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"GREEN-FRIENDLY" BEST MANAGEMENT PRACTICES (BMPS) FOR INTERSTATE REST AREAS

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A report of the findings of
ICT-R27-74

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16. Abstract

This report presents the findings of a research project to study and develop a list of "green friendly" Best Management Practices (BMPs) for Illinois interstate rest areas. The objectives of this project are to (1) develop energy and cost baseline data for the 53 rest area buildings in Illinois by gathering utility use statements and other pertinent data for a one-year period for each building and utilize the data to compute the carbon footprint of each building; (2) perform on-site assessment of existing conditions in three selected rest areas; (3) conduct a comprehensive literature review on green design and sustainable construction, available energy saving alternatives, LEED certification requirements, and decision-making and optimization techniques that can be used for optimizing upgrade decision of rest area buildings; (4) investigate potential energy saving alternatives for the selected rest areas and study their cost savings and environmental impact; (5) conduct Life Cycle Cost Analysis (LCCA) for the suggested green friendly measures and generate a report detailing their overall costs and payback periods; (6) investigate the requirements and possibilities for the rest areas to achieve LEED certification under the LEED rating system for existing buildings; (7) develop a Decision Support Tool (DST) to identify optimal upgrade decisions for rest area buildings; and (8) develop recommendations for upgrading the three selected rest areas. To achieve these objectives, the research team carried out six major tasks: (1) developed energy cost baseline data and carbon footprint for each Illinois rest area; (2) performed onsite assessment for three selected rest areas; (3) conducted comprehensive literature review; (4) identified potential green-friendly best management practices; (5) developed a Decision Support Tool (DST) for optimizing LEED upgrade decisions of rest area buildings; and (6) developed recommendations for upgrading the three selected rest areas.

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Members of the Technical Review Panel are the following:

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Mark Seppelt, IDOT
Patricia Broers, IDOT
Stephanie L. Dobbs, IDOT
Tom Bukowski, IDOT

EXECUTIVE SUMMARY

This report presents the findings of a research project that studied and developed a list of “green friendly” best management practices (BMPs) for Illinois interstate rest areas. The objectives of this project are to (1) develop energy and cost baseline data for the 53 rest area buildings in Illinois by gathering utility use statements and other pertinent data for a one-year period for each building, and utilize the data to compute the carbon footprint of each building; (2) perform onsite assessment of existing conditions in three selected rest areas; (3) conduct a comprehensive literature review on green design and sustainable construction, available energy saving alternatives, LEED certification requirements, and decision-making and optimization techniques that can be used for optimizing upgrade decision of rest area buildings; (4) investigate potential energy saving alternatives for the selected rest areas and study their cost savings and environmental impact; (5) conduct life cycle cost analysis (LCCA) for the suggested green friendly measures and generate a report detailing their overall costs and payback periods; (6) investigate the requirements and possibilities for the rest areas to achieve LEED certification under the LEED rating system for existing buildings; (7) develop a decision support tool (DST) to identify optimal upgrade decisions for rest area buildings; and (8) develop recommendations for upgrading the three selected rest areas. To achieve these objectives, the research team carried out six major tasks: (1) developed energy cost baseline data and carbon footprint for each Illinois rest area; (2) performed onsite assessment for three selected rest areas; (3) conducted a comprehensive literature review; (4) identified potential green-friendly best management practices; (5) developed a decision support tool (DST) for optimizing LEED upgrade decisions of rest area buildings; and (6) developed recommendations for upgrading the three selected rest areas.

The first task analyzed energy cost baseline data for all 53 interstate rest area buildings in Illinois by gathering utility use statements and other pertinent data for a one-year period for each building. The collected data from each rest area included the monthly energy and water use statements and the average number of visitors each month. The analysis of these collected data was used to calculate the following for each Illinois interstate rest area:

- monthly energy consumption
- annual energy consumption and cost per square footage
- annual energy cost per visitor
- annual number and increase of visitors
- annual carbon footprint

The second task of this project focused on conducting onsite assessments for three selected rest areas (Prairie View, Funks Grove, and Pride of the Prairie) based on the recommendation of the project’s Technical Review Panel (TRP). This onsite assessment was designed to study:

- the types of services provided by each of these three rest areas
- its conditions and characteristics of appliances and fixtures
- the potential savings and energy efficiency practices

These onsite assessments were essential to provide a deep understanding of the conditions and potential improvements in these three rest areas. An energy audit was also conducted for each of these three rest areas by the Smart Energy Design Assistance Center (SEDAC). Three SEDAC energy audit reports are attached in the appendices.

In the third task of this project, a comprehensive literature review was conducted to establish baseline knowledge of the latest research and development for green-friendly measures and best management practices. This comprehensive literature review focused on:

- research studies in green design and sustainable construction
- potential green-friendly measures such as LED and induction lighting, motion activated lighting, thermal pane glass, active and passive solar practices, geothermal heat pumps, and water saving plumbing fixtures
- Illinois public sector incentive programs for energy efficiency and renewable energy
- LEED rating systems and LEED certification requirements;
- decision making and optimization techniques that can be used for optimizing upgrade decisions

The fourth task in this project focused on identifying potential green-friendly best management practices for three selected rest areas. In this task, LCCA and carbon footprint assessments were conducted for promising green-friendly measures to identify their upgrade costs, annual savings, payback periods, and reduced CO2 emissions. These measures included LED and induction lighting, motion activated lighting, thermal pane glass, geothermal heat pumps, grid connected and standalone photovoltaic systems, solar water heating systems, hand dryers and water saving plumbing fixtures. Furthermore, a feasibility analysis was conducted for indoor temperature controls, rain gardens, and gray water systems to identify their applicability and potential for energy and water savings. The results of the conducted LCCA were summarized in tabular and graphical formats to compare upgrade costs, payback periods, and annual savings for promising green-friendly measures.

In the fifth task of this project, a DST was developed to optimize LEED upgrade decisions for rest area buildings. This task focused on:

- investigating LEED certification requirements for rest area buildings
- identifying applicable LEED measures
- developing a DST to optimize LEED upgrade decisions

The developed DST incorporated two optimization models that provide the capability of minimizing upgrade costs for achieving a desired LEED certificate (certified, silver, gold or platinum) and maximizing the total number of LEED points that can be earned for any upgrade. The performance of the developed DST was tested using a rest area example.

The sixth task of this project focused on developing recommendations for upgrading the three selected rest areas. In this task, three lists of recommendations were developed based on the findings of this study and the energy audit reports that were developed by SEDAC. These lists of recommendations identify specific promising upgrade measures for each of the selected rest areas and their expected annual savings.

CONTENTS

CHAPTER 1 INTRODUCTION

1.1 PROBLEM STATEMENT

The Illinois interstate rest area buildings are among the most visible amenities in Illinois. 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 areas include 53 buildings which provide restroom facilities, vending machines, and 13 welcome centers that include tourism information for the traveling public. The facilities are presently being maintained as well as the budget allows, but they are in need of upgrades, especially to improve their environmental and economic performance to support the recent initiatives in the State of Illinois to become more "green friendly." These initiatives include the establishment of the "Green Governments Coordinating Council" (GGCC) which was enacted in October 2007. The GGCC led to the development of the "Green Building Guidelines for State Construction" which requires all construction and major renovations of IDOT and any state-owned facilities to satisfy LEED certification requirements. The pressing need to upgrade IDOT rest areas coupled with the requirements of the newly developed "Green Building Guidelines for State Construction" present a unique opportunity to implement cost-effective upgrade measures for these highly used and visible facilities.

1.2 RESEARCH OBJECTIVES

The main goal of this project is to investigate, determine, and provide a list of "green-friendly" best management practices (BMPs) for upgrading Interstate rest areas. To accomplish this goal, the main research objectives of this study are to:

(1) Develop energy cost baseline data for the 53 rest area buildings in Illinois by gathering utility use statements and other pertinent data for a one-year period for each building, and utilize this data to compute the carbon footprint of each building.
(2) Perform onsite assessment of existing conditions in three selected rest areas.
(3) Conduct a comprehensive literature review on the latest research studies in green design and sustainable construction, available energy saving alternatives, LEED certification requirements, and decision making and optimization techniques that can be used for optimizing upgrade decisions for rest area buildings.
(4) Investigate potential energy saving alternatives for the selected rest areas and study their cost savings and environmental impact.
(5) Conduct Life Cycle Cost Analysis (LCCA) for the suggested green friendly measures and generate a report detailing their overall costs and payback periods.
(6) Investigate the requirements and possibilities for the rest areas to achieve LEED certification under the LEED rating system for existing buildings.
(7) Develop a Decision Support Tool (DST) to identify optimal upgrade decisions for rest area buildings.
(8) Develop recommendations for upgrading the three selected rest areas.

1.3 RESEARCH METHODOLOGY

The research team investigated and analyzed "green-friendly" best management practices for Illinois interstate rest areas and developed a DST for optimizing LEED upgrade decisions. The research team conducted the research work in six major tasks:

(1) Developing energy cost baseline data and carbon footprint for each Illinois rest area.
(2) Performing onsite assessment for three selected rest areas.
(3) Conducting comprehensive literature review.
(4) Identifying potential green-friendly best management practices.

(5) Developing a DST for optimizing LEED upgrade decisions of rest area buildings.
(6) Developing recommendations for upgrading the three selected rest areas.

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

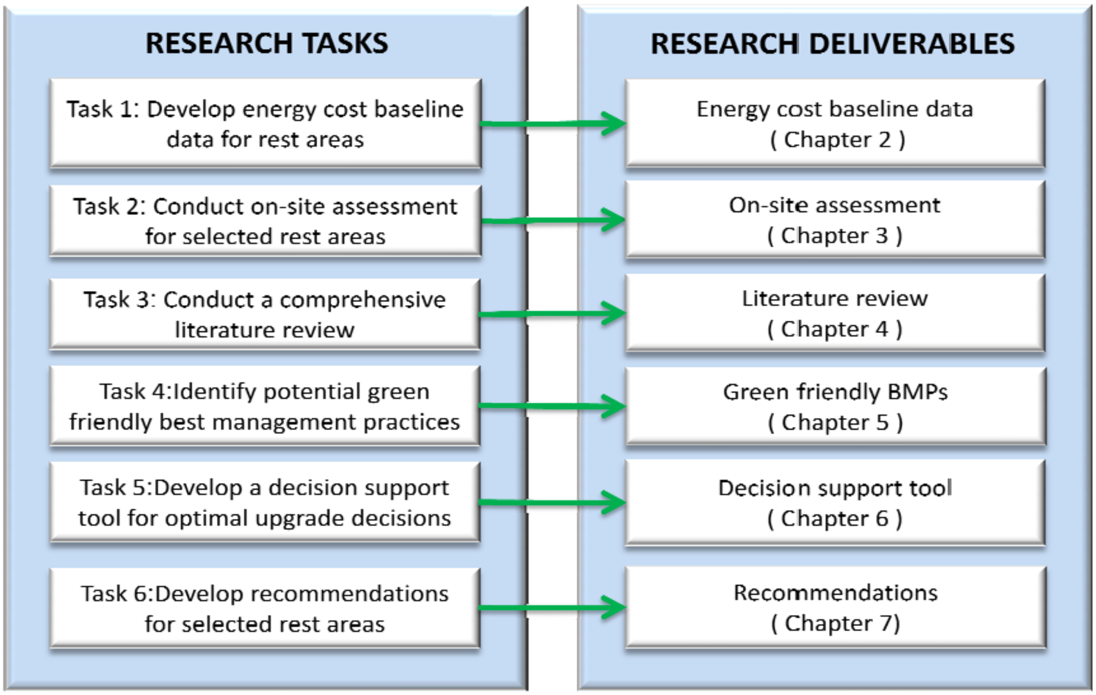
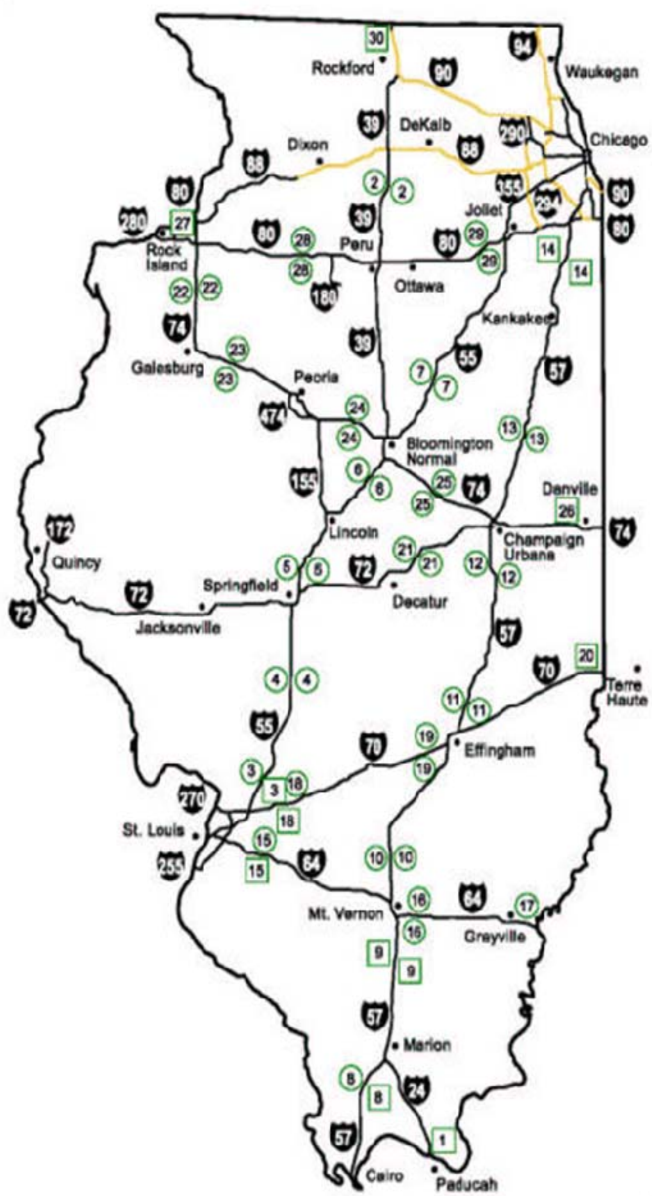


Figure 1. Project tasks and research deliverables.

CHAPTER 2 ENERGY CONSUMPTION DATA AND ONSITE ASSESSMENTS OF REST AREAS

To better understand how much energy and water the Illinois rest areas are consuming, the project team analyzed the energy and water bills for all these facilities. This analysis was essential to identify potential improvements to each building and to compare the cost effectiveness of various energy saving alternatives. The energy consumption is also used to compute the carbon footprint of each rest area. The following sections discuss: (1) energy and water consumption data for all rest areas in Illinois; (2) average number of visitors to Illinois Interstate rest areas; and (3) estimated carbon footprint of all rest areas in Illinois. Figure 2 shows a map for the 30 Interstate rest areas in Illinois.



Illinois Interstate Rest Areas

1. Fort Massac
2. Willow Creek
3. Homestead
4. Coalfield
5. Rail Splitter
6. Funks Grove
7. Limestone
8. Trail of Tears
9. Rend Lake
10. Post Oak
11. Green Creek
12. Illinois Prairie
13. Main Line Station
14. Prairie View
15. Gateway
16. Goshen Road
17. Skeeter Mountain
18. Silver Lake
19. National Trail
20. Cumberland Road
21. Pride of the Prairie
22. KrisdalaBaka
23. Spoon River
24. Mackinaw Dells
25. Farm Land
26. Salt Kettle
27. Mississippi Rapids
28. Green Sauk Trail
29. Three Rivers
30. Turtle Creek

Figure 2. Illinois Interstate rest areas.

2.1 ENERGY CONSUMPTION DATA FOR ILLINOIS REST AREAS

2.11 Monthly Energy and Water Use Statements

The analysis of energy and water consumption of Illinois interstate rest areas was necessary to (1) develop a baseline for energy and water usage of these buildings; and (2) identify potential improvements for each building and analyze the cost effectiveness of its potential energy savings alternatives. The main contributors to energy consumption in these rest areas include: lighting, space heating, air conditioning, water heating, water treatment equipment, vending machines, and hand driers. The main contributors to water consumption in rest areas include: toilets, urinals, faucets, and coffee machines.

The monthly electrical energy consumption for each of the 30 rest areas (that include 54 buildings) in Illinois is shown in Figure 4 through Figure 11. The electrical energy consumption of these rest areas are organized and grouped based on their districts in Illinois (one through nine). The monthly natural gas consumption for nine rest areas that use natural gas is shown in Figure 12 through Figure 18. The natural gas consumption of these nine rest areas is also organized and grouped based on their districts in Illinois. The annual electrical energy, natural gas, and water consumption as well as their costs are summarized in Table 1 for the 30 rest areas in Illinois.

To allow for a comparison among the 30 rest areas, the investigators calculated and analyzed annual energy and rates per square foot and per visitor. Table 2 summarizes the results of this analysis and shows the following for each rest area: (1) annual electricity consumption in 2009 per square foot; (2) annual energy cost in 2009 per square foot; and (3) annual energy cost in 2009 per visitor. The annual electricity consumption in 2009 per square foot for each rest area that uses no natural gas ranges from 29 KWH/square foot to 133.5 KWH/square foot, as shown in Figure 19. The rest areas with the highest energy consumption per square foot are Coalfield, Cumberland Road, Skeeter Mountain, Funks Grove, and Goshen Road. The rest areas with the lowest electricity consumption per square foot are Spoon River, Pride of the Prairie, Trail of Tears, Salt Kettle, and Mississippi Rapids.

The annual natural gas consumption in 2009 per square foot for each rest area that uses natural gas and electricity ranges from 0.3therm/square foot to 1.6therm/square foot, shown in Figure 20. The rest areas with the highest natural gas consumption per square foot are Turtle Creek, Post Oak, and Green Creek. On the other hand, the rest areas with the lowest natural gas consumption per square foot are Farm Land, Fork Massac, and Willow Creek.

The annual energy cost in 2009 per square foot for each rest area ranges from 2.1 $/square foot to 16.8 $/square foot, as shown in Figure 21. The rest areas with the highest energy cost per square foot are Coalfield, Cumberland Road, Turtle Creek, Funks Grove, and Limestone. These five rest areas need improvements to reduce their energy consumption. The rest areas that had the lowest energy cost per square foot are Rend Lake, Farm Land, Spoon River, Trail of Tears, and Pride of the Prairie.

The annual energy cost per visitor for each rest area ranges from 0.6 cent/visitor for Rend Lake rest area to 7.4 cent/visitor for Willow Creek rest area, as shown in Figure 22. The rest areas with the highest energy cost per visitor are Willow Creek, Great Sauk Trail, Goshen Road, Skeeter Mountain, and Farm Land. On the other hand, the rest areas with the lowest energy cost per visitor are Rend Lake, RailSplitter, Fort Massac, Gateway, and Prairie View.

The analysis of data from energy bills shows that the average unit cost of electrical energy for Illinois Interstate rest areas is 0.095 $/KWH and the average unit cost of natural gas is 0.97$/therm. Based on the histograms of electrical energy consumption for rest areas that use electrical furnaces, the electrical consumption increases significantly in November, December, January, and February to provide space heating for these rest areas. It also indicates that space heating represents a major part of electrical energy consumption in rest areas. Based on the histograms of natural gas consumption of rest areas, the natural gas consumption decreases significantly or reaches zero for most rest areas in the summer months which indicates that natural gas consumption is mostly used for furnaces.

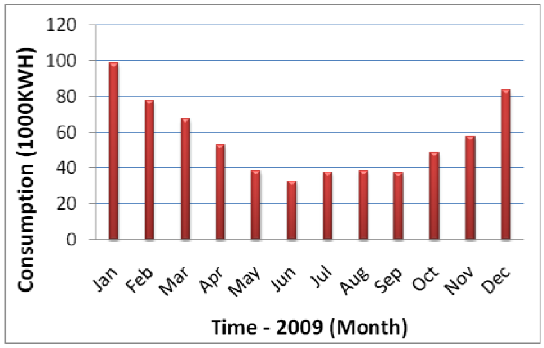
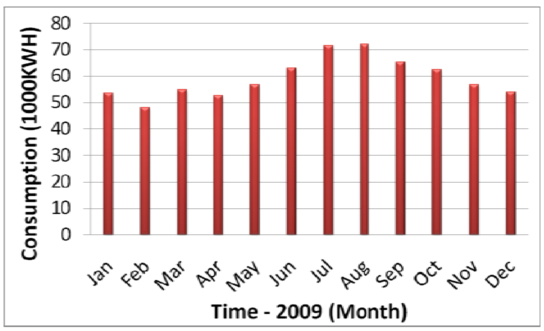
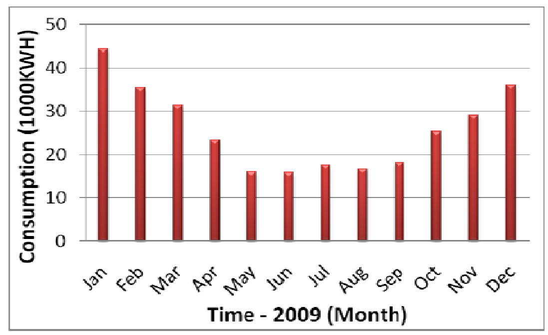


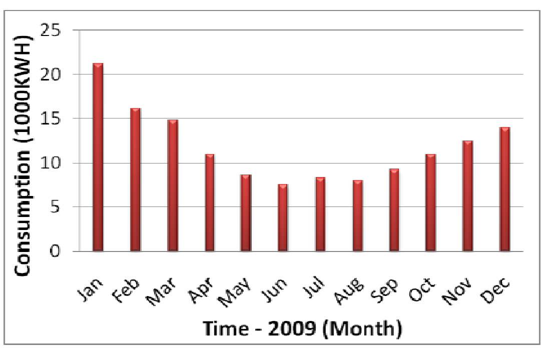
Figure 3. Electricity consumption for Prairie View rest area – District 1 – Illinois.



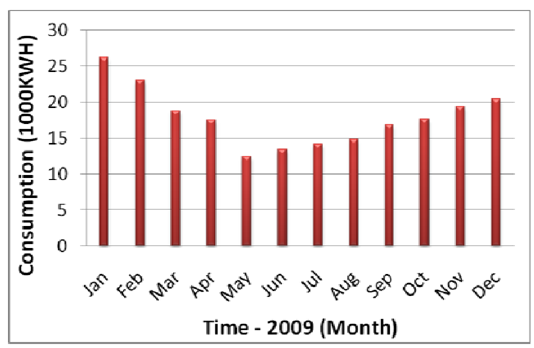
Willow Creek



KrisdalaBaka

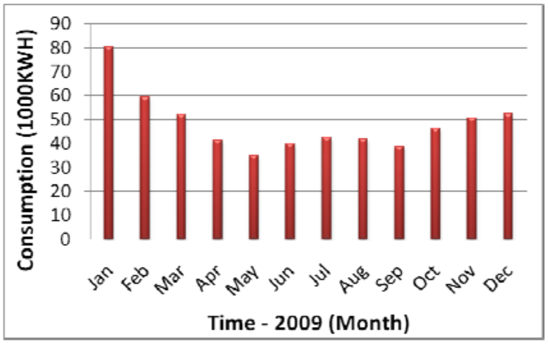


Mississippi Rapids

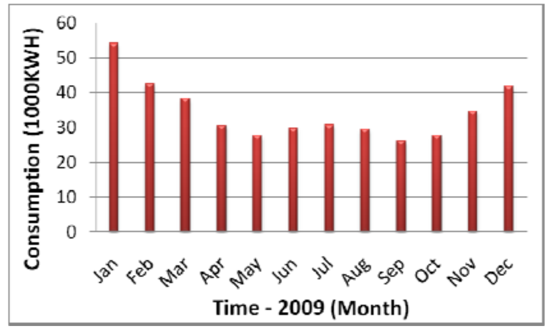


Turtle Creek

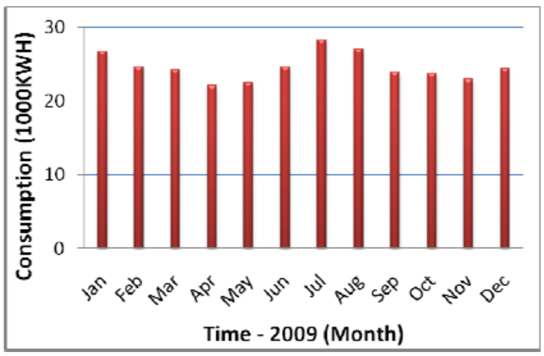
Figure 4. Electricity consumption for rest areas – District 2 – Illinois.



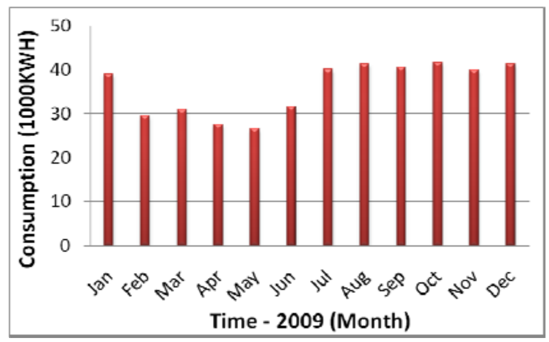
Great Sauk Trail



Limestone

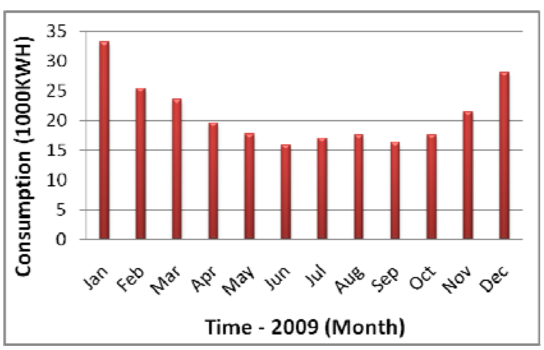


Mainline Station

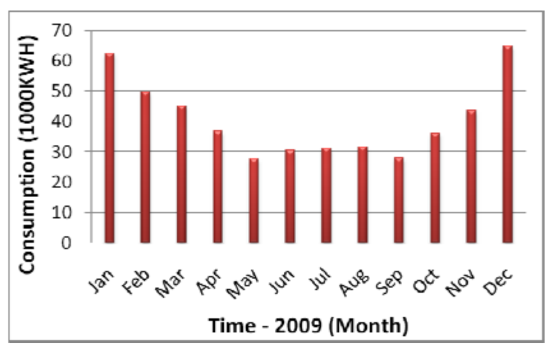


Three Rivers

Figure 5. Electricity consumption for rest areas – District 3 – Illinois.

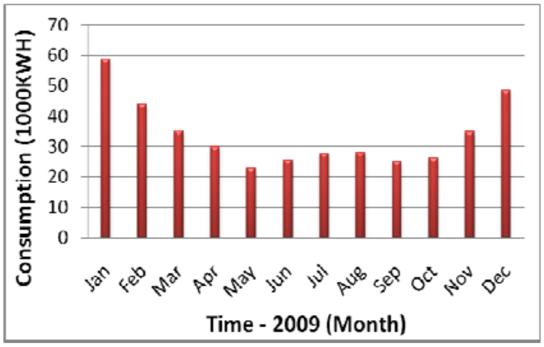


Spoon River

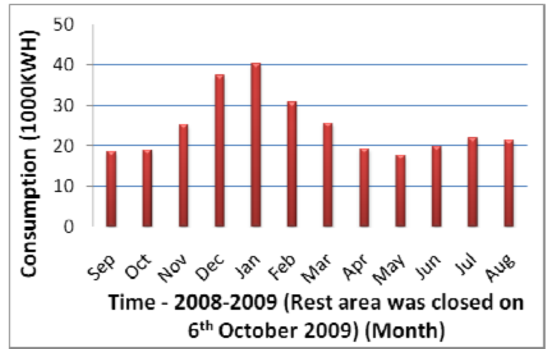


Mackinaw Dells

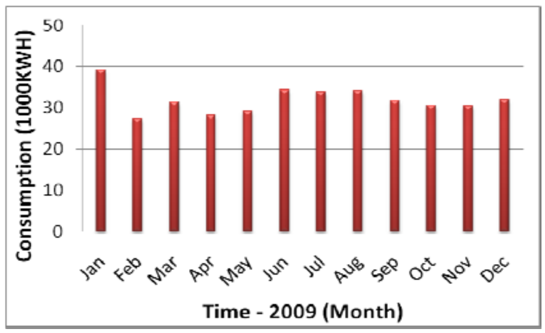
Figure 6. Electricity consumption for rest areas – District 4 – Illinois.



Funks Grove

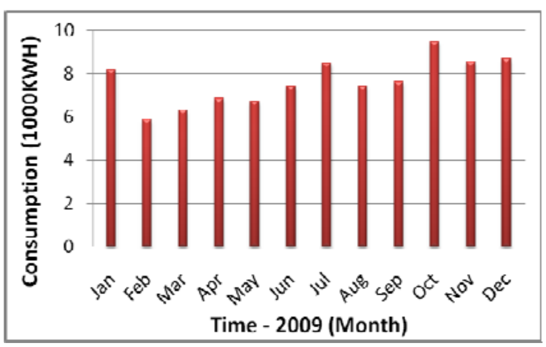


Illini Prairie

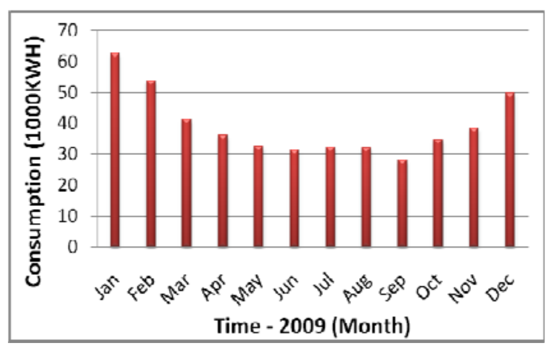


Farm Land

Figure 7. Electricity consumption for rest areas – District 5 – Illinois.

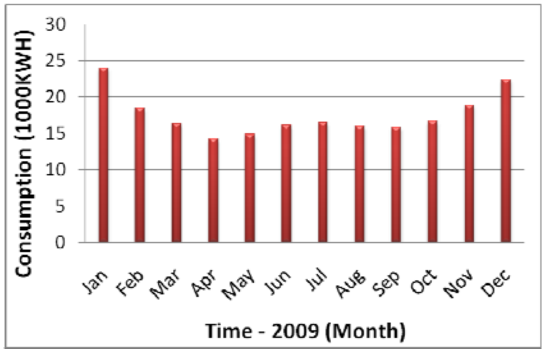


Rail Splitter

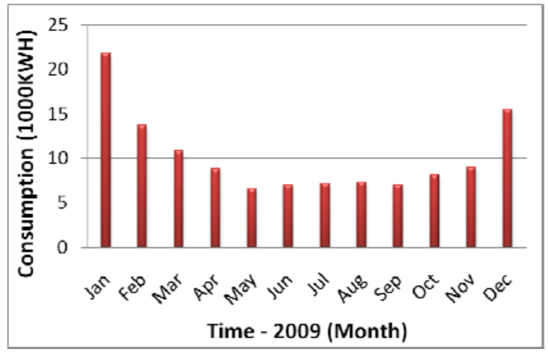


Coalfield

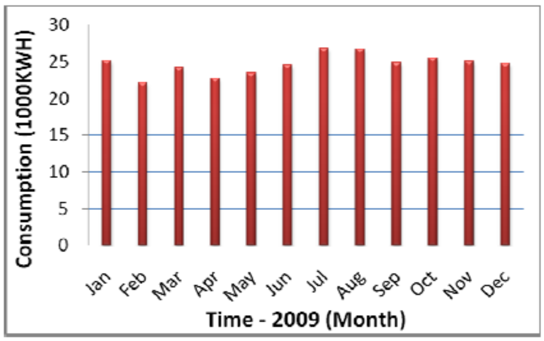
Figure 8. Electricity consumption for rest areas – District 6 – Illinois.



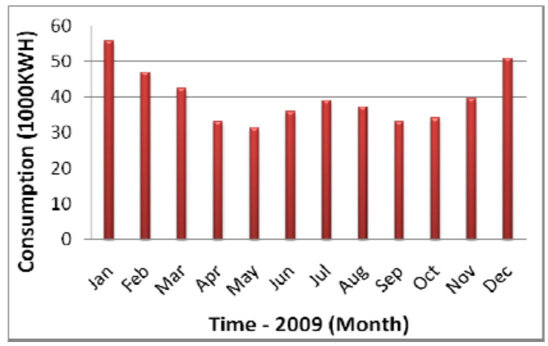
Cumberland Road



Pride of the Prairie

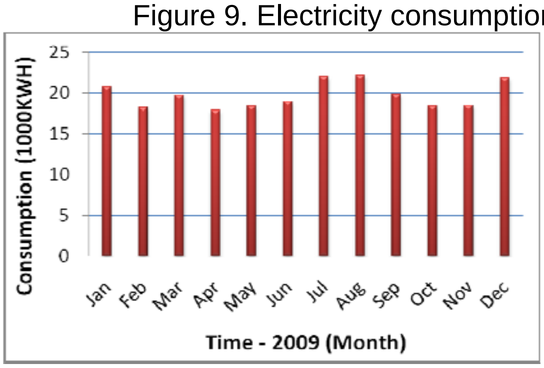


Green Creek

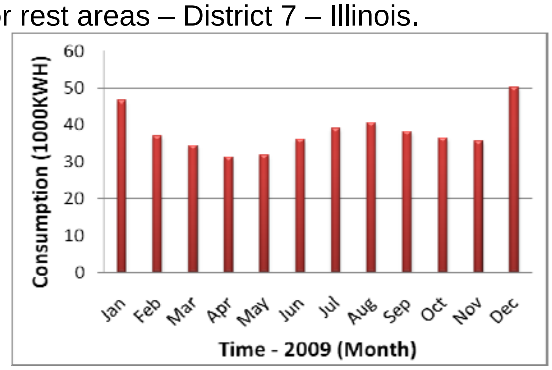


National Trail

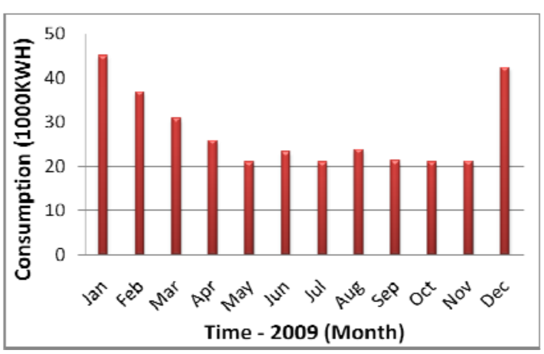
Figure 9. Electricity consumption for rest areas – District 7 – Illinois.



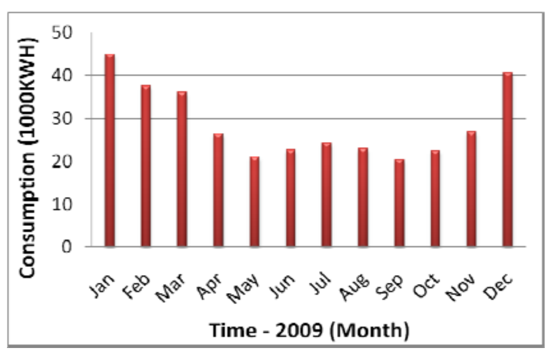
Post Oak



Homestead

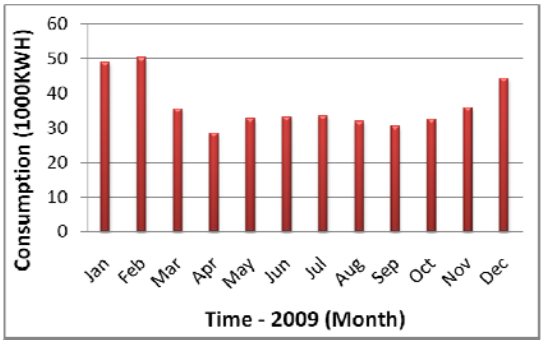


Gateway

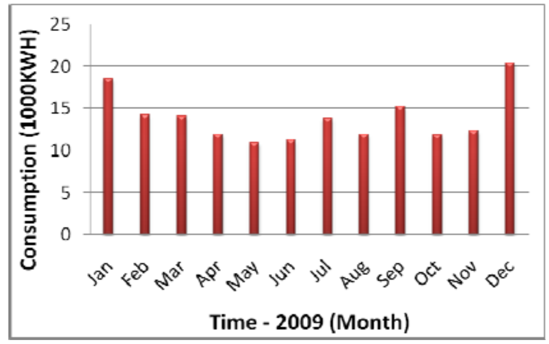


Silver Lake

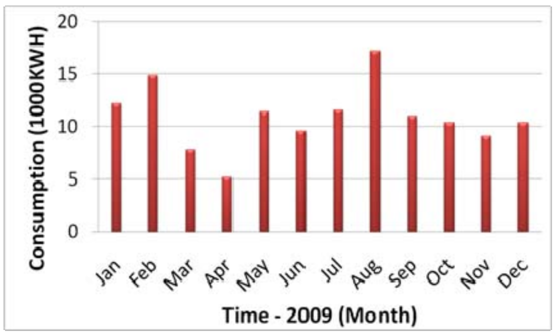
Figure 10. Electricity consumption for rest areas – District 8 – Illinois.



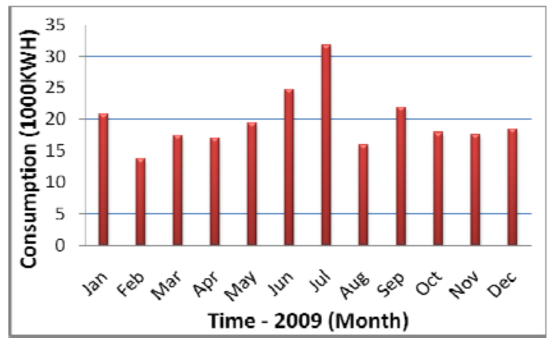
Goshen Road



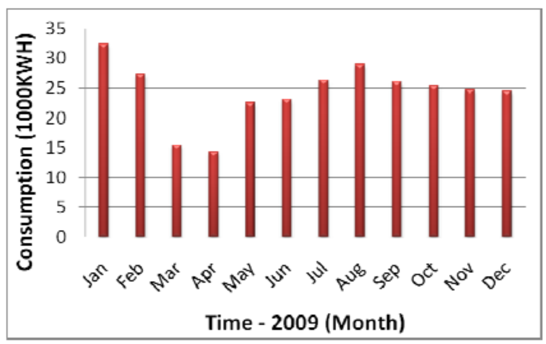
Skeeter Mountain



Fort Massac

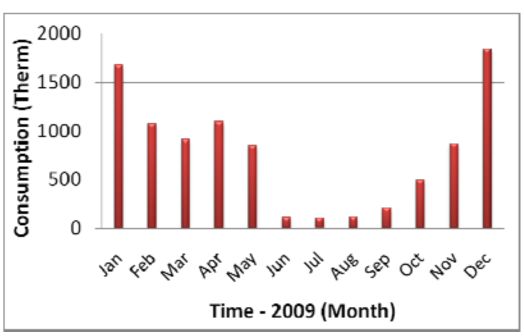


Rend Lake

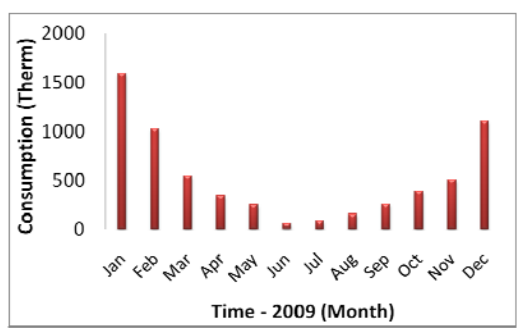


Trail of Tears

Figure 11. Electricity consumption for rest areas – District 9 – Illinois.

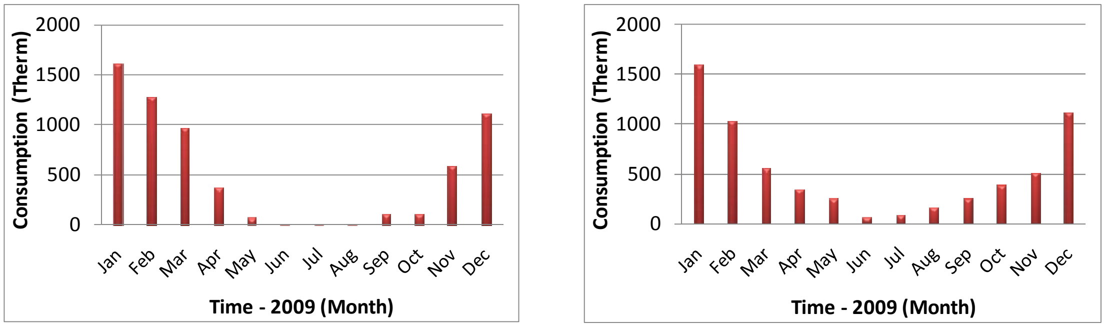


Willow Creek



Turtle Creek

Figure 12. Natural gas consumption for rest areas – District 2 – Illinois.



Mainline Station

Three Rivers

Figure 13. Natural gas consumption for rest areas – District 3 – Illinois.

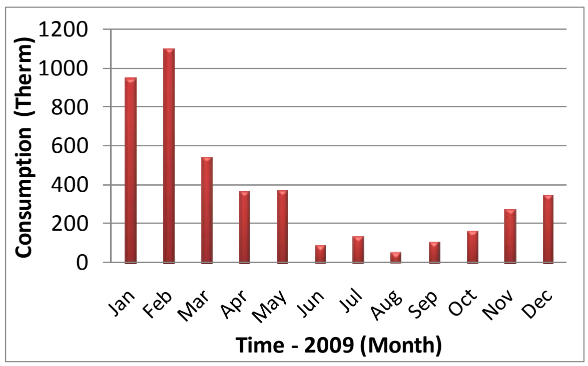


Figure 14. Natural gas consumption for Farm Land rest area – District 5 – Illinois.

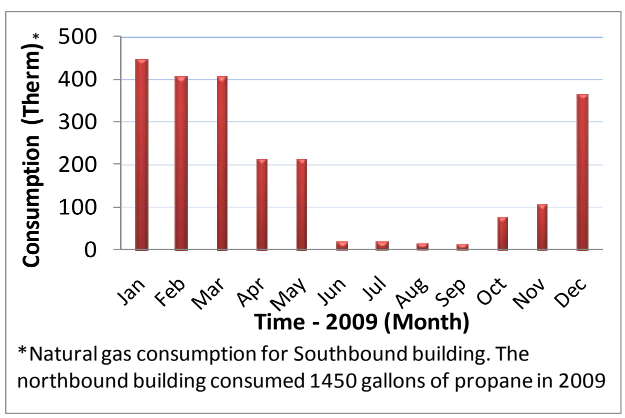


Figure 15. Natural gas consumption for Rail Splitter rest area – District 6 – Illinois.

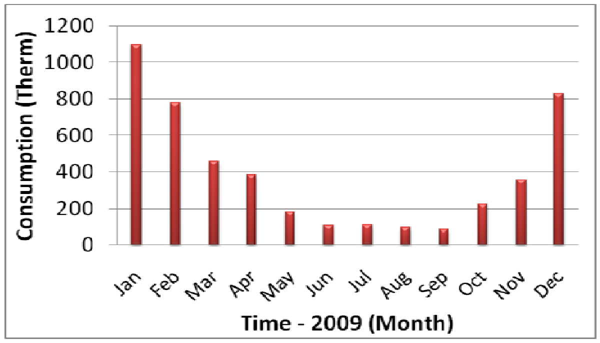


Figure 16. Natural gas consumption for Green Creek rest area – District 7 – Illinois.

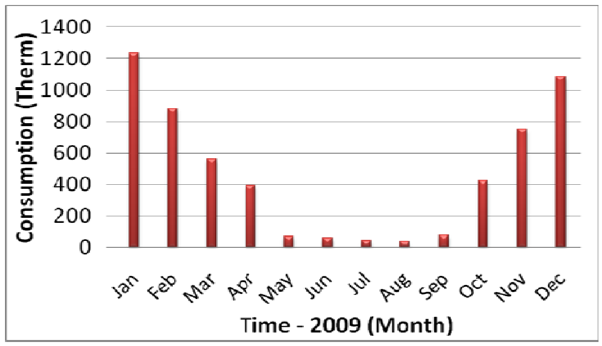
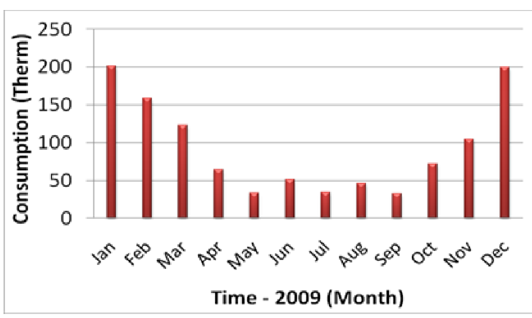
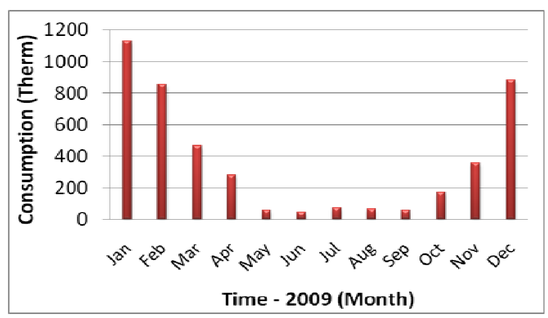


Figure 17. Natural gas consumption for Gateway rest area – District 8 – Illinois.



Fort Massac



Rend Lake

Figure 18. Natural gas consumption for rest areas–
District 9 – Illinois.

Table 1. Annual Energy and Water Consumption and Cost in 2009 for Interstate Rest Areas in Illinois

#	Rest area	Electrical consumption (KWH)	Electrical cost ($)	Natural gas consumption (Therm)	Natural gas cost ($)	Water consumption (Gallons)	Water cost ($)	Sewer cost ($)
1	Fort Massac	130,612	12,014	1,120	1,223	1,126,091	7,277	2,606
2	Willow Creek	705,112	76,428	9,288	6,398	N.A.	N.A.	N.A.
3	Homestead	458,004	41,767	-		2,318,696	6,882	19,144
4	Coalfield	478,665	66,605	-		2,198,741	10,503	N.A.
5	RailSplitter	88,768	10,398	2,299*	4,220**	N.A	5,194	N.A.
6	Funks Grove	405,957	45,682	-		N.A.	N.A.	N.A.
7	Limestone	409,720	43,993	-		N.A.	9,862	N.A.
8	Trail of Tears	290,947	27,126	-		2,422,186		17,111
9	Rend Lake	236,737	6,306	4,448	4,761	4,653,450	19,311	16,561
10	Post Oak	236,720	21,093	5,608	6,720	70,990	53,930	
11	Green Creek	296,042	22,969	4,708	4,783	N.A.	6,737	N.A.
12	Illini Prairie	297,047	21,898	-		N.A.	N.A.	N.A.
13	Mainline Station	297,457	26,483	6,196	7,316	2,106,848	N.A.	20,925
14	Prairie View	670,901	62,153	-		N.A.	N.A.	N.A.
15	Gateway	333,322	27,525	-		22,117	9,818	
16	Goshen Road	437,320	37,570	-		1,291,459	8,711	N.A.
17	Skeeter Mountain	166,250	15,301	-		10,631	2,923	N.A.
18	Silver Lake	345,508	24,577	-		3,362,935	20,659	N.A.
19	National Trail	479,147	38,122	-		3,713,483	21,031	N.A.
20	Cumberland Road	210,312	22,277	-		23,327	11,151	N.A.
21	Pride of the Prairie	122,800	13,130	-		N.A.	N.A.	N.A.
22	KrisdalaBaka	308,859	17,679	-		1,650,415	N.A.	6,988
23	Spoon River	252,856	25,166	-		N.A.	N.A.	N.A.
24	Mackinaw Dells	486,880	54,781	-		N.A.	N.A.	N.A.
25	Farm Land	382,500	39,167	4,490	4,910	3,214,389	20,853	N.A.
26	Salt Kettle	153,066	15,423	-		1,089,452	3,353	N.A.
27	Mississippi Rapids	141,120	10,851	-		N.A.	N.A.	N.A.
28	Great Sauk Trail	580,287	65,076	-		2,780,354	N.A.	9,783
29	Three Rivers	429,927	45,898	6,317	4,890	334,805	N.A.	11,116
30	Turtle Creek	212,381	21,184	3,139	2,938	N.A.	N.A.	1,544
Total		10,045,223	958,640	47,613	48,159	-	-	-

N.A.: Not Available *Natural gas consumption for southbound building. The northbound building used 1450 gallons of propane in 2009

** total cost of natural gas and propane for northbound and southbound buildings of RailSplitter rest area

Table 2. Annual Energy Consumption and Cost Indexes in 2009 for Interstate Rest Areas in Illinois

#	Rest Area	Rest area square footage (sq. ft)	Annual electricity consumption (2009) per square foot (KWH/sq. ft)	Annual energy cost (2009) per square foot ($/sq. ft)	Annual energy cost (2009) per visitor ($/visitor)
1	Fort Massac	1,984	66	7	0.007
2	Willow Creek	12,330	57	7	0.074
3	Homestead	7,600	60	6	0.024
4	Coalfield	3,966	121	17	0.038
5	RailSplitter	2,376	37	5	0.006
6	Funks Grove	4,690	86.6	9.7	0.034
7	Limestone	4,960	83	9	0.034
8	Trail of Tears	8,728	33	3	0.037
9	Rend Lake	5,280	45	2	0.006
10	Post Oak	4,524	52	6	0.025
11	Green Creek	4,200	70	7	0.028
12	Illini Prairie	3,966	75	6	0.017
13	Main Line Station	6,400	46	5	0.035
14	Prairie View	9,072	74	7	0.016
15	Gateway	4,814	69	6	0.015
16	Goshen Road	5,200	84	7	0.057
17	Skeeter Mountain	1,800	92	9	0.041
18	Silver Lake	4,752	73	5	0.017
19	National Trail	5,776	83	7	0.028
20	Cumberland Road	1,800	117	12	0.037
21	Pride of the Prairie	3,952	31	3	0.020
22	KrisdalaBaka	4,400	70	4	0.022
23	Spoon River	8,728	29	3	0.027
24	Mackinaw Dells	8,800	55	6	0.036
25	Farm Land	15,700	24	3	0.038
26	Salt Kettle	3,244	47	5	0.021
27	Mississippi Rapids	2,700	52	4	0.021
28	Great Sauk Trail	9,200	63	7	0.066
29	Three Rivers	7,572	57	7	0.021
30	Turtle Creek	2,000	106	12	0.029

N.A.: Not Available

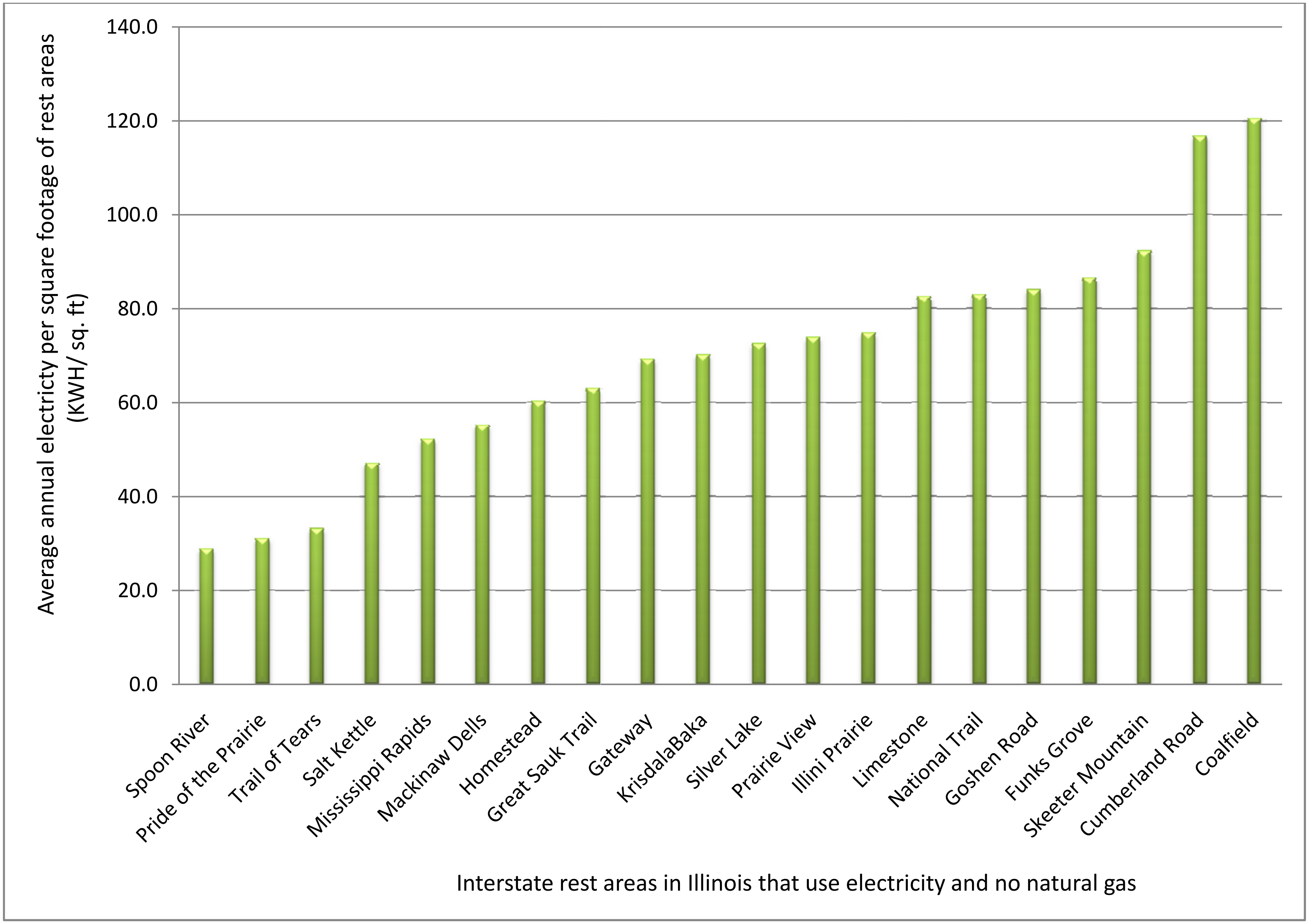


Figure 19. Annual electricity consumption in 2009 per square foot for Illinois interstate rest areas that use no natural gas.

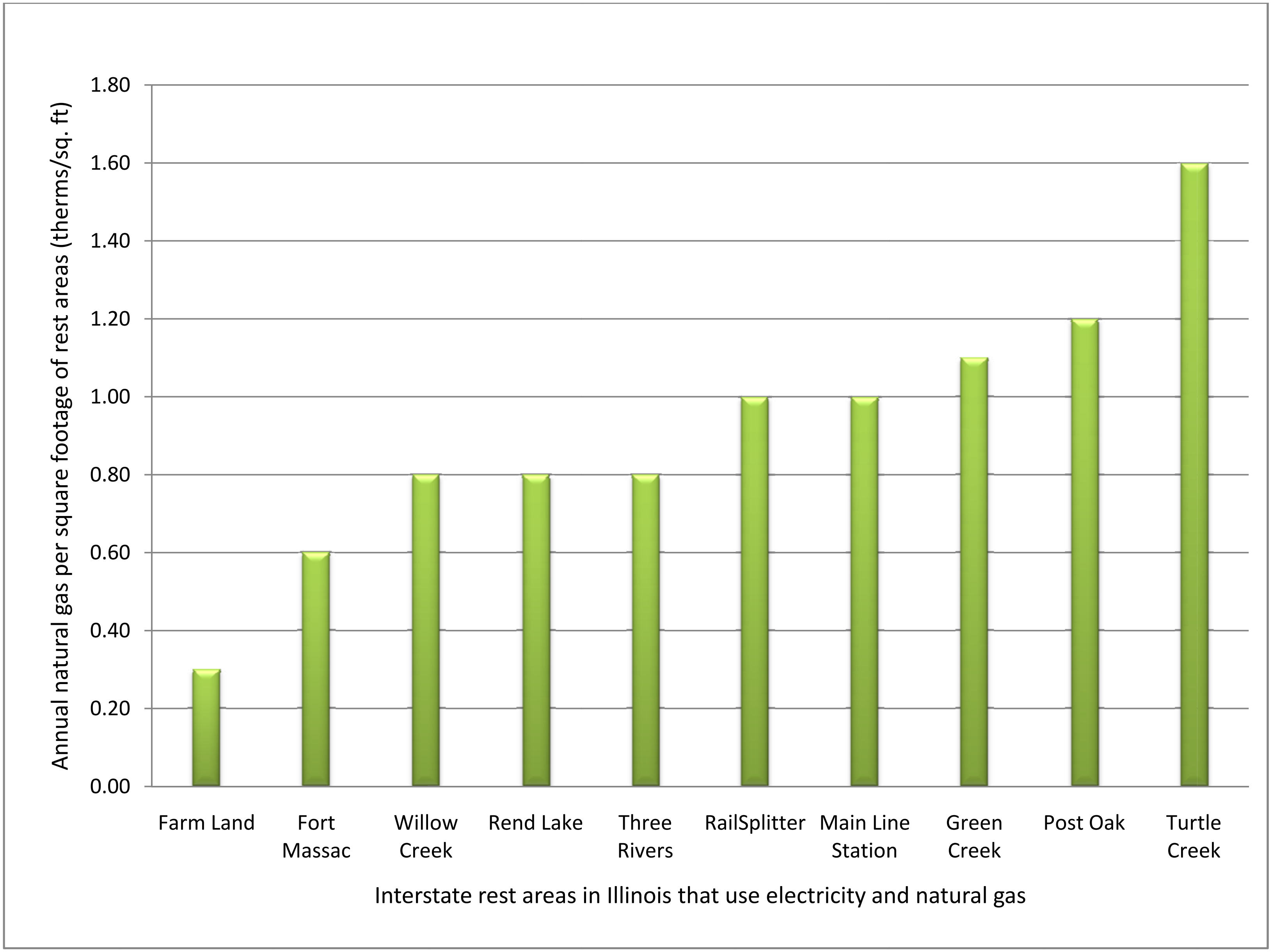


Figure 20. Annual natural gas consumption in 2009 per square foot for Illinois interstate rest areas that use natural gas.

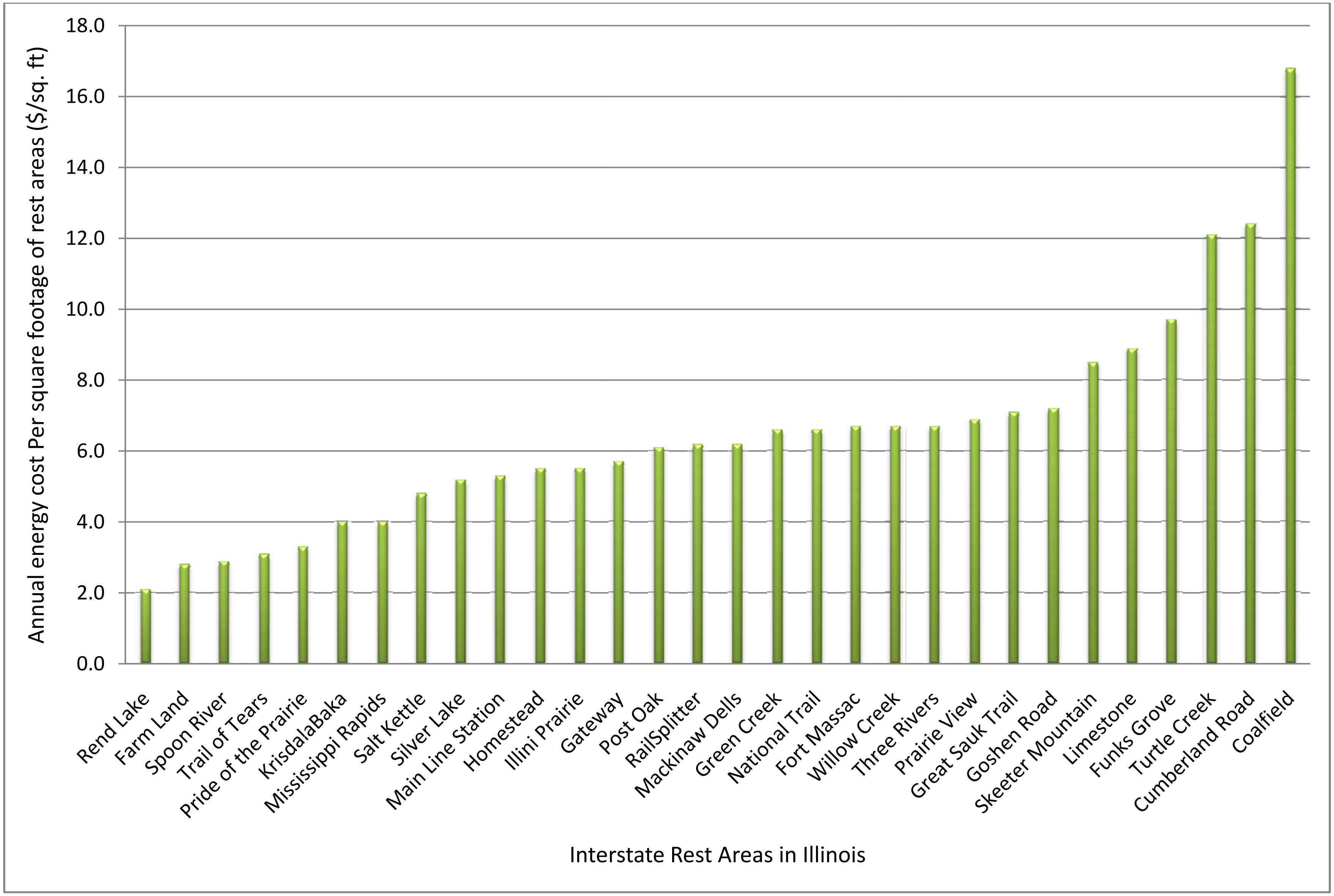


Figure 21. Annual energy cost in 2009 per square foot for Illinois interstate rest areas.

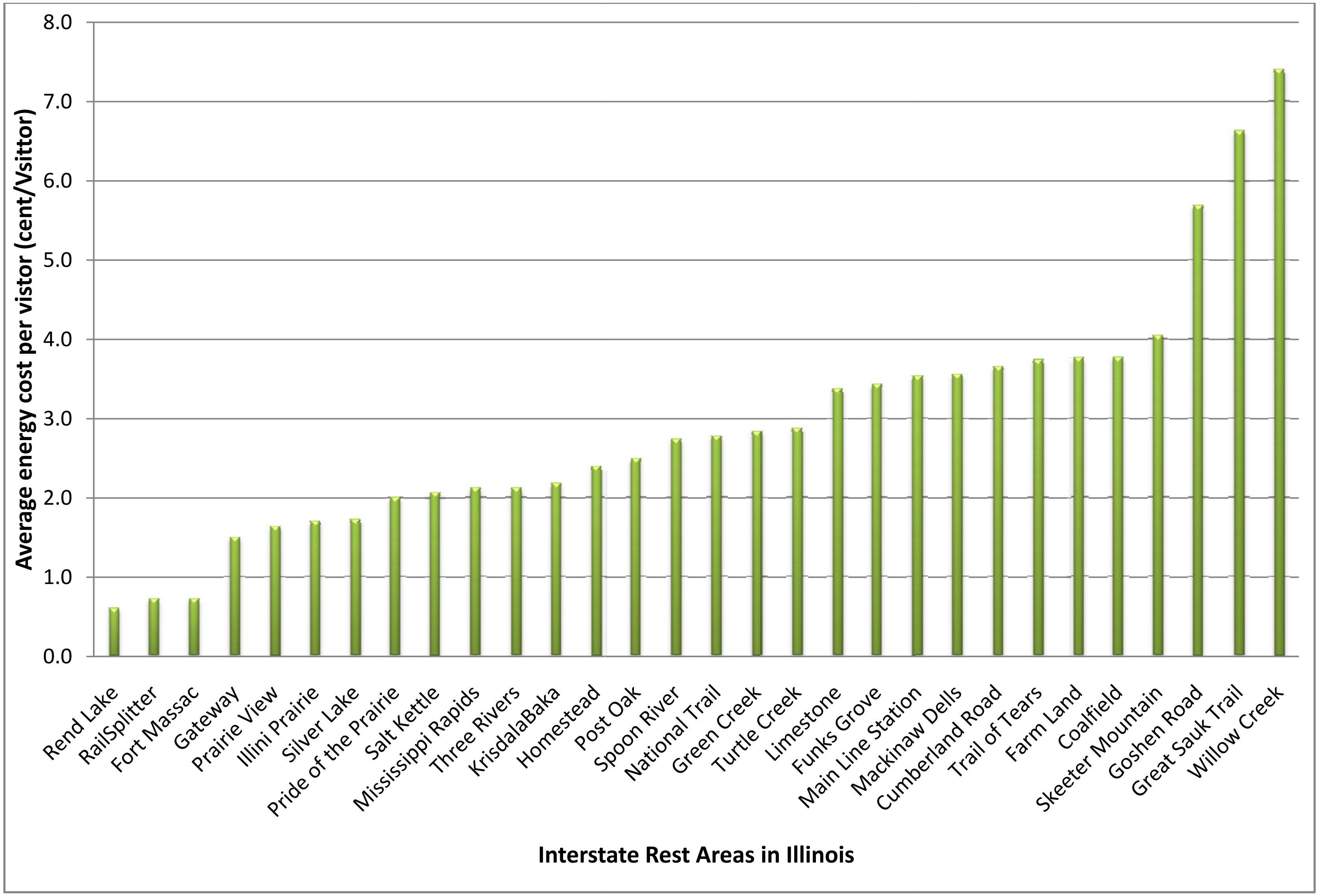


Figure 22. Annual energy cost in 2009 per visitor for Illinois interstate rest areas.

2.2 AVERAGE NUMBER OF VISITORS EACH MONTH

The number of visitors in each rest area has a significant impact on its energy and water consumption. An increase in the number of visitors leads to an increased demand for space heating, air conditioning, vending machines, water treatment, water heating and raw and sewer water usage. The number of visitors in 2001, 2007, 2009, and average number of visitors per month for interstate rest areas in Illinois are shown in Table 3. The Table shows that the number of visitors increased by 10.6% from 2001 to 2009. The most visited rest area in Illinois based on 2009 statistics is Prairie View with more than 3.5 million visitors annually, and the least visited rest area in Illinois is Skeeter Mountain with approximately 380,000 visitors annually.

The number of visitors for rest areas in Illinois is calculated based on the vehicles passing by the rest areas, the vehicle usage rate of rest areas, and vehicle occupancy. The passing vehicles by rest areas are multiplied by the vehicles usage rate to obtain the number of vehicles that use the rest areas. Then, this number is multiplied by vehicle occupancy to obtain the total number of visitors for each rest area. An example calculation of these estimated numbers of visitors for the three selected rest areas is shown in Table 4.

2.3 ENVIRONMENTAL IMPACTS OF REST AREAS

The consumption of fossil fuel (coal, petroleum, and gas) has increased in the last few decades at a rapid rate which caused significant increases in the emissions of unfavorable gases to the environment. The production of electricity using fossil fuel is responsible for the largest part of these unfavorable emissions. The environmental impact is measured by the amount of carbon footprint generated over the lifecycle of a product or a process. Wiedmann and Minx defined carbon footprint in 2007 as “the exclusive total amount of carbon dioxide emissions that is directly and indirectly caused by an activity or is accumulated over the life stages of a product. For electricity production, the carbon footprint is calculated in terms of CO2 weight per unit generation of electricity. Carbon footprint is calculated using the life-cycle assessment (LCA) method which analyzes the cumulative environmental impact of a product or a process throughout all stages of its life. This analysis takes into consideration energy input and generated emissions throughout the whole production process including extraction of raw materials, processing, transporting and final usage (Parliamentary Office of Science and Technology 2006).

Generation of electricity using coal produces the highest emissions of CO2 gases while generation of electricity using gas produces the lowest CO2 emissions. The output rates of coal, petroleum, and gas electricity generation are 2.095, 1.969, and 1.321 pounds of CO2 per kilowatt hour (KWH) respectively (DOE and EPA 2000). The amount of carbon footprint for electricity power plants is calculated based on the method(s) used to generate electricity. The Department of Energy (DOE) and Energy Information Administration (EIA) have identified electricity emission factors that affect the carbon footprint per KWH generated in each state such as transmission and distribution losses incurred in delivering electricity to points of use. Accordingly, the DOE and EIA reported in 2007 that the average Illinois carbon emissions are 1.4065 pound of CO2/KWH (0.638 Kg of CO2/KWH) (DOE and EIA 2007). Similarly, natural gas generation is another contributor of carbon footprint in the United States. The amount of carbon footprint of natural gas is measured in terms of CO2 weight per volume of natural gas. DOE and EIA have reported in 2007 that the weighted national average emissions of natural gas are 11.698 pound of CO2/therm (5.306 Kg of CO2/therm) (DOE and EIA 2007).

Table 3. Rest Areas Visitors 2001, 2007, and 2009

#	Rest area	Annual visitors - 2001	Annual visitors - 2007	Annual visitors - 2009	Monthly visitors - 2009	% Difference 2001-2009
1	Fort Massac	1,753,095	1,786,310	1,804,560	150,380	2.94%
2	Willow Creek	1,074,925	1,117,265	1,117,265	93,105	3.94%
3	Homestead	1,560,740	1,852,375	1,740,320	145,027	11.51%
4	Coalfield	1,621,330	1,622,790	1,760,760	146,730	8.60%
5	RailSplitter	1,599,065	1,817,335	1,989,980	165,832	24.45%
6	Funks Grove	1,546,870	1,355,245	1,329,695	110,808	-14.04%
7	Limestone	1,435,910	1,234,430	1,299,035	108,253	-9.53%
8	Trail of Tears	679,995	749,710	724,160	60,347	6.49%
9	Rend Lake	1,703,820	2,027,940	1,814,780	151,232	6.51%
10	Post Oak	1,114,345	1,112,520	1,112,520	92,710	-0.16%
11	Green Creek	920,165	1,071,275	978,200	81,517	6.31%
12	Illini Prairie	1,083,320	1,259,980	1,281,515	106,793	18.30%
13	MainLine Station	825,265	873,445	955,935	79,661	15.83%
14	Prairie View	1,887,780	2,455,720	3,767,895	313,991	99.59%
15	Gateway	1,656,735	2,051,665	1,819,525	151,627	9.83%
16	Goshen Road	568,670	659,920	660,285	55,024	16.11%
17	Skeeter Mountain	339,085	403,325	377,775	31,481	11.41%
18	Silver Lake	1,403,790	1,500,880	1,417,660	118,138	0.99%
19	National Trail	1,325,315	1,332,250	1,369,845	114,154	3.36%
20	Cumberland Road	692,405	673,790	607,725	50,644	-12.23%
21	Pride of the Prairie	704,085	679,630	653,715	54,476	-7.15%
22	KrisdalaBaka	748,250	883,665	807,015	67,251	7.85%
23	Spoon River	789,130	881,475	915,420	76,285	16.00%
24	Mackinaw Dells	1,514,385	1,562,200	1,535,920	127,993	1.42%
25	Farm Land	1,085,510	1,273,485	1,168,365	97,364	7.63%
26	Salt Kettle	645,320	750,440	743,140	61,928	15.16%
27	Mississippi Rapids	427,050	509,175	509,175	42,431	19.23%
28	Great Sauk Trail	1,005,575	1,204,135	979,660	81,638	-2.58%
29	Three Rivers	2,148,025	2,306,800	2,388,925	199,077	11.21%
30	Turtle Creek	915,785	883,300	838,770	69,898	-8.41%
Total		34,775,740	37,892,475	38,469,540	3,205,795	10.62%

Table 4. Daily Visitors of three Rest Areas in Illinois

Rest area	Vehicle type	Daily mainline AADT *	% Using rest areas	Vehicle occupancy	Total daily visitors of rest area
Pride of the Prairie	Passing vehicles	8,350	8	2.06	1,792
	Single units	450	12.2	1.73	
	Multiple units	1,800	15.6	1.14	
Funks Grove	Passing vehicles	15,450	8	2.06	3,644
	Single units	650	12.2	1.73	
	Multiple units	5,400	15.6	1.14	
Prairie View	Passing vehicles	58,500	8	2.06	10,323
	Single units	700	12.2	1.73	
	Multiple units	3,000	15.6	1.14	

* AADT: Annual Average Daily Traffic

Based on the consumption of electricity and usage of natural gas, the carbon footprint for each rest area was calculated and summarized in Table 5. The U.S EIA has published statistics for state carbon dioxide emissions which reports that the Illinois electrical power generation accounts for 97.1 million metric tons (MMT) of carbon dioxide. These emissions represent 40% of the total carbon dioxide emissions in Illinois. Accordingly, the carbon footprint of rest areas in Illinois represents 0.0069% of the carbon footprint of Illinois' electrical power generation.

Table 5. Carbon Footprint for Interstate Rest Areas in Illinois

#	Rest Area	Consumed Electricity-2009 (KWH)	Carbon footprint of consumed electricity - 2009 (Pounds)	Consumed Natural gas - 2009 (terms)	Carbon footprint of consumed natural gas - 2009 (Pounds)	Total Carbon footprint - 2009 (Pounds
1	Fort Massac	130612	183,705	1,120	13,102	196,807
2	Willow Creek	705112	991,739	9288	108,647	1,100,386
3	Homestead	458004	644,183	-		644,183
4	Coalfield	478665	673,242	-		673,242
5	RailSplitter	88768	124,852	2,299	26,894	151,746
6	Funks Grove	405957	570,978	-		570,978
7	Limestone	409720	576,271	-		576,271
8	Trail of Tears	290947	409,217	-		409,217
9	Rend Lake	236737	332,971	4,448	52,033	385,004
10	Post Oak	236720	332,947	5,608	65,602	398,549
11	Green Creek	296042	416,383	4,708	55,074	471,457
12	Illini Prairie	297047	417,797	-		417,797
13	Main Line Station	297457	418,373	6,196	72,481	490,854
14	Prairie View	670901	943,623	-		943,623
15	Gateway	333322	468,817	-		468,817
16	Goshen Road	437320	615,091	-		615,091
17	Skeeter Mountain	166250	233,831	-		233,831
18	Silver Lake	345508	485,957	-		485,957
19	National Trail	479147	673,920	-		673,920
20	Cumberland Road	210312	295,804	-		295,804
21	Pride of the Prairie	122800	172,718	-		172,718
22	KrisdalaBaka	308859	434,410	-		434,410
23	Spoon River	252856	355,643	-		355,643
24	Mackinaw Dells	486880	684,797	-		684,797
25	Farm Land	382500	537,986	4,490	52,524	590,510
26	Salt Kettle	153066	215,287	-		215,287
27	Mississippi Rapids	141120	198,485	-		198,485
28	Great Sauk Trail	580287	816,173	-		816,173
29	Three Rivers	429927	604,692	6,317	73,896	678,588
30	Turtle Creek	212381	298,714	3139	36,721	335,435
Total		10,045,223	14,128,606	47,613	556,974	14,685,580

CHAPTER 3 ONSITE ASSESSMENT OF SELECTED REST AREAS

The investigators conducted an onsite assessment of selected rest areas so they could better understand the conditions and recommend potential improvements for these rest areas. The purpose of the onsite assessments was to study: (1) types of services provided, (2) conditions and characteristics of appliances and fixtures, (3) potential savings and energy efficiency practices. Illinois has 30 interstate rest areas with 53 buildings. Therefore, carrying out onsite assessments for all these buildings was not possible within the time frame for this study. Thus, selecting few rest areas for onsite assessment provided a reasonable understanding of the conditions of rest areas.

The selection of rest areas for onsite assessment was based on the recommendation of the project's Technical Review Panel (TRP). This recommendation considered four main factors for prioritizing rest areas for onsite assessment: (1) facility age; (2) number of visitors; (3) energy consumption; and (4) renovation date. This selection process identified three rest areas for onsite assessment: (1) Prairie View; (2) Funks Grove; and (3) Pride of the Prairie. The three rest areas selected for onsite assessment are shown in Figure 23.

The site visits and assessments for these three rest areas were conducted on March 8 and on March 15, 2010. The site visit and assessment team included the research team members and representatives from the Smart Energy Design Assistance Center (SEDAC) of the University of Illinois, the chair of the technical review panel, members of the technical review panel, and Illinois Department of Transportation (IDOT) maintenance personnel.

Figure 23. Selected rest areas for onsite assessment.

3. 1 ONSITE ASSESSMENT OF SELECTED REST AREAS

3.1.1 Prairie View

Prairie View is one of the oldest and most visited rest areas in Illinois. It has approximately 3.77 million visitors annually based on 2009 statistics. Prairie View was built in 1971 and was renovated in 1989. It is comprised of two buildings that serve the north and south bounds of I-57 at mile marker 333. This rest area provides several services for visitors including:

weather information, travel information and guides, bathrooms, vending machines, and outdoor picnic areas.

The components of energy consumption in the northbound Prairie View rest area include exterior lighting, interior lighting, space heating, air conditioning, water heating, water treatment, vending machines, surveillance cameras, “Code Blue” emergency phones, weather information, hand driers, and water coolers. The exterior lighting includes lighting poles for the road between I-57 and the rest area parking lot, lighting poles for parking lot, and outdoor lighting fixtures for the rest area entrance. The interior lighting includes fixtures for the lobby, men’s’ bathroom, women’s bathroom, mechanical room, water treatment room, and maintenance office. The most frequently used interior lightings are summarized in Table 6.

The Prairie View rest area is air conditioned using a high capacity unit manufactured by Carrier. Manufactured in 1997, the AC unit serves all spaces of the rest area. Two electrical water heaters are used to heat water for men’s and women’s bathrooms with the capacities of 30 gallons and 6 gallons respectively. The AC unit and the men’s bathroom water heater are shown in Figure 24. A water treatment station is used to treat well water with a capacity of three pressure filters each with a capacity of 119 gallons. The three pressure filters used for this water treatment station are shown in Figure 25. The Prairie View rest area has six vending machines for snacks and cold and hot drinks. Surveillance cameras and Code Blue units are used to maintain safety for visitors of the rest area. The surveillance cameras need interior lighting at all times to increase the clarity of video recording. The weather information is provided on a television in the rest area lobby.

Table 6. Interior Lighting of the Northbound Prairie View Rest Area

	Type of lighting fixture	**Quantity**	**Lamp(s) per fixture**	**Characteristics**
Lobby	Double bulbs fixture	24	2	30~40 watt
	Recessed fixture	2	1	30~40 watt
Vending machine area	Fluorescent fixture	4	2	32 watt
	Recessed fixture	3	1	30~40 watt
Men's bathroom	Recessed fixture	1	1	30~40 watt
	Fluorescent fixture	11	2	32 watt
Women's bathroom	Recessed fixture	1	1	30~40 watt
	Fluorescent fixture	11	2	32 watt

Space heating and air conditioning

Men's bathroom water heater

Figure 24. Space heater and air conditioner and men's bathroom water heater of the northbound Prairie View rest area.

Figure 25. Three pressure filters of the water treatment system of Prairie View rest area.

The men's and women's bathrooms include eight hand driers with a 20 Amp electrical capacity for each unit. Two water coolers are available in the lobby of the rest area to provide cold drinking water for visitors. Water consumption in the Prairie View rest area covers faucets, urinals, and toilets, as shown in Figure 26. The quantities and characteristics of water fixtures in this rest area are shown in Table 7.

Table 7. Water Fixtures of Northbound Prairie View Rest Area

	Type of water fixture	Quantity	Characteristics
Men's bathroom	Faucets	4	Electronic high flow faucet
	Toilets	4	Electronic flushing system
	Urinals	4	Electronic flushing system
Women's bathroom	Faucets	4	Electronic high flow faucet
	Toilets	6	Electronic flushing system

Figure 26. Water fixtures of Prairie View rest area.

3.1.2 Funks Grove

The Funks Grove rest area has a medium visitation rate, and it was recently renovated in 2002. It has approximately 1.33 million visitors annually based on 2009 statistics. Funks Grove was built in 1982 and was renovated in 1991. It is comprised of one building that serves both sides of I-55 at mile marker 149. This rest area provides several services for visitors including: weather information, bathrooms, and vending machines.

The primary energy consumption in the Funks Grove rest area includes exterior lighting, interior lighting, space heating, air conditioning, water heating, surveillance cameras, “Code Blue” emergency phones, water treatment, vending machines, weather information, hand driers, and water coolers. The exterior lighting include lighting poles for roads between both sides of I-55 and the rest area parking lots, lighting towers for parking lots, and outdoor lighting poles and fixtures for rest area entrance. The lighting tower and the exterior lighting pole are shown in Figure 27. The interior lighting includes lighting fixtures for the lobby, men’s bathroom, women’s bathroom, mechanical room, water treatment station, storage rooms, and maintenance office. The most frequently used interior lightings are shown in Table 8.

Figure 27. Lighting tower and exterior lighting poles of Funks Grove rest area.

Table 8. Interior Lighting of Funks Grove Rest Area

	Type of Lighting Fixture	Quantity	Lamp(s) per fixture	Characteristics
Lobby	Spot fixture	10	1	Spiral fluorescent bulb
	Fluorescent fixture	6	2	32 watt
	Recessed fixture	12	2	26 watt
Maintenance office	Fluorescent fixture	3	2	32 watt
Vending area	Rectangular fixture	4	1	100 watt incandescent bulb
Men's bathroom	Fluorescent fixture	19	2	32 watt
	Recessed fixture	3	2	26 watt
Women's bathroom	Fluorescent fixture	19	2	32 watt
	Recessed fixture	3	2	26 watt
Family bathroom	Fluorescent fixture	2	2	32 watt
	Recessed fixture	2	2	26 watt

The Funks Grove rest area is air conditioned using four units manufactured by Carrier. Three identical units are used to serve the lobby, maintenance office, vending area, storage rooms, and women’s bathroom. The fourth unit is used to serve the men’s bathroom. The two models of the air conditioning units are shown in Figure 28. Surveillance cameras and Code Blue units are used to maintain safety for visitors of the rest area. Two electrical water heaters are used to heat water for the men’s and women’s bathrooms. A water treatment station is used to treat water with a capacity of three pressure filters and a hydropneumatic tank with a capacity of 560 gallons, as shown in Figure 29. The Funks Grove rest area has six vending machines for snacks, cold and hot drinks, as shown in Figure 30. Weather information is provided by a television in the lobby of the rest area.

Figure 28. Two models of the air conditioning units in Funks Grove rest area.

Figure 29. Pressure filters and hydropneumatic tank of Funks Grove rest area.

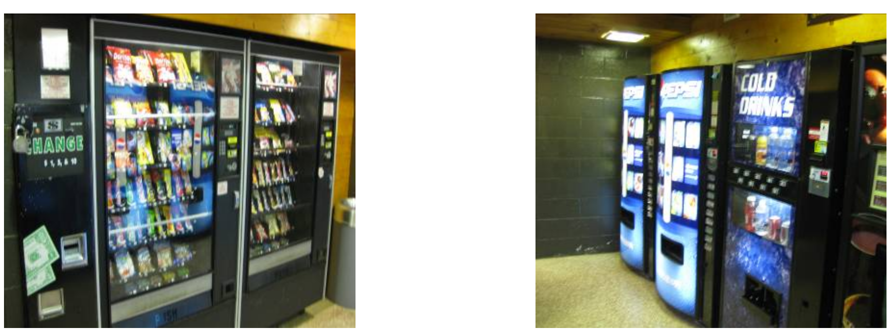


Figure 30. Vending machines of Funks Grove rest area.

The men's and women's bathrooms include 14 hand driers with 20 Amp electrical capacity for each unit. Two water coolers in the lobby provide cold drinking water for visitors. The water consumption in the Funks Grove rest area covers faucets, urinals, and toilets. The quantities and characteristics of the Funks Grove water fixtures are shown in Table 9. The water fixtures of the men's bathroom in this rest area are shown in Figure 31.

Table 9. Water Fixtures of Funks Grove Rest Area

	Type of water fixture	**Quantity**	**Characteristics**
Men's bathroom (two Parts)	Faucets	6	Electronic low flow faucet
	Toilets	7	Electronic - 3 gallons/flush
	Urinals	6	Electronic - 1 gallon/flush
Women's bathroom (two parts)	Faucets	6	Electronic low flow faucet
	Toilets	13	Electronic - 3 gallons/flush
Family bathroom (two)	Faucets	2	Electronic Faucet
	Toilets	2	Electronic -3 gallons/flush

Figure 31. Water fixtures of Funks Grove rest area.

3.1.3 Pride of the Prairie

The Pride of the Prairie rest area has a low visitation rate of approximately 650,000 annual visitors based on 2009 statistics. Pride of the Prairie was built in 1986 without any renovation until now. It includes two buildings that serve the east and west bounds of I-72 at mile post 152. This rest area provides several services for visitors including: weather information, bathrooms, vending machines, and outdoor seats.

The components of energy consumption in the eastbound of Pride of the Prairie rest area include exterior lighting, interior lighting, space heating, air conditioning, water heating, water treatment, vending machines, surveillance cameras, "Code Blue" emergency phones, weather information, hand driers, and water coolers. The exterior lighting includes poles for the road between I-72 and the rest area parking lot, lighting towers for the parking lot, and outdoor lighting fixtures for the rest area entrance. The interior lighting includes lighting fixtures for the lobby, men's bathroom, women's bathroom, mechanical room, and storage room. The most frequently used interior lightings are shown

Table 10. Interior Lighting Fixtures of the Eastbound Pride of the Prairie Rest Area

	Type of Lighting fixture	**Quantity**	**lamp(s) per fixture**	**Characteristics**
Lobby	Recessed fixture	7	1	MHL bulb
	Square lighting fixture	10	2	35 Watt
Mechanical room	Fluorescent fixture	8	2	34 Watt
Men's bathroom	Fluorescent fixture	3	2	34 Watt
	Square Fluorescent fixture	2	2	35 Watt
Women's bathroom	Fluorescent fixture	3	2	34 Watt
	Square Fluorescent fixture	2	2	35 Watt

The Pride of the Prairie rest area is air conditioned using one unit that serves all indoor rooms of the rest area. Two electrical water heaters are used to heat water in this rest area with a capacity of 30 gallons each. The air conditioner and the water heater model are shown in Figure 32. The westbound Pride of the Prairie rest area includes a small water treatment station with a capacity of two pressure filters and a hydropneumatic tank that serves both east and west bound rest areas, as shown in Figure 33. The Pride of the Prairie rest area has two vending machines for snacks and cold drinks, as shown in Figure 34. Surveillance cameras and Code Blue units are used to enhance safety for visitors of the rest area. The surveillance cameras need interior lighting at all times to increase the clarity of video recording. A television in the rest area lobby provides weather information.

Figure 32. Air conditioning and water heater units of Pride of the Prairie rest area.

Figure 33. Water treatment pressure filters of Pride of the Prairie rest area.

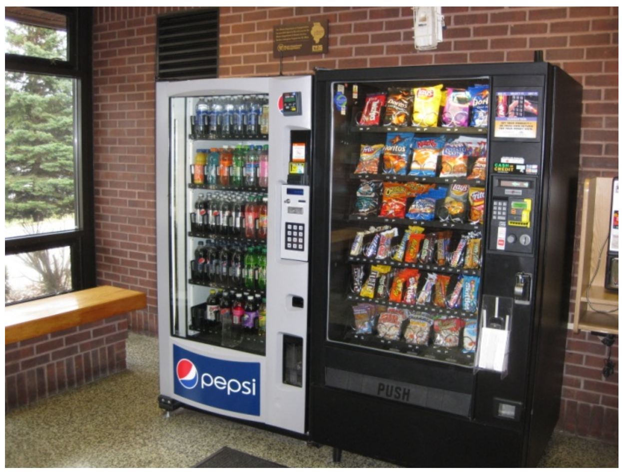


Figure 34. Vending machines of Pride of the Prairie rest area.

The men's and women's bathroom include four hand driers with 10A electrical capacity for each unit. Two water coolers are available in the lobby of the rest area to provide cold drinking water for visitors, as shown in Figure 35. Water consumption in the Pride of the Prairie rest area includes faucets, urinals, and toilets. The quantities and characteristics of these water fixtures are depicted in Table 11. The water fixtures for the Pride of the Prairie rest area are shown in Figure 36.

Figure 35. Water cooler of Pride of the Prairie rest area.

Table 11. Water Fixtures of the Eastbound Pride of the Prairie Rest Area

	Type of water fixture	Quantity	Characteristics
Men's bathroom	Faucets	3	Controlled low flow faucet
	Toilets	3	Manual - 3 gallons/flush
	Urinals	2	Manual - 1 gallon/flush
Women's bathroom	Faucets	3	Controlled low flow faucet
	Toilets	5	Manual - 3 gallons/flush

Figure 36. Water fixtures of Pride of the Prairie rest area.

3.2 ENERGY AUDIT BY THE "SMART ENERGY DESIGN ASSISTANCE CENTER" (SEDAC)

A detailed energy audit analysis was conducted by the "Smart Energy Design Assistance Center" (SEDAC) for the three selected areas of Prairie View, Funks Grove, and

Pride of the Prairie. SEDAC was established in 2005 and its mission is to encourage communities, municipalities, school districts, business owners, design professionals, and building contractors to incorporate energy efficiency practices and renewable energy systems. The SEDAC team simulated and modeled the energy consumption of the Prairie View, Funks Grove, and Pride of the Prairie rest areas using eQUEST energy simulation tool that was developed by the U.S. Department of Energy (U.S. DOE) in 1998 and went through several updates until 2009. The SEDAC audit report provides: (1) a brief description of the analyzed rest area; (2) utility profile and energy consumption breakdown; (3) a number of recommended and energy reduction measures including interior lighting, exterior lighting, air source heat pump, geothermal heat pump, hand dryers, vending occupancy controls, exhaust heat recovery, double pane windows, solar photovoltaic systems, and solar water heaters; and (4) available incentives for energy reduction measures. The entire SEDAC reports for Prairie View, Funks Grove, and Pride of the Prairie rest areas are attached in Appendix A, Appendix B, and Appendix C respectively.

CHAPTER 4 LITERATURE REVIEW

The use of green friendly practices and sustainable technologies has increased in recent years to reduce the consumption and depletion rate of non-renewable sources of energy and to protect the environment from their harmful effects. These technologies and practices aim at improving energy efficiency, reducing energy consumption, promoting the use of renewable sources of energy, reducing greenhouse gases, and improving comfort and quality of life. Furthermore, rating systems and guidelines have been developed to improve energy efficiency, environment, and human health. For example, the Leadership in Energy and Environmental Design (LEED) rating system aims at improving energy efficiency, indoor environmental quality, material selection, sustainable site development, and water savings. Similarly, the Illinois Energy Saving Guide aims to implement energy efficiency measures that provide annual energy savings. The following sections discuss research studies that have been conducted in green design and sustainable construction, the Illinois Guide for Highway Projects, the Illinois Guide for Energy Efficiency, energy saving and sustainable technologies, and LEED certification requirements for rest areas.

4.1 RESEARCH STUDIES IN GREEN DESIGN AND SUSTAINABLE CONSTRUCTION

The use of green design practices and sustainable construction has rapidly increased in recent years to promote energy efficiency and sustainability during the construction and service life of building structures. Energy efficiency aims at achieving the best use of available resources and energy while sustainability seeks to fulfill the present needs without compromising future generations from achieving their own needs. Several organizations and programs have been developed to promote energy efficiency and sustainability during the design and construction phases of buildings, including the U.S. Green Building Council (USGBC) which developed a standard rating system that accounts for sustainability in both design and construction. The developed rating system, LEED, rates high performance and sustainable design and construction for all building types. It promotes sustainable site development, water savings, energy efficiency, improved materials and resources selection, and enhanced indoor environmental quality.

Several studies have been conducted to evaluate the performance of sustainable construction. For example, a recent study examined 11 LEED buildings and analyzed their energy and indoor water usage and compared them to the design estimates and to the averages of existing commercial buildings. This study showed that six of the considered buildings use less energy than what was estimated during the design phase. The energy consumption of these buildings was also evaluated, and it was concluded that all buildings provide an average of 40% energy savings compared to their initial baseline. Based on the LEED buildings that applied for water reduction, the study found that the actual consumption compared to the initial baseline produced an average water savings of 13% although two of these building consumed more water than their baselines (Turner 2006).

Another study conducted by the U.S. Green Building Council analyzed the application of LEED rating system for existing buildings. This study analyzed the utilized approaches to pursue LEED-EB certificate, the cost and benefits of the considered LEED credits, and the related problems that may arise and their solutions. Acquiring the gold LEED-EB certificate has led to several building benefits, including reduction in energy consumption compared to similar buildings without integrated energy efficiency measures, reduction in potable water use due to collection of stormwater, recycling 50% of the generated solid waste, and controlling of CO_2 emissions. The implementation cost of this LEED-EB certification was reported to be almost half the annual savings which led to only half year return on investment (USGBC 2004).

Another recent research study focused on measuring the performance of post-occupancy LEED projects in Illinois. This study examined the performance of 25 Illinois LEED-NC Projects in terms of energy performance, greenhouse gas emissions, water use, commute transportation, construction and operating costs, green premium, health, and occupant comfort. This study compared the performance of these Illinois LEED projects to the Commercial Building Energy Consumption Survey (CBECS 2003).The study found that these Illinois LEED projects perform better in energy efficiency than the national average for all commercial buildings (CBECS 2003) with an average improvement of 24%. The study also reported that a building with higher energy optimization points consumes less energy and performs better. This study reported that the energy consumption of the analyzed buildings caused 70% of their CO2 emissions, and accordingly the achieved reduction in energy consumption generated significant reductions in their CO2 emissions. The study was not able to estimate the savings in water consumption because it was able to obtain water consumption data for only 12 of the 25 projects, and the data did not distinguish between exterior and interior water usage(USGBC (a) 2009).

The Illinois Department of Transportation has also conducted a study that considers the use of wind power to provide electricity at the Illinois Department of Transportation interstate highway rest areas, weigh stations, and team section buildings. The main purpose of this study was to analyze the feasibility of using wind power to (i) offset electricity costs; (ii) provide an appropriate return on investment; and (iii) offset non-renewable energy use. The study gathered and analyzed data on wind resources that are available at/near these facilities and compared them to commercially available wind turbines. The cost of generating electricity using wind power was then estimated and compared to current electricity rates in Illinois. This study found that selected combinations of locations and wind turbines can provide electricity at competitive rates. The study also concluded that small wind turbines are more feasible than large ones in terms of return on investment; however, they cannot completely eliminate electrical bills (Chapman and Wiczkowski 2009).

Another study was conducted by Ohio University to evaluate the performance of solar energy in a rest area located on Interstate Highway I-75 in Cincinnati, Ohio. The study monitored the effectiveness of the solar water heating system over a one year period and used life cycle cost analysis used to compare the performance of conventional and solar water heating systems. The study concluded that the solar system was able to cover 100% of the summer heating needs and only 4% of the winter needs. Overall, the solar contribution represented 20% of the domestic hot water heating load in 1991. The study also estimated that the solar water heating system can be more economical than the conventional system over a life of 20 years (Sebnem 1992).

The North Carolina Department of Transportation (NCDOT) investigated in another study the feasibility of designing and building a new green rest area in 2001. After this study, a LEED architectural firm was selected in 2003 to design the green rest area and construction was started in 2008. The facility was designed to achieve gold LEED certification and it was open for the public in October 2009. This rest area utilized several green technologies including: motion sensor lights, domestic solar hot water, photovoltaic cells, geothermal heat pumps, and rain water catchment. The reported benefits of this green rest area include a 37% reduction in its energy consumption compared to non-green buildings with the same size as well as a decrease in its carbon footprint (NCDOT 2009; Town Newsletter 2009).

Another research study analyzed the performance of LED Street lighting test project in downtown Raleigh over a period of six months. The LED lighting test project was found to produce 43% reduction in environmental impacts and 42% reduction in energy consumption (Robert 2009). Another study was conducted to increase energy efficiency in Municipal buildings in Indian Wells, California. The study analyzed the impact of replacing existing lights with compact fluorescent (CFL) and LED lighting. These new types of lighting were found to produce 87% energy reduction and significant improvements in environmental impacts (CREE Corporation 2009). Furthermore, CREE Inc. launched a LED University Program to accelerate the adoption of energy efficient LED lighting systems. Several universities have participated in this program including North Carolina State University, Marquette University, University of California at Santa Barbara, University of Arkansas, University of Alaska at Anchorage, and University of Tianjin Polytechnic in China (CREE, Inc. 2009).

Another life-cycle cost study was conducted to compare the performance of green technology geothermal heat pumps with conventional HVAC system for a new office building in northeastern Nebraska. This study analyzed the performance of three HVAC systems including (i) gas heating and direct expansion cooling; (ii) air-source heat pumps; and (iii) geothermal heat pumps. The life cycle cost carried out for 30 years and showed that geothermal heat pumps had approximately 18% lower net present value as compared to the other conventional methods. This study also reported that the payback period of the geothermal system based on the annual energy savings ranges from 4.1 to 6.6 years based on the utilized system (GHC 2006). Another study analyzed the feasibility of geothermal HVAC systems and photovoltaic systems in a historical library building which was built in 1867 and renovated in 2005. The study analyzed the feasibility of various heating systems including oil, electrical, propane, natural gas, hard wood, air-to-air heat pump, and geothermal heat pump. The study concluded that the geothermal heat pump is the most cost efficient alternative. A similar analysis was performed for the cooling and hot water systems and the geothermal heat pump was found to be the most economical alternative with a payback period of less than 7 years. A feasibility analysis was also carried out for the photovoltaic systems and it showed that it had a 10 year payback period based on a life span of 25 years. The renovated library building was found to achieve a 20% savings in annual energy bills (Erickson, et al. 2007).

Another study was conducted to measure the impact of using water saving plumbing fixtures, and it found that using low-flow fixtures conserves water especially in the case of toilets. Based on a study of 1200 homes in 12 sites, homes with water conservation toilets were found to consume 40% less water for flushing than conventional homes in the study (GAO 2000).

4.2 ILLINOIS GUIDE FOR SUSTAINABLE HIGHWAY PROJECTS

In order to improve the sustainability of highway projects in Illinois, the Illinois Livable Sustainable Transportation (I-LAST) rating system and guide was developed by the Illinois Department of Transportation (IDOT), the American Council of Engineering Companies (ACEC), and the Illinois Road and Transportation Builders Association (IRTBA). I-LAST incorporates new sustainability measures in the development and execution of state highway projects. The purpose of this guide is to provide a comprehensive list of measures that improves the sustainability of highway projects; set an efficient method for evaluating transportation projects in terms of livability, sustainability, and effect on the environment; and identify the use of sustainable practices in the transportation industry.

The goals of providing sustainability measures for the design and construction of highway projects in the I-LAST guide are to minimize the environmental effects, reduce materials and energy consumption, improve the scenic and aesthetic context of highway projects, integrate highway projects into the community in order to protect and improve community life, involve community in the transportation planning process, account for non-motorized means of transportation in state highway projects, and find a tradeoff between the importance of transportation function to facility, community, natural environment, and economy.

The I-LAST guide contains a list of potential sustainability measures which are categorized into sections. The objective of each section is described in this guide as well as the rational and measures of effectiveness for each item under these sections. Achieving each item of these measures leads to a certain number of points. Several items of these sustainability measures are not applicable for all highway projects due to the varying nature of these projects and the large number of sustainability measures included in the I-LAST guide. Accordingly, comparing the absolute score of different highway projects is not an indicator for achieving sustainability in these projects. Projects can be evaluated using the I-LAST guidelines based on the practices that were applicable to the project. The evaluation process can be carried out into two main steps: identifying applicable elements which will be considered in the development of the project and then determining which of these indentified elements were considered in the project plans (I-LAST 2009).

4.3 ILLINOIS PUBLIC SECTOR INCENTIVE PROGRAMS FOR ENERGY EFFICIENCY AND RENEWABLE ENERGY SYSTEMS

Several programs have been developed in Illinois to foster the application of energy efficiency measures and renewable energy systems. For example, the Illinois Department of Commerce and Economic Opportunity (DCEO) sponsors the Public Sector Energy Efficiency (PSEE) program which aims at implementing energy efficiency measures that provides energy savings. The PSEE program provides incentives for projects that improve electrical energy efficiency in local, state, and federal government, public school districts, community college districts, colleges, and universities. This program limits its incentives for: (i) projects located in the state of Illinois; (ii) building and facilities located in the territories of Ameren Illinois Utilities and Commonwealth Edison Company (ComED); (iii) energy efficiency projects that provide energy savings through efficient improvements in buildings, equipment, or processes; (iv) total incentives cannot exceed 100% of the incremental measure cost and 75% of the project total cost.

The PSEE incentives are classified based on standard and custom programs. The Standard program provides incentives for various energy saving measures including: efficient and high performance lighting fixtures and lamps, efficient HVAC systems, and efficient refrigeration and motor units. The custom program provides incentives per annual KWH of energy savings for measures with a payback periods of 1 to 7 years which involves capital investment in new equipment. The detailed specifications of the Standard and Custom programs are listed in the PSEE Guide (PSEE 2009).

In addition to the (PSEE) program, there are many other federal programs which offer incentives for the implementation of renewable energy. The Federal Renewable Energy Production Incentive (REPI) offers incentive payments for electricity generated and sold by new qualifying renewable energy facilities. Qualifying systems are offered annual incentive payments of 1.5 cents per kilowatt-hour. These systems are eligible for the first 10 years of their operation life and apply only to electricity sold to another entity. The renewable energy systems that are eligible for this incentive include solar, wind, geothermal, biomass, landfill gas, livestock methane and ocean resources (US DOE 2007).

Furthermore, the DOE Loan Guarantee Program offers loan guarantees for projects that avoid/reduce air pollutants or emissions of greenhouse gases; and account for new or innovative technologies. The amount varies based on the project scope and size; however, the program focuses on projects with budgets over $25 million. Full repayment of loans should not exceed the lesser of 30 years or 90% of the projects useful life (US DOE 2005).

4.4 "GREEN FRIENDLY" BEST MANAGEMENT PRACTICES

Energy costs have recently increased in Illinois interstate rest areas and will continue to rise due to (i) the instability of crude oil prices which control the production cost of conventional energy; and (ii) the increasing number of rest areas visitors. In addition, the conventional production of electrical power has adverse environmental impacts as it increases CO2 emissions and greenhouse gases which harm the environment and cause global warming. These economic and environmental concerns increase the need for sustainable technologies that provide potential savings in energy consumption, substitute the use of fossil fuels, and protect the environment from CO2 and greenhouse gases. "Green Friendly" Best Management Practices (BMPs) are effective and practical techniques that can be used to increase energy efficiency, promote the use of renewable energies, and reduce CO2 and greenhouse gases. The following sections discuss seven types of BMPs that can be used in Illinois interstate highway rest areas. The discussion of these BMPs includes a description of each BMP; its applicability in the rest areas; its appropriateness to Illinois weather conditions; and its efficiency and potential benefits.

4.4.1 LED Lighting

Light Emitting Diodes (LEDs) are solid state devices which are used to convert electricity to light and they are characterized by potential high efficiency and long life compared to other sources of light. The early applications of the LEDs were monochromatic with low light output which was used mainly for red traffic signals and exit signs. The output of LED light has recently increased and lighting manufactures currently produce white light using ultraviolet LEDs which can be used as a promising lighting product in a wide range of applications (BetaLED; KramerLED 2008; ACEEE 2004). LED lighting starts with a small chip, around one square millimeter comprised of semi-conducting layers. The LED package may consist of one or multiple chips which are mounted on a heat conducting material called sink and enclosed in a lens, as shown in Figure 37. The LED device consists of typically 7 to 9 LEDs which can be used separately or in arrays. These LED devices are installed on a circuit board which is mounted on another heat sink to manage heat from all LEDs in the array and the entire system is enclosed in lighting fixture (US EPA/DOE 2007).

LED is a rapidly evolving technology that produces light in a new way with the following main characteristics: (1) small sources of light that are illuminated due to the movement of electrons in a semiconductor material similar to an electronic chip than a light bulb; (2) LEDs produce heat that is conducted through the back of the fixture rather than radiation in all direction as in other sources of light; and (3) LED is a directional light which increases its efficiency in applications that need directed light. In directional applications, LEDs can produce energy savings more than 50% compared to fluorescent and High Intensity Discharge (HID) lighting, and more than 75% savings compared to incandescent lighting (Efficiency Vermont 2009).

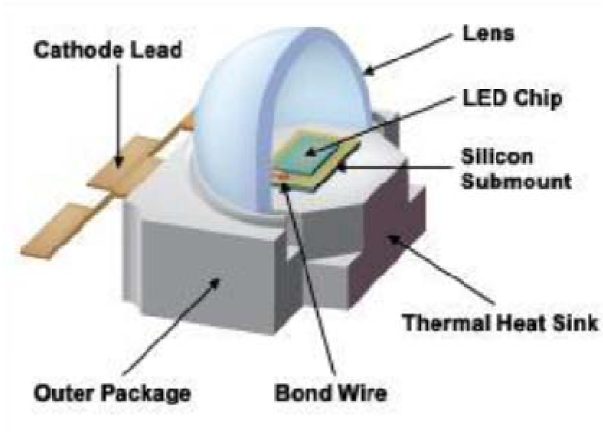


Figure 37. Cross section in LEDpackage (US EPA/DOE 2007).

According to the Department of Energy (DOE), lighting consumes approximately 22% of electrical consumption in the U.S. This highlights the importance of utilizing energy efficient lighting systems such as LEDs and their potential impact on reducing electricity consumption. The potential benefits of utilizing LED lighting in Illinois rest areas include (BetaLED and KramerLED 2008):

1) Energy reduction: LEDs consumes less electricity than other sources of light which can lead to a significant reduction in the energy consumption of the rest areas.
2) Environmental Impact: most of LED lighting fixtures are made of aluminum which can be recycled. LEDs also contain no mercury and no lead unlike other sources of light. Furthermore, LEDs reduce energy consumption which decreases the CO2 emissions that are generated during electricity production.
3) Low maintenance and disposal cost: the long life of LEDs results in a low maintenance and labor cost. In addition, the disposal cost is low compared to conventional lighting.
4) Compatibility with Photovoltaics: LEDs are low power consuming devices which make them more compatible with Photovoltaic systems.
5) Compatibility with lighting control systems: LEDs have no re-strike times which make them compatible with motion activated lighting and other lighting controls.

4.4.2 Motion Activated Lighting

Motion Activated Lighting (MAL) is one of the green technologies that provide energy savings by activating light when it is needed. The MAL system uses infrared sensors to detect the movement of a heat source in a specific area of reach. As soon as the motion is detected, the MAL system triggers light bulbs to turn on. The light bulbs remain on as motion from the heat source is still in detection. When the last motion of the heat source is detected, the MAL system remains in detection mode for a specified short time. If no motion is detected, the MAL system turns off the light bulbs automatically. There are several applications for this technology including outdoor and indoor security lighting and regular indoor lighting (Makerere Uni. 2009). This technology has many potential benefits for rest areas since it will increase the efficiency of light usage, reduce electricity consumption and cost, and reduce the adverse environmental impacts of conventional energy production. It is noted that using the MAL systems needs to consider minimum safety lighting for video surveillance and egress requirements.

4.4.3 Geothermal HVAC

Geothermal heating, ventilation and air conditioning (HVAC) systems are one of the green and sustainable technologies that utilize earth's energy to help heat and cool buildings. The temperature of the earth's surface changes significantly with seasons; however, the temperature inside the earth is much more stable. Therefore, the ground is warmer than the outside air in the winter and cooler than the outside air in the summer. Geothermal HVAC systems use this concept to provide a mechanism to use underground as a source of heating and cooling. This technology provides heating or cooling by moving heat from/to earth rather than creating heat as in traditional furnaces. In the winter, this system extracts heat from earth and uses it to heat buildings. In the summer, this system obtains heat from the building and deposits it in the ground (Hardin Geotech Inc. 2009; California Energy Comission 2008; A Tin Man Heating & Air Conditioning, LLC 2009).

Geothermal HVAC systems consist of four main components: (i) local soil and geological environment which are considered the source of geothermal heat and determines the efficiency of the system; (ii) thermal transfer exchange system which transfers heat between its fluid and the earth; (iii) mechanical system or heat pump which moves heat between the building and the fluid used in the system; and (iv) ventilation ducts or distribution system to deliver heating or cooling to the building. Geothermal systems use underground loops made of high-strength polyethylene pipes which represent the thermal transfer exchange system. This system is filled either with water in regions with temperature ranges above water freezing point or anti-freeze in northern regions of the U.S. These pipes are buried in the ground where the liquid is circulating in the pipes and into the geothermal unit in the building using the geothermal pump. The circulating liquid extracts or discharges heat from or into the ground in order to heat or cool the building. Eventually, the ventilation ducts or the distribution system is used to distribute heating or cooling throughout the building (Frontier Associates, LLC 2008; Informed Building 2008).

Four types of geothermal HVAC systems are available which are classified mainly based on the thermal transfer exchange system. The choice of the geothermal HVAC systems is performed based on the climate, soil conditions, available land, and local installation cost at site. Three of the geothermal HVAC systems (horizontal, vertical, and lake) are closed loop systems while the fourth type is an open loop system. The horizontal system is generally cost-effective for new construction where sufficient land is available for system installation as it requires trenches at least 4 feet deep. The layout is either two main pipes at two different depths or two main pipes placed at the same depth with separation distance, as shown in Figure 38. The vertical system is usually used for large commercial buildings and schools where the land area that is required for the horizontal loops is limited. The vertical system is also used if the soil is too shallow for trenching and to minimize disturbance to existing landscape. In the vertical system several holes with 4 inches in diameter are drilled with separation distances, two vertical pipes are installed in each of these holes that are connected with a U-bend at the bottom to form a loop. These vertical loops are connected together using a horizontal pipe placed in a trench and connected to the geothermal pump in the building, as shown in Figure 39.The lake system is the cheapest geothermal HVAC system however it needs an adequate water body that meets minimum volume, depth, and quality criteria. A supply line pipe is run underground from the building to the lake and coiled into circuits with minimum depth of eight feet, as shown in Figure 40. The open loop system uses well or surface water as the heat exchange fluid. Once the fluid circulates through the system, the fluid is returned back to the ground fluid source. This system is practical only when an adequate supply of clean water is available that is accepted according to local codes, as shown in Figure 41(Cogeneration Technologies 2008).

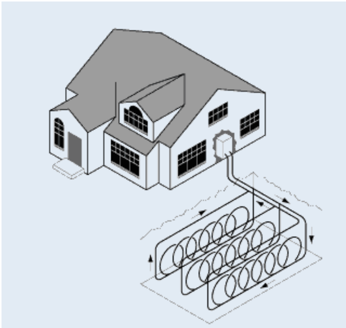


Figure 38. Horizontal heat transfer system of geothermal HVAC (Cogeneration Technologies 2008).

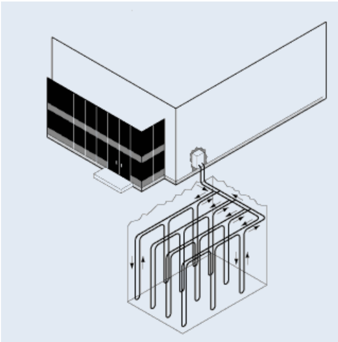


Figure 39. Vertical heat transfer system of geothermal HVAC (Cogeneration Technologies 2008).

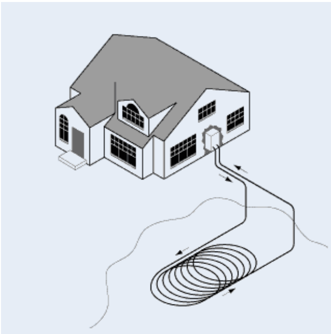


Figure 40. Lake heat transfer system of geothermal HVAC (Cogeneration Technologies 2008).

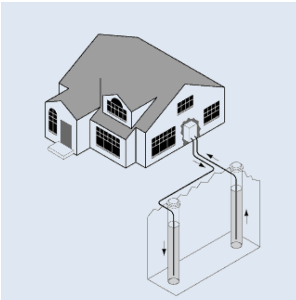


Figure 41. Open loop heat transfer system of geothermal HVAC (Cogeneration Technologies 2008).

Several benefits could be achieved from geothermal HVAC systems in rest areas including: (1) cleaner and safer systems compared to conventional oil or gas HVAC systems since they have no combustion units; (2) improved energy efficiency as they consume 25% to 50% less electricity than conventional heating or cooling systems; (3) reduced consumption of fossil fuel; (4) reduced emissions of CO_2 and greenhouse gasses; (5) better and reduced utilization of space; and (6) reduced noise generation since they have no condensing units (Cogeneration Technologies 2008; Hardin Geotech Inc. 2009).

4.4.4 Thermal Pane Glass

Windows have a significant impact on heat transfer between the interior and exterior environments of buildings. They also allow the sun's rays to heat and light the interior of buildings during daytime. Windows typically cause 3% to 10% greater heat loss than walls and therefore the type of windows needs to be carefully selected in order to maximize energy efficiency in buildings. Thermal pane is a type of window that provides better insulation than other regular/single pane types. It has double glass panes separated with air space where the trapped air reduces the heat flux lost or gained by the window, as shown in Figure 42. Thermal pane glass can reduce energy loss by 15~30% (Liu 2007; Scofield 2009).

The insulation of windows is determined based on the thermal conductivity of glass and frame as metal frames conduct more heat than wood or vinyl frames. The insulation of a metal frame can be improved by installing a thermal break into the frame where it splits the frame into two parts. The overall insulation of windows is described by Fourier's Heat Law and window scan be classified based on their U-values which specify their potential insulation (Scofield 2009). To improve the insulation of windows, a thin film that can be applied to the interior face of a window to absorb and reflect more solar energy, as shown in Figure 43. This thin film can provide more control on solar heat, reduces energy costs and increases comfort inside buildings (WFAANZ 2008).

Thermal pane glass can provide several benefits over conventional glass including: (1) better thermal resistance to summer heat gain and winter heat loss; (2) less heating cost; (3) reduced condensation (4) more comfort as it maintains a steady room temperature; and (5) more protection for the environment as it reduces the consumption of fossil fuel (Kansas State University Engineering Extension 2000; SGM 2010)

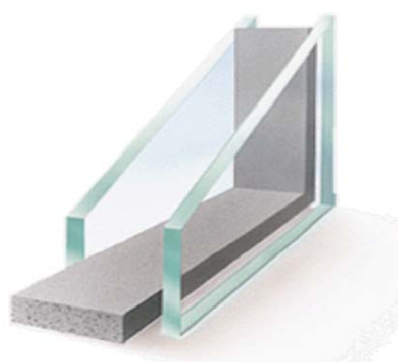


Figure 42.Cross section in a thermal pane window (Liu 2007).

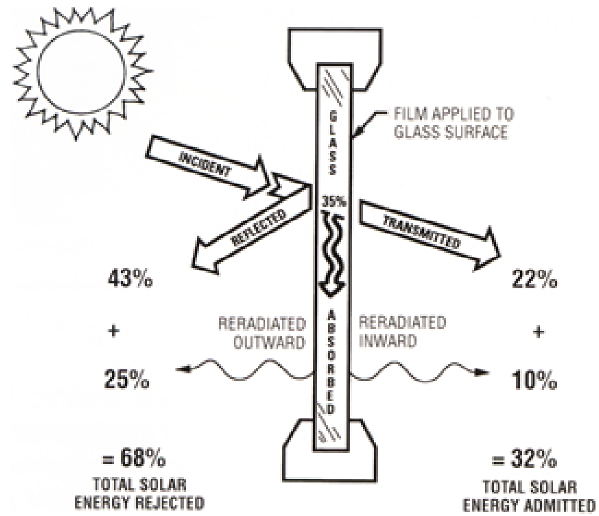


Figure 43.Glass thin film (WFAANZ 2008).

4.4.5 Active and Passive Solar Practices

Active and passive solar practices are sustainable technologies which use solar energy in producing electricity or heating for buildings. These technologies provide alternative renewable sources of energy that protect the environment from greenhouse gases. The following section discusses two main applications of solar practices: integrated photovoltaic power systems and solar hot water heating systems.

4.4.5.1 Building Integrated Photovoltaic Power Systems

Photovoltaic power systems can be used to convert solar energy into electrical energy. These systems utilize photovoltaic cells which are the basic units for energy production, where each is made of semiconductor material that is sensitive to sunlight and usually has an area of 1~100cm2. Several individual cells are connected together to form a module with an area of 0.5 ~2 m2. Modules are then combined together to create a photovoltaic array which provides the needed electricity (Oikkonen, et al. 2005).There are several types of photovoltaic arrays which can be installed either on the roof of buildings or separately on the ground, as shown in Figure 44.

The orientation of solar panels is an important factor in determining their output. Solar panels should face south in the Northern Hemisphere to face the sunlight but tilted to the ground with a certain angle to maximize their output. The orientation of solar panels differs based on season and latitude however for fixed solar panels, they are oriented based on the winter setting to maximize their productivity in cold weather. The optimum orientation of solar panels in winter is calculated by multiplying 0.9 by the latitude of the installation location and adding 29˚. The latitude in Illinois ranges from 37˚ to 42.5˚, and accordingly, the optimum orientation of solar panels in Illinois ranges from 62.3˚ to 67.3 from horizontal(Landau. 2008)..

Solar panels are affected by weather conditions as they provide their best performance in summer time since bright sunshine produce more power than cloudy and snowy weather. In cloudy weather, the solar panels produce 20~30% less power than in bright sunshine. In snow weather and harsh weather conditions, the output of solar panels may be significantly reduced or cut off which often requires cleaning solar panels from snow. In case of light snowfall, the heat stored in the solar panels will probably be sufficient to clear the panels by melting snow. In case of rainy weather, the orientation of solar panels will allow rain to slip over their faces

(DAVIS 1999; Home-Solar-Systems 2009). Furthermore, the output of solar panels is affected by hours of light available throughout the year. The available sun hours change based on the latitude and season. In middle latitudes, the summer days might have 14 hours of light however the winter days might have as few as 10 hours. In higher latitudes, the sun hours are significantly reduced during the winter (DAVIS 1999). Figure 45 illustrates the annual average daily peak sun hours in the United States.

Figure 44. Solar panels of photovoltaic systems.

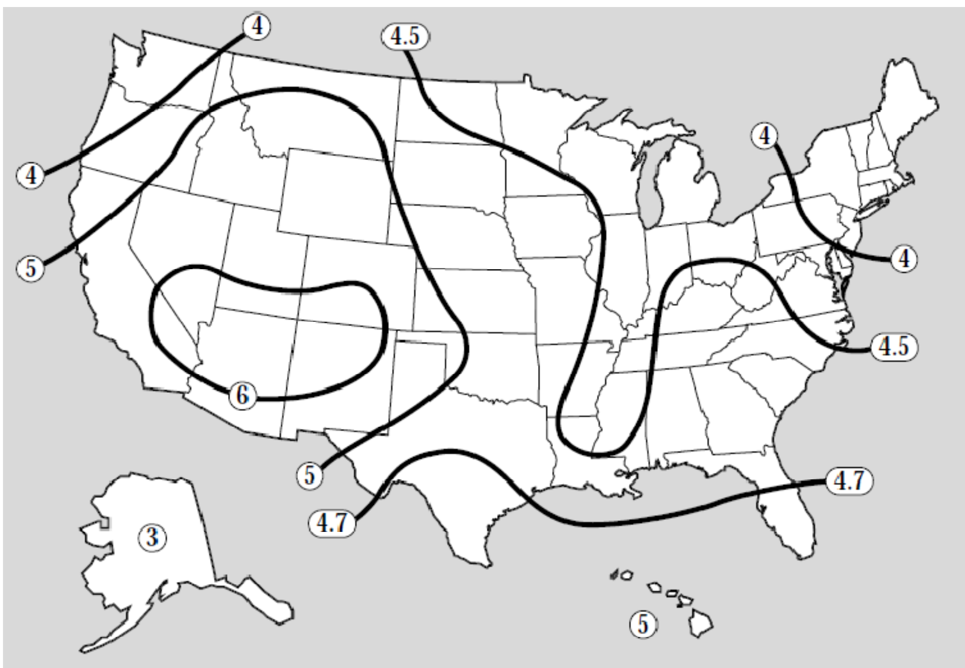


Figure 45. The annual average daily peak sun hours for the United States (DOE 1997).

Building integrated photovoltaic systems (PV) can be classified into two types: stand-alone systems and grid-connected systems. Stand-alone systems are designed to operate independently of the local electrical utility grid. The major components of stand-alone system are solar panel(s), charge controller(s), battery(s), and inverter(s), as shown in Figure 46. The developed current of the PV array, which is a Direct Current (DC), passes through charge controller to the battery bank where it is stored. The charge controller performs two functions: (1) it prevents the battery from being overcharged; and (2) it eliminates any reverse current from the battery to the PV array at night. The stored energy in the battery bank can be used at any time of the day or night. The stored energy can also be used in the harsh weather condition where the PV array cannot supply sufficient energy for the building. Inverters carry out the inversion of Direct Current (DC) into Alternating Current (AC) where it can be used for different appliances in the building.

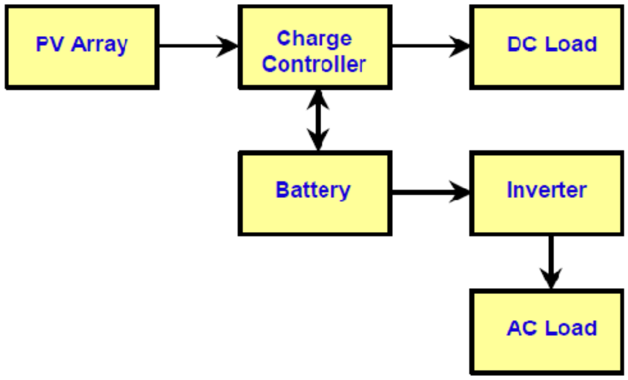


Figure 46. Major components of stand-alone photovoltaic systems (Florida Solar Energy Center 1999).

The grid-connected system is designed to operate while being interconnected with an electrical utility grid. The major components of the system are: solar panel(s), inverter or power conditioning unit, and distribution panel, as shown in Figure 47. The developed current of the PV array is directly inverted to Alternating Current (AC) using the inverter where it can be used to power the different appliances of a building. When the electrical power of the PV system exceeds the demand for the building, the excess electricity is re-routed to the utility line where it can be sold back to the utility company if the utility company installs such net-metering devices on site. On the other hand, when the demand for the building exceeds the electrical power of the PV system, the utility grid provides electricity to cover the energy shortage in the building. The utility grid also provides power in the absence of sun light and during night times (Smart Water & Energy 2007; Florida Solar Energy Center 1999).

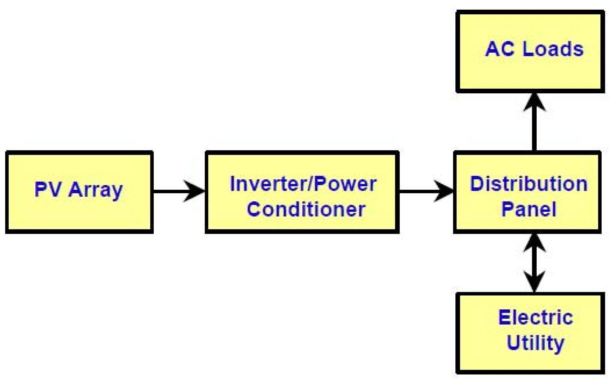


Figure 47. Major components of grid-connected photovoltaic systems (Florida Solar Energy Center 1999).

Photovoltaic systems provide many economical and environmental benefits, including energy savings of up to 100% using renewable and clean solar source of energy. They are capable of reducing the consumption rate of non renewable sources of energy which contributes to preserving these limited natural resources and minimizing the emissions of greenhouse gases. In addition, PV systems have no moving parts and therefore they provide a quiet source of energy.

The design of PV systems needs to consider a number of important factors, including (a) ensuring that the available roof area or other installation site is capable of handling the system size; (b) verifying that the orientation and type of the roof is suitable for PV panels; and (c) selecting the locations of the PV arrays to avoid shadings from trees, pipes, and nearby structures (Endecon Engineering 2001).

4.4.5.2 Water Heating Systems

Solar water heating systems use the energy of sunlight to heat water which can then be used in different building purposes. Solar water heating systems reduce the need for conventional water heating. The amount of hot water that solar energy will provide depends on the type and size of the system, quality of solar access to “collectors”, and climate conditions. A backup heating system for water is necessary for this technology where it can be used when the solar energy is not sufficient to meet hot water demand or in the absence of solar energy (Solar Center Information 2002; DOE 1996).

Solar water heating systems can be classified as active or passive systems. Active systems use electrical driven pumps and valves to control the movement of the heat absorbing fluid. Passive systems rely on the natural convection to move the fluid through the pipes of the collector. Using electronic pumps in active solar systems allows greater flexibility than in passive systems since the hot water storage tank does not need to be near or above the solar collectors. Furthermore, active systems are designed to operate throughout the year without suffering breakdowns due to freezing conditions. Major active systems include Draindown, Pressurized Glycol, and Drainback while major passive systems include Integral Collector Storage and Thermosiphon systems (Solar Center Information 2002).

Hot water systems can also be classified as direct and indirect systems depending on whether the building water is heated directly in the collectors or using a heat exchange mechanism, as shown in Figure 48. In direct systems, potable water is heated directly in the collector which flows directly to faucets. This direct system is not suitable in areas with hard or acidic water which can clog the inside of the absorber tubing. The direct system is also not efficient in freezing conditions where water can be frozen in the collectors and can cause breakdowns to the system. The major direct systems include Integral Collector Storage and Draindown.

The indirect systems utilize treated water as the heat transfer fluid in order to tolerate freezing weather. The treated water in these systems can be a non-freezing liquid such as anti-freeze solution, hydrocarbon oil, or silicon. The heat that is absorbed from the collector is transferred to the potable water through a heat exchange mechanism such as coil that is either placed inside the storage tank or wrapped around it. It should be noted that a double walled heat exchange system is required when a toxic heat transfer liquid is used to avoid contamination of potable water. The major types of indirect systems include Thermosiphon, Drainback, and Pressurized Glycol (Solar Center Information 2002).

Due to the cold weather conditions in Illinois, the direct solar heating systems may not be suitable and accordingly this report will not provide a detailed discussion of these direct systems such as Integral Collector Storage and Draindown. Similarly, the Thermosiphone system will not be discussed in more detail in this report because it is not best suited for rest areas due to the high demands of hot water in these facilities which cannot be handled with the limited capacity of the Thermosiphone system. This system also requires the hot water storage tank to be placed above or near the collector which often requires reinforcement for the roof and/or special insulation for the hot water storage tank to tolerate freezing conditions at night if it is placed outside the building(DOE 1996). The following sections provide a more detailed discussion of the Drainback and Pressurized Glycol systems which can be more suitable than the aforementioned systems for Illinois rest areas.

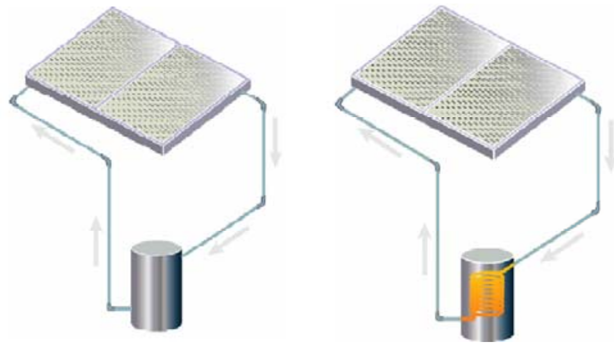


Figure 48. Direct and indirect solar water heating systems (Solar Center Information 2002).

The main components of the Drainback system are drainback tank, storage tank, collector, and control, as shown in Figure 49. The collector uses solar energy to heat the non-freezing liquid which is then used to heat the potable water using a heat exchange unit. The drainback tank is used to store the non-freezing liquid when the system is shut down. The control is used to manage the operation of the system components. The non-freezing liquid is pumped from the drainback tank to the collector and back again using an electrical pump. In some systems, the PV module is used to convert sunlight to Direct Current (DC) electricity where it can be used to power a DC pump to circulate the non-freezing liquid throughout the collector. The DC pump is used only when there is enough sunlight to pump the non-freezing liquid. In case that the solar system cannot reach the desired water temperature or in the absence of solar energy, conventional heater can be used to supplement the difference in temperature (Solar Center Information 2002).

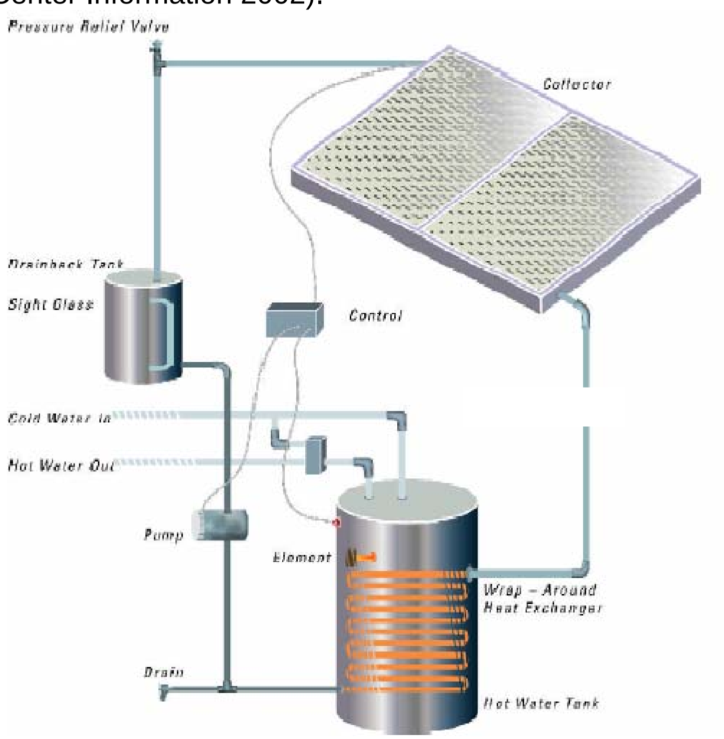


Figure 49. Drainbacksolar water heating system (Solar Center Information 2002).

The main components of the Pressurized Glycol system are collector, storage tank, expansion tank, and control, as shown in Figure 50. The heat transfer liquid used in this system is either a glycol (usually propylene or ethylene) or other hydrocarbon which can provide freezing protection. The basic concept of Pressurized Glycol system is similar to the Drainback system while the main difference is that the loop between the holding tank and the collector is pressurized and an expansion tank is used. As stated earlier, a double walled heat exchange system must be used if the heat transfer liquid is toxic to protect the potable water from contamination. If the liquid is not toxic, a single walled heat exchange system is sufficient. The glycol solution also needs to be inspected regularly (Solar Center Information 2002).

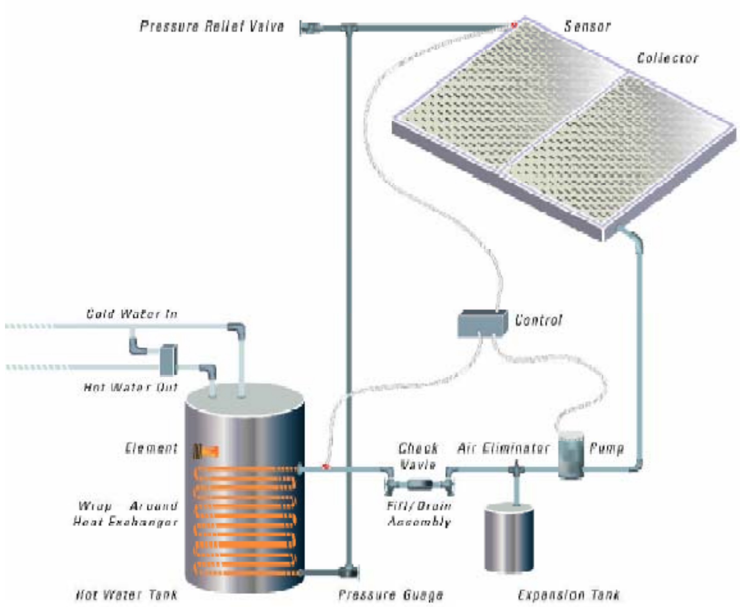


Figure 50. Pressurized Glycol solar water heating system (Solar Center Information 2002).

The collectors of solar hot water systems are classified into three types: flat-plate collectors, integral collectors, and evacuated-tube solar collectors. The flat plate collectors are insulated weatherproofed boxes that contain dark absorber plate which is covered with one or more sheets of transparent material. The dark material absorbs heat from the sunlight that passes through the cover and conveys it to the heat transfer liquid through tubes under the absorber plate. This type of collector is typically used in solar pool heating and domestic applications. The Integral collectors include one or more black tanks or tubes in an insulated and glazed box. The solar heat is absorbed using the black tanks or tubes and then it is conveyed to the heat transfer liquid. The evacuated-tube solar collectors have parallel rows of transparent glass tubes and it is typically used in commercial applications. Each tube is covered with an outer vacuumed glass tube that contains a metal absorber tube attached to a fin where it absorbs the solar energy. This vacuum tube helps to reduce heat loss (DOE 2009).

The potential benefits of utilizing solar water heating systems in rest areas include: (i) reduction in energy and maintenance cost especially when there is a high demand for hot water; (ii) providing a clean and renewable source of energy which reduces the consumption of limited traditional fossil fuel; (iii) protecting the environment from the emissions of greenhouse gasses; and (iv) enhanced reliability with an expected life of more than 20 years (DOE 2001).

4.4.6 ENERGY STAR Appliances and Fixtures

ENERGY STAR is a program sponsored by U.S. Environmental Protection agency and The U.S. Department of Energy which aims at evaluating the energy efficiency of appliances and fixtures (Ecomii 2008). This program was established to (1) reduce greenhouse gas emissions and other pollutants resulting from the inefficient use of energy; and (2) identify products that can provide energy savings without sacrificing functionality, characteristics, and comfort. A product can earn the ENERGY STAR rating by meeting the energy efficiency requirements set in the ENERGY STAR product specifications. These specification were established based on the following principals: (i) the product category should provide significant contributions to national energy savings; (ii) qualified products must achieve the required features and performance for customers and improvements in energy efficiency; (iii) qualified products that are more expensive than conventional ones should provide a reasonable payback period through savings in energy bills; (iv) products should be commercially available through more than one manufacturer; (v) energy performance and efficiency should be evaluated through testing; and (vi) products should be labeled with an ENERGY STAR labels that are obvious for customers (Energy Star (a) 2010).

The rating of ENERGY STAR can be applied to different appliances and fixtures including refrigerants, lighting fixtures, windows, boilers, ceiling fans, geothermal heat pumps, water coolers, vending machines, AC units, and furnaces. For example, oil and gas furnaces can earn the ENERGY STAR rating by achieving: higher Annual Fuel Utilization Efficiency (AFEU) of 85%and 90% or greater and higher efficient blower motors. These requirements make them up to 15% more efficient than non-qualified furnaces (ENERGY STAR (b) 2010).

This program can also be applied to buildings through the Environmental Protection Agency (EPA) program. The EPA’s energy performance program utilizes a method that ranks the performance of facilities based on a scale of 1 to 100 based on the facility’s performance compared to similar buildings in the U.S. A facility with a ranking of 50 indicates that the performance of the facility is in the middle of its peers, 50% of buildings in U.S. have higher energy efficiency and 50% of buildings have lower energy efficiency than this example building. Buildings with a ranking of 75 or higher are eligible to apply for an ENERY STAR rating (ENERGY STAR (c) 2010).The research team will consider the ENERGY STAR rated appliances and fixtures in the study of interstate rest areas and investigate the best alternatives that are capable of providing the highest energy savings and the least negative environmental impacts.

4.4.7 Water Saving Plumbing Fixtures

Indoor water usage represents a significant component of the overall water consumption in United States. A number of technologies are available to minimize indoor water consumption including the use of water efficient fixtures and fittings. For example, these new technologies were able to significantly reduce the water consumption of toilets. Before 1994, the water consumptions of traditional toilets are 3.5, 5.0, and 7.0 gallons per flush. More recent water conservation toilets have a much lower water consumption that ranges from 0 gallons to 1.6 gallons per flush, as shown in Figure 51.

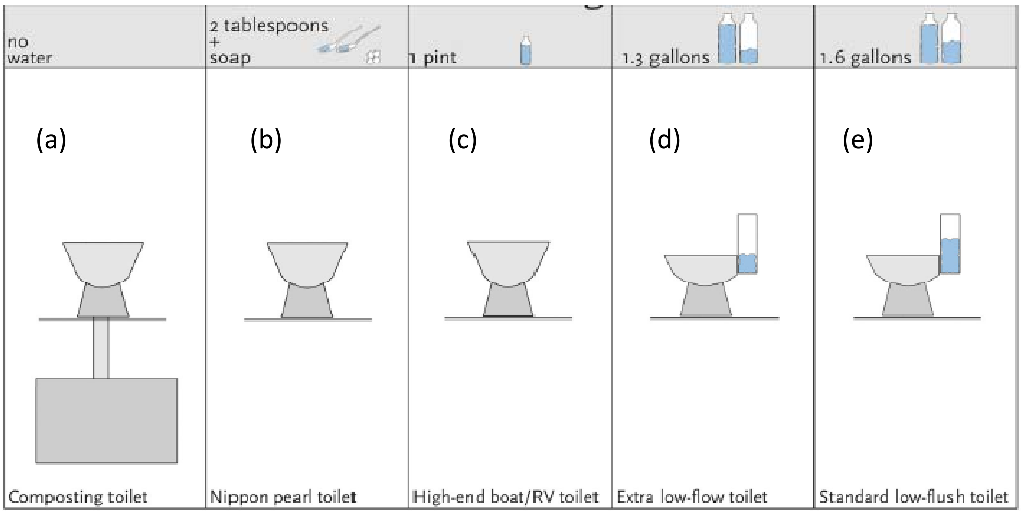


Figure 51.Water conservation toilets (UEI (a)2002).

Dual flush is another technology in toilets that can provide savings in water consumption. This flushing system uses compressed air instead of the siphon action of gravity, as shown in Figure 52. The air in the dual flush vessel is compressed as the vessel fills with water. During the flushing process, the compressed air drives water from the bowel through the trapway to the disposal. In addition to providing significant savings in water consumption, dual flush toilets provide better cleaning of the bowel than traditional ones. The water consumption for the dual flush toilet is approximately 0.8 to1.1 gallons per flush for liquid waste and 1.6 gallons per flush for solid waste (FOREMOST 2009).

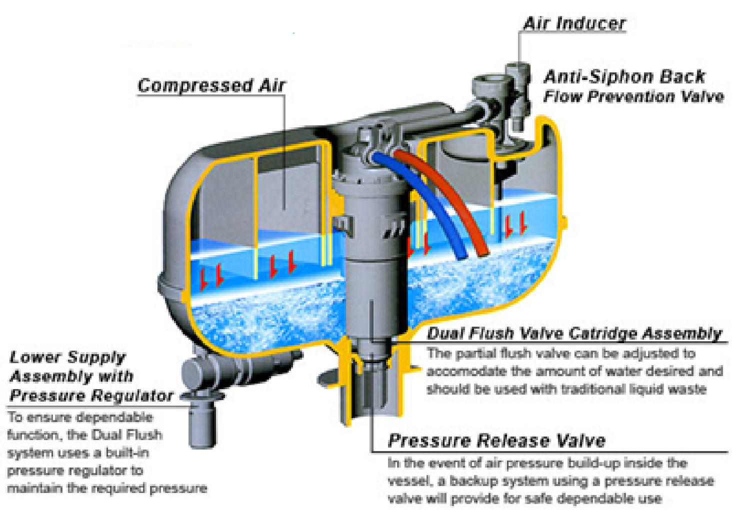


Figure 52.Dual flush toilets (FOREMOST 2009).

Savings in water consumption can also be achieved using low-flush water urinals or waterless urinals. Figure 53 shows a cross section in a waterless urinal that uses a special drain that traps urine below a blue liquid which forms a barrier against sewer vapor escape. The blue liquid has lower density than urine which allows urine to sink below the blue liquid. This waterless urinal can achieve three benefits by reducing maintenance, reducing water consumption, and improving indoor air quality. On the other hand, waterless urinals require limited operating costs as the blue liquid cartage needs to be replaced 2 to 4 times a year due to the sediments that are collected in the cartage. The replacement of the cartage is simple and takes 3 to 4 minutes (Waterless Co. Inc. 2009).

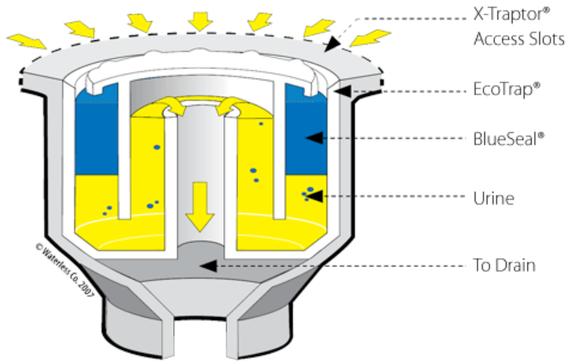


Figure 53. Cross section in waterless urinal (Waterless Co. Inc. 2009).

Water efficient faucets can also provide savings in water consumption through a reduction in water discharge. Water flow in these faucets can be controlled either mechanically or electronically, as shown in Figure 54. A controlled faucet delivers water in a pre-set amount of water and then shuts off automatically when the user moves away from the faucet range. Controlled faucets can be installed as new fixtures and provide water savings up to 70% compared to regular faucets. These faucets can also provide proportional savings in water heating energy, water treatment and sewage due to the savings in water consumption (Schultz Communications 1999).

Figure 54. Mechanical and electronic faucets.

Manual faucets can also be upgraded using flow restrictors or aerators, as shown in Figure 55. Flow restrictors are washers-like disks that are installed in the faucet head to reduce its water flow. These flow restrictors can reduce maximum flow to 0.5 to 2.5 gallons per minute. Flow aerators replace the faucet head screen to lower the water flow by adding air to water stream. Aerators increase the effectiveness of faucets and decrease their water flows. Despite the fact that aerators allow less water to flow through faucets, they provide unnoticeable difference in their performance (Schultz Communications 1999).

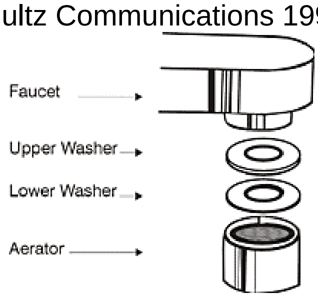


Figure 55. Aerators upgrade of manual faucets (Schultz Communications 1999).

4.5 LEED CERTIFICATION REQUIREMENTS FOR REST AREAS

Leadership in Energy and Environmental Design (LEED) is an ecological-oriented building certification program that runs under the supervision of the U.S. green Building Council (USGBC). The USGBC is a nonprofit organization founded in 1993 which promotes sustainability and green building design and construction. The USGBC has developed the LEED rating system in order to improve buildings performance in five key areas: energy efficiency, indoor environmental quality, materials selection, sustainable site development, and water savings.

Several rating systems have also been developed by the USGBC according to the purpose and status of the building under consideration. These rating systems include (i) new construction rating system for new buildings; (ii) existing buildings rating system for existing buildings; (ii) commercial interiors rating system which helps tenants and designers to make sustainable choices; (iii) schools rating system which rates the features of the design, construction, and spaces of schools; (iv) healthcare rating system which addresses the unique needs of healthcare services; (v) neighborhood development rating system which integrates the measures of smart growth, urbanism, and green buildings with neighborhood design; and (vi) homes rating system which categorizes the design and construction of green homes (USGBC (b) 2009).

The potential LEED certification of Illinois rest areas can be achieved using the LEED rating system for existing buildings which is divided into seven main divisions: 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). Each of these seven divisions is divided into subdivision(s) which determines what items need to be fulfilled in order to earn LEED credits, as shown in Table 12 and Table 13. A LEED certified project should fulfill all the prerequisites and earn a sufficient number of points to achieve the desired certification level. Four certification levels are available for ranking green buildings using the LEED rating system: certified level which requires 40 – 49 points; silver level which requires 50 – 59 points; gold level which requires 60 – 79 points; and the platinum level which requires 80 points or more, as shown in Figure 56 (USGBC (c) 2009).

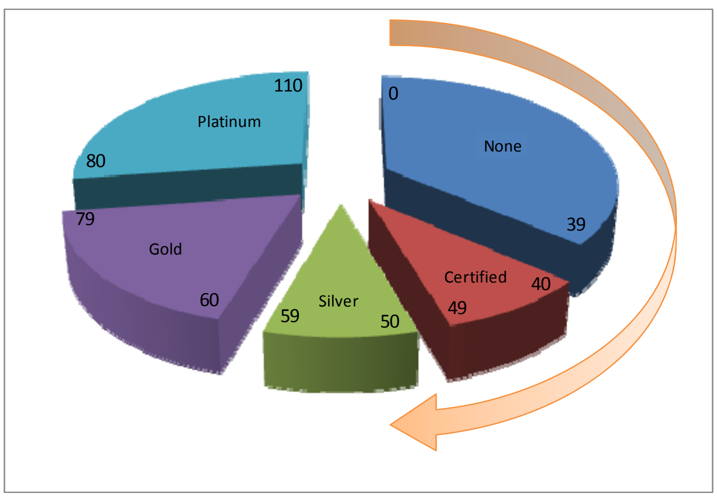


Figure 56. Different levels of the LEED rating system for existing buildings 2009, (modified, Miranda 2005).

Table 12. Subdivision of three Main Divisions of LEED Rating System for Existing Buildings, Version 2009 (USGBC (c) 2009)

#	Subdivisions	Max. Possible points
Sustainable Sites (SS) (26 Possible points)		
1.0	LEED Certified Design and Construction	4
2.0	Building Exterior and Hardscape Management Plan	1
3.0	Integrated Pest Management, Erosion Control, and Landscape Management Plan	1
4.0	Alternative Commuting Transportation	3-15
5.0	Site Development-Protect or Restore Open Habitat	1
6.0	Stormwater Quantity Control	1
7.1	Heat Island Reduction-Nonroof	1
7.2	Heat Island Reduction-Roof	1
8.0	Light Pollution Reduction	1
Energy and Atmosphere (EA) (35 Possible points)		
P1*	Energy Efficiency Best Management Practices—Planning, Documentation, and Opportunity Assessment	Required
P2*	Minimum Energy Efficiency Performance	Required
P3*	Fundamental Refrigerant Management	Required
1.0	Optimize Energy Efficiency Performance	1-18
2.1	Existing Building Commissioning-Investigation and Analysis	2
2.2	Existing Building Commissioning-Implementation	2
2.3	Existing Building Commissioning-Ongoing Commissioning	2
3.1	Performance Measurement-Building Automation System	1
3.2	Performance Measurement-System Level Metering	1-2
4.0	Onsite and Off-site Renewable Energy	1-6
5.0	Enhanced Refrigerant Management	1
6.0	Emissions Reduction Reporting	1
Materials and Resources (MR) (10 Possible points)		
P1*	Sustainable Purchasing Policy	Required
P2*	Solid Waste Management Policy	Required
1.0	Sustainable Purchasing-Ongoing Consumables	1
2.0	Sustainable Purchasing-Durable Goods	1-2
3.0	Sustainable Purchasing-Facility Alterations and Additions	1
4.0	Sustainable Purchasing-Reduced Mercury in Lamps	1
5.0	Sustainable Purchasing-Food	1
6.0	Solid Waste Management-Waste Stream Audit	1
7.0	Solid Waste Management-Ongoing Consumables	1
8.0	Solid Waste Management-Durable Goods	1
9.0	Solid Waste Management-Facility Alterations and Additions	1

*P: Prerequisite for acquiring a LEED certificate

Table 13. Subdivision of three Main Divisions of LEED Rating System for Existing Buildings, Version 2009 (USGBC (c) 2009)

#	Subdivisions	Max. Possible points
Indoor Environmental Quality (IEQ) **(15 Possible points)**		
P1*	Minimum Indoor Air Quality Performance	Required
P2*	Environmental Tobacco Smoke (ETS) Control	Required
P3*	Green Cleaning Policy	Required
1.1	Indoor Air Quality Best Management Practices-Indoor Air Quality Management Program	1
1.2	Indoor Air Quality Best Management Practices-Outdoor Air Delivery Monitoring	1
1.3	Indoor Air Quality Best Management Practice-Increased Ventilation	1
1.4	Indoor Air Quality Best Management Practices-Reduce Particulates in Air Distribution	1
1.5	Indoor Air Quality Best Management Practices-Indoor Air Quality Management for Facility Alterations and Additions	1
2.1	Occupant Comfort-Occupant Survey	1
2.2	Controllability of Systems-Lighting	1
2.3	Occupant Comfort-Thermal Comfort Monitoring	1
2.4	Daylight and Views	1
3.1	Green Cleaning-High Performance Cleaning Program	1
3.2	Green Cleaning-Custodial Effectiveness Assessment	1
3.3	Green Cleaning-Purchase of Sustainable Cleaning Products and Materials	1
3.4	Green Cleaning-Sustainable Cleaning Equipment	1
3.5	Green Cleaning-Indoor Chemical and Pollutant Source Control	1
3.6	Green Cleaning-Indoor Integrated Pest Management	1
Water Efficiency (WE) **(14 Possible points)**		
1.0	Minimum Indoor Plumbing Fixture and Fitting Efficiency	Required
2.0	Water Performance Measurement	1-2
3.0	Additional Indoor Plumbing Fixture and Fitting Efficiency	1-5
4.0	Water Efficient Landscaping	1-5
5.0	Cooling Tower Water Management	1-2
Innovation in Operations (IO) **(6 Possible points)**		
1.0	Innovation in Operations	1-4
2.0	LEED Accredited Professional	1
3.0	Documenting Sustainable Building Cost Impacts	1
Regional Priority (RP) **(4 Possible points)**		
1.0	Regional Priority	1-4

*P: Prerequisite for acquiring a LEED certificate

4.6 DECISION MAKING AND OPTIMIZATION TECHNIQUES FOR UPGRADING REST AREAS

Decision making can be defined as the process of identifying and choosing alternatives based on the preferences of the decision maker. The process of making decision includes identifying objectives and goals of the decision problem, identifying possible alternatives and constrains, and selecting the best alternative that most fits the problem under consideration. Several techniques have been introduced in computer science and mathematics that aids decision makers in: 1) identifying alternatives with the highest probability of success and effectiveness, and 2) identifying the alternative that best fits the decision making goals, objectives, and constrains(Harris 1998). Optimization is a division of decision making which aims at either maximizing or minimizing objective function(s). The next section discusses the Life Cycle Cost Analysis (LCCA) which can be used to analyze the performance of energy saving alternatives and to aid in selecting the most cost effective option. The following section discusses three widely used optimization techniques (evolutionary algorithms, dynamic programming, and weighted linear and integer programming) that can be used to optimize the upgrade decisions in Illinois rest areas.

4.6.1 Life-Cycle Cost Analysis

Life-Cycle Cost Analysis (LCCA) is an economical method for evaluating product/project alternatives where all costs associated with an alternative throughout its lifecycle are taken into consideration. This method is suitable for evaluating building upgrade and design alternatives that satisfy the same requirements of performance including occupant comfort, engineering standards, system reliability, and aesthetics considerations; however, they differ in one or more elements of cost. These alternatives need to be compared in order to maximize net savings using Life-Cycle Cost (LCC) (Fuller and Petersen 1995). The LCC of an upgrade/ design alternative is calculated by summing up all costs starting from the purchasing/construction phase till the end of the study period. These costs include, initial costs, energy and water costs, operating and maintenance costs, replacement costs, residual values, and other costs.

The initial costs may include any capital investment for land acquisition, construction, and/o requipments needed for the facility. The energy and water costs are calculated based on consumption, current rates, and price projection and they are usually difficult to predict with high accuracy. Maintenance and repair costs are also difficult to estimate as they vary significantly from one building to another. Some guides are available to estimate these costs such as the Facility Maintenance and Repair Cost Reference (M&R cost reference) and The U.S. Army Corps of Engineers (USACE). Replacement costs are calculated based on the estimated life of the building system and the length of the study period. The residual value represents the remaining value of the system at the end of the study period or at the time the system is replaced within the study period. If the service life of the system is greater than the study period, a reasonable estimate to calculate the residual value of the system is based ona linear proportion to its initial cost.

In order to calculate the LCC, all the aforementioned costs need to be converted to present values based on a reasonable discount/interest rate. This rate can be determined based on the investor's rate of return. For Feral energy and water conservation projects, the discount rate is determined based on the Federal Energy Management Program (FEMP)(WBDG (a) 2010). Eq. (1) shows the LCC calculations of a design alternative; Figure 57shows an example for the LCC cash flow with the included costs. The purpose of the LCCA is to choose the best alternative that provides the lowest LCC of all alternatives and consistent with the required quality and functionality.

$LCC = IC + P_{E\&W} + P_{OMR} + P_R - P_{RV} + P_O$(Eq. 1) (WBDG (a) 2010)

Where: IC: initial costs;$\mathrm{P}_{\mathrm{E\&}W}$: present value of energy and water costs; $\mathrm{P}_{\mathrm{OMR}}$: present value of operation, maintenance, and repair costs;P_{R}: present value of replacement costs; P_{RV}: present value of residual value; and P_{O}: present value of other costs.

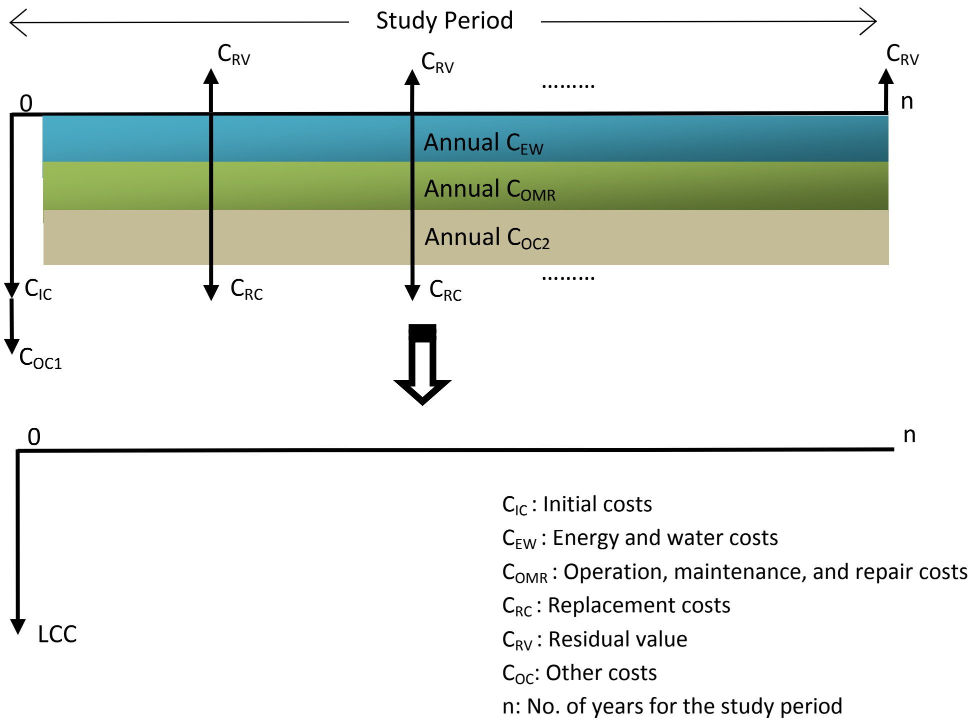


Figure 57. LCC cash flow example.

4.6.2 Evolutionary Algorithms

Evolutionary algorithms (EAs) are search algorithms that simulate the biological evolution and behavior of species (Elbeltagi et al. 2005). The main concept of EAs is that the environment causes natural selection of species and the survivor of the fittest which results in a rise in the population fitness. The process of finding the near optimum solution in EAs is summarized following six main steps: (1) creating a population of individuals with a random genome; (2) the values of the objective function is calculated for each individual of the population; (3) a fitness value can be assigned for each individual of the population based on the objective function and characteristics of the solution candidate; (4) a selection process is carried out to filter solutions based on their fitness and allow solutions with good fitness to survive and reproduce with higher probability than solutions with less fitness; (5) offspring are created by combining or varying genotypes in the parent solutions through combination and mutation processes; and (6) repeat the same procedure starting from step 2 unless a termination condition is satisfied(Weise 2009). Figure 58 shows the process of EAs in searching for the near optimum solution.

Several algorithms have been developed in EAs including: genetic algorithms, genetic programming, evolution strategies, learning classifier systems, and Evolutionary programming. These different evolutionary algorithms are classified based on the problem space and search mechanism. The selection of the appropriate optimization algorithm depends on the characteristics of the problem under consideration. EAs have several benefits over traditional optimization techniques including: (1) they can identify global optimum or near optimum solution; (2) EAs can deal with nonlinear objective functions and a large number of variables; (3) EAs are capable of optimizing problems with multi-objective functions; (4) EAs require little problem specific knowledge as compared to other methods. The limitations of EAs include: (1) the optimum solution is not guaranteed in a finite amount of time; (2) parameter tuning is achieved mostly by trial and error; however, it can be remediated by self-adaptation (Elbeltagi, et al. 2005; Weise 2009).

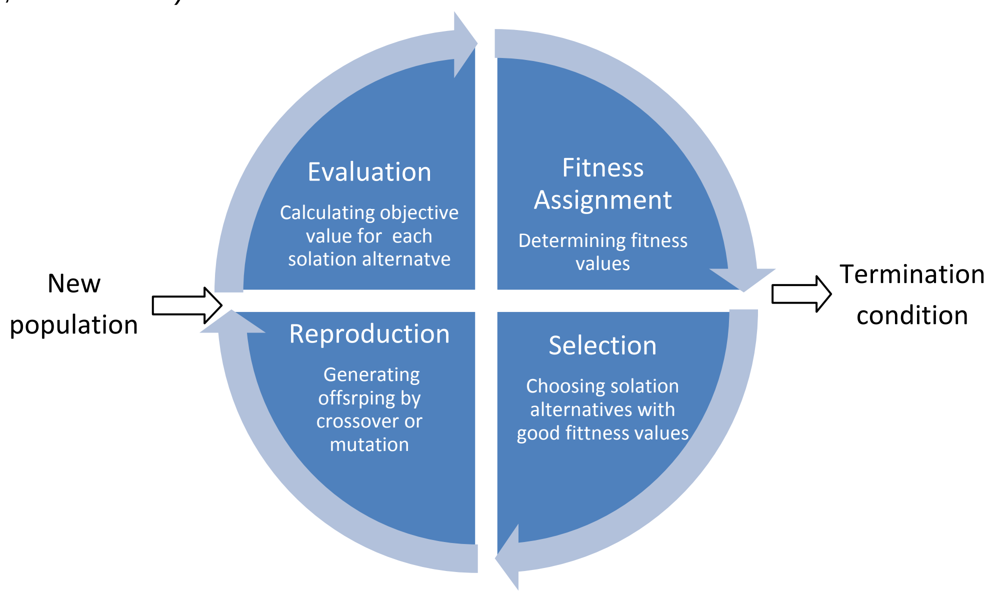


Figure 58. Evolutionary algorithms process (Weise, 2009).

4.6.3 Dynamic Programming

Dynamic programming is a powerful optimization technique that makes a sequence of interrelated decisions. It is a recursive method which adds information to a stack each time until stopping conditions are met. Once the stopping conditions are met, the optimum solution is revealed by removing information from stack in an appropriate sequence. The dynamic programming problem is divided into simple sub-problems where optimization can be applied systematically to these sub-problems. The approach of dynamic programming can be summarized into four main steps: (1) defining a small part of the problem starting from the end and finding the optimum solution for this part; (2) enlarging the small part of the problem slightly and finding the optimum solution based on the previous optimum solution; (3) repeating step 2 until enlarging the small problem to reaches to the original problem where the stopping conditions are met; and (4) tracking back the optimum solution through the whole problem until the small part of the problem initiated at step 1 (Chinneck 2006).

Figure 59 shows a typical problem for dynamic programming where the goal of this problem is to find the shortest path from node 1 to node 8. Arcs in this network represent the travel time from node i to node j (tij). Also, the movement direction between these nodes is indicated with the arrows directions. Finding the optimum solution of this problem starts at node 8. At this stage, the dynamic programming approach searches for the shortest time from node 8 to node 8 which is 0. After that, the next stage starts to account for other nodes such as nodes 5 and 7. Again, the dynamic programming approach searches for the shortest time between node 8 and nodes 5 and 7, as shown in Eq.(2). This process is repeated until reaching to node 1. Finally the optimum solution is revealed and the shortest path from node 8 to node 1 is determined.

$$\text{Shortest time from origin to node } j = \text{Min}_{i,j}\left\{\text{Shortest time from origin to solved node } i + \text{Shortest time from solved node } i \text{ to node } j\right\} \quad \text{.....Eq. (2)} \qquad \text{(Chinneck 2006)}$$

Dynamic programming has several benefits in optimizing decision-making problems because (1) it divides the problem under consideration into simple sub-problems that can be optimized easily; (2) it is capable of optimizing most multi stage decision making problems; (3) it can identify the global optimum solution; and (4) it can be applied to optimize many problems including minimizing energy consumption. The main limitations of traditional dynamic programming are: (1) it is limited to single objective problems; and (2) its computational time for large scale decision problems is often impractical. These limitations however can be overcome by new algorithms such as Approximate Dynamic Programming (ADP) which can optimize large problems in a practical time, and multi-objective dynamic programming which can deal with more than one objective function.

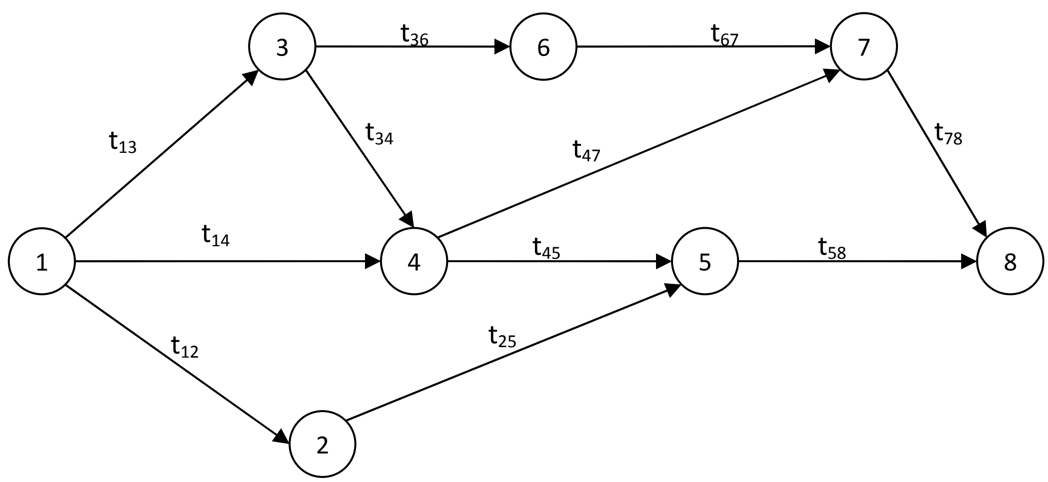


Figure 59.Typical problem of dynamic programming.

4.6.4 Weighted Linear and Integer Programming

The concept of linear programming is to find the highest or the lowest point of an objective function. Figure 60 shows a simple example for unconstrained linear programming, where each point on the curve represents a solution for the problem. The problem has infinite number of solutions since it is unconstrained problem with single variable. The purpose of linear programming is to search for the best solution among the available solutions for the problem, the best solution depends on the type of the problem under consideration; it might be the solution that provides the maximum savings or the solution that provides the minimum consumption of available resources (Chinneck 2006).

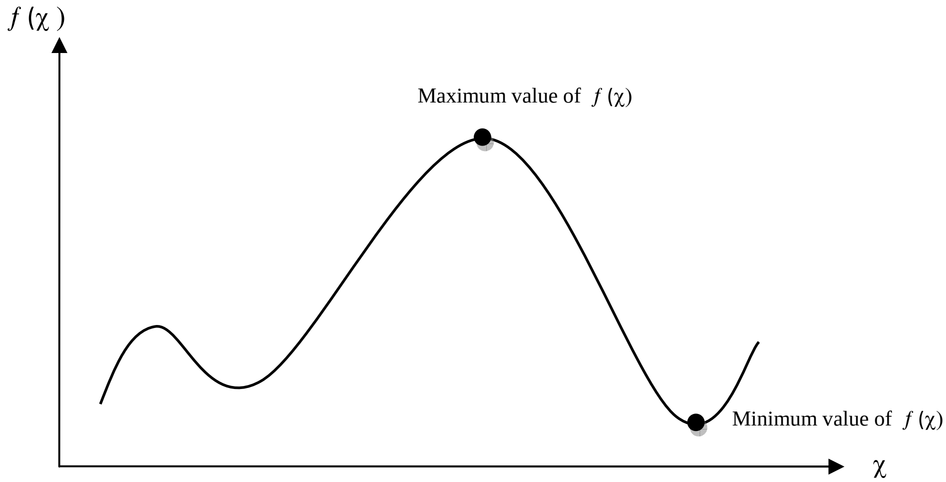


Figure 60. Simple unconstrained optimization (Chinneck 2006).

Decision problems are not always unconstrained; however, they are limited with the available resources and other variables that might narrow the available solutions of the problem. The optimization of constrained problems is much harder than unconstrained problem since it searches for the best solution that complies with all constraints. The main elements of constrained optimization problems are decision variables, objective function, and constrains. Decision variables represent values of parameters that need to be adjusted or controlled in the problem. The values of these variables are not known before carrying out the optimization where the goal of the optimization is to find the values of these variables that provide the best outcome of the objective function. The objective function is a mathematical expression for the goal of the problem which needs to be minimized or maximized and it is expressed in terms of the defined decision variables. Constraints are mathematical expressions which define limits in possible solutions in terms of decision variables (Chinneck 2006).

Linear programming requires that all the mathematical representations in the objective function and the decision variables be linear. Linear programming is widely used and can optimize large problems with a large number of variables (Chinneck 2006). The decision variables of linear programming are not always continuous as they might be defined as integers to represent non fractional variables such as number of products. In this case, this problem is called integer programming. If some of the decision variables are restricted to be integers, the problem is called mixed integer programming. However, if all decision variables are integers, the problem is called pure integer programming(Bradley, et al.1977).Traditional linear programming techniques deal with single objective function however this limitation can be overcome with a weighted linear programming approach. This approach combines the multiple objectives in a single objective function by assigning a weight for each objective function that represents its relative importance.

CHAPTER 5 POTENTIAL LIST OF "GREEN FRIENDLY" BEST MANAGEMENT PRACTICES

5.1 LIFE CYCLE COST ANALYSIS AND CARBON FOOTPRINT OF PROMISING "GREEN FRIENDLY" MEASURES

Life-Cycle Cost Analysis (LCCA) is an economical method for evaluating product/project alternatives where all costs associated with an alternative throughout its life cycle are considered. This method 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, they differ in one or more elements of cost (Fuller and Petersen 1995). Furthermore, this method is suitable for comparing new technologies with existing/current technologies in order to estimate net savings, payback periods as well as potential benefits that could be achieved by applying these new technologies. The next section provides LCCA for seven technologies that can be utilized in rest areas as well as their potential environmental benefits in terms of reductions in carbon foot print. The LCCA accounted for possible incentives that are available through the public sector electric efficiency program that is offered by the Illinois Department of Commerce and Economic Opportunity (DCEO), where applicable. The analysis accounted for these incentives for only Prairie View and Funks Grove since these incentives are applicable for the Illinois electric service territories of Ameren Illinois Utilities and Commonwealth Edison Company ("ComEd").

5.1.1 Energy Efficient Lighting

According to the Department of Energy (DOE), lighting consumes approximately 22% of electrical consumption in the U.S. This highlights the importance of utilizing the most energy efficient lighting systems such as LED, induction and T8 fluorescent lighting in order to minimize energy consumption and emissions of carbon dioxide. Light Emitting Diodes (LEDs) are solid state devices which are used to convert electricity to light. It is characterized by potential high efficiency and long life compared to traditional sources of light.

Induction lighting is another technology which is characterized by high frequency light sources. Induction lighting follows the same basic principles of visual radiation of conventional electrical power such as fluorescent lamps. The main difference between induction lighting and fluorescent lighting is that induction lighting does not operate with filaments and electrodes. The main advantage of not having electrodes (metal contact) in induction lighting is that when a bulb heats up, the metal and glass components expand and contract by different amounts. After many cycles of heating and cooling, the lamp's glass becomes stressed by these thermal expansions and contractions. This eventually leads to air leaks and the lamp becomes no longer functional. Therefore, the presence of electrodes in fluorescent lamps imposes many restrictions on lamp design, performance and lamp life (AITI 2008). The elimination of filaments and electrodes results in a lamp of very high durability rated at more than 100,000 hours. Induction lighting is based on the principles of induction and light generation via a gas discharge (Lai and Lai 2004). Induction lamps are most suitable for high ceiling applications where lamps are difficult to reach, costly to replace or hazardous to access. Also, induction lamps are suitable for applications that have extremely cold temperatures. On the other hand, the main drawback of induction lighting is its high initial cost relative to other types of lamps (Induction lighting and electrodeless lamps 2007).

The LCC components of installing/replacing lighting fixtures include initial cost, operating cost, and replacement cost, as shown in Figure 61. The initial cost includes fixtures purchase cost, bulbs purchase cost and labor installation cost of the lighting fixture. The operating cost represents annual electricity cost for powering lamps that often have annual increases due to inflation and the increasing cost of fossil fuel used for power generation. The replacement cost includes bulb purchase cost as well as labor cost for replacing lighting bulbs.

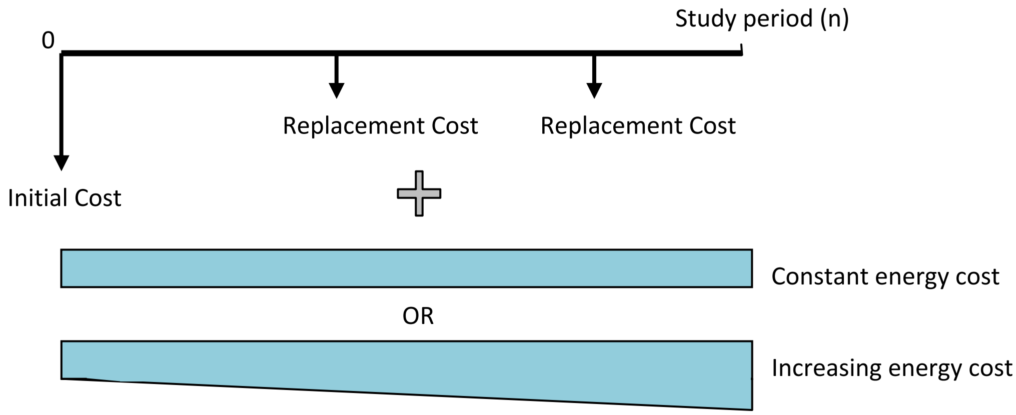


Figure 61. LCC components of lighting fixtures.

LED and induction lighting provide several benefits over traditional lighting in terms of energy consumption, maintenance cost, and carbon footprint; however their major drawback is their initial cost. In order to identify the feasibility of replacing the current lighting in rest areas, a LCC analysis needs to be conducted in order to determine cost components as well as payback periods of lighting replacement in rest areas. Due to the diversity of light characteristics, shapes, fixtures, and aesthetics requirements for each building, a spreadsheet was developed in order to (1) analyze the feasibility of utilizing 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 developed spreadsheet takes into consideration the aforementioned LCC components, utility cost, annual increase in utility cost, discount rate, incentives, and a study period of 30 years.

5.1.1.1. Interior Lighting

The aforementioned spreadsheet can be easily used to analyze the impact of replacing existing interior lighting with LED or induction lighting on energy savings and reductions in carbon footprint for any rest area. The spreadsheet was used to analyze two example scenarios for replacing existing T12 Fluorescent lighting in the Prairie View rest area with LED tube lamps. The first example is designed to maintain existing lighting fixtures and replaces only the light bulbs leading to a reduction in luminance levels, as shown in Table 14. The second example considers replacing the current T12 lighting bulbs with LED bulbs and adding new LED lighting fixtures in order to maintain the same luminance levels in the rest area, as shown in Table 15.

The LCCA assumptions of Example 1 and the other input parameters that are used in the developed spreads sheet are summarized in Table 14. The installation and fixture costs are set to zero since this example considers only the replacement of the fluorescent light bulbs with LED light bulbs using the same fixture. Also, labor replacement cost is set to zero since it can be performed by existing maintenance crews. Figure 62 shows the cumulative LCC for both bulbs, cumulative savings over the 30 years study period, and the estimated CO2 emissions during the study period. The impact of replacing fluorescent lighting with LED on carbon footprint is analyzed by calculating the CO2 emissions generated by the consumed energy of each alternative.

Table 14. LCC Spreadsheet Assumptionsfor LED Replacement Example 1 that Allows Luminance Reduction in Prairie View Rest Area

Economic and general assumptions		
Annual interest rate (%)	2%	
Average electricity cost ($/KWH)	0.093	
Average annual increase in electricity cost (%)	5%	
Lighting hours per day (hrs)	24	
Fixtures input parameters	**Current fixtures/bulbs**	**Replacement fixtures/bulbs**
Type of bulb	Fluorescent T12	LED
Number of bulbs	26	26
Luminance (lumen/bulb)	2,900	1,500
Total Luminance (Lumen)	75,400	39,000
Life time (hours)	20,000	50,000
Consumption (watt)	40	15
Bulb cost ($)	3.5	75

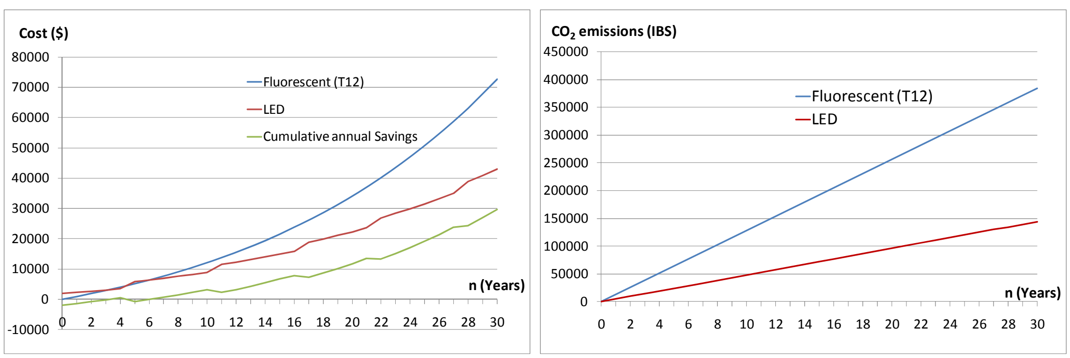


Figure 62. Cumulative LCC and CO2 emissions for LED replacement - example 1.

The results of analyzing Example 1 indicates that the replacement of fluorescent bulbs with LED light bulbs provide a payback period of 4.9 years. It should be noted that this example considered only the replacement of the tube fluorescent lighting bulbs with the same number of LED tube lighting bulbs which resulted in a reduction of 48.3% in luminance. In order to achieve the same luminance of the fluorescent lighting, additional LED fixtures need to be added.

Example 2 was analyzed to consider this scenario which requires the addition of fourteen LED fixtures to provide a luminance in the rest area similar to those generated by fluorescent bulbs, as shown in Table 2. The results of this analysis in Example 2 indicate that its payback period is infeasible. Figure 63 shows the cumulative costs, cumulative savings, as well as CO2 emissions generated by energy consumption for Example 2. It should be noted that luminance is not the only factor that determines the clarity of a lighting source. Luminance determines the amount of light produced by a lamp. Other factors should also be considered such as the luminance performance throughout the life of a light bulb and color rendering index which determines the clarity of color appearance (Light Sout Services 2010).

Table 15. LCC Spreadsheet Assumptionsfor LED Replacement Example 2 that Maintains Existing Luminance Levels

Fixture input parameters	**Current fixtures/bulbs**	**Replacement fixtures/bulbs**
Type of bulb	Fluorescent (T12)	LED
Number of bulbs	26	50
Luminance (lumen/bulb)	2,900	1,500
Total luminance (lumen)	75,400	75,000
Life time (hours)	20,000	50,000
Consumption (watt)	40	15
Bulb cost ($)	3.5	75
Fixture cost without bulb ($/each)	0	41.9
Installation cost (Labor) ($/each)	0	61.1
Number of new fixtures	0	12

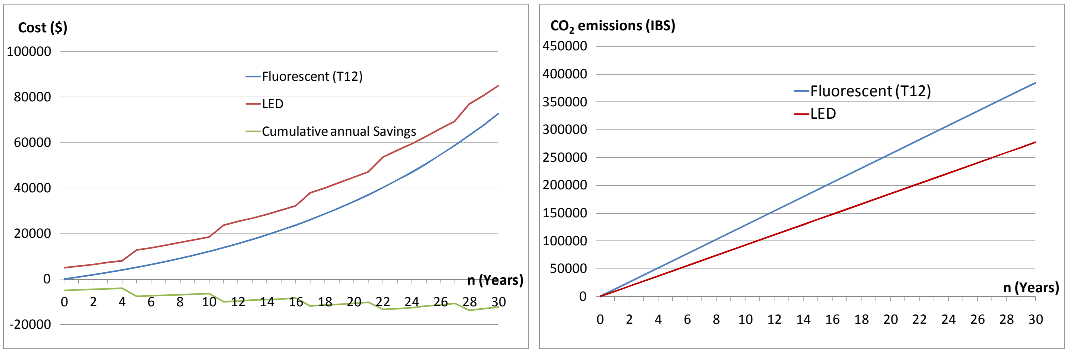


Figure 63.Cumulative LCC and CO2 emissions for LED replacement - example 2.

Another life cycle cost analysis was conducted to evaluate the cost-effectiveness of replacing current T12 bulbs with efficient 28W T8 bulbs in Prairie View, Funks Grove, and Pride of the Prairie rest areas. During the site visit of these rest areas, the research team found that T12 bulbs were used in (1) the bathrooms, mechanical, and storage rooms of the Prairie View rest area; (2) the mechanical room of Funks Grove rest area; and (3) the bathrooms, lobby, and mechanical room of Pride of the Prairie rest area. Table 16 and Table 17 provide a detailed analysis of replacing current T12 bulbs with efficient T8 bulbs in these three rest areas. This analysis assumes that the number of efficient T8 bulbs is slightly adjusted to provide total output lumens that are similar to or higher than the current levels in these rest areas, as shown in Table 16 and Table 17. The results of this analysis show that these lighting replacements provide (a) reduction in annual energy consumptions and costs; and (b) payback periods that range from 0.24 year to 5.27 years in the three rest areas which highlights the cost effectiveness of these replacements, as shown in Table 16 and Table 17.

5.1.1.2. Exterior Lighting

Another LCCA was conducted to analyze the impact of the one-for-one replacement of current exterior lighting in Prairie View, Funks Grove, and Pride of the Prairie rest areas with LED and induction lighting. The main assumptions of this analysis include 5% annual increase in utility bills, 2% discount rate, and average lighting operation of 12 hours per day. Table 3 shows the characteristics of current and replacement lighting that are used in the LCC analysis for Prairie View, Funks Grove, and Pride of the Prairie rest areas. Due to the unavailability of the exact brand and luminance characteristics of current exterior lighting in these rest areas, reasonable assumptions were made giving the fact that the luminance characteristics of HPS bulbs that are currently used in these rest areas are not significantly affected by the type of lighting manufacturer. The LCC for the Prairie View rest area considered lighting replacement for the parking lot in the northbound facility. The parking lot lighting consists of four lighting poles each with single lamp of 400 watt HPS, four poles each with double lamps of 400 watt HPS each, and two poles with a single lamp of 150 watt HPS. The analysis considered the replacement of these lights with the lighting fixtures identified in Table 18. The cumulative cost and savings for replacing the current parking lot lighting of Prairie View rest area are shown in Figure 64. In addition, the carbon footprint and reductions in CO2 emissions due to these replacements are shown in Figure 65. It should be noted that this one-for-one replacement is expected to reduce current light output (lumen) by 66.5% and 61.7% for LED and induction lighting, respectively.

The current exterior lighting of Funks Grove rest area consists of two poles with 400 watt HPS, 32 poles with 250 watt HPS, three underpass fixtures of 55 watt, and two lighting towers with eight lamps of 400 watt HPS each. The exterior lighting of Pride of the Prairie rest area (eastbound) consists of fifteen lighting poles with 400 watt HPS, and two lighting towers with six lamps of 400 watt HPS each. The analysis considered the replacement of these lighting fixtures with the lighting fixtures shown in Table 18. The cumulative cost and savings for Funks Grove and Pride of the Prairie rest areas are shown in Figure 66 and Figure 68, respectively. The carbon footprint and reductions in CO2 emissions are shown in Figure 67 and Figure 69 for Funks Grove and Pride of the Prairie rest areas, respectively. It should be noted that this one-for-one replacement for Funks Grove rest area will lead to 66.8% and 61.0% reduction in light output for LED and induction lighting, respectively. Similarly, this one-for-one replacement for Pride of the Prairie rest area will lead to 66.6%, and 62.2% reduction in light output for LED and induction lighting, respectively.

Based on the LCC analysis for the three rest areas, induction lighting outperforms current and LED lighting based on payback periods, energy savings, reductions in CO2 emissions, and service life. The payback periods for LED lighting replacement for Prairie View, Funks Grove and Pride of the Prairie rest areas are infeasible, 28.2, and 27.7 years, respectively. The payback periods for induction lighting replacement for Prairie View, Funks Grove and Pride of the Prairie rest areas are 4.7,4.3, and 4.4 years, respectively. Accounting for the public sector electric efficiency program incentives for Prairie View and Funks Grove, the payback periods for induction lighting are 4.5 years for Prairie View rest area and 4.1 years for Funks Grove rest area. These incentives are not applicable for LED lighting because LED lighting has a payback period that exceeds the maximum allowable 7 years specified by the program requirements. It should be noted that HPS lights have higher average lighting output (lumen) than LED and induction lighting; however LED and induction lighting have 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 however having low CRI causes some colors to appear washed out or to take a completely different color (Light Sout Services 2010).

Another upgrade that can be considered in Illinois interstate rest areas is the replacement of the current high pressure sodium or metal halide bulb that are used for the area light in the Code Blue emergency phones with LED retrofits. This will reduce the energy consumption of these Code Blue emergency phones by 95% as it reduces consumption from 91 watts to 4 watts. The developed spreadsheet was used to analyze this potential replacement based on the following assumptions: replacement cost of $100 per bulb including labor cost; 50,000hrs life for the LED retrofit; $13 replacement cost of the current lighting; 20,000hrs for HPS or MH bulbs; 24 operating hours; and the current utility rate at each rest area. The results of this analysis indicate that this replacement can produce annual savings of $71, $84, and $81 for the Prairie View, Funks Grove, and Pride of the Prairie rest areas, respectively. The payback periods for installing these LED retrofits are 17 months, 15 month, and 15 month for the Prairie View, Funks Grove, and Pride of the Prairie rest areas, respectively. Considering other incentives provided by Department of Commerce through its Energy Efficiency Portfolio Standard (EEPS), the payback period can be reduced to 5 months, 4 months, and 4 months for the Prairie View, Funks Grove, and Pride of the Prairie rest areas, respectively. It should be noted that the light of this LED replacement might not be visible during daytime; however it will be easily visible during nighttime for a distance of over half a mile.

Table 16. Replacement Analysis of Current T12 Bulbs with Efficient T8 Bulbsin Prairie View and Funks Grove Rest Areas

Rest area	Prairie View				Funks Grove	
	Bathrooms		Mechamical and storgae rooms		Mechanical room	
Lighting	Current bulbs	Replacement bulbs	Current bulbs	Replacement bulbs	Current bulbs	Replacement bulbs
Average electricity cost ($/KWH)	0.093		0.093		0.11	
lighting hours per day (hrs)	24		8		8	
Type of bulb	T12[1]	T8[2]	T12[1]	T8[2]	T12[3]	T8[2]
Number of bulbs	26	30	34	40	18	16
Design lumens (lumen/bulb)	2970	2645	2970	2645	2300	2645
Total lumens (Lumen)	77,220	79,350	100,980	105,800	41,400	42,320
Life time (hours)	20000	24000	20000	24000	20000	24000
Consumption (watt)	40	28	40	28	32	28
Bulb cost ($/each)	2.95	3.25	2.95	3.25	1.9	3.25
Fixture cost without bulb ($/each)	0	42	0	42	0	0
Installation cost (Labor) ($/each)	0	60	0	60	0	0
Number of new fixtures	0	2	0	3	0	0
Improvements in lumens levels	N/A	2.8%	N/A	4.8%	N/A	2.2%
Total initial cost ($)	77	302	100	436	34	52
Annual Energy cost - first year ($/year)	847	684	369	304	185	144
Annual energy savings - first year ($/year)	163		65		41	
Payback period (years)	1.45		4.96		0.44	

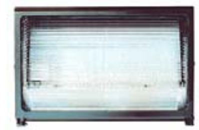
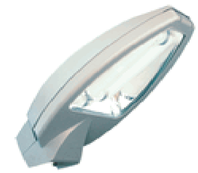
[1] Fluorescent T12 bulb model, Philips - F40T12 40W 835 ALTO
[2] Fluorescent T8 bulb model, Philips - F32T8 28W ADV830 EW ALTO
[3] Fluorescent T12 bulb model, Philips - F34T12 CW RS EW ALTO

Table 17. Replacement Analysis of Current T12 Bulbs with Efficient T8 Bulbs in Pride of the Prairie Rest Areas

Rest area	Pride of the Prairie					
	Bathroom		Mechanical rooms		Lobby and bathroom	
Lighting	Current bulbs	Replacement bulbs	Current bulbs	Replacement bulbs	Current bulbs	Replacement bulbs
Average electricity cost ($/KWH)	0.106		0.106		0.106	
lighting hours per day (hrs)	24		8		24	
Type of bulb	T12[1]	T8[2]	T12[1]	T8[2]	U-T12[3]	T8[2]
Number of bulbs	12	12	16	16	28	28
Design lumens (lumen/bulb)	2300	2645	2300	2645	2169	2645
Total lumens (Lumen)	27,600	31,740	36,800	42,320	60,732	74,060
Life time (hours)	20000	24000	20000	24000	18000	24000
Consumption (watt)	34	28	34	28	35	28
Bulb cost ($/each)	1.9	3.25	1.9	3.25	7.72	3.25
Fixture cost without bulb ($/each)	0	0	0	0	0	42
Installation cost (Labor) ($/each)	0	0	0	0	0	60
Number of new fixtures	0	0	0	0	0	14
Improvements in lumens levels	N/A	15.0%	N/A	15.0%	N/A	21.9%
Total initial cost ($)	23	39	30	52	216	1519
Annual Energy cost - first year ($/year)	379	312	168	139	910	728
Annual energy savings - first year ($/year)	67		30		182	
Payback period (years)	0.24		0.74		5.29	

[1] Fluorescent T12 bulb model, Philips - F34T12 CW RS EW ALTO
[2] Fluorescent T8 bulb model, Philips - F32T8 28W ADV830 EW ALTO
[3] Fluorescent U-shaped T12 bulb model, GE - 12203 – F35CW/U/6/WM

Table 18. Characteristics of Current and Replacement Lighting for Exterior Lighting of Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Light characteristic items	**Current Lighting**		**Replacement (LED lighting)**		**Replacement (induction lighting)**	
	Type	**Characteristics**	**Type**	**Characteristics**	**Type**	**Characteristics**
Mean lumens (lumen)	HPS 50w	3240	LED Wall-Pak Luminaire	2460	Light-Wall Pack	3400
Color temperature (Kelvin)		2100K		6000K		5000K
Color rendering index (CRI)		21		75		80
Life time (hours)		20000		50000		100000
Consumption (w)		60		56		40
Lamp cost ($)		14.69		-		102
Lamp and fixture cost ($)		-		495		360
Mean lumens (lumen)	HPS 150w	14000	LED Outdoor Luminaires	4800	Street Light-Cobra Head	6800
Color temperature (Kelvin)		2100K		5500K		5000K
Color rendering index (CRI)		21		65		80
Life time (hours)		24000		50000		100000
Consumption (w)		188		80		82
Lamp cost ($)		20		-		150
Lamp and fixture cost ($)		-		995		355
Mean lumens (lumen)	HPS 250w	25600	LED Outdoor Luminaires	8400	Street Light-Cobra Head	10200
Color temperature (Kelvin)		2100K		5500K		5000K
Color rendering index (CRI)		22		65		80
Life time (hours)		24000		50000		100000
Consumption (w)		300		140		120
Lamp cost ($)		20		-		210
Lamp and fixture cost ($)		-		1600		440
Mean lumens (lumen)	HPS 400w	45000	LED Outdoor Luminaires	15040	Street Light-Cobra Head	17000
Color temperature (Kelvin)		2100K		5500K		5000K
Color rendering index (CRI)		21		65		80
Life time (hours)		24000		50000		100000
Consumption (w)		464		225		204
Lamp cost ($)		20		-		270
Lamp and fixture cost ($)		-		2000		605

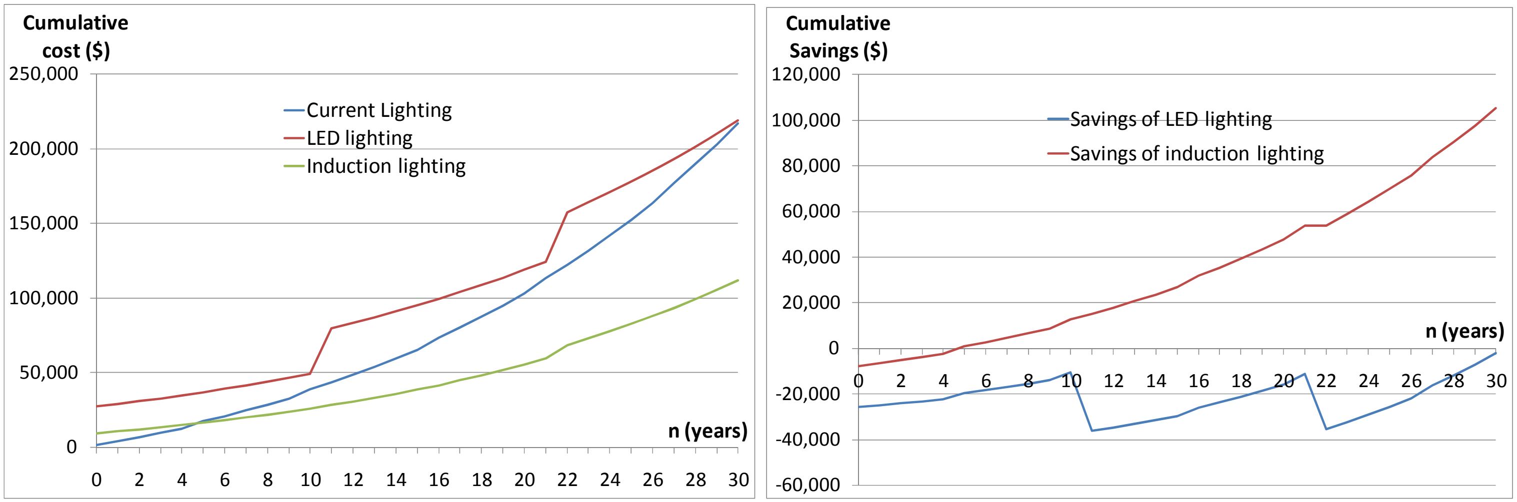


Figure 64. Cumulative cost and savings of replacing parking lot lighting with LED and induction lighting for Prairie View rest area – northbound.

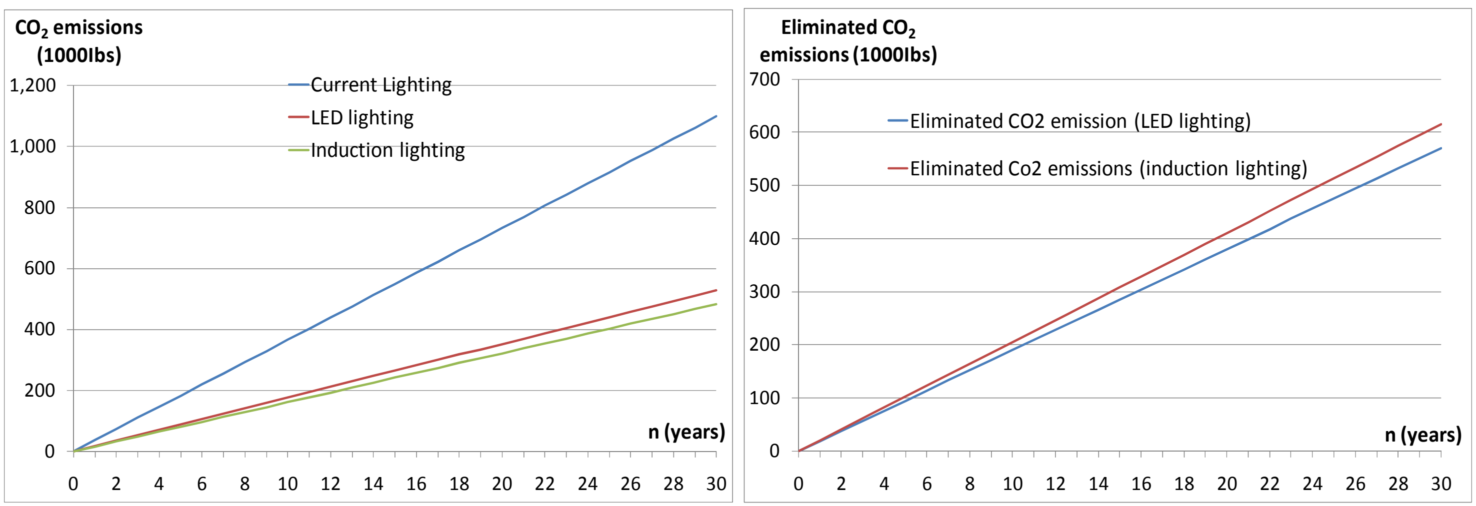


Figure 65. Cumulative carbon footprint and eliminated CO2 emissions for replacing parking lot lighting with LED and induction lighting for Prairie View rest area – northbound.

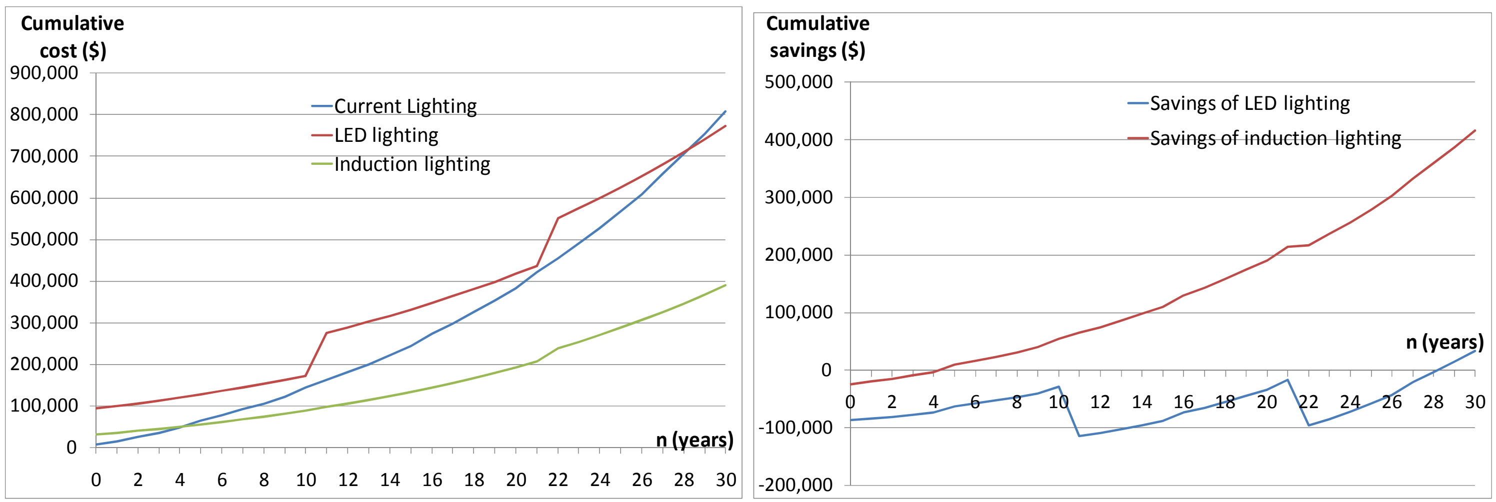


Figure 66. Cumulative cost and savings of replacing exterior lighting with LED and induction lighting for Funks Grove rest area.

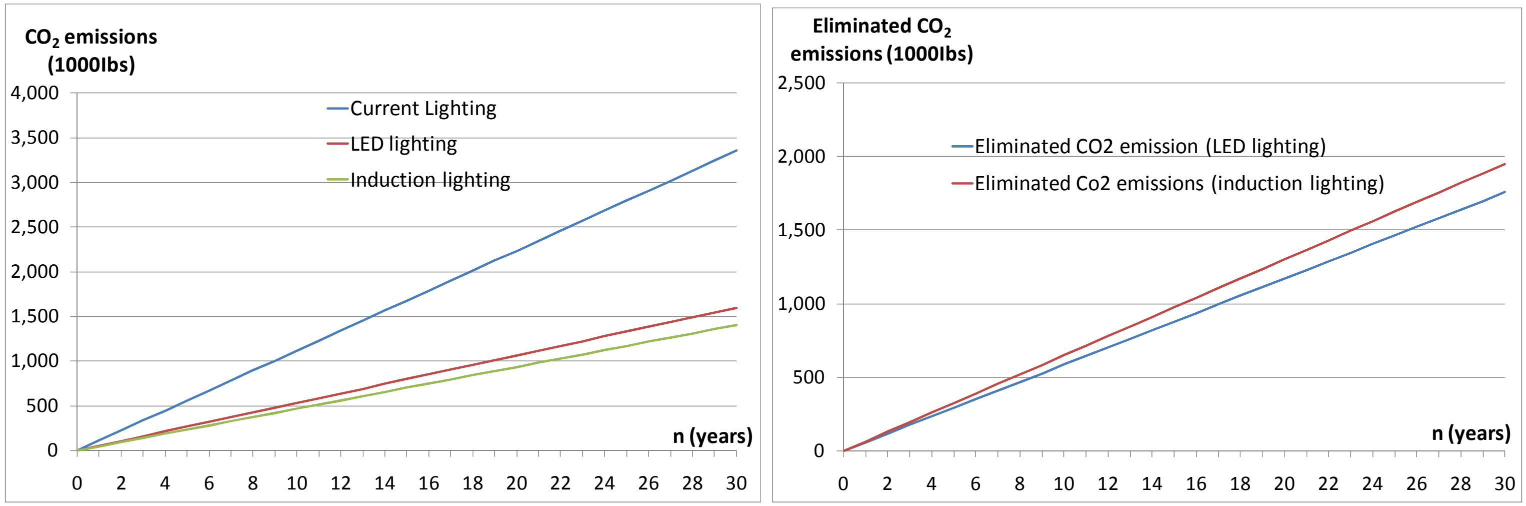


Figure 67. Cumulative carbon footprint and eliminated CO2 emissions of replacing exterior lighting with LED and induction lighting for Funks Grove rest area.

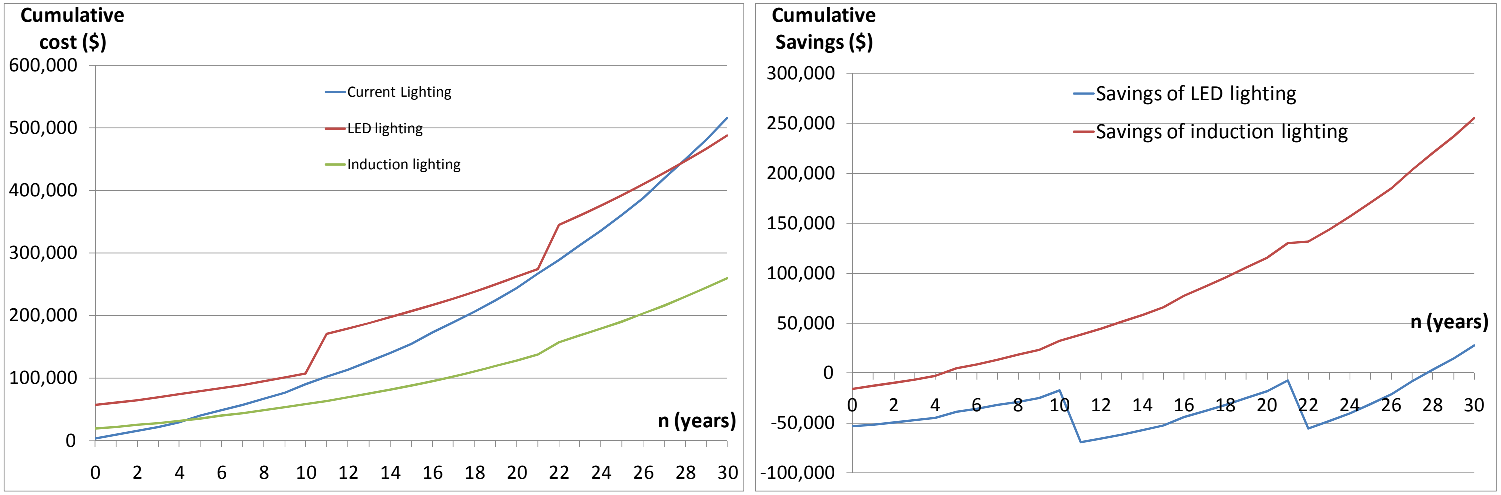


Figure 68. Cumulative cost and savings of replacing exterior lighting with LED and induction lighting for Pride of the Prairie rest area – eastbound.

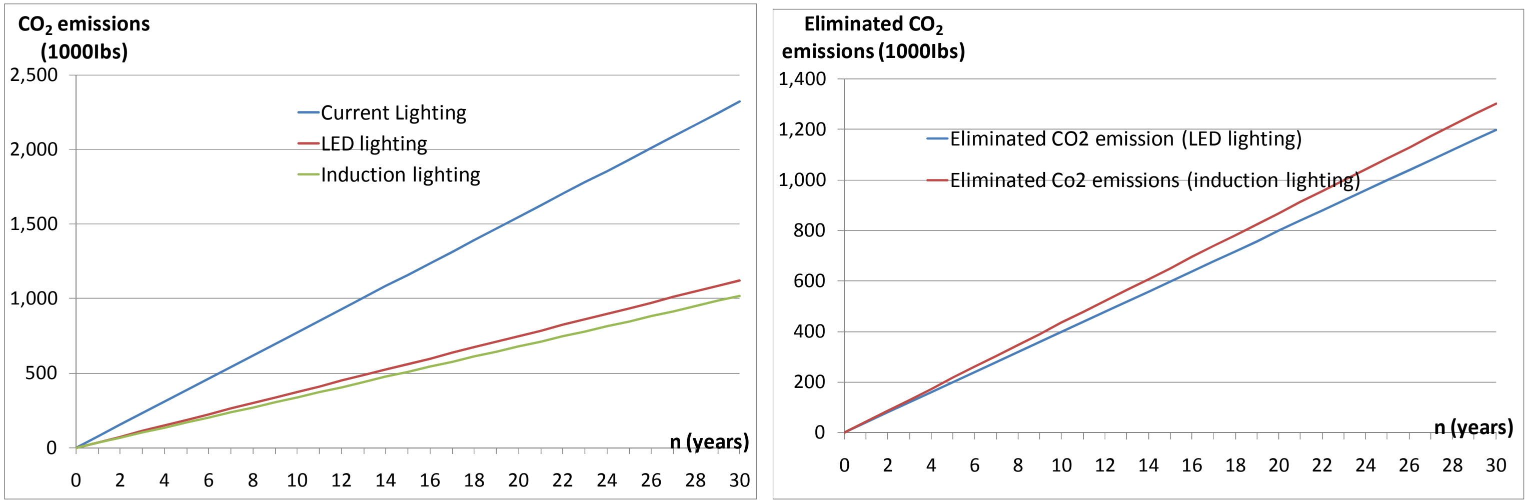


Figure 69. Cumulative carbon footprint and eliminated CO2 emissions for replacing exterior lighting with LED and induction lighting for Pride of the Prairie rest area – eastbound.

5.1.2 Motion Activated Lighting

Motion Activated Lighting (MAL) is a green technology that increases energy efficiency by activating light only when it is needed. MAL systems use motion sensors in order to detect the movement of a heat source in a specific area where the light is being activated. Once the heat source is out of reach, the MAL system remains in detection for a certain time and then it turns off the light automatically. The LCC components of incorporating this system in rest areas include initial cost and replacement cost. The initial cost of this system covers the cost of occupancy sensors as well as their installation cost. The installation cost varies based on several factors including: number of power sources feeding each room; number of occupancy sensors and control units; type of occupancy senor; type of surface where the sensor can be mounted or anchored; length of wire and conduit required for the system; and labor installation cost. The replacement cost covers the required cost to replace the motion sensor at the end of its life. Figure 70 shows the main LCC components of MAL systems. It should be noted that this system may require additional initial cost to replace existing lighting fixtures/bulbs if they are not compatible with MAL systems.

In order to estimate the initial cost of MAL system for rest areas, the number of motion sensors needs to be estimated based on the layout of the rest area facility and the number of lighting fixtures which often require one motion sensor for every five lighting fixtures (Missouri Industrial Assessment Center 2008). The lifetime of occupancy sensors is approximately 10 years and there is no expected maintenance cost for the MAL system except the replacement of motion sensors at the end of their useful life (Herring and Miller 2008).

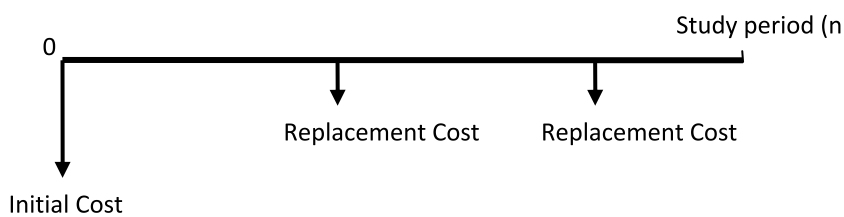


Figure 70.Main LCC components of MAL systems.

In order to calculate the amount of saved energy due to the integration of MAL system in rest area lighting, the occupancy time needs to be estimated. The occupancy time in rest areas cannot be precisely determined since it is controlled by several factors including: lighting operation time; weather conditions; number of rest area visitors; average elapsed time of rest area visitors; possibility of having more than one visitor at the same time; and average increase in visitors of rest area. A study conducted by the U.S. Environmental Protection Agency (EPA) to calculate the potential energy savings of occupancy controls in buildings in 24 States representing a range of commercial building types. This study reported occupancy rates and number of hours that the lights were on in 158 rooms including 37 private offices, 42 restrooms, 35 classrooms, 33 conference rooms and 11 break rooms. According to this study, occupancy sensors can provide energy savings that range from 30% to 90% in restrooms (VonNeida, et al. 2001). Based on the conditions of the three rest areas that were visited, lobbies and vending areas require interior lighting to be on all the time to maintain clarity of video recording. Therefore, applying MAL systems in lobbies and vending areas will not be appropriate due to security requirements. As a result, applying MAL system can be limited to restrooms, mechanical room, and storage room to ensure that potential savings in lighting energy can be achieved without compromising the security of rest area facilities. Table 19 provides an analysis of applying MAL system in restrooms of the three selected rest areas (Prairie View, Funks Grove, and Pride of the Prairie).

Table 19. MAL Systems Analysis for Restrooms of the three Selected Rest Areas

Rest Area	**Prairie View-Northbound**	**Funks Grove**	**Pride of the Prairie-Eastbound**
Number of lighting fixtures in restrooms	31	59	18
Total load of lighting fixtures (watt)	1670	3,776	1,232
Electricity cost ($/KWH)	0.093	0.11	0.106
Occupancy sensors needed	7	15	6
Occupancy sensors cost ($)	1050	2,250	900
Labor installation cost ($)	510	1,093	437
Total Initial cost ($)	1,560	3,343	1,337
Annual lighting energy cost ($)	1,056	3,315	807
Annual lighting energy savings 30% ($)	317	995	242
Payback period for 30% savings (years)	4.74	3.31	4.5
Amount of eliminated CO2 for 30% savings (Ibs)	4,805	12,411	3,221
Annual lighting energy savings 90% ($)	951	2,984	727
Payback period for 90% savings (years)	1.65	1.14	1.85
Amount of eliminated CO2 for 90% savings (Ibs)	14,414	37,233	9,664
Annual visitors in 2009	1,883,948	1,329,695	326,858
Average annual increase in rest area visitors 2001-2009 (%)	12.45%	-1.75%	-0.89%
Average visitor rate (visitor/minute)	3.6	2.5	0.6

Based on the MAL systems analysis in the restrooms of the three selected rest areas, the payback period of this system ranges from 1.14 year for Funks Grove rest area at 90% energy savings to 4.5 years for Pride of the Prairie rest area at 30% energy savings. The amount of eliminated CO2 emissions increases as the savings in the electricity consumption increases. The annual amount of eliminated CO2 emissions ranges from 3,221Ibs at 30% energy savings for Pride of the Prairie rest area to 37,233Ibs at 90% energy savings for Funks Grove rest area. It should be noted that Prairie View rest area has the highest average visitor rate (3.6 visitors per minute). The efficiency of MAL system tends to decrease as the frequency of rest area visitors increases. In addition, the average number of visitors of Prairie View rest area has increased during the period from 2001 to 2009 while the average number of visitors to Funks Grove and Pride of the Prairie rest areas has slightly decreased during the same period, as shown in Table 4. As a result, utilizing the MAL system in Funks Grove and Pride of the Prairie rest areas can be more efficient. Accounting for the public sector electric efficiency program incentives, the payback period for Prairie View will range from 1.46 year to 4.22 years for the 90% and 30% annual energy savings rates, and the payback period for Funks Grove will range from 1.0 year to 2.91 years for the 90% and 30% annual energy savings rates.

5.1.3 Thermal Pane Glass Windows and Doors

Glass front doors and windows have a significant impact on heat transfer between the interior and exterior environments of rest area buildings. This significant impact is caused by a number of factors including (1) the reduced insulation of these types of building enclosures compared to other building materials; (2) the amount of sunlight that passes through these transparent surfaces and heats and lights the interior of rest area buildings; and (3) the amount of heat flux that transfers between both environments when doors of these facilities are open. Therefore, the type of glass front doors and windows need to be carefully selected in order to maximize energy efficiency in rest areas. Thermal pane glass provides better insulation than single pane types. The replacement of single pane windows glass with thermal pane glass can reduce energy loss by 15-30% (Liu 2007). Accordingly, the potential reduction in energy losses that can be achieved by replacing the glass front entrances of rest areas is higher than 15-30% due to the larger surface area compared to windows.

The insulation capacity is represented by U-value which indicates the rate of heat transfer. The lower the U-value, the slower it transfers heat from the warm to the cold environment. Several types of glazing are available in the market including: (1) multiple-pane glass which consists of two or more layers of glass that are separated with a spacer and filled with either air or gas; (2) low-e coating which refers to a microscopically thin, transparent layer of metal or metal oxide that is applied to window glazing to reduce the transfer of heat while allowing the full amount of sunlight to pass through; and (3) thermally improved edge spacer which refers to improved edge spacer that incorporate new materials and designs to improve performance. There are also windows that are labeled as ENERGYSTAR which signifies and insures that the glazing is energy efficient and has met the energy criteria of the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency (EPA) (Engineering Extension 2001). The windows area, frame type, and glazing type are commonly used to determine the performance of windows, doors, and glass entrance fronts.

The main LCC components of replacing glass front doors and windows in rest areas include initial cost, maintenance cost, and replacement cost, as shown in Figure 71. The initial cost of glass doors and windows replacement includes removal cost of existing windows/doors, framing and glazing cost, doors and windows cost, and installation cost. Several factors have an impact on estimating the initial cost of glass doors and windows including: size, type of frame and glazing, type of glass doors and window, and aesthetic requirements. Therefore, the replacement cost for glass front doors and windows in rest areas can vary significantly. The maintenance cost represents the required cost for maintaining the glass front doors and windows to ensure that they function properly and efficiently throughout their life. Maintenance is an important component since glass front doors and windows are considered a major investment and expected to last more than 30 years. During their lifetime, glass doors and windows are exposed to extreme weather conditions and temperature differences which can cause leakage and hardware problems if they are not properly maintained. The replacement cost represents the required cost to replace glass doors and windows at the end of their useful life. Table 20 lists average LCC components for replacing glass doors and windows in Prairie View and Pride of the Prairie rest area. Based on the site visits that were conducted, Funks Grove rest area has airlock entrance which provides efficient insulation for cooling and heating energy. Also, it has windows in the men’s and women’s bathroom which achieve appropriate energy performance. Prairie View rest area has no windows and accordingly its LCC analysis in Table 20 was limited only to the replacement of its glass front doors.

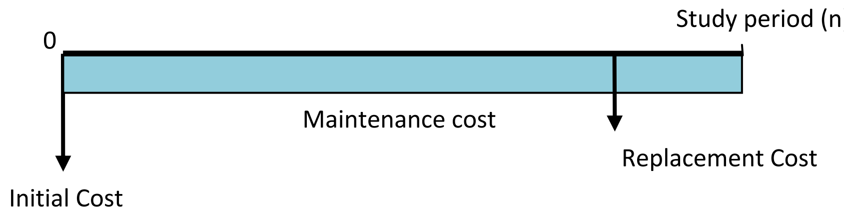


Figure 71. LCC components of doors and windows replacements.

Table 20. LCC Analysis for Replacing Glass Front Doors and Windows for Prairie View and Pride of the Prairie Rest Areas

Rest area	**Prairie View (Northbound)**	**Pride of the Prairie (Eastbound)**	
Replacement	Glass front doors	Glass front doors	Windows
Initial Cost ($)	60,900*	50,900*	1,922*
Annual maintenance cost -1% ($)	609	509	19
Annual energy cost – 2009 ($)	28,299	6,787	
Average increase in utility cost (%)	5%	5%	
Discount rate (%)	2%	2%	
Study period (years)	40	40	
Annual energy savings based on (15%) energy loss reduction ($)	1,061**	509***	
Annual eliminated CO_2 emissions based on (15%) energy loss reduction (lbs)	16,153	6,753	
Annual energy savings based on (30%) energy loss reduction ($)	2,122*	1,018**	
Annual eliminated CO_2 emissions based on (30%) energy loss reduction (lbs)	32,306	13,506	
Payback period based on (15%) energy loss reduction (years)	40.0	more than 40 years	
Payback period based on (30%) energy loss reduction (years)	24.3	37.5	

*Initial cost was calculated based on RSMeans Building Construction Cost Data

** Annual savings based on the cooling and heating energy in the lobby of the rest area

*** Annual savings based on the cooling and heating energy in the entire rest area

Based on the analysis of LCC for Prairie View and Pride of the Prairie rest areas, replacing the glass front doors and windows has a payback period of 40 years, which is infeasible for 15% reduction in cooling and heating cost. Replacing glass doors and windows based on 30% reduction in cooling and heating cost has payback periods of 24.3, 37.5 years for Prairie View and Pride of the Prairie rest areas, respectively. The reason for having long/infeasible payback period is that the replacement cost for glass doors and windows is recovered through the expected reduction in cooling and heating costs which represents a small portion of the replacement cost. It should be noted that replacing of the single pane glass doors with thermal glass doors will provide better insulation for the energy loss between the interior environment and the exterior environment; however, the energy loss due to the dissipation of energy from the interior environment to the exterior environment when the doors are open can be more significant. Based on the average number of visitors of the three selected rest areas, the average rate of visitors ranges from 0.6 visitor/minute for Pride of the Prairie rest area to 3.6 visitors/minute for Prairie View rest area. Accordingly, the doors of Prairie View rest area are opened approximately 3 to 4 times per minute which highlights the importance of using airlock doors to reduce the dissipation of heat through the opening of rest area doors. As a result, the glass doors can be replaced with airlock entrance in order to minimize energy losses. Another possible solution is to install air curtains which are described in more detail in the next section, although they are reported to be less efficient than airlock entrances.

The replacement of the entrance glass doors for Prairie View rest area with airlock doors will require a small extension in the rest area building which in turn will end up with high initial cost. The layout of Pride of the Prairie rest area entrance can be adjusted for double door entrance as shown in Figure 72. The implementation of this door will reduce the dissipation of energy through the opening of the rest area doors.

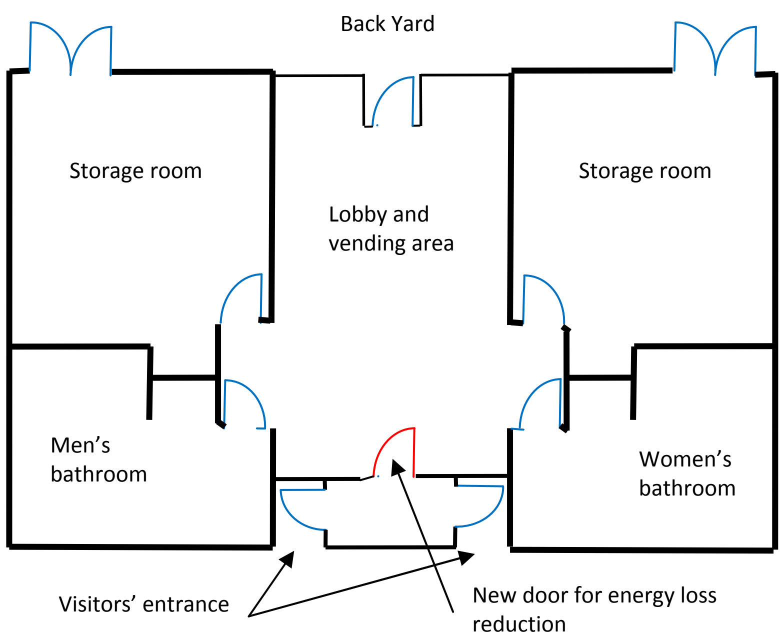


Figure 72. Layout for added door at Pride of the Prairie rest area to reduce energy loss.

5.1.4 Geothermal HVAC Systems

Geothermal heating, ventilation and air conditioning (HVAC) systems are one of the green and sustainable technologies that utilize earth's energy to heat and cool buildings. These systems are developed based on the concept that the surface temperature of earth changes significantly according to seasons, however, the temperature inside the earth is almost constant (55°F) throughout the seasons. Therefore, geothermal HVAC systems use this temperature difference to provide heating for buildings in winter and cooling in summer. The utilization of these systems reduces cooling and heating energy as well as carbon footprint by 30% to 50% (Hardin Geotech Inc. 2010; Carrier 2010).

The LCC components of replacing existing HVAC systems with geothermal HVAC systems include initial cost, maintenance cost, operating cost, and replacement cost. The initial cost represents the required capital cost to replace the current HVAC system with a geothermal system. It includes removal of the old system, constructing the geothermal loop, and installing the geothermal heat pump. The maintenance cost represents the annual required cost to maintain the system including inspection and maintenance to prevent duct leakage and equipment breakdown problems. The lifetime of conventional HVAC equipments ranges from 15 to 20 years while the lifetime of geothermal heat pumps are typically 20 years (Chiasson 2006). The operating cost represents the annual energy cost required to operate the system during its life. The replacement cost represents the capital cost to replace the system at the end of its useful life.

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 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. On the other hand, the vertical loop system has a higher initial cost; however, it needs very limited outdoors area to be placed. The average horizontal loop system cost is $2,750 per ton of capacity while, the average vertical loop system cost is $3,200 per ton of capacity (Geothermal Design Associates 2009; Kozlowski 2007, Blackie's 2010). 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 quality and proper installation, the geothermal loop has a life expectancy of over 100 years. The loop length varies based on the used loop system in construction, where the horizontal system needs 100 - 150 feet of trench per ton of heat exchange with an average of 125 feet of trench per ton, and the trench width is specified to be 2 feet to account for four longitudinal pipes. The vertical system needs 130 to 300 feet of depth per ton of heat exchange with an average of 215 feet of depth per ton, and each well includes two pipes connecting at the bottom to form a "U" shape (Ground Loop 2009; Geothermal Design Associates 2009).

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/SF/year (Bloomquist 2001). The operating cost can be estimated to account for the potential savings that could be achieved compared to the current HVAC systems in rest areas. According to a study conducted by Moore in 1999 that compared the operating energy cost for geothermal systems with conventional HVAC systems, the geothermal systems has an average energy savings of 41% as compared to air-source heat pump systems. The geothermal heat pump will need to be replaced after 20 years of installation with the same installation cost of $2,500 per ton of capacity. Table 21summarizes the LCC components of replacing the current HVAC systems with geothermal heat pump systems in Prairie View, Funks Grove, and Pride of the Prairie rest areas.

Table 21. LCC Data for Geothermal HVAC System that can be used to Replace Existing HVAC Systems in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area/LCC components	Prairie View – Northbound	Funks Grove	Pride of the Prairie - Eastbound
Total Initial cost of horizontal system ($)	71,170	106,640	37,263
Total Initial cost of vertical system ($)	77,200	115,640	40,413
Annual maintenance cost ($)	590	610	257
Annual operating cost ($)	4,442	5,138	679
Replacement cost of heat pump ($)	34,320	51,640	18,013
Life of heat pump (years)	20	20	20

In order 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 2010 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 same aforementioned study that was conducted to compare the maintenance cost of different HVAC systems. Air-source heat pumps have an average annual maintenance cost of 0.28 $/SF/year (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 22 shows the LCC components of the current HVAC systems in Prairie View, Funks Grove, and Pride of the Prairie rest areas.

Table 22. LCC Data for Existing HVAC Systems in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area/LCC components	Prairie View – Northbound	Funks Grove	Pride of the Prairie - Eastbound
Capital cost	19,870	35,990	11,243
Annual maintenance cost	1,270	1,313	553
Annual operating cost	8,828	8,708	1,151
Replacement cost	19,870	35,990	11,243
Life	17	17	17
Manufacture year	1997	1998	1998
Replacement year	2014	2015	2015

LCCA was used to compare the potential replacement of existing HVAC systems in the three rest areas with geothermal HVAC systems based on the assumed data in Table 23. The results of this analysis are summarized in Table 24. The payback period for replacing existing HVAC systems in the three rest areas with geothermal systems ranges from 12.3 years for the Prairie View rest area with horizontal loop system to 33.1 for the Pride of the Prairie rest area with vertical loop system. The payback periods for the vertical loop systems are higher than the horizontal systems due to the higher initial cost needed to construct/install this system. The cumulative costs for the horizontal loop geothermal system, vertical loop geothermal system, current HVAC system, and savings are shown in Figure 73, Figure 74, and Figure 75 for Prairie View, Funks Grove, and Pride of the Prairie rest areas, respectively. The public sector electric efficiency program incentives are not applicable for Prairie View and Funks Grove since the payback period for the geothermal system is longer than 7 years.

Table 23. Economical Factors for the LCC Comparison between the Current and Geothermal HVAC Systems

Economical factor	**Rate**
Utility Escalation rate (%)	5%
Discount rate (%)	2%
Annual increase in maintenance cost (%)	2%

Table 24. LCCA for Replacing Existing HVAC Systems with Geothermal HVAC Systems in Prairie View, Funks Grove and Pride of the Prairie Rest Areas

Rest area	**Prairie View - Northbound**	**Funks Grove**	**Pride of the Prairie - Eastbound**
Annual KWH saved	66,383	64,913	8,902
Annual energy savings - first year	6,174	7,140	944
Annual eliminated CO2 emissions (lbs)	93,601	91,527	12,552
Payback period - horizontal system (years)	12.3	15.0	30.3
Required total area for the horizontal system (SF)	16,951	18,975	8,855
Required area for excavation (SF)	3,350	3,750	1,750
Payback period - vertical system (years)	13.5	17.7	33.1

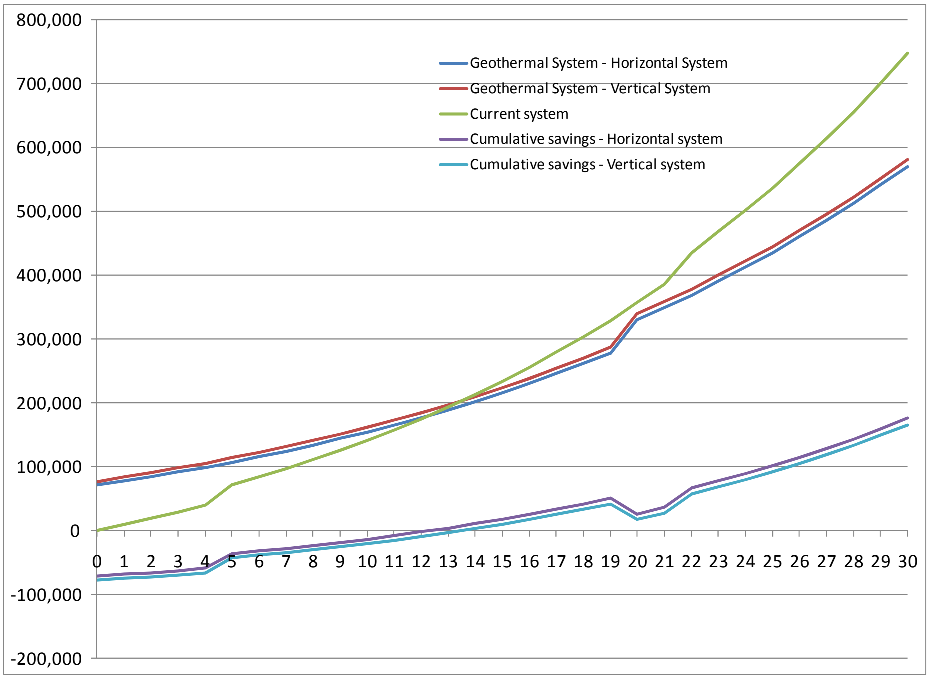


Figure 73. Cumulative costs of horizontal loop geothermal system, vertical loop geothermal system, current HVAC system, and savings for Prairie View rest area.

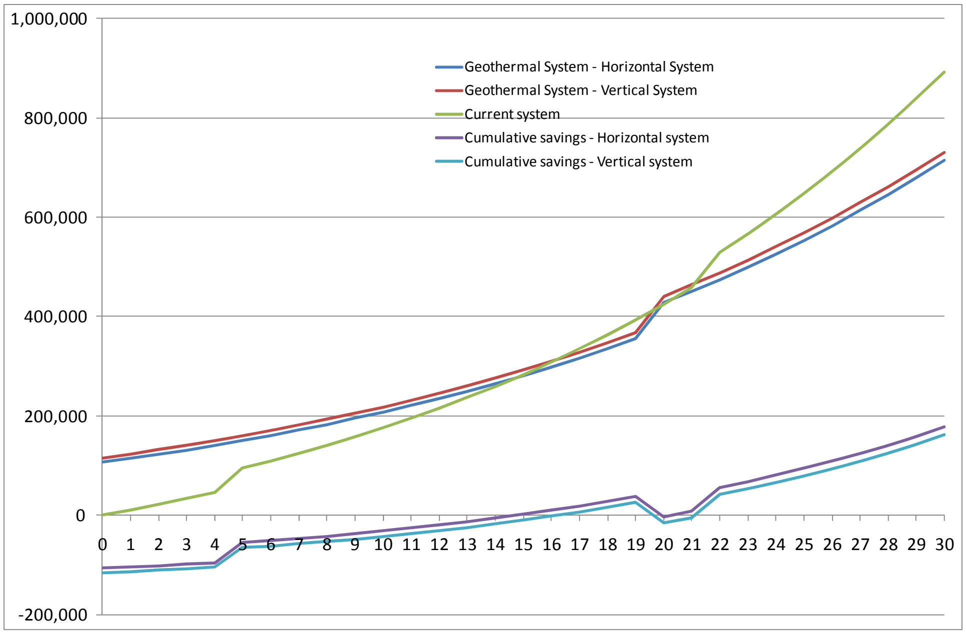


Figure 74. Cumulative costs of horizontal loop geothermal system, vertical loop geothermal system, current HVAC system, and savings for Funks Grove rest area.

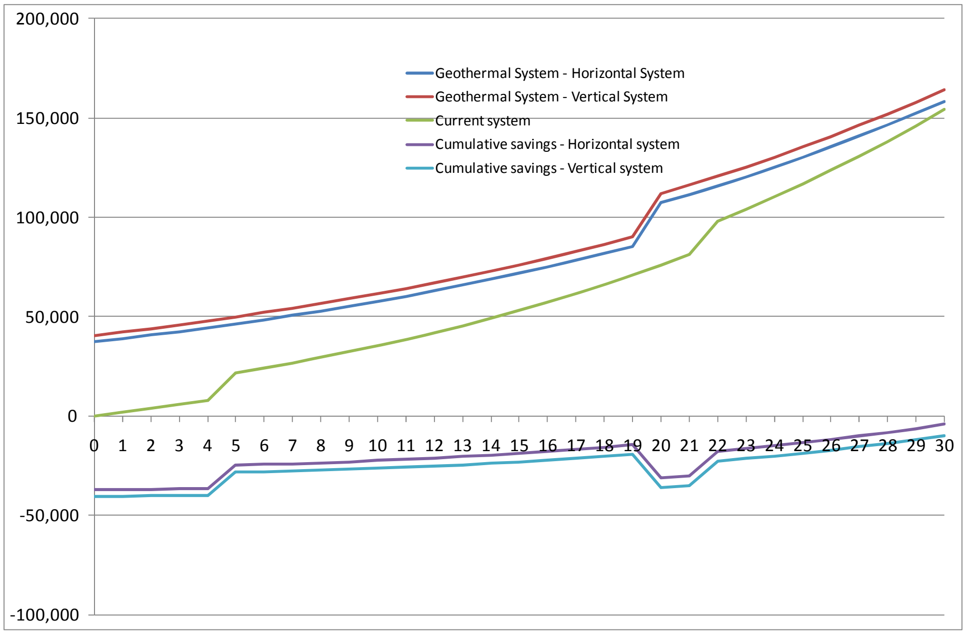


Figure 75. Cumulative costs of horizontal loop geothermal system, vertical loop geothermal system, current HVAC system, and savings for Pride of the Prairie rest area.

5.1.5 Active and Passive Solar Practices

Active and passive solar practices are sustainable technologies which use solar energy in producing electricity or heating for buildings. These technologies provide alternative renewable sources of energy and protect the environment from greenhouse gases. The following sections describe two life-cycle cost analyses that were performed to investigate the cost effectiveness of utilizing building integrated photovoltaic power systems and solar water heating systems in the selected three rest areas.

5.1.5.1. Building Integrated Photovoltaic Power Systems

Building Integrated Photovoltaic Power Systems (BIPS) are one of the green technologies which can be used to convert solar energy into electrical energy. These systems use renewable and clean source of energy to replace the use of non-renewable sources of energy such as fossil fuel. Building integrated photovoltaic systems can be classified into two types: grid-connected systems and stand-alone systems. The grid-connected systems are designed to operate while being interconnected with an electrical utility grid. The generated current of this system is used to power different building appliances and equipments. When the electrical power of the PV system exceeds the demand for the building, the excess electricity is re-routed to the utility line where it can be sold back to the utility company. However, when the demand for the building exceeds the electrical power of the PV system, the utility grid provides electricity to cover the energy shortage in the building. The stand-alone systems are designed to operate independently of the local electrical utility grid.

The LCC components of incorporating BIPS in facilities include initial cost, maintenance cost, replacement cost, and annual savings. The initial cost of the system includes materials and labor cost for solar panels, roof/ground mounting of solar panels, inverters, wiring, switches, fuses, connectors and other parts for grid-connected and stand-alone systems. In addition, the stand-alone system has two additional parts (batteries and charge controller) which are needed to store the power generated by the solar panels. The maintenance cost includes the annual cost to maintain the functionality and performance of the system throughout its useful life. This system requires limited maintenance cost to cover the replacement of the system parts. The replacement cost covers the required cost to replace the system at the end of its useful life. The annual savings represent the annual reduction in energy cost. Figure 76 shows the components of LCC for incorporating photovoltaic systems in rest area facilities.

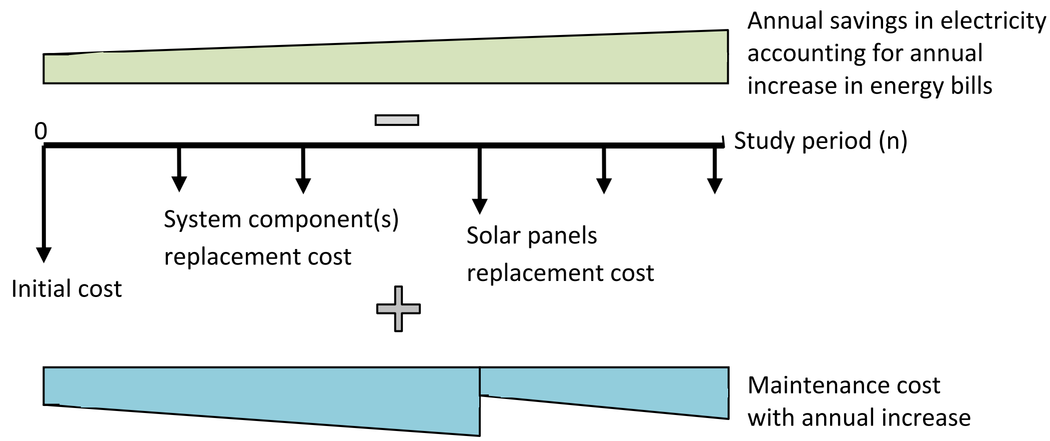


Figure 76. LCC components of incorporating building integrated photovoltaic systems in buildings.

Grid-connected photovoltaic systems

In order to perform LCC analysis for incorporating grid-connected photovoltaic systems in the three selected rest areas, these systems need to be designed to estimate the number and types of system parts. The design of grid-connected systems differs from stand-alone systems because the grid-connected system does not require energy storage. 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 three rest areas is considered 4.4 hours/day based on the annual average daily peak sun hours data of the Department of Energy for United States (DOE 1997). The characteristics of the system parts that are used in the design as well as its unit costs are summarized in Table 25. The assumed economic parameters of the LCC analysis for the grid-connected system are summarized in Table 26. The design of the grid-connected system was carried out to provide a reduction in total annual energy consumption by 5%. The number of solar panels is identified based on the amount of power needed to be generated per day. The average daily consumption of electricity is calculated where it is divided by average daily sun hours per day and solar panel capacity to determine the required number of solar panels. The capacity of the required inverter is determined based on 110% of the total capacity of solar panels in order to allow for safe and efficient operation (State Energy Conservation Office 2006). The initial cost of the system can be calculated by summing up all equipment and labor costs needed to install the system. An additional 20% of hardware costs were added to account for wiring, switches, fuses, connectors and other parts. The labor cost is calculated using a rate of $1.75/watt (State Energy Conservation Office 2006; Affordable Solar 2010). 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 27summarizes the designed system components as well as their costs for Prairie View, Funks Grove, and Pride of the Prairie rest areas.

Table 25. Characteristics of the System Parts that are used in the Design of Grid-Connected Photovoltaic System

System parts	Type (manufacture)	Size	Capacity	Unit cost ($/unit)	Life
Solar panel	YINGLI SOLAR	65" X 39" X 2"	225 w	538	25
Inverter (1)	Fronius	17.1" X 24.8" X 9.6"	(2.5-3.45) KW	2,581	10~15*
Inverter (2)	Fronius	17" X 36.4" X 9.6"	(6.35-8.6) KW	5,099	10~15*
Inverter (3)	Fronius	17.1" X 48.1" X 9.6"	(9.7-13.1) KW	7,078	10~15*
Roof mounted - mini clamp	S-5	4 clamps per panel	-	4.2	-
Ground mounted	IRONRIDGE	2 panels per mount	-	81	-

* Life is considered 13 years for the analysis

Table 26. Assumed Economic Parameters for the LCC Analysis

Factor	Rate
Utility Escalation rate (%)	5%
Discount rate (%)	2%
Annual increase in maintenance cost	2%
Percentage of Energy Consumption Needed to be Provided by the Solar Panels (%)	5%

Table 27. System Design Components and costs for Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Design components \ cost item	Prairie View - Northbound	Funks Grove	Pride of the Prairie - Eastbound
Total number of solar panels	43	57	9
Number of inverters	1	2	1
System capacity (KW)	9.7	12.8	2.0
Utility cost ($/KWH)	0.093	0.113	0.106
Initial cost ($)	53,957	73,553	12,864
Annual maintenance cost ($)	186	256	47
Solar Panels replacement cost ($)	26,604	35,266	5,568
Inverter replacement cost ($)	7,078	10,198	2,581
Annual savings ($)	1,421	2,284	339
Cost per watt ($/w)	5.61	5.75	6.40

The analyses were conducted for the three rest areas in order to determine annual savings, payback period, amount of eliminated CO2 emissions, and required area for the system. Table 28 shows the results of the carried out analysis for these three rest areas. The payback period for incorporating grid-connected systems in the three rest areas ranges from 32.0 years for Funks Grove rest area to 36.5 years for Pride of the Prairie rest area. The required area for the system in Prairie View rest area is approximately 80% of the roof where solar panels can be installed using clamps. The required area for this system in Funks Grove and Pride of the Prairie rest areas is 808 SF and 169 SF respectively based on 51° degrees tilt angel of solar panels and preventing shading that might occur due to layout of solar panels in winter and summer. Figure 77 shows the cumulative cost of incorporating grid-connected system in the three rest areas.

Table 28. Results of the LCC Analysis for Incorporating Grid-Connected Photovoltaic System in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Results\ Rest area	**Prairie View - Northbound**	**Funks Grove**	**Pride of the Prairie - Eastbound**
Annual eliminated CO2 emissions (lbs)	21,537	28,620	4,502
Number of solar panels on roof	43	22	0
Number of solar panels on the ground	0	35	9
Required ground area for solar panels (SF)	0	808	169
Tilt angel of solar panels (winter orientation)	51	51	51
Payback period (years)	35.6	32.0	36.5

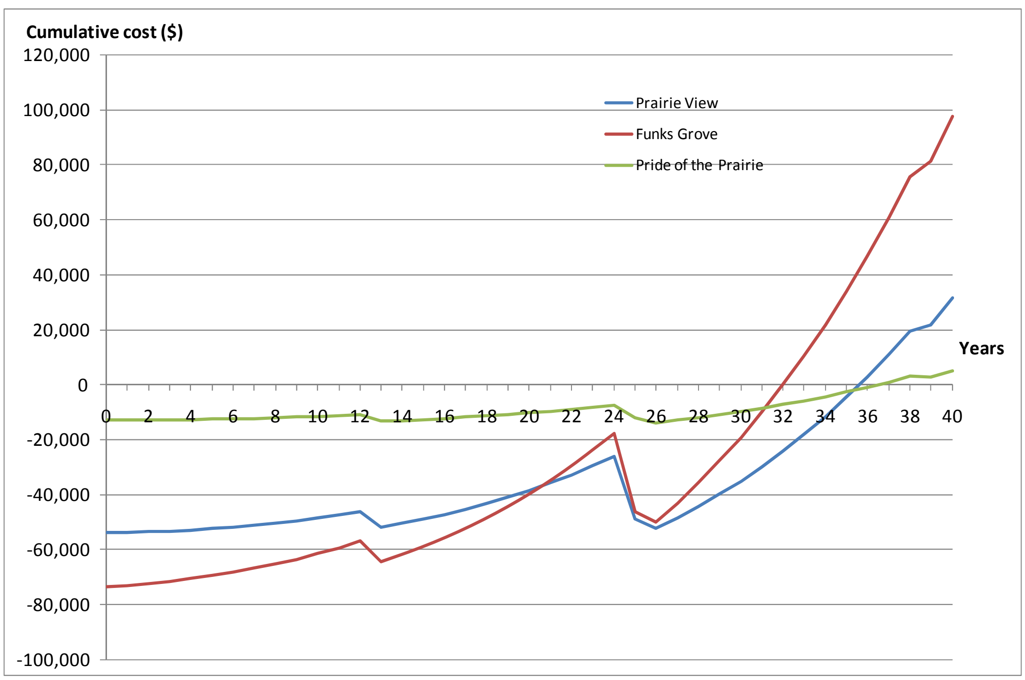


Figure 77. Cumulative cost of incorporating grid-connected system in Prairie View, Funks Grove, and Pride of the Prairie rest areas.

Stand-Alone Photovoltaic Systems

The design of the stand-alone photovoltaic systems accounts for generating energy that covers the whole demand of the facility throughout the year. The main difference between the design of this system and the grid-connected system is that the stand-alone system is designed based on the amount of useful sunshine available for the panels on an average day during the worst month of the year which is called “insolation value”. The worst month is the governing factor used in the analysis in order to ensure that the system will operate year round. The worst month of available solar energy occurs during the winter when energy consumption reaches its peak due to building heating requirements in Illinois. Therefore, the design of this system will end up generating adequate energy for the winter season and generating much higher energy in the summer because (1) the capacity of the system is much higher than the demand in summer; and (2) the available sunshine hours in summer are much higher than in winter. In order to carry out the design and analysis of this system, the characteristics of the system parts need to be identified. The required number of solar panels in the stand-alone system is identified based on the amount of power needed per day in the worst solar month. The average daily electricity consumption is calculated in this month where it is divided by the “insolation value” and solar panel capacity to calculate the required number of solar panels. The average insolation value in Illinois is 3.25 hours per day. The capacity of the required inverter(s) should be sized to provide 125% of the maximum load of the building at any time. The required amount of battery bank is determined based on providing energy for the facility for 5 days continuously to account for winter storms and bad weather conditions. (State Energy Conservation Office 2006). The system costs were calculated using the same approach that was described earlier in the grid-connected system. Table 28 summarizes the design system components and costs for Prairie View, Funks Grove, and Pride of the Prairie rest areas. Table 29 shows the characteristics of system parts that have been chosen to design and analyze the utilization of stand-alone BIPS in rest areas. The required number of solar panels in the stand-alone system is identified based on the amount of power needed per day in the worst solar month. The average daily electricity consumption is calculated in this month where it is divided by the “insolation value” and solar panel capacity to calculate the required number of solar panels. The average insolation value in Illinois is 3.25 hours per day. The capacity of the required inverter(s) should be sized to provide 125% of the maximum load of the building at any time. The required amount of battery bank is determined based on providing energy for the facility for 5 days continuously to account for winter storms and bad weather conditions. (State Energy Conservation Office 2006). The system costs were calculated using the same approach that was described earlier in the grid-connected system. Table 30 summarizes the design system components and costs for Prairie View, Funks Grove, and Pride of the Prairie rest areas.

Table 29. Characteristics of the System Parts that are used in the Design of the Stand-Alone System

System parts	Type	Size	Capacity	Unit cost ($/unit)	Life
Solar panel	YINGLI SOLAR	65" X 39" X 2"	225 w	538	25
Inverter (1)	SOLECTRIA	76" X 56" X 29.3"	60 KW output	31,750	10~15*
Inverter (2)	SOLECTRIA	34.5" X 26 X 13.6	15KW output	11,104	10~15*
roof mount - mini clamp	S-5	4 clamps per panel	-	4.2	-
Ground mount	IRONRIDGE	2 panels per mount	-	81	-
Battery	Surrette	22" X 11.25" X 18.25"	12V	1073	12 ~ 15**
Charge Controller	Xantrex	10" X 5" X 2.5"	-	175	12 ~ 15**

* Life is considered 13 years for the analysis
* *Life is considered 14 years for the analysis

Table 30. System Design Components and Costs for Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Design components / cost item	Prairie View - Northbound	Funks Grove	Pride of the Prairie - Eastbound
Total number of solar panels	1,821	2,585	495
Number of inverters	2	3	2
Number of batteries	78	110	21
System capacity (KW)	409.7	581.6	111.4
Initial cost ($)	2,170,321	3,090,990	596,394
Annual maintenance cost ($)	7,267	10,367	2,009
Solar Panels replacement cost ($)	1,126,653	1,599,340	306,257
Battery replacement cost ($)	63,500	95,250	22,208
Inverter replacement cost ($)	95,865	136,090	26,016
Annual Savings – first year ($/year)	28,411	45,670	6,788
Cost per watt ($/w)	5.30	5.32	5.36

The analysis was conducted for the three rest areas based on the same assumptions of economic parameters that were used in the grid-connected analysis. Table 31 shows the results of the analysis for the three rest areas. The payback periods for incorporating stand-alone Photovoltaic systems in the three rest areas are not feasible within the study period of 40 years. The reason for this finding is that the stand alone system is designed based on the highest energy consumption and lowest available sunshine hours in winter which led to a substantial initial cost. In addition, the annual savings of the system are accrued based on the total annual consumption which includes peak energy consumption in winter and low energy consumption in summer. Furthermore, these systems provide much higher energy in summer which exceeds the demand of rest area buildings. In order to accelerate the payback period of these systems, excessive energy during the summer months can be sold to nearby buildings, or the system can be built on only one of the rest areas that have facilities on both sides of the highway. Figure 78 shows the cumulative cost of incorporating stand-alone systems in the three rest areas. It should be noted that the required area of the solar panels might require the removal of some trees which will affect the landscape aesthetics in the rest areas.

Table 31. Results of Incorporating Stand-Alone Photovoltaic System in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Results\ Rest area	**Prairie View - Northbound**	**Funks Grove**	**Pride of the Prairie - Eastbound**
Annual eliminated CO2 emissions (lbs)	430,744	572,399	90,043
Number of solar panels on roof	113	22	0
Number of solar panels on the ground	1,708	2,563	495
Required area for solar panels (SF)	48,052	69,869	12,599
Tilt angel of solar panels	51	51	51
Payback period (years)	Infeasible*	Infeasible*	Infeasible*

* Infeasible within the time period of the study (40 years)

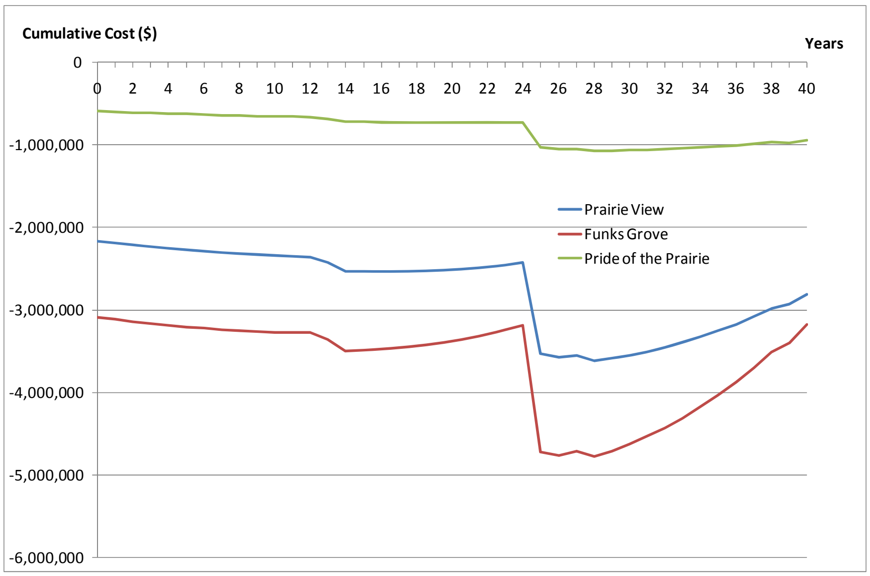


Figure 78. Cumulative cost of incorporating grid-connected system in Prairie View, Funks Grove, and Pride of the Prairie rest areas.

5.1.5.2.Solar Water Heating Systems

Solar water heating systems are one of the green technologies that use the energy of sunlight to heat water which can then be used for different building purposes. Solar water heaters work in collaboration with a backup water heater where water is heated by solar energy when the sun rays are available to heat water. When the sun rays are unavailable or insufficient to heat water to the desired temperature, a conventional water heater is used. In order to maximize the cost effectiveness of this technology in rest areas, solar water heating systems can be installed along with existing water heaters that can work as a backup system. The LCC components of installing this technology in rest areas include initial cost, maintenance cost, replacement cost, and annual savings. The initial cost represents material and labor cost for solar collector(s), collector's mounting, heat exchanger, circulator, antifreeze (glycol), water storage tank(s), controller, fittings, pipes, insulation, and optional small photovoltaic panel to operate the pump. Collector(s) can be installed on roof by clamps or straps or on the ground where a rack is used to hold the collector(s). The maintenance cost represents the required annual cost to maintain the functionality and performance of the system throughout its useful life. The replacement cost of the system represents the capital cost that is required to replace the system at the end of its useful life. The annual savings represent the annual reduction in water heating energy. Figure 79 shows the components of the LCC for incorporating solar water heating systems in rest areas.

In order to carry out a LCC analysis of incorporating solar water heating technology in rest areas, the components of the LCC need to be calculated and identified. The initial capital cost of the system can be calculated for the three rest areas using the RSMeans Building Construction Cost Data (2010). 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 have 16 years in this analysis. System circulators usually have more than 5 years useful life and are assumed to have a life of 5 years in this analysis (Radiantec 2009). The potential savings of this system varies according to several factors including system size, quality of solar access to collectors, climate conditions, annual water usage, system insulation, and temperature of water source. Accordingly, potential energy savings of the system cannot be accurately estimated. According to the National Institute of Building Design, solar water heating systems can provide up to 80% of the building needs. According to a study conducted to measure the performance of solar water heaters in Cincinnati and New Jersey rest areas, the energy savings accrued in these rest areas were 20% and 70% respectively. The study calculated the hot water usage using a BTU meter that was installed in the rest area sites to measure the BTU usage of the water heaters (Yahsi 1992; WBDG (b) 2010). Due to the significance in the accrued energy savings in these rest areas, the LCC analysis of the three rest areas was performed based on 20% and 70% energy savings to identify the payback period range based on these percentages, as shown in Table 31. Also, the cumulative savings for incorporating solar water heaters in Prairie View, Funks Grove, and Pride of the Prairie rest areas are shown in Figure 80, Figure 81, and Figure 82 respectively based on average energy savings in hot water consumption of 45%.Table 32 summarizes the characteristics and costs for incorporating solar water heater systems in the three rest areas Prairie View, Funks Grove, and Pride of the Prairie rest areas.

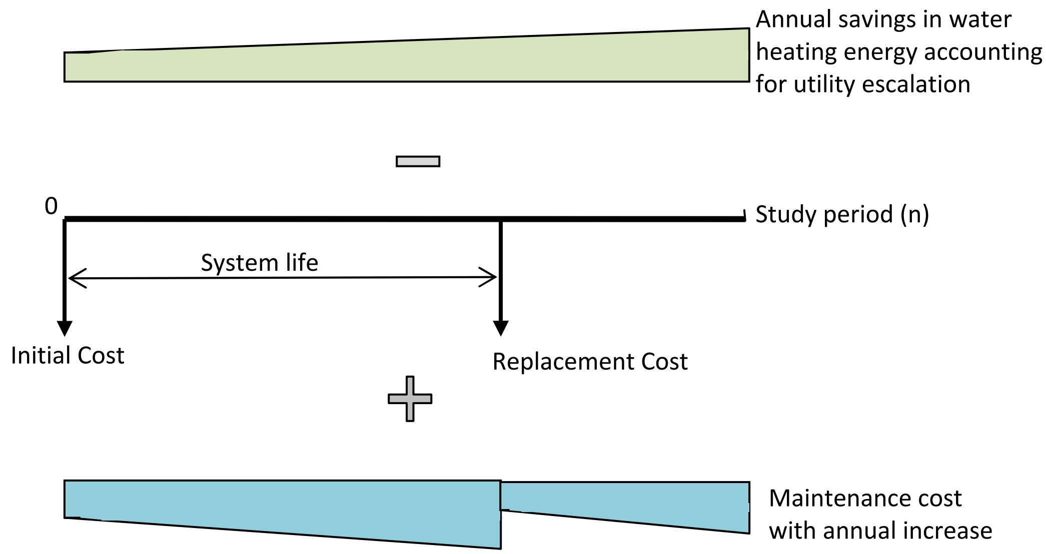


Figure 79. Cash flow of LCC components of incorporating solar water heating systems in rest areas.

The potential savings of this system varies according to several factors including system size, quality of solar access to collectors, climate conditions, annual water usage, system insulation, and temperature of water source. Accordingly, potential energy savings of the system cannot be accurately estimated. According to the National Institute of Building Design, solar water heating systems can provide up to 80% of the building needs. According to a study conducted to measure the performance of solar water heaters in Cincinnati and New Jersey rest areas, the energy savings accrued in these rest areas were 20% and 70% respectively. The study calculated the hot water usage using a BTU meter that was installed in the rest area sites to measure the BTU usage of the water heaters (Yahsi 1992; WBDG (b) 2010). Due to the significance in the accrued energy savings in these rest areas, the LCC analysis of the three rest areas was performed based on 20% and 70% energy savings to identify the payback period range based on these percentages, as shown in

Table 33. Also, the cumulative savings for incorporating solar water heaters in Prairie View, Funks Grove, and Pride of the Prairie rest areas are shown in Figure 80, Figure 81, and Figure 82 respectively based on average energy savings in hot water consumption of 45%.

Table 32. Characteristics and Costs of Incorporating Solar Water Heaters in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area/LCC components	**Prairie View - Northbound**	**Funks Grove**	**Pride of the Prairie - Eastbound**
Number of solar collectors	1	2	1
Capacity of storage tank (gallons)	80	120	80
Capital cost - Roof mount ($)	5,485	7,185	5,485
Capital cost - Ground mount ($)	5,810	7,835	5,810
Annual maintenance cost - Roof mount ($)	55	72	55
Annual maintenance cost - Ground rack ($)	58	78	58
Utility Cost ($/KWH)	0.09	0.11	0.11
Conventional water heater consumption (KWH)*	27,494	36,536	5,747
Annual savings -20% ($)	509	822	122
Annual Savings - 70% ($)	1,783	2,878	428
Replacement cost for pump @ 5 years	250	250	250
Replacement cost for water tank @ 16 years	1,600	1,800	1,600

*Consumption estimated based on the energy consumption categories developed by SEDAC

Table 33. Results of the LCC Analysis of Incorporating Solar Water Hester Systems in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area/LCC components	**Prairie View - Northbound**	**Funks Grove**	**Pride of the Prairie - Eastbound**
Annual KWH saved - 20% savings (KWH)	5499	7307	1149
Annual KWH saved - 70% savings (KWH)	19246	25575	4023
Annual eliminated CO2 emissions - 20% savings (lbs)	7,698	10,230	1,609
Annual eliminated CO2 emissions - 70% savings (lbs)	26,944	35,805	5,632
Payback period - roof mount - 20% savings (years)	11.2	8.87	Infeasible*
Payback period - ground rack - 20% savings (years)	11.26	8.93	Infeasible*
Payback period - roof mount - 70% savings (years)	3.13	2.54	13.16
Payback period - ground rack - 70% savings (years)	3.14	2.55	13.24

* Infeasible within the time period of the study (30 years)

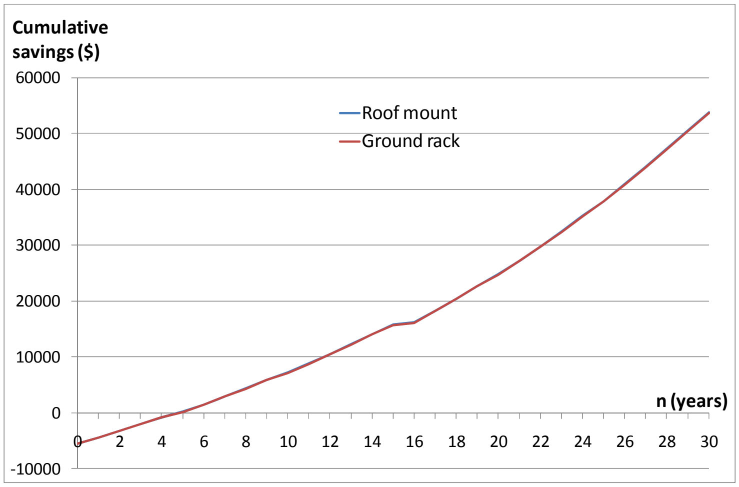


Figure 80. Cumulative savings for incorporating solar water heater in Prairie View rest area.

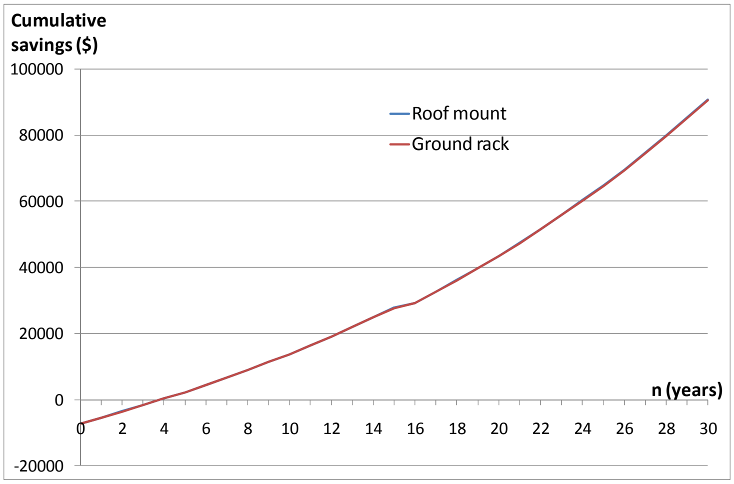


Figure 81. Cumulative savings for incorporating solar water heater in Funks Grove rest area.

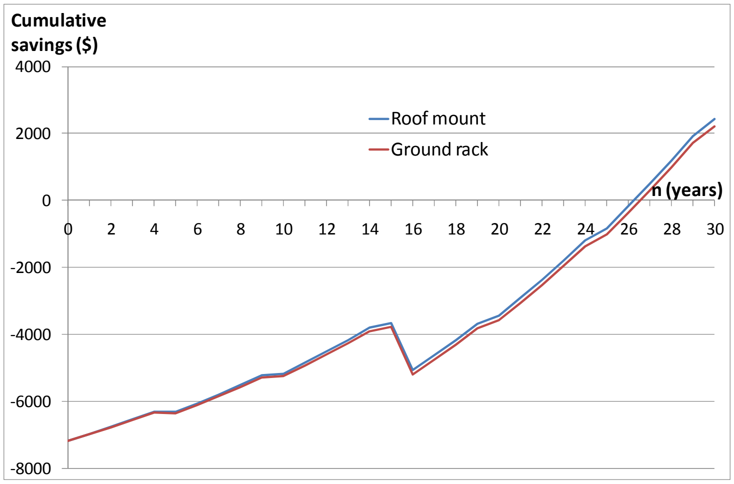


Figure 82. Cumulative savings for incorporating solar water heater in Pride of the Prairie rest area.

The analysis showed that incorporating solar water heaters in the three rest areas with 20% energy savings will result in an average payback period of 11.2 and 8.9 years for Prairie View and Funks Grove rest areas respectively and infeasible payback period for Pride of the Prairie rest area. The payback periods for incorporating this system are based on 45% energy savings in hot water consumption are 5.0, 3.9, and 23.2 respectively. The payback period for incorporating this system based on 70% energy savings in hot water consumption ranges from 2.5 years for Funks Grove rest area to 13.2 years for Pride of the Prairie rest area.

The ground rack installation has a slight higher payback period since it needs higher costs for the ground rack than the roof mount installation. It should be noted that the roof mount installation requires the roof to satisfy the collector(s) load requirements as well as being suitable for being fixed on the roof.

Due to the significance in energy savings for incorporating solar water heaters in buildings, this system needs to be designed based on actual measurements of hot water consumption. The hot water consumption is a crucial factor in maximizing energy savings in solar water heating systems. A BTU meter can be used to measure hot water usage and energy consumption on regular bases. These measurements can then be used in determining the size of the system which leads to the highest energy savings in hot water consumption. There are also ENERGYSTAR water heaters that are available which can be considered when replacing the current heaters in the rest areas at the end of their useful life. These ENERGYSTAR rated water heaters consume lower energy and have a higher useful life of 20 years.

Tankless/instant water heaters can also provide savings in water heating energy and can provide a longer service life than conventional water heaters. This type of heater, however, has a higher initial cost (two to four times the cost of conventional water heaters) and a higher maintenance cost. Tankless/instant water heaters can provide 8%-34% savings in water heating energy according to the U.S. Department of Energy (DOE 2010).

5.1.6 Energy Efficient Hand Dryers

Existing hand dryers in rest rooms of the three rest areas need 30-40 seconds to dry hands. New energy efficient hand dryers such as “blast” and “airblade” hand dryers are available on the market and they can be used to dry hands in less time while consuming less energy. Blast hand dryers are one of these energy efficient hand dryers which need only 10 seconds to dry hands and consume much less energy than the existing ones in the three rest areas. These hand dryers are similar to existing ones however they use higher flow of air which leads to improved energy efficiency, as shown in Figure 83. Airblade hand dryers also require less time and energy than the existing models in the rest areas. Airblade hand dryers need 12 seconds to dry hands by scraping water from hands like a windshield wiper. Airblade hand dryers also use High Efficiency Particulate Air (HEPA) filters which clean the air before blowing it onto hands which make them hygienic. Furthermore, these hand dryers consume less energy and can provide savings up to 80% over old/conventional hand dryers, as shown in Figure 84.

The LCC components of replacing current hand dryers with new hand dryers include initial cost, operation cost, maintenance cost, and replacement cost. The initial cost includes the material and labor to remove the old dryers and install the new ones. The operation cost represents the annual cost needed to operate these hand dryers throughout the year. The maintenance cost represents the required annual cost to maintain the functionality of the hand dryers’ throughout their life. The replacement cost represents the capital cost required to replace the hand dryers at the end of their useful life. The initial cost of replacing the current hand dryers in rest areas can be calculated using RSMeans Building Construction Cost Data (2010), Abt electronics company (Abt 2010), and Fixture Universe (Fixture Universe 2010). The operation cost can be calculated based on usage and energy consumption of hand dryers. The maintenance cost can be considered the same as the existing hand dryers in rest areas and therefore it can be removed from the comparative analysis. The replacement cost can be considered the same as the initial cost since the hand dryers will be replaced with the same hand dryer at the end of their useful life. Table 34 shows a comparison of the current hand dryers, Blast hand dryers, and Airblade hand dryers for Prairie View, Funks Grove, and Pride of the Prairie rest area. The payback period for replacing the current hand dryers with Airblade hand dryers ranges from 6.4 years for Prairie View rest area to 14.2 years for Pride of the Prairie rest area. The payback period for replacing the current hand dryers with Blast hand dryers ranges from 3.7 years for Prairie View rest area to 8.6 years for Pride of the Prairie rest area.

Figure 83. Blast hand dryer.

Figure 84. Airblade hand dryer.

Table 34. Comparison between the Current, Blast, and Airblade Hand Dryers in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area	**Prairie View - Northbound**			**Funks Grove**			**Pride of the Prairie - Eastbound**		
	Current hand dryers	**Airblade hand dryers***	**Blast hand dryers***	**Current hand dryers**	**Airblade hand dryers***	**Blast hand dryers***	**Current hand dryers**	**Airblade hand dryers***	**Blast hand dryers***
Number of hand dryers	8			12			4		
Hand dryer consumption (w)	2,300	1400	1450	2,300	1400	1450	2,300	1400	1450
drying time (s)	35	12	10	35	12	10	35	12	10
Initial cost ($)	n/a	10,440	6,048	n/a	15,660	9,072	n/a	5,220	3,024
Annual visitors - 2009	1,883,948			1,329,695			326,858		
Percentages savings over the currwnt hand dryers	n/a	79%	82%	n/a	79%	82%	n/a	79%	82%
Utility cost ($/KWH)	0.09			0.11			0.11		
Annual operating cost based on 50% usage of visitors (Up to $)	1950	407	351	1673	349	301	388	81	70
Annual savings (Up to $)	n/a	1543	1599	n/a	1323	1371	n/a	307	318
Payback period	n/a	6.4	3.7	n/a	10.5	6.2	n/a	14.2	8.6

n/a: Not Applicable

* (RSMeans 2010;Fixture Universe 2010; Abt 2010)

5.1.7 Water-saving Plumbing Fixtures

Rest areas in Illinois have high water consumption due to the considerable number of visitors that utilize their bathrooms. Accordingly, using water conservation fixtures in these rest areas will provide significant savings in water consumption. A number of available technologies can be used to minimize water consumption in rest areas including efficient faucets, aerators, toilets, and urinals.

The LCC components of replacing the current fixtures with water saving fixtures include initial cost, maintenance cost, operating cost, and replacement cost. The initial cost includes material and labor costs required to remove the existing fixtures and install the water saving fixtures. The maintenance cost represents the annual costs required to maintain the functionality and efficiency of the fixtures during their useful life. Operating cost represents the annual water cost needed to operate these fixtures. The replacement cost represents the capital cost of replacing these water fixtures after the end of their useful life. The annual savings that could be achieved from these fixtures are represented in the annual water savings from the reduction in water consumption.

In order to analyze the cost effectiveness of replacing the current water fixtures in rest areas with water saving fixtures, LCC components need to be calculated. The initial cost of this replacement can be calculated based on the RSMeans Building Construction Cost Data (2010). The maintenance cost can be considered the same as the maintenance cost of the current water fixtures in rest areas; and therefore this cost component can be ignored during this comparative analysis. The replacement cost can be considered the same as the initial cost at the end of the fixture's useful life. The operating cost and savings depend on the water cost and consumption rate throughout the year. Since Prairie View, Funks Grove, and Pride of the Prairie use well water, water consumption and water unit cost were not available for these rest areas. The current faucets in Funks Grove (low flow faucets) and Pride of the Prairie (mechanical faucet) rest areas are suitable for water conservation measures. The current automatic sensor faucets in Prairie View rest area have higher flow than newer water saving faucets. These faucets can either be replaced with lower flow faucets or adjusted using aerators which can reduce water flow to (0.5-3.0GPM). The initial cost of replacing these faucets is approximately $510 X 8 while adding faucet aerators has an initial cost of $7.5 X 8. The replacement of these faucets or adding aerators to the current faucets in Prairie View rest area will provide adequate savings in faucets water consumption. The amount of water savings cannot be precisely determined because data on current faucet water consumption is unavailable; and the duration of utilizing the new faucets or added aerators by each visitor can be longer than the old ones due to their reduced flow rate. The replacement of the current toilets and urinals with more conservation fixtures will provide significant savings in water consumption of rest areas. Table 35 shows the cost and savings of replacing the toilets in Prairie View, Funks Grove, and Pride of the Prairie rest areas. Table 36 shows the cost and savings of replacing the urinals in Prairie View, Funks Grove, and Pride of the Prairie rest areas. Replacing the current plumbing fixtures with water saving plumbing fixtures will reduce the water pumping of the ground water, reduce drying up the wells, reduce energy required for pumping water, and prolong the service life of the ground water well.

Table 35. Cost and Savings of Replacing the Toilets in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area	**Prairie View - Northbound**	**Funks Grove**	**Pride of the Prairie - Eastbound**
Current fixture rate (GPF)	N.A.	3	3
# of fixtures	10	17	8
Type	Wall mount	Wall mount	Ground mount
Conservation toilets rate (GPF)	1.6	1.6	1.25
Initial Cost ($)	6,190*	10,523*	7,816*
Savings per flush (G)	N.A.	1.4	1.75
Percentage savings (%)	N.A.	47%	58%
Annual visitors 2009	1,883,948	1,329,695	326,858
Annual savings for 50% visitors (G)	N.A.	Up to: 930,787	Up to: 286,001

* (RSMeans 2010; Water & Energy Solutions 2010)
N.A.: Not Available

Table 36. Cost and Savings of Replacing the Urinals in Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area	**Prairie View - Northbound**	**Funks Grove**	**Pride of the Prairie - Eastbound**
Current fixture rate (GPF)	N.A.	1	1
# of fixtures	4	6	2
Conservation water urinals rate (GPF)	0.125	0.125	0.125
Initial Cost ($)	5,504*	8,256*	2,551*
Savings per flush (G)	N.A.	0.875	0.875
Percentage savings (%)	N.A.	88%	88%
Annual visitors 2009	1,883,948	1,329,695	326,858
Annual savings for 25% visitors (G)	N.A.	Up to: 290,862	Up to: 71,500

* (RSMeans 2010; Water & Energy Solutions 2010)
N.A.: Not Available

5.2 FEASIBILITY ANALYSIS OF POTENTIAL ENERGY AND WATER SAVING MEASURES

5.2.1 Indoor Temperature Control

Controlling the indoor temperature in rest areas is an important measure which increases the efficiency of the heating and cooling system as well as reducing its energy consumption costs. Several measures can be used to control temperature in rest areas including air curtains, programmable thermostats, heat recovery air exchangers, and fans. Each of these measures utilizes a different approach to improve the efficiency of the heating and cooling system in buildings.

Air curtains are fan-powered devices that are used to separate two building spaces. They provide air streams with significant strength to resist the infiltration of wind and windborne driven dust, pollen, smoke, and flying insects while at the same time maintaining the building's desired indoor temperature. Several benefits could be achieved from utilizing air curtains in rest areas including: enhanced level of hygiene, higher comfort, and reduced energy cost for heating and cooling in rest areas. Air curtains are mounted over door openings at a height ranging from 7 to 30 feet. Programmable thermostats are smart controls which adjust heating and cooling inside buildings according to the typical use of these buildings. These thermostats can be programmed for timed setting changes. For instance, some thermostats can be programmed for four periods per day to account for four different building usages throughout a day. Therefore, these thermostats can be used in rest areas to set back heating and cooling at night where lower visitation rates are expected. A heat recovery air exchanger is a device which uses the heat in the indoor air that needs to be ventilated to the outside to preheat the incoming cold fresh air from the outside during the winter, as shown in Figure 85. In the summer, the system works in an opposite manner where exhausting air is used to cool the hot fresh incoming air. Several benefits could be achieved from heat recovery air exchanges including: reducing energy bills, constant/controlled supply of outside air, enhancing indoor air quality, and reducing the concentration of allergens such as pollen, dust, and dander (OTTERTAIL Power Company 2010). Fans such as commercial air circulators are also used to circulate air in order to ensure better distribution of heating/cooling throughout the room as well as increasing comfort. Table 37 summarizes the initial cost of utilizing these temperature control options in Prairie View, Funks Grove, and Pride of the Prairie rest areas.

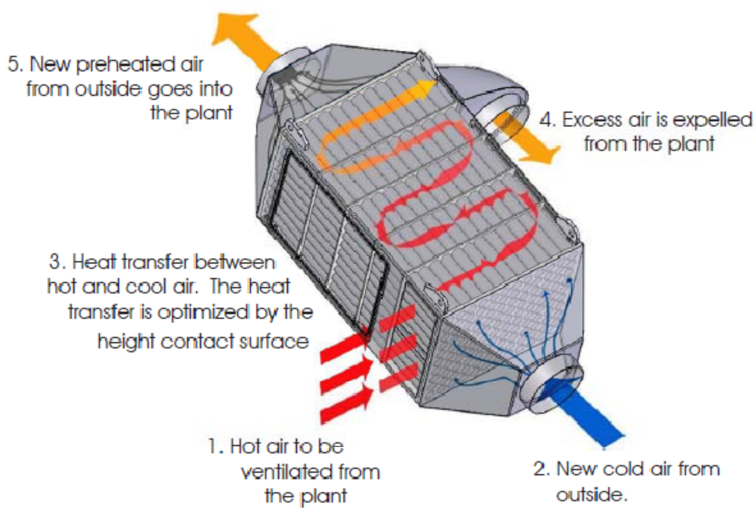


Figure 85. Flow of air in heat recovery air exchanger (Redwood Plastics 2010).

Table 37. Initial Costs of Temperature Control Techniques for Prairie View, Funks Grove, and Pride of the Prairie Rest Areas

Rest area\ Technique	Air curtains[1]			Programmable thermostat[3]		Heat recovery air exchanger[4]		Commercial air circulator[5]	
	#	Initial cost ($)	Annual O. C. ($)[2]	#	Initial cost ($)	#	Initial cost ($)	#	Initial cost ($)
Prairie View - Northbound	4	6,020	226	1	130	1	1,371	2	440
Funks Grove	-	-	-	3	390	3	4,113	2	440
Pride of the Prairie - Eastbound	3	4,515	46	1	130	1	1,371	1	220

[1] Retrieved from (RSMeans 2010)
[2] Approximate annual operating cost based on non-heating model
[3]Honeywell 7-Day touch screen programmable thermostat. Retrieved from (Energy Star) and (J&R 2010)
[4] Retrieved from RSMeans (2010) and (ATrendyhome 2010) (installation included flexible ducting (25feet per line), and operating energy cost is similar to 100~120 watt lamp.
[5] Air master commercial air circulators wall and ceiling mounts (Reliable Paper Inc 2010)

5.2.2 Rain Gardens

Rain plays a vital environmental role because it refills underground water reservoirs and maintains flow levels in streams and rivers. The vital environmental role of rain can be compromised due to human generated pollutants that often flow with rain overland to the nearest waterway. These undesirable pollutants include petroleum products, fertilizers, pesticides, and household chemicals. These products are used daily in our life and water need to be protected from these pollutants. One way to protect waterways from being polluted is to alter human behavior to minimize the usage and waste and accordingly reduce their negative impact on waterways. Another way is to intercept storm water runoff before it enters waterways (Virginia Department of Forestry 2008). Rain gardens can be used as a way to protect water from being polluted. They are depressions in the landscape that capture and temporarily store storm-water until it is filtrated into the soil. Capturing runoff in a rain garden allows water to infiltrate into the soil rather than run into streets and storm drains. Rain gardens are an infiltration storm water management practice that relies on soil percolation rates to help in managing rainfall and eventually protect water quality. The benefits of considering rain gardens in rest areas include: enhancement of the beauty of green yards, recharging the ground water supply, creating landscapes and plants that improve aesthetics and provide shade, and creating hydrologically functional landscapes that benefits from rainfall water instead of generating runoff that leads to water quality problems and contributes to flooding (Virginia Department of Forestry 2008; Adamson 2008).

Rain gardens consist of six layers including: grass buffer strip that slows down the velocity of runoff; mulch layer which allows biological activities to occur and keep the soil moist; plants which use runoff for moisture and nutrient requirements; soil layer which provide an environment for plants to collect moisture and nutrients for their growth; ponding area or depression which provides the storage needed for runoff; and berm with at least 6 inches of soil or rock which works as a dam to pond water runoff, as shown in Figure 86 (Virginia Department of Forestry 2008). Rain garden location is one of the important components of its success and it must be located where runoff naturally flows to. Rain garden is an infiltration storm water management practice which relies mainly on the soil percolation rates which allow water to move down easily through the soil profile. Therefore, soils that can retain water for extended period of time are not suitable for rain gardens. A rain garden should retain water for a maximum of 12 to 24 hours. Possible locations for rain gardens might be near to rest area buildings to capture the roof runoff or farther from the rest area building to collect water from lawns and parking lots. Rain gardens should not be installed in upslope from buildings, closer than 10 feet from foundation, under trees, in high water tables, or in steep slopes (Adamson 2008). The installation cost of rain gardens varies significantly based on many factors including: existing landscape, soil characteristics, rain garden design, size, number and type of plants, source of runoff water (roof, lawn, or parking lot), and ground water table. Infiltration tests might be performed to identify the percolation rate of the soil under consideration and whether it needs to be amended. A rough estimate for constructing a rain garden can be approximately $20/square foot of surface area including design and installation (Adamson 2008). The maintenance of a rain garden is almost the same as regular landscapes. The only differences are the potential need to replace the soil if (1) ponding areas start to retain water longer than the designed time which indicates clogged soil pores; (2) compacted soil is formed which causes a decreased soil porosity; or (3) excessive acidity or alkalinity are encountered in the soil (Virginia Department of Forestry 2008).

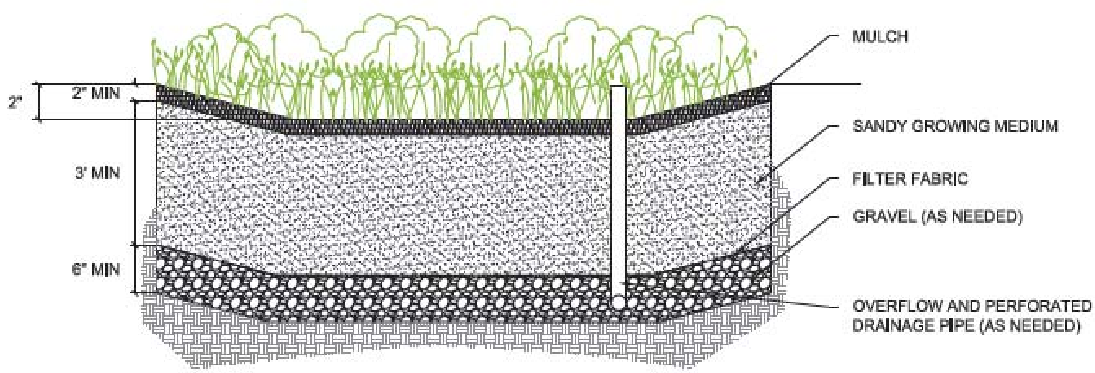


Figure 86. Typical cross-section for a rain garden (CRWA 2008).

5.2.3 Gray Water Systems

Gray water reuse is a sustainability concept which is used to reduce the consumption of clean water sources. There are two types of gray water: light-gray water and dark-gray water. The light-gray water includes water waste from bathroom sinks, tubs, showers, and often laundry. All these wastewater categories contain a wide range of organic and inorganic contaminants as well as disease-causing microorganisms. Dark-gray water includes both light gray water sources plus waste water from kitchen sinks, automatic dishwashers, or other sinks involving food preparation. Food waste increases the contamination loads including disease-causing microorganisms (BC Green Building Code 2007). For rest areas, the only source of gray water is bathroom sinks. Gray water can be used for outdoor purposes such as irrigation or indoor purposes such as flushing toilets and urinals. As shown in Figure 87, the outdoor gray water reuse for irrigation is performed in three steps that are designed to: (1) collect the gray water from sinks, laundry, and showers; (2) store and potentially filter it before use; and (3) pressurize and distribute it via subsurface system (UEI (b) 2002). For indoor reuse, gray water must be treated after its collection before it can be used in flushing toilets. There are several regulations that should be considered for using gray water for flushing toilets and urinals: (1) distribution pipes should be clearly identified as containing non-potable water; (2) gray water must be filtered, disinfected, and dyed; (3) gray water storage reservoirs should be sized appropriately and must have a back-up potable water supply; and (4) storage reservoirs must have drains and overflow pipes which are indirectly connected to the sanitary drainage system (University of Florida 2009). The main components of the system include filter system, storage reservoir, disinfection unit, and coloring dye injection unit, as shown in Figure 88.

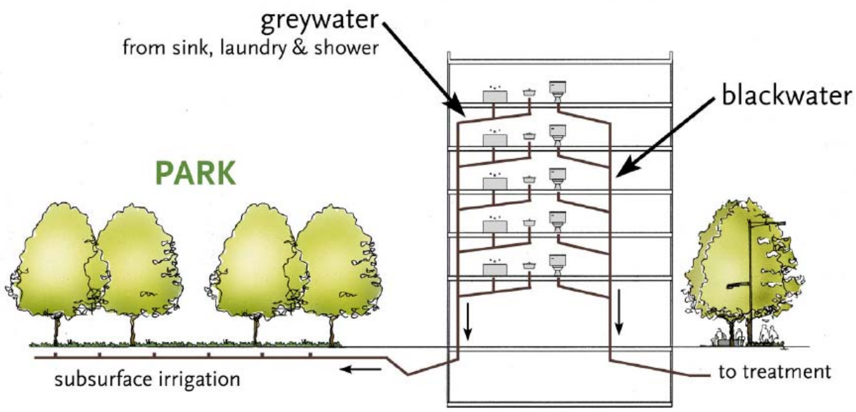


Figure 87. Graywater reuse for irrigation (UEI 2002).

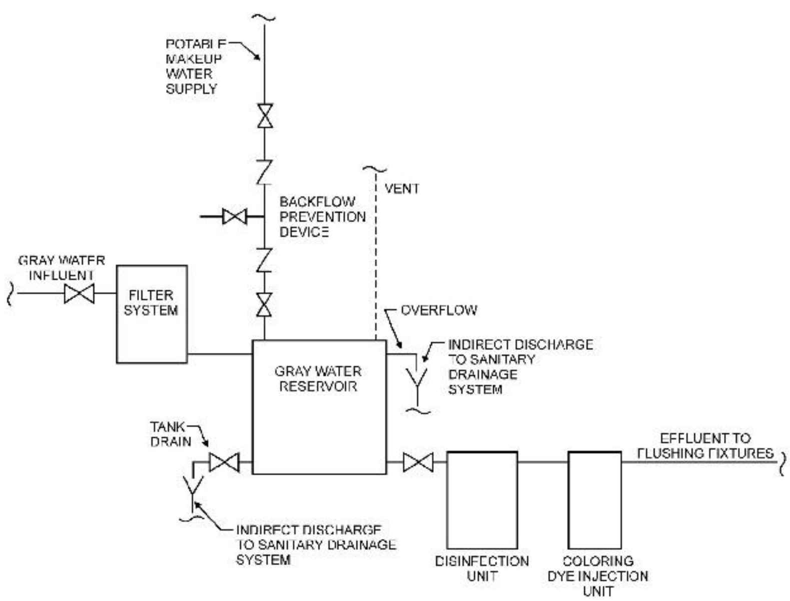


Figure 88. Graywater reuse for indoor purposes (University of Florida 2009).

The advantages of using gray water in buildings include: minimizing the use of existing fresh water, releasing pressure on sanitary systems, and providing savings in water and sewer bills. On the other hand the drawbacks of irrigation gray water reuse include: effects on soil physical and mechanical properties, effects on plant health, contamination risk of groundwater, and initial cost of a gray water system and plumbing requirements. Furthermore, the drawbacks of indoor gray water reuse include higher plumbing maintenance cost, potential for pollution and undesirable health effects if the gray water is not reused correctly or treated well, and initial cost of a gray water system and plumbing requirements (Salama 2010) and (Mayo 2007).

Accordingly, the utilization of gray water for irrigation in rest areas may not be appropriate since it may compromise soil characteristics, plant health and the quality of groundwater which is used in many rest areas as a source of potable water. The indoor gray water reuse systems are used commonly for residential buildings however, incorporating these systems in public facilities like rest areas might risk the quality of health and spread of diseases if gray water is not properly treated. The cost of gray water reuse systems varies significantly based on application and the underlying technology of the system, design and quality of water treatment, and system size. These systems are more ideally suited to new construction applications and areas with limited sources of water and it may not be cost-effective as a retrofit in existing buildings such as rest areas (Alliance for Water Efficiency 2009).

5.3 SUMMARY OF GREEN FRIENDLY MEASURES FOR THE SELECTED REST AREAS

This section summarizes and compares the performance of the "green friendly" measures that were analyzed in this report for the three selected rest areas. The analyzed "green friendly" measures include: induction lighting, motion activated lighting, solar water heating systems, geothermal heat pumps, building integrated photovoltaic systems, thermal pane glass windows and doors, programmable thermostats, water saving toilets, water saving urinals, energy efficient hand dryers, air curtains, heat recovery air exchangers, and commercial air circulators. The initial cost, cumulative cost, annual savings, payback period, and energy/water percentage savings for all these measures are listed in Table 38,

Table 39, and Table 40 for Prairie View, Funks Grove, and Pride of the Prairie rest areas, respectively. The application of induction lighting, motion activated lighting, solar water heating systems, building integrated photovoltaic systems, geothermal heat pumps, thermal pane glass, and hand dryers are grouped in the upper part of these tables and ranked based on their initial cost since their payback periods were calculated in the LCCA sections of this study. Other green technologies that did not have payback periods in the aforementioned LCCA section of this study due to lack of data were grouped in the lower part of these tables and ranked based on their initial cost. The utilization of induction lighting, motion activated lighting, solar water heating systems, building integrated photovoltaic systems, geothermal heat pumps, thermal pane glass, and hand dryers are presented in a graphical format for Prairie View, Funks Grove, and Pride of the Prairie rest areas as shown in Figure 89, Figure 90, and Figure 91. These figures accounted for the ranges of energy savings that these technologies can provide and the impact of these ranges on the initial costs and payback periods. Based on this comparison, motion activated lighting is the cheapest technology with the fastest payback periods, and building integrated photovoltaic systems and thermal pane windows have the highest initial costs and payback periods. The initial cost for implementing all these measures are $212,419; $210,580; and $140,316 for Prairie View, Funks Grove, and Pride of the Prairie, respectively.

Table 38. Comparison among Green Friendly Measures for Prairie View Rest Area

Best Management Practice (BMP)	Initial Cost ($)	Cumulative Initial Cost ($)	Annual savings - first year ($)	Payback period (years)	Energy/water Savings (%)[1]
Motion activated lighting	1,560	1,560	634	3.2	2.2%
Solar water heating systems[3]	5,810	13,418	1,146	5.03	4.3%
Hand dryers	6,048	7,608	1,599	3.7[2]	82%[4]
Exterior Induction lighting[5]	9,398	22,816	1,357	4.7	56.1%[6]
Geothermal heat pump[7]	67,820	90,636	6,147	8.7	21.7%
Building integrated photovoltaic system	53,957	144,593	1,421	35.6	5.0%
Thermal pane glass	60,900	205,493	1,592	30.3	5.6%
Programmable thermostat	130	205,623	N.A.	N.A.	N.A.
Commercial air circulator	440	206,063	N.A.	N.A.	N.A.
Heat recover air exchanger	1,371	207,434	N.A.	N.A.	N.A.
Water conservation urinals	5,504	212,938	N.A.	N.A.	N.A.[8]
Air Curtains	6,020	218,958	N.A.	N.A.	N.A.
Water conservation toilets	6,190	225,148	N.A.	N.A.	N.A.[9]

N.A.: Not Available/ Not Applicable
[1] Percentage of energy saving based on total energy consumption in 2009
[2] approximate payback period based on 50% usage of rest area visitors
[3] Ground mount solar water heater
[4] Energy savings based on hand dryers energy consumption
[5] One-for-one light replacement which reduces light output by 61.7%
[6] Energy savings of exterior lighting energy cost
[7] Geothermal heat pump with horizontal loop
[8] water savings based on urinals water consumption
[9] Water savings based on toilets water consumption

Table 39. Comparison among Green Friendly Measures for Funks Grove Rest Area

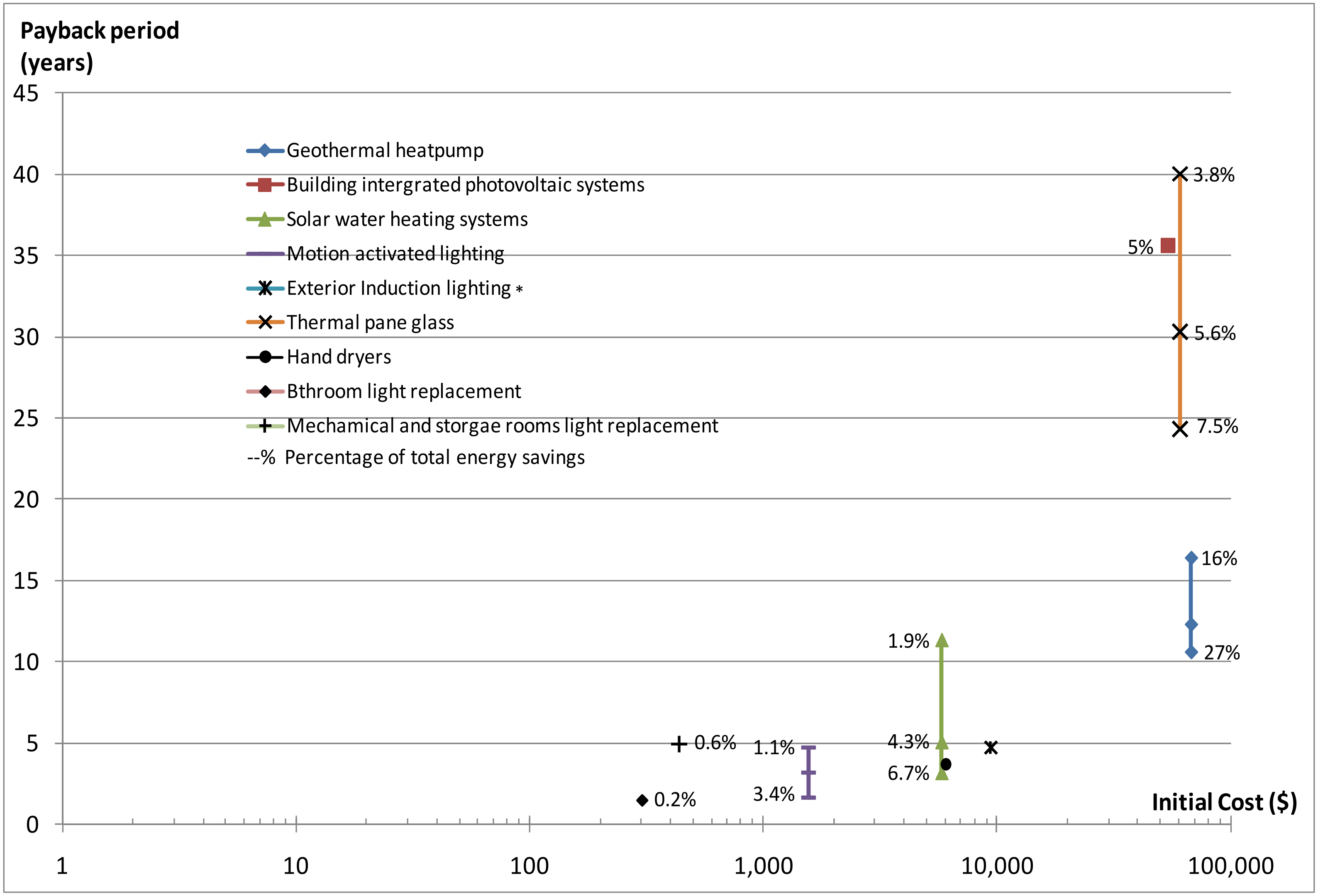
Best Management Practice (BMP)	**Initial Cost ($)**	**Cumulative Initial Cost ($)**	**Annual savings - first year ($)**	**Payback period (years)**	**Energy/water Savings (%)**[1]
Motion activated lighting	3,343	3,343	1,990	2.2	4.3%
Solar water heating systems[2]	7,835	11,178	1,850	3.95	4.1%
Hand dryers	9,072	20,250	1,371	6.2[3]	82%[4]
Exterior Induction lighting[5]	30,994	51,244	5,226	4.25	58.2%[6]
Building integrated photovoltaic system	73,553	231,437	2,284	32	5.0%
Geothermal heat pump[7]	106,640	157,884	7,140	8.7	16%
Programmable thermostat	390	231,827	N.A.	N.A.	N.A.
Commercial air circulator	440	232,267	N.A.	N.A.	N.A.
Heat recover air exchanger	4,113	236,380	N.A.	N.A.	N.A.
Water conservation urinals	8,256	244,636	N.A.	N.A.	88%[8]
Water conservation toilets	10,523	255,159	N.A.	N.A.	47%[9]

N.A.: Not Available/ Not Applicable
[1] Percentage of energy saving based on total energy consumption in 2009
[2] Ground mount solar water heater
[3] approximate payback period based on 50% usage of rest area visitors
[4] Energy savings based on hand dryers energy consumption
[5] One-for-one light replacement which reduces light output by 61.0%
[5]Energy savings of exterior lighting energy cost
[6] Geothermal heat pump with horizontal loop
[7] water savings based on urinals water consumption
[8] Water savings based on toilets water consumption

Table 40. Comparison among Green Friendly Measures for Pride of the Prairie Rest Area

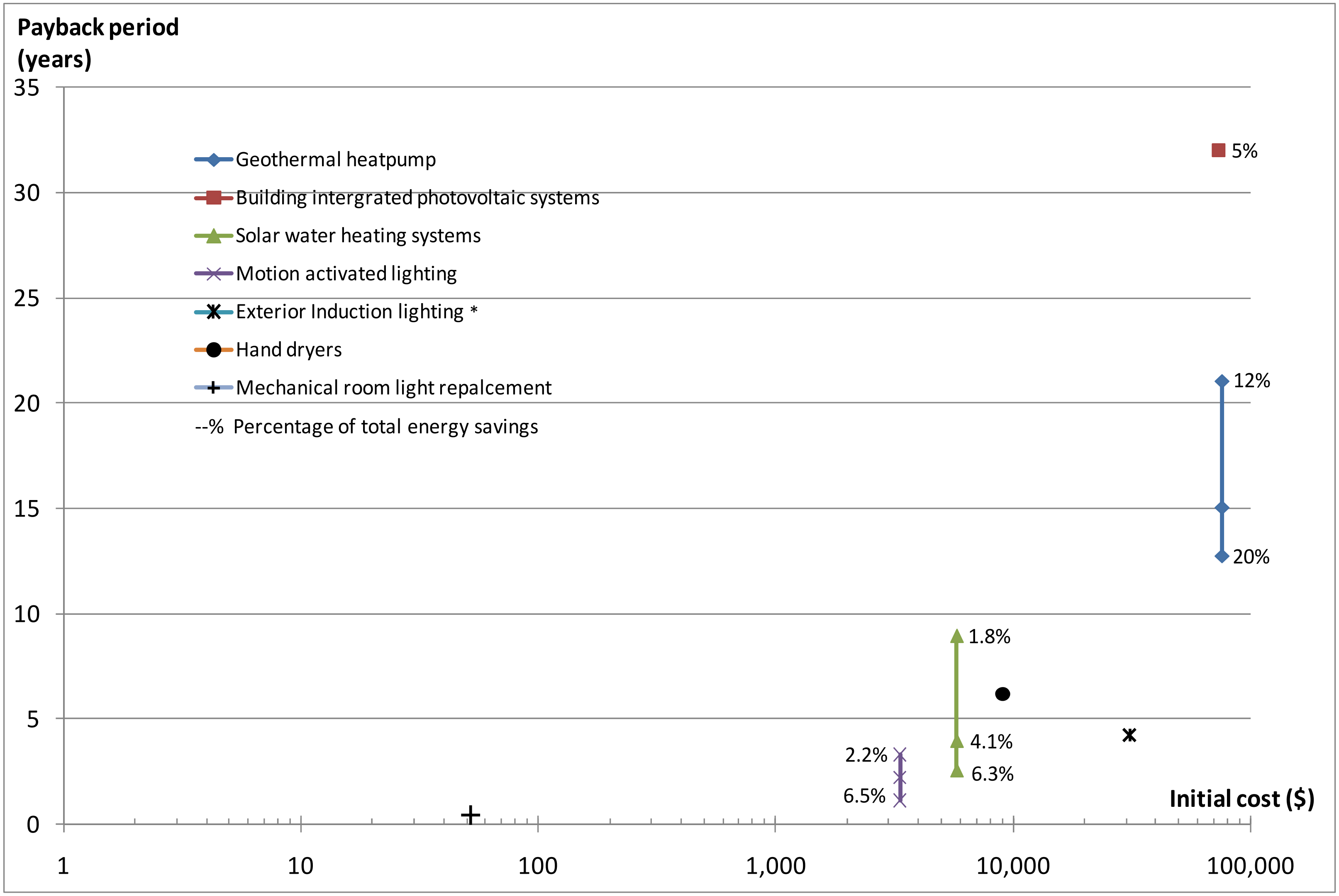
Best Management Practice (BMP)	Initial Cost ($)	Cumulative Initial Cost ($)	Annual savings - first year ($)	Payback period (years)	Energy/water Savings (%)[1]
Motion activated lighting	1,337	1,337	485	3.6	7.2%
Hand dryers	3,024	4,361	318	8.6[2]	82%[3]
Solar water heating systems[4]	5,810	29,260	275	23.2	4.1%
Building integrated photovoltaic system	12,864	77,637	339	36.5	5.0%
Exterior Induction lighting[5]	19,089	23,450	3,272	4.36	56.1%[6]
Geothermal heat pump[7]	35,513	64,773	944	24.5	14%
Thermal pane glass	52,822	130,459	764	45.0	11.3%
Programmable thermostat	130	130,589	N.A.	N.A.	N.A.
Commercial air circulator	220	130,809	N.A.	N.A.	N.A.
Heat recover air exchanger	1,371	132,180	N.A.	N.A.	N.A.
Water conservation urinals	2,551	134,731	N.A.	N.A.	88%[8]
Air Curtains	4,515	139,246	N.A.	N.A.	N.A.
Water conservation toilets	7,816	147,062	N.A.	N.A.	58%[9]

N.A.: Not Available/ Not Applicable
[1] Percentage of energy saving based on total energy consumption in 2009
[2] approximate payback period based on 50% usage of rest area visitors
[3] Energy savings based on hand dryers energy consumption
[4] Ground mount solar water heater
[5] One-for-one light replacement which reduces light output by 62.2%
[6] Energy savings of exterior lighting energy cost
[7] Geothermal heat pump with horizontal loop
[8] water savings based on urinals water consumption
[9] Water savings based on toilets water consumption



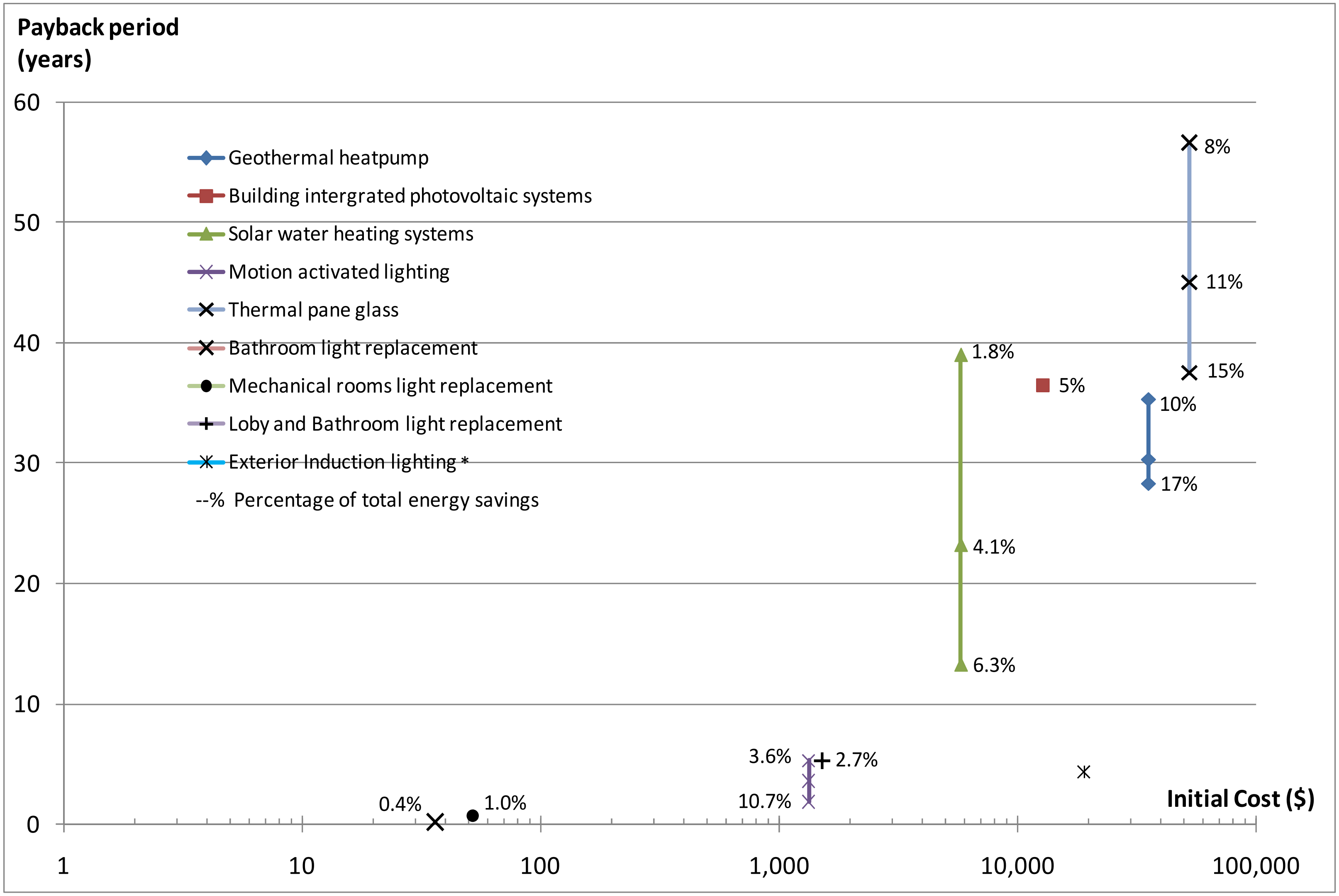
*One-for-one light replacement which reduces light output by 61.7%

Figure 89. Energy saving ranges of green friendly measures for Prairie View rest area.



*One-for-one light replacement which reduces light output by 61.0%

Figure 90**.** Energy saving ranges of green friendly measures for Funks Grove rest area.



*One-for-one light replacement which reduces light output by 62.2%

Figure 91. Energy saving ranges of green friendly measures for Pride of the Prairie rest area.

CHAPTER 6 DECISION SUPPORT TOOL FOR OPTIMIZING UPGRADE DECISIONS OF REST AREA BUILDINGS

6.1 OPTIMIZING UPGRADE DECISIONS OF REST AREAS

The U.S. Green Building Council (USGBC) has developed several LEED rating systems to promote the sustainability of buildings and their performance in five main divisions: energy efficiency, indoor environmental quality, materials selection, sustainable site development, and water savings. These rating systems are designed to address the specific requirements of various types of buildings, including new construction rating system for new buildings; existing buildings rating system for existing buildings; commercial interiors rating system which helps tenants and designers to make sustainable choices; schools rating system which rates the features of the design, construction, and spaces of schools; healthcare rating system which addresses the unique needs of healthcare services; neighborhood development rating system which integrates the measures of smart growth, urbanism, and green buildings with neighborhood design; and homes rating system which categorizes the design and construction of green homes (USGBC (b) 2009). Each of these rating systems contains several sustainable measures and green friendly technologies which can improve the performance of buildings and reduce their harmful effect on the environment.

The performance of rest area buildings can be improved by acquiring LEED certification through the LEED rating system for Existing Buildings (LEED-EB). The LEED rating system for Existing Buildings (LEED-EB) provides several upgrade measures and green friendly techniques which are classified into six main areas including: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Material and Resources (MR), Indoor Environmental Quality (IEQ), and Innovation in Operation (IO). Each of these divisions includes items which determine what measures need to be fulfilled in order to achieve LEED points. All these upgrade and green friendly measures improve the performance of existing buildings and reduce their environmental impacts; however, they vary in initial cost, annual operating costs, environmental effect, and potential LEED credits. A LEED certified project should fulfill all the prerequisites in each division and earn a sufficient number of points to achieve the desired certification level. Four certification levels are available for ranking green buildings using the LEED rating system for existing building: (1) certified level which requires 40 – 49 points; (2) silver level which requires 50 – 59 points; (3) gold level which requires 60 – 79 points; and (4) platinum level which requires 80 points or more. These LEED certification requirements and ratings provide decision makers with new and serious challenges, including (1) which green building measures should be selected to accomplish a specified LEED certification rating (e.g. gold) with the least possible upgrade costs; and (2) which green building measures should be selected to maximize earned LEED points while complying with a specified limited budget for upgrade costs.

To support IDOT decision makers in addressing the aforementioned challenges in acquiring LEED certification, this report presents the development of a Decisions Support Tool (DST) that can be used to optimize the selection of upgrade decisions for rest area buildings in Illinois. The developed DST is designed to optimize upgrade decisions for each rest area according to its condition and potential for improvements. This optimal list of upgrade decisions seeks to (1) minimize the needed total upgrade costs; and (2) maximize the sustainability of the interstate rest areas. Accordingly, the developed DST is designed to identify a set of optimal upgrade decisions for each rest area building, where each list achieves an optimal tradeoff between sustainability (represented by the earned number of LEED points) and the required upgrade cost, as shown in Figure 92.

Several optimization techniques can be used to develop the proposed DST, including linear programming, genetic algorithms, and dynamic programming. The DST in this research was developed using linear programming because of (1) its guarantee to generate a global optimal solution for the upgrade decisions of the rest areas; (2) its reasonable computational time and effort compared to other optimization techniques; and (3) its practical implementation using Microsoft Excel spreadsheet and its add-in Solver which provides friendly graphical user interface (GUI) and facilitates the use of the DST by IDOT decision makers. In addition, the DST in its current spreadsheet format can be easily upgraded in the future to adapt to new versions of the LEED-EB rating systems which may evolve as observed in the past.

The DST is designed to provide IDOT decision makers with an optimal list of upgrade measures that achieves the highest level of LEED certification practicable (i.e., highest number of LEED points) within the specified project budget, as represented by solution 1 in Figure 92. This enables IDOT to maximize the number of their rest areas that achieve the highest level of LEED certification in order to support the newly developed "Green Building Act "Guidelines for State Construction." Furthermore, the DST will enable IDOT to generate an optimal list of upgrade measures to achieve any required level of LEED certification at the least possible cost. For example, solutions 2 and 3 in Figure 92 represent the optimal solution that can achieve the gold and platinum certifications at the least cost, respectively.

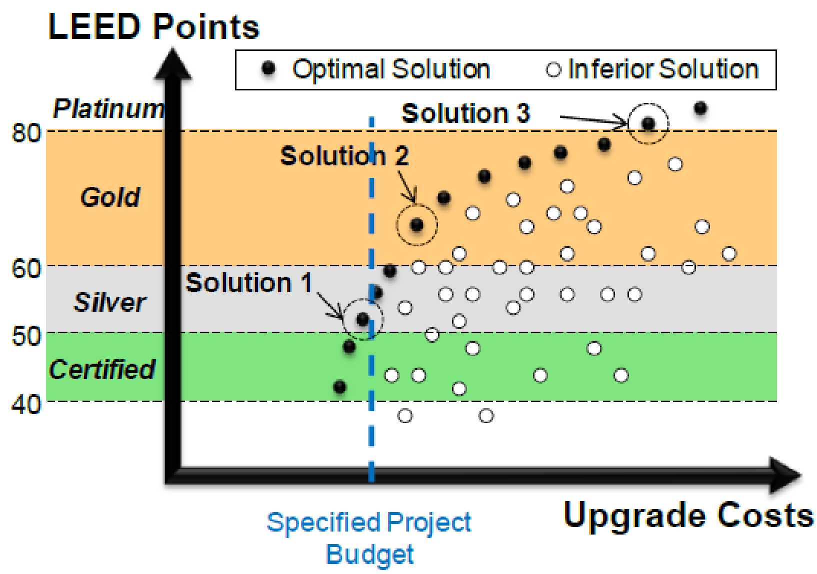


Figure 92. Optimal upgrade decisions for rest area buildings.

The decision variables in the developed DST are designed to represent feasible energy and water saving alternatives for each rest area building. These energy and water measures will help the rest area buildings accomplish LEED certification as well as reduce energy and water consumption of these buildings. The two main optimization objectives of this DST are minimizing total upgrade costs and maximizing the number of earned LEED points to maximize the sustainability of the interstate rest area buildings while maintaining upgrade cost within a certain limit, as shown in Figure 93. Accordingly, the DST is designed to incorporate two optimization models that are capable of (1) minimizing the total upgrade costs that are required to accomplish a specified LEED certification level such as Silver or Gold; and (2) maximizing the number of accredited LEED points that can be earned under a specified limited budget for upgrade costs.

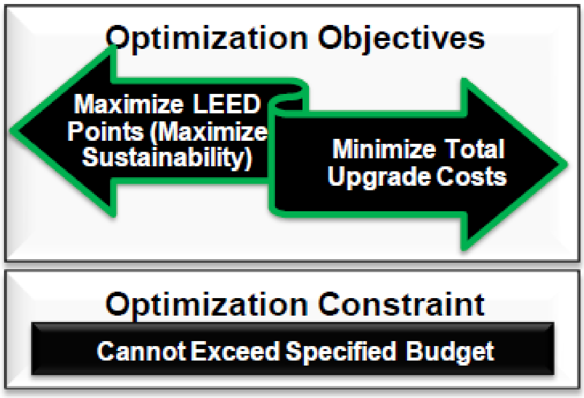


Figure 93.Main objectives of the developed DST.

6.2 POTENTIAL LEED POINTS FOR INTERSTATE REST AREAS

The LEED rating system for existing buildings (LEED-EB V3.0) is the most suitable rating system for interstate rest areas in Illinois. The LEED–EB is divided into seven main divisions: 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). Each of these seven divisions is further divided into subdivision(s) which determines what items need to be fulfilled in order to earn LEED credits. Some of these items are prerequisites which have to be fulfilled in order to achieve any LEED certification while the rest are optional which can be achieved based on the eligibility/willingness of the project/building to achieve these credits. The creditable items for rest areas need to be identified in order to be used in the Decision Support Tool to achieve the highest LEED points within a certain budget or achieve a certain LEED level with the lowest possible budget. Table 41, Table 42, Table 43, Table 44, Table 45,
Table 46, and Table 47 show the eligible LEED credits and potential LEED points that can be achieved for Prairie View, Funks Grove, and Pride of the Prairie rest areas. The eligible LEED points for these three rest areas can add up to 79 points. A LEED certified project should fulfill all the prerequisites and earn a sufficient number of points to achieve the desired certification level. Four certification levels are available for ranking green buildings using the LEED-EB rating system including: (1) certified level which requires 40 – 49 points; (2) silver level which requires 50 – 59 points; (3) gold level which requires 60 – 79 points; and (4) the platinum level which requires 80 points or more.

Table 41. Eligible Credits and Associated Points for Sustainable Site Division of LEED-EB for 2009

Sustainable Site items	**Rest area /potential points**	
Building Exterior and Hardscape Management Plan Implementing a low-impact site and green building exterior management plan that addresses overall site management, chemicals, snow and ice removal, and building exterior cleaning and maintenance. Include green cleaning and maintenance practices and materials that minimize environmental impacts. The plan must address all of the operational elements listed in LEED-EB that occur on the building and grounds.	PV	1 Point
	FG	1 Point
	PP	1 Point
Integrated Pest Management, Erosion Control, and Landscape Management Plan Implementing a low-impact site and green building exterior management plan that addresses overall site management, chemicals, fertilizers, landscape waste and pest management. The plan must address the items listed in the LEED-EX, 2009.	PV	1 Point
	FG	1 Point
	PP	1 Point
Site Development-Protect or Restore Open Habitat Implementing in place native or adapted vegetation covering a minimum of 25% of the total site area (excluding the building footprint) or 5% of the total site area (including the building footprint), whichever is greater. Activities might include removing excessive paved areas and replacing them with landscaped areas or replacing excessive turf grass area with natural landscape features.	PV	1 Point
	FG	1 Point
	PP	1 Point
Stormwater Quantity Control Implementing a stormwater management plan that infiltrates, collects and reuses runoff or evapotranspirates runoff from at least 15% of the precipitation falling on the whole project site. Stormwater uses include landscape irrigation, toilet and urinal flushing, and custodial uses. Implementing an annual inspection program of all stormwater management facilities to confirm continued performance. Maintaining documentation of inspection, including identification of areas of erosion, maintenance needs and repairs. Perform all routine required maintenance, necessary repairs or stabilization within 60 days of inspection.	PV	1 Point
	FG	1 Point
	PP	1 Point
Heat Island Reduction-Nonroof Employ strategies, materials and landscaping techniques that reduce the heat absorption of exterior materials. Shading at least 50% of the site hardscape (roads, sidewalks, courtyards and parking lots) using canopy, covered parking with a solar reflectance index (SRI) of at least 29, native or adapted trees and large shrubs, vegetated trellises, or covered parking with solar panels that produce energy used to offset some nonrenewable resource use. Also, considering new coatings and integral colorants for asphalt which achieve light-colored surfaces.	PV	1 Point
	FG	1 Point
	PP	1 Point
Heat Island Reduction-Roof Using roofing materials with a solar reflectance index (SRI) equal to or greater than the values listed in the LEED-EX, 2009 for a minimum of 75% of the roof surface.	PV	1 Point
	FG	1 Point
	PP	1 Point

PV: Prairie View rest area, FG: Funks Grove rest area, PP: Pride of the Prairie rest area.

Table 42. Eligible Credits and Associated points for Water Efficiency Division of LEED-EB for 2009

Water efficiency items	**Rest area /potential points**	
Water Performance Measurement Metering water consumption in rest areas including potable water consumption, toilets water consumption, and total water consumption or outdoor irrigation water and potable water consumption.	PV	2 Points
	FG	2 Points
	PP	2 Points
Additional Indoor Plumbing Fixture and Fitting Efficiency Accounting for strategies and systems that reduce indoor potable water use including: automatic controls; indoor plumbing fixtures and fitting that perform better than the Uniform Plumbing Codes 2006 or International Plumbing Codes 2006 requirements; or using ultrahigh-efficiency or dry fixtures and fittings and control technologies. Points are achieved based on the amount of water savings. 10% savings leads to one point and 30% savings leads to 5 points. The water savings are calculated based on the requirements of the Uniform Pluming Codes.	PV	0-5 Points
	FG	0-5 Points
	PP	0-5 Points
Water Efficient Landscaping Implement highly efficient irrigation technologies such as microirrigation, moisture sensors or weather data based controllers. Points are achieved based on the amount of water savings. 50% savings leads to one point and 100% savings leads to 5 points.	PV	0-5 points
	FG	0-5 points
	PP	0-5 points

PV: Prairie View rest area, FG: Funks Grove rest area, PP: Pride of the Prairie rest area.

Table 43. Eligible Credits and Associated Points for Energy and Atmosphere Division of LEED-EB for 2009

Energy and atmosphere items	**Rest area /potential points**	
Optimize Energy Efficiency Performance Improving levels of operating energy performance relative to typical buildings of similar type to reduce environmental and economic impacts associated with excessive energy use. Implementing energy-efficient retrofits and energy-saving techniques to reduce the building's energy use. Considering renewable energy options as a way to minimize the building's environmental impact (Geothermal heat pumps, BIPV, solar water heating systems, and wind power are eligible for this item). Points are achieved by demonstrating energy efficiency at least 21% better than the average for typical buildings of similar type by benchmarking against national average source energy data, 21% energy savings achieves 1 point and 45% energy savings achieves 18 points.	PV	0-18 Points
	FG	0-18 Points
	PP	0-18 Points
Existing Building Commissioning-Investigation and Analysis Ensure that all building systems and equipments are functioning correctly through testing and analysis; and as appropriate according to the equipment schedule. Identify opportunities to make no- or low-cost capital improvements to enhance building performance.	PV	2 Points
	FG	2 Points
	PP	2 Points
Existing Building Commissioning-Implementation Develop and Implement no and low cost operational improvements that will immediately enhance building performance. A capital plan should be developed based on the investigation and analysis phase.	PV	2 Points
	FG	2 Points
	PP	2 Points
Existing Building Commissioning-Ongoing Commissioning Developing an ongoing commissioning program that identifies the ongoing changes and maintenance needs in rest area buildings.	PV	2 Points
	FG	2 Points
	PP	2 Points
Performance Measurement-Building Automation System Install and maintain a building automation system that automatically monitors and controls building systems. Ensure that relevant staff are familiar with the system to analyze output data, make necessary adjustments and identify investment opportunities to improve energy performance	PV	1 Point
	FG	1 Point
	PP	1 Point
3.2 Performance Measurement-System Level Metering Install energy meters to measure the consumption of major energy consumer such as: heating and air conditioning, lighting, and water heating – meters must be continuous and data logged. (2 points for metering more than 80% of total energy consumption)	PV	2 Points
	FG	2 Points
	PP	2 Points
4 Onsite and Off-site Renewable Energy Design and specify the use of onsite nonpolluting renewable technologies to contribute to the total energy requirements of the building. (BIPV systems; geothermal HVAC; and solar water heating systems are eligible for this item).	PV	6 Points
	FG	6 Points
	PP	6 Points
Enhanced Refrigerant Management Operating the facility without refrigeration equipments or using equipments with the least direct impact on the ozone depletion and climate change. Using equipments with reduced refrigerant and longer life. Maintaining equipment to prevent leakage of refrigerant to the atmosphere. Use fire-suppression systems that do not contain HCFCs or halons. (Rest areas can use geothermal heat pumps to lower impact on the ozone depletion).	PV	1 Point
	FG	1 Point
	PP	1 Point
Emissions Reduction Reporting Addressing all significant types of pollutants that can be reduced through energy efficiency measures including: carbon dioxides, sulfur dioxide, nitrogen oxide, mercury, small particulate matter, large particulate matter, and volatile organic compounds.	PV	1 Points
	FG	1 Points
	PP	1 Points

PV: Prairie View rest area, FG: Funks Grove rest area, PP: Pride of the Prairie rest area.

Table 44. Eligible Credits and Associated Points for Material and Resources Division of LEED-EB for 2009

Material and resources items	**Rest area /potential points**	
Sustainable Purchasing-Ongoing Consumables Achieving sustainable purchases of at least 60% of total purchase cost (low cost items) during the performance period of rest areas. Purchasing materials, supplies or equipments that meet one or more of the criteria listed in LEED-EB, 2009.	PV	1 Point
	FG	1 Point
	PP	1 Point
Sustainable Purchasing-Durable Goods Achieving sustainable purchases of at least 40% of total purchases cost of electric powered equipments (Items available at higher cost per unit and durable goods that are replaced infrequently and/or may require capital program outlays to purchase) during the performance period. Sustainable purchases shall meet one of the criteria listed in LEED-EB, 2009.	PV	1 Point
	FG	1 Point
	PP	1 Point
Sustainable Purchasing-Facility Alterations and Additions Maintaining a sustainable purchasing program that covers materials for facility renovations, demolitions, refits and new construction additions. It applies only to base building elements permanently or semi-permanently attached to the building itself. It requires achieving sustainable purchases of 50% of total purchases cost during the performance period which meet one or more of the criteria listed in the LEED-EB, 2009.	PV	1 Point
	FG	1 Point
	PP	1 Point
Sustainable Purchasing-Reduced Mercury in Lamps Establishing and following a lamp-purchasing program that sets a minimum level of mercury content and life for all mercury-containing lamp types. A credit is achieved when at least 90% of all mercury-containing lamps purchased during the performance period comply with the purchasing plan and meet the overall target for mercury content of 90 picograms per lumen-hour.	PV	1 Point
	FG	1 Point
	PP	1 Point
Solid Waste Management-Waste Stream Audit Conducting a waste stream audit of the rest area's entire ongoing consumables waste stream in order to establish a baseline that identifies the types and amounts of waste. Also to identify opportunities for increasing recycling and waste diversion.	PV	1 Point
	FG	1 Point
	PP	1 Point
Solid Waste Management-Durable Goods Maintaining a waste reduction, reuse and recycling program that addresses durable items that are replaced infrequently and/or may require capital program outlays to be replaced. These items might include computer(s) for video recording, monitors, water coolers, and refrigerators that are used in rest areas. This item requires 75% reuse or recycle of the durable goods waste stream (by weight, volume or replacement value) during the performance period.	PV	1 Point
	FG	1 Point
	PP	1 Point

PV: Prairie View rest area, FG: Funks Grove rest area, PP: Pride of the Prairie rest area.

Table 45. Eligible Credits and Associated points for Indoor Environmental Quality Division of LEED-EB for 2009

Indoor environmental quality items	**Rest area /potential points**	
<u>Indoor Air Quality Management Program</u> Surveying and evaluating building systems to identify potential IAQ problems and implement an ongoing program to prevent these problems from occurring and to maintain a high level of IAQ. Developing and maintaining a program to enhance Indoor Air Quality (IAQ) by optimizing practices to prevent the development of IAQ in buildings and maintain the well-being of the occupants.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Outdoor Air Delivery Monitoring</u> Install and maintain permanent ventilation monitoring systems that provide feedback on system performance to ensure minimum ventilation rates. Monitoring must be performed for at least 80% of the building's total outdoor air intake flow serving occupied spaces.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Increased Ventilation</u> Providing additional outdoor air ventilation to improve indoor air quality (IAQ) for improved occupant comfort, well-being and productivity. Achieving ventilation rates at least 30% in mechanical ventilation above the minimum rates described by ASHRAE Standard 62.1-2007. Also, Ensuring that the additional ventilation rate does not adversely affect building humidity control during all expected operating conditions.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Reduce Particulates in Air Distribution</u> Installing and maintaining filtration media with a minimum efficiency reporting value (MERV) of 13 or greater for all outside air intakes and returns for the recirculation of inside air. Establishing and following a regular schedule for maintenance and replacement of these filters.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Occupant Comfort-Thermal Comfort Monitoring</u> Implementing system for continuous tracking and optimization of systems that regulate indoor comfort and conditions (air temperature, humidity, air speed and radiant temperature) in occupied spaces. Implement systematic monitoring of the actual performance of the building to the comfort criteria defined by ASHRAE Standard 55-2004.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Daylight and Views</u> Achieve a direct line of sight to the outdoor environment via vision glazing between 30 inches and 90 inches above the finished floor for building occupants in 45% of all regularly occupied areas.	PV	1 Point
	FG	0 Point
	PP	1 Point
<u>Green Cleaning-High Performance Cleaning Program</u> Implementing a high-performance cleaning program, supported by green cleaning policy, staffing plans, standard operating procedures and storage procedures that address sustainable and effective cleaning and hard floor maintenance. The green cleaning policy should address the criteria listed in LEED-EB, 2009.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Green Cleaning-Custodial Effectiveness Assessment</u> Conducting a walk-through inspection of a sample of rooms in the rest area buildings to evaluate the effectiveness of the cleaning program. Identify areas that fall below the owner's expected standard and make improvements to the cleaning program accordingly. Credit is achieve by Conduct an audit in accordance with APPA Leadership in Educational Facilities' (APPA) "Custodial Staffing Guidelines" to determine the appearance level of the facility and The facility must score 3 or less.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Green Cleaning-Purchase of Sustainable Cleaning Products and Materials</u> Purchasing materials that meet the criteria listed in the LEED-EB, 2009 including: cleaning products; disposable janitorial paper products and trash bags; and hand soaps.	PV	1 Point
	FG	1 Point
	PP	1 Point
<u>Green Cleaning-Indoor Integrated Pest Management</u> Using Integrated Pest Management (IPM) plan for effective pest management. An IPM program employs commonsense strategies to reduce sources of food, water and shelter for pests in buildings and on the grounds and minimizes the use of pesticides. The plan	PV	1 Point
	FG	1 Point

must include the elements listed in the LEED-EB, 2009 integrated with any outdoor IPM plan used for the site as appropriate.	PP	1 Point

PV: Prairie View rest area, FG: Funks Grove rest area, PP: Pride of the Prairie rest area.

Table 46. Eligible Credits and Associated Points for Innovation in Operation Division of LEED-EB for 2009

Innovation in operation items	**Rest area /potential points**	
Innovation in Operations Implementing and maintaining actions that provide added environmental benefits. These can be either substantial actions that exceed an existing LEED-EB, 2009 performance credit requirement or actions not addressed in the LEED-EB, 2009. One point for each action. (Maximum 4 points for action not addressed in LEED-EB and maximum 3 points for actions that addressed in the LEED-EB).	PV	0-4 Points
	FG	0-4 Points
	PP	0-4 Points
LEED Accredited Professional Engaging a principal participant within IDOT that is LEED Accredited Professional (AP).	PV	1 Point
	FG	1 Point
	PP	1 Point
Documenting Sustainable Building Cost Impacts Document overall building operating costs for the past 5 years and track changes in overall building operating costs according with the achieved LEED-EB achieved credits. Documenting building operating costs and financial impacts of all aspects of LEED-EB, 2009 implementation on an ongoing basis.	PV	1 Point
	FG	1 Point
	PP	1 Point

PV: Prairie View rest area, FG: Funks Grove rest area, PP: Pride of the Prairie rest area.

Table 47. Eligible Credits and Associated Points for Regional Priority Division of LEED-EB for 2009

Regional priority items	**Rest area /potential points**	
Regional Priority One point bonus is awarded for each Regional Priority credit achieved, maximum 4 credits applicable as Regional Priority credits. The bonus point(s) are earned based on the location of rest areas and the identified credits by USGBC that need to be fulfilled in order to earn these bonus points.	PV	0-4 Points
	FG	0-4 Points
	PP	0-4 Points

PV: Prairie View rest area, FG: Funks Grove rest area, PP: Pride of the Prairie rest area.

6.3 DECISION SUPPORT TOOL FOR OPTIMIZING UPGRADE DECISIONS

6.3.1 Tool Design and Capabilities

The LEED rating system for existing buildings 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). Each of these divisions includes a set of items that describe the requirements needed to achieve the specified credits. All these items vary in initial upgrade cost, requirements that need to be satisfied, and accredited LEED points. The next section "tool development" describes in detail how these divisions are modeled in the developed DST. The methodologies of optimizing the LEED upgrade decisions are then described in the "Optimizing upgrade decisions for the LEED rating system for existing buildings" section.

6.3.2 Tool Development

The LEED rating system for existing buildings consists of seven main divisions 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). Each of these divisions includes a set of credits that represent a set of sustainability measures representing each division. The proposed DST is designed to account for different alternatives to satisfy each of these credits. A number of parameters and rates are used throughout the optimization problem, and they include building characteristics, energy and water consumption rates, and baselines for energy and water consumption rates of similar buildings. The DST is designed to enable decision makers to input these parameters and rates only once at the beginning of the problem definition. Table 48 lists these input parameters and rates that are used to optimize the upgrade decisions of LEED-EB rating system.

Table 48. Input Parameters and Rates in the Developed DST

Parameter	Dimensions
Annual interest rate	%
Building square footage	SF
Annual electricity consumption	KWH
Annual indoor water consumption	Gallons
Annual outdoor water consumption	Gallons
Average electricity rate	$/KWH
Average electricity rate for off-site renewable energy	$/KWH
Average water rate	$/Gallon
Annual indoor baseline consumption based on Uniform Plumbing Code (UPC)	Gallons
Annual outdoor water consumption based on conventional means of irrigation	Gallons
National average source energy use based on Commercial Building Energy Consumption Survey (CBECS 2003)	KBTU/SF
Building zip code	N/A

The Sustainability Sites division in the LEED-EB rating system includes nine credit areas that can achieve a total of 26 points, as shown in Table 49. The first credit area of this division "LEED certified design and construction" is modeled by indicating the number of LEED points that could be achieved if the building under consideration was previously certified by any of the LEED rating systems. The cost and potential points of this credit are assumed to be zero since all rest areas have not had LEED certification for design and construction. Credits areas 2 through 7.1 of this division are modeled by two alternatives for each credit area, the input data for each alternative include required initial cost to achieve this alternative and associated LEED points based on the LEED-EB rating system.

Credit area 7.2 which focuses on the "heat island reduction-roof" is modeled based on five alternatives according to the options available in the LEED-EB rating system: (i) using roof material with solar reflectance index equal/greater than 78 for low sloped roof (less than or equal 2:12) or equal/greater than 29 for steep sloped roof (more than 2:12); (ii) installing vegetated roof that cover at least 50% of the roof area; (iii) installing high albedo and vegetated roof surfaces; (v) using photovoltaic system on the roof; or (vi) user defined alternative. It should be noted that the fourth alternative of "using photovoltaic system on roof" is linked to the first alternative of photovoltaic system in the Energy and Atmosphere division, and therefore this alternative is selected only if the first alternative of photovoltaic system in the energy division is selected. The first alternative of photovoltaic system in "Energy and Atmosphere" division should satisfy the requirements of "Heat island reduction-roof" credit; otherwise it can be defined as the second alternative in the photovoltaic system in the "Energy and Atmosphere" division. All these alternatives can be defined by assigning their initial cost and one accredited point based on the LEED-EB rating system while the fourth alternative can be defined with zero cost and one accredited LEED point since its cost will be included in the "Energy and Atmosphere" division.

The last credit of this divisions "Light pollution reduction" is modeled by three alternatives. The input data for the first two alternatives are initial costs and the associated LEED points based on the LEED-EB rating system. The third alternative of this credit area is linked to the Motion activated lighting in the first credit area of the "Energy and Atmosphere" division. This alternative is selected if any alternative of motion activated lighting is considered. The "Light pollution reduction" credit requires installing indoor motion activated lighting and achieving one of three options for exterior lighting as indicated in the LEED-EB rating system. Accordingly, the input data for this alternative includes the initial cost for achieving one of the options for exterior lighting and one LEED point according to the LEED-EB rating system. It should be noted that, if this alternative will be defined in this credit, the defined motion activated lighting systems in the "Energy and Atmosphere" division should satisfy the requirements of this credit. The proposed DST allows decision makers to assign the annual savings or expenses and service life for acquiring each of the aforementioned alternatives in order to calculate its Net Present Value (NPV) and payback period, if applicable. The first four credits of this division are modeled in the developed DST as shown in the sample spreadsheet design in Figure 94.

Table 49. Credits of Sustainable Site Division of the LEED Rating System for Existing Buildings

#	**Sustainable Sites (SS)** (26 Possible points)	**Max. Possible points**
1.0	LEED Certified Design and Construction	4
2.0	Building Exterior and Hardscape Management Plan	1
3.0	Integrated Pest Management, Erosion Control, and Landscape Management Plan	1
4.0	Alternative Commuting Transportation	3-15
5.0	Site Development-Protect or Restore Open Habitat	1
6.0	Stormwater Quantity Control	1
7.1	Heat Island Reduction-Nonroof	1
7.2	Heat Island Reduction-Roof	1
8.0	Light Pollution Reduction	1

The Water Efficiency (WE) division includes one required credit (prerequisite) and four optional credits with a total of 14 LEEP points, as shown in Table 50. The DST was designed to account for this prerequisite by reducing (if needed) the water consumption to meet the requirements of the LEED-EB rating system. If the current water consumption of the building does not meet the requirements of the LEED-EB rating system, the developed DST uses the water reduction measures that are defined in the first credit of this division to reduce the building water consumption. It should be noted that the DST will provide infeasible solution if the water reduction measures cannot meet the requirements of this prerequisite. A warning message will be provided to the decision maker, feature under development, to highlight such condition. The first possible credit of this division "Water performance measurements" is modeled by two alternatives that account for installing a meter system for the whole building and a sub-meter system for the building in addition to the whole building meter unit. The input data for each of these alternatives include their initial cost and associated LEED points according to the LEED-EB rating system.

The second credit of this division "Additional indoor plumbing fixtures and fitting efficiency" is modeled by defining up to four indoor water measures that can reduce indoor water consumption of the building. The input data of each of these measures include the initial cost and amount of water savings for up to two alternatives. These two alternatives in each measure are mutually exclusive to enable decision makers to compare two alternative types or models that fulfill the same function but with varying initial costs and performances. Measures for "Improving indoor water performance" include installing water conservation urinals, water conservation toilets, low flow faucets, and/or aerator upgrade for manual faucets. The DST calculates automatically the number of accredited LEED points based on the current performance of the building and the selected indoor water performance measures. The second credit of this division is modeled in the developed DST as shown in the sample spreadsheet design in Figure 95. To enable the use of linear programming in the DST, an approximate method was used to calculate the accredited LEED points of this credit by converting the non-linear relationship between percentage of water reduction and accredited points to a linear relationship that can be used in a linear programming model.

The third credit of this division "Water efficient landscaping" is modeled by defining up to four outdoor water measures that can reduce the required amount for irrigation. The input data of each of these measures includes its initial cost and amount of water savings for up to two alternatives. The last credit of this divisions "Cooling tower water management" is modeled by two alternatives which are mutually exclusive. The input data for each of these alternatives include their initial cost and associated LEED points according to the LEED-EB rating system. The proposed DST enables the decision maker to assign the annual savings or expenses and service life for acquiring each of the aforementioned alternatives in order to calculate its Net Present Value (NPV) and payback period.

Table 50. Credits of Water Efficiency Division of the LEED Rating System for Existing Buildings

#	**Water Efficiency (WE)** (14 Possible points)	**Max. Possible points**
1.0	Minimum Indoor Plumbing Fixture and Fitting Efficiency	Required
2.0	Water Performance Measurement	1-2
3.0	Additional Indoor Plumbing Fixture and Fitting Efficiency	1-5
4.0	Water Efficient Landscaping	1-5
5.0	Cooling Tower Water Management	1-2

C 1.0	LEED Certified Design and Construction (4 Points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Previously LEED certified building	0	0	N/A	N/A	N/A	N/A	*

C 2.0	Building Exterior and Hardscape Management Plan (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Simple payback period (years)	
1	Alternative (1)	0	1			0.0	None	*
2	Alternative (2)					0.0	None	*

C 3.0	Integrated Pest Management, Erosion Control, and Landscape Management Plan (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	0	1			0.0	None	*
2	Alternative (2)					0.0	None	*

C 4.0	Alternative Commuting Transportation (3-15 Points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	0	0			0.0	None	*
2	Alternative (2)					0.0	None	*

*Not available due to lack of input data on Intial cost, annual savings, and service life

Figure 94. Modeling the first four credits of Sustainable Site division.

C 2.0	Additional Indoor Plumbing Fixture and Fitting Efficiency (1-5 points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)
2	Performance of indoor water consumption	3774	5	0	N/A	N/A	N/A

Indoor water efficiency measures

Additional indoor water savings - measure # 1	Initial Cost ($)	Annual expected water savings (gallons)	Annual water savings ($)	Service life (years)	NPV ($)	Payback period (years)	
Alternative 1	4080	400339	0		-4080	None	*
Alternative 2	60	341466	0		-60	None	*

Additional indoor water savings - measure # 2	Initial Cost ($)	Annual expected water savings (gallons)	Annual water savings ($)	Service life (years)	NPV ($)	Payback period (years)	
Alternative 1	5504	659382	0		-5504	None	*
Alternative 2			0		0	None	**

Additional indoor water savings - measure # 3	Initial Cost ($)	Annual expected water savings (gallons)	Annual water savings ($)	Service life (years)	NPV ($)	Payback period (years)	
Alternative 1	3714	1318764	0		-3714	None	*
Alternative 2	6190	1582516	0		-6190	None	*

Additional indoor water savings - measure # 4	Initial Cost ($)	Annual expected water savings (gallons)	Annual water savings ($)	Service life (years)	NPV ($)	Payback period (years)	
Alternative 1			0		0	None	**
Alternative 2			0		0	None	**

*Not available due to lack of input data on water rate and service life, **Not available due to lack of input data on Intial cost, annual savings, and service life

Figure 95. Modeling the second credit of Water Efficiency division through four energy efficiency measures and eight alternatives.

The Energy and Atmosphere Division includes three required credits (prerequisites) and nine optional credits with a total of 35 points, as shown in Table 51. The input data for the three prerequisite includes the initial cost for fulfilling the requirements of these prerequisites. The DST was designed to account for the second prerequisite of this division by reducing the energy consumption (if needed) to meet the requirements of the LEED-EB rating system. If the current energy consumption of the building does not meet the requirements of the LEED-EB rating system, the developed DST uses the energy reduction measures that are defined in the first credit of this division to reduce the building energy consumption. It should be noted that the DST will provide an infeasible solution if the defined energy reduction measures cannot reduce the building energy consumption to meet the requirements of this prerequisite.

The first credit of this division measures the energy performance of the building under consideration. This credit was designed similar to the second credit of the “Water Efficiency” division. It is designed to improve the energy performance of the building through motion activated lighting, more efficient HVAC systems, and two other user defined energy efficiency measures. The input data of each of these measures include the initial cost and amount of energy savings for up to two alternatives. These two alternatives in each measure are mutually exclusive to enable decision makers to compare two alternatives that fulfill the same function but with varying initial costs and performances. Other energy efficiency measures include double plane glass, more efficient hand dryers and/or more energy efficient lighting. The DST calculates automatically the number of accredited LEED points based on the current performance of the building and the selected energy efficiency measures. To enable the use of linear programming in the DST, an approximate method was used to calculate the accredited LEED points of this credit to convert the non-linear relationship between percentage of energy reduction and accredited points to a linear relationship that can be used in a linear programming model. The first credit of this division is modeled in the developed DST as shown in the sample spreadsheet design in Figure 96. Credits two through five of this division are modeled by two alternatives for each credit which are mutually exclusive. The input data for each of these alternatives include their initial cost and associated LEED points according to the LEED-EB rating system. The sixth credit is defined to account for two scenarios, (1) installing energy sub-metering systems for at least 40% of the building consumption and achieving one LEED credit, and (2) installing energy sub-metering systems for at least 80% of the building consumption and achieving two LEED points. These two scenarios are mutually exclusive and include initial cost and accredited LEED points as input parameters.

The seventh credit “Onsite and off-site renewable energy” is designed to account for renewable energy measures through two scenarios, onsite and offsite renewable energy. Onsite renewable energy is accounted for through four types of renewable energy sources including geothermal heat pumps, photovoltaic systems, solar water theater systems, and wind power energy. The input data for each of these renewable energy sources include initial cost and amount of renewable energy produces for up to two alternatives. These two alternatives in each renewable energy source are mutually exclusive to enable decision makers to compare two alternative types or models that fulfill the same function but with varying initial costs and performances. Off-site renewable energy sources are accounted for through two alternatives which are mutually exclusive. The input data for these two alternatives include initial cost and amount of off-site renewable energy. The DST is designed to calculate the accredited LEED points automatically based on the selected renewable energy sources. To enable the use of linear programming in the DST, an approximate method was used to compute the accredited LEED points of this credit to convert the non-linear relationship between percentage of renewable energy and accredited points to a linear relationship that can be used in a linear programming model. It should be noted that the geothermal heat pump alternatives are linked to the “more efficient HVAC system” alternatives of the first credit of this division where the DST is allowed only to choose either more efficient HVAC system or geothermal heat pump.

The last two credits of this division are modeled by two mutually exclusive alternatives for each credit. The input data for each of these alternatives include their initial cost and associated LEED points according to the LEED-EB rating system. The DST optimizes the selection of all these aforementioned alternatives in this division based on the initial cost and improvements in performance which is represented by the number of accredited LEED points. The proposed DST enables the decision maker to assign the annual savings or expenses and service life for acquiring each of the aforementioned alternatives in order to calculate its Net Present Value (NPV) and payback period.

Table 51. Credits of Energy and Atmosphere Division of the LEED Rating System for Existing Buildings

#	**Energy and Atmosphere (EA)** (35 Possible points)	**Max. Possible points**
P1*	Energy Efficiency Best Management Practices—Planning, Documentation, and Opportunity Assessment	Required
P2*	Minimum Energy Efficiency Performance	Required
P3*	Fundamental Refrigerant Management	Required
1.0	Optimize Energy Efficiency Performance	1-18
2.1	Existing Building Commissioning-Investigation and Analysis	2
2.2	Existing Building Commissioning-Implementation	2
2.3	Existing Building Commissioning-Ongoing Commissioning	2
3.1	Performance Measurement-Building Automation System	1
3.2	Performance Measurement-System Level Metering	1-2
4.0	Onsite and Off-site Renewable Energy	1-6
5.0	Enhanced Refrigerant Management	1
6.0	Emissions Reduction Reporting	1

C 1.0	Optimize Energy Efficiency Performance (0-18 Points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)
2	Performance of building energy consumption	7185	3	2186	N/A	N/A	N/A

Energy Efficiency Measures

Additional energy savings - Motion Activated Lighting (MAL) Systems	Initial Cost ($)	Annual expected energy savings (KWH)	Annual energy savings ($)	Service life (years)	NPV ($)	Payback period (years)	
Alternative 1	1137	5800	539.4	10	3708	2.2	
Alternative 2			0		0	None	*

More efficient HVAC system	Initial Cost ($)	Annual expected energy savings (KWH)	Annual energy savings ($)	Service life (years)	NPV ($)	Payback period (years)	
Alternative 1	19870	17700	1646.1	17	3656	14.0	
Alternative 2			0		0	None	*

Additional energy savings - measure # 1	Initial Cost ($)	Annual expected energy savings (KWH)	Annual energy savings ($)	Service life (years)	NPV ($)	Payback period (years)
Alternative 1	10440	17100	1590.3	10	3845	7.1
Alternative 2	6048	17700	1646.1	8	6010	3.9

Additional energy savings - measure # 2	Initial Cost ($)	Annual expected energy savings (KWH)	Annual energy savings ($)	Service life (years)	NPV ($)	Payback period (years)	
Alternative 1	60900	17700	1646.1	40	-15870	30.3	
Alternative 2			0		0	None	*

*Not available due to lack of input data on Intial cost, annual savings, and service life

Figure 96. Modeling the first credit of Energy and Atmosphere division through four energy efficiency measures and eight alternatives.

The Materials and Resources division includes two required credits (prerequisites) and nine optional credits with a total of 10 points, as shown in Table 52.The input data for the two prerequisites include initial costs for fulfilling the requirements of these prerequisites. Also, the DST is designed to select at least one of credits two through four (MRc2 to MRc4) according to prerequisite number one in this division. Each credit in this division is modeled by two alternatives that are mutually exclusive. The input data for each of these alternatives include their initial cost and associated LEED points according to the LEED-EB rating system. The proposed DST enables the decision maker to assign the annual savings or expenses and service life for acquiring each of the aforementioned alternatives in order to calculate its Net Present Value (NPV) and payback period. The first four credits of this division are modeled in the developed DST as shown in the sample spreadsheet design in Figure 97.

Table 52. Credits of Materials and Resources Division of the LEED Rating System for Existing Buildings

#	**Materials and Resources (MR)** (10 Possible points)	**Max. Possible points**
P1*	Sustainable Purchasing Policy	Required
P2*	Solid Waste Management Policy	Required
1.0	Sustainable Purchasing-Ongoing Consumables	1
2.0	Sustainable Purchasing-Durable Goods	1-2
3.0	Sustainable Purchasing-Facility Alterations and Additions	1
4.0	Sustainable Purchasing-Reduced Mercury in Lamps	1
5.0	Sustainable Purchasing-Food	1
6.0	Solid Waste Management-Waste Stream Audit	1
7.0	Solid Waste Management-Ongoing Consumables	1
8.0	Solid Waste Management-Durable Goods	1
9.0	Solid Waste Management-Facility Alterations and Additions	1

The Indoor Environmental Quality division includes three requires credits (prerequisites) and 15 optional credits with a total of 15 points, as shown in Table 53. The input data for the three prerequisites include initial costs for fulfilling the requirements of these prerequisites. Each credit in this division is modeled by two alternatives that are mutually exclusive. The input data for each of these alternatives include their initial cost and associated LEED points according to the LEED-EB rating system. Furthermore, Credits 1.2, 1.3, and 2.2 allow the decision maker to assign the effect of improving the indoor air quality and controllability of systems lighting on the annual energy consumption. The proposed DST enables the decision maker to assign the annual savings or expenses and service life for acquiring each of the aforementioned alternatives in order to calculate its Net Present Value (NPV) and payback period. The first four credits of this division are modeled in the developed DST as shown in the sample spreadsheet design in Figure 98.

Table 53. Credits of Indoor Environmental Quality Division of the LEED Rating System for Existing Buildings

#	**Indoor Environmental Quality (IEQ)** **(15 Possible points)**	**Max. Possible points**
P1*	Minimum Indoor Air Quality Performance	Required
P2*	Environmental Tobacco Smoke (ETS) Control	Required
P3*	Green Cleaning Policy	Required
1.1	Indoor Air Quality Best Management Practices-Indoor Air Quality Management Program	1
1.2	Indoor Air Quality Best Management Practices-Outdoor Air Delivery Monitoring	1
1.3	Indoor Air Quality Best Management Practice-Increased Ventilation	1
1.4	Indoor Air Quality Best Management Practices-Reduce Particulates in Air Distribution	1
1.5	Indoor Air Quality Best Management Practices-Indoor Air Quality Management for Facility Alterations and Additions	1
2.1	Occupant Comfort-Occupant Survey	1
2.2	Controllability of Systems-Lighting	1
2.3	Occupant Comfort-Thermal Comfort Monitoring	1
2.4	Daylight and Views	1
3.1	Green Cleaning-High Performance Cleaning Program	1
3.2	Green Cleaning-Custodial Effectiveness Assessment	1
3.3	Green Cleaning-Purchase of Sustainable Cleaning Products and Materials	1
3.4	Green Cleaning-Sustainable Cleaning Equipment	1
3.5	Green Cleaning-Indoor Chemical and Pollutant Source Control	1
3.6	Green Cleaning-Indoor Integrated Pest Management	1

C 1.0	Sustainable Purchasing-Ongoing Consumables (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	0	1			0	None	*
3	Alternative (2)					0	None	*
C 2.0	Sustainable Purchasing-Durable Goods (1-2 Points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	10200	1			-10200	None	*
2	Alternative (2)	7100	1			-7100	None	*
C 3.0	Sustainable Purchasing-Facility Alterations and Additions (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)					0	None	*
2	Alternative (2)					0	None	*
C 4.0	Sustainable Purchasing-Reduced Mercury in Lamps (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	200	1			-200	None	*
2	Alternative (2)					0	None	*

*Not available due to lack of input data on Intial cost, annual savings, and service life

Figure 97. Modeling the first four credits of the Material and Resources division.

C 1.1	Indoor Air Quality Best Management Practices-Indoor Air Quality Management Program (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)					0.0	None	*
2	Alternative (2)					0.0	None	*

C 1.2	Indoor Air Quality Best Management Practices-Outdoor Air Delivery Monitoring (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Annual expected increase in energy (KWH)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	7300	1				-7300.0	None	*
2	Alternative (2)						0.0	None	*

C 1.3	Indoor Air Quality Best Management Practice-Increased Ventilation (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Annual expected increase in energy (KWH)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	1400	1		-12400		-1400.0	None	*
2	Alternative (2)						0.0	None	*

C 1.4	Indoor Air Quality Best Management Practices-Reduce Particulates in Air Distribution (1 Point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)	
1	Alternative (1)	90	1			-90.0	None	*
2	Alternative (2)					0.0	None	*

*Not available due to lack of input data on Intial cost, annual savings, and service life

Figure 98. Modeling the first four credits of the Indoor Environmental Quality division.

The Innovation in Operation division includes three optional credits with a total of 6 points, as shown in Table 54. The first credit of this division "Innovation in operation" is modeled through three options: (1) innovation in operation, (2) exemplary performance, and (3) pilot credit according to the LEED-EB rating system. Each option is modeled through two alternatives that are mutually exclusive. The input data for each of these options include initial cost and associated LEED points according to the LEED-EB rating system. The total accredited points of this credit cannot exceed 4 points according to the LEED-EB rating system, therefore the DST was designed to account for this constraint. The "innovation in operation" option is fulfilled by achieving significant, measurable environmental performance using an operation, maintenance or system upgrade strategy that is not addressed in the LEED-EB rating system, one point is accredited for each innovation achieved up to four points. The "exemplary performance" option is fulfilled by achieving double the credit requirements and/or achieving the next incremental percentage threshold of an existing credit in the LEDD-EB rating system, one point is achieved for every exemplary performance achieved up to three points. The "Pilot credit" option is fulfilled by achieving any of the items listed in the U.S. Green Building Council (USGBC) website (USGBC (d) 2010); one credit is achieved for each item. The DST is designed to allow the decision maker to account for the effect of these six alternatives on the annual energy and water consumption by assigning the amount of energy and water reduction. The first credit of this division is modeled in the developed DST as shown in the sample spreadsheet design in Figure 99. The input data for the second and third credits of this division include initial cost and accredited LEED points according to the LEED-EB rating system. The proposed DST enables the decision maker to assign the annual savings or expenses and service life for acquiring each of the aforementioned alternatives in order to calculate its Net Present Value (NPV) and payback period.

Table 54. Credits of Innovation in Operation Division of the LEED Rating System for Existing Buildings

#	**Innovation in Operation (IO)** (6 Possible points)	**Max. Possible points**
1.0	Innovation in Operations	1-4
2.0	LEED Accredited Professional	1
3.0	Documenting Sustainable Building Cost Impacts	1

The last division of the LEED-EB rating system includes one possible credit with a total of 4 points. This credit provides an incentive for the achievement of credits that address geographically specific environmental priorities in the United States. Six regional priority credits are available for each location; these credits are identified by the U.S. Green Building Council (USGBC) Regional Councils and Chapters as having additional regional environmental importance. A spreadsheet of "Regional Priority" credits and their geographic applicability is available on the U.S. Green Building Council (USGBC) website. One extra point is accredited if any of these credits in the regional priority credits achieved up to four points. The DST is designed to allow the decision maker to assign the zip code of the building where the tool retrieves the associated regional priority credits. These regional priority credits are considered in optimizing the upgrade decision of the LEED-EB rating system. The DST was designed to account for the "Regional Priority" credits with a maximum of 4 points according to the LEED-EB rating system. This division is modeled in the developed DST as shown in the sample spreadsheet design in Figure 100.

C	1.0	Innovation in Operations (1-4 Points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Service life (years)	NPV ($)	Payback period (years)
	2	Customized credit as follow	0	0	0	N/A	N/A	N/A

Innovation in operation (1-4 points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Expected energy savings (KWH)	Expected water savings (gallons)	Service life (years)	NPV ($)	Payback period (years)	
Alternative (1)							0	None	*
Alternative (2)							0	None	*

Exemplary performance (1-3 points)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Expected energy savings (KWH)	Expected water savings (gallons)	Service life (years)	NPV ($)	Payback period (years)	
Alternative (1)							0	None	*
Alternative (2)							0	None	*

Pilot credit (1 point)	Initial Cost ($)	Accredited points (points)	Annual savings or expenses ($)	Expected energy savings (KWH)	Expected water savings (gallons)	Service life (years)	NPV ($)	Payback period (years)	
Alternative (1)							0	None	*
Alternative (2)							0	None	*

*Not available due to lack of input data on Intial cost, annual savings, and service life

Figure 99. Modeling the first credit of Innovation in Operation division.

Zip code \ Regional Priority credits	Credit -1	Credit -2	Credit -3	Credit -4	Credit -5	Credit -6
60449	SSc2	SSc4(25%)	WEc3(100%)	MRc6	IEQc1.3	IEQc1.4

C 1	Regional Priority (1-4 Points)	Select Credits	working step calculations	Conditions	Adjusted Accredited points (points)	Actual Accredited points (points)
1	Regional credit # 1	SSc2	2	None	1.00	1.00
2	Regional credit # 2	SSc4(25%)	4	Not applicable	0.00	0.00
3	Regional credit # 3	WEc3(100%)	12	(100%)	1.00	1.00
4	Regional credit # 4	MRc6	28	None	0.00	0.00
5	Regional credit # 5	IEQc1.3	46	None	1.00	1.00
6	Regional credit # 6	IEQc1.4	46	None	1.00	1.00

Figure 100. Modeling Regional Priority division.

6.3.3 Optimizing Upgrade Decisions of the LEED Rating System for Existing Buildings

The LEED rating system for existing buildings includes seven divisions with nine prerequisites, 50 credits, and a total of 110 possible points. Each of these credits can be achieved with multiple upgrade measures, which highlights the large search space that represent the possible combinations of upgrade decisions for rest area buildings. These upgrade decisions can also be used to earn LEED points in order to achieve LEED certification. Four certification levels are available for ranking green buildings using the LEED rating system for existing buildings: (1) certified level which requires 40 – 49 points; (2) silver level which requires 50 – 59 points; (3) gold level which requires 60 – 79 points; and (4) platinum level which requires 80 points or more.

This required number of points adds a constraint for optimizing upgrade decisions of existing buildings for achieving a certain certificate. Two models were developed in the proposed DST for optimizing the upgrade decisions of LEED-EB rating system. The first 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. The constraints of the first scenario optimization problem are listed in Equation 2 through Equation 8, the required number of LEED-EB points to achieve a certain LEED certificate is satisfied through Equation 2. The mutually exclusive alternatives that are defined in each credit are achieved through Equation 3. The decision variables that are used in optimizing LEED-EB upgrade decisions are limited to binary values as shown in Equation 4. 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 through Equation 5. The number of achieved LEED points for the first credit of Innovation in the Operation division is limited to four points through Equation 6. The minimum requirements for water and energy performance are satisfied through Equation 7, and the maximum possible points for energy and water performance as well as regional priority credits are satisfied through equation 8.

<u>Optimization Model # 1: Minimizing upgrade cost for attaining a certain LEED certificate</u>

$$\mathbf{T.C.} = \sum_{\mathbf{i=1}}^{\mathbf{n}} \sum_{\mathbf{j=1}}^{\mathbf{m}} \mathbf{C_{ij}} * \mathbf{X_{ij}} \qquad \text{Equation 1}$$

<u>Subject to:</u>

$$\sum_{i=1}^{n} \sum_{j=1}^{m} P_{ij} * X_{ij} \geq a \qquad \text{Equation 2}$$

$$\sum_{j=1}^{m} X_{ij} \leq 1 \,;\, i = 1 \text{ to } n \qquad \text{Equation 3}$$

$$X_{ij} \rightarrow \text{Binary variables} \qquad \text{Equation 4}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} P_{ij} * X_{ij} \geq 1 \,;\; i = MR_{c2}, MR_{c3}, \text{ and } MR_{c4} \qquad \text{Equation 5}$$

$$\sum_{j=1}^{m} P_{ij} * X_{ij} \leq 4 \,;\, i = IO_{c1} \qquad \text{Equation 6}$$

$$P_i \geq 0 \,;\; i = WE_{c2}, WE_{c3}, EA_{c1}, \text{ and } EA_{c7} \qquad \text{Equation 7}$$

$$P_i - Y_i \leq c \,;\, i = WE_{c2}, WE_{c3}, EA_{c1}, EA_{c7}, \textit{and } RP_{c1} \qquad \text{Equation 8}$$

Where:
$\mathrm{T.C.}$: Total upgrade cost for achieving a certain LEED-EB certificate
X_{ij}: A binary decision variable to decide whether to achieve a certain alternative j of LEED-EB credit i
C_{ij}: Cost of achieving a certain alternative j of a LEED-EB credit i
P_{ij}: Possible LEED points for a certain alternative j of a LEED-EB credit i
n: Total number of LEED-EB rating systems credits.
m: Total number of alternatives in a certain LEED-EB credit.
a: Number of required LEED-EB points for achieving a certain LEED certificate (certified, silver, gold, or platinum).
c: maximum possible points of a certain credit.
Y: adjustment variable

The second model maximizes the number of accredited LEED points that can be earned, the objective function of maximizing the upgrade cost for this model is illustrated in Equation 9. The constraints of the second scenario optimization problem are listed in Equation 10 through Equation 16. The available budget for upgrading a certain building according to the LEED-EB rating system measures is constrained through Equation 10. The mutually exclusive alternatives that are defined in each credit are achieved through Equation 11. The decision variables that are used in optimizing LEED-EB upgrade decisions are limited to binary values as shown in Equation 12. 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 through Equation 13. The number of achieved LEED points for the first credit of Innovation in Operation division is limited to four points through Equation 14. The minimum requirements for water and energy performance are satisfied through Equation15, and the maximum possible points are constrained for energy and water performance as well as regional priority credits are satisfied through equation 16.

Optimization Model # 2: Maximizing accredited LEED points within a certain budget

$$\mathrm{T.A.L.P.} = \sum_{i=1}^{n} \sum_{j=1}^{m} P_{ij} * X_{ij} \qquad \text{Equation 9}$$

Subject to:

$$\sum_{i=1}^{n} \sum_{j=1}^{m} C_{ij} * X_{ij} \le b \qquad \text{Equation 10}$$

$$\sum_{j=1}^{m} X_{ij} \le 1 ; i = 1 \text{ to } n \qquad \text{Equation 11}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} X_{ij} \rightarrow \text{Binary variables} \qquad \text{Equation 12}$$

$$\sum_{i=1}^{n} \sum_{j=1}^{m} P_{ij} * X_{ij} \ge 1 ;\ i = MR_{c2}, MR_{c3}, \text{and } MR_{c4} \qquad \text{Equation 13}$$

$$\sum_{j=1}^{m} X_{ij} \le 1 ;\ i = IO_{c1} \qquad \text{Equation 14}$$

$$P_i \ge 0 ;\ i = WE_{c2}, WE_{c3}, EA_{c1}, \text{and } EA_{c7} \qquad \text{Equation 15}$$

$$P_i - Y_i \leq c\ ; i = WE_{c2}, WE_{c3}, EA_{c1}, EA_{c7}, and\ RP_{c1}$$ Equation 16

Where:
$T.A.L.P.$: Total Accredited LEED-EB Points (TALP)
X_{ij}: A binary decision variable to decide whether to achieve a certain alternative j of LEED-EB credit i
C_{ij}: Cost of achieving a certain alternative j of a LEED-EB credit i
P_{ij}: Possible LEED points for a certain alternative j of a LEED-EB credit i
n: Total number of LEED-EB rating systems credits.
m: Total number of alternatives in a certain LEED-EB credit.
b: Available budget for upgrading a certain rest area
c: maximum possible points of a certain credit.
Y: adjustment variable

Microsoft Excel Solver add-in was used to carry out the calculations of optimizing the upgrade decisions of LEED-EB rating system using linear programming. The results of this model are shown through a tabular form that summarizes the selected LEED-EB credits/alternatives and associated LEED points, total upgrade cost for the building under consideration, and total number of accredited LEED points.

6.4 PERFORMANCE EVALUATION

An application example of the Northbound building of the Prairie View rest area is analyzed to (1) illustrate the use of the developed DST; (2) demonstrate its newly developed and unique optimization capabilities; and (3) evaluate its performance and verify its results. The following sections briefly describe the Illinois rest area example, specify its input data that are required by the DST, and summarize the findings of this analysis.

6.4.1 Brief Description of the Rest Area Example

Prairie View is one of the oldest and most visited rest areas in Illinois. It has approximately 3.77 million annual visitors based on 2009 statistics and a total square footage of 9072. Prairie View was built in 1971 and was renovated in 1989. It is comprised of two buildings that serve the north and south bounds of I-57 at mile marker 333. This application example focuses only on the northbound building of this rest area and analyzes the optimization of its green upgrade measures. The northbound building includes, lobby, women's bathroom, men's bathroom, mechanical room, water treatment room, storage room, and technician office. This rest area also has 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 for the northbound of Prairie View rest area include exterior lighting, interior lighting, space heating, air conditioning, water heating, water treatment, vending machines, surveillance cameras, "Code Blue" emergency phones, weather information, hand driers, 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 bathroom, women's bathroom, mechanical room, water treatment room, and maintenance office. The northbound building of the Prairie View rest area is air conditioned using a central unit manufactured in 1997. Two electrical water heaters are used to heat water for men's and women's bathrooms with capacities of 30 gallons and 6 gallons respectively. A water treatment station is located onsite and is used to treat well water. The northbound building of this rest area has six vending machines for snacks and 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 the northbound building include faucets, urinals, toilets, and drinking water.

6.4.2 Modeling of the Rest Area Example

To optimize the upgrade decisions for the Prairie View northbound building, the upgrade cost for prerequisites and LEED credits as well as its associated LEED points need to be identified. This requires the decision maker to enter the following data: (1) general input parameters and rates for the rest area building; (2) the 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 fifty credits. The required general input parameters and rates for the Prairie View rest area building are specified and listed in Table 55. The LEED-EB prerequisites and their upgrade costs for the Prairie View rest area building are specified and listed in Table 56. 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 57, Table 58, Table 59,

Table 60, Table 61, and Table 62, 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 Prairie View rest area is 56 points.

Table 55. General Input Parameters and Rates for Optimizing Upgrade Decisions for the Prairie View Northbound building

Parameters	Value
Annual interest rate	2%
Building square footage	4539 SF
Annual electricity consumption	605,492 KWH
Annual indoor water consumption	4,662,771 Gallons
Annual outdoor water consumption	0 Gallons
Average electricity rate	0.093 $/KWH
Average water rate	0 $/Gallon
Annual indoor baseline consumption based on Uniform Plumbing Code (UPC)	4,287,866 Gallons
Annual outdoor water consumption based on conventional means of irrigation	1 Gallons*
National average source energy use based on Commercial Building Energy Consumption Survey (CBECS 2003)	612 KBTU/sf
Building zip code	60449

* Annual outdoor water consumption for conventional irrigation systems is not needed since it is compared to zero water irrigation system.

Table 56. Modeling LEED-EB Prerequisites in the DST for Prairie View Northbound Building 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 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 equipments 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. An energy audit was conducted through Smart Energy Design Assistant Center SEDAC 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
	The DST will analyze the use of geothermal heat pump or non-CFC air source heat pump which will limit the use of CFC based refrigerants in heating, ventilating, air conditioning and refrigeration. A CFC audit might be needed to limit the CFC leakage if the geothermal/air source heat pump were not considered in the results, or the air conditioner can be replaced with non-CFC unit.
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 850 was created to be used in the model.

Table 57.Considered Credits of Sustainable Site Division in the DST and Associated Upgrade Costs for Prairie View Northbound Building Rest Area.

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 which 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 which 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. Prairie View rest area will account for rainwater catchments for water reuse and rain gardens for water infiltration.	65,000	1
Heat Island Reduction-Nonroof		
Alternative 1: Using permeable pavement to cover 50% of pavement area	130000	1
Heat Island Reduction-Roof		
Alternative 1: The current roof of Prairie View rest area can satisfy the requirements of the LEED-EB rating system of this credit.	0	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 58.Considered Credits of Water Efficiency Division in the DST and Associated Upgrade Costs for Prairie View Northbound Building Rest Area.

	Credit	Cost ($)	Accredited Points
Water Performance Measurement			
Whole building metering: Installing water meter to measure total water consumption of the rest area building		900	1
Sub-metering: Installing three water meters to measure total water consumption, toilets water consumption, and urinals water consumption.		2200	2
Additional Indoor Plumbing Fixture and Fitting Efficiency - conservative faucets			
1	indoor water savings - measure # 1 - low flow faucets		
	Alternative 1: Installing low flow faucets to reduce potable water consumption by 400,339 gallons	4080	N/A
	Alternative 2: Installing faucet aerators to reduce potable water consumption by 341,466 gallons	60	N/A
2	indoor water savings - measure # 2 - conservative urinals		
	Alternative 1: Installing water conservative urinals to reduce water consumption by 659,382 gallons	5,504	N/A
3	indoor water savings - measure # 3 - conservative toilets		
	Alternative 1: Installing water conservative toilets for women's bathroom to reduce water consumption by 1,318,764 gallons.	3714	N/A
	Alternative 2: Installing new water conservative toilets for women’s and men’s bathrooms to reduce water consumptionby 1582516 gallons	6190	N/A
Water Efficient Landscaping			
	Rainwater is used for the current irrigation system in Prairie View rest area which achieves100% savings in water irrigation.	0	N/A

Table 59.Considered Credits of Energy and Atmosphere Division in the DST and Associated Upgrade Costs for Prairie View Northbound Building Rest Area.

	Credit	Cost ($)	Accredited Points
C1-Optimize Energy Efficiency Performance			
1	Additional energy savings - Motion Activated Lighting (MAL) Systems		
	Alternative 1: Installing motion activated lighting for bathrooms to reduce energy consumption by 5,800 KWH	1,137	N/A
2	Additional energy savings – More efficient HVAC system		
	Alternative 1: Installing more efficient HVAC system to reduce energy consumption by 59,400 KWH	19,870	N/A
3	Additional energy savings - measure # 1 - Hand Dryers		
	Alternative 1: Installing Air blade hand dryers for women's and men's bathrooms to reduce energy consumption by 17,100KWH	10,440	N/A
	Alternative 2: Installing blast hand dryers for women's and men's bathroom to reduce energy consumption by 17,700KWH	6,048	N/A
4	Additional energy savings - measure # 2 - thermal pane glass		
	Alternative 1: Installing double pane glass for rest area entrance to reduce energy consumption by 17,700	60,900	N/A
C2.1-Existing Building Commissioning-Investigation and Analysis			
Alternative 1: The developed energy audit report by Smart Energy Design Assistant Center (SEDAC) for Prairie View rest area shows the distribution of energy consumption, 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 survey by SEDAC. These no or low cost operation improvements will end up with low upgrade cost which 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			
Alternative 1: Installing electricity metering system to measure energy consumption for HVAC system. This new meter is data logger which can provide more analysis for energy consumption of the HVAC system.		680	1
Alternative 2: In addition to installing meter for HVAC system, another three meters will be installed to measure energy consumption of exterior lighting, water heaters, and hand dryers.		1,760	2
C4-Onsite and Off-site Renewable Energy			
1	Geothermal HVAC systems		
	Alternative 1: Installing geothermal heat pump with horizontal loop to reduce energy consumption by 62,625 KWH	49,730	N/A
	Alternative 2: Installing geothermal heat pump with vertical loop to reduce energy consumption by 62,625 KWH	55,760	N/A
2	Photovoltaic Systems		
	Alternative 1: Install photovoltaic system to offset 5% of energy consumption	54,000	N/A
3	Solar water heaters		
	Alternative 1: Installing roof mount solar water heater to reduce energy consumption by 12,700 KWH	5,480	N/A
	Alternative 1: Installing ground mount solar water heater to reduce energy consumption by 12,700 KWH	5,810	N/A
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 60.Considered Credits of Material and Resources Division in the DST and Associated Upgrade Costs for Prairie View Northbound Building Rest Area.

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.	10200	1
Alternative 2: Replacing two snacks vending machines and video recording system with Energy Star units.	7100	1
Sustainable Purchasing-Reduced Mercury in Lamps		
Alternative 1: Reducing the mercury levels in indoor and outdoor lighting to 90 picograms per lumen hour or less. Replacing some of the lighting lamps to reduce mercury levels to the allowable level.	200	1
Sustainable Purchasing-Food		
Alternative 1: The project team will account for 25% sustainable food purchases according to the LEEDEB 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 61.Considered Credits of Indoor Air Quality Division in the DST and Associated Upgrade Costs for Prairie View Northbound Building Rest Area.

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.	7300	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 by approximately 12,400KWH per year.	1400	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.	90	1
Controllability of Systems-Lighting		
Alternative 1: Installing controllable task lighting for the IDOT technicians that are working in the rest area facility.	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 equipments, Prairie View rest area has limited cleaning equipments which leads to a low upgrade cost for these equipments.	1600	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.	1100	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 62.Considered Credits of Innovation in Operation Division in the DST and Associated Upgrade Costs for Prairie View Northbound Building Rest Area.

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 Prairie View rest area building. No additional cost required for this credit.	0	1

6.4.3 Analysis Results

The developed DST was used to analyze the aforementioned input data in order to optimize the upgrade decisions for the Northbound building of the Prairie View rest area. Two types of optimization analyses were conducted to illustrate the capabilities of the DST in optimizing the aforementioned two practical objectives: (1) minimizing the total upgrade costs that are required to accomplish a specified LEED certification level such as Silver or Gold; and (2) maximizing the number of accredited LEED points that can be earned under a specified limited budget for upgrade costs..

The first optimization analysis focused on minimizing the upgrade costs that are required to achieve a certified LEED-EB level. The results of this analysis indicate that the minimum upgrade cost that is required to achieve 40 points (i.e., certified LEED-EB level) was estimated by the DST to be $68,709 . 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 101 and Figure 102 show for a sample of the output results of the DST for optimizing upgrade decisions of Prairie View rest area building for achieving certified LEED-EB level. The DST was then used to identify another set of optimal upgrade decisions that can achieve a silver LEED-EB rating. The DST estimated that the minimum upgrade cost to achieve this silver rating (50 points) is $136,669. The DST was not able to provide feasible solutions for the gold and platinum LEED-EB levels since the maximum number of LEED credits that can be earned by this building example is 56 points due to the inapplicability of some credit points for the rest area building and its high energy consumption compared to similar buildings.

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 $25,000 to $425,000 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 63 and Figure 103.

Table 63. Accredited LEED Points Associated with each Solution for Maximizing LEED Points within a Certain Budget for Prairie View Northbound Building Rest Area.

Budget cost for upgrade ($)	Actual budget	Maximum LEED points
25,000	N/A	Infeasible*
50,000	N/A	Infeasible*
75,000	73,969	46.4
100,000	89,969	49.4
125,000	89,969	49.4
150,000	143,969	51.6
175,000	150869	51.9
200,000	197569	53.04
225,000	204869	54.04
250,000	204869	54.04
275,000	269869	55.05
300,000	269869	55.05
325,000	269869	55.05
350,000	269869	55.05
375,000	269869	55.05
400,000	399869	56.04
425000	399869	56.04

* Energy division needs more budget to satisfy its prerequisites

#	LEED divisions and Items	Alternative	Action	Initial Cost ($)	Credits
Total Achieved Credits		**40 Points**			
Total Cost of Achieved Credits		**$68,709**			
Sustainable Sites (SS)					
1	LEED Certified Design and Construction	None		0	0
2	Building Exterior and Hardscape Management Plan	1	X	0	1
3	Integrated Pest Management, Erosion Control, and Landscape Management Plan	1	X	0	1
4	Alternative Commuting Transportation	None		0	0
5	Site Development-Protect or Restore Open Habitat	1	X	0	1
6	Stormwater Quantity Control	None		0	0
7.1	Heat Island Reduction-Nonroof	None		0	0
7.2	Heat Island Reduction-Roof	1	X	0	1
8	Light Pollution Reduction	None		0	0
Water Efficiency (WE)					
1	Water Performance Measurement	None		0	0
2	Additional Indoor Plumbing Fixture and Fitting Efficiency	N/A	N/A	3774	5
	a) Additional indoor water savings - measure # 1	2	X	60	N/A
	b) Additional indoor water savings - measure # 2	None		0	N/A
	c) Additional indoor water savings - measure # 3	1	X	3714	N/A
	d) Additional indoor water savings - measure # 4	None		0	N/A
3	Water Efficient Landscaping	N/A	N/A	0	5
	a) Additional outdoor water savings - measure # 1	None		0	N/A
	b) Additional outdoor water savings - measure # 2	None		0	N/A
	c) Additional outdoor water savings - measure # 3	None		0	N/A
	d) Additional outdoor water savings - measure # 4	None		0	N/A
4	Cooling Tower Water Management	None		0	0
Energy and Atmosphere (EA)					
1	Optimize Energy Efficiency Performance	N/A	N/A	7185	0
	a) Additional energy savings - (MAL) Systems	1	X	1137	N/A
	b) Additional energy savings - More efficient HVAC system	None		0	N/A
	c) Additional energy savings - Measure # 1	2	X	6048	N/A
	d) Additional energy savings - Measure # 2	None		0	N/A
2.1	Existing Building Commissioning-Investigation and Analysis	1	X	0	2
2.2	Existing Building Commissioning-Implementation	1	X	0	2
2.3	Existing Building Commissioning-Ongoing Commissioning	None		0	0
3.1	Performance Measurement-Building Automation System	None		0	0
3.2	Performance Measurement-System Level Metering	None		0	0
4	On-site and Off-site Renewable Energy	N/A	N/A	55210	5.55963
	a) Geothermal HVAc systems	1	X	49730	N/A
	b) Photovoltaic Systems	None		0	N/A
	c) Solar water heaters	1	X	5480	N/A
	d) Wind power energy	None		0	N/A
	e) Off-site renewable enery	None		0	N/A
5	Enhanced Refrigerant Management	None		0	0
6	Emissions Reduction Reporting	1	X	0	1

Figure 101. Results of the DST for minimizing upgrade costs for achieving certified level in the LEED-EB rating system – SS, WE, and EA divisions - Prairie View northbound building rest area.

#	LEED divisions and Items	Alternative	Action	Initial Cost ($)	Credits
Materials and Resources (MR)					
1	Sustainable Purchasing-Ongoing Consumables	1	X	0	1
2	Sustainable Purchasing-Durable Goods	None		0	0
3	Sustainable Purchasing-Facility Alterations and Additions	None		0	0
4	Sustainable Purchasing-Reduced Mercury in Lamps	1	X	200	1
5	Sustainable Purchasing-Food	1	X	0	1
6	Solid Waste Management-Waste Stream Audit	None		0	0
7	Solid Waste Management-Ongoing Consumables	None		0	0
8	Solid Waste Management-Durable Goods	None		0	0
9	Solid Waste Management-Facility Alterations and Additions	1	X	0	1
Indoor Environmental Quality (IEQ)					
1.1	Indoor Air Quality Best Management Practices-Indoor Air Quality Management Program	None		0	0
1.2	Indoor Air Quality Best Management Practices-Outdoor Air Delivery Monitoring	None		0	0
1.3	Indoor Air Quality Best Management Practice-Increased Ventilation	1	X	1400	1
1.4	Indoor Air Quality Best Management Practices-Reduce Particulates in Air Distribution	1	X	90	1
1.5	Indoor Air Quality Best Management Practices-Indoor Air Quality Management for Facility Alterations and Additions	None		0	0
2.1	Occupant Comfort-Occupant Survey	None		0	0
2.2	Controllability of Systems-Lighting	None		0	0
2.3	Occupant Comfort-Thermal Comfort Monitoring	None		0	0
2.4	Daylight and Views	None		0	0
3.1	Green Cleaning-High Performance Cleaning Program	1	X	0	1
3.2	Green Cleaning-Custodial Effectiveness Assessment	None		0	0
3.3	Green Cleaning-Purchase of Sustainable Cleaning Products and Materials	1	X	0	1
3.4	Green Cleaning-Sustainable Cleaning Equipment	None		0	0
3.5	Green Cleaning-Indoor Chemical and Pollutant Source Control	None		0	0
3.6	Green Cleaning-Indoor Integrated Pest Management	1	X	0	1
Innovation in Operations (IO)					
1	Innovation in Operations	N/A	N/A	0	0
	a) Innovation in operation	None		0	0
	b) Exemplary performance	None		0	0
	c) Pilot credit	None		0	0
2	LEED Accredited Professional	1	X	0	1
3	Documenting Sustainable Building Cost Impacts	1	X	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 102. Results of the DST for minimizing upgrade costs for achieving certified level in the LEED-EB rating system – MR, IQ, IO, and RP divisions - Prairie View northbound building rest area.

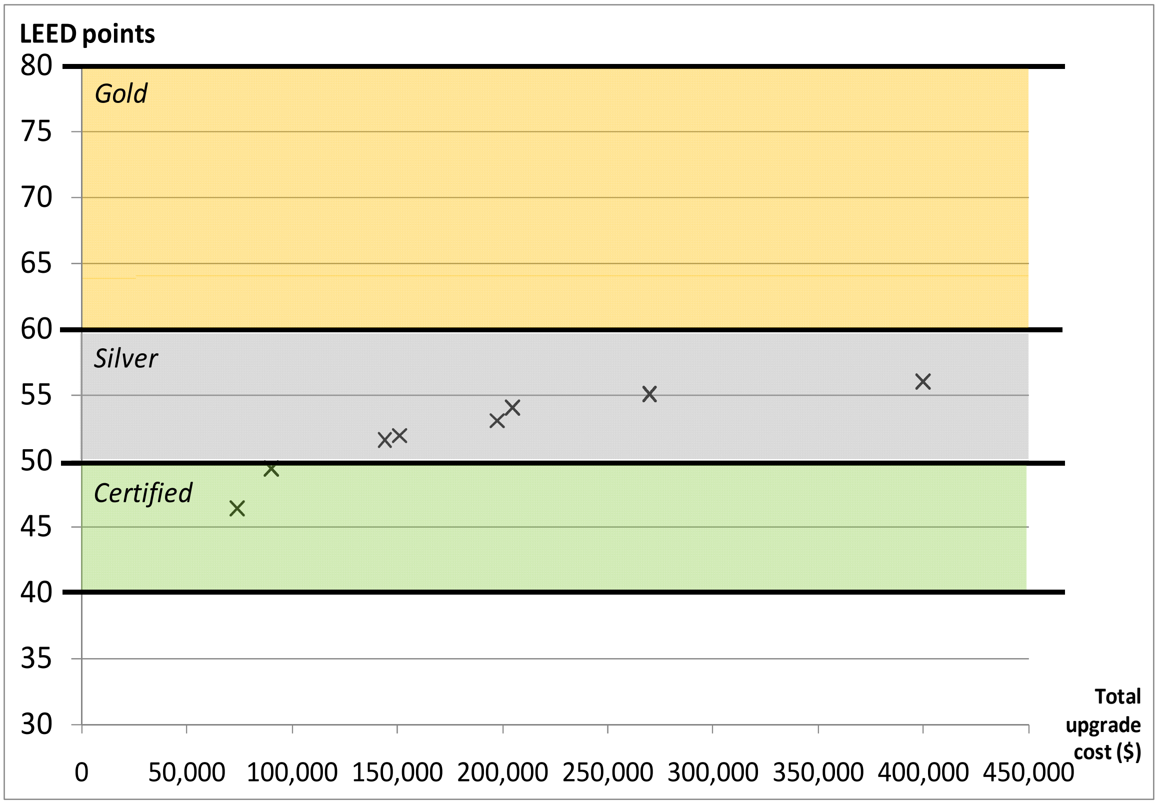


Figure 103. Accredited LEED points associated with each solution and obtained LEED certificate for maximizing LEED point within a certain budget - Prairie View northbound building rest area.

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 that were identified based on the findings of this research study and the energy audit reports by SEDAC. These recommended green friendly upgrade measures are summarized for each of the selected three rest areas as follows:

7.1.1 Prairie View Rest Area (Northbound)

1. Replacing all T12 lamps with reduced wattage T8 (28W), removing unnecessary CFL lamps in the lobby, installing solar daylight tubes in the restrooms along with daylight sensors, and installing motion activated lighting in men’s and women’s bathrooms, storage room(s), and technicians’ office. This upgrade measure is estimated to reduce current energy consumption by 2.1%.
2. Investigating the possibility of replacing existing 400HPS lamps in the parking area with 320 PSMH after considering the impact of this replacement on the luminance level in the parking area using the developed spreadsheet for lighting.
3. Investigating the replacement of current bulbs that are used in Code Blue emergency phones with LED retrofits to reduce their light energy consumption by 95% while considering the impact of this replacement on their visibility at night.
4. Using the developed spreadsheet for lighting to investigate the possibility of replacing interior and exterior lighting with LED/induction lighting as the lighting industry advances to provide higher luminance and reduced energy consumption.
5. Replacing existing hand driers in women’s and men’s bathrooms with more efficient machines such as Blast hand driers, which is estimated to reduce energy consumption by 4.4%.
6. Investigating the use of a heat recovery unit for the ventilation system, which is reported to reduce energy consumption by 5.4%.
7. Installing a solar water heating system for the rest area building, which is estimated to reduce its energy consumption by 7.2%.
8. Adding/installing vending occupancy controls which can reduce energy consumption by 0.9%.
9. Adding an insulated glass front vestibule with a second set of doors along with new double glazed windows in the front and rear that will help reduce air infiltration and better insulate the lobby area. This upgrade measure is estimated to reduce current energy consumption by 8.6%.
10. Installing a high efficiency air source heat pump or geothermal heat pump. This measure is expected to reduce current energy consumption by 20% if a high efficiency air source heat pump is used or by 33.5% if a geothermal heat pump is installed.
11. Considering the implementation of additional upgrade measures that are listed by the SEDAC report under “other recommendations” in Appendix A (page A-11).
12. Installing water saving plumbing fixtures including more efficient toilets, urinals, and faucets to reduce water consumption.
13. Using the developed Decision Support Tool (DST) in this research study to investigate the potential for earning the maximum number of LEED credit points within a specified budget, or achieving a specified LEED certification level (e.g. silver or gold) with the least possible upgrade cost.

Implementing the aforementioned upgrade measures can reduce energy consumption by up to 60.8%. These green-friendly measures could be applied to the Southbound building of this rest area as well.

7.1.2 Funks Grove Rest Area

1- Replacing all T12 lamps with reduced wattage T8 (28W), replacing 100w MH in the vending area with two lamp CFL fixtures, installing solar daylight tubes in the restrooms along with daylight sensors, and installing motion activated lighting in men's and women's bathrooms, storage room, and technicians' office. This upgrade measure is estimated to reduce current energy consumption by 2.4%.
2- Investigating the possibility of replacing the current 400W HPS lighting bulbs of the exterior lighting with 320W pulse-start metal halide (PSMH) and the 100W acorn pole fixtures with 75W PSMH after considering the impact of this replacement on the luminance level using the developed spreadsheet for lighting.
3- Investigating the replacement of current bulbs that are used in Code Blue emergency phones with LED retrofits to reduce their light energy consumption by 95% while considering the impact of this replacement on their visibility at night.
4- Using the developed spreadsheet for lighting to investigate the possibility of replacing interior and exterior lighting with LED/induction lighting as the lighting industry advances to provide higher luminance and reduced energy consumption.
5- Replacing existing hand driers in women's and men's bathrooms with more efficient ones such as Blast hand driers, which is estimated to reduce energy consumption by 2.5%.
6- Sealing HVAC ducts with mastic in the attic space and add duct board insulation which is estimated to reduce energy consumption by 1.9%.
7- Investigating the use of heat recovery unit for the ventilation system, which is expected to reduce energy consumption by 6.7%.
8- Adding/installing vending occupancy controls, which can reduce energy consumption by 0.7%.
9- Reducing energy consumption of the HVAC system and the water heating system by either (1) replacing the current HVAC system with geothermal heat pump and installing solar water heating system which is estimated to reduce energy consumption by 18.7%; or (2) replacing the current HVAC system with geothermal heat pump and a desuperheater to reduce energy consumption by 27%.
10- Considering the implementation of additional upgrade measures that are listed by the SEDAC report under "other recommendations" in Appendix B (page B-12).
11- Installing water saving plumbing fixtures including more efficient toilets, urinals, and faucets to reduce water consumption.
12- Using the developed Decision Support Tool (DST) in this research study to investigate the potential for earning the maximum number of LEED credit points within a specified budget, or achieving a specified LEED certification level (e.g. silver or gold) with the least possible upgrade cost.

Implementing the aforementioned upgrade measures can reduce energy consumption by up to 38.7%.

7.1.3 Pride of the Prairie Rest Area (Eastbound)

1- Replacing U-tube and T12 lamps with reduced wattage T8 (28W), installing solar daylight tubes in the restrooms along with daylight sensors, and installing motion activated lighting in men's and women's bathrooms, storage room, and technicians' office. These upgrade measures are estimated to reduce current energy consumption by 6.9%.

2- Investigating the possibility of replacing the current HPS 200W exterior lighting with reduced wattage pulse-start metal halide (PSMH) after considering the impact of this replacement on the luminance level using the developed spreadsheet for lighting.
3- Investigating the replacement of current bulbs that are used in Code Blue emergency phones with LED retrofits to reduce their light energy consumption by 95% while considering the impact of this replacement on their visibility at night.
4- Using the developed spreadsheet for lighting to investigate the possibility of replacing interior and exterior lighting with LED/induction lighting as the lighting industry advances to provide higher luminance and reduced energy consumption.
5- Replacing existing hand driers in women's and men's bathrooms with more efficient ones such as Blast hand driers, which is estimated to reduce energy consumption by 3.3%.
6- Sealing HVAC ducts with mastic in the attic space and add duct board insulation which is estimated to reduce energy consumption by 1.9%.
7- Investigating the use of a heat recovery unit for the ventilation system which is estimated to reduce energy consumption by 6.7%.
8- Adding/installing vending occupancy controls which can reduce energy consumption by 0.9%.
9- Reducing energy consumption of the HVAC system and water heating system by either (1) replacing the current HVAC system with a geothermal heat pump and installing solar water heating system which are estimated to reduce energy consumption by 16.3%; or (2) replacing the current HVAC system with a geothermal heat pump and a desuperheater to reduce energy consumption by 21%.
10- Installing occupancy sensors for exhaust fans, which are expected to reduce energy consumption by 9.4%.
11- Installing a second entrance door to create a vestibule, which are estimated to reduce dissipation of cooling and heating energy by 1.8%.
12- Considering the implementation of additional upgrade measures that are listed by the SEDAC report under "other recommendations" in Appendix C (page C-12).
13- Installing water saving plumbing fixtures including more efficient toilets, urinals, and faucets to reduce water consumption.
14- Using the developed Decision Support tool (DST) in this research study to investigate the potential for earning the maximum number of LEED credit points within a specified budget, or achieving a specified LEED certification level (e.g. silver or gold) with the least possible upgrade cost.

Implementing the aforementioned upgrade measures can reduce energy consumption by up to 47.1%. These green friendly measures could be applied to the Westbound building of this rest area as well.

7.2 FUTURE RESEARCH

During the course of this one-year study, the research team identified a number of promising research areas that need further in-depth analysis and investigation in phase II of this research project. The duration of phase I of this completed project was one year and it focused on three rest areas (Prairie View, Funks Grove, and Pride of the Prairie) that were selected based on their number of visitors, energy consumption, age, and provided services. The main goal of the proposed research in phase II is to investigate, determine and provide a list of "Green Friendly" Best Management Practices (BMP's) for six additional rest areas that have the highest energy consumption in Illinois. hese six potential rest areas include Willow Creek, Coalfield, Great Sauk Trail, Mackinaw Dells, Cumberland Road, and Turtle Creek. These six facilities are responsible for 32% of IDOT rest areas energy bills, and improvements in their energy consumption can lead to significant annual savings for IDOT. To accomplish this critical goal, the objectives of the proposed phased II research are to:

1) Conduct online and/or paper survey to gather information from all state Departments of Transportation (DOTs) on their experiences in implementing “Green Friendly” Best Management Practices in their rest areas in terms of improved performance, cost effectiveness, and environmental impact.
2) Investigate the feasibility and cost effectiveness of installing temporary and/or permanent metering systems to measure, monitor, and analyze the actual energy consumption and performance of selected rest areas.
3) Conduct onsite assessment and field measurements of six rest areas that have the highest energy consumption bills and highest energy consumption per square footage. A suggested list of these areas includes Willow Creek, Coalfield, Great Sauk Trail, Mackinaw Dells, Cumberland Road, and Turtle Creek.
4) Explore and identify energy saving alternatives that can be implemented in the selected rest areas such as LED and induction lighting, motion activated lighting, active and passive solar practices, thermal pane glass, geothermal heat pumps, and water saving plumbing fixtures.
5) Perform energy audit analysis for the selected 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.
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 System (DSS) to identify optimal upgrade measures for the selected rest areas and other similar buildings that can (1) provide the highest level of LEED certification while complying with the limited upgrade budget; or (2) ascertain the least possible budget to achieve a specified level of LEED certification such as silver, gold, or platinum.
8) Prepare a plan/report with recommendations for each rest area detailing the recommended “Green Friendly” BMPs to use with cost estimates for full implementation, including payback periods.

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) a comprehensive energy audit analysis of six rest areas that have the highest energy consumption in Illinois; (2) 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 its rest areas; (3) significant savings in IDOT rest areas’ energy consumption and bills; (4) environmental benefits such as improving air and water quality; (5) social benefits such as enhancing visitors comfort and health; and (6) a practical decision support system that enables IDOT to identify a set of optimal upgrade measures for its rest areas in order achieve the highest level of LEED certification within the specified project budget. These deliverables will ensure that limited IDOT budgets for upgrading their rest areas are spent in the most cost-effective manner. The proposed DSS will also enable IDOT to maximize the number of its LEED certified facilities and to accomplish the highest level of practicable LEED certification for these facilities. 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. SEDAC Audit Report for Prairie View Rest Area

Illinois Smart Energy Design Assistance Center

SEDAC Level 2 Audit Report
Prairie View Rest Area: I-57 Northbound

Published:	8/28/2010
Site Visit:	3/8/2010
Location:	I-57 Northbound, North of Kankakee, Will County

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UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

dceo ILLINOIS DEPARTMENT OF COMMERCE AND ECONOMIC OPPORTUNITY

Background:

The Illinois Department of Transportation has applied to the University of Illinois Smart Energy Design Assistance Center (SEDAC) for an energy audit of the Prairie View rest area. This energy audit is in conjunction with a facility review being undertaken with help from the University of Illinois Engineering Department.

In order to enhance the economy, the Illinois Department of Commerce and Economic Opportunity (DCEO) has implemented the Smart Energy Design Assistance Center (SEDAC) for the commercial, municipal, and educational building sectors. The program is funded by DCEO and is managed by the School of Architecture at the University of Illinois at Urbana-Champaign. SEDAC's mission is to encourage communities, municipalities, school districts, business owners, design professionals, and building contractors to incorporate energy efficiency practices and renewable energy systems.

Facility Description:

The I-57 northbound Prairie View rest area was built in 1971 with a major renovation in 1988 and is along one of the highest traffic routes in the state with an estimated 1.9 million visitors per year. The building is a one story pyramid structure with a standing seam metal roof. The roof and masonry walls have an estimated R-10 of 4" fiberglass batt insulation or rigid foam sheathing. There is a skylight in the center of the roof above the lobby that has had a tinted coating applied to the outside and a second pane of glass added to the inside. The front and rear doors open directly into the lobby and are located along a single pane curtain wall.

Figure 1: Aerial View of the Northbound Prairie View Rest Area

The 1988 mechanical system consists of a central furnace with electric resistance coils for heat and a direct expansion split cooling system with an assumed efficiency of 9 EER. The condenser for the cooling system is located in a ducted area of the mechanical room and has reports of failing during periods of heavy operation. The thermostat is reported to be kept at

70°F year round. During the time of the site visit, the men's room was found to be heated to over 80°F while the lobby was 72°F—a sign of improper balancing of the system. Exhaust for the men's restroom was recorded at approximately 300 CFM (while the women's room exhaust fan was not operational at the time of the visit).

Figure 2: Rear Entry Vending Area, Lobby Lighting Shining Down and Up into Skylight

The lighting in the facility is a mixture of older T12 lamps in the restrooms and maintenance rooms and newer T8 fluorescent lamps in the vending area. The lobby area has 24 can lights below the skylight that have two compact fluorescent lamps (CFLs) each. These lights are kept illuminated regardless of the light levels in the lobby. The majority of exterior lighting consists of metal halide (MH) lamps including (18) 400W pole-mounted lights in the parking area that are on a timer.

Plug loads consist of three drink vending, three snack vending machines, and two chilled water fountains. There is a single weather station in the lobby with an older CRT computer screen along with some cameras and a computer recording surveillance system. The restrooms each have three 2.2kW low velocity pushbutton-start electric hand dryers. Water for the facility is pumped from a well on site and waste water is treated in a nearby gravity fed holding pond. Water is heated with two 30 gallon electric water heaters, one of which was not operational at the time of the visit.

The public areas of the facility have 24 hour operation. The mechanical and storage areas are in use from 6am-11pm 6 days a week and the lobby tourism desk is staffed during normal business hours.

Utility Profile:

A good method for benchmarking a building's energy efficiency is to determine its energy use intensity (kBtu/ft^2/yr) and energy cost intensity ($/ft^2/yr). Compared to an office building, this facility uses a very high 227 kBtu/sf/yr (or $6.11/yr), however this is not unusual in relation to other public rest areas as shown in the full engineering report. A summary of energy use and energy cost for the Prairie View northbound facility in 2009 is shown below.

2009	Annual Consumption		Annual Cost		Average Unit Cost	
Electricity	301,337	kWh	$27,734		$0.092	$/kWh
Floor Area	4,536	sf				
Energy Use Intensity	227	kBtu/sf/yr	**Energy Cost Intensity**	$6.11	$/sf/yr	
*Electricity supplied and delivered by ComEd, Rate Class:"100 to 400 kW w/ space heat"						

Table 1: Energy Use Intensity

The following figure shows the billed monthly electric energy consumption profile compared to the eQuest model (within 10%) with heating and cooling degree days, which are indicative of climate intensity. Monthly increases and decreases in electric consumption approximately follow the degree day trends for this space. The general baseline building electric energy use is approximately 12,500 kWh per month, which would account for electricity used for lighting, hot water, vending, and plug loads. The electric heating coils are metered separately and account for 47% of electricity use.

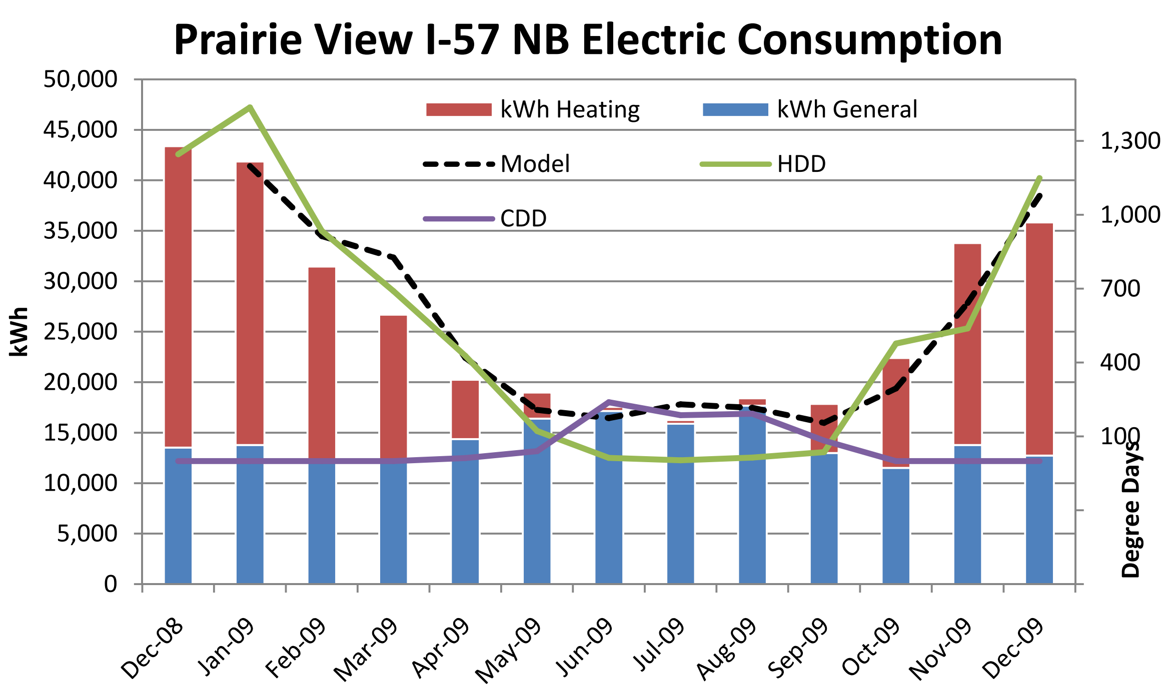

Figure 3: Billed and Modeled Electricity Usage with Cooling and Heating Degree Days

Determining where and in what quantities energy is used throughout the building helps to prioritize energy improvement efforts. The following chart shows a breakdown of the building's energy use by equipment type as estimated from modeling in eQUEST. The energy cost for the building is dominated by electric space heating.

The greatest use of energy for heating purposes, approximately 21%, is to heat ventilation (outside) air. This is air that replaces the air that has been exhausted by the restroom fans. Additionally, 12% of the energy budget is used to heat air that has leaked into the building (infiltration), primarily through the frequent opening and closing of entry doors.

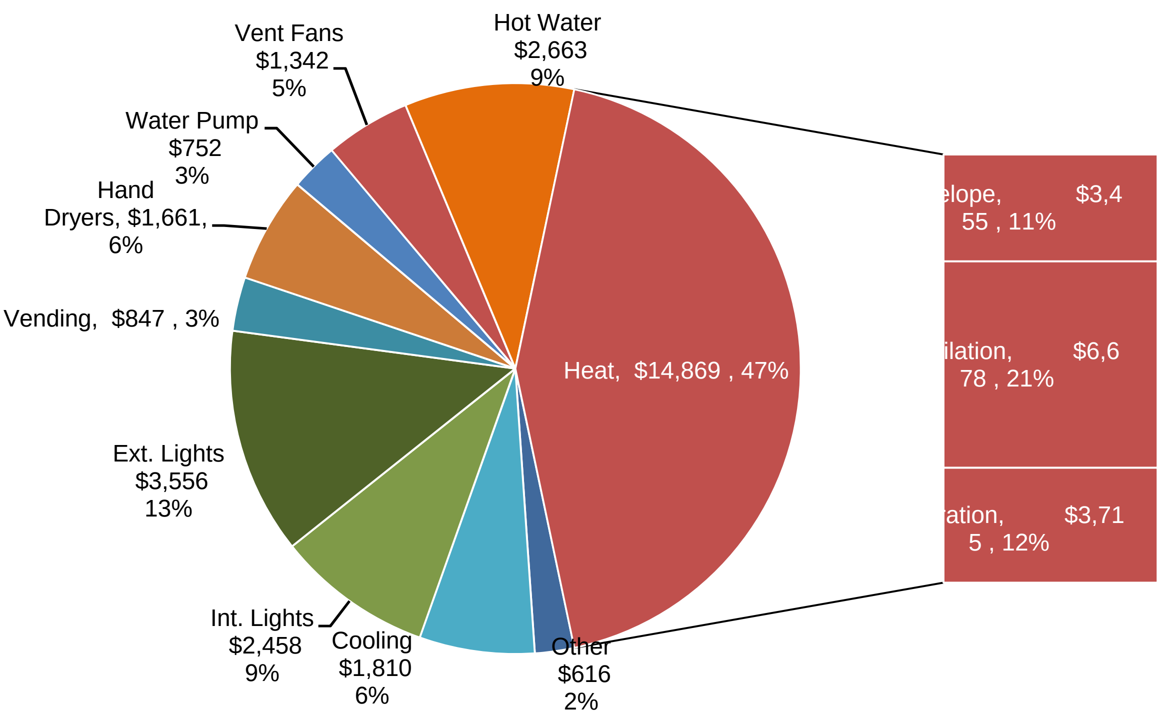

Figure 4: Energy Cost Breakdown by Use

Recommended Energy Cost Reduction Measures (ECRMs)1

ECRM 1 - Interior Lighting

Interior lighting consists of linear fluorescent T12 and newer T8 lighting along with compact fluorescent lamps (CFL). This measure recommends:

- Replacing 60 T12 lamps and magnetic ballasts with high efficiency (or reduced wattage 25W) T8 lamps and program start electronic ballasts (necessary for advanced controls).
- Removing half of the CFL lamps in the lobby, those that point up to the skylight.
- Installing daylight sensors in the lobby lighting and vending area lights.
- Installing solar daylight tubes in the restrooms along with daylight sensors.
- Installing wireless motion sensors for the lighting in the restrooms and maintenance rooms with a 15-20 minute delay to avoid false turn-offs.

These measures together result in a lighting power density that drops from 0.93 W/sf down to 0.67 W/sf, in addition with a reduction of operating hours. Not all of the lighting power reduction is realized in savings due to an increase in the electric heating system during the winter months. Incentives are available through DCEO for T8 lighting, daylight sensors, and motion sensors, see page 11.[2]

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 1 - Interior Lighting	9,491	1.2	0	$874	3.1%

ECRM 2 - Exterior Lighting

The majority of the exterior lighting consists of 400W metal halide (MH) pole lamps in the parking area. This measure recommends replacing the 400W MH lamps with newer more efficient 320W pulse-start metal halide (PSMH) lamps and the appropriate ballast. PSMH lamps experience less lumen loss over a longer operational lifetime and therefore can have lower rated wattage but achieve the same lumen output. When replacing fixtures, look for a design that minimizes losses through light spill, poor optics, and uneven light distribution.[3]

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 2 - Parking Lights	11,125	2.5	0	$1,024	3.7%

At this time, SEDAC doesn't fully endorse the newest LED and induction fluorescent lighting technologies due to concerns with cost, efficiency, and reliability. However, the potential for these technologies is promising and they should be considered in the future or in limited test scenarios.

[1] Our work does not replace engineering design which will be necessary for project implementation.
[2]http://www.illinoisbiz.biz/dceo/Bureaus/Energy_Recycling/Energy/Energy+Efficiency/
[3]http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-ParkingLotEvaluation-Revised-Jan2010.pdf

ECRM 3 - Air Source Heat Pump

The existing electric resistance heater is very costly to operate and the cooling system is difficult to maintain. This measure recommends installing an air source heat pump to heat and cool the building along with a programmable thermostat to setback temperatures during periods of low-occupancy. Heat pumps are generally two to three times more efficient at heating a space than electric resistance coils.

This system should have a heating performance rating of 8.8 HPLV and a cooling efficiency of over 12 EER. This system should also have the ability to operate in economizer mode when the outdoor air temperature is sufficient to condition the space. There would still be an electric resistance coil that acts as supplemental heat in extremely cold weather. Dual stage cold climate heat pumps that work at even lower temperatures are available and would offer greater energy savings but are a newer unproven technology and may be difficult to obtain from multiple sources.

This measure is eligible for a standard incentive from DCEO of $19-$38/ton but it is likely more advantageous to apply for the custom incentive of $0.09/kWh saved (or $5,400) due to the large kWh reduction.

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 3 - Air Source Heat Pump	60,010	0	0	$5,523	20%

An alternative measure could be to install a ground source heat pump (GSHP) that would be even more efficient and would require backup electric heat less often. An option to consider would be to use the water that is already pumped out of the ground for the building's use as the heat transfer medium. All of these systems could have the added option of heating domestic hot water during cooling periods with a desuperheater.

ECRM 4 - Exhaust Heat Recovery

In buildings of this type, conditioning fresh air, commonly referred to as ventilation air, is one of the largest portions of the overall heating costs. This measure recommends installing a run-around loop heat exchanger to help recover some of the heat exhausted by the HVAC system and the bathroom exhaust fans without contaminating incoming air. The model assumes that the intake air and the exhaust air pass over a run-around loop heat exchanger with 50% effectiveness. Heat recovery can be a more effective solution in air tight structures that have very little air infiltration, for example, heat lost through the door is unrecoverable. The applicability of this measure will depend on how makeup air is mechanically supplied to the space, compared to how much air is introduced by infiltration through the entry doors. This should be investigated further to determine if it is technically feasible in this building.

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 4 - Exhaust Heat Recovery	16,270	0	0	$1,497	5.4%

ECRM 5 - Hand Dryers

Although the electric hand dryers use a relatively small amount of energy, they are one of the most visible aspects of public building energy use for visitors. Slow, ineffective hand dryers may feel like a waste of time and electricity, or possibly discourage people from washing at all. This measure recommends installing high velocity hand dryers that run for half the time and require half the power to operate. Many varieties are available and options are even available from the manufacturer of the current installed units.[4]

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 5 - Hand Dryers	13,177	6.6	0	$1,213	4.4%

ECRM 6 - Vending Occupancy Controls

Vending machines are illuminated and cycle their cooling compressors all day regardless of building occupancy. This measure recommends that occupancy sensing controls be used to turn off the lighting and cycle the cooling less frequency when no one is around.[5] This can be accomplished with an external motion sensing unit (commonly called a vending miser)[6] or these controls can be integrated into newer machines from the manufacturer and should be specified during contract negotiations.[7] At the very least, the lamps can be removed from the front of drink machines in well lit areas and a sign can be applied that indicates the machines are still functioning but are saving energy.

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 6 - Vending Occupancy Controls	2,667	0	0	$247	0.9%

ECRM 7 - Add a Vestibule

Adding an insulated glass front vestibule with a second set of doors along with new double glazed windows in the front and rear would help reduce air infiltration and better insulate the lobby area. The model shows significant savings from reducing the air change per hour (ACH) from 1.5 ACH to 1.2 ACH (20% reduction) and adding a second wall of insulated glazing. Simply insulating the front and rear walls with double glazed windows contributes about half of the savings. This measure shows good energy savings but is possiblyvery expensive. Note that the savings would be greatly reduced by the addition a more efficient heating system.

	Annual Savings

[4] http://www.worlddryer.com/products/smartdri™
[5] https://www1.eere.energy.gov/femp/technologies/eep_beverage_vending_machine.html
[6] http://www.usatech.com/energy_management/energy_vm.php
[7] http://www.energystar.gov/index.cfm?c=vending_machines.pr_proc_vendingmachines

	kWh	kW	Therms	$	Energy %
ECRM 7 -Adding a Vestibule	25,980	0	0	$2,391	8.6%

ECRM 8 - Solar PV

This site is a good candidate for a solar photovoltaic (PV) installation since the SSW orientation of the roof and the lack of large trees or obstructions on the south help maximize solar exposure. Also, the existing standing seam metal roof allows for direct panel attachment, reducing the cost of mounting equipment.Some PVs can even be laminated directly to the existing metal roof.[8]

This measure recommends installing a 10kW solar PV system. This system would cover roughly 60% of the south roof and, would offset 3.2% of the yearly electricity usage through net metering. Solar PV systems generally cost around $8 per installed watt, however the direct roof attachment might allow for a reduced cost around $6 per watt. There are federal tax incentives that could rebate 30% of the system cost; however this would only apply to a private business with federal tax liability. For public entities, there is a 50% rebate offered by the state of Illinois that may be available.[9] There are also occasionally groups that will purchase the Renewable Energy Credits generated at a rate of around $0.06/kWh.

After a 50% rebate, the system would cost around $30,000 and if it offsets $1,000 per year[10], then it would just be cost effective over the warrantee 30 year life of the system at today's energy prices.

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 8 –10 kW Solar PV	10,869	0	0	$1,000	3.6%

If the primary merit of this measure was for educational purposes then a smaller 1-2kW system could be installed and it could include an informational kiosk. A public/private partnership may be a way to promote this beneficial emerging technology at lower cost to the state.

ECRM 9 - Solar Hot Water

Creating hot water from the heat of the sun is generally the most cost effective form of renewable energy. This is especially true when compared to heating water with electricity, which is very expensive. This measure recommends installing a solar thermal hot water system to help offset the nearly constant hot water demand. In northern climates, evacuated tube or insulated concentrating flat plate collectors[11] with antifreeze and heat exchanger storage tanks with backup electric heat are both good options. A system with 12 collector panels would cover about 20% of the roof, generate about 250 gallons of hot water a day (70% of estimated use),

[8] http://www.uni-solar.com/products/commercial-products/pvl/
[9] http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=IL05F&re=1&ee=1
[10] http://www.nrel.gov/eis/imby/
[11] http://www.solargenixchicago.com/home.cfm

and save nearly $2,000 per year. Even before an Illinois 50% rebate, the estimated cost of around $13,000 has a favorable payback period.

The solar thermal system should be sized to not exceed the hot water demand during the summer months to limit possibilities of overheating. For cloudy periods and at night, storage tanks can be sized to help level the load. The electric resistance heating coils will still be required during periods of heavy use with little sun.

	Annual Savings				
	kWh	kW	Therms	$	Energy %
ECRM 9 - Solar Hot Water	21,665	0	0	$1,994	7.2%

Other options for electric heating include an air source heat pump water heater which is around 250% efficient, or using a desuperheater which draws rejected heat from the cooling system during the summer months.

Package 1 - ECRMs 1-9

This package combines all of the investigated ECRMs together in the model and shows savings allowing for interactions between measures.

- ECRM 1 - Interior Lighting
- ECRM 2 - Parking Lights
- ECRM 3 - Air Source Heat Pump
- ECRM 4 - Exhaust Heat Recovery
- ECRM 5 - Hand Dryers
- ECRM 6 - Vending Occupancy Controls
- ECRM 7 - Adding a Vestibule
- ECRM 8 - Solar PV
- ECRM 9 - Solar Hot Water

	Annual Savings				
	kWh	kW	Therms	$	Energy %
Package 1 -ECRMs 1-9	153,912	10.1	0	$14,166	51%

Other Recommendations

- Replace any incandescent exit signs with LED exit signs or lamp retrofit kits. Replacing two 20W lamps per sign with a 5W red LED kit will save 306 kWh, or $35 each year.
- Investigate using light-tubes for brightening dim restrooms.
- Install low-flow sink aerators to reduce hot water use and use low-flow fixtures to reduce water pumping and treatment costs.
- Install an air source heat pump water heater. Or, install a desuperheater in the current cooling system (or new heat pump system) to heat water during the summer months.
- Reapply the low-e coating to the central skylight.
- Install programmable thermostats on the current HVAC system to setback the temperature during periods of low-occupancy to have an immediate payback.

- Experiment with lowering the winter air temperature and providing contact heating pads or radiant heat panels to staff.
- Provide informational kiosks that show energy use for this facility and detail energy saving measures utilized.
- Replace the weather station CRT monitor with an EnergyStar LCD screen. Replacing a 120W CRT monitor with a 40W LCD will save 700 kWh, or $79 each year.
- If the well pump could be run at a slower speed or is pumping against a volume reducing valve, consider installing a variable frequency drive (VFD).
- Small wind turbines can be an educational and viable renewable energy resource in rural areas. However, maintenance and safety may be a large factor for a public area.

AVAILABLE INCENTIVES FOR 2010

DCEO – Energy Efficiency Portfolio Standard

DCEO's Public Sector Electric Efficiency Program offers incentives for energy efficiency measures for customers in the ComEd or Ameren service areas. Rebate incentives are limited to $200,000 per building per year. Multiple applications with project subsections may be submitted. Further, incentives are limited to 75% of the total project cost, and 100% of the incremental project cost (beyond standard replacement option).

SEDAC has created a Web page to post relevant documents and link to programs and services at www.IllinoisEEPS.org. Please bookmark this page and watch for further developments.

DCEO's Public Sector Electric Efficiency Program can be found at: http://www.commerce.state.il.us/dceo/Bureaus/Energy_Recycling/

A list of the incentives for government facilities applicable to ECRMs in this report is shown below.

ECRM	Incentive
Upgrade 4' T12 to T8 and eBallast	$8.50 per lamp
Permanent Removal of T12 Lamp	$7.50 per lamp
Occupancy Controls	$0.13 per watt controlled
LED Exit Sign or Kit	$23 per fixture
AC >5.4 Tons, 14 SEER (11.5 EER)	$33 per ton
AC >5.4 Tons, 15 SEER (12 EER)	$38 per ton
Beverage Machine Control	$100 per control
Snack Machine Control	$45 per control
Custom kWh Reduction	$0.09/kWh (1-7 year payback)

Table 2: List of Possible Applicable EEPS Incentives

DCEO provides solar energy rebates of 50% of cost, up to $50,000, to public institutions. More information is available at:
http://www.commerce.state.il.us/dceo/Bureaus/Energy_Recycling/Energy/Clean+Energy

Summary:

The table below lists the recommended estimated energy saving opportunities at the Prairie View rest area. Implementing Package 1 should reduce the current building energy use and utility costs by an estimated 51%. Other recommendations listed can help reduce energy and support sustainability.

The next steps should be to consult contractors about feasibility and obtain quotes. All of these recommendations area applicable to the southbound side and should be considered there as well.

ECRM 1 – Replace T12 lamps with T8, remove unnecessary CFLs, add motion controls, add daylight controls

ECRM 2 – Upgrade parking lighting with pulse start metal halide lamps

ECRM 3 – Replace HVAC with a high efficiency Air Source Heat Pump

ECRM 4 – Investigate adding heat recovery to the ventilation system

ECRM 5 – Install high velocity hand dryers

ECRM 6 – Add or specify vending occupancy controls

ECRM 7 – Add new exterior glass wall and doors creating vestibule areas in front and rear

ECRM 8 – Install a solar photovoltaic system and an educational kiosk

ECRM 9 – Install a solar thermal water heating system

Package 1 – ECRMs 1-9

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 1 - Interior Lighting	9,491	1.2	$874	3.1%
ECRM 2 - Parking Lights	11,125	2.5	$1,024	3.7%
ECRM 3 - Air Source Heat Pump	60,010	0	$5,523	20%
ECRM 4 - Exhaust Heat Recovery	16,270	0	$1,497	5.4%
ECRM 5 - Hand Dryers	13,177	6.6	$1,213	4.4%
ECRM 6 - Vending Occupancy Controls	2,667	0	$246	0.9%
ECRM 7 - Adding aVestibule	25,980	0	$2,391	8.6%
ECRM 8 - Solar PV	10,869	0	$1,000	3.6%
ECRM 9 - Solar Hot Water	21,665	0	$1,994	7.2%
Package 1 - ECRMs 1-9	153,912	10.1	$14,166	51%

Table 3: Calculated Energy Savings

(1) When ECRMs are implemented as a package, results vary from application of individual ECRMs.

Appendix B. SEDAC Audit Report for Funks Grove Rest Area

Illinois Smart Energy Design Assistance Center

SEDAC Level 2 Audit Report
Funks Grove Rest Area: I-55 North/South

Published: 9/29/2010

Site Visit: 3/15/2010

Location: I-55 North and Southbound, South of Bloomington, IL

Contacts: Craig Mitckes: ILDOT (217) 782-2984 — Liang Liu: University of Illinois (217) 333-6951

Auditor: Andy Robinson aar@illinois.edu

University of Illinois at Urbana-Champaign

dceo — Illinois Department of Commerce and Economic Opportunity *constitute an endorsement. All numerical data are order of magnitude estimates and the number of digits shownare an artifact of the calculation procedure; they are not meant to imply greater accuracy or precision.*

Background:

The Illinois Department of Transportation has applied to the University of Illinois Smart Energy Design Assistance Center(SEDAC) for an energy audit of the Funks Grove rest area. This energy audit is in conjunction with a facility review being undertaken with help from the University of Illinois Engineering Department.

In order to enhance the economy, the Illinois Department of Commerce and Economic Opportunity (DCEO) has implemented the Smart Energy Design Assistance Center (SEDAC) for the commercial, municipal, and educational building sectors. The program is funded by DCEO and is managed by the School of Architecture at the University of Illinois at Urbana-Champaign. SEDAC's mission is to encourage communities, municipalities, school districts, business owners, design professionals, and building contractors to incorporate energy efficiency practices and renewable energy systems.

Facility Description:

The I-55 Funks Grove rest area was built in 1982 with an addition and major renovation in 1991. The single 4,690 sf building serves both northbound and southbound traffic and is estimated to have 1.33 million visitors per year. There is a separate water treatment building which houses pumps, filters, and treatment chemicals. The winding roadway covers a large portion of the site and the exterior lighting for the road and parking area accounts for a large portion of the energy budget.

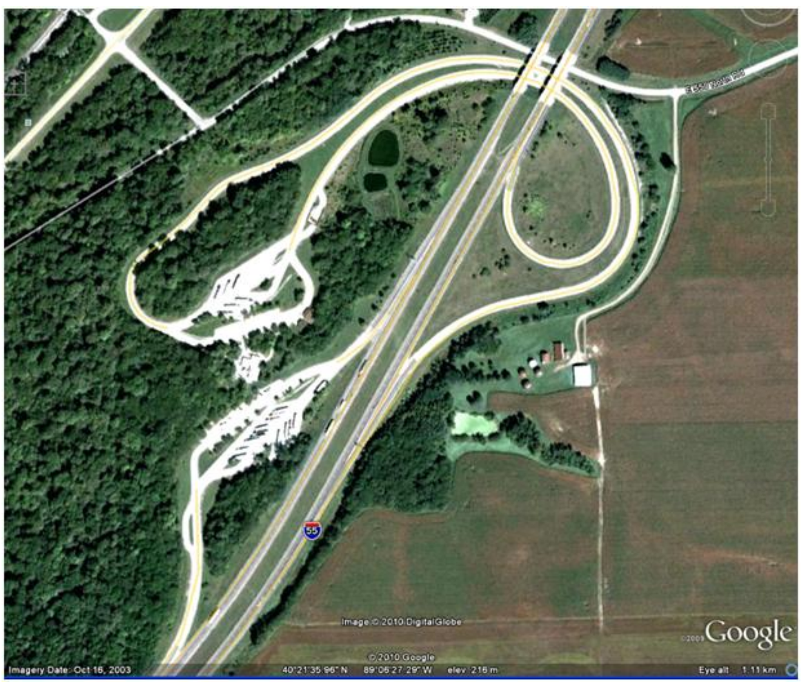

Figure 1: Aerial View of the Funks Grove Rest Area

The building's exterior walls have a brick veneer, air gap, 2" of rigid foam insulation (R-8), and backed by concrete masonry units. There is a standing seam metal roof above an unconditioned and vented attic space that has 6" batt insulation (R-19) above the plaster ceiling. The lobby is accessed by a large front vestibule and has a clerestory skylight, both with insulated glass. The interior lobby walls are covered by wooden boards which have up to 0.5" gaps between each board showing the underlying batt insulation and wood framing members. This is a concern in that there is no vapor barrier over the insulation to reduce the possibility of vapor reaching dew point within the fiberglass insulation.

There are two sets of both men's and women's restrooms that can be closed separately for cleaning along with two private accessible restrooms.

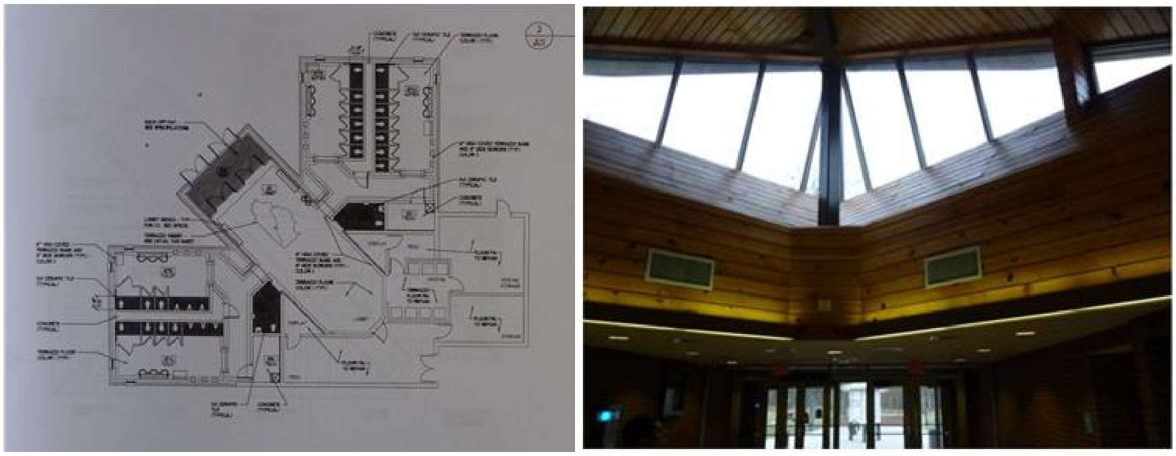

Figure 2: Floor Plan of the Facility and View from Lobby of the Front Doors and Skylight

The HVAC system for the two restrooms, lobby, and mechanical space consists of four split system air conditioners with electric resistance duct heaters. The system has a cooling capacity of about 20 tons (at an assumed efficiency of 10 EER) while the heating system has a capacity of about 40 kW. Three of the four thermostats are digital and programmable but manually set to around 70°F in winter and reported to be set to 74°F in summer. The space temperatures read 71°F, 73°F, and 62°F at the visit with the system in heating mode. The fourth non-programmable thermostat on the original system was noted to be set to 70°F winter and summer. Exhaust for the two men's restrooms was recorded at approximately 300 CFM each (totaling 1,200 CFM for the building). The outdoor air louvers provide fresh makeup air to the system and there are motorized economizer dampers to enable natural conditioning. Ducts are routed through unconditioned attic spaces. There appeared to be signs of air leakage at joints, and the ducts were not insulated.

Figure 3: Uninsulated Duct Showing Signs of Air Leakage in the Vented Attic Space

The lighting in the facility is a mixture of 34W T12 lamps in the maintenance rooms and newer 32W T8 fluorescent lamps in the lobby and restrooms. The lobby area has (12) can lights that each have two 26W pin-type compact fluorescent lamps (CFLs) along with (10) display CFL lamps at 26W each. These lights are kept illuminated regardless of the light levels in the lobby. The majority of exterior lighting consists of 400W yellow high pressure sodium (HPS) lamps on a timer. The roadway area has (37) pole-mounted lights, the parking area has two 8-lamp poles, and the walkways have (8) 100W acorn lights.

Plug loads consist of three drink vending machines, three snack vending machines, and two chilled water fountains. There is a single weather station in the lobby with an older CRT computer screen along with some cameras and a computer recording surveillance system. The restrooms have (14) 2.2kW low velocity pushbutton-start electric hand dryers. Water is heated by two 80 gallon electric resistance water heaters.

Water for the facility is pumped and treated in a small water treatment building with three pressure filter tanks, a 560 gallon hydropneumatic tank, and a several thousand gallon storage tank. Chemical costs total around $3,000 per year (17 drums of chlorine) with a fixed cost of around $10,000 per year for a licensed professional to provide treatment and monitoring. When the 900 sf water treatment building is occupied and the lights are turned on, the ventilation system exhausts at a rate of 600 CFM for safety. Makeup air is conditioned by a dehumidification system which has a 5.5 ton compressor and a desiccant wheel that is heated by a 13.5 kW heater located downstream.

The public areas of the facility have 24 hour operation. The mechanical and storage areas are in use from 6am-11pm 6 days a week.

Utility Profile:

A method for benchmarking a building's energy efficiency is to determine its energy use intensity (kBtu/ft^2/yr) and energy cost intensity (\$/ft^2/yr). This facility uses a very high 298 kBtu/sf/yr (or \$9.81/yr), however this is not unusual in relation to other public rest areas (as shown in the full engineering report) when considering it serves both north and southbound traffic. A summary of energy use and energy cost for the Funks Grove facility in 2009 is shown below.

2009	Annual Consumption		Annual Cost		Average Unit Cost	
Electricity	409,000	kWh	$46,021		$0.113	$/kWh
Floor Area	4,690	sf				
Energy Use Intensity	298	kBtu/sf/yr	**Energy Cost Intensity**	$9.81	$/sf/yr	
*Electricity supplied by UIC then Integrys at an average of $0.081/kWh and delivered by AmerenIL at winter rate of $0.027/kWh and a summer rate of $0.043/kWh, (Rate Class: DS-2)						

Table 1: Funks Grove North and Southbound Energy Use Intensity

The following figure shows the billed monthly electric energy consumption profile compared to the eQuest model (within 5% match) with heating and cooling degree days, which are indicative of climate intensity. Monthly increases and decreases in electric consumption approximately follow the degree day trends for this space. The general baseline building electric energy use is approximately 21,000 kWh per month, which would account for electricity used for lighting, hot water, vending, and plug loads.

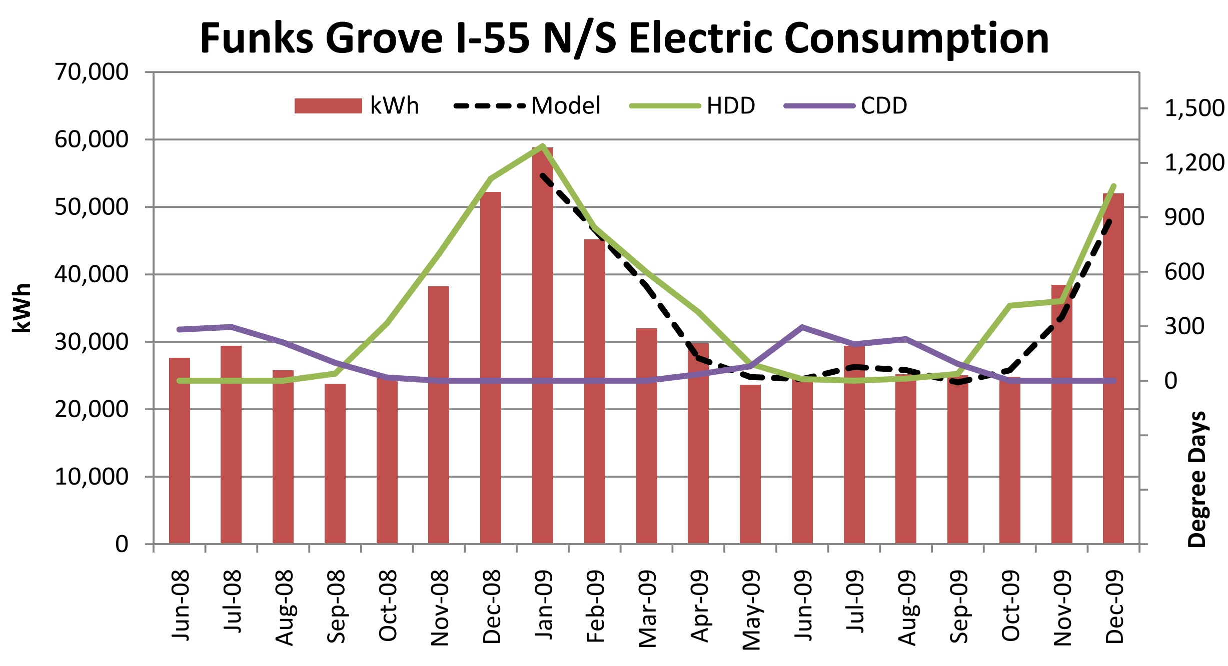

Figure 4: Billed and Modeled Electricity Usage with Cooling and Heating Degree Days

Determining where and in what quantities energy is used throughout the building helps to prioritize energy improvement efforts. The following chart shows a breakdown of the building's energy use by equipment type as estimated from modeling in eQUEST. The energy cost for the building is dominated by electric space heating with exterior lighting coming in a close second.

The greatest use of energy for heating purposes, approximately 13%, is to heat ventilation (outside) air. This is air that replaces the air that has been exhausted by the restroom fans. Additionally, 10% of the energy budget is used to heat air that has leaked into the building (infiltration modeled at 2 air changes per hour), primarily through the frequent opening and closing of entry doors.

The "Other" category likely includes the ventilation and conditioning of the water treatment building which has a very large capacity system but limited hours of use.

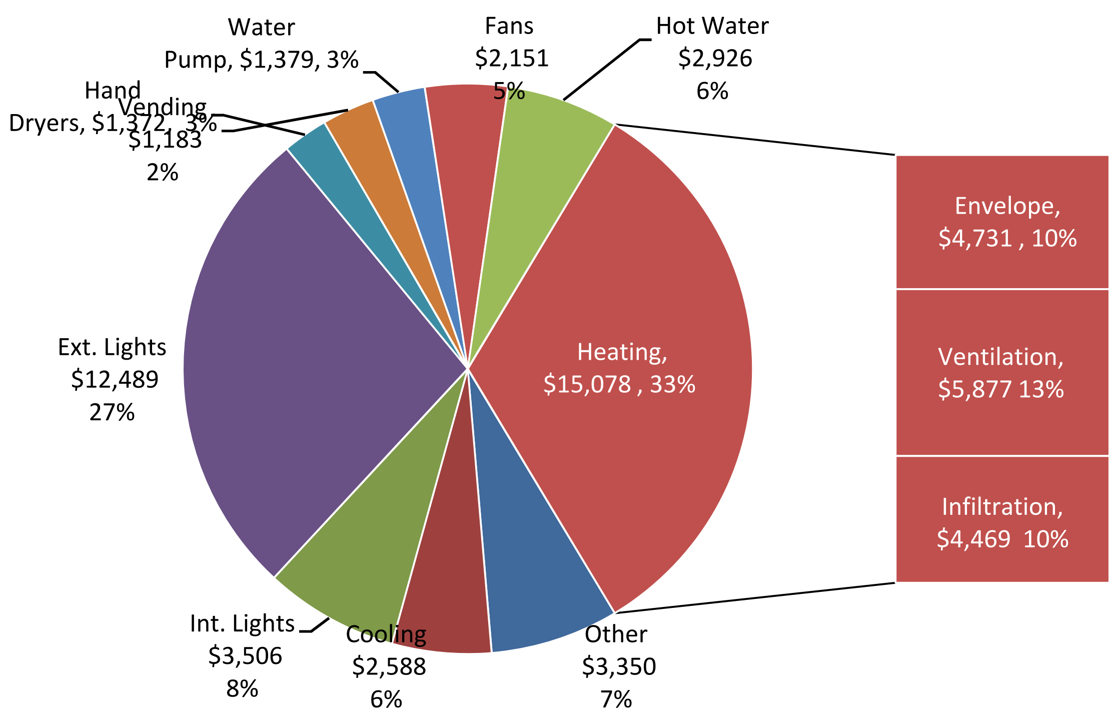

Figure 5: Energy Cost Breakdown by Use

Recommended Energy Cost Reduction Measures (ECRMs)12

ECRM 1 - Interior Lighting

Interior lighting consists of linear fluorescent T12 and newer T8 lighting along with compact fluorescent lamps (CFLs). This measure recommends:

- Replacing (18) T12 lamps and magnetic ballasts with reduced wattage 28W T8 lamps. Ballasts should be program start electronic ballasts (necessary for advanced controls) with a 0.9 ballast factor.
- Replacing (60) T8 lamps and electronic ballasts with high reduced wattage 28W T8 lamps and program start electronic ballasts.
- Replacing (4) 100W MH lamps in the vending area with the two lamp CFL fixtures used throughout.
- Installing daylight sensors in the lobby to reduce operation time.
- Installing solar daylight tubes in the restrooms along with daylight sensors.
- Installing wireless motion sensors for the lighting in the restrooms and maintenance rooms with a 30 minute delay to avoid false turn-offs (required by current code).

These measures together result in a lighting power density that drops from 0.86 W/sf down to 0.66 W/sf. Additionally there is a reduction of operating hours. Not all of the lighting power reduction is realized in savings due to an increase in the electric heating system during the winter months; however, this would be lessened with a more efficient heating system. Incentives are available through DCEO for T8 lighting, daylight sensors, and motion sensors, see page 11.[13]

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 1 - Interior Lighting	9,293	1.2	$1,117	2.4%

ECRM 2 - Exterior Lighting

The exterior lighting consists of high pressure sodium (HPS) pole lamps for the parking area (two poles with eight 400W lamps), roadway area (thirty seven 400W poles), and walkways (eight 100W acorn pole fixtures). This measure recommends investigating replacing the yellow HPS lighting with reduced wattage pulse-start metal halide (PSMH) lamps (400W to 320W, and 100W to 75W),and the appropriate ballasts.

Reduced illumination of the area should be considered, however PSMH lamps produce a white light that is better perceived by our eyes than the yellow light of sodium lighting.[14] The better color rendering would also assist surveillance cameras used outdoors. Furthermore, it is not clear that the winding roadway pole spacing currently achieves, or is expected to achieve, a constant illumination like a parking lot.

[12] Our work does not replace engineering design which will be necessary for project implementation.
[13] http://www.illinoisbiz.biz/dceo/Bureaus/Energy_Recycling/Energy/Energy+Efficiency/
[14] http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-VisualEfficacy-Jan2009.pdf

PSMH lamps also experience less lumen loss and therefore can have lower rated wattage but achieve the same average lumen output with a longer expected lifetime. When upgrading lighting, consider replacing fixtures. Look for a design that minimizes losses through light spill, poor optics, and uneven light distribution.[15]

This measure is eligible for a custom incentive from DCEO of $0.09/kWh saved (~$3,051) if there is a 1-7 year simple payback.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 2 - Exterior Lighting	33,901	7.7	$3,815	8.3%

At this time, SEDAC doesn't fully endorse the newest LED and Induction Fluorescent lighting technologies due to concerns with cost, efficiency, and reliability. However, the potential for these technologies is promising and they should be considered in the future, or in limited test scenarios. The directionality of LED lighting may be of particular use in roadway areas where the goal is a linear lighting design instead of general area lighting. There is a DCEO custom lighting incentive for LED or Induction lighting of $0.23/kWh.

ECRM 3 - Duct Sealing

The HVAC ducts are not insulated or sealed and run through unconditioned attic spaces. This measure recommends both sealing the joints with mastic tape and applying duct board insulation. Current Illinois code requirements (IECC 2009) for ducts in a vented attic are insulation of R-3.5. A conservative estimate of 5% HVAC savings was assumed,[16] however additional savings potential exists in downsizing any future systems.

This measure may be eligible for a custom incentive from DCEO of $0.09/kWh saved (~$707) if there is a 1-7 year simple payback.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 3 - Duct Sealing	7,850	0	$883	1.9%

ECRM 4 - Exhaust Heat Recovery

In buildings with large ventilation requirements, conditioning fresh air is one of the largest portions of the overall heating costs. This measure recommends installing a run-around loop heat exchanger to help recover some of the heat exhausted by the HVAC system and the bathroom exhaust fans without contaminating incoming air. The model assumes that the intake air and the exhaust air pass over a run-around loop heat exchanger with 50% effectiveness. This is a passive system with no moving parts and therefore should require very little maintenance aside from general cleaning. An energy recovery wheel would have a higher

[15] http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-ParkingLotEvaluation-Revised-Jan2010.pdf
[16] http://www.energystar.gov/index.cfm?c=home_improvement.hm_improvement_ducts

efficiency (70%) and is allowed by code[17] however maintenance and fan energy could be of concern.

Heat recovery can be a more effective solution in air tight structures that have very little air infiltration, for example, heat lost through the doors is unrecoverable. The applicability of this measure will depend on how makeup air is mechanically supplied to the space, where exhaust ducts are located, and how much air is introduced by infiltration through the entry doors. However, due to the potential for savings, and the possibility to downsize other systems, this should be investigated further to determine if it is technically feasible in this building.

This measure may be eligible for a custom incentive from DCEO of $0.09/kWh saved (~$2,467)if there is a 1-7 year simple payback.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 4 - Exhaust Heat Recovery	27,410	0	$3,084	6.7%

ECRM 5 - Ground Source Heat Pump

This measure recommends installing a ground source heat pump with vertical wells to heat and cool the space along with a desuperheater to heat water in the cooling season. A ground source heat pump is many times more efficient than an air source heat pump since it uses the nearly constant temperature of the earth to transfer heat and is not affected by the outdoor air temperature.

This system was modeled to have a heating coefficient of performance (COP) of 4.0 and a cooling efficiency of 18 EER.[18] This system should also have the ability to operate in economizer mode, bringing in fresh air when the outdoor air temperature is sufficient to condition the space. The desuperheater uses heat that is removed from the space to heat domestic hot water. This essentially creates free hot water whenever the system is in cooling mode (estimated to save 8,500 kWh each summer).

Although SEDAC doesn't size equipment, we suggest that correctly sizing a geothermal system will greatly reduce the upfront costs. For example, at $6,000/ton, a 20 ton horizontal system would cost around $120,000, while modeling suggests the current space might be sufficiently served by a 15 ton system. Furthermore, included as a package, with options such as heat recovery and duct sealing the system could be sized even smaller.

This measure may be eligible for a custom incentive from DCEO of $0.09/kWh saved (~$9,750) if there is a 1-7 year simple payback.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 5 - Ground Source Heat Pump	108,340	35	$12,190	27%

An air source heat pump would less initial cost but would be a less efficient option. An air source heat pump was modeled that meets energy star recommendations with a cooling

[17] http://www.airxchange.com/Collateral/Documents/English-US/Acceptable_Cross_Leakage_for_Energy_Recovery_Ventilation.pdf

[18] http://www1.eere.energy.gov/femp/procurement/eep_groundsource_heatpumps.html

efficiency of 12 EER and a heating performance rating of 8.2HSPF.[19] This system also had a desuperheater but only saved 64,730 kWh annually. Dual stage cold climate heat pumps that heat at lower temperatures, without electric resistance backup, are available and would offer greater energy savings but are a newer unproven technology and may be difficult to obtain from multiple sources.

ECRM 6 - Hand Dryers

Although the electric hand dryers use a relatively small amount of energy due to their sporadic usage, they are one of the most visible aspects of public building energy use for visitors. Slow, ineffective hand dryers may feel like a waste of time and electricity, or possibly discourage people from washing at all. It is assumed that half of the visitors use a hand dryer for 30 seconds. Note, if all (14) 2.2kW hand dryers are run at the same time, there would be a 31 kW load on the electrical system (20% of peak load).

This measure recommends installing high velocity hand dryers that run for half the time and require half the power to operate, effectively reducing energy use by 75%. Many varieties are available and options are even available from the manufacturer of the current installed units.[20]

This measure will be eligible for a custom incentive from DCEO of $0.09/kWh saved (~$801) if there is a 1-7 year simple payback.Note that the savings may be less for this facility due to the large number of dryers to have to replace. Replacing only several may have similar results.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 6 - Hand Dryers	8,900	15.4	$1,001	2.2%

ECRM 7 - Vending Occupancy Controls

Vending machines are illuminated and cycle their cooling compressors all day regardless of building occupancy. This measure recommends that occupancy sensing controls be used to turn off the lighting and cycle the cooling less frequency when no one is around.[21] This can be accomplished with an external motion sensing unit (commonly called a vending miser)[22] or these controls can be integrated into newer machines from the manufacturer and should be specified during contract negotiations.[23] At the very least, the lamps can be removed from the front of drink machines in well lit areas and a sign can be applied that indicates the machines are still functioning but are using less energy.

This measure is eligible for a standard incentive from DCEO of $100 per drink machine and $45 per snack machine control.

	Annual Savings			
	kWh	kW	$	Energy %

[19] http://www.energystar.gov/index.cfm?c=airsrc_heat.pr_crit_as_heat_pumps
[20] http://www.worlddryer.com/products/smartdri™
[21] https://www1.eere.energy.gov/femp/technologies/eep_beverage_vending_machine.html
[22] http://www.usatech.com/energy_management/energy_vm.php
[23] http://www.energystar.gov/index.cfm?c=vending_machines.pr_proc_vendingmachines

ECRM 7 - Vending Occupancy Controls	3,048	0	$343	0.7%

Package 1 - ECRMs 1-2, 4-7

This package combines the ECRMs with the best potential energy savings together in the model to account for any interactions between the measures. This package, in its entirety, is recommended for implementation.

- ECRM 1 - Interior Lighting
- ECRM 2 -Exterior Lighting
- ECRM 3 - Duct Sealing
- ECRM 4 - Exhaust Heat Recovery
- ECRM 5 - Geothermal Heat Pump
- ECRM 6 - Hand Dryers
- ECRM 7 - Vending Occupancy Controls

	Annual Savings			
	kWh	kW	$	Energy %
Package 1 -ECRMs 1-7	192,038	59	$21,608	47%

Other Recommendations

- Replace any incandescent exit signs with LED exit signs or lamp retrofit kits. Replacing two 20W lamps per sign with a 5W red LED kit will save 306 kWh, or $35 each year.
- Install an air source heat pump with desuperheater to condition the space and heat water for less initial cost but also less savings than a ground source unit.
- Add a desuperheaterto the current cooling system to heat water during the summer months. This could save around 8,500 kWh, or $960 each year.
- Use the programmable thermostats on the current HVAC system to setback the temperature during periods of low-occupancy.
- Provide informational kiosks that show energy use for this facility and detail energy saving measures utilized.
- Replace the weather station CRT monitor with an EnergyStar LCD screen. Replacing a 120W CRT monitor with a 40W LCD will save 700 kWh, or $79 each year.
- If any water pumps could be run at a slower speed or are pumping against a volume reducing valve, consider installing variable frequency drives (VFDs).
- Small wind turbines can be an educational and viable renewable energy resource in rural areas. However, maintenance and safety may be large hindering factors for a public area.
- Solar PV and solar thermal (water heating and ventilation air heating) can be good long-term renewable energy options given proper roof orientation and sun exposure. It was not clear from the site visit if the south facing roof sections were clear of trees.
- Install low-flow sink aerators to reduce hot water use and use low-flow fixtures to reduce water pumping and treatment costs.

AVAILABLE INCENTIVES FOR 2010

DCEO – Energy Efficiency Portfolio Standard

DCEO's Public Sector Electric Efficiency Program offers incentives for energy efficiency measures for customers in the ComEd or Ameren service areas. Rebate incentives are limited to $200,000 per building per year. Multiple applications with project subsections may be submitted. Further, incentives are limited to 75% of the total project cost, and 100% of the incremental project cost (beyond standard replacement option).

SEDAC has created a Web page to post relevant documents and link to programs and services at www.IllinoisEEPS.org. Please bookmark this page and watch for further developments.

DCEO's Public Sector Electric Efficiency Program can be found at: http://www.commerce.state.il.us/dceo/Bureaus/Energy_Recycling/

A list of the incentives for government facilities applicable to ECRMs in this report is shown below.

ECRM	Incentive
Upgrade 4' T12 to T8 and elec. Ballast	$8.50 per lamp
Permanent Removal of T12 Lamp	$7.50 per lamp
Occupancy Controls	$0.13 per watt controlled
LED Exit Sign or Kit	$23 per fixture
AC <5.4 Tons, 14 SEER (11.5 EER)	$33 per ton
AC >5.4 Tons, 15 SEER (12 EER)	$38 per ton
Beverage Machine Control	$100 per control
Snack Machine Control	$45 per control
Custom kWh Reduction	$0.09/kWh (1-7 year payback)
Custom kWh Exterior Lighting (LED or Induction)	$0.23/kWh (1-7 year payback)

Table 2: List of Possible Applicable EEPS Incentives from DCEO for a State Facility

DCEO provides solar energy rebates of 50% of cost, up to $50,000, to public institutions. More information is available at: http://www.commerce.state.il.us/dceo/Bureaus/Energy_Recycling/Energy/Clean+Energy

Summary:

The table below lists the recommended estimated energy saving opportunities at the Funks Grove rest area. Implementing Package 1 should reduce the current building energy use and utility costs by an estimated 47%. Other recommendations listed that can help reduce energy and support sustainability.

The next steps should be to consult contractors about feasibility and obtain quotes. DCEO incentives should be applied for before starting any work or purchasing equipment. Many of these savings will be applicable across other rest areas in the state.

ECRM 1 - Replace T12 lamps with T8, replace interior metal halide lamps with CFLs, add motion controls, add solar-tubes with daylight controls

ECRM 2 - Upgrade exterior lighting with reduced wattage pulse start metal halide lamps

ECRM 3 - Seal HVAC ducts with mastic in the attic space and add duct board insulation

ECRM 4 - Investigate adding heat recovery to the ventilation system

ECRM 5 - Replace the HVAC system with a high efficiency Geothermal Heat Pump

ECRM 6 - Install high velocity hand dryers

ECRM 7 - Add or specify vending occupancy controls

Package 1 - ECRMs 1-9

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 1 - Interior Lighting	9,293	1.2	$1,117	2.4%
ECRM 2 - Exterior Lights	33,901	7.7	$3,815	8.3%
ECRM 3-Duct Sealing	7,850	0	$883	1.9%
ECRM 4 - Exhaust Heat Recovery	27,410	0	$3,084	6.7%
ECRM 5-Ground Source Heat Pump	108,340	35	$12,190	27%
ECRM 6 - Hand Dryers	8,900	15	$1,001	2.2%
ECRM 7 - Vending Occupancy Controls	3,048	0	$343	0.7%
Package 1 - ECRMs 1-9	192,038	59	$21,608	47%

Table 3: Calculated Energy Savings

(2) When ECRMs are implemented as a package, results vary from application of individual ECRMs.

Appendix C. SEDAC Audit Report for Pride of the Prairie Rest Area

Illinois Smart Energy Design Assistance Center

SEDAC Level 2 Audit Report
Pride of the Prairie Rest Area: I-72 Eastbound

Published: 9/30/2010

Site Visit: 3/15/2010

Location: I-55 North and Southbound, South of Bloomington, IL

Contacts: Craig Mitckes: ILDOT (217) 782-2984 | Liang Liu: University of Illinois (217) 333-6951

Auditor: Andy Robinson aar@illinois.edu

UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN

dceo ILLINOIS DEPARTMENT OF COMMERCE AND ECONOMIC OPPORTUNITY *constitute an endorsement. All numerical data are order of magnitude estimates and the number of digits shown are an artifact of the calculation procedure; they are not meant to imply greater accuracy or precision.*

Background:

The Illinois Department of Transportation has applied to the University of Illinois Smart Energy Design Assistance Center (SEDAC) for an energy audit of the Pride of the Prairie rest area. This energy audit is in conjunction with a facility review being undertaken with help from the University of Illinois Engineering Department.

In order to enhance the economy, the Illinois Department of Commerce and Economic Opportunity (DCEO) has implemented the Smart Energy Design Assistance Center (SEDAC) for the commercial, municipal, and educational building sectors. The program is funded by DCEO and is managed by the School of Architecture at the University of Illinois at Urbana-Champaign. SEDAC’s mission is to encourage communities, municipalities, school districts, business owners, design professionals, and building contractors to incorporate energy efficiency practices and renewable energy systems.

Facility Description:

The I-55 Funks Grove rest area was built in 1986. The eastbound building (1,950 sf) is estimated to serve 327,000 visitors per year. The westbound building is not specifically analyzed in this report but it is nearly identical and the same savings measures can be applied there. The winding roadway covers a large portion of the site and the exterior lighting for the road and parking area accounts for a large portion of the energy budget.

Figure 1: Aerial View with Eastbound on the Right and Westbound on the Left

The plans show the exterior walls being built with brick veneer, ½" foam board insulation, and 6" concrete block filled with perlite (although the perlite was not confirmed by site staff). This assembly is assumed to have an insulation value of R-8.5. The exterior walls of the lobby area are double pane storefront windows with two doors on the front (west car lot) and one door to the back (east truck lot). The restrooms each have a 3'x9' glass block window. The two maintenance rooms each have a matching glass block window and two hollow core steel doors to the outside. There is a pitched wood shake roof above an unconditioned attic space. The plans show 4" (R-13) of fiberglass batt insulation on the attic floor. The maintenance staff said that the ducts in the unconditioned attic are not insulated or air sealed.

Figure 2: Exterior View of the Eastbound Rest Area

The HVAC system consists of one air handler served by two 3.5 ton Trane XE 1000 air source heat pumps ca. 1998. The cooling system has an assumed efficiency of 10 EER while the heating mode is rated at 8.2 HSPF.[24]The digital heat pump programmable thermostat is located in the return air duct and is set at a constant 68°F in the winter and 78°F in the summer. According to Tom Strohl, the District 7 Service Manager, these are the mandated temperature sepoints for all rest areas in the state; however of the three visited, this is the only one at that setting. The two mechanical rooms have supplemental electric resistance unit heaters which were set to 60°F and assumed to come on infrequently.

Exhaust for the restrooms was recorded at approximately 170 CFM each (totaling 340 CFM for the building). The outdoor air louvers provide fresh makeup air to the system and there are motorized economizer dampers to enable natural conditioning. This control appeared to be

[24]http://www.customengineering.info/products/xe1000.html

manually disconnected at the site visit but was said to be reconnected in the spring and fall seasons. Ducts are reported to be uninsulated and routed through unconditioned attic spaces.

Figure3: Lobby and Restroom Lights on Near Windows Despite Ample Daylight

The lighting in the lobbyconsists of 2’x2’ U-tubetwo-lamp fluorescent fixtures that were on despite adequate daylight from the windows on a cloudy day. The restrooms each have two square fixtures (each with two U-tube lamps) on near the windows, along with 3 (2-lamp) T12 fixtures near the darker wall. Light levels were recorded at 66 fc near the windows and 25 fc on the opposite wall under a fixture. This indicates the potential for reducing light levels by delamping, or with new controls based on daylight and occupancy.

The majority of exterior lighting consists of 400W yellow high pressure sodium (HPS) lamps. The winding roadway area has (15) pole-mounted lights, the parking area has two six-lamp poles, and the exterior of the building has (7) 100W recessed fixtures. According to bills and modeling, these lights appear to use less power than expected. This is likely due to a well-tuned photo sensor that operates lights for around 7 hours per night in the summer and 12 hours per night in the winter.

Location	Quantity	Fixture Type
Lobby	10	2’x2’ 2-lamp U-Tube (35W per lamp)
Restrooms	4	2’x2’ 2-lamp U-Tube (35W per lamp)
Restrooms	6	4’ 2-lamp T-12 (34W per lamp)
Mechanical	8	4’ 2-lamp T-12 (34W per lamp)
Exterior	7	Recessed 100W HPS Lamp
Roadway	15	200W HPS Single Head Pole Lamps*
Parking	2	200W HPS Six Head Pole Lamps*

* The wattage of the exterior lighting will be checked at the next relamping on site

Plug loads consist of one drink vending machine, one snack vending machines, and two chilled water fountains. There is a single weather station in the lobby with an older CRT computer screen along with some cameras and a computer recording surveillance system. The restrooms have (4) 2.2kW low velocity pushbutton-start electric hand dryers. Water is heated by an 80 gallon electric resistance water heater.

The public areas of the facility have 24 hour operation. The mechanical and storage areas are in use from 6 a.m. -11 p.m. 6 days a week; however, the lights are usually left off.

Utility Profile:

A method for benchmarking a building's energy efficiency is to determine its energy use intensity ($kBtu/ft^2/yr$) and energy cost intensity ($\$/ft^2/yr$). This facility uses a relatively low 112 kBtu/sf/yr (or $3.48/yr). A summary of energy use and energy cost for the Funks Grove facility in 2009 is shown below.

2009	Annual Consumption		Annual Cost		Average Unit Cost	
Electricity	63,860	kWh	$6,787		$0.106	$/kWh
Floor Area	1,950	sf				
Energy Use Intensity	112	kBtu/sf/yr	**Energy Cost Intensity**	$3.48	$/sf/yr	
*Electricity supplied and delivered by Corn Belt Energy Coop(Rate Class: 3)						

Table 1: Pride of the Prairie Eastbound Energy Use Intensity

The following figure shows the billed monthly electric energy consumption profile compared to the eQuest model (within 7% match) with heating and cooling degree days, which are indicative of climate intensity. Monthly increases and decreases in electric consumption approximately follow the degree day trends for this space. The general baseline building electric energy use is approximately 3,000 kWh per month, which would account for electricity used for lighting, hot water, vending, and plug loads.

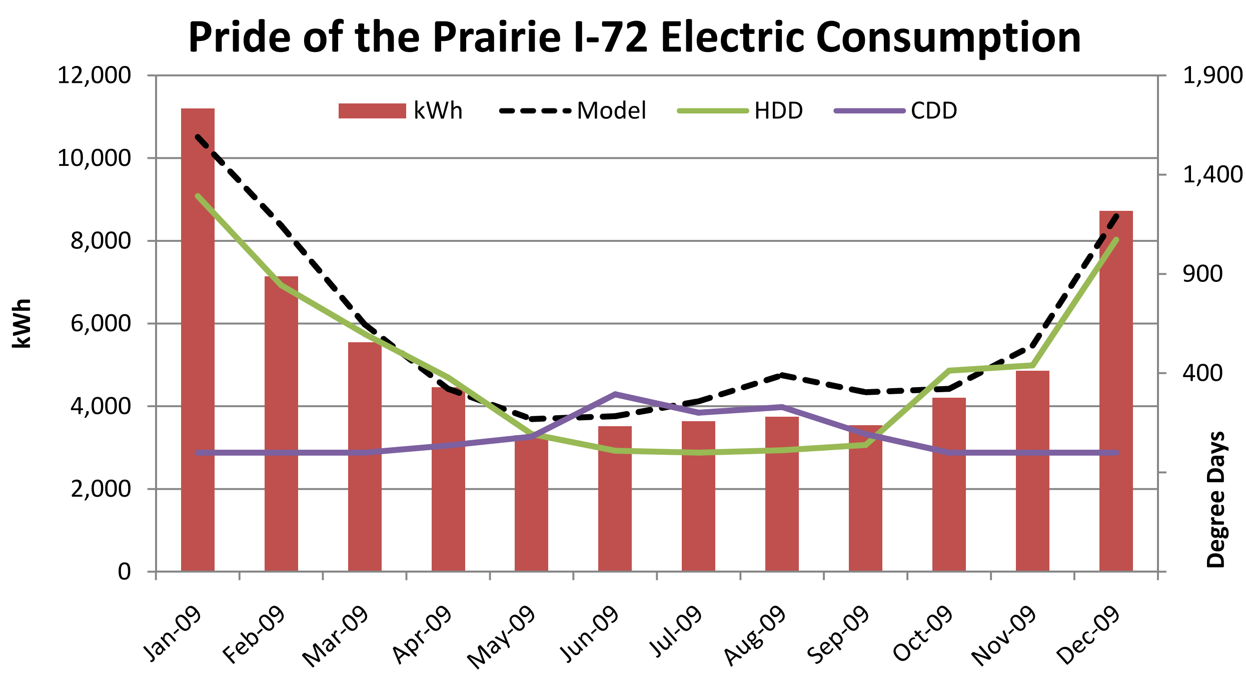

Figure 4: Billed and Modeled Electricity Usage with Cooling and Heating Degree Days

Determining where and in what quantities energy is used throughout the building helps to prioritize energy improvement efforts. The following chart shows a breakdown of the building's energy use by equipment type as estimated from modeling in eQUEST. The energy cost for the building is dominated by electric space heating with exterior lighting coming in a close second.

The greatest use of energy for heating purposes, approximately 13%, is to heat ventilation (outside) air. This is air that replaces the air that has been exhausted by the restroom fans. Additionally, 6% of the energy budget is used to heat air that has leaked into the building (infiltration modeled at 1 air change per hour), primarily through the frequent opening and closing of entry doors.

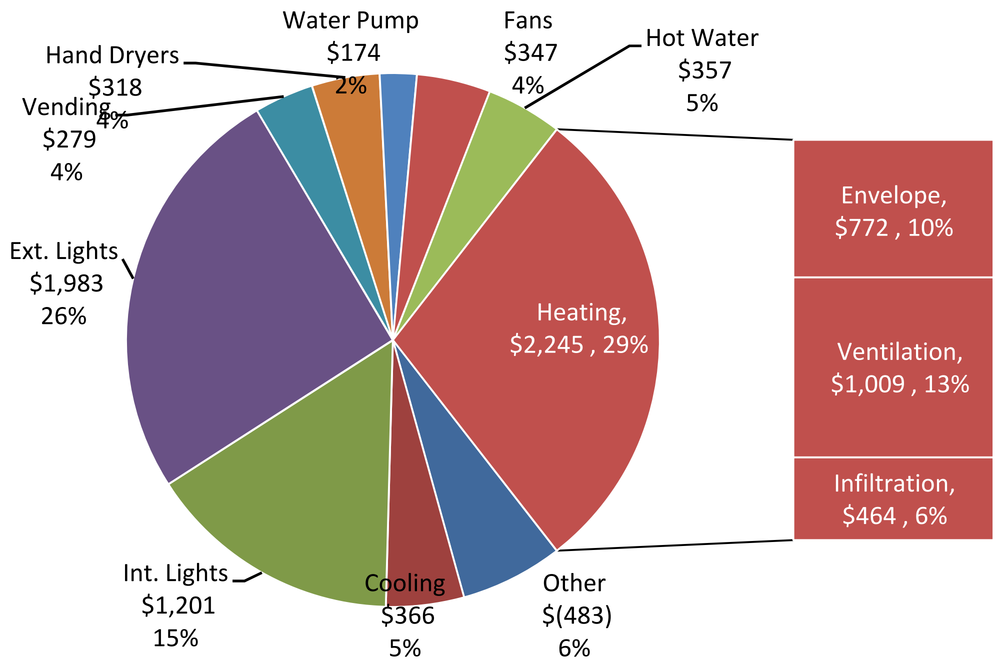

Figure 5: Modeled Energy Cost Breakdown by Use

Recommended Energy Cost Reduction Measures (ECRMs)25

ECRM 1 - Interior Lighting

Interior lighting consists of linear fluorescent T12 and newer T8 lighting along with compact fluorescent lamps (CFLs). This measure recommends:

- ReplacingU-tube and 4' T12 lamps and magnetic fixtures with reduced wattage 28W T8 fixtures. Ballasts should be program start electronic ballasts (necessary for advanced controls) with a 0.9 ballast factor.
- Replacing (4) 100W MH lamps in the vending area with the two lamp CFL fixtures used throughout.
- Installing daylight sensors in the lobby to reduce operation time.
- Installing solar daylight tubes in the restrooms along with daylight sensors.
- Installing wireless motion sensors for the lighting in the restrooms and maintenance rooms with a 30 minute delay to avoid false turn-offs (required by current code).

These measures together result in a lighting power density that drops from 0.89 W/sf down to 0.66 W/sf. Additionally there is a 40% reduction of operating hours. Not all of the lighting power reduction is realized in savings due to an increase in the electric heating system during the winter months; however, this would be lessened with a more efficient heating system.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 1 - Interior Lighting	4,390	0.1	$467	6.9%

ECRM 2 - Exterior Lighting

This measure recommends investigating replacing the yellow HPS exterior lighting with reduced wattage pulse-start metal halide (PSMH) lamps (200W to 150W),and the appropriate ballasts.

Reduced illumination of the area should be considered, however PSMH lamps produce a white light that is better perceived by our eyes than the yellow light of sodium lighting.[26] The better color rendering would also assist surveillance cameras used outdoors. Furthermore, it is not clear that the winding roadway pole spacing currently achieves, or is expected to achieve, a constant illumination like a parking lot.

PSMH lamps also experience less lumen loss and therefore can have lower rated wattage but achieve the same average lumen output with a longer expected lifetime. When upgrading lighting, consider replacing fixtures. Look for a design that minimizes losses through light spill, poor optics, and uneven light distribution.[27]

	Annual Savings			
	kWh	kW	$	Energy %

[25] Our work does not replace engineering design which will be necessary for project implementation.
[26] http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-VisualEfficacy-Jan2009.pdf
[27] http://www.lrc.rpi.edu/programs/solidstate/assist/pdf/AR-ParkingLotEvaluation-Revised-Jan2010.pdf

ECRM 2 - Exterior Lighting	4,435	1.4	$471	6.9%

At this time, SEDAC doesn't fully endorse the newest LED and Induction Fluorescent lighting technologies due to concerns with cost, efficiency, and reliability. However, the potential for these technologies is promising and they should be considered in the future, or in limited test scenarios. The directionality of LED lighting may be of particular use in roadway areas where the goal is a linear lighting design instead of general area lighting.

ECRM 3 - Duct Sealing

The HVAC ducts are not insulated or sealed and run through unconditioned attic spaces. This measure recommends both sealing the joints with mastic tape and applying duct board insulation. Current Illinois code requirements (IECC 2009) for ducts in a vented attic are insulation of R-3.5. A conservative estimate of 5% HVAC savings was assumed,[28] however additional savings potential exists in downsizing any future systems.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 3 - Duct Sealing	1,228	0	$131	1.9%

ECRM 4 - Exhaust Heat Recovery

In buildings with large ventilation requirements, conditioning fresh air is one of the largest portions of the overall heating costs. This measure recommends installing a run-around loop heat exchanger to help recover some of the heat exhausted by the HVAC system and the bathroom exhaust fans without contaminating incoming air. The model assumes that the intake air and the exhaust air pass over a run-around loop heat exchanger with 50% effectiveness. This is a passive system with no moving parts and therefore should require very little maintenance aside from general cleaning. An energy recovery wheel would have a higher efficiency (70%) and is allowed by code[29] however maintenance and fan energy could be of concern.

Heat recovery can be a more effective solution in air tight structures that have very little air infiltration, for example, heat lost through the doors is unrecoverable. The applicability of this measure will depend on how makeup air is mechanically supplied to the space, where exhaust ducts are located, and how much air is introduced by infiltration through the entry doors. However, due to the potential for savings, and the possibility to downsize other systems, this should be investigated further to determine if it is technically feasible in this building.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 4 - Exhaust Heat Recovery	4,271	0	$454	6.7%

[28] http://www.energystar.gov/index.cfm?c=home_improvement.hm_improvement_ducts
[29] http://www.airxchange.com/Collateral/Documents/English-US/Acceptable_Cross_Leakage_for_Energy_Recovery_Ventilation.pdf

ECRM 5 - Ground Source Heat Pump

This measure recommends installing a ground source heat pump with vertical wells to heat and cool the space along with a desuperheater to heat water in the cooling season. A ground source heat pump is many times more efficient than an air source heat pump since it uses the nearly constant temperature of the earth to transfer heat and is not affected by the outdoor air temperature.

This system was modeled to have a heating coefficient of performance (COP) of 4.0 and a cooling efficiency of 18 EER.[30] This system should also have the ability to operate in economizer mode, bringing in fresh air when the outdoor air temperature is sufficient to condition the space. The desuperheater uses heat that is removed from the space to heat domestic hot water. This essentially creates free hot water whenever the system is in cooling mode (estimated to save 1,100 kWh each summer).

Although SEDAC doesn't size equipment, we suggest that correctly sizing a geothermal system will greatly reduce the upfront costs. For example, at $6,000/ton, a 7 ton horizontal system would cost around $42,000, while modeling suggests the current space might be sufficiently served by a 4 ton system. Furthermore, included as a package, with options such as heat recovery and duct sealing the system could be sized even smaller.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 5 - Ground Source Heat Pump	13,289	21	$1,412	21%

ECRM 6 - Hand Dryers

Although the electric hand dryers use a relatively small amount of energy due to their sporadic usage, they are one of the most visible aspects of public building energy use for visitors. Slow, ineffective hand dryers may feel like a waste of time and electricity, or possibly discourage people from washing at all. It is assumed that half of the visitors use a hand dryer for 30 seconds.

This measure recommends installing high velocity hand dryers that run for half the time and require half the power to operate, effectively reducing energy use by 75%. Many varieties are available and options are even available from the manufacturer of the current installed units.[31]

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 6 - Hand Dryers	2,187	4.4	$232	3.4%

[30] http://www1.eere.energy.gov/femp/procurement/eep_groundsource_heatpumps.html

[31] http://www.worlddryer.com/products/smartdri™

ECRM 7 - Exhaust Fan Sensors

As this rest area has relatively low usage compared to others in the state, it may be possible to reduce the hours that ventilation fans are operating. This measure recommends operating the exhaust fans on occupancy sensors that will automatically turn the fans on and turn off after 30 minutes of no activity. This is assumed to reduce operating hours by 40%, with many of those hours occurring on the coldest winter nights when heating is most difficult.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 7 -Exhaust Fan Sensors	5,990	0	$637	9.4%

ECRM 8 - Add a Vestibule

Adding a front vestibule with a second set of doors in the front and rear would help reduce air infiltration and better insulate the lobby area. The model shows significant savings from reducing the air change per hour (ACH) from 1.0 ACH to 0.8 ACH (20% reduction) and adding a second wall of insulated glazing. Simply insulating the front and rear walls with double glazed windows contributes about half of the savings. This measure shows marginalsavings considering the expense of installation and is not recommended.

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 8-Adding a Vestibule	1,130	0	$120	1.8%

Package 1 - ECRMs 1-7

This package combines the ECRMs with the best potential energy savings together in the model to account for any interactions between the measures. This package, with the exclusion of ECRM 8 - Vestibule, is recommended for implementation.

- ECRM 1 - Interior Lighting
- ECRM 2 - Exterior Lighting
- ECRM 3 - Duct Sealing
- ECRM 4 - Exhaust Heat Recovery
- ECRM 5 - Geothermal Heat Pump
- ECRM 6 - Hand Dryers
- ECRM 7 - Exhaust Sensors
- ECRM 8 - Vestibule

	Annual Savings			
	kWh	kW	$	Energy %
Package 1 - ECRMs 1-7	34,249	27	$3,640	54%

Other Recommendations

- Replace any incandescent exit signs with LED exit signs or lamp retrofit kits. Replacing two 20W lamps per sign with a 5W red LED kit will save 306 kWh, or $35 each year.
- Add a desuperheaterto the current cooling system to heat water during the summer months. This could save around 1,100 kWh, or $116 each year.
- Use the programmable thermostats on the current HVAC system to setback the temperature during periods of low-occupancy.
- Provide informational kiosks that show energy use for this facility and detail energy saving measures utilized.
- Replace the weather station CRT monitor with an EnergyStar LCD screen. Replacing a 120W CRT monitor with a 40W LCD will save 700 kWh, or $79 each year.
- If any water pumps could be run at a slower speed or are pumping against a volume reducing valve, consider installing variable frequency drives (VFDs).
- Small wind turbines can be an educational and viable renewable energy resource in rural areas. However, maintenance and safety may be large hindering factors for a public area.
- Solar PV and solar thermal (water heating and ventilation air heating) can be good long-term renewable energy options given proper roof orientation and sun exposure. It was not clear from the site visit if the south facing roof sections were clear of trees.
- Install low-flow sink aerators to reduce hot water use and use low-flow fixtures to reduce water pumping and treatment costs.

AVAILABLE INCENTIVES FOR 2010

There are no known energy efficiency incentives provided by Corn Belt Energy Coop. At this time, the state does not require cooperatives to participate in the Energy Efficiency Portfolio Standard (EEPS) which provides public clients of Ameren and ComEd incentives through DCEO.

DCEO provides solar energy rebates of 50% of cost, up to $50,000, to public institutions. More information is available at:
http://www.commerce.state.il.us/dceo/Bureaus/Energy_Recycling/Energy/Clean+Energy

Summary:

The table below lists the recommended estimated energy saving opportunities at the Pride of the Prairie rest area. Implementing Package 1 should reduce the current building energy use and utility costs by an estimated 47%. Other recommendations listed can help reduce energy and support sustainability.

The next steps should be to consult contractors about feasibility and obtain quotes. All of these recommendations area applicable to the westbound side and should be considered there as well.

ECRM 1 - Replace T12 lamps with T8, add motion controls, add daylight controls

ECRM 2 - Upgrade exterior lighting with reduced wattage pulse start metal halide lamps

ECRM 3 - Seal HVAC ducts with mastic in the attic space and add duct board insulation

ECRM 4 - Investigate adding heat recovery to the ventilation system

ECRM 5 - Replace the HVAC system with a high efficiency Geothermal Heat Pump

ECRM 6 - Install high velocity hand dryers

ECRM 7 - Install occupancy sensors on the exhaust fans

ECRM 8 - Retrofit a second entrance door to create a vestibule (Not recommended)

Package 1 - ECRMs 1-7

	Annual Savings			
	kWh	kW	$	Energy %
ECRM 1 - Interior Lighting	4,390	0.1	$467	6.9%
ECRM 2 - Exterior Lights	4,435	1.4	$471	6.9%
ECRM 3 - Duct Sealing	1,228	-	$131	1.9%
ECRM 4 - Exhaust Heat Recovery	4,271	-	$454	6.7%
ECRM 5 - Ground Source Heat Pump	15,349	21.0	$1,631	24.0%
ECRM 6 - Hand Dryers	2,187	4.4	$232	3.4%
ECRM 7 - Exhaust Sensors	5,990	-	$637	9.4%
ECRM 8 - Vestibule (Not Recommended)	1,130	-	$120	1.8%
Package 1 - ECRMs 1-7	34,249	27	$3,640	54%

Table 3: Calculated Energy Savings

(3) When ECRMs are implemented as a package, results vary from application of individual ECRMs.