Energy Efficiency, Water Efficiency, and Renewable Energy Site Assessment:

Seneca Rocks Discovery Center, Seneca Rocks, West Virginia

Kosol Kiatreungwattana, James Salasovich, and Alicen Kandt

Produced under direction of the U.S. Forest Service by the National Renewable Energy Laboratory (NREL) under Interagency Task No. WFHV.1001

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Technical Report
NREL/TP-7A40-65935
March 2016

Contract No. DE-AC36-08GO28308

Energy Efficiency, Water Efficiency, and Renewable Energy Site Assessment:

Seneca Rocks Discovery Center, Seneca Rocks, West Virginia

Kosol Kiatreungwattana, James Salasovich, and Alicen Kandt

Prepared under Task No. WFHV1001

NREL is a national laboratory of the U.S. Department of Energy
Office of Energy Efficiency & Renewable Energy
Operated by the Alliance for Sustainable Energy, LLC

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
303-275-3000 • www.nrel.gov

Technical Report
NREL/TP-7A40-65935
March 2016

Contract No. DE-AC36-08GO28308

This report is available at no cost from the National Renewable Energy Laboratory (NREL) at www.nrel.gov/publications.

Available electronically at SciTech Connect http:/www.osti.gov/scitech

Available for a processing fee to U.S. Department of Energy and its contractors, in paper, from:

U.S. Department of Energy
Office of Scientific and Technical Information
P.O. Box 62
Oak Ridge, TN 37831-0062
OSTI http://www.osti.gov
Phone: 865.576.8401
Fax: 865.576.5728
Email: reports@osti.gov

Available for sale to the public, in paper, from:

U.S. Department of Commerce
National Technical Information Service
5301 Shawnee Road
Alexandria, VA 22312
NTIS http://www.ntis.gov
Phone: 800.553.6847 or 703.605.6000
Fax: 703.605.6900
Email: orders@ntis.gov

Cover Photos (top) by Dennis Schroeder: (left to right) NREL 26173, NREL 18302, NREL 19758, NREL 29642, NREL 19795.

NREL prints on paper that contains recycled content.

Preface

As part of ongoing efforts by the U.S. Forest Service to reduce energy use and incorporate renewable energy technologies into its facilities, the Department of Energy's National Renewable Energy Laboratory performed an energy efficiency and renewable energy site assessment of the Seneca Rocks Discovery Center in Seneca Rocks, West Virginia. This report documents the findings of this assessment, and provides site-specific information for the implementation of energy and water conservation measures, and renewable energy measures.

Contacts

United States Forest Service

Kevin Duncan
Visitor Center Director
Seneca Rocks Discovery Center
Phone: 304-567-2827
Email: kduncan@fs.fed.us

Mary Smakula
Facilities Engineer
Monongahela National Forest
Phone: 304-636-1800 x260
Email: msmakula@fs.fed.us

Jacob D'Angelo
Forest Engineer
Monongahela National Forest
Phone: 304-636-1800 x254
Email: jsdangelo@fs.fed.us

National Renewable Energy Laboratory

Alicen Kandt[2]
Project Leader, Engineer V
Phone: 303-384-7518
Email: alicen.kandt@nrel.gov

Kosol Kiatreungwattana[1,2]
Engineer IV
Phone: 303-384-7918
Email: kosol.kiatreungwattana@nrel.gov

Jimmy Salasovich[1,2]
Engineer IV
Phone: 303-384-7383
Email: james.salasovich@nrel.gov

[1] Members of the site assessment team
[2] Report authors to whom any questions should be directed

Acknowledgments

The National Renewable Energy Laboratory team thanks the United States Forest Service (USFS) for the opportunity to perform this energy efficiency and renewable energy assessment at the Seneca Rocks Discovery Center in Seneca Rocks, West Virginia. In particular, the assessment team is grateful to Kevin Duncan, Mary Smakula, and Jacob D'Angelo from the USFS for their generous assistance and cooperation throughout the site assessment.

Abbreviations and Acronyms

AC	alternating current
AHU	air-handling unit
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BAS	building automation system
BF	ballast factor
Btu	British thermal unit
CAV	constant air volume
CFL	compact fluorescent lighting
cfm	cubic feet per minute
CHW	chilled water
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
Cx	commissioning
DC	direct current
DCV	demand control ventilation
DDC	direct digital control
DHW	domestic hot water
DOE	U.S. Department of Energy
EA	excess air
EE	energy efficiency
ECM	energy conservation measure
EISA	Energy Independence and Security Act
EO	executive order
EPAct	Energy Policy Act
EPDM	ethylene propylene diene monomer
ESPC	energy savings performance contract
EUI	energy use intensity
FEMP	Federal Energy Management Program
ft^2	square foot
FY	fiscal year
GHG	greenhouse gas emissions
gpf	gallons per flush
gpm	gallons per minute
HID	high-intensity discharge
hp	horsepower
HVAC	heating, ventilation, and air conditioning
ITC	investment tax credit
kBtu	1,000 British thermal units
kW	kilowatt
kWh	kilowatt-hour
LED	light-emitting diode
LEED	Leadership in Energy and Environmental Design
LPD	lighting power density
M&V	measurement and verification

MMBtu	1,000,000 British thermal units
MAU	makeup air unit
MWh	megawatt-hour
NEMA	National Electrical Manufacturers Association
NREL	National Renewable Energy Laboratory
O&M	operation and maintenance
OA	outdoor air
PLC	programmable logic controller
PV	photovoltaic
ppm	parts per million
RE	renewable energy
REM	renewable energy measure
RH	relative humidity
SHW	solar hot water
SRDC	Seneca Rocks Discovery Center
Ta	ambient temperature
UL	Underwriters Laboratory
USDA	United States Department of Agriculture
USFS	United States Forest Service
VAV	variable air volume
VFD	variable frequency drive
W	watt
WCM	water conservation measure
WE	water efficiency
yr	year

Executive Summary

This report summarizes the results from an energy efficiency, water efficiency, and renewable energy site assessment of the Seneca Rocks Discovery Center (SRDC) and site in Seneca Rocks, West Virginia. A team led by the U.S. Department of Energy's National Renewable Energy Laboratory (NREL) conducted the assessment with USFS personnel on November 3, 2015, as part of ongoing efforts by USFS to reduce energy and water use and implement renewable energy technologies. Staff at the site also participates in USFS's Net Zero Fellow program to identify potential net zero energy sites in its building stock, and this assessment was also in support of that program.

During the site visit, the team identified a total of 14 possible energy conservation measures (ECMs), two water conservation measure (WCMs), and two renewable energy measures (REMs). A bulleted summary of the major findings is given below:

- 14 ECMs investigated
- 2 WCMs investigated
- 2 REMs investigated
- Simple paybacks range from 0.3 years to 87.7 years

A bundled analysis was carried out to determine the economics of all of the measures combined. Not all measures are recommended at this time due to the relatively long payback periods, and these measures are not included in the bundled analysis. The measures that are not recommended are:

- Window Tint
- Low Flow Toilets.

In addition, the ground source heat pump (GSHP) is not included in the bundled analysis because GSHPs cannot be combined with many of the other heating, ventilation, and air conditioning (HVAC) ECMs (e.g., the condensing boiler ECM cannot be combined with the GSHP system). This is not to say that the GSHP is not recommended, it is just not included in the bundled analysis. Furthermore, only the 42 kW ground-mounted PV system is included in the bundled analysis because it is the most financially viable PV option and including both PV system options that were analyzed would have meant the results would be double-counted.

Results from the bundled analysis are summarized below:

- Installed cost = $159,469
- Annual cost savings = $13,270/year
- Simple payback = 12.0 years
- Annual carbon dioxide equivalent (CO_2e) savings = 90.1 metric tons/year.

Individual Measures

Table ES-1 through Table ES-6 summarize the quantified energy savings by the financially viable individual energy and water conservation measures and the renewable energy measures prioritized in order from the shortest simple payback to the longest. The tables provide an annotated list of measures, estimated economics, and the CO_2e emissions savings.

Table ES-1. HVAC Energy Conservation Measures Summary

ECM#	Energy Conservation Measures	Annual Electricity Savings (kWh/yr)	Annual Propane Savings (gallons/yr)	Annual Cost Savings ($)	Installed Costs ($)	Simple Payback Period (yrs)	Annual CO_2e Savings (metric tons/yr)
1.1	Retrocommissioning (RCx) Air Handling Units (AHUs)	2,817	870	$1,855	$1,040	0.6	6.1
1.2	Condensing Boilers	0	655	$1,199	$1,941 [c]	1.6	3.2
1.3	Cogged V-Belts	2,421	(33)	$165	$312	1.9	1.5
1.4	Efficient Air Conditioning	8,750	0	$818	$6,500 [c]	7.9	6.1
1.5	Demand Control Ventilation	(891)	200	$283	$2,400	8.5	0.3
1.6	Energy Recovery Ventilator	(2,484)	549	$772	$7,800	10.1	0.9
1.7	Economizer	3,744	(43)	$271	$3,900	14.4	2.4
1.8	Variable Air Volume System	18,982	(62)	$1,662	$25,896	15.6	12.9
1.9	GSHP	(24,031)	6,391	$9,448	$195,000	20.6	14.2
HVAC	**Totals [a, b]**	**33,339**	**2,137**	**$7,025**	**$45,889**	**6.5**	**33.4**

[a] Total savings do not take into account interactive effects of combining measures.
[b] Total savings do not include GSHP.
[c] This is an incremental cost.

Table ES-2. Lighting Energy Conservation Measures Summary

ECM#	Energy Conservation Measures	Annual Electricity Savings (kWh/yr)	Annual Propane Savings (Gallons/yr)	Annual Cost Savings ($)	Installed Costs ($)	Simple Payback Period (yrs)	Annual CO_2e Savings (metric tons/yr)
2.1	**Daylighting**	**20,966**	**559**	**$938**	**$3,640**	**3.9**	**17.2**
Lights	Totals	20,966	559	$938	$3,640	3.9	17.2

Table ES-3. Plug Loads Energy Conservation Measures Summary

ECM#	Energy Conservation Measures	Annual Electricity Savings (kWh/yr)	Annual Propane Savings (Gallons/yr)	Annual Cost Savings ($)	Installed Costs ($)	Simple Payback Period (yrs)	Annual CO_2e Savings (metric tons/yr)
3.1	Remove Excess Printers	1,365	(2)	$90	$65	0.7	0.9
3.2	Energy Star Refrigerator	905	(2)	$77	$195 [a]	2.5	0.6
Plugs	**Totals**	**2,270**	**(4)**	**$167**	**$260**	**1.6**	**1.6**

[a] This is an incremental cost.

Table ES-4. Envelope Energy Conservation Measures Summary

ECM#	Energy Conservation Measures	Annual Electricity Savings (kWh/yr)	Annual Propane Savings (Gallons/yr)	Annual Cost Savings ($)	Installed Costs ($)	Simple Payback Period (yrs)	Annual CO_2e Savings (metric tons/yr)
4.1	Motorized Window Controls	5,014	0	$466	$3,900	8.4	3.5
4.2	Window Tint [a]	2,747	201	$625	$54,795	87.7	2.9
Envelope	**Totals**	**7,761**	**201**	**$1,091**	**$58,695**	**53.8**	**6.3**

[a] This measure is not recommended at this time.

Table ES-5. Water Conservation Measures Summary

ECM#	Water Conservation Measures	Annual Water Savings (gal/yr)	Annual Propane Savings (Gallons/yr)	Annual Cost Savings ($)	Installed Costs ($)	Simple Payback Period (yrs)	Annual CO_2e Savings (metric tons/yr)
5.1	Install Low-Flow Urinals	4,875	0	$49	$780	15.9	0
5.2	Install Low-Flow Toilets [a]	6,500	0	$65	$5,460	84.0	0
Water	**Totals**	**11,375**	**0**	**$114**	**$6,240**	**54.7**	**0**

[a] This measure is not recommended at this time.

Table ES-6. Renewable Energy Measures Summary

REM#	Renewable Energy Measures	Annual Electricity Savings (kWh/yr)	Annual Propane Savings (Gallons/yr)	Annual Cost Savings ($)	Installed Costs ($)	Simple Payback Period (yrs)	Annual CO_2e Savings (metric tons/yr)
6.1	42 kW PV	49,731	0	$4,625	$88,200	19.1	34.5
6.2	Combination 26 kW Roof and 16 kW Ground PV	49,429	0	$4,597	$97,300	21.2	34.3
RE	**Totals [a]**	**49,731**	**0**	**$4,625**	**$88,200**	**19.1**	**34.5**

[a] The total only includes REM #6.1

Commissioning

The assessment team strongly recommends that any recommended measures from this report are commissioned when implemented. Commissioning (Cx) is a quality control process that can be integrated with the installation of new systems. Cx ensures optimal equipment and energy efficiency performance. When energy efficiency measures are not commissioned by an expert experienced in the recommended systems (and advanced control strategies), the anticipated energy savings may not be achieved.

For this reason, the assessment team has included funding for Cx in all of the cost and payback data presented in this report. The assessment team recommends that any hired Cx agent be responsible for reviewing retrofit design documents, completing and signing installation checklists, and witnessing startup and functional testing, at a minimum.

Measurement and Verification

It is also recommended that a measurement and verification (M&V) plan be implemented in conjunction with any major retrofit effort. The M&V plan should follow International Performance and Measurement Verification Protocol (IMPVP) and provide ongoing energy use information to building operators. This information will serve as a diagnostic tool to ensure the durability of energy savings. The M&V plan should not simply provide a one-year check on the retrofit's impact, but should provide continuous feedback on energy consumption by end use.

A cost for M&V is not provided in this report, but it is anticipated that the effort would add less than 0.5 years to the payback period of the bundled implementation effort.

Sustainable Operation Options

Other sustainable operation options include sustainable purchasing, minimizing waste, recycling programs, composting programs, transportation efficiency programs, and energy awareness campaigns.

Table of Contents

List of Tables

List of Figures

1 Background

The United States Forest Service (USFS), acting in compliance with Executive Order 13693, is pursuing the implementation of energy conservation measures (ECM), water conservation measures (WCM), and renewable energy measures (REM). Further, three sites—the Mendenhall Glacier Visitor Center in Juneau, AK, the Tiller Ranger District in Roseberg, OR, and the Seneca Rocks Discovery Center (SRDC) in Seneca Rocks, WV—are evaluating site energy and water consumption and renewable energy technologies. Along with the pursuit of energy goals within the EO 13693, the USFS is strongly considering pursuing Net Zero Energy (NZE) and Leadership in Energy and Environmental Design (LEED) status at these sites to showcase their commitment to sustainability and environmental stewardship. The inclusion of the investigated ECM, WCM, and REMs would move the SRDC closer to obtaining these goals, accruing LEED points, and being labelled a high performance and sustainable building (HPSB). These audits were conducted in support of USFS's Net Zero Network program.

The U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL) is solely dedicated to advancing energy efficiency (EE) and renewable energy (RE) technologies and applications. Since its inception, NREL has supported both the federal and the private sectors in implementing EE, water efficiency (WE), RE systems and strategies to lower energy use, and to meet remaining energy needs with resources that have minimal environmental impact. NREL assistance was requested to identify and assess the feasibility of incorporating sustainable opportunities within the SRDC, including:

- Optimizing the energy performance of the building
- Assessing the potential for water efficiency measures and improvements in the overall environmental quality of the building interior
- Using on-site renewable energy technologies.

1.1 Project Background and Intent

USFS chose to conduct this assessment as a means of identifying energy and water conservation measures and renewable energy options. The no-cost/low-cost operational modifications that NREL has identified should be the first items to be implemented. The cost savings associated with these measures can then be redirected to implement the more capital-intensive projects, which will result in further energy and water savings. Conservation measures implemented from performance contractors should be sub-metered and evaluated based on measured savings. Through active participation by the site to implement the projects, USFS will be closer to meeting and exceeding the goals set forth in the applicable legislation. Applicable legislation includes, but is not limited to, EPAct 2005, Energy Independence and Security Act (EISA) (2007), EO 13693 (2015), and other mandates.

1.1.1 Energy Policy Act of 2005

- [§103] federal buildings must be metered by October 1, 2012, with data provided at least daily and electricity consumption measured hourly (requires an implementation plan and personnel responsible).

- [§104] federal agencies shall incorporate energy efficiency criteria consistent with ENERGY STAR and Federal Energy Management Program (FEMP)-designated products for all procurements involving energy-consuming products and services.
- [§203] renewable energy is not less than:
  - 2.5% of total consumption during fiscal year (FY) 2006
  - 3% of total consumption during FY 2007-2009
  - 5% of total consumption during FY 2010-2012
  - 7.5% of total consumption during FY 2013 and thereafter.

  Note: Accounting of renewable energy can be doubled if on federal or Indian land and used at a federal facility.

1.1.2 Energy Independence and Security Act 2007

- [§431] reduce building energy intensity 3% annually through 2015, or 30% total reduction by 2015, relative to a 2003 baseline.
- [§432] energy and water evaluations must be completed every four years for covered facilities. Facility energy managers are also responsible for commissioning equipment and establishing operation and maintenance (O&M) plans for measuring, verifying, and reporting energy and water savings.
- [§434] ensure major replacements of installed equipment, renovation, or expansion of existing space employ the most energy-efficient designs, systems, equipment, and controls if life cycle cost-effective.
- [§434(b)] by October 16, 2016, each agency shall provide for equivalent metering of natural gas and steam.
- [§523] 30% of hot water demand in new federal buildings and major renovations must be met with solar hot water if life cycle cost-effective.
- [§524] encourages agencies to minimize standby energy use in purchases of energy-using equipment.
- [§525] requires procurement to focus on ENERGY STAR and FEMP-designated products.
- [§527] each federal agency must issue an annual report that describes the status of initiatives to improve energy efficiency, reduce energy costs, and reduce greenhouse gas (GHG) emissions.

1.1.3 Executive Order 13693

- [§3(a)(i)] reducing agency building energy intensity measured in British thermal units per gross square foot by 2.5 percent annually through the end of fiscal year 2025, relative to the baseline of the agency's building energy use in fiscal year 2015.
- [§3(b)(v)] ensure that at a minimum, not less than 25 percent of the total amount of building electric energy and thermal energy shall be clean energy, accounted for by renewable electric energy and alternative energy by fiscal year 2025.

- [§3(f)(i)] reducing agency potable water consumption intensity measured in gallons per gross square foot by 36 percent by fiscal year 2025 through reductions of 2 percent annually through fiscal year 2025 relative to a baseline of the agency's water consumption in fiscal year 2007.
- [§3(g)(ii)(C)] if the agency operates a fleet of at least 20 motor vehicles, improve agency fleet and vehicle efficiency and management by taking actions that reduce fleet-wide per-mile greenhouse gas emissions from agency fleet vehicles, relative to a baseline of emissions in fiscal year 2014, to achieve reductions not less than 30 percent by the end of fiscal year 2025.
- [§3(h)(i)] ensuring, beginning in fiscal year 2020 and thereafter, that all new construction of Federal buildings greater than 5,000 gross square feet that enters the planning process is designed to achieve energy net-zero and, where feasible, water or waste net-zero by fiscal year 2030.
- [§3(h)(iii)] identifying, as part of the planning requirements of section 14 of this order, a percentage of the agency's existing buildings above 5,000 gross square feet intended to be energy, waste, or water net-zero buildings by fiscal year 2025 and implementing actions that will allow those buildings to meet that target.
- [§3(j)(ii)] advance waste prevention and pollution prevention by diverting at least 50 percent of non-hazardous solid waste, including food and compostable material and pursuing opportunities for net-zero waste or additional diversion opportunities.

1.1.4 Other Mandates

- [EPAct 1992 §152] install in federal buildings owned by the United States all energy and water conservation measures with payback periods of less than 10 years.
- [EPA Mandatory Greenhouse Gas Reporting Rule] facilities and suppliers of fossil fuels or industrial GHGs that emit more than 25,000 metric tons of carbon dioxide equivalent (CO_2e) per year must report their emissions by March 31, 2011, for 2010 emissions. Reports submitted annually thereafter.

2 Seneca Rocks Discovery Center

2.1 Introduction

This report summarizes the results from the EE, WE, and RE site assessment of the SRDC in Seneca Rocks, WV. A team led by NREL conducted the assessment on November 3, 2015. During the site visit, the team identified a total of 14 possible ECMs, 2 WCMs, and 1 REM.

2.2 Site Overview

The SRDC is located in the Monongahela National Forest at 13 Roy Gap Road in Seneca Rocks, WV. The site visitor center is located at the base of the prominent Seneca Rocks rock formation. The SRDC is 9,835 square feet (ft^2) and houses educational exhibits, an auditorium, an observational deck, a gift shop, a classroom, and office spaces for the full-time and temporary employees. The site hosts approximately 80,000 visitors every year. The SRDC has historically been open from April 1 through October 15, and it will remain open through October 31 in the upcoming years. The trails and parking facilities remain open year round.

The SRDC was originally built in 1998 and has one level above grade and a basement that houses the mechanical equipment. The building is a steel framed structure with a rock and mortar façade and a standing seam metal roof. Figure 1 shows an aerial view of the SRDC taken in Google Earth and Figure 2 shows photos of the SRDC.

Figure 1. Seneca Rocks Discovery Center (aerial view).
Source: Google Earth

Figure 2. Seneca Rocks Discovery Center.
Photo by Jimmy Salasovich, NREL

2.3 Climate Data

The SRDC is located in Seneca Rocks, West Virginia. The SRDC is at an elevation of approximately 1,560 feet above sea level and latitude and longitude of 38.83° N, 79.38° W, respectively. The climate in Seneca Rocks is a humid continental climate. The winters are cold and the summers are warm and humid. Table 1 gives a historic weather summary for Seneca Rocks.

Table 1. Seneca Rocks, West Virginia, Historic Weather Summary

Average Temperature												
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
F	47	25	28	35	47	56	63	67	66	60	50	40	30
Average High Temperature													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
F	58	35	38	46	57	67	74	77	77	71	61	50	40
Average Low Temperature													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
F	37	16	18	25	36	45	53	57	56	49	39	30	21
Highest Recorded Temperature													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
F	97	67	70	78	84	86	95	97	93	90	92	78	71
Lowest Recorded Temperature													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
F	-25	-25	-15	-7	7	18	27	35	34	24	10	-6	-22
Average Precipitation													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
inches	40.4	2.9	2.9	3.7	3.5	3.8	3.9	3.7	3.4	3.2	3.2	3.1	3.0
Average Number of Rainy Days													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Days	143	13	13	14	13	12	11	12	11	9	10	12	13
Most Rain Reported in a Month													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
in.	58.9	6.4	6.8	7.1	7.1	7.8	7.5	6.6	7.8	8.8	9.2	13.7	6.7
Least Recorded Rainfall													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
inches	29.5	0.8	0.6	1.4	1	0.8	1.7	1.3	0.4	0.3	0.4	1.1	0.6
Average Snowfall													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
inches	105.1	24.5	24.5	21	7.6	0.3	---	---	--	---	1.3	8.1	17.8
Average Morning Relative Humidity													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
%	87	81	81	82	83	87	92	94	96	95	90	83	82
Average Evening Relative Humidity													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
%	59	64	60	55	51	54	59	62	62	61	54	58	64
Heating Degree Days													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Days	6669	1231	1039	877	552	303	120	43	56	175	468	729	1076
Cooling Degree Days													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Days	329	---	---	---	---	21	66	108	94	31	9	---	---
Growing Degree Days													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Days	1917.2	---	---	---	---	186	396	527	502.2	306	---	---	---
Average Daily Global Solar Radiation													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
kWh/m^2	3.7	1.8	2.5	3.4	4.5	5.0	5.7	5.6	4.9	4.2	3.2	2.0	1.6
Average Wind Speed													
	ANNUAL	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
mph	9	11	11	11	11	9	8	7	7	7	8	10	11

Source: Weatherbase. Accessed November, 2015: http://www.weatherbase.com.

2.4 Utility Data

The electricity provider at the SRDC is Monongahela Power Company. Propane is purchased and stored on-site for use in the SRDC's hot water boilers and hot water heater. The propane provider is SS Petersburg Co-Op. A local well provides water to the site, and costs for water have not been estimated. The average annual utility consumption and costs are summarized in Table 2.

Table 2. Annual Electricity, Propane, and Water Use at the SRDC

		Latest Available 12 Months of Data – 2014 to 2015
Electricity 2014 & 2015	**Annual Use** *(kWh/year)*	111,320
	Blended Rate *($/kWh)*	$0.091
	Annual Cost *($/year)*	$10,167
	Percent of Total Cost *(%)*	42.5%
Propane 2014	**Annual Use** *(gallons/year)*	7,506
	Rate *($/gallon)*	$1.83
	Annual Cost *($/year)*	$13,743
	Percent of Total Cost *(%)*	57.5%
Water 2015	**Annual Use** *(gallons/year)*	95,400
	Rate *($/gallon)*	N/A
	Annual Cost *($/year)*	N/A
	Percent of Total Cost *(%)*	N/A
Total	**Annual Cost** *($)*	$23,910

The total electricity cost for the SRDC site makes up 42.5% of the total annual utility costs. Propane makes up the remaining 57.5% of the total annual utility cost. Figure 3 shows the average utility cost breakdown at the SRDC site for the latest year of available data, which is 2014–2015.

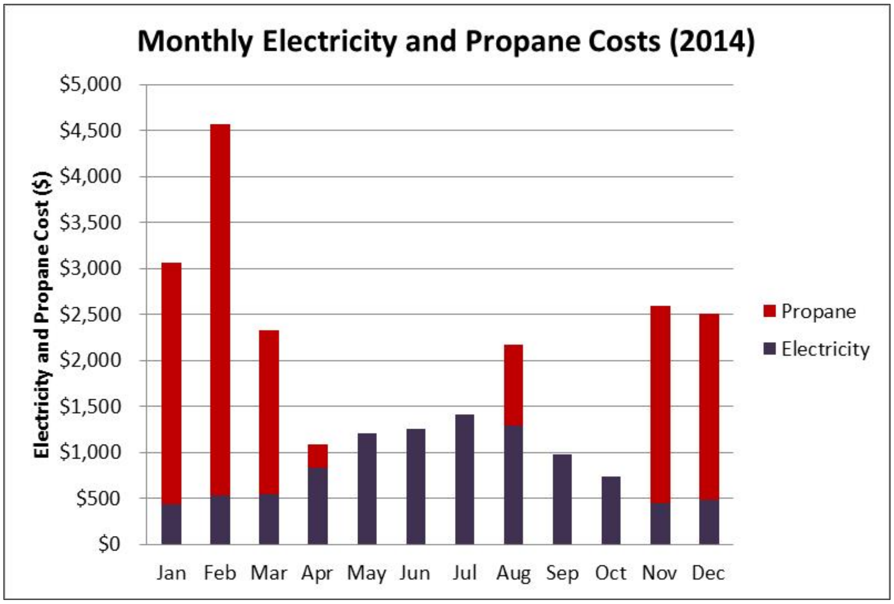

Figure 3. SRDC site utility cost breakdown for 2014.

The monthly electricity consumption for the SRDC site for 2013 through August 2015 is given in Figure 4. As shown, the electricity consumption is higher in summer and during the peak of tourist season and tapers off in the winter.

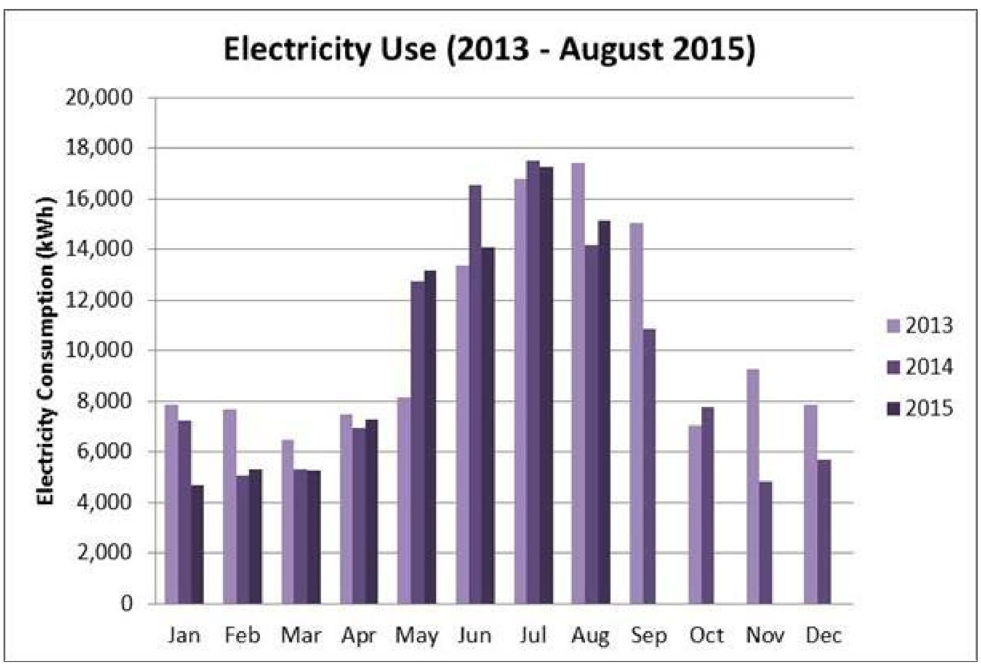

Figure 4. SRDC site monthly electricity consumption for 2013 to August 2015.

The monthly propane delivery for the SRDC site for 2013–2014 is given in Figure 5. Propane deliveries can be correlated to how much propane is being used each month. As shown, the propane use is highest in the winter months when the site is using propane for space heating and domestic hot water. The propane use during the summer months is attributed to domestic hot water use. Note that even though there are no propane deliveries in May, June, September, and October, propane is being used for domestic hot water; however, the amount used is small enough that it does not warrant a propane delivery.

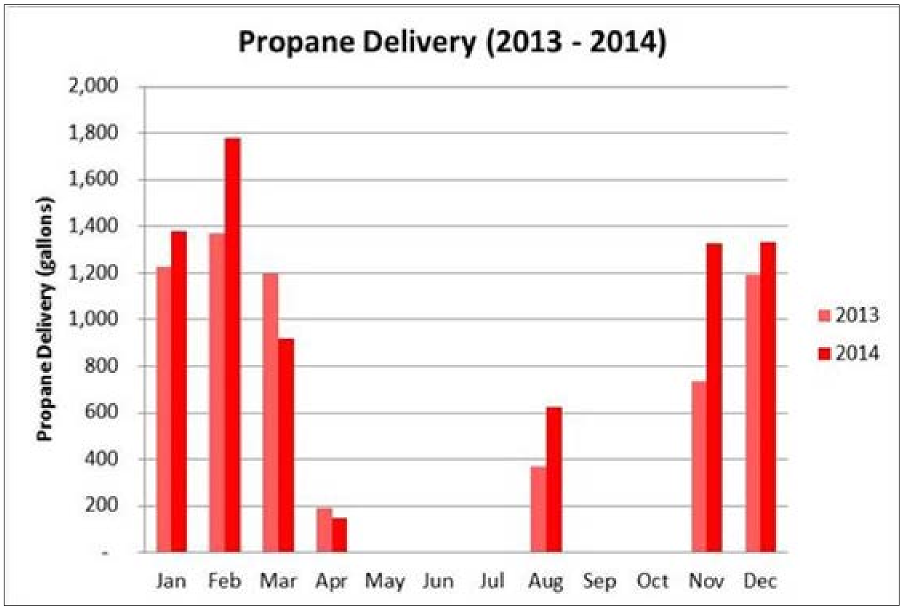

Figure 5. SRDC monthly propane deliveries for 2013–2014.

Figure 6 shows the monthly water consumption at the SRDC. Water usage is primarily due to guests utilizing the restroom facilities. Water use data were only provided for March through September 2015, and the remaining months are estimated based on whether the building is open to the public or not. (e.g., the SRDC is not open to the public in March and therefore this month's water use was used for January, February, November, and December).

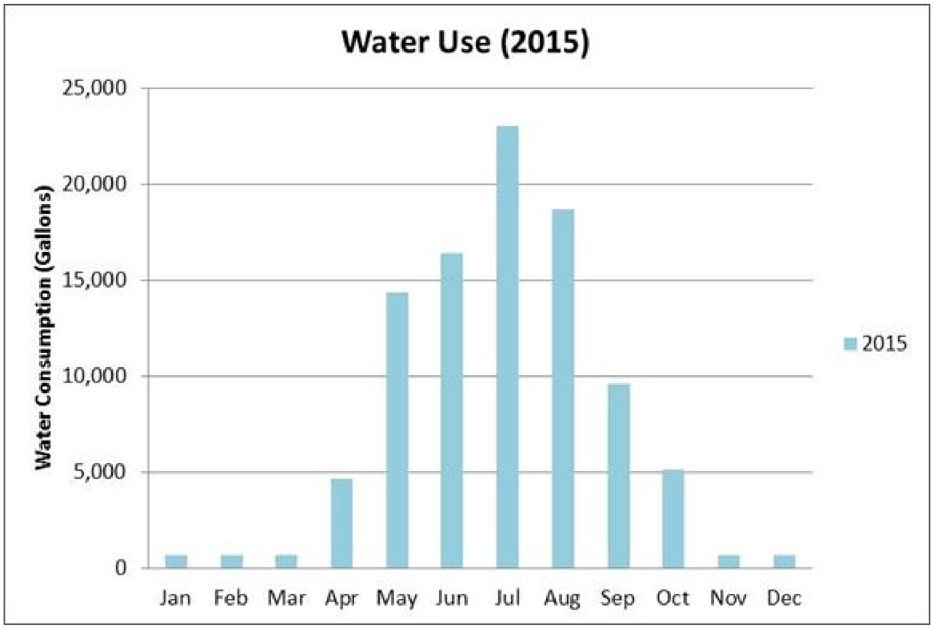

Figure 6. SRDC site monthly water consumption for 2015.

2.5 Building Description

A description of the SRDC building is given below and includes occupancy, envelope, HVAC, cooling plant, heating plant, domestic hot water, building automation, lighting, plug loads, and a list of current best practices at the site.

2.5.1 Occupancy

The SRDC has two distinct seasons: March 1 through October 31 (starting in 2016), the season when the SRDC is open to the public, and November 1 to February 28, the season when the SRDC is not open to the public. The SRDC peak operating hours are between 7:00 a.m. and 7:00 p.m., seven days a week and the off peak operating hours are from 7:00 a.m. to 7:00 p.m., Monday through Friday. There are two full-time employees at the site year round and addition employees are at the site during the peak months.

2.5.2 Heating, Ventilation, and Air Conditioning Systems

The SRDC building is served by three air handling units (AHU) located in the basement mechanical room. All of the AHUs are constant air volume (CAV) units. AHU 1 serves the exhibit hall, AHU 2 serves the auditorium and the area between the classrooms and exhibit hall, and AHU 3 serves the classroom and offices. All AHUs have high-efficiency motors, constant speed fans, standard v-belts, and time clocks. Filters are on a regular maintenance schedule, and the filters were in good condition at the time of the assessment. No carbon dioxide (CO_2) sensors are installed for demand control ventilation. There are perimeter fin tube radiators in the classroom, auditorium, and restrooms.

2.5.3 Cooling Plant

The SRDC is served by three standard efficiency Trane packaged air-conditioning units, located outside on the southwest side of the building. The units were installed when the building was built in 1998 and are approaching the end of their useful life. Air-conditioner 1 serves the exhibit hall and has a 10-ton capacity and an energy efficiency ratio (EER) of 9.9. Air-conditioner 2 serves the auditorium and the space between the classrooms and exhibit hall and has a 5-ton capacity and an efficiency of 9.6 EER. Air-conditioner 3 serves the classroom and offices and has a 10-ton capacity and an EER of 9.9.

2.5.4 Heating Plant

The SRDC is heated by one Lochinvar propane-fired low pressure boiler located in the basement mechanical space. The boiler was installed when the building was built in 1998 and is approaching the end of its useful life. The boiler output is 630,000 British thermal unit (Btu) per hour (hr) and the boiler efficiency is 84%. The boiler serves the AHUs and the fin tube radiators.

2.5.5 Domestic Hot Water

Domestic hot water in the SRDC is provided by a 48-gallon Rheem propane-fired hot water heater with a thermal efficiency of 80%. Domestic hot water is mainly used for hand washing and light kitchen use in the employee breakroom.

2.5.6 Building Automation System

The SRDC has Trane controls at each of the AHUs that are used to schedule operation and temperature set points. The controls are fairly antiquated and require an HVAC technician to do a majority of the reprogramming while on site. The exterior lighting is on an astronomical timeclock.

2.5.7 Lighting

A majority of the light levels at the SRDC are appropriate for the given space uses. A majority of the lighting at the SRDC has been converted to light-emitting diode (LED) lighting and includes linear T-8 LED lighting in the classroom, LED track lighting in the auditorium space, and LED parking lot lighting. There is an issue with the LED track lighting so that some LED lamps do not turn on or they flicker. This may be related to compatibility issues between the MR-16 LED lamps and the existing track lighting transformer and driver. Lighting occupancy sensors are installed in the exhibit hall, classroom, auditorium, restrooms, janitorial closet, and storage area. The building has LED exit signs throughout.

2.5.8 Plug Loads

The plug loads in the SRDC consist mainly of office equipment that includes laptop computers with docking stations, desktop computers, LCD monitors, multi-function printers, fax machine, secondary printers, visual and audio displays, and LCD televisions. The breakroom contains a standard coffee maker, refrigerator, and microwave.

2.5.9 Building Envelope

The exterior of the SRDC is rock and mortar façade with framed walls and R-20 insulation. The roof is a standing seam metal roof with R-30 insulation. Windows are double pane clear glass.

2.5.10 Current Best Practices and Observations

Numerous ECMs, WCMs, and best practices have been implemented as part of various renovation projects. The following is a list of current energy efficiency projects and practices that were identified:

General

- Knowledgeable and enthusiastic staff
- Staff takes recyclables to Elkins for recycling
- Signage for energy and water awareness.

HVAC

- High efficiency hot water pumps
- The humidifiers' AHUs are disabled
- Scheduled air filter replacements on AHUs
- Hot water pipe insulation
- Domestic hot water set to 120°F (not over heated).

Lighting

- Installed linear T-8 LEDs, MR-16 LEDs, and LED parking lot lighting
- Appropriate lighting levels in most spaces
- Lighting occupancy sensors in exhibit hall, classroom, auditorium, restrooms, janitorial closet, and storage area
- Culture of turning lights off (good occupant awareness)
- Astronomical timeclocks for exterior lighting
- Good daylighting in exhibit hall and classroom
- LED exit signs.

Plug Loads

- Minimal extraneous plug loads
- Vending machines are not powered during the off season
- Vending machines are delamped.

Envelope

- Local building materials
- Double pane windows
- Operable windows for natural ventilation
- R-30 roof insulation
- R-21 wall insulation
- Standing seam metal roof for simplifying PV installation.

Water

- No irrigation.

2.6 Building Energy Modeling

Building energy modeling was used to determine the energy use characteristics of the building and to calculate energy and energy cost savings from various ECMs. eQUEST was selected as the building simulation software tool to perform the energy modeling of this site. eQUEST is a commercially available interface for the DOE-2 hourly building energy simulation program originally developed by DOE. The program is capable of evaluating energy and energy cost savings that can be achieved by applying ECMs such as improved envelope components, lighting and plug load system improvements, and HVAC system improvements. The software is commonly used to analyze new construction buildings and building retrofits. eQUEST requires a detailed description of the building envelope, internal loads, operating schedules, lighting, plug load, HVAC system requirements, and utility rate schedules. The major benefits of eQUEST include the ease of defining building geometry, space characteristics, schedules, HVAC systems, and running parametric analyses to study design and retrofit options. Another major benefit of eQUEST is the relatively short simulation run times.

An eQUEST energy model of the SRDC was created. The existing operating condition of HVAC, lighting, and plug loads systems was modeled including current operating schedules and equipment operational characteristics determined from discussion with the facilities team.

A graphical representation of the building energy model developed in eQUEST is shown in Figure 7. The geometry of the buildings was simplified for modeling purposes to accurately simulate energy transfer through all surfaces in the building.

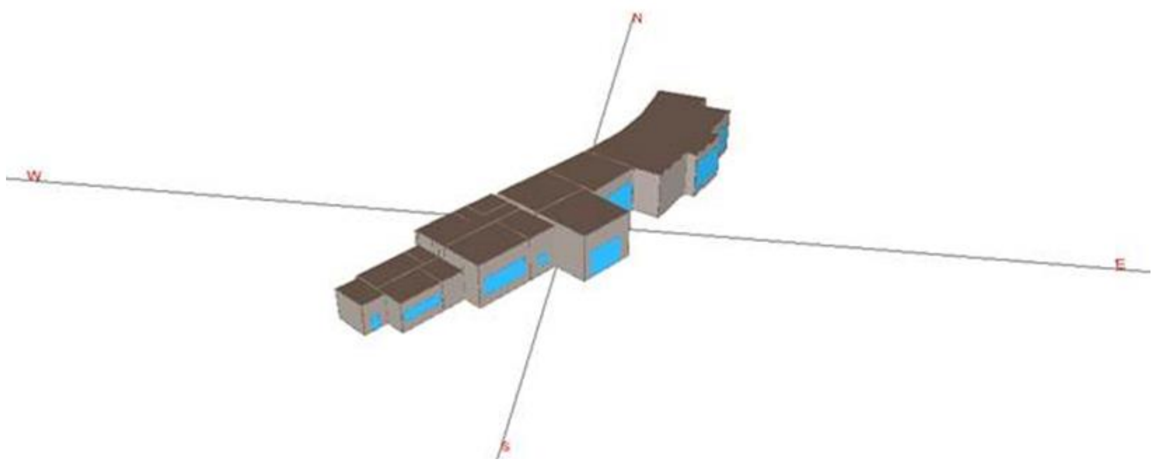

Figure 7. SRDC eQUEST model representation.
Source: Image generated using eQUEST

The NREL team used the data gathered during the assessment to develop the eQUEST model. The general facility characteristics that were modeled are provided in Table 3.

Table 3. SRDC eQUEST Summary Information

Seneca Rocks Discovery Center—Seneca Rocks, West Virginia		
Project	Weather Data	Elkins, WV (geographically closest weather file)
	Building Types	Visitors Center
	Total Number of Buildings Modeled	1
	Building Areas	9,835 ft^2
	Above-Grade Floors	1
	Below-Grade Floors	1
Building Footprint	Building Orientation	Plan North
	Zoning Pattern	AHU zoning
	Roof Pitch	Modeled at 0˚ in order to simplify the energy model
Roof	Construction	Steel frame with R-30 insulation
	Roof	Standing seam metal roof
Walls	Construction	Steel framed with mass walls and R-20 insulation
	Finish	Rock and mortar
Ground Floor	Over Basement	8" concrete
Below-Grade Walls	Construction	8" concrete
Floors	Interior Finish	Wood
	Construction	Concrete
Exterior Doors	Door Type	Glass
Exterior Windows	Window Type	Double pane clear with aluminum frames
Power Density	Lighting	0.7 to 1.6 W/ft^2
	Plug Loads	0.1 to 0.75 W/ft^2
HVAC Systems	System Type	Constant Air Volume (CAV) system
	System Cooling Source	SEER 9.6 to 9.9 air-conditioning units
	System Heating Source	Hot water coils
Fan Schedules	Operation Schedule	7:00 a.m. to 7:00 p.m. - On season
Primary Cooling Equipment	Cooling Type	1 x 5-ton air-conditioning units SEER 9.6 2 x 10-ton air-conditioning units SEER 9.9
	Chilled Water Pumping	Constant-speed pumping
Primary Heating Equipment	Heating Type	1 x 0.630 MMBtu propane boiler
	Hot Water Pumping	Constant-speed pumping

The baseline energy model for the SRDC was calibrated to within approximately 3.0% of the annual energy use from the existing electricity and within 7.3% of the Propane use utility data for the past three years. Figure 9 presents the eQUEST output for the calibrated baseline energy model for the SRDC.

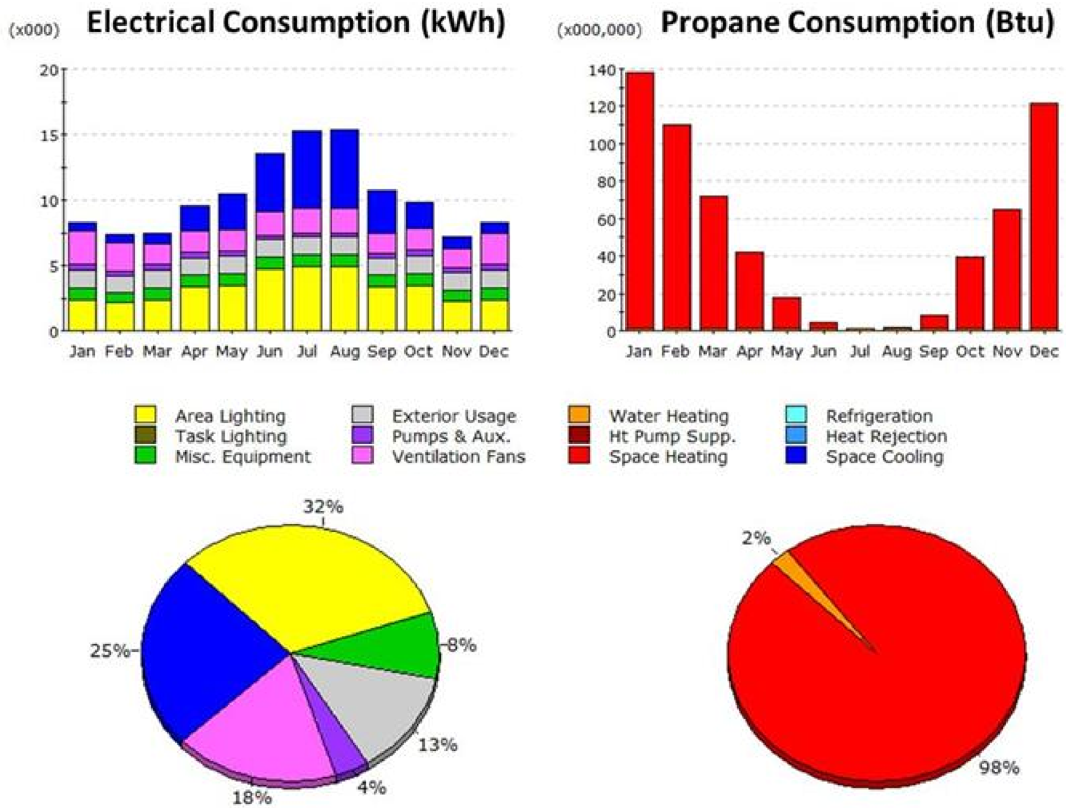

Figure 8. SRDC eQUEST calibrated baseline results for annual energy use.
Source: Figures generated using eQUEST

2.7 Energy Conservation, Water Conservation, and Renewable Energy Measures

The following sections contain the HVAC, lighting, plug loads, envelope, WCMs, and REMs that were analyzed. The CO_2e emissions are also given, derived from the electricity generation by the local utility. The CO_2e emissions rate for electricity is 0.000693 metric tons/kWh consumed, and the emissions rate for propane is 0.00482 metric tons/gallon of propane.

2.7.1 Heating, Ventilation, and Air Conditioning Measures

The following sections contain the HVAC ECMs that were analyzed.

2.7.1.1 Retro-Commission Air-Handling Units

Current Condition: Currently the SRDC has controls at each AHU that can be used to schedule the AHU and to program the temperature set points. The HVAC controls have to be programmed by a technician. Figure 9 shows the current controls for AHU #2.

Figure 9. Controls on the AHU.

Investigated Action: Hire a technician to retro-commission the AHUs with temperature set back and set up schedules.

Table 4 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for installing a building automation system (BAS). Calculation assumptions are also given below.

Table 4. Energy and Cost Savings Retro-Commissioning AHUs

Energy and Cost Savings	
Electricity Savings (kWh/yr)	2,817
Propane Savings (gallons/yr)	870
Cost Savings ($/yr)	$1,855
Implementation Costs ($)	$1,040
Simple Payback (yrs)	0.6
CO_2e Savings (metric tons/yr)	6.2

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings of reprogramming the HVAC controls
- The cost is assumed to be $100/hr for 8 hours of labor, which include travel time
- A 30% contingency was added to the implementation cost.

2.7.1.2 Condensing Boiler

Current Condition: The SRDC is heated by one Lochinvar propane-fired low-pressure boiler located in the basement mechanical space. The boiler was installed when the building was built in 1998 and is approaching the end of its useful life. The boiler output is 630,000 Btu/hr and the boiler efficiency is 84%. The boiler serves the AHUs and the fin tube radiators.

Investigated Action: When the boiler is ready to be replaced, specify a condensing boiler with an efficiency of 93% and a low-fire setting. Table 5 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for implementing this measure. Calculation assumptions are also given below.

Table 5. Energy and Cost Savings from Hot Water Condensing Boiler

Energy and Cost Savings	
Electricity Savings (kWh/yr)	0
Propane Savings (gallons/yr)	655
Cost Savings ($/yr)	$1,199
Implementation Costs ($)	$1,941*
Simple Payback (yrs)	1.6
CO_2e Savings (metric tons/yr)	3.2

*Only incremental costs considered

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings from implementing the measure.
- The existing boiler is 84% efficient.
- The existing boiler would be replaced with a hot water condensing boiler that is 93% efficient.
- The boiler is replaced at the end of life and only incremental costs are considered.
- There is an 11% cost premium for condensing boilers.[1]
- A standard dual fuel boiler costs $13,570[2] and the total cost premium for a condensing boiler is $1,493.
- A 30% contingency was added to the overall cost.

---

[1] www.gsa.gov/portal/content/163495.

[2] RSMeans Facility Construction Cost Data 2013.

2.7.1.3 Cogged V-Belts

Current Condition: The assessment team observed standard v-belts on all the HVAC fan drives of three air-handling units that each have supply and return fans and asynchronous induction motors. The motors are currently operated for an estimated runtime of 8,760 hr/yr.

Investigated Action: Replace all the standard v-belts with cogged v-belts. Cogged v-belts have slots that run perpendicular to the belt's length, which reduce the bending resistance of the belt.

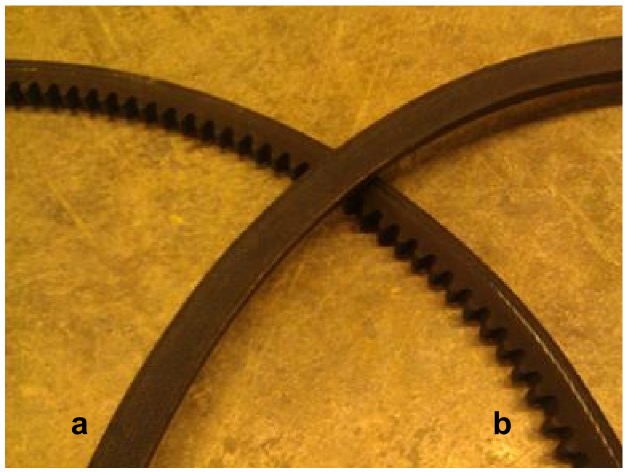

Figure 10. Standard v-belt (a) and cogged v-belt (b).
Photo by Caleb Rockenbaugh, NREL

Cogged v-belts can be used with the same pulleys as equivalent rated v-belts. They have less slip, run cooler, last longer, and have an efficiency that is on the order of 2%–3% higher than standard v-belts. The belts associated with the largest motors and the motors that are run closest to full load should be given priority when making replacements. Table 6 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for installing cogged v-belts. Calculation assumptions are also given below.

Table 6. Energy and Cost Savings Summary for Cogged V-Belts

Energy and Cost Savings	
Electricity Savings (kWh/yr)	2,421
Propane Savings (gallons/yr)	(32.5)
Cost Savings ($/yr)	$165
Implementation Costs ($)	$312
Simple Payback (yrs)	1.9
CO_2e Savings (metric tons/yr)	1.5

Assumptions:

- Energy savings were calculated using the eQUEST energy model.
- Savings are calculated using a 3% efficiency improvement from the cogged v-belt.

- Labor costs were estimated at \$50/hr × 0.5 hr/motor for 6 motors (3 supply fans and 3 return fans).
- Belt costs were estimated at \$15/belt.
- A 30% contingency was added to the implementation cost.

2.7.1.4 High Efficiency Air-Conditioning Units

Current Condition: The SRDC is served by 3 standard efficiency Trane packaged air-conditioning units. The units were installed when the building was built in 1998 and are approaching the end of their useful life. Air-conditioner 1 serves the exhibit hall, is 10 tons, and has an efficiency of 9.9 EER. Air-conditioner 2 serves the auditorium and the space between the classrooms and exhibit hall, is 5 tons, and has an efficiency of 9.6 EER. Air-conditioner 3 serves the classroom and offices, is 10 tons, and has an efficiency of 9.9 EER.

Investigated Action: Incrementally replace the standard efficiency air-conditioning units with the highest available efficiency units at the end of their useful lives. Air-conditioning units with a cooling efficiency of 14 EER are recommended. Table 5 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for implementing this measure. Calculation assumptions are also given below.

Table 7. Energy and Cost Savings from High Efficiency Air-Conditioning Units

Energy and Cost Savings	
Electricity Savings (kWh/yr)	8,750
Propane Savings (gallons/yr)	0
Cost Savings (\$/yr)	\$818
Implementation Costs (\$)	\$6,500*
Simple Payback (yrs)	7.9
CO_2e Savings (metric tons/yr)	6.1

*Only incremental costs considered

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings from implementing the measure.
- The existing air conditioning units have an EER of 9.6 to 9.9.
- The existing air-conditioning units are incrementally replaced with EER 14 units.
- The air-conditioning units are replaced at the end of life and therefore only incremental costs are considered.
- The incremental cost for a 5-ton air-conditioning unit with an EER of 14 is assumed to be \$1,500.
- The incremental cost for a 10-ton air-conditioning unit with an EER of 14 is assumed to be \$2,000.

- A 30% contingency was added to the overall cost.

2.7.1.5 Demand Control Ventilation in Auditorium

Current Condition: The SRDC does not have a demand-control ventilation (DCV) system with CO_2 sensors in the return-air ductwork. Currently, the outside air is introduced and conditioned at a fixed rate based on the maximum design occupancy in order to satisfy the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) Standard 62.1, which recommends 15-20 cubic feet per minute (cfm) per person, depending on the space type. Building occupancy in the auditorium fluctuates and is often less than the maximum design occupancy. As a result, the auditorium is effectively being over-ventilated and consumes more energy than necessary. This is particularly true of spaces where the occupancy levels vary such as in auditoriums, conference rooms, and training rooms. The building CO_2 level is closely related to the occupancy levels. The typical outside CO_2 level is relatively low concentration—around 400–500 ppm—and is used to dilute the higher indoor CO_2 levels.

Investigated Action: Install a DCV system in the auditorium using CO_2 sensors in the return-air ductwork to measure and control the amount of outside air that is used to ventilate the building. This will allow the building to satisfy ASHAE 62.1 ventilation standards without over-ventilation. Outside air regulation will be based on the actual occupancy rather than the maximum design occupancy, reducing the energy demand of the fans and heating/cooling coils used to transport and condition the air throughout the building. Table 8 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for converting the CAV system to a VAV system. Calculation assumptions are also given below.

Table 8. Energy and Cost Savings from Installing DCV in the Auditorium

Energy and Cost Savings	
Electricity Savings (kWh/yr)	(891)
Propane Savings (gallons/yr)	200
Cost Savings ($/yr)	$283
Implementation Costs ($)	$2,400
Simple Payback (years)	8.4
CO_2e Savings (metric tons/yr)	0.3

Assumptions:

- The eQUEST energy model was used to estimate the savings from installing CO_2 sensors in the return-air ducts for DCV.
- Equipment and programming costs were estimated assuming one CO_2 sensor would be installed in the return-air ducts of the auditorium AHU at a cost of $1,000.
- Labor costs were estimated at 20 hours per sensor x $50/hr, which totals $1,000.
- A 30% contingency was added to the overall cost.

2.7.1.6 Energy Recovery Ventilator

Current Condition: The SRDC does not have energy recovery ventilators (ERV) on the AHUs to capture the energy of the air that is being exhausted from the building.

Investigated Action: Install ERVs on the exhaust of the AHUs at the SRDC. Table 9 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for installing an ERV. Calculation assumptions are also given below.

Table 9. Energy and Cost Savings from Installing ERVs

Energy and Cost Savings	
Electricity Savings (kWh/yr)	(2,484)
Propane Savings (gallons/yr)	549
Cost Savings ($/yr)	$772
Implementation Costs ($)	$7,800
Simple Payback (years)	10.1
CO_2e Savings (metric tons/yr)	0.9

Assumptions:

- The eQUEST energy model was used to estimate the savings from installing ERVs.
- Assume one ERV is required for each AHU.
- Assume an installed cost of $2,000 per ERV.
- A 30% contingency was added to the overall cost.

2.7.1.7 Air-Side Economizer

Current Condition: The SRDC does not have air-side economizers on the AHUs that provide cool unconditioned outside air to the AHUs when the outside conditions allow.

Investigated Action: Install air-side economizers on the AHUs at SRDC. Table 10 provides the calculated energy and cost savings, simple payback, and CO_2 emissions savings for installing air-side economizers. Calculation assumptions are also given below.

Table 10. Energy and Cost Savings from Installing Air-Side Economizers

Energy and Cost Savings	
Electricity Savings (kWh/yr)	3,744
Propane Savings (gallons/yr)	(43)
Cost Savings ($/yr)	$271
Implementation Costs ($)	$3,900
Simple Payback (years)	14.4
CO_2e Savings (metric tons/yr)	2.4

Assumptions:

- The eQUEST energy model was used to estimate the savings from installing air-side economizers.
- Assume the installed cost of each air-side economizer is $1,000 and there are 3 AHUs.
- A 30% contingency was added to the overall cost.

2.7.1.8 Constant Air Volume to Variable Air Volume System

Current Condition: Currently, there are three CAV air handlers at the SRDC. In a CAV system, variations in the thermal requirements of the building are satisfied by varying the temperature of a constant volume of air delivered to the building. Alternatively, a variable air volume (VAV) system can adjust the flow rate of conditioned air to the space, saving significant fan energy as well as cooling energy.

Investigated Action: The CAV systems in the SRDC can be retrofitted to a VAV system. This will require converting each CAV box to VAV, and variable frequency drives (VFDs) need be installed on the supply and return fans. Each VAV box should be specified with an electronic damper actuator and an electronic temperature and relative humidity (temp/RH) sensor that are controlled through the direct digital control (DDC) system. The occupants should not be given the ability to modify the temp/RH set-points. VAV box damper position should be connected to the DDC system. Table 11 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for converting the CAV system to a VAV system. Calculation assumptions are also given below.

Table 11. Energy and Cost Savings from Converting the CAV System to a VAV System

Energy and Cost Savings	
Electricity Savings (kWh/yr)	18,982
Propane Savings (gallons/yr)	(62)
Cost Savings ($/yr)	$1,662
Implementation Costs ($)	$25,896
Simple Payback (years)	15.6
CO_2e Savings (metric tons/yr)	12.9

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings from implementing the measure.
- The total area served by the current CAV system is estimated to be 10,000 ft^2.
- There are a total of three CAV AHUs that serve the SRDC.
- The cost to install VFDs on the AHUs is $1,250 per AHU, which totals $3,750.

- It was assumed that a total of 6 VAV boxes would be needed.
- The cost of each VAV box was estimated to be $695 per box, totaling $4,170 for all 6 VAV boxes.
- The labor cost associated with installing the VAV boxes was estimated to be $2,000 per box, totaling $12,000 for all 6 VAV boxes.
- A 30% contingency was added to the final cost.

2.7.1.9 Ground Source Heat Pump System

Current Conditions: The SRDC is currently served by a CAV system with propane boilers and no cooling. The site is looking for potential ways to move to an all-electric site and net-zero energy options.

Ground source heat pumps (GSHPs) are heat pumps that use the near-constant temperature of the earth as a heat source (in heating) or sink (in cooling). These heat pumps produce the hot and cold water that is used to heat/cool a building, and they can also be used to produce some of the hot water needed for occupant use. The fact that the temperature of the ground below 20 to 30 feet stays relatively consistent throughout the year leads to much higher coefficients of performance (measured as COP: the amount of thermal energy produced per unit of input energy) than air heat exchange units like a standard split DX air conditioner. Most GSHPs are able to attain COPs of 3 to 6, whereas average air-source heat pumps have a COP of 1.75 to 2.5. This higher efficiency can lead to large reductions in energy use over the lifetime of a building.

There are essentially four types of GSHPs: closed-loop vertical, closed-loop horizontal, closed-loop lake, and open loop. The most common type is the closed-loop system, in which a closed loop of water/antifreeze is pumped through a series of pipes/wells in the ground (absorbing or rejecting heat through the pipe walls into the earth) and is then used in the heat exchanger. This type of system avoids the environmental issues of water usage and water contamination that are present in open-loop systems. The type of system chosen depends upon the soil and rock type at the installation, the land available, and whether a water well can be drilled economically or is already on site. For the SRDC, it is assumed that the systems will be a closed-loop ground system.

GSHPs can serve almost any building with both heating and cooling in a wide range of building sizes, from 100 to 1 million square feet. Large buildings may require multiple GSHPs. The same loop may serve multiple smaller buildings. GSHPs are most cost-effective when replacing old equipment, when used in extreme climates (with cold winters, hot summers, or large daily temperature swings), and when electricity is less than three times as expensive per Btu as heating fuels. GSHPs tend not to be cost effective in buildings without both heating and cooling requirements, buildings without ductwork, newer buildings (less than four years old), buildings in mild climates, buildings with air source heat pumps, or buildings on central energy plants.

A high-level analysis was done to determine the feasibility of using GSHPs at the SRDC. The analysis was carried out by using eQUEST energy modeling software to determine the potential energy and cost savings from installing a closed-loop vertical bore GSHP; estimates were made for installation cost.

After calibrating the energy model of the site, a closed-loop vertical bore GSHP system was modeled with the same building characteristics and schedules as the baseline building. The major energy modeling assumptions for the GSHP system that was modeled are listed below.

Investigated Action: Install a closed-loop vertical bore GSHP system. Table 12 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings for installing a GSHP system. Calculation assumptions are given below.

Table 12. Energy and Cost Savings from Installing a GSHP System

Energy and Cost Savings	
Electricity Savings (kWh/yr)	(24,031)
Propane Savings (gallons/yr)	6,391
Cost Savings ($/yr)	$9,448
Implementation Costs ($)	$195,000
Simple Payback (yrs)	20.6
CO_2e Savings (metric tons/yr)	14.2

Assumptions:

- The eQUEST energy model was used to model the closed loop vertical bore GSHP system.
- The installed cost was assumed to be $7,500/ton, which includes the bore field and HVAC equipment.
- The estimated total size of the GSHP system is 20 tons, which totals $150,000 for the system.
- The annual energy cost savings is $9,448/yr, which is based on an increased annual electricity use of 24,031 kWh/yr and the elimination of propane use.
- A 30% contingency was added to the implementation cost.

2.7.1.10 Lighting Measures

The light levels throughout the building were analyzed and determined to be adequate in most spaces. Light levels are measured in footcandles (fc). Acceptable lighting levels vary by space-type; office spaces are recommended to approximately 40 fc whereas corridors and lobbies are recommended between 5 to 10 fc.[3] The following table lists the lighting measurements recorded during the energy assessment.

[3] NREL Lighting System Assessment Guidelines: http://www.nrel.gov/docs/fy11osti/50125.pdf

Table 13. Measured Lighting Levels at SRDC

Space	Light Level (Footcandles)
Study Hall	91.2
Corridor	11.4
Back Open Office	24.4
Back Closed Office	65.1
Restrooms	21.5
Entrance	41.2
Exhibit	12.8
Rock Climbing	35.0
Cashier	13.2
In Front of Fireplace	48.5

The following sections contain the lighting ECMs that were analyzed.

2.7.1.11 Daylighting Controls

Current Condition: The perimeter spaces of the SRDC do not have daylighting controls. The window to wall ratio is relatively high throughout the building and provides opportunity to implement daylighting.

Investigated Action: Daylighting control systems dim or shut off lights when there is sufficient natural light available using photocells, dimmable ballasts, and logic controllers. Daylighting controls for the SRDC will only control the ambient lighting and not the display lighting. It is very important that any daylighting system is professionally commissioned after installation and that it is properly and regularly maintained thereafter.

The energy and cost savings for installing perimeter continuous daylighting controls are given below along with the calculation assumptions and simple payback.

Table 14. Energy and Cost Savings from Daylighting Controls

Energy and Cost Savings	
Electricity Savings (kWh/yr)	20,966
Propane Savings (gallons/yr)	(559)
Cost Savings ($/yr)	$938
Implementation Costs ($)	$3,640
Simple Payback (yrs)	3.9
CO_2e Savings (metric tons/yr)	17.2

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings for installing perimeter continuous day lighting controls.

- Labor costs are assumed to be $200 per photocell, which totals $2,000.
- A total of approximately 10 photocells are needed at an installed cost of $80 per photocell, which totals $800.
- A 30% contingency was added to the overall cost.

2.7.1.12 Investigate Issues with LED Track Lighting

Current Condition: The MR-16 halogen track lighting was recently replaced with LEDs and a majority of LEDs were not functioning.

Investigated Action: The problem associated with the LED track lighting appears to be that the transformer for the fixtures is not compatible with LEDs. See Appendix A for a best-practices guide on MR-16 LED track lighting. The economics for this measure were not analyzed.

2.7.2 Plug Load Measures

The following sections contain the plug load ECMs that were analyzed.

2.7.2.1 Remove Excess Printer and Utilize Network Printer

Current Condition: There are currently three larger networked printers in the office of the SRDC.

Investigated Action: Remove the oldest model networked printers. Printers consume energy at all times when plugged into an outlet. Decommissioning two of the networked printers will save on the active, suspended, and standby energy consumed and should have minimal effect on the productivity of the office. Table 15 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings; calculation assumptions are also given below.

Table 15. Energy and Cost Savings from Removing Excess Networked Printers

Energy and Cost Savings	
Electricity Savings (kWh/yr)	1,365
Propane Savings (gallons/yr)	(19.8)
Cost Savings ($/yr)	$90
Implementation Costs ($)	$65
Simple Payback (yrs)	0.7
CO_2e Savings (metric tons/yr)	0.9

Assumptions:

- Energy Assessment Calculation Worksheets were used to calculate the energy and cost savings from implementing the measure.
- The total number of networked printers is two.
- The energy rating of the secondary printer's active, suspended, and stand-by modes was estimated to be 80 W, 30 W, and 5 W, respectively.

- The secondary printer was estimated to be in stand-by 95% of the day.
- The labor time associated with removing the networked printers was assumed to be 1 hour total at $50/hour.
- A 30% contingency was added to the final cost.

2.7.2.2 Replace Refrigerator with ENERGY STAR Refrigerator

Current Condition: The refrigerator currently located in the break room is an older model that was installed at the time the building was built. This refrigerator was currently in working condition and is utilized by the staff.

Investigated Action: When the current refrigerator is due to be replaced, replace the unit with an ENERGY STAR-rated refrigerator with the same size capacity. Table 16 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings; calculation assumptions are also given below.

Table 16. Energy and Cost Savings from Replacing the Existing Refrigerator with an ENERGY STAR Refrigerator

Energy and Cost Savings	
Electricity Savings (kWh/yr)	905
Heating Energy Savings (MMBtu/yr)	(2.2)
Cost Savings ($/yr)	$77
Implementation Costs ($)	$195*
Simple Payback (yrs)	2.5
CO_2e Savings (metric tons/yr)	0.6

*Only incremental costs considered

Assumptions:

- Energy Assessment Calculation Worksheets were used to calculate the energy and cost savings from implementing the measure.
- The total number of refrigerators due to be replaced was estimated to be one.
- The incremental cost of the ENERGY STAR replacement refrigerator was estimated to be $150.
- A 30% contingency was added to the final cost.

2.7.3 Envelope Measures

The following sections contain the envelope ECMs that were analyzed.

2.7.3.1 Motors and Control for Operable Clerestory Windows

Current Condition: The clerestory windows are manually operable, and currently they are always closed because they are difficult to manually open and it is unclear when they should be open.

Investigated Action: Install motors and controls on the clerestory windows to allow them to open when outside conditions are favorable. Table 17 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings; calculation assumptions are also given below.

Table 17. Energy and Cost Savings from Installing Motor and Controls on Clerestory Windows

Energy and Cost Savings	
Electricity Savings (kWh/yr)	5,014
Propane Savings (gallons/yr)	0
Cost Savings ($/yr)	$466
Implementation Costs ($)	$3,900
Simple Payback (yrs)	8.4
CO_2e Savings (metric tons/yr)	3.5

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings from installing motors and controls on the clerestory windows.
- The cost of the motors and controls for the clerestory windows is assumed at $3,000.
- A 30% contingency was added to the final cost.

2.7.3.2 Window Film

Current Condition: The double pane windows are clear glass with a high solar heat gain coefficient (SHGC). This means the windows allow significant heat gain to the space.

Investigated Action: Install window film with a low SHGC of 0.56 and a u-factor of 0.46 while still providing a visible transmittance of 70%. Table 18 provides the calculated energy and cost savings, simple payback, and CO_2e emissions savings; calculation assumptions are also given below. Due to the long simple payback, this measure is not recommended at this time.

Table 18. Energy and Cost Savings from Installing Window Film

Energy and Cost Savings	
Electricity Savings (kWh/yr)	2,747
Propane Savings (gallons/yr)	201
Cost Savings ($/yr)	$625
Implementation Costs ($)	$54,795
Simple Payback (yrs)	87.7
CO_2e Savings (metric tons/yr)	2.9

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings from installing window tint.

- The window area is 2,810 ft^2.
- The installed cost of the window tint is $15/ft^2.
- A 30% contingency was added to the final cost.

2.7.4 Water Conservation Measures

The following sections contain the water conservation measures that were analyzed. The SRDC is on a well water and septic system and a combined water and sewer rate of $10/1,000 gallons was assumed for the water calculations.

2.7.4.1 Low-Flow Urinals

Current Condition: The current SRDC restroom facilities for men contain a single urinal rated at the federal standard of 1.0 gallons per flush (GPF).

Investigated Action: Replace the current urinal in the SRDC with a pint flush urinal. Table 19 provides the calculated water and cost savings, simple payback, and CO_2e emissions savings; calculation assumptions are also given below.

Table 19. Water and Cost Savings from Replacing the Existing Urinal with a Pint Flush Urinal

Water and Cost Savings	
Water Savings (gal/yr)	4,875
Propane Savings (gallons/yr)	0
Cost Savings ($/yr)	$49
Implementation Costs ($)	$780
Simple Payback (yrs)	15.9
CO_2e Savings (metric tons/yr)	0.00

Assumptions:

- Energy Assessment Calculation Worksheets were used to calculate the water and cost savings from implementing the measure.
- One 1.0 GPF urinal would be replaced with a pint flush urinal.
- The cost of a pint flush urinal was estimated to be $400.
- The labor time associated with installing the waterless urinal was estimated to be 4 hours.
- A 30% contingency was added to the final cost.

2.7.4.2 Low-Flow Toilets

Current Condition: The current restroom facilities contain toilets rated at the federal standard of 1.6 gallons per flush (GPF). There are a total of 7 public toilets at the facility.

Investigated Action: Replace the current toilets at the facility with low-flow toilets rated at 1.1 GPF. More efficient flushing toilets save water and sewer costs. Table 20 provides the calculated water and cost savings, simple payback, and CO_2e emissions savings; calculation assumptions are also given below. Due to the long simple payback, this measure is not recommended at this time.

Table 20. Water and Cost Savings from Replacing the Existing Toilets with Low-Flow Toilets

Water and Cost Savings	
Water Savings (gal/yr)	6,500
Propane Savings (gallons/yr)	0
Cost Savings ($/yr)	$65
Implementation Costs ($)	$5,460
Simple Payback (yrs)	84.0
CO_2e Savings (metric tons/yr)	0.0

Assumptions:

- Energy Assessment Calculation Worksheets were used to calculate the water and cost savings from implementing the measure.
- The total number of toilets due to be replaced was estimated to be seven.
- The current flush rating of the toilets was estimated to be 1.6 GPF.
- The cost of the low-flow toilets was estimated to be $400 per fixture.
- The labor time associated with installing the new toilets was estimated to be 4 hours per fixture
- A 30% contingency was added to the final cost.

2.7.4.3 Install Water Bottle Filling Station

Current Condition: There are currently two standard water fountains at the SRDC.

Investigated Action: Install a water bottle filling station in order to reduce the purchase of bottled water, which would in turn reduce the amount of waste generated at the site. A photo of a water bottle installed at the USFS site at Mendenhall Glacier is shown in the figure below. Water bottle filling stations have an impact on reducing site waste and promote a culture of reusing water bottles. The economics for this measure were not analyzed.

Figure 11. Water Bottle Filling Station at Mendenhall Glacier
Photo by Jimmy Salasovich, NREL

2.7.5 Renewable Energy Measures

The following sections contain the renewable energy measures that were analyzed. Photovoltaic (PV) systems were the only renewable energy technology analyzed for the SRDC site. Other renewable energy technologies were considered but ruled out for various reasons. Additional information on renewable energy technologies is given in Appendix B.

2.7.5.1 42 kW Ground-Mounted Photovoltaic System

Current Condition: There is considerable land area around the site that could potentially accommodate PV without greatly impacting the view of the Seneca Rocks rock formation or impacting the archeological site to the west of the building. A detailed shading analysis was conducted, and the ground area was determined to have greater than 90% solar access, which makes the site feasible for PV from a shading point of view. Figure 12 shows the shading analysis to determine solar access.

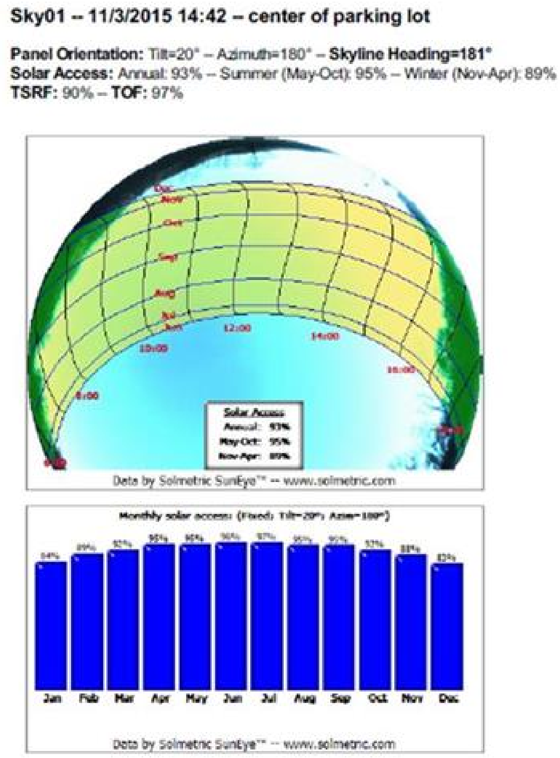

Figure 12. Shading analysis at Seneca Rocks showing 93% annual solar availability.

Image by Solmetric SunEye

Investigated Action: A ground-mounted PV system sized to meet the annual electricity use of the site after all recommended ECMs are implemented was analyzed. A 42 kW ground-mounted PV system would provide enough electricity on an annual basis (49,731 kWh/year) to make the site net zero electric, assuming all of the recommended measures are implemented. A 42 kW ground-mounted PV system would require approximately 9,150 ft^2 of ground area.

A detailed analysis using PVWatts simulation software for a ground-mounted PV system indicated that the shortest possible payback period, assuming the current 30% Federal Investment Tax Credit (ITC) is 15.9 years. This incentive is valid through 2019. In order to gain the ITC, a private party would have to install and own the system. Net metering in West Virginia for utilities with less than 30,000 customers is limited to a system size of 50 kW for commercial entities. A sample 9,150 ft^2 ground-mounted PV system at the SRDC site is shown below in Figure 13. This figure is meant to provide the scale of the PV system required to make the site net zero electric. The predicted performance and economics for the investigated PV system are given in Table 21.

Figure 13. Sample 42 kW PV system size (9,150 ft^2).

Source: Google Earth Pro

Table 21. Predicted Solar Output from 42 kW Ground-Mounted PV System

Estimated Energy and Cost Savings	
Direct Current Nameplate Capacity (kW)	42
Orientation	South
Tilt	20° fixed
Estimated Alternating Current Electricity Production (kWh/yr)	49,731
Estimated Cost Savings ($/yr)	$4,625
Installed Cost with No Incentives	$126,000
Simple Payback with No Incentives (yr)	27.2
CO_2e Savings (metric tons/yr)	34.5
Economics Assuming 30% Federal Investment Tax Credit	
Installed Cost with Incentives	$88,200
Simple Payback with Incentives (yr)	19.1

Assumptions:

- PVWatts software was used to model PV.

- The blended electricity rate of \$0.093//kWh was used to calculate cost savings.
- A total installed cost was \$3.00/Watt.
- System performance degradation of 0.5% per year.
- Balance of system derate factor of 77% was used to calculate energy savings.

2.7.5.2 Combination 26 kW Roof-Mounted and 16 kW Ground-Mounted Photovoltaic System

Current Condition: The SRDC site building has a standing seam metal roof, sloped and oriented to the southeast and northwest. There is approximately 2,600 ft^2 of southeast facing potential roof area available for PV. There is also considerable land area around the site that could potentially accommodate PV without greatly impacting the view of the Seneca Rocks rock formation or impacting the archeological site to the west of the building.

Investigated Action: A combination of roof-mounted and ground-mounted PV system sized to meet the annual electricity use of the site after all recommended ECMs are implemented was analyzed. A combination of a 26 kW roof-mounted PV system and a 16 kW ground-mounted PV system would provide enough electricity on an annual basis (49,731 kWh/year) to make the site net zero electric assuming all of the recommended measures are implemented. A 26 kW roof-mounted PV system would require approximately 2,600 ft^2 of roof area and a 16 kW ground-mounted PV system would require approximately 3,500 ft^2 of ground area.

A detailed analysis using PVWatts simulation software for a combination of a 26 kW roof - mounted and a 16 kW ground-mounted PV system indicated that the shortest possible payback period—assuming the current 30% Federal Investment Tax Credit (ITC) is captured—is 15.9 years. This incentive is valid through 2019. In order to receive the ITC, a private party would have to install and own the system. The 2,600 ft^2 of roof area and a sample 3,500 ft^2 ground area for the combination PV system at the SRDC site is given below in Figure 14. The ground area shown in the figure is meant to provide the scale of the ground-mounted PV system required to make the site net zero electric when combined with the roof-mounted PV system. The predicted performance and economics for the investigated combination PV system is given in Table 22.

Figure 14. Combination 26 kW roof-mounted and 16 kW ground-mounted PV areas.
Source: Google Earth Pro

Table 22. Predicted Solar Output from Combination 26 kW Roof and 16 kW Ground PV System

Estimated Energy and Cost Savings for 26 kW Roof-Mounted PV System		
	Direct Current Nameplate Capacity of Ground-Mounted PV (kW)	26
	Orientation	Southeast
	Tilt	20° fixed
	Estimated Alternating Current Electricity Production (kWh/yr)	30,071
	Estimated Cost Savings ($/yr)	$2,797
	Installed Cost with No Incentives	$91,000
	Simple Payback with No Incentives (yr)	32.5
	CO_2e Savings (metric tons/yr)	20.9
Economics Assuming 30% Federal Investment Tax Credit		
	Installed Cost with Incentives	$63,700
	Simple Payback with Incentives (yr)	22.8

Estimated Energy and Cost Savings for 16 kW Ground-Mounted PV System		
	Direct Current Nameplate Capacity of Ground-Mounted PV (kW)	16
	Orientation	South
	Tilt	20° fixed
	Estimated Alternating Current Electricity Production (kWh/yr)	19,358
	Estimated Cost Savings ($/yr)	$1,800
	Installed Cost with No Incentives	$48,000
	Simple Payback with No Incentives (yr)	26.7
	CO_2e Savings (metric tons/yr)	13.4
Economics Assuming 30% Federal Investment Tax Credit		
	Installed Cost with Incentives	$33,600
	Simple Payback with Incentives (yr)	18.7
Estimated Energy and Cost Savings for Combination 26 kW Roof and 16 kW Ground PV System		
	Direct Current Nameplate Capacity of Ground-Mounted PV (kW)	42 (total)
	Estimated Alternating Current Electricity Production (kWh/yr)	49,429
	Estimated Cost Savings ($/yr)	$4,597
	Installed Cost with No Incentives	$139,000
	Simple Payback with No Incentives (yr)	30.2
	CO_2e Savings (metric tons/yr)	34.3
Economics Assuming 30% Federal Investment Tax Credit		
	Installed Cost with Incentives	$97,300
	Simple Payback with Incentives (yr)	21.2

Assumptions:

- PVWatts software was used to model PV.
- The blended electricity rate of $0.093//kWh was used to calculate cost savings.
- A total installed cost was $3.50/Watt for roof-mounted PV.
- A total installed cost was $3.00/Watt for ground-mounted PV.
- System performance degradation of 0.5% per year.
- Balance of system derate factor of 77% was used to calculate energy savings.

3 Conclusions

The staff at the SRDC is very proactive and knowledgeable about conserving energy and water and is eager to incorporate renewable energy technologies. The staff currently incorporates many best practices to reduce energy use, including high efficiency pump motors, disabled humidifiers, scheduled air filter replacement, pipe insulation, proper hot water temperature, LED lighting, adequate light levels, occupancy sensors, timeclocks for exterior lighting, minimal plug loads, and adequate insulation levels. The staff currently does not use any site irrigation, which greatly reduces water use. They are also actively pursuing RE technologies.

The SRDC was built in 1998, and various upgrades to the building could be implemented to make the building more sustainable. A total of 14 possible energy conservation measures (ECMs), two water conservation measure (WCMs), and one renewable energy measure (REM) were analyzed. A bundled analysis was carried out to determine the economics of all of the measures combined. Not all measures are recommended at this time due to the relatively long payback periods, and these measures are not included in the bundled analysis. The measures that are not recommended include window tint and low-flow toilets.

The GSHP is not included in the bundled analysis because many of the other HVAC ECMs cannot be combined with the GSHP system (e.g., the condensing boiler ECM cannot be combined with the GSHP system). This is not to say that the GSHP is not recommended, it is just not included in the bundled analysis. Furthermore, only the 42 kW ground-mounted PV system is included in the bundled analysis because it is the most financially viable PV option and including both PV system options that were analyzed would have meant the results would be double-counted. A summary of the bundled analysis is given below in Table 23.

Table 23. SRDC Site Assessment Summary Table

Measure Type	Number of Measures Investigated	Bundled Installed Cost ($)	Bundled Annual Cost Savings ($/yr)	Bundled Simple Payback (yrs)	Bundled Annual CO_2e Savings (metric tons/yr)
Energy Conservation Measures	14	$159,469	$13,270	12.0	90.1
Water Conservation Measures	2				
Renewable Energy Measures	2				

The audit team found that HVAC measures that could be installed without major renovations or construction included replacing standard V-belts with cogged v-belts and retro-commissioning the AHUs. Incremental replacement of boilers, air-conditioning units, and refrigerators for more efficient equipment should be considered at the time of replacement. Lighting measures to implement include installing daylighting controls and solving the issue with the MR-16 LED track lighting discussed above. A 42kW ground-mounted PV system would make the site a net-zero electric site.

Appendix A. LED Lighting Fact Sheet from U.S. DOE

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Building Technologies Program
SOLID-STATE LIGHTING TECHNOLOGY FACT SHEET

LED MR16 LAMPS

Directional lamps are a key component of the focal lighting systems that are often used in retail, hospitality, residential, and museum applications. Halogen MR16 lamps are frequently used for these applications—thanks to their beam control, flexibility, and small size—and the form factor has received considerable attention from the LED industry. However, LED MR16 lamps vary substantially, both in their performance and compatibility with existing infrastructure. Careful consideration and evaluation of operating characteristics is required when converting from conventional sources to LED.

LED MR16 lamps are used to wash the wall behind the front desk of the InterContinental Hotel in San Francisco, CA.

Introduction

Multifaceted reflector (MR) lamps are used in many types of luminaires including track heads, monopoints, and fixed or adjustable recessed downlights. The most common MR-type lamp is the MR16, which has a diameter of 16 eighths of an inch, or 2 inches. MR16 lamps are typically operated at a low voltage (usually 12 V), which introduces an additional level of complexity that must be addressed when considering replacement of halogen sources with LEDs. This is especially important for track lighting systems, where multiple lamps on a single circuit often interact with other electronic components.

Typical halogen MR16 track lighting systems consist of low voltage lamps (commonly 20, 35, or 50 W), luminaires (track heads), optical accessories (e.g., lenses, louvers), one or more electronic or magnetic transformers, and the track itself. A dimming system may also be incorporated. The track—which provides power as well as flexibility for mounting locations—can operate at either line voltage (120 V), requiring low-voltage track heads with integral transformers, or low voltage (12 V), requiring a single remote transformer for several track heads. The majority of currently installed track is line voltage. To date, standards have not been developed for the track lighting market; as a result, track and track heads from different manufacturers typically are not directly interchangeable.

MR16 lamps are unique amongst directional lamps because they are most often operated at low voltage and their design is constrained by the small form factor. Beyond the usual performance characteristics that should be evaluated when comparing LED and conventional products, the interaction of electronic components must also be considered. These compatibility issues are of concern for both retrofit applications and new installations.

Basic Performance Characteristics

Form Factor and Lamp Appearance

Achieving the small MR16 form factor can be a challenge for integrated LED lamps, which must incorporate LED package(s), optics, thermal management, and a driver. Consequently, some LED MR16 lamps may be larger, longer, or have a different shape than the American National Standards Institute (ANSI) specifies,[1] as shown in Figure 1. This can result in the LED lamp not fitting properly into the luminaire or track head, or it may make it harder to use accessories such as lenses, louvers, screens, or filters. Additionally, some lamps have fins used for thermal management that catch on the wire retaining springs used in many MR16 fixtures, making installation and changeout of lamps more difficult.

Most halogen MR16 lamps send some light and heat backwards through the dichroic coating of the reflector; the sparkling and colorful appearance this creates is considered a desirable feature by many specifiers. As of 2012, DOE has been unable to find an LED MR16 lamp that emits substantial backlight; this may change with future designs.

Quantity of Light and Efficacy

According to CALiPER testing to date, the lumen output of most LED MR16 lamps is equivalent to the output of halogen lamps drawing 35 W or less. As of June 2012, the maximum lumen output of an LED MR16 lamp listed by LED Lighting Facts was 550 lumens (see Figure 2). At typically 40 to 60 lm/W—reaching up to 80 lm/W, according to LED Lighting Facts—the efficacy of LED MR16 lamps is much higher than for halogen MR16 lamps, which deliver approximately 5 to 20 lm/W. Notably, MR16 lamps

1 *ANSI standard C78.24-2011,* American National Standard for electric lamps: Two-inch (51 mm) Integral-reflector Lamps with Front Covers and GU5.3 or GX5.3 Bases, *stipulates dimensions for the most common type of low-voltage MR16 lamp.*

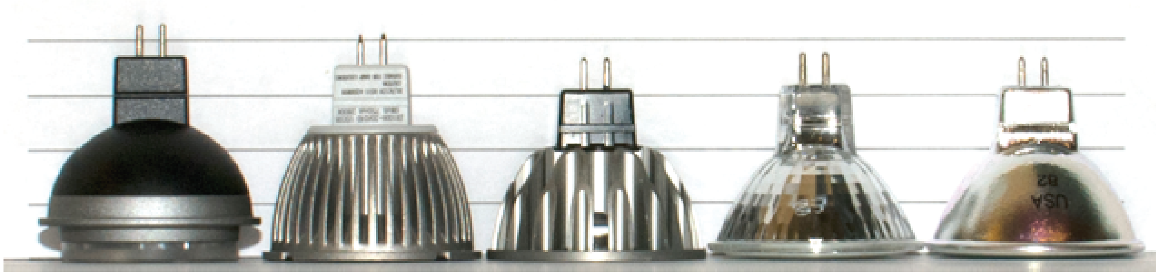

Figure 1. Some LED MR16 lamps (left three) do not match the form factor of conventional halogen MR16 lamps (right two).

are often specified based on luminous intensity distribution characteristics—specifically beam angle and center beam candlepower (CBCP)—rather than lumen output.

Distribution of Light

Halogen MR16 lamps offer a variety of distributions, ranging from narrow pin spots with a beam angle of 7° to wide flood distributions of with a beam angle of 60° or greater. Available distributions for integrated LED lamps are more limited, seldom reaching the extremes of the halogen range (see Figure 3). However, this is not a limitation of the technology, and a greater range of offerings are continually reaching the market.

One potential advantage of LED MR16 lamps is improved uniformity across the beam, with fewer hotspots, no filament images, and no ragged edges. These characteristics may allow the fixture to be operated without supplementary spread or softening lenses which can trap heat and reduce light output.

Color Quality and Spectrum

As with other LED products, LED MR16 lamps are available in a wide range of correlated color temperatures (CCTs). If seeking a visual equivalent to a halogen lamp, products with a CCT of 2700 K to 3000 K are most appropriate.

LED sources can exhibit very good color rendering, with some currently available products having a color rendering index (CRI) greater than 90 and many options available with a CRI greater than 80. However, this level of performance cannot be assumed and the CRI metric may not perfectly capture human perception. In demanding applications, visual evaluation is the best approach.

A benefit of integrated LED lamps is the substantial reduction of energy radiated in the ultraviolet (UV) and infrared (IR) regions of the electromagnetic spectrum. This is particularly advantageous in museum lighting applications where minimizing material degradation is highly desirable.

Heat Dissipation and Thermal Environment

In general, LED MR16 lamps work best in an open environment, such as with a gimbal ring track head. Unfortunately, many track heads designed for MR16 lamps are compact and enclosed. The effects of different thermal environments on temperatures inside an LED source are dramatic. For example, at the InterContinental Hotel in San Francisco (the site of a GATEWAY demonstration[2]) relative testing showed that operating a sample LED lamp inside one of the existing enclosed luminaires resulted in a heat sink temperature that was over 18°C higher than when it was operated in open air. In some cases, reduced ability to remove heat can cause LED lamps to discolor—as was the case at the InterContinental Hotel—or suffer degradation in light output and life expectancy. Beyond using enclosed fixtures, adding lenses,

2 More information on GATEWAY demonstrations, including the InterContinental Hotel, can be found at http://www.ssl.energy.gov/gatewaydemos_results.html.

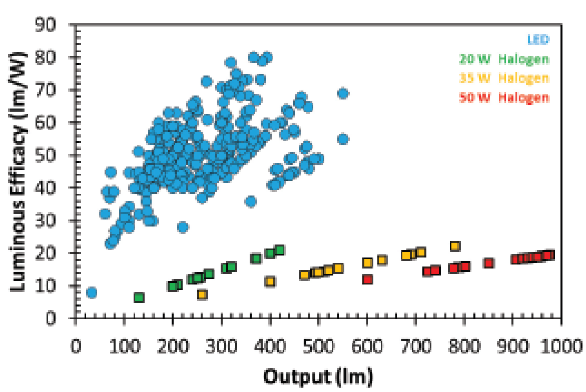

Figure 2. Luminous efficacy versus lumen output for LED MR16 lamps listed by LED Lighting Facts as of June 19, 2012 and selected nominal data for low-voltage halogen MR16 lamps.

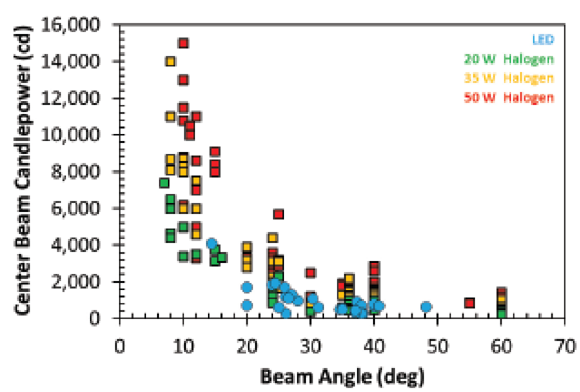

Figure 3. Center beam candlepower (CBCP) versus beam angle for a subset of LED MR16 lamps listed by LED Lighting Facts as of June 19, 2012 and selected nominal data for low-voltage halogen MR16 lamps.

gel filters, or any accessories that compromise airflow should only be done with great caution.

Some LED MR16 lamps utilize active thermal management devices, such as integral fans or vibrating membranes, to aid in cooling. It is critical that the airflow for these devices is not obstructed. Air intake holes should not be blocked (by a glass lens, for example). Some LED sources contain a thermal protector, which in extreme conditions may reduce the light output from the lamp or cease its operation altogether. In this scenario, cycling can result as the lamp turns back on after a sufficient cool down period. Also noteworthy is the additional noise caused by some active thermal management devices, which may be distracting in certain environments, such as a private residence.

Electronic Compatibility Considerations

Electronic compatibility issues arise because MR16 halogen lamps behave electrically like a simple resistor, whereas LED lamps typically require a driver comprised of multiple electronic components that present a more complex electrical interface to other electronic components, such as transformers, dimmers, and other lamps. Not all LED installations experience these problems, but without standardized components, it can be difficult to predict performance without specific compatibility testing.

When considering replacement of a low-voltage lamp, understanding the type of transformer used is an important first step. For some commercially available LED products, magnetic transformers seem to be more robust and exhibit fewer compatibility problems, although they are typically less efficient than electronic transformers. However, greater compatibility is not a fundamental characteristic of magnetic transformers; the observation of fewer problems with some products today may not translate to fewer problems as LED MR16 lamps develop in the future. Installing integrated LED lamps in systems utilizing electronic transformers warrants great care given that they contain their own set of electronic components. Incompatibilities between the electronics in the transformer and the LED driver can lead to poor performance or even premature failure of one or both components. Even minor differences in circuit design of seemingly identical transformers may produce dramatic differences in the performance of seemingly identical LED lamps.

Minimum Transformer Loads

Transformers typically have both minimum and maximum limits for the connected load. Integrated LED lamps draw fewer watts, and therefore may not meet the minimum load requirement of a transformer that was designed for halogen lamps. Depending on the specific design of the LED lamp and transformer, if the minimum load is not met the lamp may shut off completely or flicker. LED lamps can also draw high repetitive peak currents, which effectively stress the electronic components they are connected to (such as those in transformers) more than their wattage rating would suggest. Consequently, the maximum load for a transformer can be lower for LED sources than its rating for halogen sources. For example, a dimmer rated at 600 W for halogen lamps may only support a load of 150 W for a given LED lamp.

Dimming

Regardless of operating voltage, transformer location, or transformer type, compatibility with dimming technology is an important consideration, especially in retrofit applications. Pairing a magnetic low-voltage (MLV) dimmer with a magnetic transformer, or an electronic low-voltage (ELV) dimmer with an electronic transformer does not guarantee compatibility. For example, a transformer's minimum load requirement must be met throughout the dimming range, even as the effective load is continually reduced. One way to address this problem is to use a dimmer with a low-end trim, which can limit dimming to a range where the transformer is stable; below that low-end setpoint, the dimmer simply switches off the lamp.

As is the case with electronic transformers, dimmers contain their own set of electronic components that interact with other equipment on the circuit. For an LED system, dimming performance is dependent on the specific combination of transformer, LED lamp, and dimmer. The consequences of improperly matched components can vary widely but may include flicker, color shift, audible noise, premature failure, very limited or no range of dimming, or failure to light. Including a resistive load, such as a halogen lamp, on the track circuit can improve compatibility and performance, but doing so creates other challenges, such as achieving color consistency across all light sources.

Flicker

Many different approaches may be used to control the current in LEDs. These different methods, which are typically implemented by a driver, lead to wide variation in the periodic modulation of light output from LED sources. The amount and type of modulation, or flicker, present in a given LED source can be more or less than seen in comparable conventional technology sources (see Figure 4). The modulation found in halogen sources is not usually perceptible; however, higher levels of modulation may be perceived as objectionable flicker, which may cause distraction, eyestrain, headaches, or reduced visual task performance in some individuals over time. As is the case for dimming performance, flicker in LED MR16 products is dependent on the specific combination of transformer, lamp, and dimmer (if applicable).

Power Factor

The power factor of an LED MR16 lighting system depends on the design of both the lamp and transformer. In CALiPER testing to date, the power factor for LED MR16 lamps ranged from 0.29 to 0.96 when operated on a reference power supply in a laboratory environment. Additional testing showed that a given LED lamp could exhibit a varying power factor when operated on different magnetic or electronic transformers. It should be noted that tradeoffs between power factor and flicker are typical for LED MR16 lamps because the small form factor limits the incorporation of more sophisticated circuit designs.

Replacement Options

There are several options to consider when the decision has been made to convert from low-voltage halogen MR16 lamps to LED

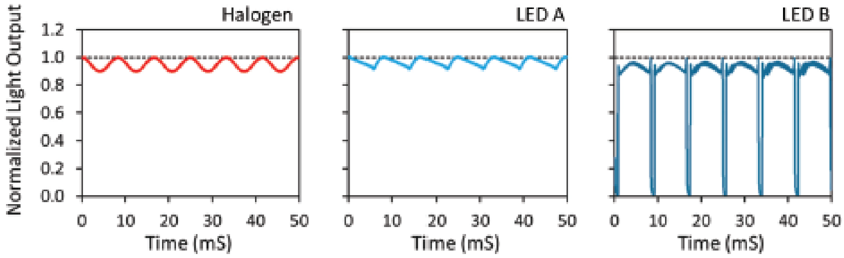

Figure 4. The modulating light output of three different MR16 lamps. The halogen and LED A lamps are not likely to produce objectionable flicker, whereas LED B might.

MR16 lamps. Although every situation is unique, basic considerations are often the same and safety requirements should always be followed. Three options are typically available:

- Replace only the halogen lamp with an integrated LED lamp. In this case, the LED product—combining LED package(s), optics, thermal management, and driver—must both conform to the MR16 form factor and operate in conjunction with the transformer built in to the track head or remotely powering the low-voltage track. Compatibility should be carefully evaluated, and following the recommended practices provided in this fact sheet is strongly encouraged. Dimming presents an added concern; if it can be avoided, finding compatible products may be more straightforward.
- Replace both the halogen lamp and existing transformer with an integrated LED lamp and new transformer—replacing the dimmer, if applicable, may also be necessary. This approach can minimize compatibility issues, but can be more costly. Even if it is physically possible, replacing the integral transformer in a track head can be labor intensive. Replacing the remote transformer powering low-voltage track is less labor intensive, as long as the transformer location is known and easily accessible.
- Replace the entire track head with a dedicated LED track head, which uses an LED array or module instead of an LED MR16 lamp and an integral driver to power the LEDs. A low-voltage LED track head may still experience compatibility issues with the remote transformer. Regardless of voltage, the dimmer may also need to be replaced.

Recommended Practices

While the considerations and potential challenges are significant, LED MR16 lamps can work as promised and as desired given the right combination of system components. Beyond basic equivalency considerations,[3] understanding the components of a full lighting system and being aware of their potential limitations are important preliminary steps. Following the recommended practices summarized below will help to ensure that expectations are met:

- Seek out compatible product lists from manufacturers. At a minimum, they should include tested combinations of lamps, transformers, and dimmers. They should also specify a minimum and maximum number of lamps (1–4, for example) per dimmed circuit, dimming range (maximum to minimum), and flicker characteristics. As system efficacy and power factor are dependent of the combination of lamp, transformer, and dimmer (if applicable), users who want to achieve specific performance targets should ask for system data rather than individual lamp data.
- Investigate whether any case studies exist that evaluate one or more components of the system under consideration. Evaluating similar installations may not guarantee success, but it can help to identify potential problems.
- Perform an extended duration mock-up of entire circuits (lamps, transformers, and dimmers). Such a mockup can be costly, but it may prevent even larger expenses incurred when dealing with problems once the lamps are installed in great numbers.
- If compatibility lists or case studies do not contain the combination of interest, and a mock-up is not possible, look for lamp manufacturers that are willing to provide a strong warranty and help in diagnosing and correcting any issues that may arise.

Looking to the Future

The best option for the long-term may be complete replacement of conventional luminaires with dedicated LED products, rather than continued use of traditional form-factor lamps, like the MR16. This will allow for the holistic design of line- or low-voltage track and LED track heads with better thermal management and compatible combinations of transformers, drivers, and dimmers. Dedicated LED products may offer more flexibility to control light output, while still maintaining the small profile of luminaires using MR16 lamps.

3 See the DOE fact sheet, "Establishing LED Equivalency," for details (http://ssl.energy.gov/factsheets.html).

U.S. DEPARTMENT OF ENERGY
Energy Efficiency & Renewable Energy

For more information, visit: ssl.energy.gov
Direct fact sheet feedback to: SSL.Fact.Sheets@pnnl.gov

PNNL-SA 89388 • July 2012
Printed with a renewable-source ink on paper containing at least 50% wastepaper, including 10% post consumer waste.

Appendix B. Renewable Energy Information

Photovoltaics

Solar PV technology converts energy from solar radiation directly into electricity. Solar PV cells are the electricity-generating component of a solar energy system. When sunlight (photons) strikes a PV cell an electric current is produced by stimulating electrons (negative charges) in a layer in the cell designed to give up electrons easily. The existing electric field in the solar cell pulls these electrons to another layer. By connecting the cell to an external load, this current (movement of charges) can then be used to power the load, e.g., light bulb.

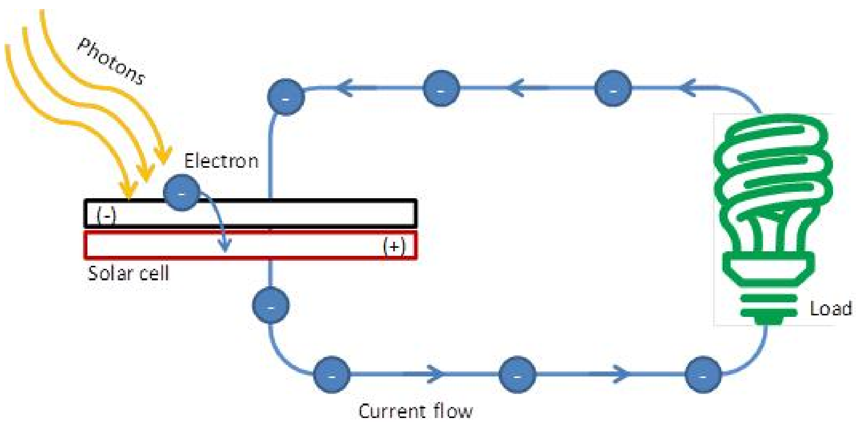

Figure A-1. Generation of electricity from a PV cell.
Illustration by Jim Leyshon, NREL

PV cells are assembled into a PV panel or module. PV modules are then connected to create an array. The modules are connected in series and then in parallel as needed to reach the specific voltage and current requirements for the array. The direct current (DC) electricity generated by the array is then converted by an inverter to useable alternating current (AC) that can be consumed by adjoining buildings and facilities or by exporting it to the electricity grid. PV systems vary in size from small residential (2-10 kilowatts (kW) and commercial (100-500 kW), to large utility scale (10+ megawatts (MW). Central distribution plants are also currently being built in the 100 MW+ scale. Electricity from utility-scale systems is commonly sold back to the electricity grid.

A typical PV system is made up of several key components including PV modules, inverters, and balance-of-system components. Figure A-2 below shows the major components of a grid-tied PV system.

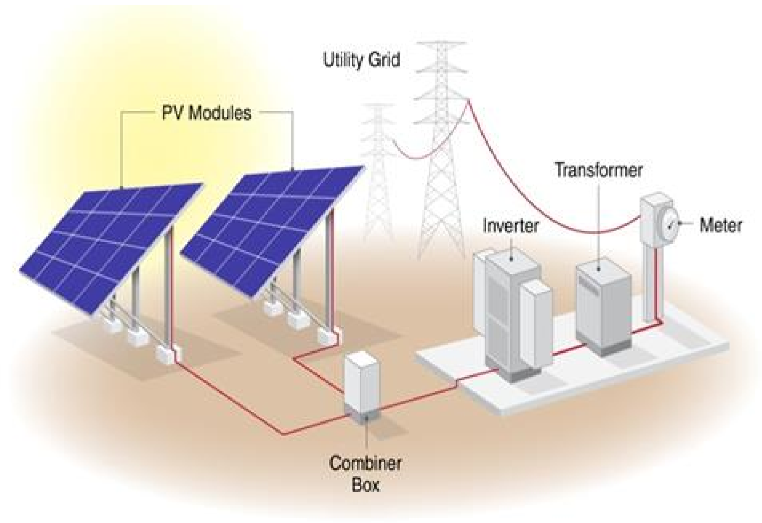

Figure A-2. Ground-mounted PV array diagram.
Illustration by Jim Leyshon, NREL

Micro-Hydro Power

A hydropower system uses the energy in flowing water to convert mechanical energy into electricity. Micro-hydropower systems are small-scale hydropower generators sized to produce between 5 to 100 kW of electricity output. There are several methods of harnessing the energy in moving water to produce energy. Most micro-hydro applications utilize run-of-the-river systems; these systems do not require large storage reservoirs. In a run-of-the-river system, a portion of the river is diverted to a channel, pipeline, or penstock, which delivers the water to a turbine to generate electricity. Micro-hydro applications are best suited to smaller communities, small enterprises, or single families. Hydropower is currently not being considered at the site due to potential impact to the stream habitat.

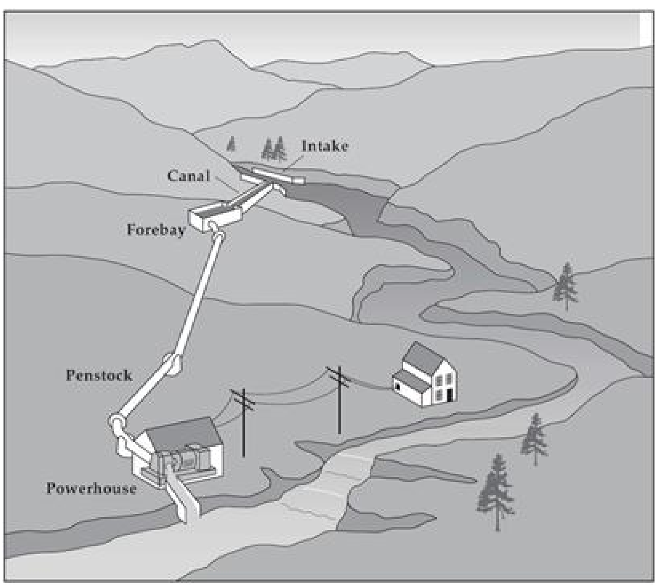

Figure A-3. Illustration of a micro-hydropower system with penstock.
Source: NREL (http://www.nrel.gov/docs/fy01osti/29065.pdf)

Wind Turbine

Large-scale wind turbines are commonly classified as any wind turbine larger than 100 kW; small-scale wind turbines are classified as less than 100 kW. The wind resource at a site has the largest impact on whether or not a wind project will be feasible. Installing a temporary anemometer and collecting at least a year's worth of wind speed data are highly recommended for large-scale turbines to determine the feasibility of wind. Figure A-4 shows the wind resource in the United States at a hub height of 30 meters. Urban settings are not ideal for wind turbines, as the surrounding buildings would shelter turbines from the wind and cause turbulence. The wind resource at the SRDC is moderate and the visual impact of installing wind turbines at the site would detract from visitors' experience. Therefore wind turbines are not being considered.

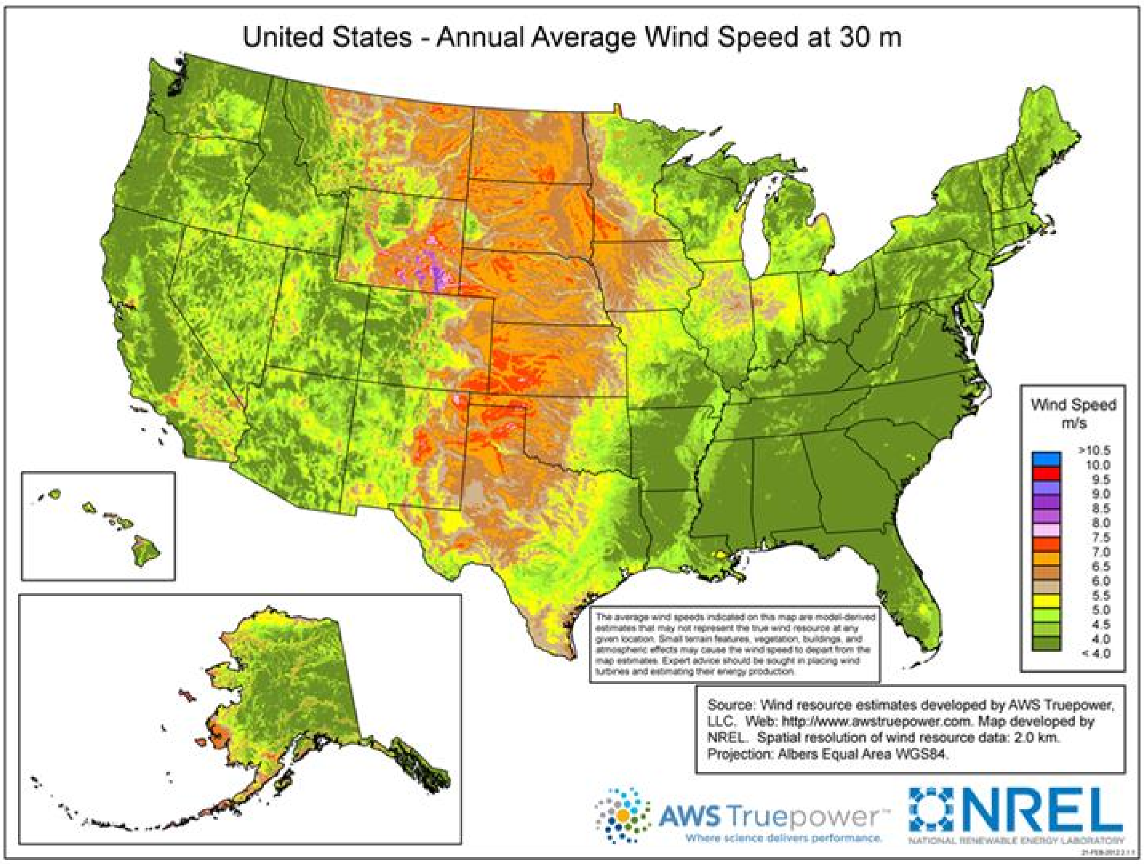

Figure A-4. United States wind resource map at a height of 30 meters.
Source: NREL (http://www.nrel.gov/gis/images/30m_US_Wind.jpg)

Biomass

Biomass is a renewable energy technology that uses biological material to produce heat and/or electricity. Wood is the largest source of biomass energy, but other sources, such as woody plants, grasses, algae, food crops, and landfill gas, are all common sources of biomass. Biomass requires frequent transport of fuel sources to a site, and this can be an issue at sites with high security. There is not a steady source of biomass in the area and, therefore, biomass is not being considered at the site.

Solar Ventilation Preheat

Solar vent preheat is a renewable energy technology that preheats the incoming ventilation air during the heating season. Figure A-5 shows an example of solar vent preheat panels installed on a building at the NREL campus. The solar vent preheat system is made up of dark perforated panels installed on façades with good solar exposure. The solar vent preheat panels are installed with an air space between the panels and the wall, and this air is heated when the conditions permit. A relatively low-horsepower fan circulates the preheated air to the ventilation system during the heating season, which offsets the need to heat the ventilated air with traditional heat sources. The solar vent preheat panels are bypassed during the cooling season. Solar vent preheat is relatively difficult to implement on existing buildings, and it changes the aesthetics of a building. In addition, there is a relatively low solar resource in Seneca Rocks, WV. For these reasons, solar vent preheat is not being considered.

Figure A-5. Example of solar vent preheat.
Photo by Pat Corkery, NREL 17424

Solar Hot Water System

Figure A-6 shows a typical configuration for a solar hot water (SHW) system. An SHW system was not considered for the SRDC because the building has a relatively small hot water load. Also, the relatively low solar resource and the nature of the water heating system in the building do not offer a convenient location in which to tie in a SHW systems.

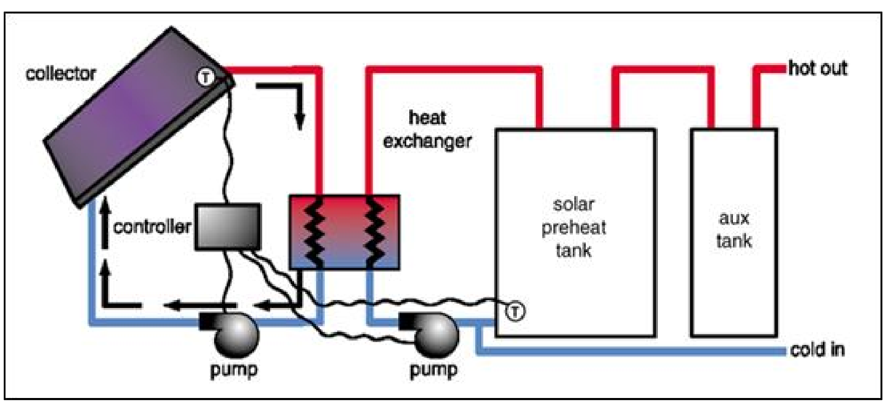

Figure A-6. Typical solar hot water system configuration.
Illustration by Jim Leyshon, NREL