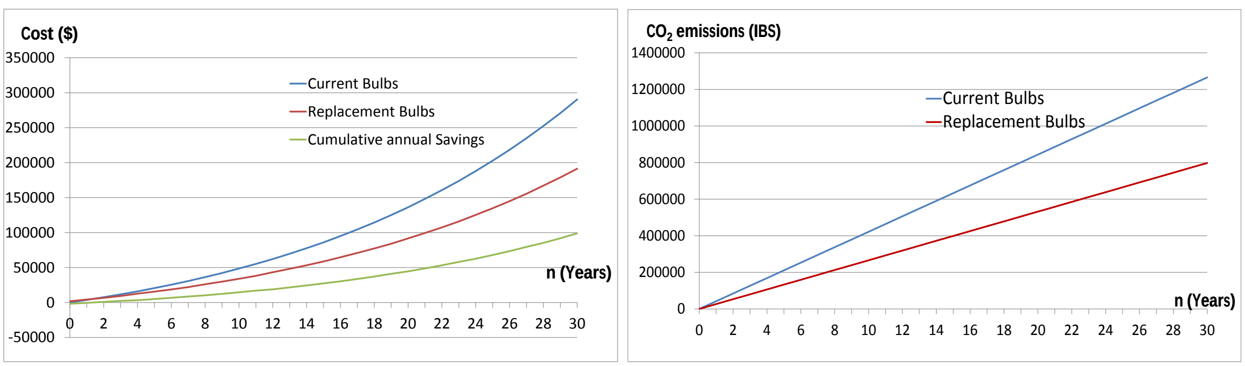


Figure 127. Energy cost, savings, and CO_2 emissions for current and replacement lighting in Mackinaw Dells rest area buildings.

D.5.2.2 Exterior Lighting

A LCC analysis was conducted to analyze the impact of replacing current exterior lighting of Mackinaw Dells rest area with LED and induction lighting. The average lighting operating hours was determined based on the previous rest area building that were analyzed using eQuest. The average lighting hours of exterior lighting was estimated as 8.94 hours. The current exterior lighting of Mackinaw Dells rest area consists of (1) seven recessed lighting fixtures with assumed 100 watt HPS bulbs in each; (2) four floodlight fixtures and a wall light fixture with assumed 250 watt HPS bulbs in each; (3) one wall light fixture with assumed 250 watt HPS bulb; (4) twelve light poles with a total of thirteen 250 watt HPS bulbs; and (5) one light tower with a total of eight 400 watt HPS bulbs. Due to the unavailability of the exact brand and luminance characteristics of current exterior lighting, reasonable assumptions were made for their luminance level giving the fact that the luminance characteristics are not significantly affected by the manufacturers. It should be noted that LCC was conducted for one-for-one replacement to reduce initial costs. This one-for-one replacement is expected to reduce the current total lighting output (lumen) of light poles, wall fixture and flood light fixtures by 47% and 54% for LED and induction lighting replacements respectively. Similarly, this one-for-one replacement will reduce the current total lighting output (lumen) of light towers by 60% and 64% for LED and induction lighting replacements. It should be noted that despite the lower average luminance of LED and induction lighting compared to HPS lighting, LED and induction lighting provide higher Color Rendering Index (CRI) than HPS lighting. CRI measures the effect of a light source on the perceived color of object and surface. Having high value of CRI makes virtually all colors look natural and reduces glare (Light Sout Services 2010).

A LCC analysis was conducted to examine the feasibility of a one-for-one replacement of the current exterior lighting of rest area building, its parking lot, as well as entrance and exit with LED and induction lighting replacements. The conducted analysis considered the possible lighting fixtures and bulbs shown in Table 175 as recommended by manufactures.

The components and results of the conducted analysis of one-for-one replacements are summarized in Table 176 through Table 178 for all lighting fixtures/bulbs of the rest area. The cumulative cost and savings as well carbon footprint and reductions in CO_2 emissions for replacing exterior lighting of Mackinaw Dells rest area are shown in Figure 128. The analysis shows that these light replacements can provide annual savings of $1,699 or 6.2% of total energy consumption for LED lighting replacements and $1,679, or 6.2% of total energy consumption for induction lighting replacements. This leads to a payback period of 21.7 years for LED light replacements and 6 years for induction lighting replacements.

Table 175. Characteristics of Current and Replacement Lighting for Exterior Lighting of Mackinaw Dells Rest Area

Light Characteristic items	Current lighting		Replacement (LED lighting)		Replacement (Induction light)	
	Type	Characteristics	Type	Characteristics	Type	Characteristics
Mean Lumens (lumen)	Incandescent 100w	1480	LED Lamp	1500	Induction Lamp	1400
Color temperature (Kelvin)		N.A.		3000-5000		2700-6500
Color rendering index (CRI)		N.A.		80		80
Life time (hours)		750		50000		100000
Consumption (w)		100		20		20
Lamp cost ($)		1.0		117		204
Lamp and fixture cost ($)		-		-		-
Initial Lumens (lumen)	HPS 250w	28500	LED Steet Light	15000	Induction Steet Light	13200
Color temperature (Kelvin)		2000		2700-8000		5000
Color rendering index (CRI)		25		75		83
Life time (hours)		30000		50000		75000
Consumption (w)		250		168		165
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1274		486
Initial Lumens (lumen)	HPS 400w	50000	LED Steet Light	20000	Induction Steet Light	18000
Color temperature (Kelvin)		2100		2700-8000		5000
Color rendering index (CRI)		20		75		83
Life time (hours)		24000		50000		75000
Consumption (w)		400		224		225
Lamp cost ($)		54		-		-
Lamp and fixture cost ($)		-		1493		538

Table 176. Replacing HPS 400W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Mackinaw Dells Rest Area

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	LED	Induction
Number of bulbs	8	8	8
Initial lumens	50000	20000	18000
Kelvin temperature	2100	2700-8000	5000
Color Rendering Index (CRI)	20	75	83
Life time (hr)	24000	50000	75000
Consumption per bulb, including ballast (watt)	481	224	230
Bulb cost ($)	54	1,493	538
Reduction in lumens output levels (%)	N.A.	60	64
Reduction in energy consumption (%)	N.A.	53	52
Annual savings in energy - first year ($/year)	N.A.	751.4	733.9
Payback period	N.A.	17.1	5.1

Table 177. Replacing HPS 100W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Mackinaw Dells Rest Area

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	Incandescent (assumed)	LED	Induction
Number of bulbs	11	11	11
Mean lumens	1480	1500	1400
Kelvin temperature	N.A.	3000-5000	2700-6500
Color Rendering Index (CRI)	N.A.	80	80
Life time (hr)	10000	50000	100000
Consumption per bulb, including ballast (watt)	125	20	21
Bulb cost	40	117	204
Change in lumens output levels (%)	N.A.	+1.4	-5.4
Reduction in energy consumption (%)	N.A.	84	83
Annual savings in energy - first year ($/year)	N.A.	422	418
Payback period (yr)	N.A.	0.2	0.2

Table 178. Replacing HPS 250W Bulbs with Energy-Efficient LED and Induction Light Bulbs in Mackinaw Dells Rest Area

Lighting Characteristics, Costs, and Savings	Current Fixtures/Bulbs	Replacement 1	Replacement 2
Type of bulb	HPS	LED	Induction
Number of bulbs	13	13	13
Initial lumens	28500	15000	13200
Kelvin temperature	2000	4900	5000
Color Rendering Index (CRI)	25	75	83
Life time (hr)	30000	50000	75000
Consumption per bulb, including ballast (watt)	315	168	168
Bulb cost ($)	54	1274	486
Reduction in lumens output levels (%)	N.A.	47	54
Reduction in energy consumption (%)	N.A.	47	47
Annual savings in energy - first year ($/year)	N.A.	698	698
Payback period (yr)	N.A.	> 30	9

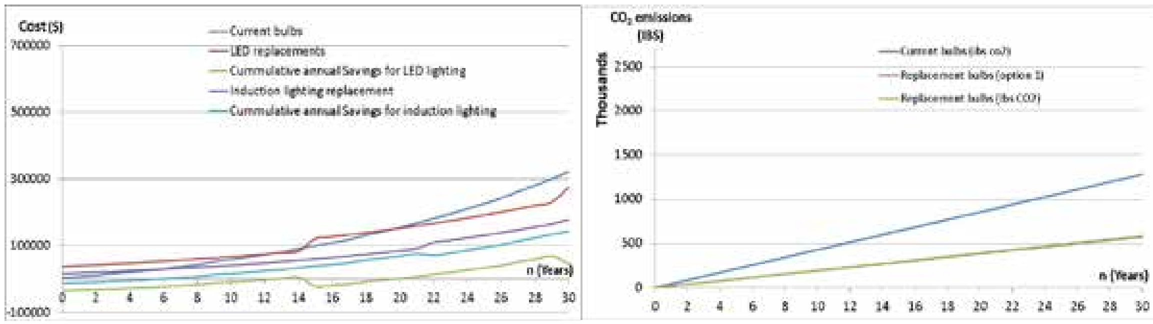
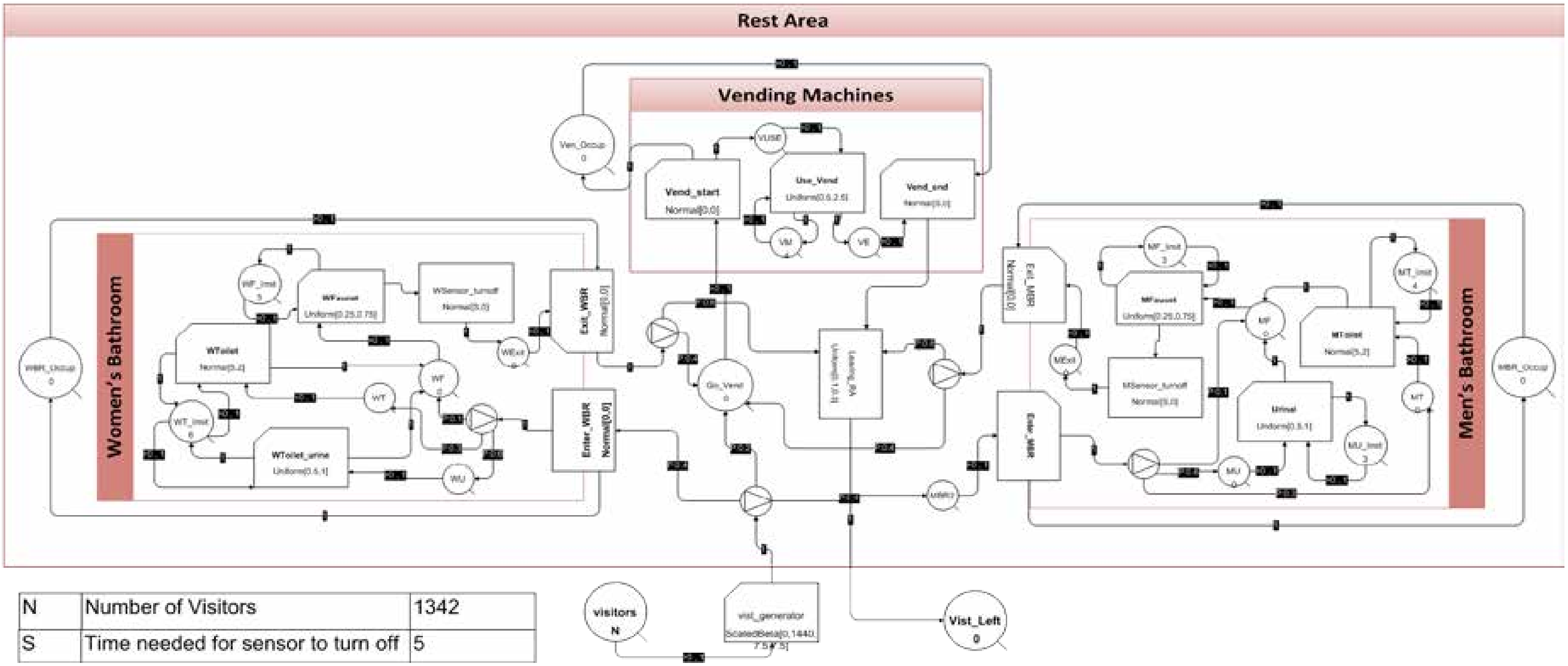


Figure 128. Cumulative cost and savings and CO_2 emission of LED and Induction exterior lighting replacements for Mackinaw Dells rest area.

D.5.3 Motion Sensors

Rest areas have different operational schedule than business and commercial buildings and they have to operate 24 hours a day with few or no occupants during low visitation periods at night. This makes motion sensors a promising technology for rest area buildings. This section analyzes the implementation of motion sensors to control the lighting of restrooms and vending machine areas. Motion sensors also can be used to reduce space heating and cooling by reducing the use of exhaust fans at night when there are few or no occupants in the restrooms.

In order to estimate the energy savings in lighting and exhaust fans, the research team developed a separate simulation model using EZstrobe simulation language (Martinez 2006) to analyze and simulate the use of restrooms and vending machines based on the number and frequency of rest area visitors. The simulation model was developed to mimic the utilization of the rest area facilities by its visitors. The model was created to generate the number of visitors to the rest area using a beta distribution function to represent a high frequency of visitors during the morning, noon, and afternoon hours and low frequency during the night and early morning hours. The model also assumes that the percentages of visitors that will use the men's restroom, women's restroom and vending machines are 40%, 40%, and 20%, respectively. Similarly, the probabilities that restroom visitors will use urinals, toilets and only faucets were assumed to be 30%, 60%, and 10%, respectively with reasonable random durations for each of these restroom tasks as, shown in Figure 129. It should be noted that the model assumes that each visitor using the toilet or urinal will also use the faucet afterwards. The developed model accounts for an amount of time for sensors to keep the light on after a visitor leaves a restroom. After a visitor leaves the restroom, the model assumes that there is a probability of 60% that the visitor will leave the rest area and 40% will use vending machines. The developed model can estimate how long the lighting in restrooms of the rest area will be turned off if motion-activated lighting were implemented in the restrooms. Similarly, the amount of time that lighting in vending machines and exhaust fans being turned/switched off can be calculated by the developed simulation model. Figure 130 shows rest area visitors while being in the men's restroom throughout a simulation day. Table 179 summarizes the percentages of occupancy for restrooms and vending machines of the Mackinaw Dells rest area assuming that the lights or fans remain turned on for 5 minutes after the departure of the last visitor. The following subsections use the developed simulation model to estimate potential savings for using motion sensors in the rest area building and their expected payback periods. The economic analysis of motion sensors accounts for an annual interest rate of 2% and escalation in utility rate of 5% in calculating payback period of implementing this technology.



N	Number of Visitors	1342
S	Time needed for sensor to turn off	5

Figure 129. Motion-sensor simulation model for Mackinaw Dells Road rest area building.

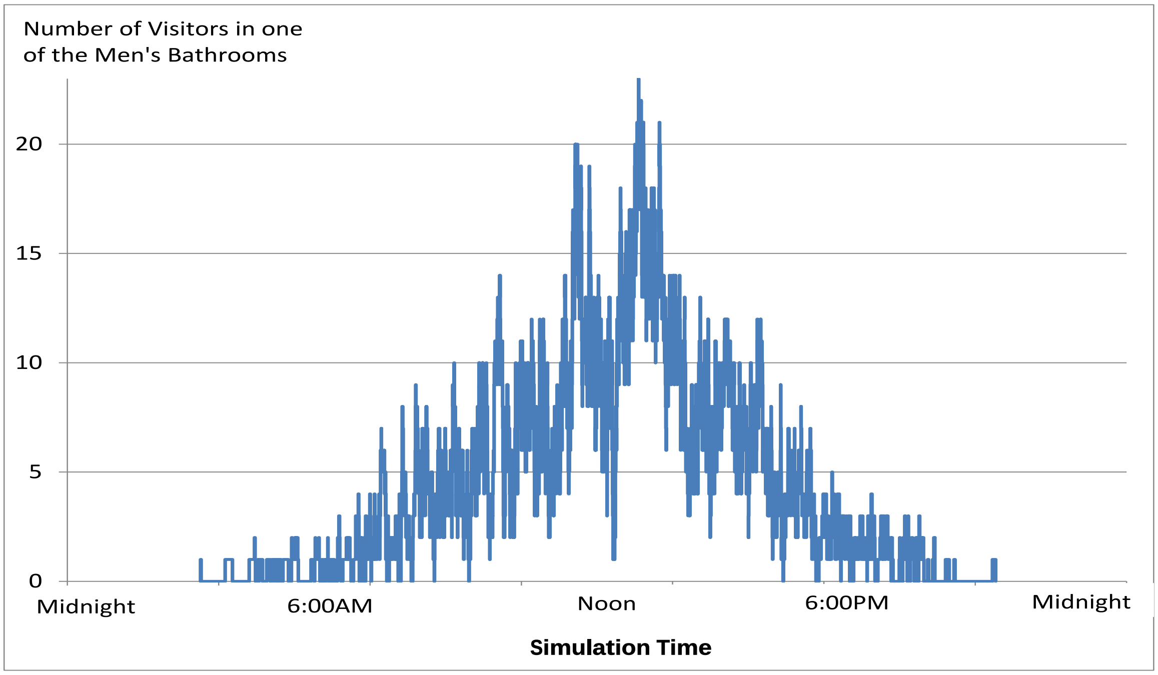


Figure 130. Number of visitors in men's restroom throughout a simulation day of Mackinaw Dells rest area buildings.

Table 179. Percentage Occupancy for Restrooms and Vending Area for Mackinaw Dells Rest Area Buildings

Percentage of Occupancy In Men's Restroom	Percentage Occupancy in Women's Restroom	Percentage Average Occupancy in Restrooms	Percentage Occupancy in Vending Machines Area
75.7%	74.7%	75.2%	72.3%

D.5.3.1 Motion-Activated Lighting

Motion-activated lighting can be installed in restrooms to turn off lights automatically when they are not occupied. As discussed in the previous section, restrooms in the Mackinaw Dells rest area have an average approximate occupancy of 75.2% including 5 minutes for the occupancy sensors remain in detection before turning off automatically. This leads to average 24.8% savings in lighting of restrooms. Table 180 shows the results of the LCC analysis for implementing motion-activated lighting in the restrooms of the Mackinaw Dells rest area. The analysis shows that the motion-activated lighting can provide approximate savings of $280 annually or 1% of total energy consumption of the Mackinaw Dells rest area buildings, which leads to a payback period of 3.7 years for this green building measure. Furthermore, motion-activated lighting in restrooms can eliminate annually 3,529 lb of CO_2 emissions.

Implementing motion-activated lighting in the lobby will not be feasible due to security requirements that require lights to be turned on at all times to ensure the proper operation of the surveillance cameras. Moreover, implementing motion-activated lighting in maintenance rooms will not provide much savings and the payback period will be long since the maintenance staff often turn off the light before leaving the mechanical rooms of the rest area.

Table 180. Motion-Activated Lighting Analysis for Restrooms of Mackinaw Dells Rest Area Buildings

Savings and Cost Items	Amount/Savings
Total load of lighting fixtures (watt)	1152
Electricity cost ($/kwh)	0.112
Occupancy sensors cost ($)	328
Labor installation cost ($)	729
Total Initial cost ($)	1,057
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	1,130
Annual lighting energy savings ($)	280
Payback period (yr)	3.69
Amount of eliminated CO_2 (Ib)	3,529
Savings in total energy consumption of building (%)	1.0

D.5.3.2 Vending Occupancy Controls

Similar to motion-activated lighting, occupancy controls can be installed for vending machines to turn off their lighting when the vending area is not occupied. Based on the developed simulation model for motion sensors, lights of vending machine are expected to be on for approximately 72.3% of hours during the day assuming a duration of 5 minutes for the sensors to remain on after detecting the last motion in the vending area. This leads to 27.3% lighting savings of the vending machine area. Table 181 shows the economic analysis of installing occupancy for vending machine area of Mackinaw Dells rest area. The analysis shows that occupancy controls for vending machines can provide approximate savings of $280 annually or 0.9% of total energy consumption of the Mackinaw Dells rest area buildings, which leads to a payback period of 1.3 years. This measure can also eliminate 3,202 Ib of CO_2 emissions annually due to the achieved reduction in energy consumption.

Table 181. Occupancy Controls Analysis for Vending Machine in Mackinaw Dells Rest Area Buildings

Savings and Cost Items	Amount/Savings
Total load of vending machines lighting (watt)	600
Electricity cost ($/kwh)	0.112
Occupancy sensors cost ($)	120
Labor installation cost ($)	219
Total Initial cost ($)	339
Lighting operation time (hr)	24
Annual lighting energy cost for restrooms ($)	589
Annual lighting energy savings ($)	254
Payback period (yr)	1.34
Amount of eliminated CO_2 (Ib)	3,202
Savings in total energy consumption of the rest area building (%)	0.9

D.5.4 More-Efficient HVAC Systems

The current HVAC system at the Mackinaw Dells rest area consists of a split system with two condensers and electric resistance duct heaters. The current HVAC system can be replaced with a more energy-efficient system that reduces heating and cooling energy consumption. The next two subsections analyze the replacement of the current HVAC system with a geothermal heat pump and Energy Star–rated air-source heat pump.

D.5.4.1 Geothermal Heat Pump

The existing HVAC system in the Mackinaw Dells rest area buildings operates continuously year round, and its consumption represents 40% of the total building consumption. A ground-source heat pump can be more efficient than an HW boiler and chiller HVAC system as it uses the nearly constant temperature of earth (55°F) to heat and cool buildings. The eQuest simulation environment can be used to model the use of a geothermal HVAC system for the Mackinaw Dells rest area buildings. The system was modeled to have heating coefficient of performance (COP) of 4.0 and a cooling efficiency of 18 EER. This system was also modeled to operate in economizer mode, which brings fresh air when the outside air temperature is sufficient to condition the space. After running eQuest model with geothermal heat pump, the model provides savings of 22.9% of total energy consumption. The installation and maintenance costs of geothermal heat pump were calculated similar to Coalfield rest area buildings. Table 127 summarizes the LCC components of replacing the current HVAC system with a geothermal heat pump.

Table 182. LCC Components for Replacing Current HVAC System with Geothermal Heat Pump at Mackinaw Dells Rest Area Buildings

Rest Area/LCC Components	**Cost/Life**
Capital cost - vertical system* ($)	41,820
Annual maintenance cost ($)	486
Annual operating cost ($)	4,608
Periodic cost ($)	25,820
Life (yr)	20

* Installation cost may vary due to soil conditions and resizing of the HVAC equipment

In order to compare the cost effectiveness and payback periods of replacing the current HVAC system at the rest area with a geothermal system, the initial, maintenance, operating and replacement costs of the current HVAC systems need to be identified. These costs were estimated similar to the Coalfield rest area buildings in order to carry out the LCC analysis. Table 128 summarizes the LCC components for the current HVAC system in the Mackinaw Dells rest area buildings.

Table 183. LCC Components for Current HVAC System in Mackinaw Dells Rest Area Buildings

Rest Area/LCC Components	Cost/Life
Capital cost ($)	18,400
Annual maintenance cost ($)	1,046
Annual operating cost ($)	10,917
Periodic cost ($)	18,400
Life (yr)	17
Manufacture year	2004
Replacement year	2021

A LCC analysis was conducted to compare the potential replacement of the current HVAC system with a geothermal heat pump based on an annual interest rate of 2%, escalation in utility rate of 5%, and annual increase of maintenance cost of 2%. Table 129 summarizes the LCC analysis results for replacing current HVAC with geothermal heat pump. The analysis shows that replacing current HVAC system with vertical loop geothermal heat pump has a payback period of 5.7 years. The cumulative costs for the horizontal loop geothermal system, vertical loop geothermal system, current HVAC system, and savings are shown in Figure 107. The geothermal heat pump can also be installed along with a desuperheater to heat water in the cooling season. The desuperheater uses heat that is removed from the building space to heat domestic hot water. This unit can provide free hot water in the summer or when the system is in cooling mode. It can provide annual savings of $795 or 2.9% of the total energy consumption. The payback period of the desuperheater is 2 years.

Table 184. LCC Analysis Results for Replacing Current HVAC System with Geothermal Heat Pump at Mackinaw Dells Rest Area Buildings

Rest Area	Savings
Annual kwh saved	56,335
Annual energy savings - first year ($/yr)	6,310
Annual eliminated CO_2 emissions (lb)	79,432
Payback period - vertical system (yr)	5.7

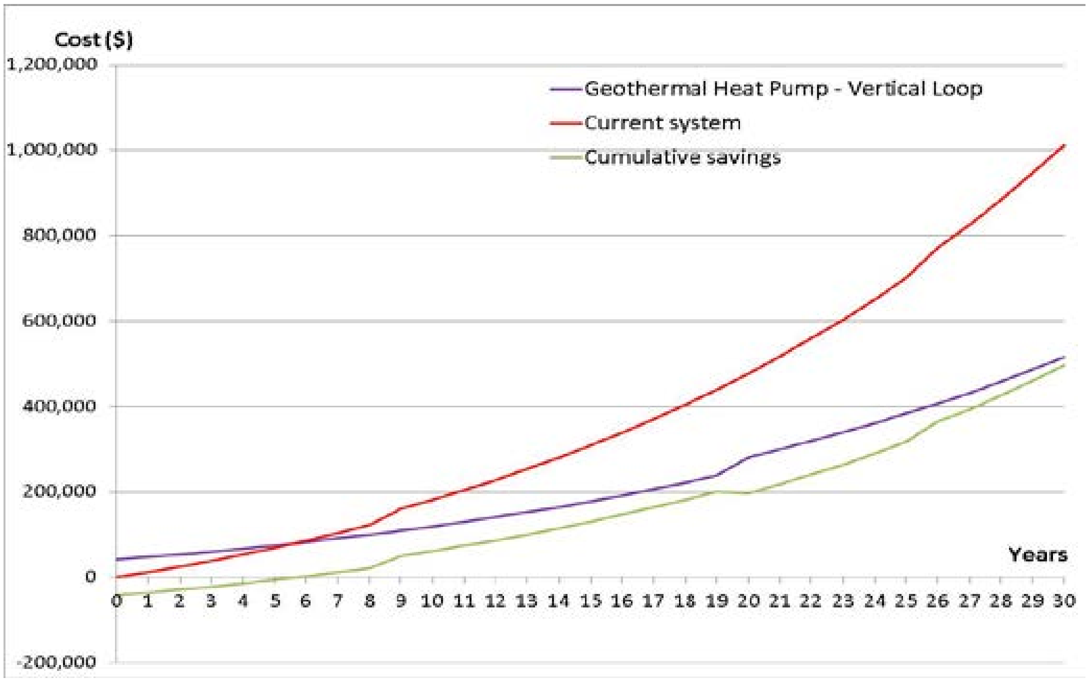


Figure 131. Cumulative costs of current HVAC system, vertical loop geothermal system, and savings for Mackinaw Dells rest area buildings.

D.5.4.2 High-Efficiency Air-Source Heat Pump

Another alternative for the current HVAC system at the Mackinaw Dells rest area is to replace it with a more-efficient Energy Star–rated air-source heat pump to reduce heating and cooling expenses. An air-source heat pump was modeled in eQuest to meet Energy Star recommendations with a cooling efficiency of 12 EER and a heating performance rating of 8.2 HSPR (Energy Star 2003). Table 130 summarizes the economic analysis results for replacing the current HVAC system with an Energy Star–rated air-source heat pump. The analysis shows that an Energy Star–rated HVAC system can provide annual savings of $5,608 annually or 20.3% of total energy consumption of the rest area building. This leads to a payback period of 3.2 years based on an annual interest rate of 2% and escalation in utility rate of 5%. This replacement can eliminate CO_2 emissions by 70,606 Ib annually.

Table 185. Analysis Results for Replacing Current HVAC System with Air-Source Heat Pump at Mackinaw Dells Rest Area Buildings

Savings and Cost Items	Amount/Savings
Electricity cost ($/kwh)	0.112
Total initial cost for air-source heat pump	18,400
Annual energy savings ($)	5,608
Payback period (yr)	3.23
Amount eliminated CO_2 (Ib)	70,606
Savings in total energy consumption of building (%)	20.3

D.5.5 Energy-Efficient Hand Dryers

Energy-efficient hand dryers are one of the green building measures that can be implemented in the Mackinaw Dells rest area buildings to reduce energy consumption of hand dryers was estimated based on a 50% use of rest area visitors each for 30 seconds according to manufacture use recommendations. Although, current hand dryers only consume approximately 3.3% of total energy consumption, they are one of the most visible devices for the rest area visitors. Moreover, slow velocity or inefficient hand dryers may discourage people to use them. This analysis considers the impact of installing three different energy-efficient hand dryers with three different models in the Mackinaw Dells rest area buildings to reduce their energy use, as shown in Table 186. The analysis shows that replacing current hand dryers may result in annual savings of $607 to $667 or 2.5% to 13.4% of total energy consumption in the rest area building based on three different models of energy-efficient hand dryers. These savings can provide a payback period of 2.5 to 13.4 years for the three different models based on an annual interest rate of 2% and escalation in utility rate of 5%. This measure can eliminate up to 8,392 Ib of CO_2 emissions in Mackinaw Dells rest area buildings.

Table 186. LCC Analysis Results for Replacing Current Hand Dryers with Energy-Efficient Units for Mackinaw Dells Rest Area Buildings

LCC Items/Savings	Current Hand Dryer - World Dryer	1- World Dryer Airforce - J Series Hand Dryers	2- Xlerator Series Hand Dryers	3- Dyson Airblade Series Hand Dryers
Number of hand dryers	6			
Hand dryer consumption (watt)	2,300	1,100	1100	1500
drying time (second)	30	12	15	12
Initial cost ($)	N.A.	1,638	2,400	9,600
Annual visitors - 2009	767,960			
Savings over the current hand dryers (%)	N.A.	81	76	74
Utility cost ($/kwh)	0.112			
Annual operating cost based on 50% use of visitors ($)	824	158	197	215
Annual savings ($)	N.A.	667	627	609
Annual savings of total energy consumption (%)	N.A.	2.4	2.3	2.2
Eliminated CO_2 emissions (Ib)	N.A.	8,392	7,896	7,670
Payback period (yr)	N.A.	2.5	3.7	13.4

* (Restroom Direct 2012)

D.5.6 Solar Measures

Several solar measures can be used to reduce energy consumption in rest area buildings. These measures can include solar daylight tubes, photovoltaic systems, and solar water heaters. These measures can reduce energy consumption of interior lighting, heating water as well as generate renewable and clean electricity. Solar daylight tubes were not analyzed for the Mackinaw Dells rest area buildings as they have metal roof that obstruct the penetration of solar tubes. The next subsections discuss the installation of photovoltaic systems and solar water heaters in Mackinaw Dells rest area buildings.

D.5.6.1 Grid-Connected Photovoltaic Systems

Photovoltaic systems are one of the renewable energy measures that can generate electricity to the Mackinaw Dells rest area buildings. In order to perform LCC for installing photovoltaic systems in the rest area, this system needs to be designed to estimate the number and type of system parts. Several factors affect the design of grid-connected systems including average daily peak sun hours, capacity of solar panels, capacity of inverters, and mounting of solar panels. The design of photovoltaic system for the Mackinaw Dells rest area was conducted using a similar procedure to the one described earlier in the Coalfield rest area.

This measure was analyzed to generate 5% of Mackinaw Dells total energy consumption. Table 187 summarizes the cost components for installing grid-connected photovoltaic system in the Mackinaw Dells rest area buildings. The LCC analysis was conducted to determine annual savings, payback period, amount of eliminated CO_2 emissions, and required area of the system. The analysis accounted for an annual interest rate of 2%, escalation in utility rate of 5%, and an annual increase of maintenance cost by 2%, as shown in Table 188. The analysis shows that incorporating a grid-connected photovoltaic system at the Mackinaw Dells rest area has a payback period of 24.1 years. The system requires 34 solar panels to be installed, approximately 5 of which can be placed on the roof of the rest area building and 29 on the ground south of the rest area building, which need 270SF. These calculations accounted for 51^{o} tilt angle for the solar panels and preventing shading that might occur due to layout of solar panels in winter and summer. Figure 132 shows the cumulative savings of installing grid-connected system in the rest area building.

Table 187. Cost Components for Installing Grid-Connected Photovoltaic System in Mackinaw Dells Rest Area Buildings

Cost Components	**Amount/Savings**
Total number of solar panels	34
Number of inverters	1
System capacity (KW)	8.0
Utility cost ($/kwh)	0.112
Initial cost ($)	34,959
Annual maintenance cost ($)	107
Solar Panels periodic cost ($)	11,800
Inverter periodic cost ($)	4,110
Annual Savings ($)	1,381
Annual Savings (kwh)	12328
Cost per watt ($/w)	4.50

Table 188. LCC Analysis Results for Incorporating Grid-Connected Photovoltaic System in the Mackinaw Dells Rest Area Buildings

LCC Items/Savings	**Amount/Savings**
Annual eliminated CO_2 emissions (Ib)	17,382
Number of solar panels on roof	5
Number of solar panels on the ground	29
Required area for solar panels (SF)	270
Tilt angle of solar panels	51
Payback period (yr)	24.1

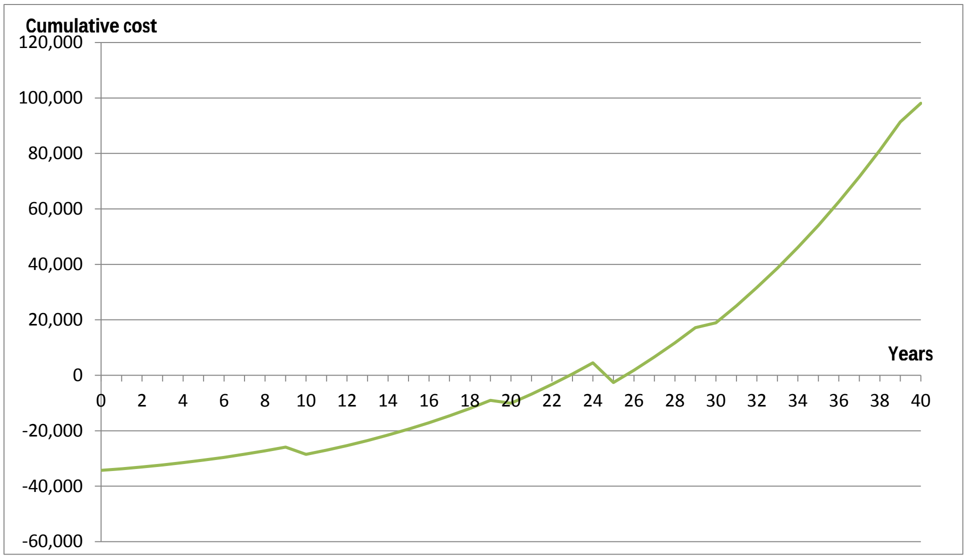


Figure 132. Cumulative cost of incorporating grid-connected system in the Mackinaw Dells rest area buildings.

It should be noted that the stand-alone photovoltaic system was not considered in this analysis because of its infeasible payback period that was identified in the first phase of this project due to its high initial and periodic costs of battery systems.

D.5.6.2 Solar Water-Heating Systems

Solar water heater is another technology that can reduce energy consumption for heating water in the rest area buildings. This technology can be installed with the current water heaters in the rest area in order to mitigate the cost of replacing current water heater. Moreover, current water heater can work as a backup when the sun rays are unavailable or insufficient to heat water to the desired temperature. The components of installing this system include solar collector(s), collector's mounting, heat exchanger, circulator, antifreeze (glycol), water storage tank(s), controller, fittings, pipes, and insulation. The initial capital cost of the system can be calculated for the three rest areas using the RSMeans Building Construction Cost Data (2012). Maintenance cost and life were calculated similar to Coalfield rest area buildings. The annual electricity use for water heater was estimated based on the created energy simulation model.

Table 189 summarizes the LCC components for incorporating solar water heaters in Mackinaw Dells rest area buildings. A LCC analysis was conducted based on an annual interest rate of 2%, escalation in utility rate by 5%, and an annual increase of maintenance cost by 2%, as shown in Table 190. The analysis shows that installing solar water heaters in Mackinaw Dells rest area buildings has a payback period by 3.96 to 13.7 years based on 70% and 20% energy savings heating water, and it can eliminate CO_2 emissions by 7,076 to 24,765 Ib annually.

It should be noted that solar collector(s) can be installed on the roof by clamps/straps or on the ground where a rack is used to hold the collector(s). Installing solar collectors on the roof might not be feasible as the building roof of the rest area was not designed to carry such extra load. Subsequently, solar collectors should be mounted on the ground.

Table 189. LCC Components for Installing Solar Water Heater
in Mackinaw Dells Rest Area Buildings

LCC Components	Amount/Savings
Capital cost (Ground mount) ($)	7,735
Annual maintenance cost (Ground mount)	77
Utility Cost ($/kwh)	0.112
Conventional water heater consumption (kwh)	25,270
Annual operating cost for conventional water heater ($)	2,830
Annual savings (20% to 70% savings) ($)	566 to 1,981
Periodic cost for pump @ 5 years ($)	250
Periodic cost for water tank @ 16 years ($)	1,600
Circulating pump life (yr)	5
Tank life (yr)	16

Table 190. LCC Analysis Results for Installing Solar Water Heater
in Mackinaw Dells Rest Area Buildings

Savings	Amount/Savings
Annual kwh saved (20% savings)	5,054
Annual kwh saved (70% savings)	17,689
Annual eliminated CO_2 emissions - 20% savings (Ib)	7,076
Annual eliminated CO_2 emissions - 70% savings (Ib)	24,765
Payback period - 20% savings (yr)	13.70
Payback period - 70% savings (yr)	3.96

D.5.7 Water-Saving Plumbing Fixtures

Rest areas have a high rate of water consumption due to the large number of visitors that use their restrooms. Using water-conserving fixtures in these rest areas will provide significant savings in water consumption. A number of feasible water-saving technologies can be used to minimize water consumption in the rest areas including efficient faucets, aerators, toilets, and urinals. Currently, the Mackinaw Dells rest area buildings have low-flow faucets,, which makes them suitable for conserving water use in the facility. Furthermore, the current toilets in Mackinaw Dells rest area building provide efficient use of water for flushing toilets as they have a flushing rate 1.6 GPF. The flushing rate for the current urinals in the rest area was not identified during the site visit, therefore, the flushing rate of urinals was assumed to be 1.0 GPF based on previously studied rest area buildings. An analysis was conducted to estimate the feasibility of installing conserving urinals in the rest area buildings. Table 191 summarizes the analysis of replacing current urinals with water-conserving ones. As it was difficult to calculate precisely the number of visitors using urinals or toilets, the analysis assumed that 24% of visitors use urinals. The replacement of current plumbing fixtures can provide savings of 87.5% to 92.5% of water consumption by urinals. This could result in a total water savings of

163,668 gallons annually. The payback period for these fixtures could not be calculated as water unit cost could not be identified as the rest area uses ground water to supply its needs.

Table 191. LCC Analysis for Replacing Current Urinals with Water Conserving Fixtures in Mackinaw Dells Rest Area Buildings

Saving/Cost Items	Urinals
Current fixture rate (GPF)	1
Number of fixtures	2
Type	Wall mount
Conserving fixtures rate (GPF)	0.112
Initial replacement Cost ($)	1,323*
Savings per flush (G)	0.888
Percentage savings (%)	88.8
Annual visitors 2009	767,960
Annual savings in water consumption for 24% of visitors use urinals (G)	163,668

* (RSMeans 2012; Lowe's 2012)

D.5.8 Summary of All Promising Green Building Measures

This section summarizes all green building measures that can be used in the Mackinaw Dells rest area buildings to reduce their energy consumption. All promising green building measures were added in the eQuest model in order to analyze the impact of their collective use and potential interactions on the overall energy consumption of the building. Table 192 summarizes all LCC components, savings and payback periods for all promising green building measures that were analyzed in the previous sections. The eQuest simulation model and energy analysis shows that the Mackinaw Dells rest area buildings can achieve a total of 49.1% reduction in energy costs by implementing the following energy-efficient measures: energy-efficient measures: fluorescent T8 bulbs, induction lighting fixtures for exterior lighting, motion-activated lighting for restrooms, vending occupancy controls, geothermal heat pump along with desuperheater, energy-efficient hand dryer, and a photovoltaic system with 7.8KW capacity.

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Table 192. All Promising Green Building Measures for Mackinaw Dells Rest Area Buildings

Green Building Measure	Estimated Initial Cost	Maintenance Cost, if Applicable	Annual Energy Savings	Annual Eliminated CO_2 Emissions (lb)	Reduction in Energy Consumption	Payback Period (yr)
Interior lighting	$1,872	N.A.	$1,215	15,297	4.5%	1.3
Exterior lighting - induction lighting	$16,922	N.A.	$1,850	23,295	6.8%	5.6
Motion-activated lighting	$1,057	N.A.	$280	3,529	1.0%	3.7
Vending occupancy controls	$339	N.A.	$254	3,202	0.9%	1.3
Geothermal heat pump	$41,820	$486	$6,310	79,432	23.1%	5.7
Energy-efficient hand dryers	$1,638	N.A.	$667	8,392	2.4%	2.5
Photovoltaic system	$34,959	$107	$1,381	17,382	5.1%	24.1
Desuperheater	$1,600	N.A.	$825	10,392	3.0%	1.9
Code Blue emergency phone	$300	N.A.	$256	3,224	0.9%	1.2
Water-conserving fixtures	$1,323	N.A.	N.A.	N.A.	N.A.	N.A.
All promising green building measures together (eQuest model)	$101,830	$593	$13,399	172,149	49.1%	7.1

APPENDIX E DECISION SUPPORT TOOL FOR OPTIMIZING UPGRADE DECISIONS OF ILLINOIS PUBLIC BUILDINGS

E.1 DST UPGRADE

E.1.1 Interior Lighting

Interior lighting is a feature that was added to the DST in order to allow the developed tool to replace current light bulbs and fixtures with more-efficient ones. The replacement of interior lighting with more energy-efficient lighting reduces the overall building energy consumption and help in complying with the LEED-EB requirements for building energy performance. The upgraded DST incorporates a database for interior lighting, which accounts for interior light bulbs and interior lighting fixtures. This database is designed to contain all relevant data on available alternatives for interior light bulbs and fixtures that can be used to replace existing lighting in order to reduce energy consumption while maintaining the required lighting levels in the building. The database for interior light bulbs contains key data sets that are needed to analyze the potential benefits of lighting replacement, including (1) general product characteristics such as brand name, model number, lamp type, fixture socket, initial lumens, mean lumens, Color Rendering Index, color temperature, and life expectancy; (2) cost data such as initial cost and annual maintenance cost; (3) energy characteristics such as bulb electricity consumption; (4) physical characteristics such as bulb dimensions; (5) vendor details such as vendor name, website, location, and data entry date, as shown in Figure 133.

Similarly, the database for interior lighting fixtures contains important data, including (1) general product characteristics such as fixture name, fixture socket, number of bulbs per fixture, ballast efficiency, and life expectancy; (2) energy consumption such as ballast consumption; (3) physical characteristics such as fixture dimensions; (4) cost data such as fixture cost, installation cost, and annual maintenance cost; and (5) vendor details such as vendor name, website, location, and data entry date, as shown in Figure 134. A GUI was designed in the DST to facilitate the input of interior lighting data in the database, as shown in Figure 135 and Figure 136.

It should be noted that, the DST is designed to search for the best lighting products that meet the current light requirement levels of buildings however it does not account for the effect of reducing light consumption on energy consumption for space heating and cooling.

14 imit of 10,000 lamp products

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
Lamp Characteristics															
General Product Characteristics										Time Characteristic	Cost Details			Energy Characterist	Physical Properties
Lamp ID #	Fixture group ID #	Brand name	Model name	Lamp Type	Fixture socket	Initial Lumens	Mean Lumens	Color Temperature (Kelvin)	Color Rendering Index (CRI)	Life expectancy (hour)	Lamp Cost ($)	Installation Cost ($)	Matenience cost($)	Consumption (Watt)	Length (ft)
0	0	None	None	T8	Medium Bi-Pin	0	0	0	0	0	0	0	0	0	4
1	1	Philips	20905-6 - F32T8/TL950	T8	Medium Bi-Pin	2000	1860	5000	98	20000	7.44	0	0	32	4
2	1	Philips	27229-4 - F32T8/TL850/ALTO	T8	Medium Bi-Pin	2850	2710	5000	82	36000	2.55	0	0	32	4
3	1	Philips	27248-4 - F32T8/TL741/ALTO	T8	Medium Bi-Pin	2800	2660	4100	78	36000	2	0	0	32	4
4	2	Sylvania	FB34/CW/6/SS/ECO	T12	Medium Bi-Pin (G13) Base	N.A.	2279	4200	62	18000	9.99	0	0	34	U-Shape
5	2	Sylvania	FBO28/841/XP/SS/ECO	T8	Medium Bi-Pin (G13) Base	N.A.	2265	4100	75	26000	15.79	0	0	28	U-shape
6	1	Sylvania	24596 - F34CW/SS/ECO	T12	Medium Bi-Pin	2650	2279	4200	62	20000	2.04	0	0	34	4
7	1	Sylvania	22179 (FO28/841/XP/SS/ECO)	T8	Medium Bi-Pin	N.A.	2725	4100	85	36000	8.99	0	0	28	4
8	4	Sylvania	F20T12/CW 20W	T12	Medium Bi-Pin	N.A.	1200	4200	62	18000	1.89	0	0	20	2
9	4	Sylvania	21770 (FO17/741/ECO)	T8	Medium Bi-Pin	N.A.	1325	4100	75	20000	5.79	0	0	17	2
10	1	Philips	30T12/CW/RS/EW, ALTO	T12	Medium Bi-Pin	N.A.	1950	4100	62	18000	3.5	0	0	25	4
11	1	Sylvania	22233 (FO32/25W/835/XP/SS/ECO)	T8	Medium Bi-Pin	N.A.	2475	4100	75	36000	7.99	0	0	25	4
12	3	Sylvania	29505 - F96T12/CW/SS/ECO	T12	Medium Bi-Pin	N.A.	4050	4200	60	12000	4.82	0	0	60	5
13	3	Sylvania	58860 (F58WT8/865)	T8	Medium Bi-Pin	N.A.	4300	5400	90	20000	24.99	0	0	58	5
14	1	Sylvania	22234 (FO32/25W/841/XP/SS/ECO)	T8	Medium Bi-Pin	N.A.	2327	4100	85	36000	7.39	0	0	25	4

Figure 133. Database for interior light bulbs in the upgraded DST.

5 imit of 10,000 fixtures

Fixture Characteristics										
Product Characteristics							Time Characteristi	Cost Details		
Fixture ID #	Fixture group ID #	Grpoup name	Fixture name	Fixture socket	Number of bulbs per fixture	Balast effect on luminance (%)	Life expectancy (years)	Fixture cost ($)	Installation Cost ($)	Matenience cost($)
0	0	None	None	None	0	0%	1000		0	0
1	1	Ceiling rectangular fluorescent fixture	Lithonia Lighting® 48in T8 Two Lamp Wraparound Light Fixture (4 feet	bi-pin socket	2	0%	10	48	60	0
2	1	Ceiling rectangular fluorescent fixture	Longitudinal Fluorescent lamp (4 feet)	bi-pin socket	4	0%	10	100	60	0
3	2	Ceiling fluorescent square fixture for U-Shape lamps	U-Shape Fluorescent lamp	Medium Bi-Pin (G13) Base	2	0%	10	75	60	0
4	3	Ceiling rectangular fluorescent fixture	Longitudinal Fluorescent lamp (5 feet)	bi-pin socket	2	0%	10	65	60	0
5	4	Ceiling rectangular fluorescent fixture	Longitudinal Fluorescent lamp (2 feet)	bi-pin socket	2	0%	10	40	60	0

Figure 134. Database used for interior lighting fixtures in the upgraded DST.

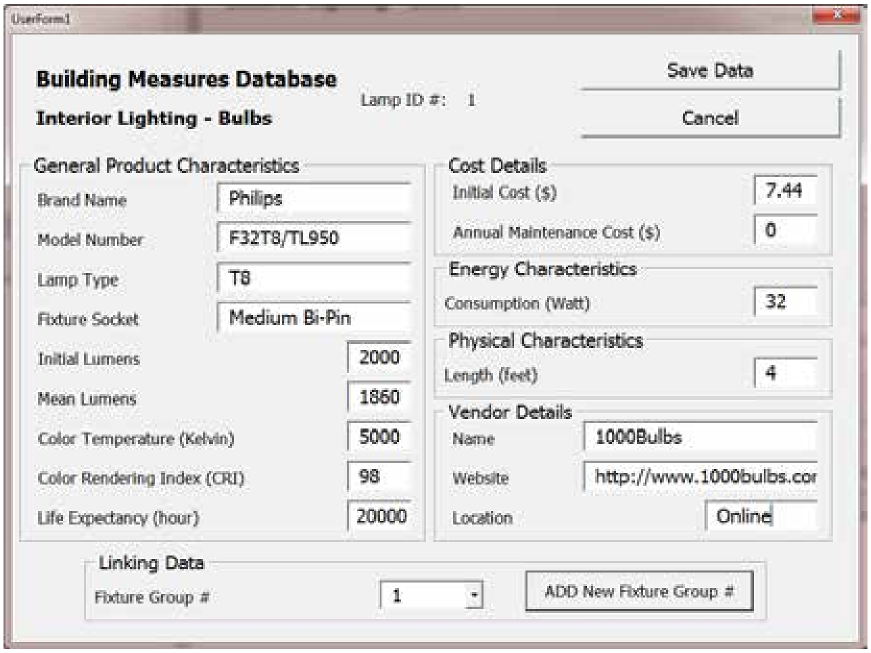

Figure 135. Designed GUI for interior light bulbs in the upgraded DST.

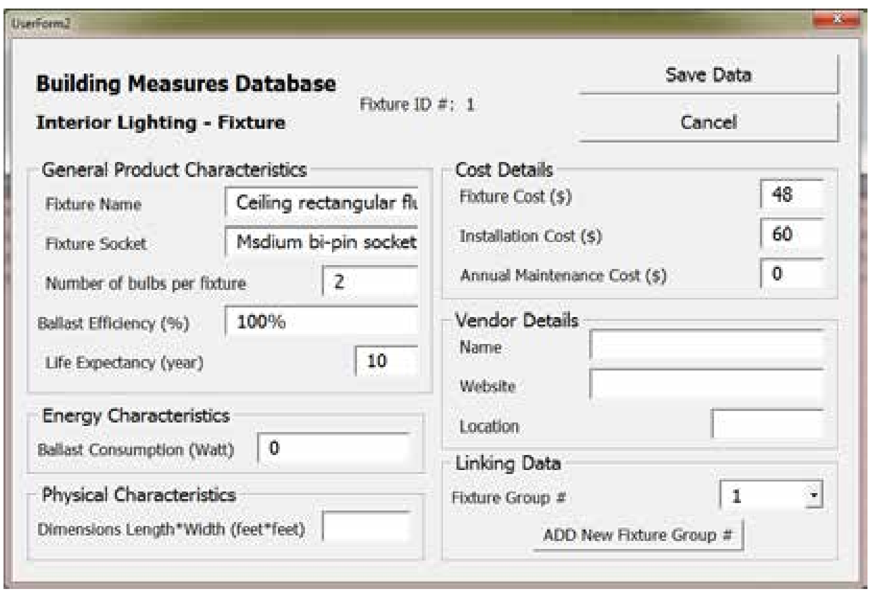

Figure 136. Designed GUI for interior lighting fixtures in the upgraded DST.

E.1.2 Exterior Lighting

Exterior lighting is a feature that was added to the DST in order to allow the decision maker to optimize the potential replacement of current light bulbs and fixtures with more-efficient ones. The replacement of exterior lighting with more energy-efficient lighting reduces the overall energy consumption and help in complying with the LEED-EB requirements for building energy performance. The upgraded DST incorporates databases that contain exterior light bulbs and exterior lighting fixtures. These databases are designed to contain all relevant data on available alternatives for exterior light bulbs and fixtures that can be used to replace existing ones to reduce energy consumption while maintaining the required lighting levels. The database for exterior light bulbs contains key data that are needed to analyze the potential benefits of lighting replacement, including (1) general product characteristics such as brand name, model number, lamp type, fixture socket, initial lumens, mean lumens, Color Rendering Index, color temperature, and life expectancy; (2) cost data such as initial cost and annual maintenance cost; (3) energy characteristics such as bulb electricity consumption; and (4) vendor details such as vendor name, website, location, and data entry date. Similarly, the database for exterior lighting fixtures contains important data, including (1) general product characteristics such as fixture name, fixture socket, number of bulbs per fixture or lighting pole, ballast efficiency, and life expectancy; (2) energy consumption such as ballast consumption; (3) physical characteristics such as fixture dimensions; (4) cost data such as fixture cost, installation cost, and annual maintenance cost; and (5) vendor details such as vendor name, website, location, and data entry date. A GUI was designed in the DST to facilitate the input of exterior lighting data in the database, as shown in Figure 136 and Figure 137

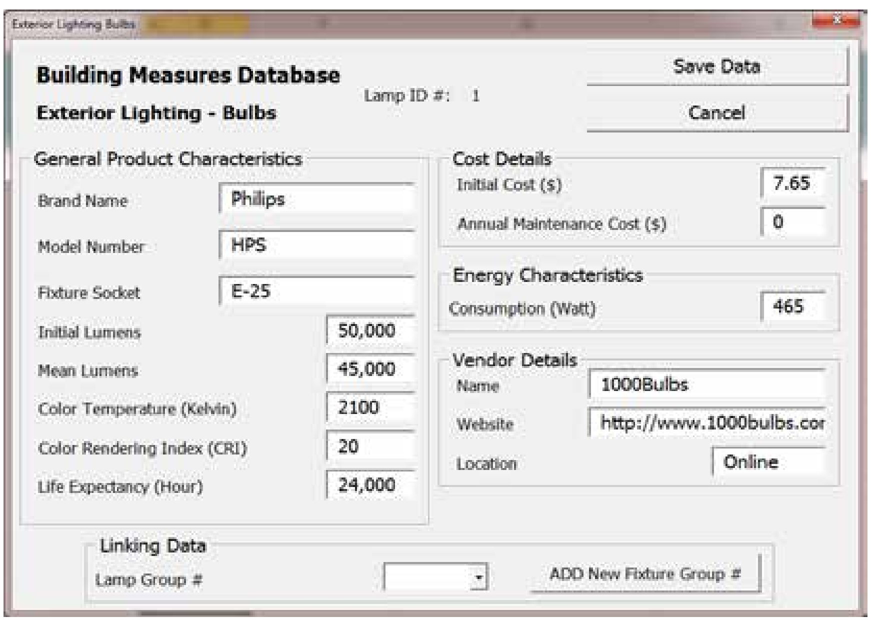

Figure 137. Designed GUI for exterior light bulbs in the upgraded DST.

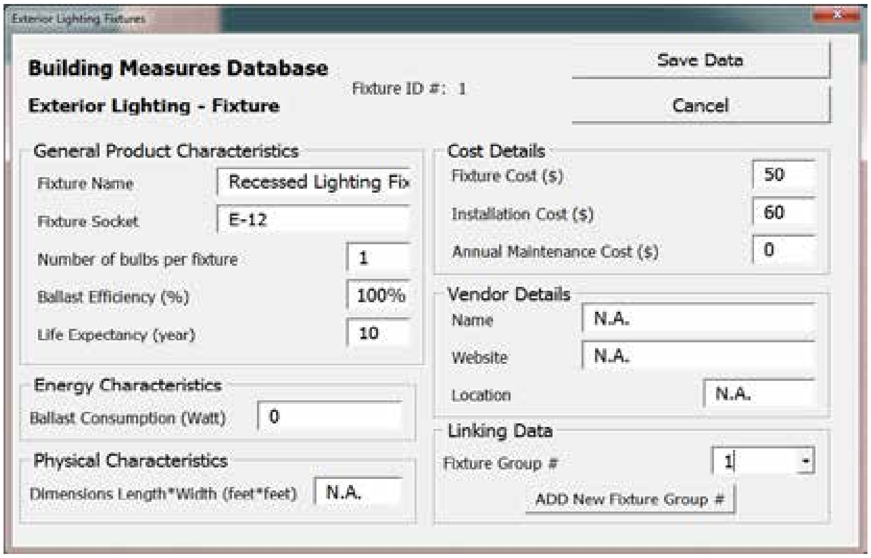

Figure 138. Designed GUI for exterior lighting fixtures in the upgraded DST.

E.1.3 Hand Dryers

Another feature was added to the DST to analyze and optimize the potential replacement of existing hand dryers with more energy-efficient units. The replacement of existing hand dryers with more energy-efficient hand dryers can reduce the overall building energy consumption and help in complying with the LEED-EB requirements for building energy performance. The upgraded DST incorporates a database of hand dryer units that contains key data that are needed in the optimization analysis, including (1) general product characteristics such as brand name, model number, air flow, loudness, life expectancy and drying time; (2) physical characteristics such as product dimensions; (3) cost data such as unit cost, installation cost, and annual maintenance cost; (4) energy characteristics such as electricity consumption; and (4) vendor details such as vendor name, website, location, and data entry date. A GUI was designed in the DST to facilitate the input data of hand dryers in the created database. Figure 139 shows a user-friendly form where input data for hand dryer can be entered and added to the DST database.

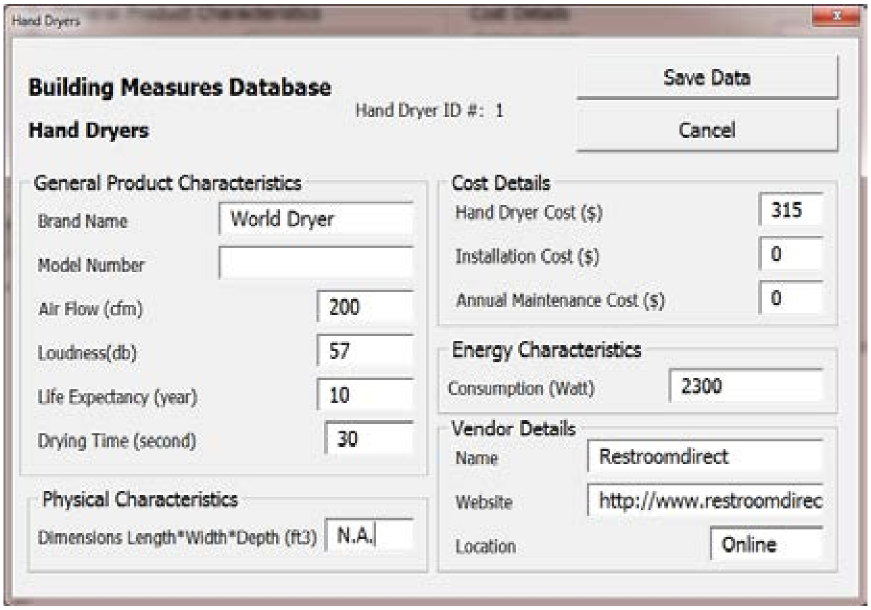

Figure 139. Designed GUI for hand dryers in the upgraded DST.

E.1.4 Vending Machines

Another feature was added to the DST to support the analysis and optimization of replacing existing vending machines with more energy-efficient units in order to reduce the overall building energy consumption and help in complying with the LEED-EB requirements. The upgraded DST incorporates a database of vending machines that contains key product data that are needed in the optimization analysis, including (1) general product characteristics such as brand name, model number, type of machine and life expectancy; (2) energy characteristics such as electricity consumption; (3) cost data such as unit cost, and annual maintenance cost; and (4) vendor details such as vendor name, website, location, and data entry date. A GUI was designed in the DST to facilitate the input data of vending machines for the created database. Figure 140 shows a user-friendly form where input data for vending machines can be entered and added to the DST database.

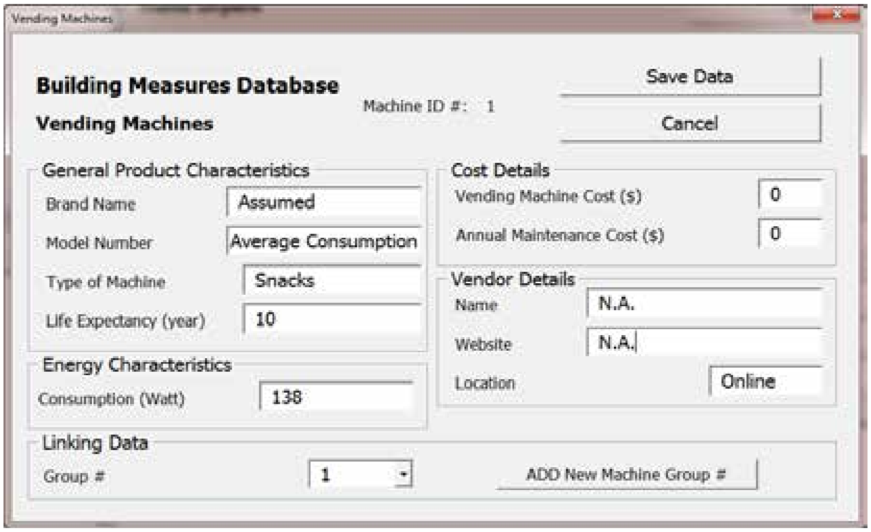

Figure 140. Designed GUI for vending machines in the upgraded DST.

E.1.5 Other Devices

An additional category was added in the DST to specify other devices that were not included in the previous categories such as personal computers, water coolers, and TVs. These devices can be replaced with more energy-efficient units that can reduce the overall building energy consumption and help in complying with the LEED-EB energy requirements. The upgraded DST incorporates a database of other devices that contains important data, including (1) general product characteristics such as description, brand name, model number, and life expectancy; (2) energy characteristics such as electricity consumption; (3) physical characteristics such as dimensions, (4) cost data such as unit cost, installation cost, and annual maintenance cost; and (5) vendor details such as vendor name, website, location, and data entry date. A GUI was designed in the DST to facilitate the input data of general devices for the created database. Figure 141 shows a user-friendly form where input data for other devices can be entered and added to the DST database.

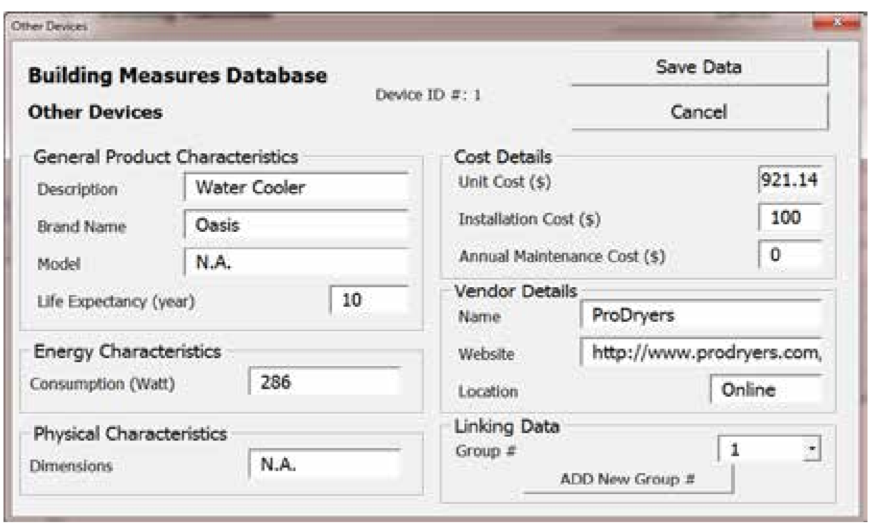

Figure 141. Designed GUI for general devices in the upgraded DST.

E.1.6 Water Heaters

The DST is also designed to analyze and optimize the potential replacement of existing water heaters with more energy-efficient units. Water heater replacement can reduce the overall building energy consumption and help in complying with the LEED-EB requirements for building energy consumption. The DST incorporates a database for water heaters that contains key data on water heater products, including (1) general product characteristics such as brand name, model number, type of water heater, tank capacity and life expectancy; (2) energy savings such as percentage reduction in electricity consumption, percentage reduction in gas consumption, electricity consumption from energy simulation software, and gas consumption from energy simulation software; (3) energy characteristics such as standby loss, energy factor, and input rating; (4) cost data such as unit cost, installation cost, and annual maintenance cost; and (5) vendor details such as vendor name, website, location, and data entry date. The database in the DST was designed to add water heaters with their percentage energy savings or energy consumption. The percentage energy savings or energy consumption can be computed from energy simulation software and added to the database. The DST can assist in selecting the heater unit that can reduce energy consumption while achieving LEED-ED energy requirements. A graphical user interface (GUI) was designed in the DST to facilitate the input of water heaters data easily. Figure 142 shows a user-friendly form where input data for water heaters can be entered and added to the DST database.

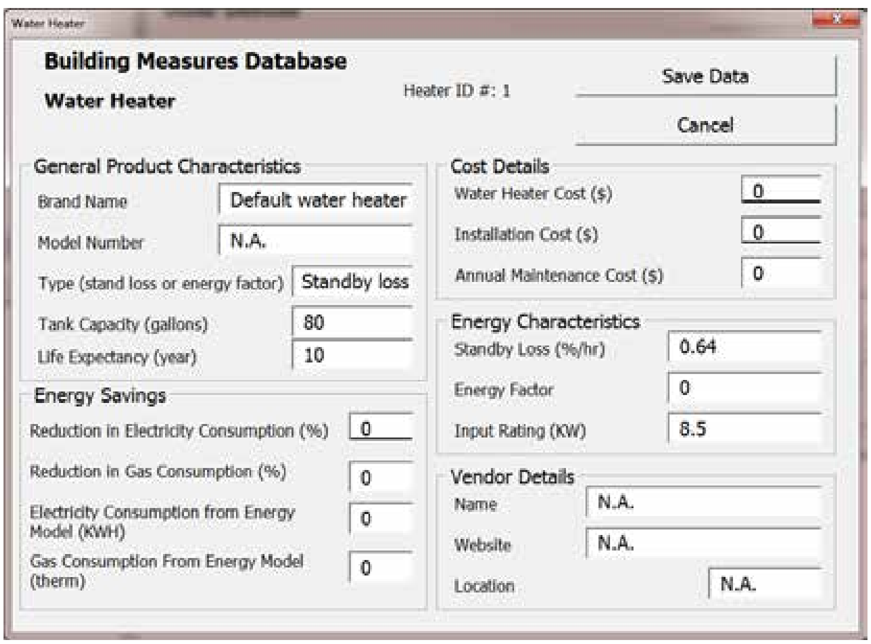

Figure 142. Designed GUI for water heater in the upgraded DST.

E.1.7 HVAC Systems

Another feature was added to the DST to allow the developed tool to consider and optimize the potential replacement of existing HVAC equipment with more energy-efficient units. HVAC replacement can reduce the overall building energy consumption and help in complying with the LEED-EB requirements for building energy consumption. The DST incorporates a database for HVAC equipment that contains key data, including (1) general product characteristics such as brand name, model number, cooling capacity, heating capacity, type of loop for geothermal heat pump if any, type of energy used for HVAC equipment, and life expectancy; (2) energy characteristics such as energy-efficiency ratio, coefficient of performance, and direct geo-exchange; (3) physical characteristics such as dimension and loop total length; (4) cost data such as HVAC equipment cost, equipment installation cost, loop installation cost, and annual maintenance cost; (5) energy consumption details such as percentage reduction in electricity consumption, percentage reduction in gas consumption, electricity consumption from energy simulation software, and gas consumption from energy simulation software; and (6) vendor details such as vendor name, website, location, and data entry date. The database in the upgraded DST was designed to add HVAC equipment with their percentage energy savings or energy consumption. The percentage energy savings or energy consumption can be computed from energy simulation software and added to the database with which the DST selects the HVAC unit that can reduce energy consumption while achieving LEED-ED energy requirements. This new user interface was designed in the DST to facilitate the input of HVAC equipment data, as shown in Figure 143.

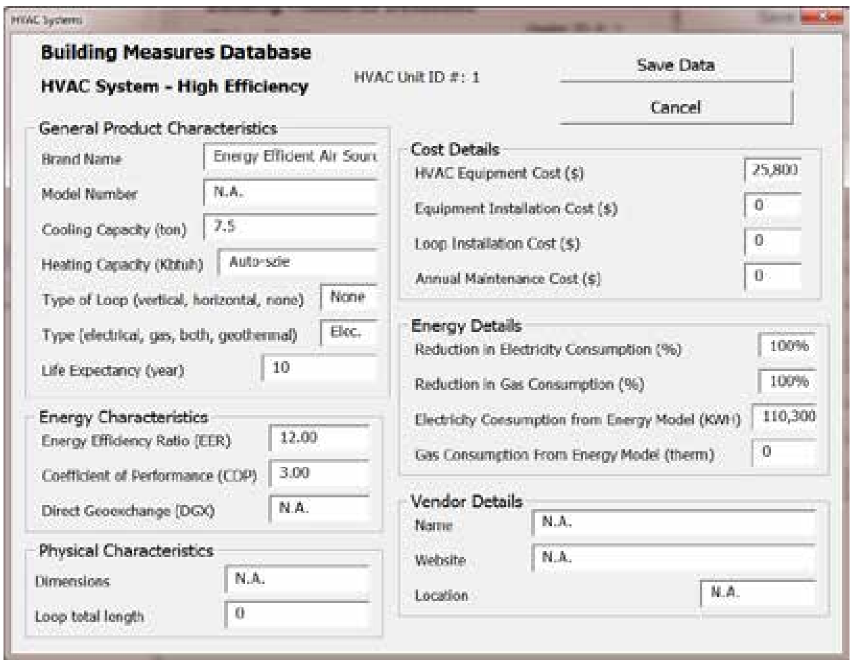

Figure 143. Designed GUI for HVAC equipment in the upgraded DST.

E.1.8 Grid-Connected Photovoltaic Systems

The DST is also designed to evaluate and optimize the potential integration of grid-connected photovoltaic systems in the analyzed building. Adding on-site renewable energy sources such as photovoltaic systems in buildings can reduce their utility consumption and achieve LEED-EB credits. The upgraded DST incorporates database systems for the two main components of grid-connected photovoltaic systems: solar panels and electricity inverters. The databases contain key data on solar panels and inverter products to enable the DST to search for and identify the optimal type and number of solar panels and inverters for a building being analyzed. The database for solar panels contains important data on (1) general product characteristics such as brand name, model number, and life expectancy; (2) physical characteristics such as length, width, depth, and weight; (3) cost data such as solar panel cost; (4) energy characteristics such as power, efficiency, and maximum volt; and (5) vendor details such as vendor name, website, location, and data entry date. Similarly, the database for electricity inverters contains important data on (1) general product characteristics such as brand name, model number, and life expectancy; (2) physical characteristics such as length, width, depth, and weight; (3) cost data such as inverter unit cost; (4) energy characteristics such as minimum inverter power, average inverter power, maximum power, volts, and efficiency; and (5) vendor details such as vendor name, website, location, and data entry date. The feature in the DST is designed to facilitate the input of the photovoltaic system components data, as shown in Figure 144and Figure 145.

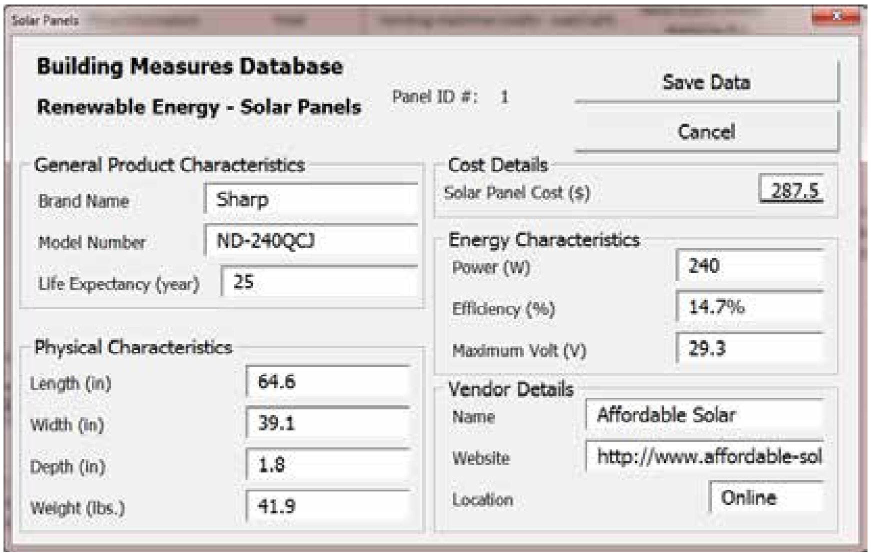

Figure 144. Designed GUI for solar panels in the upgraded DST.

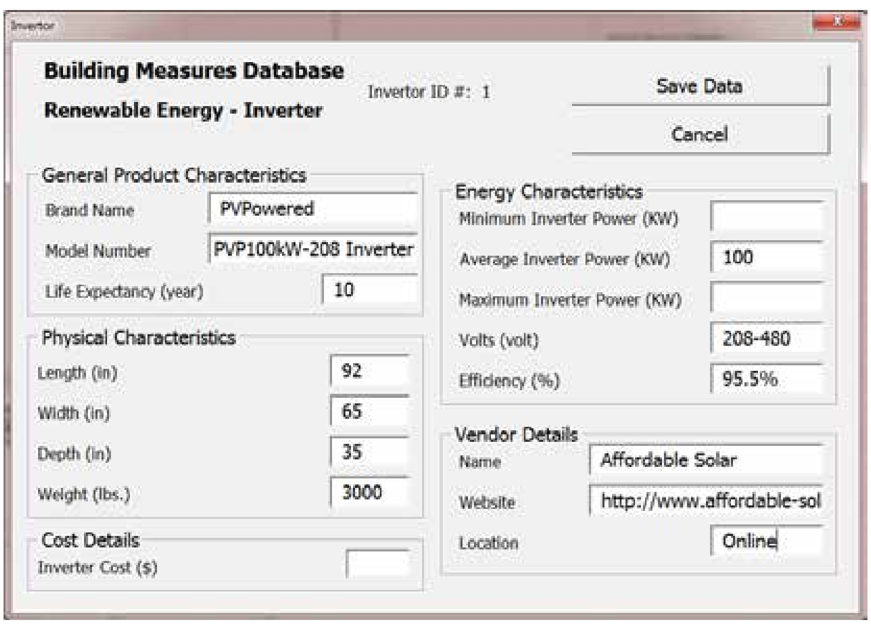

Figure 145. Designed GUI for inverters in the upgraded DST.

E.1.9 Water Fixtures

The DST is also designed to analyze and optimize the potential replacement of existing water fixtures with more-efficient units in order to reduce the overall building water consumption and help in complying with the LEED-EB water consumption requirements. The DST includes database systems for building water fixtures such as faucets, toilets, and urinals. The database for water facets contain important data, including (1) general product characteristics such as brand name, model number, type of faucet, and life expectancy; (2) water characteristics such as discharge rate; (3) cost data such as unit cost, installation cost, and annual maintenance cost; and (4) vendor details such as vendor name, website, location, and data entry date. The databases for water toilets and urinals were designed similar to the aforementioned water faucets database. This feature in the DST is designed to facilitate the input of all the required water fixtures data, as shown in Figure 146.

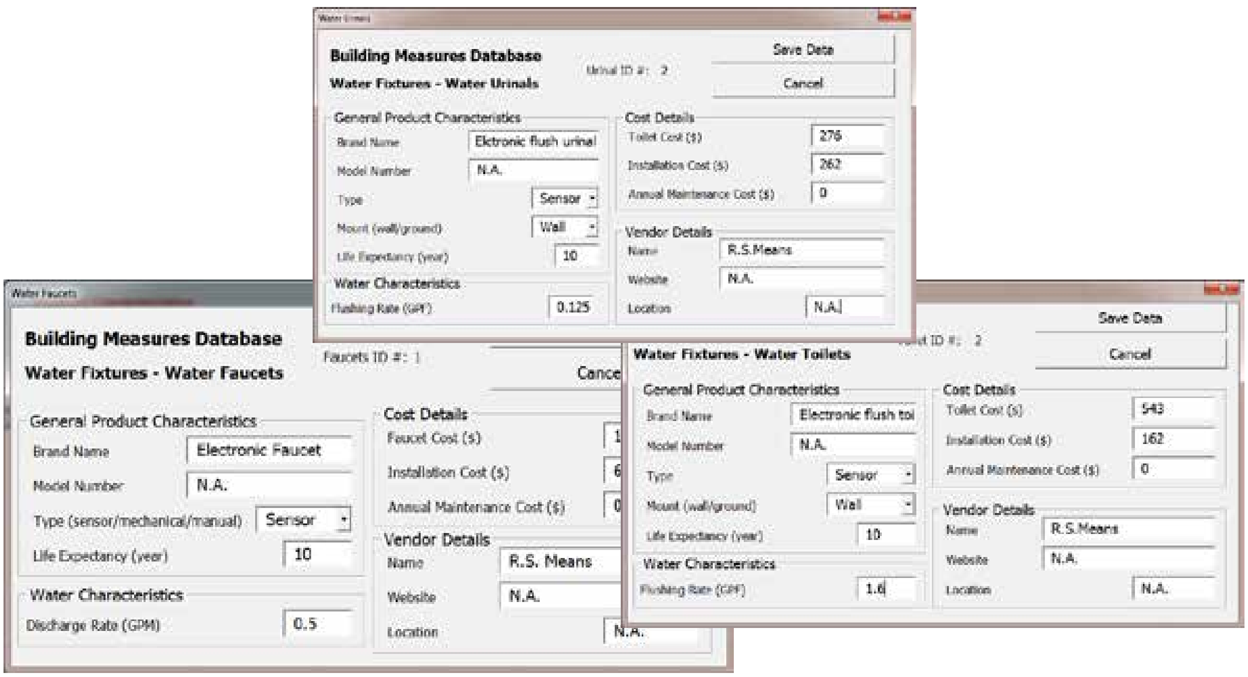

Figure 146. Designed GUI for water fixtures in the upgraded DST.

E.1.10 Metering Systems

The DST is designed to achieve LEED credits through the integration of metering and sub-metering systems for energy and water consumption in buildings. The integration of energy and water metering and sub-metering systems can achieve LEED-EB credits based on the water efficiency and energy-efficiency divisions. The DST incorporates databases for metering and sub-metering systems including water, electricity, and gas meters. The databases contain all the data that the DST requires to select meters/sub-meters based on their capacity, LEED-EB requirements, and number of LEED credits that need to be achieved. The database for metering systems contains important data including (1) general product characteristics such as brand name, model number, type of meter, meter capacity, and data log feature; (2) cost data such as unit cost, installation cost, and annual maintenance cost; and (3) vendor details such as vendor name, website, location, and data entry date. Similarly, the database for sub-metering systems contains data on (1) general product characteristics such as brand name, model number, type of meter, meter capacity, data log feature, collector ID number if any, and any additional ID number; (2) cost data such as sub-meter cost, collector cost, additional device cost, and annual maintenance cost; and (3) vendor details such as vendor name, website, location, and data entry date. The GUI in the DST is designed to facilitate the input of meters and sub-meters data, as shown in Figure 147.

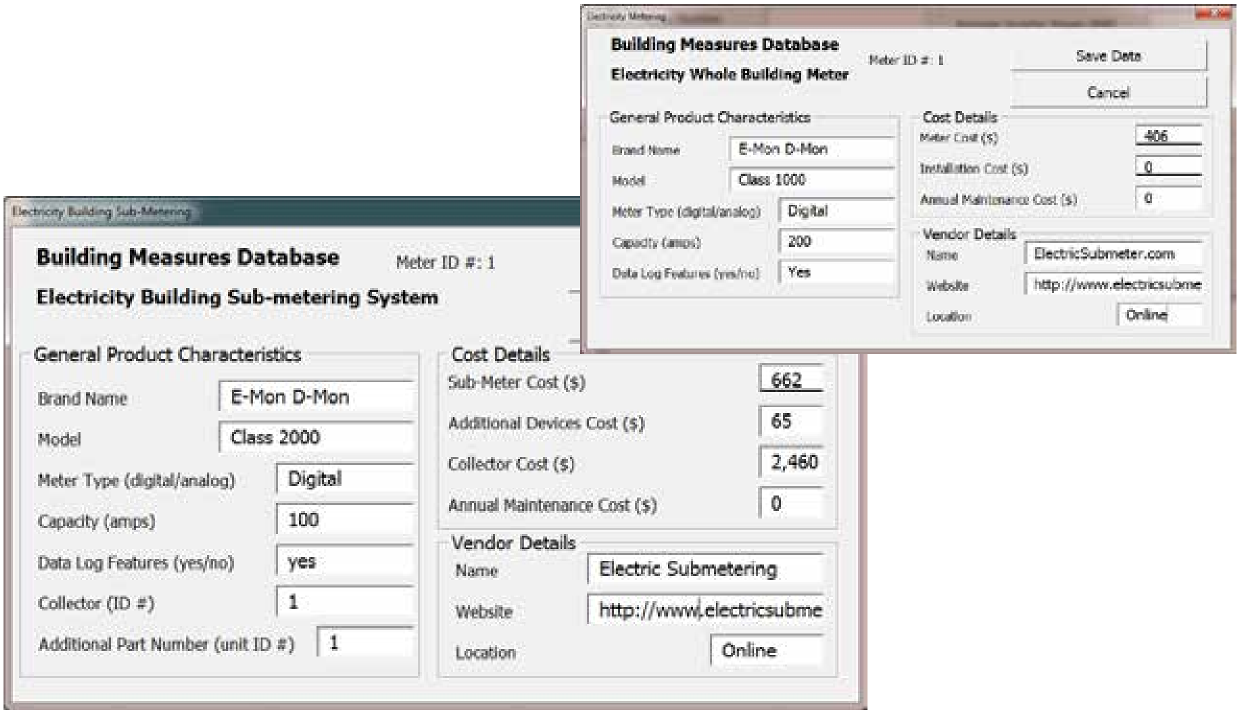

Figure 147. Designed GUI for electricity sub-meter in the upgraded DST.

E.1.11 Building Input Data

The DST includes a newly created tab to enable users to select and enter the specific data of buildings that are being investigated to achieve LEED-EB certification. This enables users to input building data, including building geometry and service information, building rooms, energy consumption historical data, interior lighting fixtures and bulbs, exterior lighting fixtures and bulbs, hand dryers, motion sensors, water heaters, water fixtures, HVAC systems, and energy and water metering systems. The DST is designed to assign these data into several sections. The first section is “general building data” that includes data on building name, geometry, building type, occupancy and visitation rates, historical data of electricity and gas consumption, and billing rates, as shown in Figure 148. This section also includes a button named “building measures” that can be used to show available databases for all building measures and add new products to these databases, if needed. The gathered building data in this section are used in the energy and water calculations as well as in the analysis of replacing existing building measures with more-efficient ones.

Electricity Consumption (KWH)

Reported Year	2008
Month	Consumption
January	
February	
March	
April	
May	
June	
July	
August	
September	
October	
November	
December	
Total	

Billing Rates

Average elerecity rate	0.0998	$/KWH
Average Natural gas rate	0.93588	$/therm
Averge water rate	0	$/gallon

Building ID number

General Building Data

Building Measures

General Building Data	
Building Name	T
Number of Rooms	
Average Width (feet)	55.28
Average Length (feet)	64.67
Average cleasr height inside building	9
Building Perimeter (feet)	247.33
Building Size (sq ft)	3575
Annual Number of visitors	838770
Type of Building	Service
Daily number of Full-Time equivelant (FTE) occupants - if any (occupant)	1
Daily number of transients per day - if any (student/visitor)	2298
Number of retail customers - if any (customer)	0

Natural Gas Consumption (therm)

Reported Year	2008	
Month	Consumption	
January	585	Therm
February	527	Therm
March	360	Therm
April	325	Therm
May	132	Therm
June	89	Therm
July	92	Therm
August	87	Therm
September	98	Therm
October	222	Therm
November	213	Therm
December	409	Therm
Total	3139	Therm

Figure 148. General building data section in the created building input data tab.

The second section of building input data is “building rooms” that includes data on room name, type, geometry and eligibility for implementing motion-activated lighting, as shown in Figure 149. This section can include up to 30 rooms in the analyzed building.

Building Rooms

Building Rooms	Name	Type of room	Average Room Width (feet)	Average Room Length (feet)	Average Room height (feet)	Eligibility for Motion lighting
Room 1	Men's bathrrom 1	Bathroom	19.3	29.7	573.5	Yes
Room 2	Women's bathroom 1	Bathroom	19.3	29.7	573.5	Yes
Room 3	Family bathroom	Bathroom	6.0	10.5	63.0	Yes
Room 4	Mechnical room	Office	16.5	22.7	373.3	Yes
Room 5	Travel information room	Office	10.5	20.5	215.3	Yes
Room 6	Lobby	Hall	24.7	55.3	1363.8	No
Room 7	Storage 1	Storage	8.0	12.0	96.0	Yes
Room 8	Storage 2	Storage	8.0	12.0	96.0	Yes
Room 9	Storage 3	Storage	12.2	18.2	221.0	Yes

Figure 149. Building rooms section in the created building input data tab.

The third section of building input data is “interior lighting” that includes data on lighting fixture ID number, number of fixtures, light bulbs ID number, light working hours per day, and allowed reduction in existing light lumens, as shown in Figure 150. This section can account for three separate lighting sets per room and up to 30 rooms. Users can input a light fixture number where the tool can extract and show the information of this fixture automatically, as shown in Figure 150. The user can also update the interior lighting database by pressing the “Add Fixture” button and add a new fixture. Similarly, users can enter a light bulb number where the tool can extract and show the light bulb brand name, model number, and consumption, as shown in Figure 150. The user can also update the interior lighting database by pressing the “Add Bulb” button and add a new bulb, which provides flexibility to add any light fixture or bulb in the database and assign it to a room in a building. The gathered data in this section are used in the DST to calculate electricity consumption for existing light bulbs and fixtures as .well as to study the feasibility of replacing existing interior lighting with more energy-efficient ones during the optimization process.

Building - Interior Lighting

Add Bulb | Add Fixture

Building Rooms	Room Name	Room Lighting - Set # 1: Type of Lighting Fixture (Fixture Number)	Number of Fixtures	Type of Lighting Bulb (Bulb Number)	Extracted bulb energy consumption - Database - (Watt)	Number of Light working hours per day (Hours)
Room 1	Men's bathrrom 1	3	6	4	34	24
		Ceiling fluorescent square fixture for U-Shape lamps		Sylvania 27248-4 - F32T8/TL741/ALTO T8		
Room 2	Women's bathroom 1	3	6	4	34	24
		Ceiling fluorescent square fixture for U-Shape lamps		Sylvania 27248-4 - F32T8/TL741/ALTO T8		
Room 3	Family bathroom	3	1	4	34	24
		Ceiling fluorescent square fixture for U-Shape lamps		Sylvania 27248-4 - F32T8/TL741/ALTO T8		
Room 4	Mechnical room	4	4	12	60	0.33
		Ceiling rectangular fluorescent fixture		Sylvania FB34/CW/6/SS/ECO T12		
Room 5	Travel information room	5	2	8	20	9
		Ceiling rectangular fluorescent fixture		Sylvania FBO28/841/XP/SS/ECO T8		
Room 6	Lobby	3	18	4	34	24
		Ceiling fluorescent square fixture for U-Shape lamps		Sylvania 27248-4 - F32T8/TL741/ALTO T8		
Room 7	Storage 1	1	1	6	34	2
		Ceiling rectangular fluorescent fixture		Sylvania 20905-6 - F32T8/TL950 T8		
Room 8	Storage 2	1	1	6	34	2
		Ceiling rectangular fluorescent fixture		Sylvania 20905-6 - F32T8/TL950 T8		
Room 9	Storage 3	0	0	0		2

Figure 150. Interior lighting section in the created building input data tab.

The fourth section of building input data is “exterior lighting” that includes data on lighting fixture ID number, number of fixtures, light bulb ID number, light working hours per day, and allowed reduction in existing light lumens, as shown in Figure 151. This section gathers data for three categories of exterior lighting including building, parking lot, and landscape and can account for up to two lighting sets per category. Users can enter a light fixture number to prompt the DST to extract and show the information of this fixture automatically, as shown in Figure 151. Similarly, users can input a light bulb number and DST will provide a collection of light bulb brand name, model number, and consumption, as shown in Figure 151. The user can also update the exterior lighting database by pressing the “Add Fixture” and/or “Add Bulb” buttons in order to add a new fixture and/or a bulb. The gathered data in this section are used in the DST to calculate electricity consumption for existing light bulbs and fixtures as well as to study the feasibility of replacing existing light bulbs and fixtures with more energy-efficient ones during the optimization process.

The fifth section of the building input data is “motion lighting sensors, hand dryers, vending machines, other devices, and general load assignment” that includes data on motion-sensor ID number and number of sensors per room, hand dryer ID number and number of hand dryers per room, vending machine ID number and number of vending machines per room, device ID number and number of devices, devices working hours per day, general loads electricity and gas consumption, and working hours for general loads per day, as shown in Figure 152. The DST is designed to account for one set of motion sensors per room, one set of hand dryers per room, three sets of vending machines per room, two sets for other devices per room, and one set for general loads. Users of the DST can assign motion-sensor ID number, hand dryer ID number, vending machine ID number, and/or device ID number to prompt the DST to extract and show the information of these machines/devices automatically, as shown in Figure 152. The user can also update the existing databases for motion sensors, hand dryers, vending machines and devices by pressing any of the available buttons in this section and add a new unit, as shown in Figure 152. The gathered data in this section are used within the DST to calculate electricity consumption for hand dryers, vending machines, and other devices, electricity and gas consumption from general loads, reduction in lighting use due to the use of motion sensors. The gathered data of this section can also be used to study the feasibility of replacing existing hand dryers, vending machines, and other devices with more energy-efficient unit and calculate their additional costs accordingly during the optimization process.

Exterior Lighting

Add Bulb | Add Fixture

Location	Exterior Lighting - Set # 1					
	Type of Lighting Fixture (Fixture Number)	Number of Fixtures	Type of Lighting Bulb (Bulb Number)	Bulb Energy Consumption (Watt)	Average annual working hours per day (Hour)	Aloowed Reduction in lumen levels (%)
Building	1	15	2	110	8.56	30%
	Recessed lighting fixtures for buildings entrance and exit		MH 100Watt			
Parking Lot	5	2	1	465	8.56	30%
	Light pole with six fixtures for street and parking lighting		HPS 400Watt			
Landscape	0	0	0		8.56	30%

Figure 151. Exterior lighting section in the created building input data tab.

The sixth section of the building input data is “water heaters and water fixtures” that includes data on water heater ID number and number of water heaters, percentage of electricity consumption as of the total building electricity consumption, percentage of gas consumption as of total building gas consumption, faucet ID number and number of faucets, toilet ID number and number of toilets, urinals ID number and number of urinals, percentage of Full-Time Equivalent (FTE) using room, percentage of visitors using room as of the total building visitors, percentage of customers using room, and installation or renovation year of water fixtures, as shown in Figure 153. During the optimization process, the DST will investigate the feasibility of replacing existing water heater(s) with more energy-efficient ones. Energy savings for water heaters can be calculated using energy simulation software such as eQuest. Users of the DST can assign water heater ID number, faucet ID number, toilet ID number, or urinal ID number to prompt the DST to extract and show the information of it automatically, as shown in Figure 153. The user can also update the existing databases with water heaters and/or water fixtures by pressing any of the available buttons in this section and add a new unit, as shown in Figure 153.

This provides flexibility for users to add any unavailable product in the database and assign it to a room in a building. The gathered data in this section are used in the DST to calculate electricity and gas consumption for water heaters and to calculate water consumption for each room. The gathered data can also be used to study the feasibility of replacing existing water heaters and/or water fixtures with more energy-efficient units and calculate their additional costs accordingly during the optimization process.

Motion Sensors, Hand Dryers, Vending Machines, other Devices, and general Load assignment

Add Motion Sensor | Add Hand Dryer | Add Vending Machine | Add Device

Building Rooms	Room Name	Motion Lighting Sensors		Hand Dryers			Vending Machine - Set # 1		Other Devices - Set # 1			er Devices - Set	General Load		
		Motion sensor ID # (Sensor Number)	Number of Sensors	Hand Dryer ID # (Unit Number)	Number of Units	Percentage of people using hand dryers out of the total number of visitors (%)	Vending Machine ID # (Machine Number)	Number of Vending Machines	Device ID # (Unit Number)	Number of Units	Number of Working hours per Day (hour)	Device ID # (Unit Number)	Electricity consumption (watt)	Gas consumption (therm)	Number of working hours (Hours)
Room 1	Men's bathrrom 1	0	0	1	4	23.5%	0	0	0	0	0	0	0	0	0
				World Dryer Model A - Cast iron - surface mounted - White											
Room 2	Women's bathroom 1	0	0	1	4	23.5%	0	0	0	0	0	0	0	0	0
				World Dryer Model A - Cast iron - surface mounted - White											
Room 3	Family bathroom	0	0	1	1	3.0%	0	0	0	0	0	0	0	0	0
				World Dryer Model A - Cast iron - surface mounted - White											
Room 4	Mechnical room	0	0	0	0	0.0%	0	0	0	0	0	0	0	0	0
Room 5	Travel information room	0	0	0	0	0.0%	0	0	0	0	0	0	0	0	0
Room 6	Lobby	0	0	0	0	0.0%	1	2	0	0	0	0	0	0	0
							Average snacks vending machine N.A.								
Room 7	Storage 1	0	0	0	0	0.0%	0	0	0	0	0	0	0	0	0
Room 8	Storage 2	0	0	0	0	0.0%	0	0	0	0	0	0	0	0	0
Room 9	Storage 3	0	0	0	0	0.0%	0	0	0	0	0	0	0	0	0

Figure 152. Motions sensors, hand dryers, vending machines, and general load assignment section in the created building input data tab.

Water Heater and Water Fixtures

Add Water Heater | Add Faucet | Add Toilet | Add Urinal

Building Rooms	Type of room	Water Heater			Faucets		Toilets		Urinals		Usage data			
		Water Heater ID # (Unit Number)	Pecentage of electricity consumption for water heater (%)	Pecentage of gas consumption for water heater (%)	Faucet ID # (Fixture Number)	Number of Faucets	Toilet ID # (Fixture Number)	Number of Toilets	Urinal ID # (Fixture Number)	Number of Urinals	Percentage of FTE occupants using room (%)	Peercentage of Students/visitors using room (%)	Percentage of customers using room (%)	Installed/rennovated on (year)
Room 1	Bathroom	1	0.0%	19.7%	1	6	1	6	1	4	100.0%	47.5%	0.0%	1980
		Default for turtle creek N.A.			Electronic facuet N.A.		Electronic 3.5 GPF None		Urinal with 1.6 GPF N.A.					
Room 2	Bathroom	1	0.0%	19.7%	1	6	1	10	0	0	0.0%	47.5%	0.0%	1980
		Default for turtle creek N.A.			Electronic facuet N.A.		Electronic 3.5 GPF None							
Room 3	Bathroom	0	0.0%	0.0%	1	1	1	1	0	0	0.0%	5.0%	0.0%	1981
					Electronic facuet N.A.		Electronic 3.5 GPF None							

Figure 153. Water heaters and water fixtures section in the created building input data tab.

The seventh section of the building input data is “HVAC systems” and includes data on HVAC equipment ID number, number of units, working hours per day, temperature set point in summer, temperature set point in winter, percentage of electricity consumption as of the total building electricity consumption, and percentage of gas consumption as of total building gas consumption. The DST tool can account for up to three HVAC systems per building, as shown in Figure 154. During the optimization process, the DST will assist decision makers in evaluating the feasibility of replacing current HVAC systems with more energy-efficient ones. Energy savings for HVAC systems can be calculated using available energy simulation software such as eQuest. Users of the DST can input HVAC unit ID number to prompt the DST to extract and show the information of it automatically, as shown in Figure 154. The user can also update the existing databases with HVAC equipment by pressing the “Add HVAC Equipment” button and add a new unit, as shown in Figure 154. The gathered data in this section are used in the DST to calculate electricity and gas consumption for HVAC systems in order to analyze and optimize the potential replacement of existing HVAC systems with more energy-efficient ones during the optimization process.

HVAC Systems

Add HVAC Equipment

HVAC Systems	HVAC ID # (Unit Number)	Number of Units	Number of Working Hours	Temperature set point in summer (°F)	Temperature set point in winter (°F)	Percentage of Electricity Consumption out of Total Electricity Consumption (%)	Percentage of Gas Consumption out of Total Gas Consumption (%)
HVAC System # 1	1	1	24	70	68	45.53%	60.61%
	Current HVAC unit	N.A.					
HVAC System # 2	0	0				0.00%	0.00%
HVAC System # 3	0	0				0.00%	0.00%

Figure 154. HVAC system section in the created building input data tab.

The eighth and final section of the building input data “metering systems” contains data on electricity meter ID number, building gas meter ID number, building water meter ID number, and sub-meter ID number for each category of energy consumption, as shown in Figure 155. Users can input a meter or sub-meter ID number to retrieve the stored information of meters/sub-meters automatically, as shown in Figure 155. The user can also update the metering system database by selecting the “Add Meter” or “Add Sub-Meter” button to add a new meter. The gathered data in this section is used to calculate the number of accredited LEED points that can be earned from measuring energy and water consumption in buildings using metering and sub-metering systems. The gathered data can also be used to study the feasibility of implementing metering or sub-metering systems and calculate the number of accredited LEED points and additional costs accordingly during the optimization process.

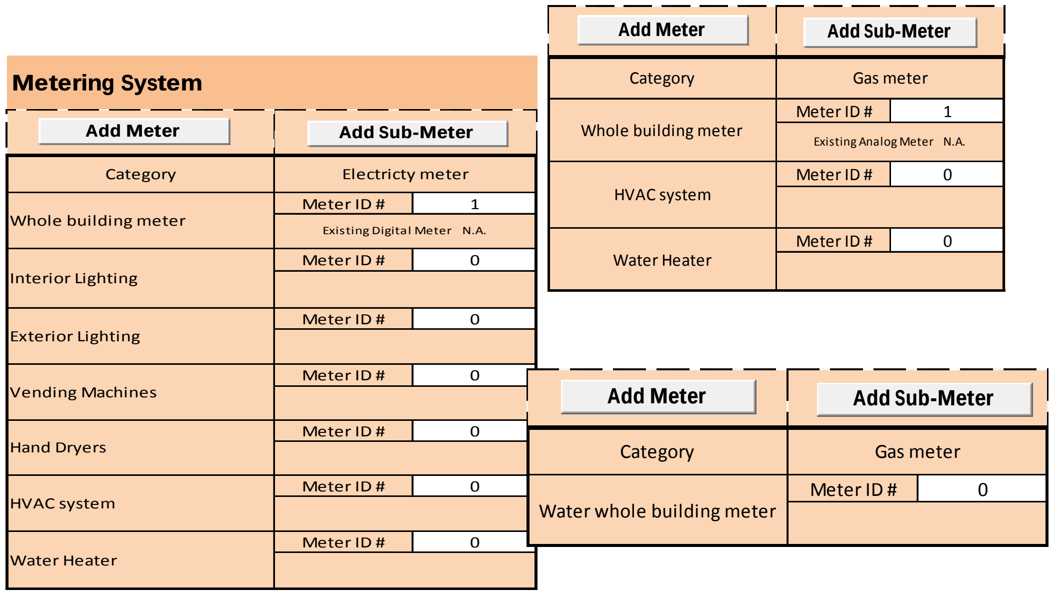

Figure 155. Metering systems section in the created building input data tab.

E.1.12 Action Report for Energy and Water Measures

The DST includes a new tab that is named “action report” that summarizes the output results of its analysis in a clear and concise format. The action report for energy and water measures shows building measures that need to be added or replaced in order to reduce or monitor energy and water consumption in buildings. This action report contains seven sections: (1) interior lighting, (2) exterior lighting, (3) vending machines, motion sensors, and other devices, (4) water heaters, water fixtures, and hand dryers, (5) HVAC systems, (vi) grid-connected photovoltaic systems, and (6) metering and sub-metering systems. Each of these sections provides recommendations for implementing energy and water measures as well as metering and sub-metering systems. The first section of interior lighting shows recommendations for interior lighting fixtures and bulbs per room, as shown in Figure 156. These recommendations identify whether a fixture or the kind of light bulbs needs to be replaced in order to reduce the current building electricity consumption. Similarly, the remaining sections of the action report show recommendations for (1) exterior light bulbs and fixtures (see Figure 157), (2) vending machines, motions sensors, and other devices (see Figure 158); (3) water fixtures, water heaters, hand dryers, and motion sensors (see Figure 159); (4) HVAC systems (see Figure 160); (5) grid-connected photovoltaic system (see Figure 161); and (6) metering and sub-metering systems (see Figure 162).

Interior Lighting

Rooms		Item	Action Needed		
			Set # 1	Set # 2	Set # 3
1	Men's bathrrom 1	Fixture	Keep existing light fixture	Keep existing light fixture	
		Bulb	Keep existing light bulb	Replace existing light bulb [24596 - F34CW/SS/ECO] With [Sylvania ; 22179 (FO28/841/XP/SS/ECO)]	
2	Women's bathroom 1	Fixture	Keep existing light fixture	Keep existing light fixture	
		Bulb	Replace existing light bulb [FB34/CW/6/SS/ECO] With [Sylvania ; FBO28/841/XP/SS/ECO]	Replace existing light bulb [24596 - F34CW/SS/ECO] With [Sylvania ; 22179 (FO28/841/XP/SS/ECO)]	
3	Family bathroom	Fixture	Keep existing light fixture		
		Bulb	Keep existing light bulb		
4	Mechnical room	Fixture	Keep existing light fixture	Keep existing light fixture	
		Bulb	Keep existing light bulb	Keep existing light bulb	
5	Travel information room	Fixture	Keep existing light fixture	Keep existing light fixture	
		Bulb	Keep existing light bulb	Keep existing light bulb	
6	Lobby	Fixture	Keep existing light fixture		
		Bulb	Replace existing light bulb [FB34/CW/6/SS/ECO] With [Sylvania ; FBO28/841/XP/SS/ECO]		
7	Storage 1	Fixture	Keep existing light fixture		
		Bulb	Keep existing light bulb		
8	Storage 2	Fixture	Keep existing light fixture		
		Bulb	Replace existing light bulb [24596 - F34CW/SS/ECO] With [Sylvania ; 22179 (FO28/841/XP/SS/ECO)]		

Figure 156. Action report for interior light bulbs and fixtures per room.

Exterior Lighting

Location		Item	Action Needed	
			Set # 1	Set # 2
1	Building	Fixture	Keep existing light fixture	
		Bulb	Keep existing light bulb	
2	Parking Lot	Fixture	Keep existing light fixture	
		Bulb	Keep existing light bulb	
3	Landscape	Fixture		
		Bulb		

Figure 157. Action report for exterior light bulbs and fixtures.

Vending Machines, Motion Sensors, and Other Devices

	Rooms	Vending Machines - Set # 1	Vending Machines - Set # 2	Vending Machines - Set # 3	Motion Sensors	Other Devices - Set # 1	Other Devices - Set # 2
1	Men's bathrrom 1				install 5 motion sensor [Cooper Lighting ; MS180W]		
2	Women's bathroom 1				install 5 motion sensor [Cooper Lighting ; MS180W]		
3	Family bathroom				install 1 motion sensor [Leviton ; ODC0S-I1W]		
4	Mechnical room				install 4 motion sensor [Cooper Lighting ; MS180W]		
5	Travel information room				install 2 motion sensor [Cooper Lighting ; MS180W]		
6	Lobby	Keep existing machine	Keep existing machine	Keep existing machine			
7	Storage 1				install 1 motion sensor [Cooper Lighting ; MS180W]		
8	Storage 2				install 1 motion sensor [Cooper Lighting ; MS180W]		
9	Storage 3				install 0 motion sensor [Cooper Lighting ; MS180W]		

Figure 158. Action report for vending machines, motion sensors, and other devices.

Water fixtures, water heaters, and hand dryers

	Rooms	Faucets	Toilets	Urinals	Water Heater	Hand Dryers
1	Men's bathrrom 1	Keep existing faucet	Keep existing toilet	Replace existing urinal with [Electronic flush urinal (0.125GPF) ; N.A.]	Keep existing water heater	Replace existing hand dryers with [World Dryer Airforce ; J Series - White]
2	Women's bathroom 1	Keep existing faucet	Replace existing toilet with [Electronic 1.6 GPF ; None]		Keep existing water heater	Replace existing hand dryers with [World Dryer Airforce ; J Series - White]
3	Family bathroom	Keep existing faucet	Keep existing toilet			Replace existing hand dryers with [World Dryer Airforce ; J Series - White]

Figure 159. Action report for water fixtures, water heater, and hand dryers.

HVAC system

	HVAC System # 1	HVAC System # 2	HVAC System # 3
Turtle Creek Rest Area	Replace existing HVAC system with [Gas HVAC system ; N.A.]		

Figure 160. Action report for HVAC system.

System Characteristics	Value
Number of solar panels on roof	22
Number of solar panels on ground	23
Required area for solar panels next to building	0
System capacity	17148
percentage of gnerated electricty as of building electricity consumption	13.94%

Grid Connect Photovoltaic System

Photovoltaic Sysyem Component	Type of comp	
Solar Panel		45
Inverter		2

Figure 161. Action report for grid-connected photovoltaic system.

Metering systems

Category	Electricty meter
Building electricity meter	Keep existing building electricity meter
Interior Lighting	Install electricity sub-meter [EKM-OmniMeter ; V1.3]
Exterior Lighting	
Vending Machines	Install electricity sub-meter [EKM-OmniMeter ; V1.3]
Hand Dryers	
HVAC system	Install electricity sub-meter [EKM-OmniMeter ; V1.3]
Water Heater	Install electricity sub-meter [EKM-OmniMeter ; V1.3]

Category	Gas meter
Building gas meter	
HVAC system	Install gas sub-meter [E-Mon D-Mon ; GDP250 Series]
Water Heater	Install gas sub-meter [E-Mon D-Mon ; GDP250 Series]

Category	Water meter
Water building meter	Install building water meter [E-Mon D-Mon ; E-Mon D-Mon]

Figure 162. Action report for metering and sub-metering systems.

E.2 PERFORMANCE EVALUATION OF DEVELOPED DST

An application example using the Turtle Creek rest area data was developed to (1) illustrate the use of the developed DST; (2) demonstrate its newly upgraded features and unique optimization capabilities; and (3) evaluate its performance and verify the results. The following sections provide a brief description of the Illinois rest area example, specify its input data that are required by the DST, and summarize the findings of this analysis.

E.2.1 Brief Description of the Rest Area Example

Turtle Creek rest area was built in 1980 and it is one of the highly visited rest areas in Illinois with approximately 839 thousand annual visitors based on 2009 statistics and a total square footage of 3575. It comprises of one building that serves the east and west bounds of I-90 at mile marker 2. The rest area building includes lobby, women's restroom, men's restroom, mechanical room, storage room, travel information desk, and technician office, see Figure 74. The rest area building has also a parking lot for visitors that accommodate cars and semi-trucks, and a large landscaped area and outdoor picnic seats.

The components of energy consumption in the Turtle Creek rest area include exterior lighting, interior lighting, space heating, air conditioning, water heating, vending machines, surveillance cameras, "Code Blue" emergency phones, weather information, hand dryers, and water coolers. The exterior lighting includes lighting poles for the parking lot of the rest area, and outdoor lighting fixtures for the rest area entrance. The interior lighting includes lighting fixtures for the lobby, men's restroom, women's restroom, mechanical room, and maintenance office. The Turtle Creek rest area building is heated and air-conditioned using two furnaces, two air-cooled condensing units, and an exhaust fan. A natural gas water heater (State water heater) is used in the rest area building to heat water with a capacity of 100 gallons. The rest area building has six vending machines for snacks, cold and hot drinks. Surveillance cameras and Code Blue units are used to maintain safety for visitors of the rest area. The weather information is provided using a television in the rest area lobby. The water consumption components of this rest area building include faucets, urinals, toilets, and drinking water.

Figure 163. Turtle Creek rest area.

E.2.2 Modeling of the Rest Area Example

In order to optimize the upgrade decisions for Turtle Creek rest area building, the upgrade cost of prerequisites and LEED credits as well as its associated LEED points need to be identified. This requires the decision maker to input the following data: (1) general input parameters, historical data of energy use, and existing energy and water consuming devices; (2) upgrade costs for satisfying the prerequisites of the LEED-EB rating system divisions; and (3) identifying the LEED-EB credits that are applicable to the building and their upgrade costs credit and associated LEED points. Due to the unavailability of some of this data, reasonable assumptions were made to estimate the upgrade costs for LEED-EB credits.

The LEED-EB rating system consists of seven divisions including: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Material and Resources (MR), Indoor Environmental Quality (IEQ), Innovation in Operation (IO), and Regional Priority (RP). These seven divisions require nine prerequisites and can be used to earn up to 50 credits. The required general input parameters, historical energy use, energy and water measures data for the Turtle Creek rest area building are specified and shown previously in Figure 148 to Figure 155.

The LEED-EB prerequisites and their upgrade costs for the Turtle Creek rest area building are specified and listed in Table 193. The remaining input data for the optional LEED points including their upgrade costs for the six main LEED divisions: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Material and Resources (MR), Indoor Environmental Quality (IEQ), and Innovation in Operation (IO) are specified and listed in Table 194, Table 195, Table 196, Table 197, Table 198, and Table 199, respectively. The potential credits of the Regional Priority division are automatically calculated by the developed DST based on the zip code of the building. The maximum number of LEED credit points that can be earned by the Turtle Creek rest area is 61 points.

Table 193. Modeling LEED-EB Prerequisites in the DST for Turtle Creek Rest Area

Division	Prerequisite
WE	**P1: Minimum Indoor Plumbing Fixture and Fitting Efficiency**
	The developed DST will account for the minimum water consumption through the defined baseline consumption. The developed tool will select the suitable water conservation measures to achieve the baseline set by the LEED-EB rating system.
E&A	**P1: Energy-Efficiency Best Management Practices—Planning, Documentation, and Opportunity Assessment**
	The tool assumes that the project team will develop a building operating plan that provides details on how the building is being operated and maintained, systems narrative of mechanical and electrical systems and equipment used in the building, and narrative of the preventive maintenance plan for equipment described in the systems narrative and documenting the preventive maintenance schedule during the performance period. The project team will also conduct an energy audit analysis to evaluate the performance of the rest area facility. Another energy audit will be required to measure the performance of the facility after accounting for energy-efficiency measures of the DST. No upgrade cost needed for this credit.
	P2: Minimum Energy-Efficiency Performance
	The developed DST will satisfy energy-efficiency at least 19% better than the average for typical buildings of similar type by benchmarking against national average source energy for similar buildings
	P3: Fundamental Refrigerant Management
	No CFC refrigerants detected or being used in the building.
MR	**P1: Sustainable Purchasing Policy**
	The project team will develop an Environmentally Preferable Purchasing (EPP) policy that includes product purchasing policies for the building and site addressing the requirements of the first credit of this division. Also, the developed DST is constrained to achieve at least one credit of MRc2 through MRc4 as indicted in this required credit.
	P2: Solid Waste Management Policy
	The project team will develop a solid waste management policy for the building and site addressing the requirements of the waste management credits MRc7 to MRc9 as well as recycling of all mercury-containing lamps. This credit requires only policies, not ongoing actual sustainable performance. No upgrade cost will be needed for this credit.
IQ	**P1: Minimum Indoor Air Quality Performance**
	The project team will Modify/maintain the current ventilation distribution system to supply at least the outdoor air ventilation rate required by ASHRAE Standards under all normal operating conditions.
	P2: Environmental Tobacco Smoke (ETS) Control
	Project team will provide signs to prohibit smoking inside rest area building as well as prohibiting smoking within 25 feet of entries to satisfy the requirements of this credit.
	P3: Green Cleaning Policy
	The project team will develop a green cleaning policy for the building and site addressing the requirements of the LEED-EB rating system for green cleaning policy. The cost for satisfy this credit varies significantly, however a rough estimate of $950 was created to be used in the model.

Table 194. Considered Credits of Sustainable Site Division in the DST and Associated Upgrade Costs

Credit	Cost ($)	Accredited Points
Building Exterior and Hardscape Management Plan		
Alternative 1: The LEED accredited professionals of IDOT will develop a plan for practices that reduce harmful chemical use, energy waste, water waste, air pollution, solid waste, and/or chemical runoff during the performance period of the rest area. IDOT has LEED accredited professionals who can help in developing this plan. No upgrade cost needed for this credit.	0	1
Integrated Pest Management, Erosion Control, and Landscape Management Plan		
Alternative 1: The LEED accredited professionals of IDOT will develop a low-impact site and green building exterior management plan that addresses overall site management, chemicals, fertilizers, landscape waste and pest management. This plan will include using of least toxic chemical pesticides, minimum use of the chemicals, and using only in targeted locations and targeted species. IDOT has LEED accredited professionals who can help in developing this plan. No upgrade cost needed for this credit.	0	1
Site Development-Protect or Restore Open Habitat		
Alternative 1: The current landscape and vegetation covers more than 25% of the site area as indicated in the LEED-EB rating system. No additional cost needed to account for this credit	0	1
Storm-water Quantity Control		
Alternative 1: The project team will implement a storm-water management plan that infiltrates, collects and reuses runoff. Turtle Creek rest area will account for rainwater catchments for water reuse and rain gardens for water infiltration. The cost for installing rainwater catchment varies significantly; however, a rough estimate of $50,000 was created to be used in the model.	50,000	1
Heat Island Reduction-Non-roof		
Alternative 1: Using permeable pavement to cover 50% of pavement area, the cost for installing permeable pavement can vary significantly however an estimate of $110,000 was used in the model.	110,000	1
Heat Island Reduction-Roof		
Alternative 1: The current roof of Turtle Creek rest area will need to be replaced with a new roof material; a rough estimate of $11,500 was calculated and used in the model.	11,500	1
Alternative 1: Installing Solar panels on the roof of the rest area building that cover more than 75% of the roof area (this alternative is considered only if the PV of renewable energy measure that is installed on roof is considered)	0	1

Table 195. Considered Credits of Water-Efficiency Division in the DST and Associated Upgrade Costs

Credit	Cost ($)	Accredited Points
Water Performance Measurement		
This credit will be investigated through the upgraded DST, the tool will use the available meters in the database for metering systems and calculate the accredited LEED points accordingly.	Varied	Up to 2 points
Additional Indoor Plumbing Fixture and Fitting Efficiency - conservative faucets		
This credit will be investigated through the upgraded DST; the tool will use the available water fixtures in the database to reduce the building water consumption and calculate the accredited LEED points accordingly. The cost for water fixture replacement will be calculated in the tool automatically from the database.	Varied	Up to 5
Water-Efficient Landscaping		
Rainwater is used for the current irrigation system in the Turtle Creek rest area, which achieves100% savings in water irrigation.	0	5

Table 196. Considered Credits of Energy and Atmosphere Division in the DST and Associated Upgrade Costs

Credit	Cost ($)	Accredited Points
C1-Optimize Energy-Efficiency Performance		
This credit will be investigated through the upgraded DST; the tool will use the available energy measures in the database to reduce the building energy consumption and calculate the accredited LEED points accordingly. The cost for the implementation/replacement of energy measures will be calculated in the tool automatically from the database.	Varied	Up to 18 points
C2.1-Existing Building Commissioning-Investigation and Analysis		
Alternative 1: The developed energy audit that was prepared in the previous tasks for Turtle Creek rest area shows the energy consumption distribution, major contributors of energy consumption, and measures that can provide annual savings, and improve comfort. No additional cost needed to achieve this credit.	0	2
Existing Building Commissioning-Implementation		
Alternative 1: The decision makers of IDOT will implement the no or low-cost operational improvements based on the conducted analysis of this study. These no or low-cost operation improvements will end up with low upgrade cost that can be paid back within 1~2 years. By the time for admission for a LEED certificate, these initial costs should be paid back. The major retrofits or upgrades for energy performance are considered in the first credit of this division.	0	2
Performance Measurement-System Level Metering		
This credit will be investigated through the upgraded DST, the tool will use the available meters in the database for metering systems and calculate the accredited LEED points accordingly.	Varied	Up to 2 points
C4-On-site and Off-site Renewable Energy		
This credit will be investigated through the upgraded DST; the tool will use the available grid-connected photovoltaic system components in the database to reduce the building energy consumption and generate on-site renewable energy. The DST will calculate the accredit LEED points automatically based on the percentage of renewable energy as of total building electricity consumption. The additional costs for this credit will be calculated based on the selected components from the database and the considered assumptions in the system design for labor and miscellaneous parts costs.	Varied	Up to 6 points
Emissions Reduction Reporting		
Alternative 1: The LEED APs of IDOT will identify and quantify the reduction in energy consumption and emissions based on the results of this DST and carbon footprint analysis develop in the previous reports.	0	1

Table 197. Considered Credits of Material and Resources Division in the DST and Associated Upgrade Costs

Credit	Cost ($)	Accredited Points
Sustainable Purchasing-Ongoing Consumables		
Alternative 1: The project team will account for sustainable purchases for paper, binders, and disk accessories. Also, the project team will account for rechargeable batteries for devices used in the rest area. These sustainability purchases will have slightly higher annual cost however there is no upgrade cost for achieving this item.	0	1
Sustainable Purchasing-Durable Goods		
Alternative 1: Installing three Energy Star vending machines for cold drinks.	10,200	1
Alternative 2: Replacing two snacks vending machines with Energy Star units.	7,100	1
Sustainable Purchasing-Food		
Alternative 1: The project team will account for 25% sustainable food purchases according to the LEED-EB rating system. No additional cost required for this credit.	0	1
Solid Waste Management-Facility Alterations and Additions		
Alternative 1: The project team will Divert 70% of waste (by volume) generated by facility during facility renovations, demolitions, and refits from disposal to landfills and incineration facilities. No upgrade cost needed for this credit however renovation or demolishing costs might increase.	0	1

Table 198. Considered Credits of Indoor Air Quality Division
in the DST and Associated Upgrade Costs

Credit	Cost ($)	Accredited Points
Indoor Air Quality Best Management Practices-Outdoor Air Delivery Monitoring		
Alternative 1: Continuous monitoring systems will be installed to provide feedback on ventilation system performance to ensure minimum outdoor airflow rates under all operating conditions. Also, airflow measuring device will be installed to maintain the minimum outdoor airflow rate. An estimate of $7,300 was used in the model.	7,300	1
Indoor Air Quality Best Management Practice-Increased Ventilation		
Alternative 1: Increasing ventilation of the rest area facility and installing heat recovery air exchanger to reduce energy consumption for ventilation. An estimate of $1,400 was used in the model.	1,400	1
Indoor Air Quality Best Management Practices-Reduce Particulates in Air Distribution		
Alternative 1: Installing filtration media with efficiency reporting value (MERV) of 13 for outside air intakes and inside air recirculation returns of the HVAC system in the rest area facility. An estimate of $90 was used in the model.	$90	1
Controllability of Systems-Lighting		
Alternative 1: Installing controllable task lighting for the IDOT maintenance staff that is working in the rest area facility. An estimate of $200 was used in the model.	200	1
Green Cleaning-High Performance Cleaning Program		
Alternative 1: The project team will account for high performance cleaning program according to the requirements of the LEED-EB rating system. These requirements will increase the annual cleaning cost however no upgrade cost needed for accounting for this credit.	0	1
Green Cleaning-Purchase of Sustainable Cleaning Products and Materials		
The project team will account for cleaning-purchase of sustainable cleaning products and materials. These purchases will increase the annual cleaning cost slightly however, no upgrade cost needed for acquiring this credit.	0	1
Green Cleaning-Sustainable Cleaning Equipment		
The project team will account for sustainable cleaning equipment; Turtle Creek rest area has limited cleaning equipment, which leads to a low upgrade cost for existing equipment. An estimate of $1,600 was used in the model.	1,600	1
Green Cleaning-Indoor Chemical and Pollutant Source Control		
Alternative 1: The project team will employ permanent entryway systems to capture dirt and particulates entering the building at all public entry points. An estimate of $1,100 was used in the model.	1,100	1
Green Cleaning-Indoor Integrated Pest Management		
Alternative 1: The project team will implement and maintain an indoor integrated pest management (IPM) plan based on the requirements of LEED-EB rating system. This pest management plan will increase the annual cost of pest control however there is no upgrade cost required for this credit.	0	1

Table 199. Considered Credits of Innovation in Operation Division in the DST and Associated Upgrade Costs

Credit	Cost ($)	Accredited Points
LEED Accredited Professional		
The project team will consider at least one of their IDOT LEED accredited professionals in this project. No additional cost required for this credit.	0	1
Documenting Sustainable Building Cost Impacts		
The project team will document the additional cost needed to achieve a LEED certificate for Turtle Creek rest area building. No additional cost required for this credit.	0	1

E.2.3 Analysis Results

The developed DST was used to analyze the aforementioned input data to explore and optimize the upgrade decisions for Turtle Creek rest area. Two types of optimization analyses were conducted to illustrate the capabilities of the DST in optimizing the aforementioned two practical objectives of: (1) minimizing the total upgrade costs that are required to accomplish a specified LEED certification level including Certified, Silver and Gold levels; and (2) maximizing the number of accredited LEED points that can be earned under a specified limited upgrade cost.

The results of the first optimization analysis indicate that the minimum upgrade cost to achieve 60 points (i.e., Gold LEED-EB level) was estimated by the DST to be $154,961. The DST also provides a detailed description of the optimal solution that produced this optimal result, including the identified optimal upgrade measures, as well as their upgrade costs and accredited points. Figure 164 and Figure 165 show a sample of the output results of the DST for optimizing upgrade decisions of the Turtle Creek rest area building. The action report of energy and water decisions for achieving a Gold LEED level is previously shown in Figure 156 through Figure 162. The DST was then used to identify another set of optimal upgrade decisions that can achieve Certified and Silver LEED-EB levels. The DST estimated that the minimum upgrade cost to achieve Certified and Silver levels was $34,184, and $58,486 respectively. The DST was not able to provide a feasible solution for the platinum LEED-EB level since the maximum number of LEED credits that can be earned by this building is 61 points due to the inapplicability of some credit areas for the rest area building such as “Alternative Commuting Transportation”. This credit area is not applicable for Turtle Creek rest area building and can achieve up to 15 points.

The second optimization analysis focused on maximizing the number of accredited LEED points that can be earned under a specified limited budget for upgrade costs. This analysis used varying scenarios of budget limits that range from $20,000 to $360,000 and the DST was able to identify the maximum number of LEED points that can be achieved under each of these budget limits as, shown in Table 200 and Figure 166. The DST searches a huge number of solutions to reach the maximum number of LEED points within a specified budget.

Table 200. Accredited LEED Points Associated with Each Solution for Maximizing LEED Points within a Certain Budget for Turtle Creek Rest Area

Budget Cost for Upgrade ($)	Actual Budget ($)	Maximum LEED Points
20,000	19,326	15
40,000	39,284	42
60,000	58,486	50
80,000	79,187	55
100,000	89,094	57
120,000	103,968	58
180,000	155,239	60
240,000	155,239	60
300,000	265,207	61
360,000	265,239	61

Total Achieved Credits		**60 Points**			
Total Cost of Achieved Credits		**$154,961**			
#	**LEED Divisions and Items**	**Alternative**	**Action**	**Initial Cost ($)**	**Credits**
Prerequisites					
1	Water Efficiency prerequisite	None		$0.0	N/A
2	Energy and Atmosphere prerequisites	None		$0.0	N/A
3	Materials and Resources prerequisites	None		$0.0	N/A
4	Indoor Environemntal Quality prerequisites	None		$850.0	N/A
Sustainable Sites (SS)					
1	LEED Certified Design and Construction	None		$0.0	0
2	Building Exterior and Hardscape Management Plan	1	X	$0.0	1
3	Integrated Pest Management, Erosion Control, and Landscape Management Plan	1	X	$0.0	1
4	Alternative Commuting Transportation	None		$0.0	0
5	Site Development-Protect or Restore Open Habitat	1	X	$0.0	1
6	Stormwater Quantity Control	1	X	$50,000.0	1
7.1	Heat Island Reduction-Nonroof	None		$0.0	0
7.2	Heat Island Reduction-Roof	4	X	$0.0	1
8	Light Pollution Reduction	None		$0.0	0
Water Efficiency (WE)					
1	Water Performance Measurement	1	X	$600.0	1
2	Additional Indoor Plumbing Fixture and Fitting Efficiency	Various	X	$9,202.0	5
3	Water Efficient Landscaping	1	X	$0.0	5
	a) Additional outdoor water savings - measure # 1	None		$0.0	N/A
	b) Additional outdoor water savings - measure # 2	None		$0.0	N/A
	c) Additional outdoor water savings - measure # 3	None		$0.0	N/A
	d) Additional outdoor water savings - measure # 4	None		$0.0	N/A
4	Cooling Tower Water Management	None		0	0
Energy and Atmosphere (EA)					
1	Optimize Energy Efficiency Performance	Various	X	$29,413.6	14
2.1	Existing Building Commissioning-Investigation and Analysis	1	X	$0.0	2
2.2	Existing Building Commissioning-Implementation	1	X	$0.0	2
2.3	Existing Building Commissioning-Ongoing Commissioning	None		$0.0	0
3.1	Performance Measurement-Building Automation System	None		$0.0	0
3.2	Performance Measurement-System Level Metering	1	X	$2,380.0	1
4	On-site and Off-site Renewable Energy	PV	X	$47,924.9	6
	a) Off-site renewable enery	None		$0.0	N/A
5	Enhanced Refrigerant Management	None		$0.0	0
6	Emissions Reduction Reporting	1	X	$0.0	1

Figure 164. Results of the DST for minimizing upgrade costs for achieving Gold level in the LEED-EB rating system—SS, WE, EA, MR divisions.

Materials and Resources (MR)					
1	Sustainable Purchasing-Ongoing Consumables	1	X	$0.0	1
2	Sustainable Purchasing-Durable Goods	1	X	$10,200.0	1
3	Sustainable Purchasing-Facility Alterations and Additions	None		$0.0	0
4	Sustainable Purchasing-Reduced Mercury in Lamps	None		$0.0	0
5	Sustainable Purchasing-Food	1	X	$0.0	1
6	Solid Waste Management-Waste Stream Audit	None		$0.0	0
7	Solid Waste Management-Ongoing Consumables	None		$0.0	0
8	Solid Waste Management-Durable Goods	None		$0.0	0
9	Solid Waste Management-Facility Alterations and Additions	1	X	$0.0	1
Indoor Environmental Quality (IEQ)					
1.1	Indoor Air Quality Best Management Practices-Indoor Air Quality Management Program	None		$0.0	0
1.2	Indoor Air Quality Best Management Practices-Outdoor Air Delivery Monitoring	None		$0.0	0
1.3	Indoor Air Quality Best Management Practice-Increased Ventilation	1	X	$1,400.0	1
1.4	Indoor Air Quality Best Management Practices-Reduce Particulates in Air Distribution	1	X	$90.0	1
1.5	Indoor Air Quality Best Management Practices-Indoor Air Quality Management for Facility Alterations and Additions	None		$0.0	0
2.1	Occupant Comfort-Occupant Survey	None		$0.0	0
2.2	Controllability of Systems-Lighting	1	X	$200.0	1
2.3	Occupant Comfort-Thermal Comfort Monitoring	None		$0.0	0
2.4	Daylight and Views	None		$0.0	0
3.1	Green Cleaning-High Performance Cleaning Program	1	X	$0.0	1
3.2	Green Cleaning-Custodial Effectiveness Assessment	None		$0.0	0
3.3	Green Cleaning-Purchase of Sustainable Cleaning Products and Materials	1	X	$0.0	1
3.4	Green Cleaning-Sustainable Cleaning Equipment	1	X	$1,600.0	1
3.5	Green Cleaning-Indoor Chemical and Pollutant Source Control	1	X	$1,100.0	1
3.6	Green Cleaning-Indoor Integrated Pest Management	1	X	$0.0	1
Innovation in Operations (IO)					
1	Innovation in Operations	N/A		$0.0	0
	a) Innovation in operation	None		$0.0	0
	b) Exemplary performance	None		$0.0	0
	c) Pilot credit	None		$0.0	0
2	LEED Accredited Professional	1	X	$0.0	1
3	Documenting Sustainable Building Cost Impacts	1	X	$0.0	1
Regional Priority (RP)					
1	Regional Priority				
	a) Regional credit # 1	SSc2	X	N/A	1
	b) Regional credit # 2	SSc4(25%)		N/A	0
	c) Regional credit # 3	WEc3(100%)	X	N/A	1
	d) Regional credit # 4	MRc6		N/A	0
	e) Regional credit # 5	IEQc1.3	X	N/A	1
	f) Regional credit # 6	IEQc1.4	X	N/A	1

Figure 165. Results of the DST for minimizing upgrade costs for achieving Gold level in the LEED-EB rating system IQ, IO, and RP divisions.

Figure 166. Accredited LEED points associated with each solution and obtained LEED certificate for maximizing LEED point within a specified budget—Turtle Creek rest area.

APPENDIX F RECOMMENDATIONS FOR SELECTED REST AREAS

F.1 CUMBERLAND ROAD REST AREA

The Cumberland Road rest area was analyzed to investigate the feasibility of implementing various green building measures to reduce its energy and water consumption as well as environmental impacts. This study of green building measures accounted for energy-efficient lighting such as energy-efficient fluorescent bulbs, LED, and induction lighting; energy-efficient HVAC systems such as geothermal heat pumps and high-efficiency air-source heat pumps; motion sensors for interior lighting, vending machines, and exhaust fans; energy-efficient hand dryers; solar practices such as solar daylight tubes, grid-connected photovoltaic systems, and solar water heaters; vestibule entrances, thermal pane glass for door and windows, and water-efficient faucets, toilets, and urinals. The results of this analysis provide a list of promising Best Management Practices (BMPs) for Cumberland Road rest area that includes: fluorescent T8 bulbs for interior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 6.8KW capacity, setting back HVAC at night, and water-conserving fixtures. The recommendations of implementing this list of BMPs are listed in Table 201 and Table 202. The implementation of this list of BMPs can reduce the energy consumption of the rest area building up to 35%.

Table 201. Recommendations for Interior and Exterior Lighting in Cumberland Road Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Interior lighting	Replace existing T12 lamps with energy-efficient T8 bulbs (28W and 25W) while maintaining the same lumens output levels as discussed previously in Appendix D. This light replacement will reduce electricity consumption for interior lighting.	$793.5	1.8%	Immediate payback period
Motion sensors	Install motion sensors for lighting in the men's and women's restrooms. These motion sensors will reduce electricity consumption of interior lighting.	$871	1.4%	2.7
Solar daylight tubes	Study the feasibility of installing solar daylight tubes in the restrooms and lobby to provide lighting during the daytime. This can provide savings in electricity consumption; however, it can cause dissipation of energy for space heating and cooling, which leads to a long payback period. A detailed analysis of this potential replacement was discussed previously in Appendix D.	$7,735	1.5%	17.9

Table 202. Recommendations for Vending Machines, Exhaust Fans, Hand Dryers, HVAC System, Water Heater, PV System, and Water Fixtures in Cumberland Road Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Vending area	Install motion sensors for lighting in the vending area and lighting of vending machines. These sensors will reduce electricity consumption of lighting in the vending area and vending machines.	$339	1.5%	1.0
Exhaust fans	Install motion sensors for exhaust fans in the men's and women's restrooms. These motion sensors will allow exhaust fans to operate only when the restrooms are occupied, which will reduce the unnecessary dissipation of energy for space heating and cooling when the restrooms are unoccupied.	$542	4.1%	0.6
Hand dryers	Replace existing hand dryers in the women's and men's restrooms with more energy-efficient units such as Blast hand dryers.	$1,092	2.2%	2.2
HVAC system	Consider the feasibility of replacing the existing HVAC system with geothermal heat pump. The rest area building is used 24/7, and accordingly it can benefit from the use of energy-efficient HVAC system such as geothermal heat pump to reduce the energy consumption for space heating and cooling.	$31,570	11.7%	9.5
Water heater	Install desuperheater along with the geothermal heat pump to provide hot water during the summer and to reduce the energy consumption of water heaters.	$1,600	3.2%	2.3
HVAC settings	Adjust the settings of the HVAC thermostat to allow the HVAC system to set back at night during the low visitation periods.	$200	2.3%	0.4
Water fixtures	Replace existing water fixtures (toilets and urinals) with water-efficient units. A detailed analysis of this potential replacement is provided in Appendix D.	$6,963	N.A.	N.A.
PV system	Investigate the feasibility of installing grid-connected photovoltaic system with a capacity of 6.8KW to generate 5% of total electricity consumed at the rest area site. It should be noted that PV systems can generate renewable electricity on-site for the rest area; however, the payback period for this system is relatively long.	$29,191	5.0%	25.9
Code Blue emergency phone	Consider the possibility of replacing existing bulbs in the Code Blue emergency phones with LED lights to reduce electricity consumption while considering the impact of this replacement on their visibility at night.	$500	%1.8	1.25
All measures	**All the above energy measures were modeled in the energy simulation software to consider all interactions among the measures and to estimate the overall reduction in energy consumption.**	**$81,397**	**35%**	**9.4**

The research team also developed a practical decision support tool (DST) that can be used to optimize the upgrade decisions for Illinois public buildings with two primary objectives (1) minimize the total upgrade cost to accomplish a desired level of LEED-EB certification; and (2) maximize the number of accredited LEED-EB points for a specified budget. IDOT decision

makers can use the developed decision support tool (DST) in this research study to investigate the potential for achieving a specified LEED certification level (e.g. silver or gold) with the lowest possible upgrade cost or earning the maximum number of LEED credit points within a specified budget.

F.2 TURTLE CREEK REST AREA

The Turtle Creek rest area was analyzed to investigate the feasibility of implementing various green building measures to reduce its energy and water consumption as well as to reduce its environmental impacts. This study of green building measures accounted for energy-efficient lighting such as energy-efficient fluorescent bulbs, LED, and induction lighting; energy-efficient HVAC systems such as geothermal heat pumps and high-efficiency air-source heat pumps; motion sensors for interior lighting, vending machines, and exhaust fans; energy-efficient hand dryers; solar practices such as solar daylight tubes, grid-connected photovoltaic systems, and solar water heaters; vestibule entrances, thermal pane glass for door and windows, and water-efficient faucets, toilets, and urinals. The results of this analysis provide a list of promising Best Management Practices (BMPs) for Turtle Creek rest area that includes: fluorescent T8 bulbs for interior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 8.2KW capacity, setting back HVAC at night, and water-conserving fixtures. The recommendations of implementing this list of BMPs are listed in Table 203 and Table 204. The implementation of this list of BMPs can reduce the energy consumption of the rest area building up to 47%.

Table 203. Recommendations for Interior and Exterior Lighting in Turtle Creek Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Interior lighting	Replace existing linear and U-shaped fluorescent T12 lamps with reduced wattage T8 (28W, 25W, and 17W) as discussed previously in Appendix D. This light replacement will reduce electricity consumption of interior lighting.	$1,637	2.6%	1.8
Motion sensors	Install motion sensors for lighting in the men's and women's restrooms. These motion sensors will reduce the electricity consumption of interior lighting.	$1,556	3.3%	2.0
Solar daylight tubes	Study the feasibility of installing solar daylight tubes in the restrooms and lobby to provide lighting during the daytime. This can provide savings in electricity consumption; however, it can cause dissipation of energy for space heating and cooling, which leads to a long payback period. A detailed analysis of this potential replacement was discussed previously in Appendix D.	$6,508	1.4%	13.4

Table 204. Recommendations for Vending Machines, Exhaust Fans, Hand Dryers, HVAC System, Water Heater, PV System, and Water Fixtures in Turtle Creek Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Vending area	Install motion sensors for lighting in the vending area and lighting of vending machines, these sensors will reduce electricity consumption of lighting the vending area and vending machines.	$339	1.1%	1.2
Exhaust fans	Install motion sensors for exhaust fans in the men's and women's restrooms, these motion sensors will allow the exhaust fans to operate only when the restrooms are occupied, this will reduce the unnecessary dissipation of energy for space heating and cooling when the restrooms are unoccupied.	$1,303	9.3%	0.6
Hand dryers	Replace existing hand dryers in women's and men's restrooms with more energy-efficient units such as Blast hand dryers	$2,184	2.7%	3.3
HVAC system	Consider the feasibility of replacing the existing HVAC system with geothermal heat pump. The rest area building is used 24/7, and accordingly it can benefit from the use of energy-efficient HVAC system such as geothermal heat pump to reduce the energy consumption for space heating and cooling.	$62,320	26.0%	5.5
Water heater	Install desuperheater along with the geothermal heat pump to provide hot water during the summer and to reduce the energy consumption of water heaters.	$1,600	1.2%	5.1
HVAC settings	Adjust the settings of the HVAC thermostat to allow the HVAC system to set back at night during the low visitation periods.	$0	0.4%	Immediat e payback
Water fixtures	Replace existing water fixtures (toilets and urinals) with water-efficient units. A detailed analysis of this potential replacement is provided in Appendix D.	$13,927	0.6%	N.A.
PV system	Investigate the feasibility of installing grid-connected photovoltaic system with a capacity of 8.2KW to generate 6% of total electricity consumed at the rest area site. It should be noted that PV systems can generate renewable electricity on-site for the rest area; however, the payback period for this system is relatively long.	$33,900	5.3%	26.6
Code Blue emergency phone	Consider the possibility of replacing existing bulbs in the Code Blue emergency phones with LED lights to reduce electricity consumption while considering the impact of this replacement on their visibility at night.	400	1.3%	1.32
All measures	**All the above energy measures were modeled in the energy simulation software to consider all interactions among the measures and to estimate the overall reduction in energy consumption.**	**$125,674**	**47%**	**9.9**

The research team also developed a practical decision support tool (DST) that can be used to optimize the upgrade decisions for Illinois public buildings with two primary objectives (1) minimize the total upgrade cost to accomplish a desired level of LEED-EB certification; and (2) maximize the number of accredited LEED-EB points for a specified budget. IDOT decision

makers can use the developed decision support tool (DST) in this research study to investigate the potential for achieving a specified LEED certification level (e.g. silver or gold) with the lowest possible upgrade cost or earning the maximum number of LEED credit points within a specified budget.

F.3 GREAT SAUK TRIAL REST AREA

The Great Sauk Trail rest area was analyzed to investigate the feasibility of implementing various green building measures to reduce its energy and water consumption as well as to reduce its environmental impacts. This study of green building measures accounted for energy-efficient lighting such as energy-efficient fluorescent bulbs, LED, and induction lighting; energy-efficient HVAC systems such as geothermal heat pumps and high-efficiency air-source heat pumps; motion sensors for interior lighting, vending machines, and exhaust fans; energy-efficient hand dryers; solar practices such as solar daylight tubes, grid-connected photovoltaic systems, and solar water heaters; vestibule entrances, thermal pane glass for door and windows, and water-efficient faucets, toilets, and urinals. The results of this analysis provide a list of promising Best Management Practices (BMPs) for Great Sauk Trail rest area that includes: fluorescent T8 and CFL bulbs for interior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, vestibule entrance, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 7.8KW capacity, setting back HVAC at night, and water-conserving fixtures. Great Sauk Trail rest area consists of two identical buildings to serve the east and west sides of I-80. The recommendations of implementing this list of BMPs are listed in Table 205 and Table 206. This list of recommendations can be implemented for each bound of the rest area buildings. The implementation of this list of BMPs can reduce the total energy consumption of the rest area building up to 39.3%.

Table 205. Recommendations for Interior and Exterior Lighting in Great Sauk Trail Rest Area Buildings

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Interior lighting	Replace existing linear fluorescent T12 and halogen flood lighting lamps with reduced wattage T8 (58W and 28W) and CFL (18W) bulbs respectively as discussed previously in Appendix D. This light replacement will reduce electricity consumption for interior lighting.	$1,632	3.5%	0.5
Motion sensors	Install motion sensors for lighting in the men’s and women’s restrooms. These motion sensors will reduce the electricity consumption of interior lighting.	$1,242	2.2%	1.8
Solar daylight tubes	Study the feasibility of installing solar daylight tubes in the restrooms and lobby to provide lighting during the daytime. This can provide savings in electricity consumption; however, it can cause dissipation of energy for space heating and cooling, which leads to a long payback period. A detailed analysis of this potential replacement was discussed previously in Appendix D.	$4,886	1.0%	12.2

Table 206. Recommendations for Vending Machines, Exhaust Fans, Hand Dryers, HVAC System, Water Heater, PV System, and Water Fixtures in Great Sauk Trail Rest Area Buildings

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Vending area	Install motion sensors for lighting in the vending area and lighting of vending machines, these sensors will reduce electricity consumption of lighting the vending area and vending machines.	$339	1.3%	0.8
Exhaust fans	Install motion sensors for exhaust fans in the men's and women's restrooms, these motion sensors will allow the exhaust fans to operate only when the restrooms are occupied, this will reduce the unnecessary dissipation of energy for space heating and cooling when the restrooms are unoccupied.	$844	3.4%	0.8
Hand dryers	Replace existing hand dryers in women's and men's restrooms with more energy-efficient units such as Blast hand dryers	$1,911	1.5%	3.9
HVAC system	Consider the feasibility of replacing the existing HVAC system with geothermal heat pump. The rest area building is used 24/7, and accordingly it can benefit from the use of energy-efficient HVAC system such as geothermal heat pump to reduce the energy consumption for space heating and cooling.	$62,320	22.0%	7.5
Water heater	Install desuperheater along with the geothermal heat pump to provide hot water during the summer and to reduce the energy consumption of water heaters.	$1,600	1.7%	2.9
HVAC settings	Adjust the settings of the HVAC thermostat to allow the HVAC system to set back at night during the low visitation periods.	$0	0.4%	Immediate payback
Water fixtures	Replace existing water fixtures (toilets and urinals) with water-efficient units. A detailed analysis of this potential replacement is provided in Appendix D.	$6,963	0.3% of electricity	N.A.
PV system	Investigate the feasibility of installing grid-connected photovoltaic system with a capacity of 7.8KW to generate 5% of total electricity consumed at the rest area site. It should be noted that PV systems can generate renewable electricity on-site for the rest area; however, the payback period for this system is relatively long.	$36,590	5.0%	20.8
Code Blue emergency phone	Consider the possibility of replacing existing bulbs in the Code Blue emergency phones with LED lights to reduce electricity consumption while considering the impact of this replacement on their visibility at night.	$400	1.2%	1.1
All measures	**All the above energy measures were modeled in the energy simulation software to consider all interactions among the measures and to estimate the overall reduction in energy consumption.**	**$118,727**	**39.3%**	**8.5**

The research team also developed a practical decision support tool (DST) that can be used to optimize the upgrade decisions for Illinois public buildings with two primary objectives (1) minimize the total upgrade cost to accomplish a desired level of LEED-EB certification; and (2) maximize the number of accredited LEED-EB points for a specified budget. IDOT decision

makers can use the developed decision support tool (DST) in this research study to investigate the potential for achieving a specified LEED certification level (e.g. silver or gold) with the lowest possible upgrade cost or earning the maximum number of LEED credit points within a specified budget.

F.4 WILLOW CREEK REST AREA

Willow Creek rest area was analyzed to investigate the feasibility of implementing various green building measures to reduce its energy and water consumption as well as to reduce its environmental impacts. This study of green building measures accounted for energy-efficient lighting such as energy-efficient fluorescent bulbs, LED, and induction lighting; energy-efficient HVAC systems such as geothermal heat pumps and high-efficiency air-source heat pumps; motion sensors for interior lighting, vending machines, and exhaust fans; energy-efficient hand dryers; solar practices such as solar daylight tubes, grid-connected photovoltaic systems, and solar water heaters; vestibule entrances, thermal pane glass for door and windows, and water-efficient faucets, toilets, and urinals. The results of this analysis provide a list of promising Best Management Practices (BMPs) for Willow Creek rest area that includes: fluorescent T8, CFL, and induction light bulbs for interior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, vestibule entrance, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with, setting back HVAC at night, and water-conserving fixtures. The recommendations of implementing the developed list of BMPs for Northbound of Willow Creek rest area are summarized in Tables 207 and 209 Similarly, the recommendations of implementing the developed list of BMPs for Southbound of Willow Creek rest area are summarized in Tables 209 and 210. These two lists of BMPs can reduce the total energy consumption of the rest area buildings up to 39.1% and 33.45% for Northbound and Southbound buildings respectively.

Table 207. Recommendations for Interior and Exterior Lighting in Northbound Willow Creek Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Interior lighting	Replace existing linear and U-shaped fluorescent T12 lamps with reduced wattage T8 (28W and 25W as discussed previously in Appendix D. This replacement will reduce electricity consumption for interior lighting. Investigate the feasibility of replacing existing HPS and MH bulbs with reduced wattage CFL (42W and 27W), and induction light bulbs (161W) respectively, while considering the impact of this replacement on lumens output levels in the corridors and lobby of the northbound building.	$9,984	8.8%	3.7
Motion sensors	Install motion sensors for lighting in the men’s and women’s restrooms. These motion sensors will reduce the electricity consumption of interior lighting.	$1,556	6.7%	0.8

Table 208. Recommendations for Vending Machines, Exhaust Fans, Hand Dryers, HVAC System, Water Heater, PV System, and Water Fixtures in Northbound Willow Creek Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Vending area	Install motion sensors for lighting in the vending area and lighting of vending machines, these sensors will reduce electricity consumption of lighting the vending area and vending machines.	$451	1.1%	1.5
Exhaust fans	Install motion sensors for exhaust fans in the men's and women's restrooms, these motion sensors will allow the exhaust fans to operate only when the restrooms are occupied, this will reduce the unnecessary dissipation of energy for space heating and cooling when the restrooms are unoccupied.	$2,606	2.2%	4.0
Hand dryers	Replace existing hand dryers in women's and men's restrooms with more energy-efficient units such as Blast hand dryers	$2,457	1.5%	5.6
HVAC system	Consider the feasibility of replacing the existing HVAC system with geothermal heat pump. The rest area building is used 24/7, and accordingly it can benefit from the use of energy-efficient HVAC system such as geothermal heat pump to reduce the energy consumption for space heating and cooling.	$70,520	8.2%	13.4
Water heater	Install desuperheater along with the geothermal heat pump to provide hot water during the summer and to reduce the energy consumption of water heaters.	$1,600	0.6%	8.4
HVAC settings	Adjust the settings of the HVAC thermostat to allow the HVAC system to set back at night during the low visitation periods.	$0	1.8%	Immediate payback
Water fixtures	Replace existing water fixtures (toilets and urinals) with water-efficient units. A detailed analysis of this potential replacement is provided in Appendix D.	$3,970	0.1% of electricity	N.A.
PV system	Investigate the feasibility of installing grid-connected photovoltaic system with a capacity of 17.4KW to generate 9.9% of total electricity consumed at the rest area site. It should be noted that PV systems can generate renewable electricity on-site for the rest area; however, the payback period for this system is relatively long.	$71,977	9.3%	27.0
Code Blue emergency phone	Consider the possibility of replacing existing bulbs in the Code Blue emergency phones with LED lights to reduce electricity consumption while considering the impact of this replacement on their visibility at night.	$300	0.8%	1.4
All measures	**All the above energy measures were modeled in the energy simulation software to consider all interactions among the measures and to estimate the overall reduction in energy consumption.**	**$165,422**	**39.1%**	**12.3**

Table 209. Recommendations for Interior and Exterior Lighting in Southbound Willow Creek Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Interior lighting	Replace existing linear and U-shaped fluorescent T12 lamps with reduced wattage T8 (28W and 25W as discussed previously in Appendix D. This light replacement will reduce electricity consumption for interior lighting. Investigate the feasibility of replacing existing HPS and MH bulbs with reduced wattage CFL (42W and 27W), and induction light bulbs (161W), respectively, while considering the impact of this replacement on lumens output levels in the corridors and lobby of the southbound building.	$13,387	7.6%	3.2
Motion sensors	Install motion sensors for lighting in the men's and women's restrooms. These motion sensors will reduce the electricity consumption of interior lighting.	$3,112	6.0%	1.1

The research team also developed a practical decision support tool (DST) that can be used to optimize the upgrade decisions for Illinois public buildings with two primary objectives (1) minimize the total upgrade cost to accomplish a desired level of LEED-EB certification; and (2) maximize the number of accredited LEED-EB points for a specified budget. IDOT decision makers can use the developed decision support tool (DST) in this research study to investigate the potential for achieving a specified LEED certification level (e.g. silver or gold) with the lowest possible upgrade cost or earning the maximum number of LEED credit points within a specified budget.

Table 210. Recommendations for Vending Machines, Exhaust Fans, Hand Dryers, HVAC System, Water Heater, PV System, and Water Fixtures in Southbound Willow Creek Rest Area Building

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Vending area	Install motion sensors for lighting in the vending area and lighting of vending machines, these sensors will reduce electricity consumption of lighting the vending area and vending machines.	$451	0.8%	1.1
Exhaust fans	Install motion sensors for exhaust fans in the men's and women's restrooms, these motion sensors will allow the exhaust fans to operate only when the restrooms are occupied, this will reduce the unnecessary dissipation of energy for space heating and cooling when the restrooms are unoccupied.	$2,606	2.7%	2.0
Hand dryers	Replace existing hand dryers in women's and men's restrooms with more energy-efficient units such as Blast hand dryers	$4,914	0.9%	10.4
HVAC system	Investigate the feasibility of replacing the existing HVAC system with geothermal heat pump, the rest area building is being used 24/7, which promotes the use of energy-efficient HVAC system such as geothermal heat pump to reduce the energy consumption for space heating and cooling.	$111,520	9.2%	12.2
Water heater	Install desuperheater along with the geothermal heat pump to provide hot water during the summer and to reduce the energy consumption of water heaters.	$1,850	0.3%	11.5
HVAC settings	Adjust the settings of the HVAC thermostat to allow the HVAC system to set back at night during the low visitation periods.	$0	0.8%	Immediate payback
Water fixtures	Replace existing water fixtures (toilets and urinals) with water-efficient units. A detailed analysis of this potential replacement is provided in Appendix D.	$5,294	0.1% of electricity	N.A.
PV system	Investigate the feasibility of installing grid-connected photovoltaic system with a capacity of 17.9KW to generate 6% of total electricity consumed at the rest area site. It should be noted that PV systems can generate renewable electricity on-site for the rest area; however, the payback period for this system is relatively long.	$73,836	5.6%	26.7
Code Blue emergency phone	Consider the possibility of replacing existing bulbs in the Code Blue emergency phones with LED lights to reduce electricity consumption while considering the impact of this replacement on their visibility at night.	$400	0.6%	1.4
All measures	**All the above energy measures were modeled in the energy simulation software to consider all interactions among the measures and to estimate the overall reduction in energy consumption.**	**$217,370**	**33.45%**	**11.5**

F.5 MACKINAW DELLS REST AREA

The Mackinaw Dells rest area was analyzed to investigate the feasibility of implementing various green building measures to reduce its energy and water consumption as well as to reduce its environmental impacts. This study of green building measures accounted for energy-efficient lighting such as energy-efficient fluorescent bulbs, LED, and induction lighting; energy-efficient HVAC systems such as geothermal heat pumps and high-efficiency air-source heat pumps; motion sensors for interior lighting, vending machines, and exhaust fans; energy-efficient hand dryers; solar practices such as solar daylight tubes, grid-connected photovoltaic systems, and solar water heaters; vestibule entrances, thermal pane glass for door and windows, and water-efficient faucets, toilets, and urinals. The results of this analysis provide a list of promising Best Management Practices (BMPs) for Mackinaw Dells rest area that includes: fluorescent T8 bulbs for interior lighting, motion-activated lighting for restrooms, vending occupancy controls, motion sensors for exhaust fans, geothermal heat pump along with desuperheater, vestibule entrance, energy-efficient hand dryer, solar daylight tubes for restrooms, photovoltaic system with 7.8KW capacity, setting back HVAC at night, and water-conserving fixtures. Mackinaw Dells rest area consists of two identical buildings to serve the north and south bounds of I-74. The recommendations of implementing the list of BMPs are listed in Table 211and Table 212. This list of recommendations can be implemented for each bound of the rest area buildings. The implementation of this list of BMPs can reduce the total energy consumption of the rest area building up to 42.3%.

Table 211. Recommendations for Interior and Exterior Lighting in Mackinaw Dells Rest Area Buildings

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Interior lighting	Replace existing linear and U-shaped fluorescent T12 and incandescent lamps with reduced wattage T8 (28W and 25W) and CFL (30W) respectively as discussed previously in Appendix D. This light replacement will reduce electricity consumption for interior lighting.	$1,872	4.5%	1.3
Motion sensors	Install motion sensors for lighting in the men’s and women’s restrooms. These motion sensors will reduce the electricity consumption of interior lighting.	$1,057	1.0%	3.7

The research team also developed a practical decision support tool (DST) that can be used to optimize the upgrade decisions for Illinois public buildings with two primary objectives (1) minimize the total upgrade cost to accomplish a desired level of LEED-EB certification; and (2) maximize the number of accredited LEED-EB points for a specified budget. IDOT decision makers can use the developed decision support tool (DST) in this research study to investigate the potential for achieving a specified LEED certification level (e.g. silver or gold) with the lowest possible upgrade cost or earning the maximum number of LEED credit points within a specified budget.

Table 212. Recommendations for Vending Machines, Exhaust Fans, Hand Dryers, HVAC System, Water Heater, PV System, and Water Fixtures in Mackinaw Dells Rest Area Buildings

Green-Friendly Measure	Recommendations	Estimated Initial Cost	Energy/ Water Reduction	Payback Period (yr)
Vending area	Install motion sensors for lighting in the vending area and lighting of vending machines, these sensors will reduce electricity consumption of lighting the vending area and vending machines.	$339	0.9%	1.3
Hand dryers	Replace existing hand dryers in women‘s and men‘s restrooms with more energy-efficient units such as Blast hand dryers	$1,638	2.4%	2.5
HVAC system	Consider the feasibility of replacing the existing HVAC system with geothermal heat pump. The rest area building is used 24/7, and accordingly it can benefit from the use of energy-efficient HVAC system such as geothermal heat pump to reduce the energy consumption for space heating and cooling.	$41,820	23.1%	5.7
Water heater	Install desuperheater along with the geothermal heat pump to provide hot water during the summer and to reduce the energy consumption of water heaters.	$1,600	3.0%	1.9
Water fixtures	Replace existing water fixtures (toilets and urinals) with water-efficient units. A detailed analysis of this potential replacement is provided in Appendix D.	$1,323	N.A.	N.A.
PV system	Investigate the feasibility of installing grid-connected photovoltaic system with a capacity of 7.8KW to generate 5% of total electricity consumed at the rest area site. It should be noted that PV systems can generate renewable electricity on-site for the rest area; however, the payback period for this system is relatively long.	$34,959	5.1%	24.1
Code Blue emergency phone	Consider the possibility of replacing existing bulbs in the Code Blue emergency phones with LED lights to reduce electricity consumption while considering the impact of this replacement on their visibility at night.	$300	0.9%	1.2
All measures	**All the above energy measures were modeled in the energy simulation software to consider all interactions among the measures and to estimate the overall reduction in energy consumption.**	**$84,908**	**42.3%**	**6.9**

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