Hawaii-Okinawa Building Evaluations

I. Metzger and J. Salasovich

National Renewable Energy Laboratory

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.

Technical Report
NREL/TP-7A40-57285
May 2013

Contract No. DE-AC36-08GO28308

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LIST OF ACRONYMS

AC	alternating current
AEDG	Advanced Energy Design Guide
AHU	air-handling unit
ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
BAS	building automation system
BF	ballast factor
CAV	constant air volume
CBECS	Commercial Building Energy Consumption Survey
CDD	cooling degree days
CFL	compact fluorescent lighting
DC	direct current
DOE	Department of Energy
DOAS	dedicated outside air system
DHW	domestic hot water
ECM	energy conservation measure
EE	energy efficiency
EER	energy efficiency ratio
EPD	equipment power density
EUI	energy use intensity
HECO	Hawaiian Electric Company
HVAC	heating, ventilation, and air conditioning
IEEE	Electrical and Electronic Engineers
IES	Illuminating Engineering Society
IPLV	integrated part load value
ITC	investment tax credit
LCD	liquid crystal display
METI	Ministry of Economy, Trade and Industry
NEMA	National Electrical Manufacturers Association
NREL	National Renewable Energy Laboratory
OPR	owner's project requirements
PPA	power purchase agreement
PV	photovoltaic
RE	renewable energy
RH	relative humidity
SHGC	solar heat gain coefficient
SHW	solar hot water
SRI	solar reflectance index
TMY	typical meteorological year
VFD	variable-frequency drives
VT	visual transmittance
WSHP	water source heat pumps

EXECUTIVE SUMMARY

NREL conducted energy evaluations at the Itoman City Hall building in Itoman, Okinawa Prefecture, Japan, and the Hawaii State Capitol building in Honolulu, Hawaii. This report summarizes the findings from the evaluations, including the best practices identified at each site and opportunities for improving energy efficiency and renewable energy. The findings from this evaluation are intended to inform energy efficient building design, energy efficiency technology, and management protocols for buildings in subtropical climates.

The five-story Itoman City Hall building is 166,130 ft^2 (15,434 m^2) and houses approximately 400 occupants. The building's primary function is office space, but it also includes storage, machine rooms, and other types of space. The climate in Itoman features some variations in temperature from season to season with consistently high humidity and precipitation year round. Itoman experiences approximately 3,399 cooling degree days[1] per year. The annual electricity use for the Itoman City Hall in 2011 was 1,777,604 kWh at a cost of $465,848 (39,597,062 Yen). The energy use intensity (EUI) in 2011 was approximately 37 kBtu/ft^2 (115 kWh/m^2).

The six-story Hawaii State Capitol building is 188,485 ft^2 and houses 300 occupants continuously, and up to approximately 900 occupants when the legislature is in session. The building's primary function is office space, but it also includes auditoriums, conference rooms, and other types of space. The climate in Honolulu features small variations in temperature from season to season with moderate humidity and precipitation year round. Honolulu experiences approximately 4,965 cooling degree days per year. The annual electricity use for the Hawaii State Capitol building in 2011 was 4,765,600 kWh at a cost of $1,397,433. The EUI in 2011 was approximately 86 kBtu/ft^2 (271 kWh/m^2).

Throughout the building evaluations, several best practices and opportunities were observed. Table 1 shows the best practices for both buildings, with the best practices found at both sites listed in the center column. Table 2 shows the opportunities for both buildings with the opportunities found at both sites listed in the center column.

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[1] Degree day is a quantitative index of the demand for energy to heat or cool buildings. A mean daily temperature of 65°F is the base for both heating and cooling degree day computations. Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/ddayexp.shtml

Table 1. Summary of Best Practices Observed During the Building Evaluations

Itoman City Hall Building	Best Practices Observed at Both Sites	Hawaii State Capitol Building
Energy saving temperature set points (27°C, 80°F)	Knowledgeable, proactive, and competent facilities staff	Cooling tower fan sequencing
Central lighting controls for scheduling	Good preventative maintenance schedules	Premium efficiency motors
No cubicle walls allows better views, ventilation, and daylight	De-lamped lighting fixtures in many spaces	Lighting occupancy sensors
Ice storage system to reduce peak daytime loads	Good shading on exterior of building	Bi-level light switching
Use of rainwater for toilets and urinals	Liquid crystal display (LCD) computer monitors	Vending machine misers
Operable windows with cross ventilation	Central building automation system	Energy awareness and education campaign
Air-side economizer based on outdoor air temperature	T8 and compact fluorescent lighting (CFL) lighting	
Vestibule doors at entrances	Variable speed drives	
Window tint on west windows	LED exit signs	
Permeable paving in parking lot	Electronic controls	
195-kW PV system	Well-insulated pipes	
Demand response	High thermal mass building	

Table 2. Summary of Opportunities Observed During the Building Evaluations

Itoman City Hall Building	Opportunities Observed at Both Sites	Hawaii State Capitol Building
De-lamp overlit spaces	Cogged V-belts on fan drives	Install PV system
Use premium efficiency motors	Convert constant air volume system to variable air volume	Utilize demand control ventilation
Consider replacing inverter with high efficiency inverter	Reduce ventilation rates to ASHRAE 62.1-2010 levels	Procure ENERGY STAR refrigerators
Investigate the performance of the current PV system	Replace desktop computers with low-energy desktops	Place timers on specific plug loads
Investigate corrosion prevention options for chillers	Consolidate the number of networked printers	Activate computer power management
Replace large chillers w/ smaller packaged units	Replace metal halide, halogen, and CFL lighting with LEDs	Install solar water heating system
	Install lighting occupancy sensors	

The opportunities were analyzed for energy and cost savings. The total potential savings for the opportunities found at Itoman City Hall building were 738,978 kWh/yr, or $204,988/yr, with a combined simple payback period of 10.2 years. Table 3 lists the energy conservation measures for the Itoman City Hall building. The total potential savings for the opportunities found at the Hawaii State Capitol building were 2,015,003 kWh/yr, or $619,715/yr, with a combined simple payback period of 5.0 years. Table 4 lists the energy conservation measures for the Hawaii State Capitol building.

Note that the energy conservation measures summarized in the tables below do not include interactions between measures. The simple summation of savings for multiple conservation measures could be an overestimation.

Table 3. Itoman City Hall Building Energy Conservation Measures

Energy and Water Conservation Measures	Category	Annual Electricity Savings (kWh/yr)	Annual Cost Savings ($)	Annual Operations and Maintenance Costs ($)	Implementation Costs ($)	Simple Payback Period (yrs)	Greenhouse Gas Reduction (lbs CO_2e)
Consolidate Network Printers	Plug Loads	16,487	$5,959	$0	$4,778	0.8	13.1
Replace the Standard V-Belts with Cogged V-Belts	HVAC	5,189	$1,430	$0	$2,210	1.6	4.1
De-lamp Over Illuminated Spaces	Lighting	6,925	$1,981	$0	$3,413	1.7	5.5
Install Low-Flow Aerators on Faucets	Water	85,167 gal. water	$1,703	$0	$3,120	1.8	0.0
Retrofit Metal Halide and Halogen Lighting with LED	Lighting	45,982	$13,227	$0	$55,361	4.2	36.4
Reduce Ventilation Rates to ASHRAE 62.1-2007 Levels	HVAC	17,916	$5,182	$0	$31,200	6.0	14.2
Replace Desktop Computers with Low-Energy Desktops	Plug Loads	105,911	$30,878	$0	$278,200	9.0	83.9
Replace the Standard Motors with High Efficiency Motors	HVAC	8,101	$2,413	$0	$23,332	9.7	6.4
Replace T-12 Lamps and Magnetic Ballasts with Low Wattage T-8 Lamps andelectronic. Ballasts	Lighting	1,989	$590	$0	$6,143	10.4	1.6
Convert Constant Air Volume Distribution to Variable Air Volume	HVAC	531,573	$141,384	$0	$1,687,966	11.9	419.9
Install Occupancy Sensors in Bathrooms, Conference Rooms, and Private Offices	Lighting	895	$241	$0	$3,016	12.5	0.7
Total		***738,978***	***$204,988***	***$0***	***$2,098,737***	***10.2***	***585.8***

Table 4. Hawaii State Capitol Building Energy Conservation Measures

Energy Conservation Measures	Category	Annual Electricity Savings (kWh/yr)	Annual Cost Savings ($)	Annual Operations and Maintenance Costs ($)	Implementation Costs ($)	Simple Payback Period (yrs)	Greenhouse Gas Reduction (metric tons CO_2e)
Replace the Standard V-Belts with High Efficiency Cogged V-Belts	HVAC	9,542	$3,268	$0	$2,214	0.7	7.6
Replace Refrigerator with ENERGY STAR Refrigerator	Plug Loads	3,279	918	$0	1,014	1.1	2.6
Reduce Ventilation Rates to ASHRAE 62.1-2007 Levels	HVAC	48,955	$15,550	$0	$31,200	2.0	38.7
Activate Computer Power Management	Plug Loads	49,784	$13,940	$8,680	$12,545	2.4	39.5
Convert Constant Air Volume Distribution to Variable Air Volume	HVAC	1,353,035	$407,404	$0	$1,909,720	4.7	1,083.3
Retrofit Metal Halide, Incandescent, and CFL Lighting with LED	Lighting	200,110	$76,142	$0	$415,249	5.5	158.6
Install PV System on the Southeast Lawn	Renewables	285,434	$79,922	$2,250	$523,598	6.7	226.0
Install Occupancy Sensors in Bathrooms, Conference Rooms, and Private Offices	Lighting	5,433	$1,521	$0	$10,556	6.9	4.3
Replace Desktop Computers with Low-Energy Desktop Computers	Plug Loads	59,431	$21,051	$0	$161,200	7.7	47.1
Total		***2,015,003***	***$619,715***	***$10,930***	***$3,067,296***	***5.0***	***1,607.70***

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BACKGROUND

In support of the U.S.–Japan Energy Policy Dialogue, the four participants (the U.S. Department of Energy (DOE), the Japanese Ministry of Economy, Trade and Industry (METI), the State of Hawaii, and the Prefecture of Okinawa) of the Hawaii-Okinawa Partnership on Clean and Efficient Energy Development and Deployment have explored and identified specific joint projects that support both Hawaii's and Okinawa's efforts to develop clean energy economies as well as identified additional areas to explore in the future. There are many countries that are located in subtropical and tropical areas, most of which are rapidly expanding their energy consumption and are in need of energy efficient buildings. Hawaii and Okinawa share this need. However, most work on energy efficient buildings has been done for countries in temperate climates. Therefore, energy efficiency building design, energy efficiency technology, and management protocols for buildings in subtropical and tropical areas offer significant potential for mutually beneficial cooperation.

DOE's National Renewable Energy Laboratory (NREL) is solely dedicated to advancing energy efficient (EE) and renewable energy (RE) technologies and applications. Since its inception, NREL has supported both the federal and the private sectors in implementing EE and RE systems and strategies to lower energy use and to meet remaining energy needs with resources having minimal environmental impact. NREL assistance was requested to conduct energy evaluations at the Itoman City Hall building in Itoman, Okinawa Prefecture, Japan, on March 20–24, 2012, and the Hawaii State Capitol building in Honolulu, Hawaii, on July 23–27, 2012. This report summarizes the findings from the evaluations, including the best practices identified at each site and opportunities for improving energy efficiency and renewable energy in buildings.

Building Description—Itoman City Hall Building

Overview

The Itoman City Hall building is located at 1-1 Shiozakicho Itoman, Okinawa Prefecture, Japan. The five-story building is 166,130 ft^2 (15,434 m^2) and houses approximately 400 occupants. The building's primary function is office space, but it also includes storage, machine rooms, and other types of space. Figure 1 shows an aerial view of the Itoman City Hall building from Google Earth and a photo of the north façade of the building.

Figure 1: Aerial view of Itoman City Hall in Okinawa, Japan; photo of north façade

Left photo: © Google Earth 2012; right photo: Ian Metzger, NREL

Occupancy

The occupancy schedule for the Itoman City Hall building is relatively constant at 8:00 a.m. to 5:00 p.m. Monday through Friday. The building is primarily unoccupied on the weekends.

Building Envelope

The building architecture was based on Chinese geomancy, with an exterior composed of reinforced concrete, concrete flat roof, and shading structures called *Amahaji* (similar to eaves) holding photovoltaic (PV) panels. The building has a square footprint with a central courtyard and auxiliary building branching from the west façade. The fenestration includes a combination of operable and fixed windows, with tints applied to the west-facing windows.

Heating, Ventilation, and Air Conditioning

The heating, ventilation, and air conditioning (HVAC) system is a constant air volume (CAV) system and some spaces have with direct-expansion split systems for supplemental cooling. The HVAC system is scheduled to operate between 8:00 a.m. and 5:00 p.m. on weekdays and be off at night and during the weekends. There is an economizer that economizes based on the outside air temperature.

Cooling Plant

The chilled water system includes three chillers—one 300-kW air-cooled chiller and two 245-kW air-cooled brine chillers for thermal storage. The brine chillers are operated at night to avoid high time-of-use electricity rates. Ice storage tanks on the roof supply cooling during the day, in conjunction with the air-cooled chiller if needed. Chilled water is distributed through constant-speed pumping for the 300-kW chiller and variable-speed pumping for the brine chillers.

Domestic Hot Water

Domestic hot water (DHW) is supplied by distributed electric hot water tanks.

Building Automation System

The HVAC systems, including air-handling units (AHUs), chillers, pumps, and lighting, are controlled by a Johnson Controls building automation system (BAS). Schedules and set points for the various pieces of equipment are implemented through the BAS.

Lighting

A majority of the fixtures use T-8 fluorescent lamps with electronic ballasts. The lighting systems are controlled by the central building automation system. Some less efficient incandescent lamps were also observed in the lobby and display areas.

Plug Loads

The primary electrical plug load in the facility consists of the office equipment. The main office equipment loads are associated with the desktop computer workstations, printers, and copiers. There are a few small data closets throughout the building but no major data centers.

Building Description—Hawaii State Capitol Building

Overview

The Hawaii State Capitol building is located at 415 S. Beretania St., Honolulu, Hawaii. The six-story building is 188,485 ft^2 and houses 300 occupants continuously, and up to approximately 900 occupants when the legislature is in session. The building's primary function is office space, but it also includes auditoriums, conference rooms, and other types of space. Figure 2 shows an aerial view of the Hawaii State Capitol building from Google Earth and a photo of the southeast façade of the building.

Figure 2: Aerial view of Hawaii State Capitol in Honolulu, Hawaii; photo of southeast façade

Left photo: © Google Earth 2012; right photo: Ian Metzger, NREL

Occupancy

The occupancy schedule for the Hawaii State Capitol building is 7:00 a.m. to 4:30 p.m. Monday through Friday when the legislature is not in session (June–November). However, occupant schedules vary widely when the legislature is in session (December–May). The building is primarily unoccupied on the weekends during nonsession times but may be occupied on weekends when the legislature is in session.

Building Envelope

The building architecture reflects the terrain of the islands, with an exterior composed of concrete construction, and a specialized roof. The building has a rectangular footprint with a central courtyard and large underground parking structure. The fenestration includes fixed-pane windows all around the perimeter of the building. Exterior corridors surround the perimeter of the courtyard and connect the legislative offices on common floors.

Heating, Ventilation, and Air Conditioning

The HVAC system is a CAV system but is scheduled to be replaced with a VAV system. The HVAC system is scheduled to operate between 7:00 a.m. and 6:00 p.m. on weekdays and is typically scheduled to be off at night and on weekends when the legislature is not in session. However, the HVAC system may be operated 24 hours per day seven days per week when the legislature is in session.

Cooling Plant
The chilled water system includes three chillers—two 380-ton variable-speed rotary hermetic centrifugal water-cooled chillers and one 250-ton screw chiller for after-hour usage. There are three cooling towers controlled by variable-frequency drives (VFDs) to cool the condenser water. Chillers and cooling towers are operated between 6:00 a.m. and 4:30 p.m. on the weekdays and are typically off at night and on weekends when the legislature is not in session. However, the cooling plant may be operated 24 hours per day seven days per week when the legislature is in session. Chilled water is distributed through variable-speed pumping and premium efficiency pump motors.

Domestic Hot Water
DHW is supplied by distributed electric hot water tanks.

Building Automation System
The HVAC systems, including AHUs, chillers, and pumps, are controlled by a WEBCtrl by Automated Logic BAS. The BAS is currently located on a terminal in the facilities office, which is located in an adjacent building. Schedules and set points for the various pieces of equipment are implemented through the BAS.

Lighting
A majority of the fixtures use T-8 fluorescent lamps with electronic ballasts. However, some less efficient metal halide and halogen lamps were observed in the auditoriums and exterior hallways.

Plug Loads
The primary electrical plug load in the facility consists of the office equipment. The main office equipment loads are associated with the desktop computer workstations, printers, and copiers. There are a few small data closets throughout the building, but no major data centers.

CLIMATE DATA

The city of Itoman, Okinawa Prefecture, Japan, is at an elevation of 9 feet above sea level, and its latitude and longitude are approximately 26.07^{o} north, 127.39^{o} east, respectively. The climate in Itoman features some variations in temperature from season to season with consistently high humidity and precipitation year round.

The Hawaii State Capitol building is located in Honolulu, Hawaii. The city is at an elevation of 24 feet above sea level, and its latitude and longitude are approximately 21.18^{o} north, 157.51^{o} west, respectively. The climate in Honolulu features small variations in temperature from season to season with moderate humidity and precipitation year round.

On average, Honolulu experiences slightly higher average temperature and therefore more cooling degree days[2] than Itoman. However, Itoman experiences higher humidity levels and significantly more precipitation. Table 5 shows the 2011 monthly weather summary for both Itoman and Honolulu.

Table 5. 2011 Historic Weather Summary[3]

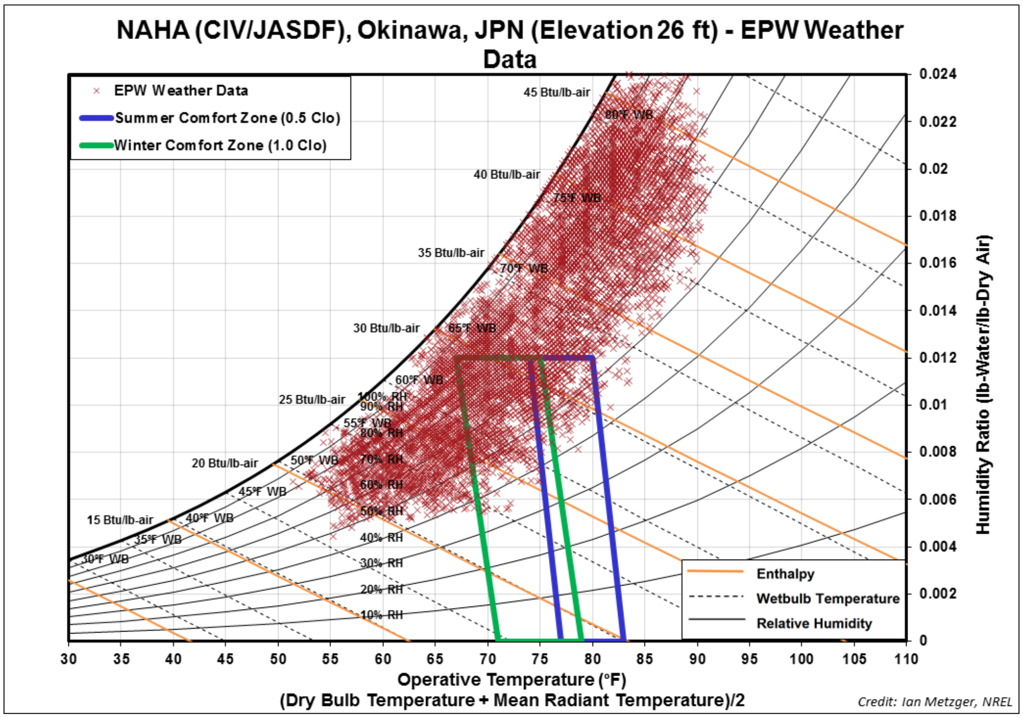
	Itoman, Okinawa Prefecture, Japan				Honolulu, Hawaii, USA			
2011	Average Precip. (inches)	Average Temp. (F)	Cooling Degree Days (65°F)	Average Dew Point (F)	Average Precip. (inches)	Average Temp. (F)	Cooling Degree Days (65°F)	Average Dew Point (F)
Jan	4.9	59	0	47	2.8	74	271	63
Feb	5.0	64	35	54	0.5	75	288	66
Mar	6.3	63	28	50	1.1	77	366	64
Apr	6.5	69	107	57	1.7	78	376	66
May	9.9	75	314	69	2.1	79	435	66
Jun	11.0	82	504	77	1.3	80	449	67
Jul	7.0	84	578	77	0.3	81	489	67
Aug	10.6	83	562	76	0.0	82	518	67
Sep	6.9	82	514	73	0.1	82	499	67
Oct	6.5	78	397	69	0.0	81	490	67
Nov	5.2	75	301	66	0.9	79	425	65
Dec	4.4	66	59	54	0.8	77	359	65
Annual	***84.2***	***73***	***3399***	***64***	***11.7***	***79***	***4965***	***66***

Figure 3 shows the annual hourly typical meteorological year (TMY) plotted on the psychrometric chart. These charts show the higher concentration of humidity and wider

[2] Degree day is a quantitative index of the demand for energy to heat or cool buildings. A mean daily temperature of 65°F is the base for both heating and cooling degree day computations. Source: http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/ddayexp.shtml

[3] Weather Underground Inc. (2012). Accessed October 29, 2012: http://www.wunderground.com.

variation of temperature in Itoman, in contrast to the higher concentration of temperature and wider variation of humidity in Honolulu. High humidity levels and temperatures in both cities create a high cooling demand, which requires mechanical cooling to achieve comfortable working conditions for a majority of hours throughout the year.



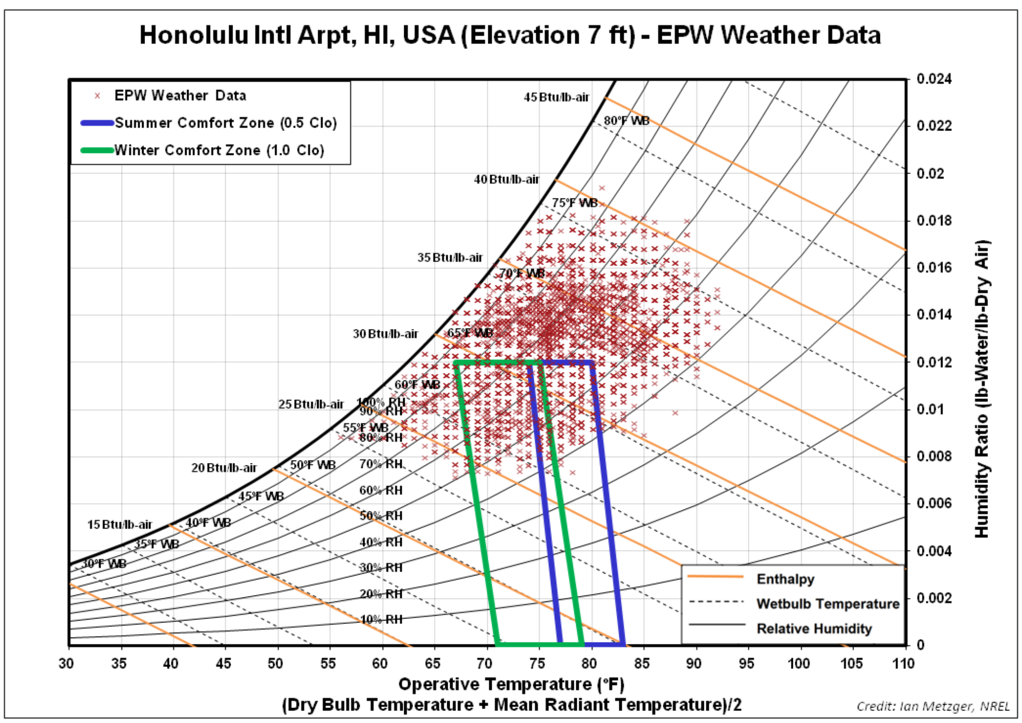
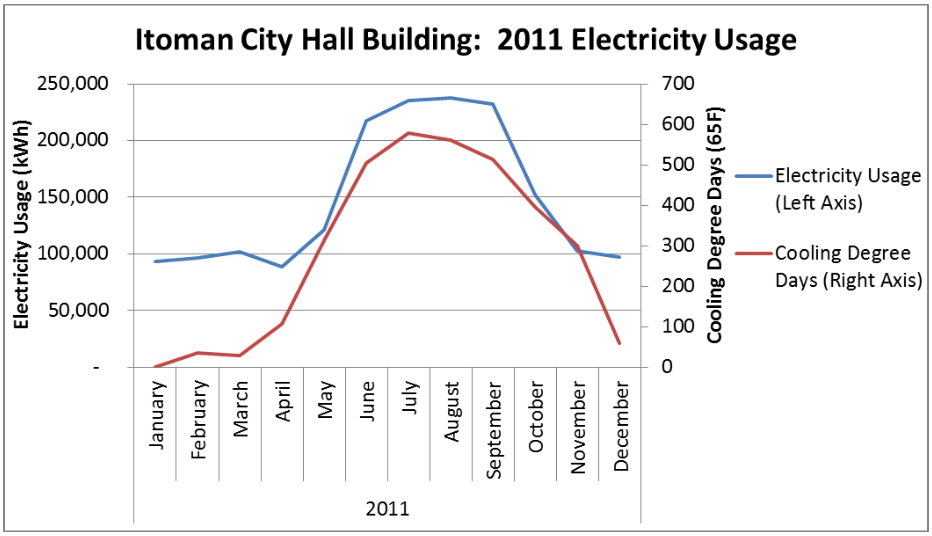


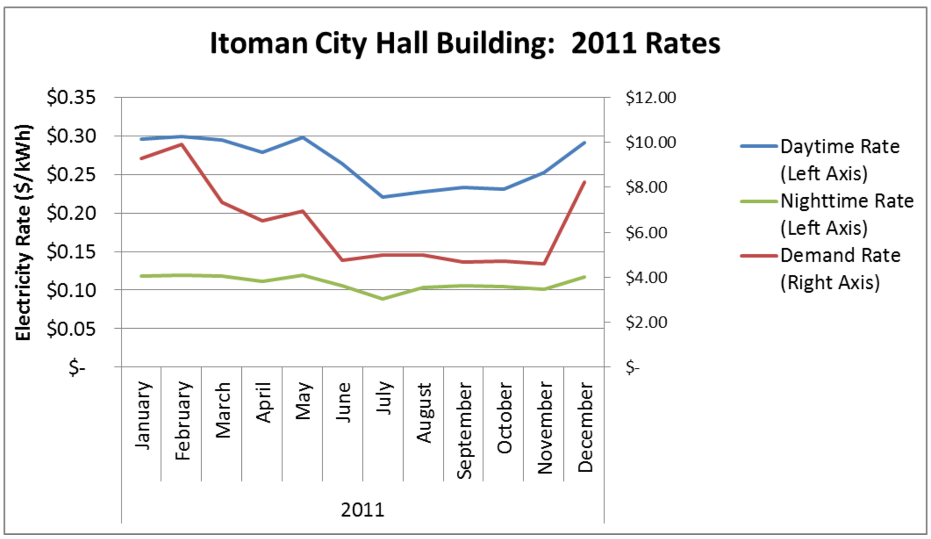
Figure 3. Annual weather data plotted on a psychrometric chart: Itoman (top), Honolulu (bottom)

UTILITY DATA

The electric provider at Itoman City Hall is Okinawa Electric Power Company Inc. (OEPC or OKIDEN). The annual electricity use for the Itoman City Hall in 2011 was 1,777,604 kWh at a cost of $465,848 (39,597,062 Yen). The energy use intensity (EUI) in 2011 was approximately 37 kBtu/ft^2 (115 kWh/m^2), which is significantly lower than the average for an office building in a semitropical climate according to the commercial building energy consumption survey (CBECS). The rate schedule is not a simple blended rate; in 2011 it included a ratcheting demand charge of approximately $6.41/kW, a time-of-use electricity charge with a daytime rate of $0.27 between 6 a.m. and 11p.m. and a nighttime rate of $0.11 between 11 p.m. and 6 a.m., and additional taxes/fees. Figure 4 shows the electricity usage, rate trends, and cost allocations. The electricity usage of the Itoman City Hall building is heavily dependent on the weather conditions. Baseline energy consumption is approximately 100,000 kWh per month and increases to 230,000 kWh per month during the summer months, a 130% increase. The electricity usage follows a trend very similar to the cooling degree days (CDD) which means that the building cooling system is correctly varying with load. The nighttime electrical cost is only 3% of the annual cost, which may be an indication that the thermal storage system is not being utilized at its full potential.

The electric provider at Hawaii State Capitol building is Hawaiian Electric Company (HECO). The current rate schedule is a Schedule P, for large power services greater than 300 kW. The annual electricity use for the Hawaii State Capitol building in 2011 was 4,765,600 kWh at a cost of $1,397,433. The EUI in 2011 was approximately 86 kBtu/ft^2 (271 kWh/m^2), which is average for an office building in a semitropical climate according to the CBECS. The rate schedule is not a simple blended rate; it includes a customer charge of $350/month, a ratcheting demand charge of $19.37/kW, an electricity charge of $0.28/kWh in 2011, and additional taxes/fees. Figure 5 shows the electricity usage, rate trends, and cost allocations. The electricity usage of the Hawaii State Capitol building is heavily dependent on the occupancy schedule of the legislature. When the legislature is in session from December through May, the electricity usage is approximately 27% higher. During the nonsession months, June through November, the building consumes a relatively constant amount of electricity, regardless of outdoor air conditions. This may be an indication that the chilled water system is not varying with load. Upon further investigation of the 2011 hourly trend data provided by NORESCO, it was determined that the VFDs on the chilled water system were operating at full speed when commanded on. Retrocommissioning of the chilled water system is recommended.





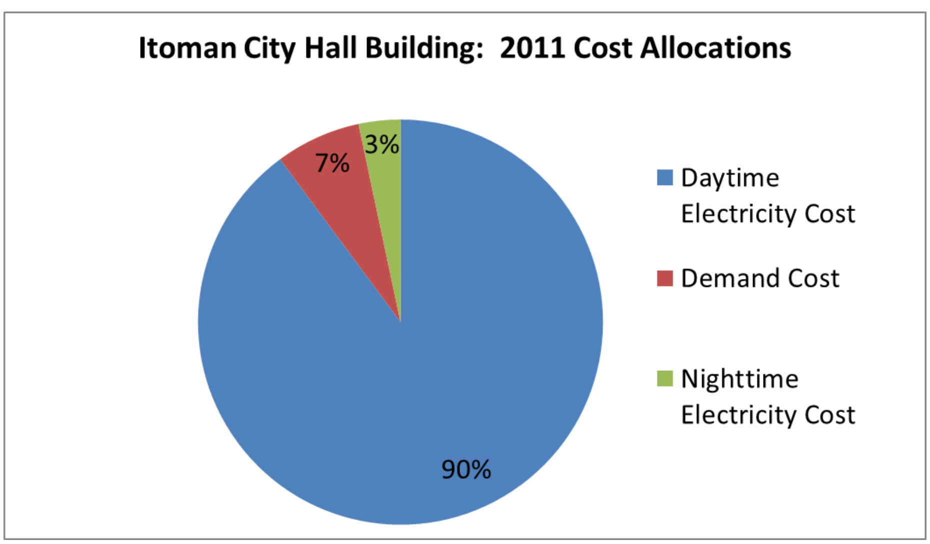
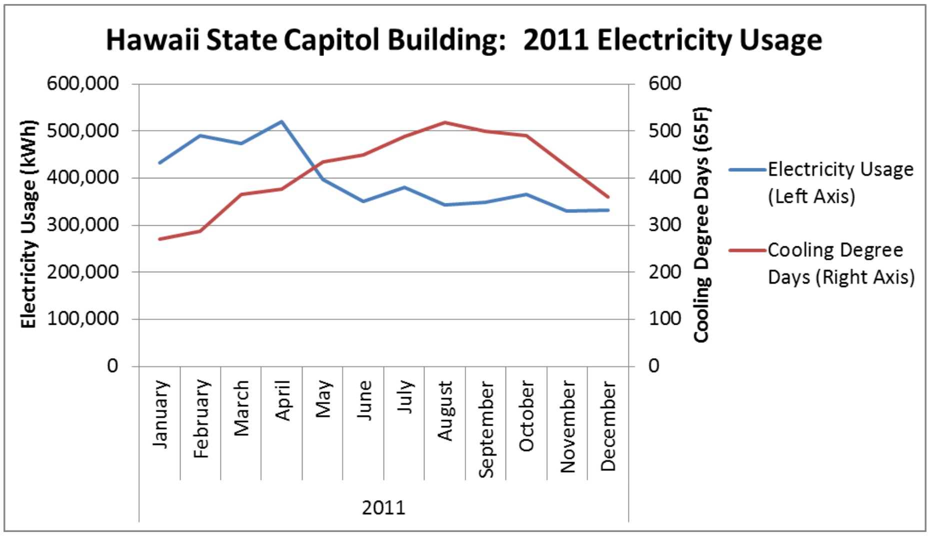
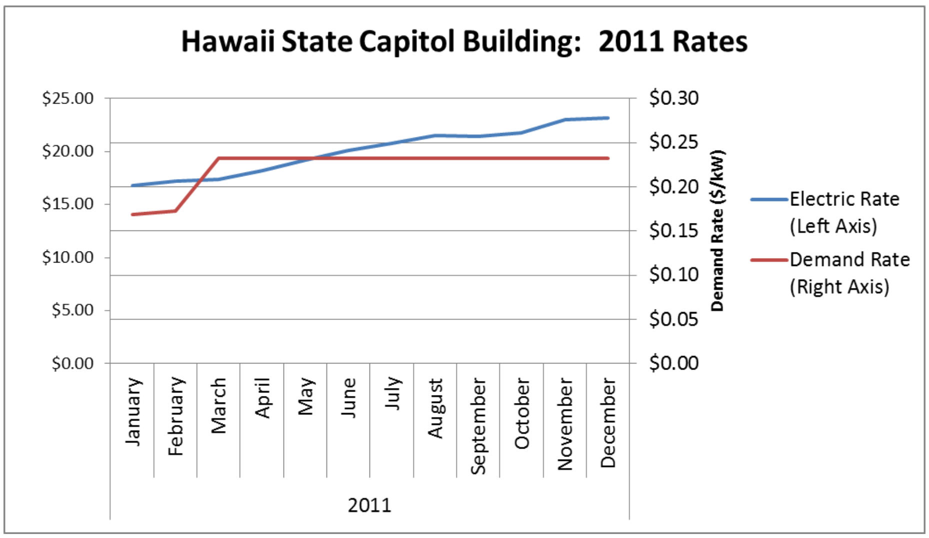


Figure 4. Itoman City Hall electricity usage (top), rates (middle), cost allocation (bottom)





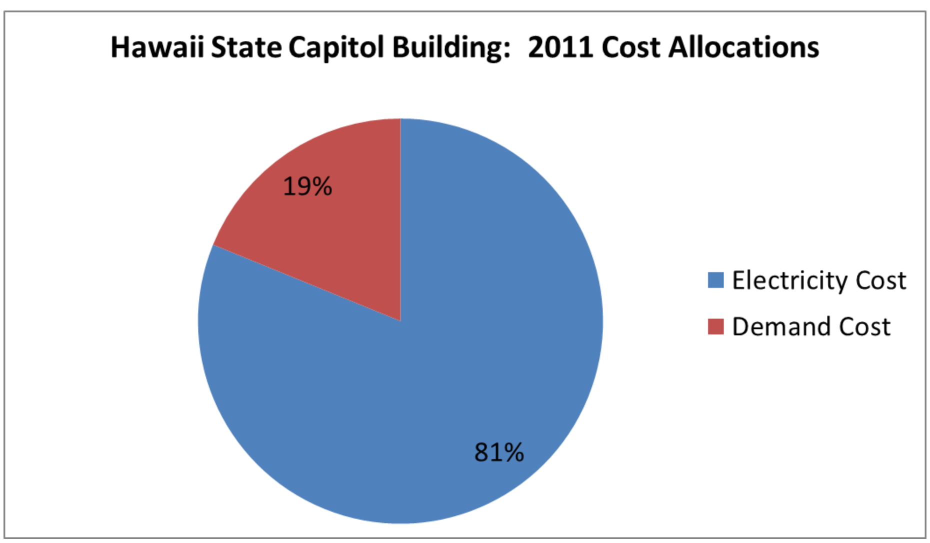


Figure 5. Hawaii State Capitol electricity usage (top), rates (middle), cost allocation (bottom)

BEST PRACTICES AND OBSERVATIONS

50% Design Guide Recommendations

The following list is a summary of recommendations from the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 50% Advanced Energy Design Guide (AEDG) for Small to Medium Office Buildings. This guide outlines design and operating strategies for buildings to achieve 50% energy savings toward net zero. The following recommendations are typically considered for new construction, but several of the concepts can be used in retrofit opportunities.

Integrated Design Process

Create an integrated design team as early as possible, typically during the pre-schematic design phase. Include energy and water efficiency performance in construction contract or owner's project requirements (OPR) and include energy use intensity targets (kBtu/ft^2 or kWh/m^2). Incorporate energy and daylight modeling during the design phase from specialized consultants. Make sure to conduct detailed training for building owners and operators. Utilize enhanced commissioning efforts as well as measurement and verification of performance. Consider using award fee incentive to ensure quality and performance goals are met.

Site Selection

Consider sustainability options when selecting a site, such as land reuse, recycled materials, and public transportation. Orient the building with the long axis parallel to east-west axis for good daylighting. Consider a narrow footprint to allow deeper penetration of daylight and natural ventilation. Minimize ecological impacts (e.g., rainwater runoff).

Envelope

Reduce thermal transmittance with strategies such as continuous insulation and mitigating thermal bridging. Control solar gains with shading devices (east, west, and south facades). Minimize window areas on east and west facades with a whole building target of 20%-40% window-to-wall ratio. Reduce infiltration with strategies such as positive internal pressure and vestibule entrances. Design the roof surface to have high reflectance (greater than 0.7), high emissivity (greater than 0.86), and high solar reflectance index (SRI) (greater than 0.85). Specify fenestration with a low U-value (less than 2.9 W/m^2-K or 0.51 BTU/hr-ft^2-^{o}F) and a low solar heat gain coefficient (SHGC) (less than 0.26). Utilize high thermal mass construction materials to reduce the impacts of peak temperatures.

Figure 6. Example cross section of exterior wall with continuous insulation

Photo by Pat Corkery, NREL/PIX 16763

HVAC
Design HVAC zoning to accommodate different space orientations and use types. Consider radiant cooling with tight envelope and good humidity controls or VAV systems with variable speed drives to reduce fan energy. Utilize central building automation systems to enable controls with scheduling and setbacks for applicable systems. Utilize high efficiency air delivery systems, such as dedicated outside air systems (DOAS) with energy recovery, demand control ventilation, and under-floor air distribution. Install equipment with the highest efficiency available, such as premium efficiency motors and cogged or synchronous V-belts. Consider multistage chillers with high full load energy efficiency ratio (EER) (greater than 10) and high integrated part load value (IPLV) (greater than 12.75). Consider water source heat pumps (WSHP) with high full load EER (greater than 15) and high part load EER (greater than 17.6). Utilize variable-flow pumping for all applicable chilled water distribution.

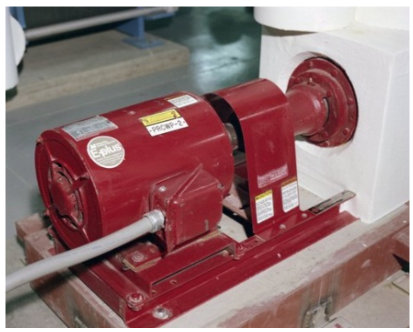


Figure 7. Example of premium efficiency pump motor

Photo by Warren Gretz, NREL/PIX 01208

Service Hot Water
Utilize high efficiency service hot water heaters (greater than 90%). Ensure insulated service hot water distribution pipes. Consider high efficiency heat pump water heaters to simultaneously heat water and cool the surrounding area (greater than 3.0 coefficient of performance [COP]). Consider using on-demand hot water heaters to reduce tank losses and distribution pipe losses.

Figure 8. Example of heat pump service water heater

Photo by NREL/PIX 20289

Lighting
Design the lighting system to have a low lighting power density (LPD) (less than 8.1 watts [W]/m^2 or 0.75 W/ft^2). Utilize high-efficacy lamps (greater than 90 lumens/W). Consider high-performance lensed luminaires and reflectors. Utilize super T8 and T5 linear fluorescent lighting with low ballast factor (BF) electronic ballasts (less than 0.77). Consider LED lights for displays, exterior, and parking lighting. Utilize occupancy and vacancy sensors in all applicable spaces, such as private offices, open offices, restrooms, conference rooms, and break rooms. Consider high color temperature lighting (3,700–4,100 kelvins [K]) for higher perceived brightness. Design the egress lighting to have a low LPD (less than 0.81 W/m^2 or 0.075 W/ft^2). Consider occupancy sensor egress lighting, but consult building codes for compliance requirements. Design the exterior lighting system to have a low LPD (less than 1.1 W/m^2 or 0.1 W/ft^2) and consider timer controls.

Daylighting
Design the building to allow diffuse light through the north façade and redirect the direct light into the space through the south façade. Utilize shading devices on east, west, and south façades. Avoid direct solar heat gain and direct solar glare with tints, light shelves, or louvers. Design daylighting windows to have high visual transmittance (VT), low SHGC, and a high VT/SHGC ratio (greater than 1.1). Design view windows to have low VT to avoid glare and low SHGC. Utilize dimming ballasts on electrical lighting with photocell controls, preferably with electronic program start ballasts and continuous dimming controls. Design space walls and ceilings to have high internal surface reflectance (greater than 80% reflectance).

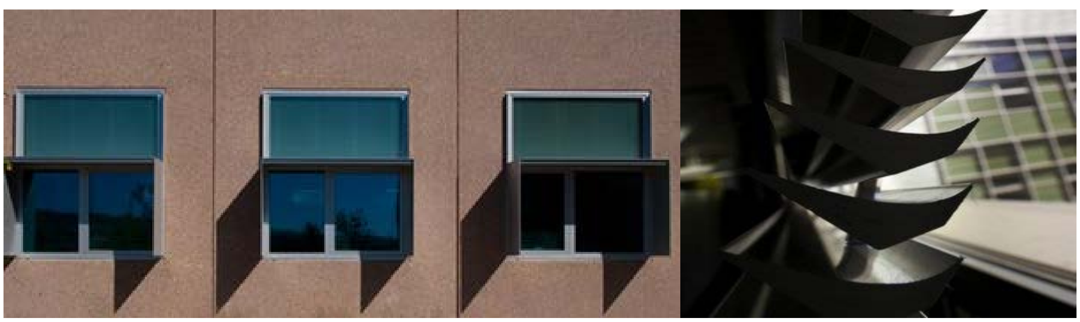


Figure 9. Example of window shading (left) and sunlight redirection device (right)

Photos by Dennis Schroeder NREL/PIX 19798 and 17900

Plug Loads
Design office spaces to have a low equipment power density (EPD) (less than 5.92 W/m^2 or 0.55 W/ft^2). Consider low energy computing options, such as laptops or low-energy desktops. Require procurement standards to include the ENERGY STAR label for all computers, equipment, and appliances. Enable computer power management settings on all computers to “Turn off monitor” after 5 minutes of nonuse, “System standby” after 10 minutes of nonuse, and “Turn off hard disk” set at 10 minutes. Remove vending machine advertising lighting and install misers on all applicable machines. Remove personal printers and consider setting a standard to utilize network printing with 60 occupants per printer. Consider using plug load controls (occupancy, timers) to turn off devices during unoccupied periods. Discourage the use of thermal comfort devices, such as fans or heaters.

Figure 10. Example of various plug load control devices

Photo by Chad Labato, NREL

Water Efficiency

Consider waterless or high efficiency fixtures, such as toilets (less than 1.3 gallons/flush), urinals (less than 0.5 gallons/flush), faucets (less than 1.5 gallons/minute), and shower heads (less than 2.0 gallons/minute). Minimize cooling tower blow down with controls and chemical treatments. Utilize climate-appropriate landscape and consider opportunities for water reuse.

Figure 11. Example of waterless urinal

Photo by NREL/PIX 12313

On-site Generation

Consider installing a PV system, either roof-mounted, ground-mounted, or building-integrated. Utilize solar water heating (non-freeze-protected) for service hot water. Consider other renewable energy systems such as fuel cells, biomass, and wind for on-site electricity generation.

Figure 12. Example of rooftop photovoltaic system

Photo by Dennis Schroeder, NREL/PIX 21582

Summary of Best Practices Observed

Several energy efficiency, water efficiency, and renewable energy best practices were observed during the site visits to Itoman City Hall building and Hawaii State Capitol building. Table 6 shows a summary of the best practices observed during the building evaluations, with those found at both sites listed in the center column.

Table 6. Summary of Best Practices Observed During the Building Evaluations

Itoman City Hall Building	Best Practices Observed at Both Sites	Hawaii State Capitol Building
Energy saving temperature set points (27°C, 80°F)	Knowledgeable, proactive, and competent facilities staff	Cooling tower fan sequencing
Central lighting controls for scheduling	Good preventative maintenance schedules	Premium efficiency motors
No cubicle walls allows better views, ventilation, and daylight penetration	De-lamped lighting fixtures in many spaces	Lighting occupancy sensors in private offices and restrooms
Ice storage system to reduce peak daytime loads	Good shading on exterior of building	Bi-level light switching
Use of rainwater for toilets and urinals	LCD computer monitors	Vending machine misers
Operable windows with cross-ventilation	Central building automation system	Energy awareness and education campaign
Air-side economizer based on outdoor air temperature	T8 and CFL lighting	Low-flow water fixtures
Vestibule doors at entrances	Window tint to reduce solar heat gain	Demand control ventilation
Permeable paving in parking lot	Electronic controls	
195-kW PV system	Well-insulated pipes	
Demand response	High thermal mass building	
	Variable speed drives	
	LED exit signs	

Figure 13. Itoman City Hall building photovoltaic system (left) and cold brine storage (right)

Photos by Ian Metzger, NREL

Figure 14. Energy awareness and education campaign observed at the Hawaii State Capitol building

Photos by Ian Metzger, NREL

Energy Efficiency, Water Efficiency, and Renewable Energy Opportunities

Although several best practices were observed, there were also several energy efficiency, water efficiency, and renewable energy opportunities observed during the site visits to the Itoman City Hall building and Hawaii State Capitol building. Table 7 shows a summary of the opportunities observed during the building evaluations, with the opportunities found at both sites listed in the center column. Detailed descriptions of the current conditions, recommended actions, and energy/cost savings analysis can be found in Appendix A for the Itoman City Hall building and Appendix B for the Hawaii State Capitol building.

Table 7. Summary of Opportunities Observed During the Building Evaluations

Itoman City Hall Building	Opportunities Observed at Both Sites	Hawaii State Capitol Building
De-lamp overilluminated spaces	Install cogged V-belts on all fan drives	Implement computer power management
Install premium efficiency motors on pumps	Convert CAV distribution to VAV system	Procure ENERGY STAR refrigerators
Investigate replacing large chillers with staging units	Reduce ventilation rates to ASHRAE 62.1-2010 levels	Install timers on plug loads
Replace T12 lighting with T8 lamps and electronic ballasts	Replace desktop computers with laptops (or low-energy desktops) during normal replacement cycle	Install PV system on southeast lawn
Install low-flow aerators on faucets	Consolidate the number of networked printers	Consider a solar water heating system
	Replace metal halide, halogen, and CFL lighting with LEDs	
	Install lighting occupancy sensors	

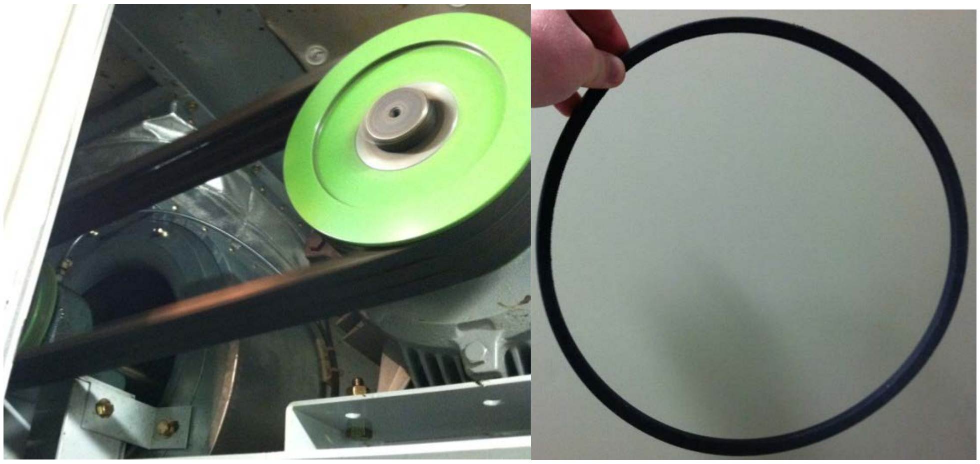


Figure 15. Standard V-belt fan motor drive at Itoman City Hall building

Photos by Ian Metzger, NREL

Figure 16. Nighttime exterior metal halide lighting at Hawaii State Capitol building

Photo by Ian Metzger, NREL

APPENDIX A: DETAILED ENERGY ANALYSIS FOR ITOMAN CITY HALL BUILDING

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 energy conservation measures (ECMs) analyzed for the project. 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, passive heating and cooling strategies, lighting 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 (for thermal and optical properties), internal loads, operating schedules, lighting, HVAC system requirements, and utility rate schedules. The major benefits of eQUEST include the ease of defining building geometry, space characteristics, schedules, and HVAC systems, and the ability to run 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 Itoman City Hall building was created. The existing operating condition of lighting, equipment, and HVAC systems was modeled, including current operating schedules and, as much as possible, 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 17. The geometry of the buildings was simplified for modeling purposes to accurately simulate energy transfer through all surfaces in the building.

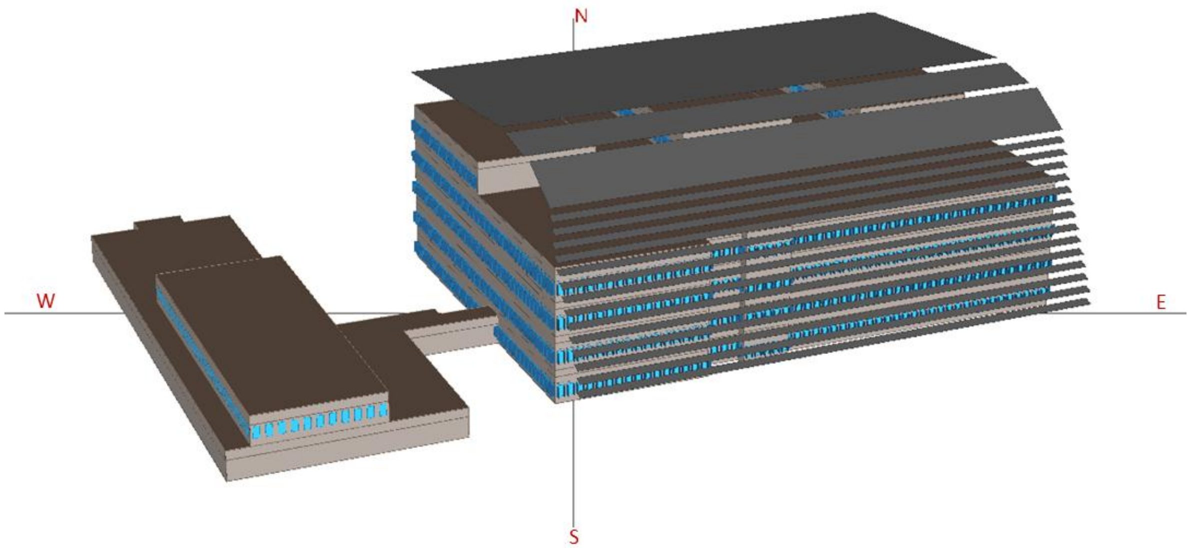


Figure 17. Itoman City Hall building eQUEST model representation

Figure 18 presents the eQUEST output for the calibrated baseline energy model for the Itoman City Hall building. The energy model was calibrated to within 5% of the actual energy use of the building. As shown, cooling energy is the largest energy consumer followed by lighting, plug loads (miscellaneous equipment), and ventilation.

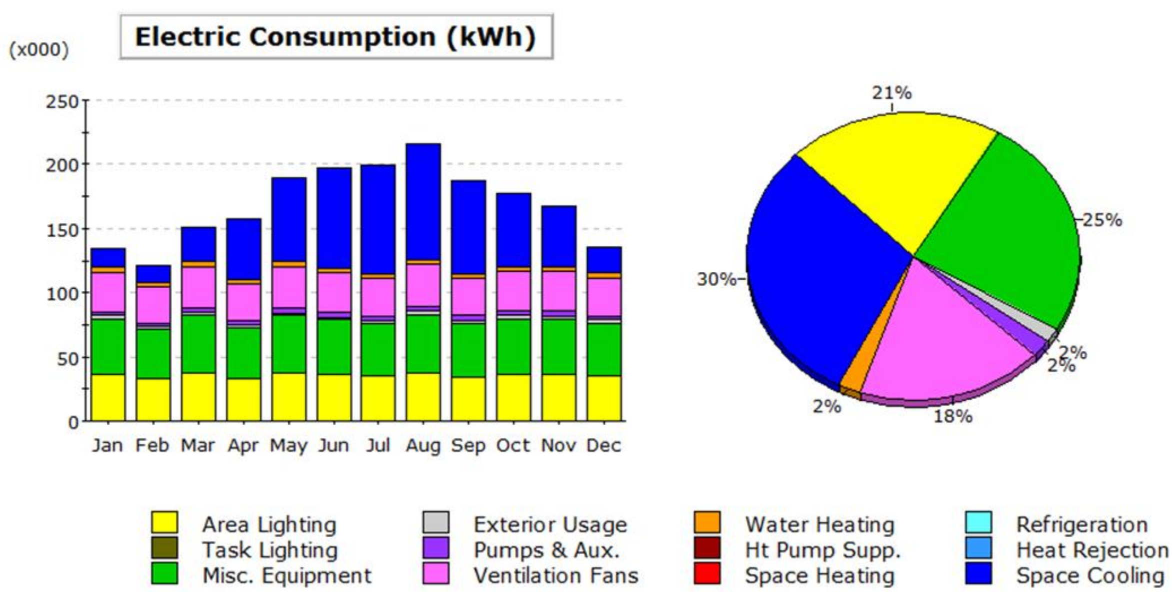


Figure 18. Itoman City Hall building eQUEST model calibrated results for annual energy use

Energy Efficiency and Renewable Energy Opportunities

This section describes the various energy efficiency, water conservation, and renewable energy opportunities observed during the site visit of Itoman City Hall building. The opportunities are organized by building energy system type and describe the current conditions, recommended actions, and energy/cost savings analysis.

HVAC Energy Conservation Measures

Replace Standard V-Belts with Cogged V-Belts

Current Condition: The assessment team only observed a small sample of the AHUs but found standard V-belts on most of the HVAC fan drives. These motors are asynchronous induction motors. The motors are currently operated for an estimated run time of 2,346 hours per year. The typical AHU had a 10-horsepower (Hp) motor and 89.5% efficiency. Each floor was assumed to have to air handlers, and all were assumed to be identical.

Recommended Action: Replace all of 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. This design reduces slip and increases the overall efficiency of the motor-belt-fan drive.

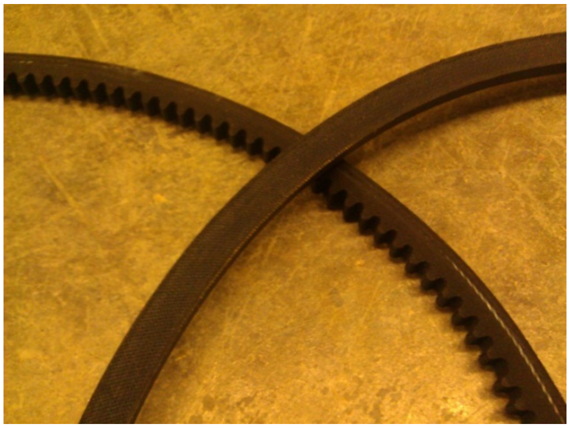


Figure 19. Cogged V-belt (left) and standard V-belt (right)

Photo by Caleb Rockenbaugh, NREL

Cogged V-belts can be used with the same pulleys as equivalent rated V-belts. They 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 8. Energy and Cost Savings Summary for Replacing V-Belts

Energy and Cost Savings	
Electricity Savings (kWh/yr)	5,189
Cost Savings ($/yr)	$1,430
Implementation Costs ($)	$2,210
Simple Payback (years)	1.5
CO_2 Savings (metric tons/yr)	4.1

Assumptions:

- Assumed two air handlers per floor and all are identical
- Assumed standard efficiency for all motors because nameplates did not contain efficiency
- Savings are calculated using a 3% efficiency improvement from the cogged V-belt
- Assumed the motor load to be 75%
- Estimated labor costs at $75/hr x 2 hrs/motor
- Belt costs were estimated at $20/motor
- Energy savings take into account interactions with the cooling systems
- A 30% contingency was added to the implementation cost

Reduce Ventilation Rates to Meet Current Standards

Current Condition: The Itoman City Hall building was originally designed for ventilation rates that are set to approximately 20 cubic feet per minute (cfm) per person or higher. In the past 10 years since the building was designed, ventilation standards have reduced the amount of ventilation air required. It is estimated that the current percentage of outside air is approximately 15% higher than is required by 2012 ventilation standards.

Recommended Action: Reduce ventilation airflow rates to current ventilation standards. It will be necessary to carry out a more detailed engineering analysis to determine required rates for each AHU.

Implementing this ECM includes:

- Carrying out detailed ventilation rate calculations for each AHU
- Rebalancing outside airflow dampers at each AHU.

Table 9. Energy and Cost Savings Summary for Reducing Ventilation Rates

Energy and Cost Savings	
Electricity Savings (kWh/yr)	17,916
Cost Savings ($/yr)	$5,182
Implementation Costs ($)	$31,200
Simple Payback (years)	6.0
CO_2 Savings (metric tons/yr)	14.2

Assumptions:

- The eQUEST energy model was used to estimate the savings from reducing the ventilation rates.
- The ventilation rate was assumed to be reduced by 15%.
- The design of the ventilation rates was assumed to be 40 hours x $200/hr, which totals $8,000.
- The labor time to implement reducing the ventilation rates was assumed to take 120 hours x $100/hr, which totals $12,000.
- Commissioning the AHUs was assumed to take 40 hours x $100/hr, which totals $4,000.
- A 30% contingency was added to the overall cost.

Convert CAV Distribution to VAV

Current Condition: Currently a majority of the spaces at the Itoman City Hall building are served by constant air volume systems. 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 system can adjust the flow rate of conditioned air to the space, saving significant fan energy as well as cooling energy.

Recommended Action: Retrofit the CAV systems at the Itoman City Hall building to a VAV system. This will require converting each CAV box to a VAV box and installing VFDs on the supply and return fans of the air-handling units (AHUs). 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 BAS. The occupants should not be given the ability to modify the temp/RH set points. VAV box damper position should be connected to the BAS.

Table 10. Energy and Cost Savings Summary for Converting CAV to VAV System

Energy and Cost Savings	
Electricity Savings (kWh/yr)	531,573
Cost Savings ($/yr)	$141,384
Implementation Costs ($)	$1,687,966
Simple Payback (years)	11.9
CO_2 Savings (metric tons/yr)	419.9

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings for installing a VAV system that serves the Itoman City Hall building.
- The total area served by the proposed VAV system is estimated to be 166,130 ft^2.
- The building is estimated to have 17 AHUs, based on each AHU serving 10,000 ft^2 of floor area.
- It was assumed that 17 air handlers would have to be converted from CAV to VAV and two VFDs are required per air handler (supply and return).
    - *34 VFDs will be needed at $2,000 each, which totals $68,000.*
- It was assumed that each VAV box could cover 500 sq ft, resulting in an estimated 333 VAV boxes.
- The cost of each VAV box was estimated to be $695 per box, totaling $231,435 for all 333 VAV boxes.
- The labor cost associated with installing the VAV boxes was estimated to be $2,000 per box, totaling $666,000 for all 333 VAV boxes.
- The cost of the control points at each VAV box was estimated to be $1,000 per point, totaling 333,000.
- A 30% contingency was added to the final cost.

Install Premium Efficiency Motors on all HVAC Fan and Pump Motors

Current Condition: The assessment team observed standard efficiency motors driving the majority of HVAC fans/pumps. These motors are asynchronous induction motors; the majority have open, drip-proof enclosures and efficiency ratings below the National Electrical Manufacturers Association (NEMA) Premium efficiency rating. The motors are currently operated for an estimated run time of 2,346 hours annually. It is good practice to install premium efficiency motors when replacing a motor because the slight cost increase is justified by significant savings in energy cost, which is especially true of larger motors that have long operating hours. The following motors were investigated for replacement with NEMA Premium efficiency motors:

Table 11. Existing Motor Inventory

Existing Motors	Quantity	Horsepower	Standard Efficiency	Premium Efficiency
AHU Fan Motors	10	10	89.50%	92.50%
Chilled Water Pumps 3 & 4	2	15	90.50%	93.10%
Chilled Water Pump 5	1	20	91.50%	93.50%

Recommended Action: Replace all of the standard efficiency, three-phase, asynchronous induction motors feeding HVAC fans/pumps. Specify premium efficiency motors with similar enclosure type, speed, mounting, and electrical input.

The Copper Development Association recently introduced a line of ultra-efficient motors into the U.S. market, which exceed NEMA Premium standards. These motors utilize a die-cast copper rotor, which reduces the energy requirements of the motor and allows it to run cooler. The motor also features an improved heat-dissipation system and new low-friction bearings, both of which help extend the life of the motor. The motor also has a smaller weight and size compared to the standard NEMA Premium efficiency motors. The motors are showing efficiency improvements on the order of 3%–10% higher than current NEMA Premium standards.

Table 12. Energy and Cost Savings Summary for Installing Premium Efficiency Motors

Energy and Cost Savings	
Electricity Savings (kWh/yr)	8,101
Cost Savings ($/yr)	$2,413
Implementation Costs ($)	$23,332
Simple Payback (years)	9.7
CO_2 Savings (metric tons/yr)	6.4

Assumptions:

- Assumed two air handlers per floor and all are identical
- Assumed standard efficiency for all motors because nameplates did not contain efficiency
- Calculated energy savings using the MotorMaster+ International software tool
- Assumed the existing motor load was 75% and the proposed motor load was 75%
- Estimated labor costs at $75/hr x 2 hrs/motor
- Estimated motor costs using the MotorMaster database
- Energy savings take into account interactions with the cooling systems
- Added a 30% contingency to the overall cost

Additional HVAC ECMs

Investigate Corrosion-Prevention Options for Chillers

Some of the condensing units located on the rooftop were showing signs of corrosion. The high rate of corrosion may be due to the high salt content in the humid ocean air. Further investigation is required to test corrosion-resistant coating for rooftop equipment.

Consider Replacing Large Chillers with Modular Chillers

Currently, there are three large air-cooled chillers that serve the Itoman City Hall building: one 300-kW air-cooled chiller and two 245-kW air-cooled brine chillers for thermal storage. The two 245-kW brine chillers that are used for thermal storage typically operate at full load when making ice during the night. The 300-kW chiller is typically operating during the day to supplement the cooling provided by the thermal storage system. The 300-kW chiller typically operates at part load, which results in reduced chiller efficiency. Modular chillers have multiple compressors and operate at much higher efficiencies when part loaded.

Lighting Energy Conservation Measures

De-lamp Overilluminated Spaces

Current Condition: The assessment team observed several spaces that were illuminated over the Illuminating Engineering Society's (IES's) recommended levels for office space types. The table below shows the IES-recommended light levels for typical space types.

Table 13. IES-Recommended Light Levels by Task Area

Recommended Light Levels	
Task Area	Foot-candles
Corridors/Stairways/Restrooms	10–20
Storage Rooms	10–50
Conference Rooms	20–50
General Offices	50–100
Drafting/Accounting	100–200
Areas with VDTs	75
Classrooms	50–75
Cafeterias	50
Gymnasiums	30–50
Merchandising	30–150
Manufacturing Assembly	50–500
Parking Areas (uncovered)	1–2

Recommended Action: Using a light meter, de-lamp fixtures in overilluminated spaces until the light levels reach an acceptable range. Educate staff about the recommended light levels and train facilities staff not to "fix" de-lamped fixtures in the future.

Table 14. Energy and Cost Savings Summary for De-Lamping

Energy and Cost Savings	
Electricity Savings (kWh/yr)	6,925
Cost Savings ($/yr)	$1,981
Implementation Costs ($)	$3,413
Simple Payback (years)	1.7
Annual CO_2 Savings (metric tons/yr)	5.5

Assumptions:

- Total number of fixtures de-lamped was estimated to be 70.
- Labor costs were estimated at $75/hr x 30 minutes/fixture.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the implementation cost.

Install Occupancy Sensors in Restrooms

Current Condition: The assessment team observed some spaces where occupancy sensors could be applicable that did not already have them installed. The assessment team observed most spaces already had occupancy sensors; approximately 16 restrooms did not. These spaces had approximately 80, one-lamp, 32-W, T8 fixtures with a total load of 2.6 kW and an estimated operational time of 2,920 hours per year.

Figure 20. Typical wall-switch lighting occupancy sensor
Photo by Dennis Schroeder, NREL/PIX 19323

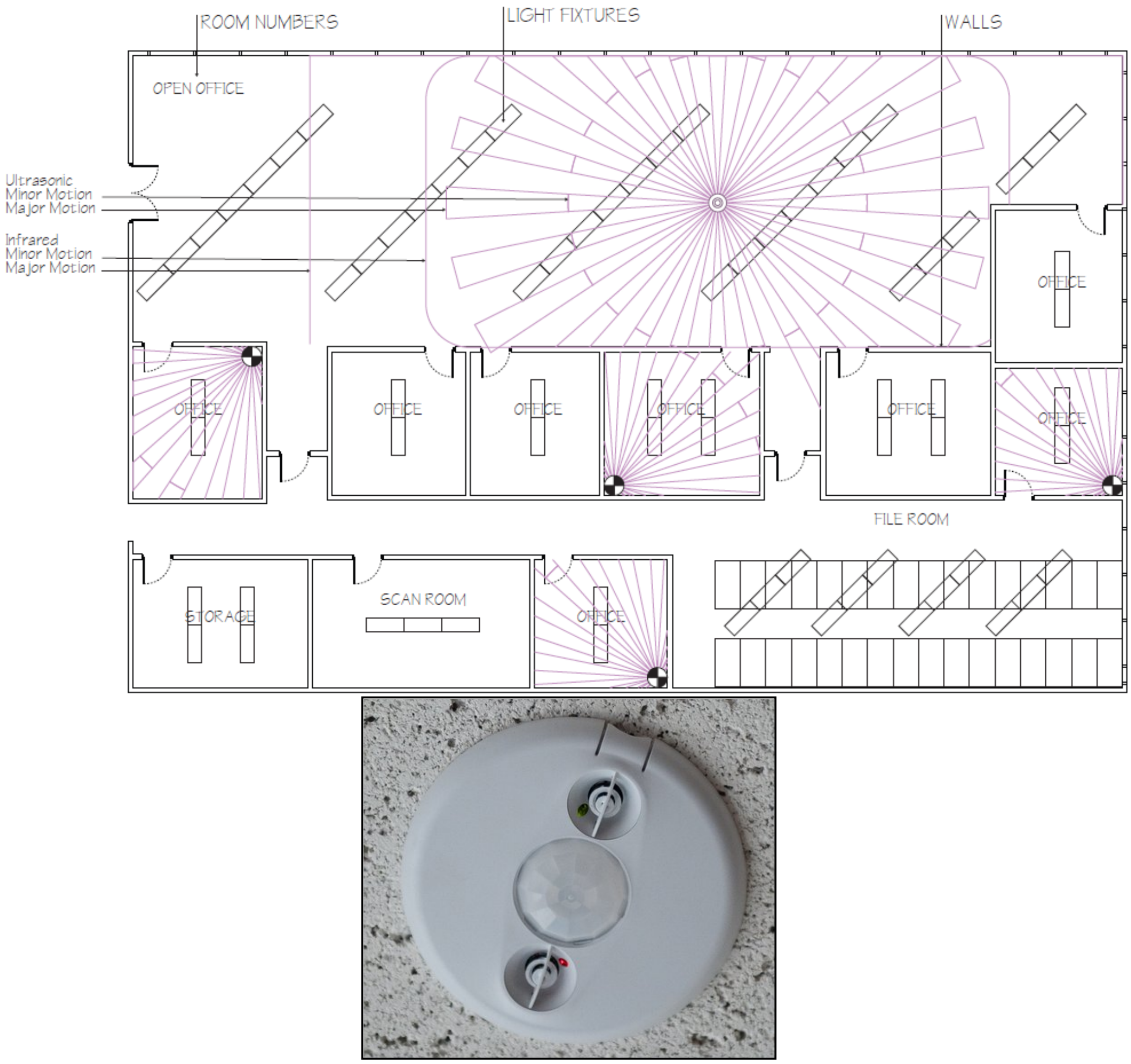


Figure 21. Typical ceiling-mounted lighting occupancy sensor coverage (top) and application (bottom)

Illustration by Josh Bauer, NREL; photo by NREL/PIX 19322

Recommended Action: Install passive electronic sensors to automatically activate and deactivate space-lighting circuits based on occupancy. There are two commonly used sensors: infrared and ultrasonic. Infrared sensors detect occupants by sensing changes in heat patterns as occupants move, while ultrasonic sensors detect physical movement. The type and location of each sensor must be carefully selected for each individual room layout and expected activity. In many instances, a simple wall-switch replacement is adequate. In other cases, a ceiling-mount sensor or wall-mount sensor may provide better coverage. In rooms with multiple lighting circuits or devices, multipole power packs and auxiliary relays can be configured to operate from a single sensor head. In larger spaces, multiple sensors can be wired in parallel to keep all lights on if any one sensor is triggered. This measure will not reduce peak demand but will reduce annual energy consumption.

Table 15. Energy and Cost Savings Summary for Installing Occupancy Sensors

Energy and Cost Savings	
Electricity Savings (kWh/yr)	1,739
Cost Savings ($/yr)	$468
Implementation Costs ($)	$6,032
Simple Payback (years)	12.9
Annual CO_2 Savings (metric tons/yr)	1.4

Assumptions:

- Percent reductions in operating time were estimated to be 30% due to occupancy sensors.
- Labor costs were estimated at $100/hr x 2 hrs/sensor x 16 sensors.
- Occupancy sensor costs were estimated at $90/sensor x 16 sensors.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the implementation cost.

Retrofit Metal Halide and Halogen Lighting with LED

Current Condition: The assessment team observed several metal halide and halogen lamps throughout the building. These lamps use significantly more than the LED-equivalent lamps.

Table 16. Inventory and Location of Existing Lamps

	200-Watt Metal Halide	100-Watt Metal Halide	130-Watt Halogen
Building Façade		26	
Interior Lobby	35		
Second Floor Display Area			31
First and Fourth Floor Offices and Conference Room			35

Recommended Action: It is recommended that a comparison be conducted for replacement of lamps with a substitute ballast and lamp combination utilizing the existing fixture or that of a substitution luminaire (lamp, ballast, and/or fixture) with the existing voltage and circuitry. LED-equivalent lamp wattage and costs are described in the table below.

Table 17. LED-Equivalent Lamp Wattages and Costs

	100-Watt Metal Halide	200-Watt Metal Halide	130-Watt Halogen
LED-Equivalent Wattage	35 Watts	52 Watts	22 Watts
Cost per Lamp	$85.00	$350.00	$250.00

Table 18. Energy and Cost Savings Summary for LED Lighting

Energy and Cost Savings	
Electricity Savings (kWh/yr)	45,982
Cost Savings ($/yr)	$13,227
Implementation Costs ($)	$55,361
Simple Payback (years)	4.2
CO_2 Savings (metric tons/yr)	36.4

Assumptions:
- Labor rates were estimated at $75/hr.
- Labor time was estimated to be 30 minutes per halogen lamp and 2 hours per metal halide lamp.
- Cost savings does not include disposal costs.
- Energy savings take into account interactions with the cooling systems for interior lamps.
- A 30% contingency was added to the overall cost.

Retrofit Remaining T12 Lighting with T8 Lighting and Electronic Ballasts

Current Condition: T-12 lamps with magnetic ballasts were observed scattered throughout the building. The assessment team identified 35 T-12 lamps in use at the time of the site visit with an estimated total connected load of 1.4 kW and an estimated usage of 2,920 hours/year.

Recommended Action: On-site personnel should conduct a survey of the remaining lighting fixtures containing T-12 lamps and magnetic ballasts, and replace them with T-8 lamps and electronic ballasts. Ballasts should be specified to have a BF equal to or less than 0.9.

Table 19. Energy and Cost Savings Summary for T8 Lighting

Energy and Cost Savings	
Electricity Savings (kWh/yr)	1,989
Cost Savings ($/yr)	$590
Implementation Costs ($)	$6,143
Simple Payback (years)	10.4
CO_2 Savings (metric tons/yr)	1.6

Assumptions:
- Labor rates were estimated at $100/hr.
- Labor time was estimated to be 2 hours per fixture.
- Replacement costs were estimated to be $5 per lamp and $30 per fixture.
- Cost savings does not include disposal costs.

- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the overall cost.

Plug-Load Energy Conservation Measures

Replace Desktop Computers with Low-Energy Desktops at Technology Refresh

Current Condition: The assessment team observed approximately 428 desktop computers in the building. Desktop computers use significantly more energy than low-energy desktops with the same processing capabilities. The typical office desktop computer has the following energy characteristics: Active/On Mode = 104 W, Suspended Mode = 15 W, Off Mode = 3 W.

Recommended Action: Convert all desktop computers to low-energy desktops. A typical low-energy desktop computer has the following energy characteristics: Active/On Mode = 19 w, Suspended Mode = 3 w, Off Mode = 2 w.

The analysis for an immediate replacement was found to have an unreasonable payback period; therefore, the desktops should be replaced incrementally at their scheduled time of replacement during the normal technology refresh cycle. The implementation cost incurred with this approach will be the incremental cost of purchasing a low-energy desktop instead of a standard desktop computer.

Table 20. Energy and Cost Savings Summary for Low-Energy Desktops

Energy and Cost Savings	
Electricity Savings (kWh/yr)	105,911
Cost Savings ($/yr)	$30,878
Implementation Costs ($)	$278,200
Simple Payback (years)	9.0
CO_2 Savings (metric tons/yr)	83.9

Assumptions:

- Computers are replaced at the end of their useful life. Labor costs are not included for incremental replacements.
- It was assumed that 95% of the computers were already using computer power management.
- It was assumed that computers are not in use 5% of the time.
- Incremental cost for low-energy desktop compared to standard model is $500/computer.
- Cost savings does not include disposal.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the overall cost.

Consolidate Network Printers

Current Condition: The assessment team observed approximately 67 networked printers and 30 large multifunction printers (print, copy, scan, fax) in the building. These printers use a considerable amount of energy. Currently, the persons-to-printer ratio is about 13:1.

Recommended Action: Consolidate the number of printers and remove unnecessary printers. The assessment team estimates that approximately half of the printers can be removed.

Table 21. Energy and Cost Savings Summary for Low-Energy Desktops

Energy and Cost Savings	
Electricity Savings (kWh/yr)	16,487
Cost Savings ($/yr)	$5,959
Implementation Costs ($)	$4,778
Simple Payback (years)	0.8
CO_2 Savings (metric tons/yr)	13.1

Assumptions:

- It was assumed that 34 network printers and 15 multifunction printers are removed.
- It was assumed that printers are in standby mode 95% of the time.
- Labor costs are estimated to be 1 hour per printer at $75/hour.
- Cost savings does not include disposal or storage costs.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the overall cost.

Water Conservation Measures

Install Low-Flow Aerators on Faucets

Current Condition: The assessment team observed approximately 40 standard efficiency faucets in the building. The baseline water use characteristics were calculated assuming each male occupant washes his hands three times a day and each female occupant washes her hands four times a day. The faucets are standard water faucets with a rated flow rate of 2.5 gallons per minute (gpm).

Recommended Action: Install low-flow aerators on all existing standard faucets. The savings calculation was based on installing aerators on all faucets with 1.5-gpm flow rates.

Table 22. Energy and Cost Savings Summary for Low-Flow Aerators

Energy and Cost Savings	
Water Savings (Gal/yr)	85,167
Cost Savings ($/yr)	$1,703
Implementation Costs ($)	$3,120
Simple Payback (years)	1.8
CO_2 Savings (metric tons/yr)	0.0

Assumptions:

- Assumed 200 male occupants and 200 female occupants
- Assumed a wash duration of 0.17 minutes/wash
- Assumed faucets are used 260 days per year
- Estimated labor costs at $75/hr at 30 minutes per fixture
- Estimated faucet aerator costs at $10/faucet x 40 faucets
- Energy savings were not taken into account
- A 30% contingency was added to the overall cost

Renewable Energy Measures

Investigate Performance Issues of Current PV System

The Itoman City Hall building currently has 195-kW of PV mounted on the roof and façade of the building. The system appears to be operating normally, as shown by the comparison to PVWatts simulation in the Table 23. The simulated annual electricity production has a percent difference of 9% when compared to the actual metered performance. A spot check of the inverter showed efficiencies in the low 90% range. Some maintenance issues have resulted from the high salt content in the humid ocean air, which has caused corrosion. It is recommended that the PV and inverter performance continue to be monitored on a regular basis.

Table 23. Comparison of PV Performance Simulation to Actual

Month	PVWatts Simulation (kWh)	Actual (kWh)
1	8,777	11,771
2	10,444	12,739
3	15,909	15,449
4	17,490	16,103
5	18,604	15,398
6	17,220	19,618
7	19,348	15,029
8	19,410	10,222
9	17,884	12,110
10	13,687	8,301
11	10,775	13,463
12	10,720	15,145
Year	180,268	165,348

APPENDIX B: DETAILED ENERGY ANALYSIS FOR HAWAII STATE CAPITOL BUILDING

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 analyzed for the project. 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, passive heating and cooling strategies, lighting 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 (for thermal and optical properties), internal loads, operating schedules, lighting, HVAC system requirements, and utility rate schedules. The major benefits of eQUEST include the ease of defining building geometry, space characteristics, schedules, and HVAC systems, and the ability to run 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 Hawaii State Capitol building was created. The existing operating condition of lighting, equipment, and HVAC systems was modeled, including current operating schedules and, as much as possible, 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 22. The geometry of the building was simplified for modeling purposes to accurately simulate energy transfer through all surfaces in the building.

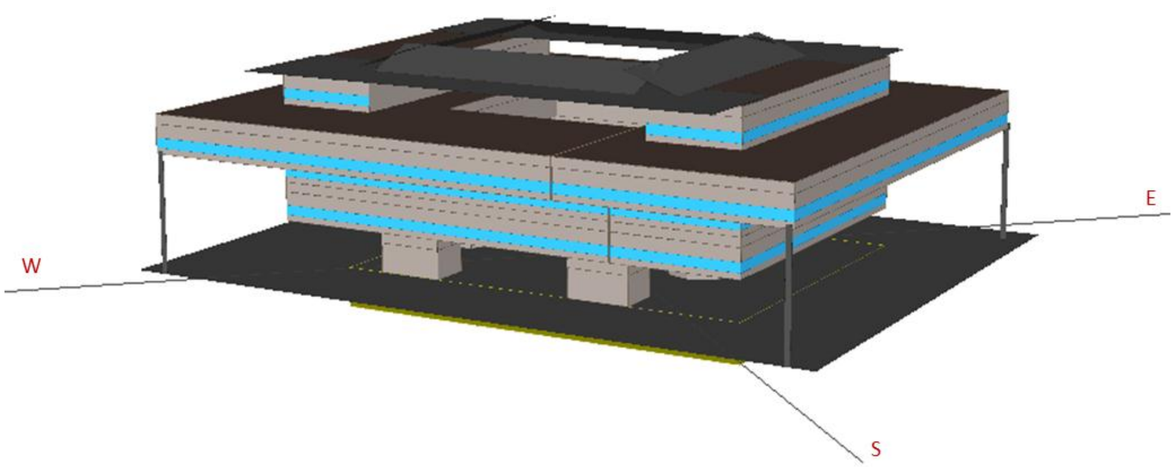


Figure 22. Hawaii State Capitol building eQUEST model representation

Figure 23 presents the eQUEST output for the calibrated baseline energy model for the Hawaii State Capitol building. The energy model was calibrated to within 5% of the actual energy use of the building. As shown, lighting energy is the largest energy consumer followed by plug loads (miscellaneous equipment) and ventilation.

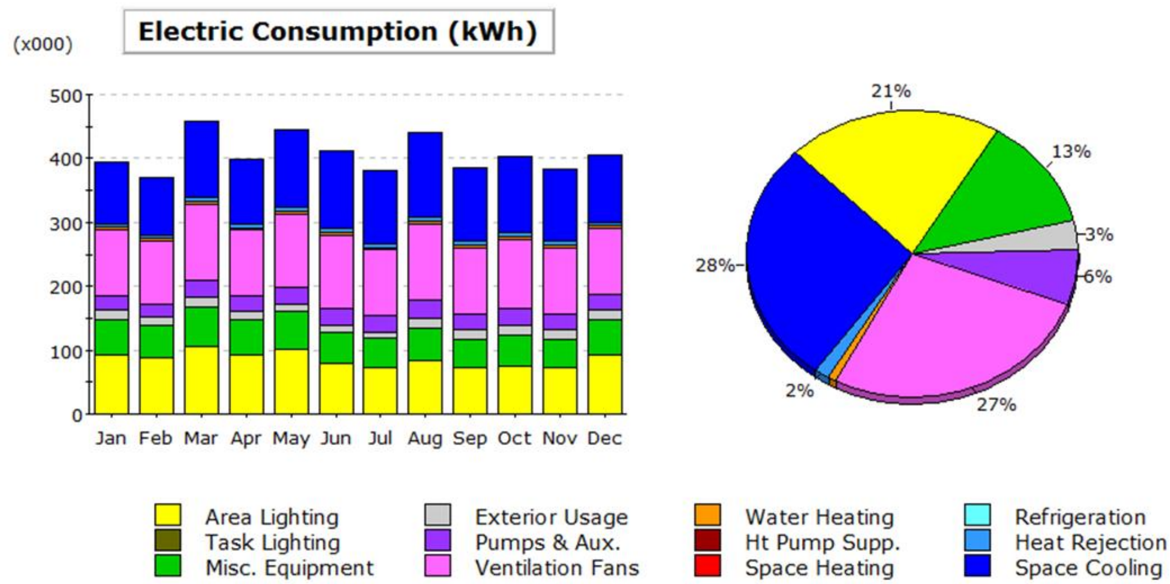


Figure 23. Hawaii State Capitol building eQUEST model calibrated results for annual energy use

Energy Efficiency and Renewable Energy Opportunities

This section describes the various energy efficiency, water conservation, and renewable energy opportunities observed during the site visit of the Hawaii State Capitol building. The opportunities are organized by building energy system type and describe the current conditions, recommended actions, and energy/cost savings analysis.

Heating, Ventilation, and Air-Conditioning (HVAC) Energy Conservation Measures

Replace Standard V-Belts with Cogged V-Belts

Current Condition: The assessment team only observed a small sample of the AHUs but found standard V-belts on most of the HVAC fan drives. These motors are asynchronous induction motors. The motors are currently operated for an estimated run time of 3,129 hours per year.

Table 24. Observed Fan Drives with Standard V-belts

Fan Name	Horsepower	Efficiency
C-11B	3	88.5%
C-8	3.5	88.5%
C-5	15	82.0%
C-4	25	93.6%
C-13A	5	90.2%
C-13B	3	89.5%
C-6	10	92.4%
C-3	10	92.4%
Cooling Tower 1	50	95.0%
Cooling Tower 2	50	95.0%
Cooling Tower 3	50	95.0%

Recommended Action: Replace all of 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. This design reduces slip and increases the overall efficiency of the motor-belt-fan drive.

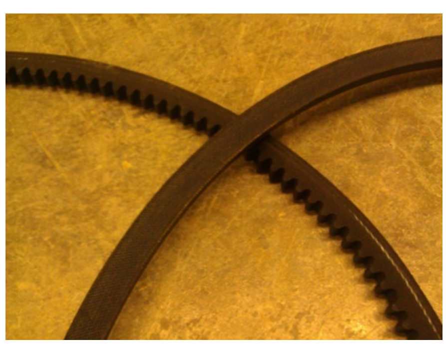


Figure 24. Cogged V-belt (left) and standard V-belt (right)
Photo by Caleb Rockenbaugh, NREL

Cogged V-belts can be used with the same pulleys as equivalent-rated V-belts. They 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 25. Energy and Cost Savings Summary for Replacing V-Belts

Energy and Cost Savings	
Electricity Savings (kWh/yr)	9,542
Cost Savings ($/yr)	$3,268
Implementation Costs ($)	$2,214
Simple Payback (years)	0.7
CO_2 Savings (metric tons/yr)	7.6

Assumptions:

- Savings are calculated using a 3% efficiency improvement from the cogged V-belt.
- The motor load was assumed to be 50%.
- Labor costs were estimated at $75/hr x 2 hrs/motor.
- Belt costs were estimated at $20/motor.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the implementation cost.

Convert CAV Distribution to VAV

Current Condition: Currently a majority of the spaces at the Hawaii State Capitol building are served by CAVs. 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 VAV can adjust the flow rate of conditioned air to the space, saving significant fan energy as well as cooling energy.

Recommended Action: Retrofit the CAV systems at the Hawaii State Capitol building to a VAV system. This will require converting each CAV box to a VAV box, and VFDs will need to be installed on the supply and return fans of the air-handling units. 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 BAS. The occupants should not be given the ability to modify the temp/RH set points. VAV box damper position should be connected to the BAS.

Table 26. Energy and Cost Savings Summary for Converting CAV to VAV System

Energy and Cost Savings	
Electricity Savings (kWh/yr)	1,353,035
Cost Savings ($/yr)	$407,404
Implementation Costs ($)	$1,909,720
Simple Payback (years)	4.7
CO_2 Savings (metric tons/yr)	1,083.3

Assumptions:

- The eQUEST energy model was used to calculate the energy and cost savings for installing a VAV system that serves the Hawaii State Capitol building.
- The total area served by the proposed VAV system is estimated to be 188,485 ft^2.
- The building is estimated to have 19 AHUs, based on each AHU serving 10,000 ft^2 of floor area.
- It was assumed that 19 air handlers would have to be converted from CAV to VAV and that two VFDs are required per air handler (supply and return).
    - *38 VFDs will be needed at $2,000 each, which totals $76,000.*
- It was assumed that each VAV box could cover 500 sq ft, resulting in an estimated 377 VAV boxes.
- The cost of each VAV box was estimated to be $695 per box, totaling $262,015 for all 377 VAV boxes.
- The labor cost associated with installing the VAV boxes was estimated to be $2,000 per box, totaling $754,000 for all 377 VAV boxes.
- The cost of the control points at each VAV box were estimated to be $1,000 per point, totaling $377,000.
- A 30% contingency was added to the final cost.

Reduce Ventilation Rates to ASHRAE 62.1-2007 Levels

Current Condition: The Hawaii State Capitol building was originally designed for ventilation rates that are set to 20 cfm/person or higher. The ventilation rates were taken off the original construction. The current ventilation requirement for offices as specified by ASHRAE 62.1-2007 is 17 cfm/person. Therefore, the percentage of outside air required by ASHRAE is approximately 15% lower than the current ventilation rates.

Recommended Action: Reduce ventilation airflow rates to ASHRAE 62.1-2007 required levels. It will be necessary to carry out a more detailed engineering analysis to determine required rates for each AHU using the ASHRAE ventilation rate procedure. Complying with ASHRAE 62.1-2007 should reduce ventilation airflow rates in the building by approximately 15%. It is estimated that the minimum ventilation rate of the Hawaii State Capitol building could be set to 94,150 cfm.

Implementing this ECM includes:

- Carrying out detailed ventilation rate calculations for each AHU using the ventilation rate procedure in ASHRAE 62.1-2007
- Rebalancing outside airflow dampers at each AHU.

Table 27. Energy and Cost Savings Summary for Reducing Ventilation Rates

Energy and Cost Savings	
Electricity Savings (kWh/yr)	48,955
Cost Savings ($/yr)	$15,550
Implementation Costs ($)	$31,200
Simple Payback (years)	2.0
CO_2 Savings (metric tons/yr)	38.7

Assumptions:

- The eQUEST energy model was used to estimate the savings from reducing the ventilation rates.
- The ventilation rate was assumed to be reduced by 15%.
- The design of the ventilation rates was assumed to be 40 hours x $200/hr, which totals $8,000.
- The labor time to implement reducing the ventilation rates was assumed to take 120 hours $100/hr, which totals $12,000.
- Commissioning the AHUs was assumed to take 40 hours x $100/hr, which totals $4,000.
- A 30% contingency was added to the overall cost.

Lighting Energy Conservation Measures

Install Occupancy Sensors in Conference Rooms and Offices

Current Condition: The assessment team observed several spaces where occupancy sensors could be applicable that did not already have them installed. The assessment team observed that although most spaces already had occupancy sensors, approximately 12 offices and four conference rooms did not. These spaces had approximately 232, two-lamp, 25-W, T8 fixtures with a total load of 10.4 kW and an estimated operational time of 2,920 hours per year.

Figure 25. Typical wall-switch lighting occupancy sensor

Photo by NREL/PIX 19323

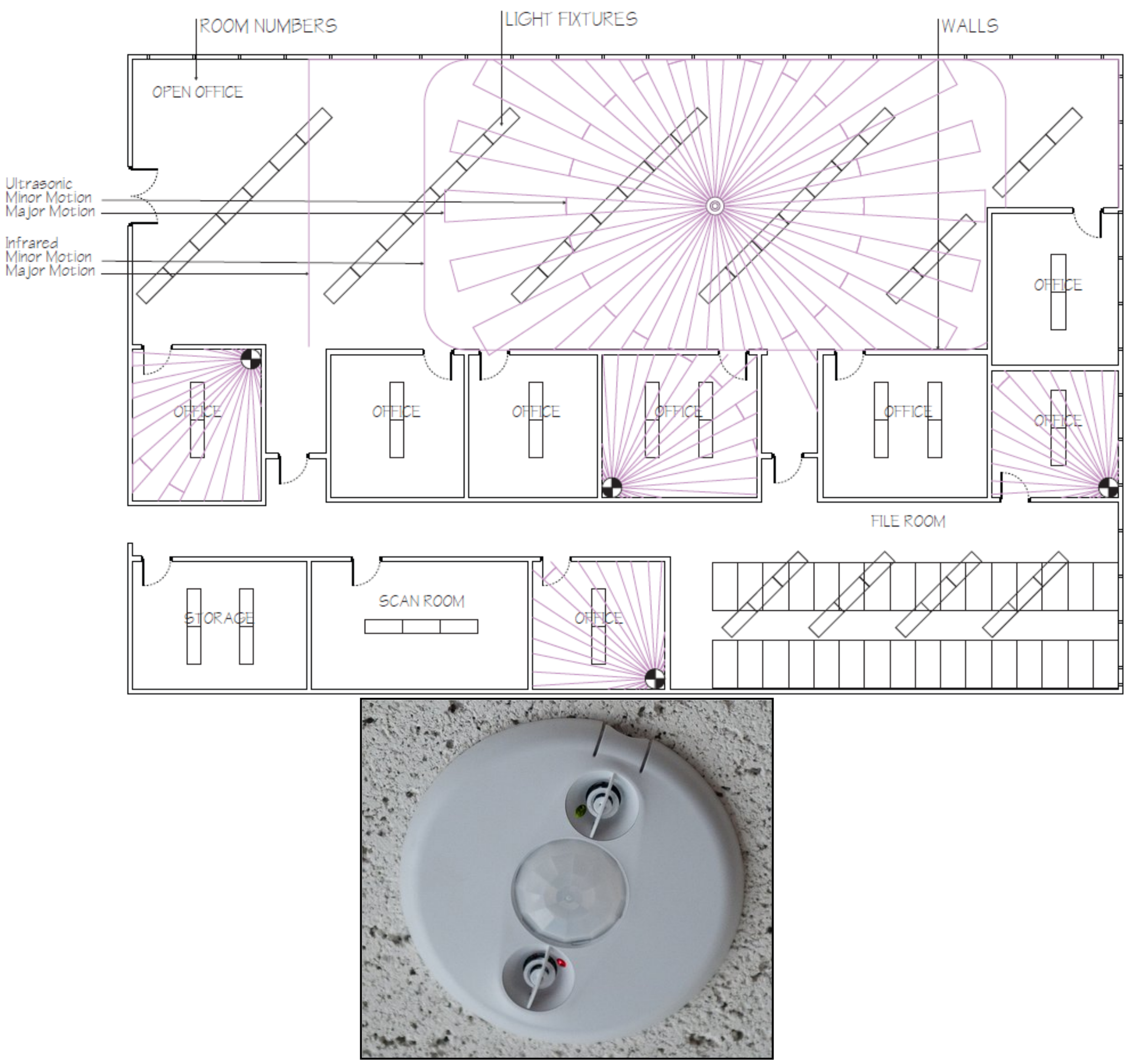


Figure 26. Typical ceiling-mounted lighting occupancy sensor coverage (top) and application (bottom)

Illustration by Joshua Bauer, NREL; photo by NREL/PIX 19322

Recommended Action: Install passive electronic sensors to automatically activate and deactivate space-lighting circuits based on occupancy. There are two commonly used sensors: infrared and ultrasonic. Infrared sensors detect occupants by sensing changes in heat patterns as occupants move, while ultrasonic sensors detect physical movement. The type and location of each sensor must be carefully selected for each individual room layout and expected activity. In many instances, a simple wall-switch replacement is adequate. In other cases a ceiling-mount sensor or wall-mount sensor may provide better coverage. In rooms with multiple lighting circuits or devices, multi-pole power packs and auxiliary relays can be configured to operate from a single sensor head. In larger spaces, multiple sensors can be wired in parallel to keep all lights on if any one sensor is triggered. This measure will not reduce peak demand but will reduce annual energy consumption.

Table 28. Energy and Cost Savings Summary for Installing Occupancy Sensors

Energy and Cost Savings	
Electricity Savings (kWh/yr)	5,433
Cost Savings ($/yr)	$1,521
Implementation Costs ($)	$10,556
Simple Payback (years)	6.9
Annual CO2 Savings (metric tons/yr)	4.3

Assumptions:

- Percent reductions in operating time were estimated to be 15% due to occupancy sensors.
- Labor costs were estimated at $100/hr x 2 hrs/sensor x 28 sensors.
- Occupancy sensor costs were estimated at $90/sensor x 28 sensors.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the implementation cost.

Retrofit Metal Halide, Incandescent, and CFL Lighting with LED

Current Condition: The assessment team observed several metal halide, incandescent, and high-wattage CFL lamps throughout the building. Each light uses significantly more than the LED-equivalent lamps.

Table 29. Inventory and Location of Existing Lamps

	70-Watt Metal Halide	175-Watt Metal Halide	90-Watt Incandescent	150-Watt Halogen	28-Watt CFL, 2-Lamp Can Fixture
Exterior Corridors	551				18
House and Senate Chambers		430			
Governor and Lt. Governor Offices			108		128
Auditorium			24	24	

Recommended Action: It is recommended that a comparison be conducted for replacement of lamps with a substitute ballast and lamp combination utilizing the existing fixture or that of a substitution luminaire (lamp, ballast, and/or fixture) with the existing voltage and circuitry. LED-equivalent lamp wattage and costs are described in the table below.

Table 30. LED-Equivalent Lamp Wattages and Costs

	70-Watt Metal Halide	175-Watt Metal Halide	90-Watt Incandescent	150-Watt Halogen	28-Watt CFL, 2-Lamp Can Fixture
LED-Equivalent Wattage	35 Watts	52 Watts	20 Watts	22 Watts	7 Watts
Cost per Lamp	$85.00	$350.00	$60.00	$250.00	$40.00

Table 31. Energy and Cost Savings Summary for LED Lighting

Energy and Cost Savings	
Electricity Savings (kWh/yr)	200,110
Cost Savings ($/yr)	$76,142
Implementation Costs ($)	$415,249
Simple Payback (years)	5.5
CO_2 Savings (metric tons/yr)	158.6

Assumptions:

- Labor rates were estimated at $75/hr.
- Labor time was estimated to be 30 minutes per lamp, except labor for the chambers, which was estimated to be two hours per lamp.
- Energy savings take into account interactions with the cooling systems for interior lamps
- A 30% contingency was added to the overall cost.

Plug-Load Energy Conservation Measures

Replace Refrigerators with ENERGY STAR Refrigerators

Current Condition: The assessment team observed approximately 26 large refrigerators in the building. The refrigerators were older models (top-mount freezer without through-the-door ice) and were not ENERGY STAR rated. These refrigerators tend to use 20% more energy than newer ENERGY STAR models.

Recommended Action: Replace all older refrigerators with newer ENERGY STAR-rated refrigerators incrementally as the older models approach the end of their useful life.
The analysis for an immediate replacement was found to have an unreasonable payback period; therefore, the refrigerators should be replaced incrementally at their scheduled time of

replacement during the normal technology refresh cycle. The implementation cost incurred with this approach will be the incremental cost of purchasing an ENERGY STAR refrigerator instead of a standard refrigerator (approximately $30).

Table 32. Energy and Cost Savings Summary for ENERGY STAR-Rated Refrigerators

Energy and Cost Savings	
Electricity Savings (kWh/yr)	3,279
Cost Savings ($/yr)	$918
Implementation Costs ($)	$1,014
Simple Payback (years)	1.1
CO_2 Savings (metric tons/yr)	2.6

Assumptions:

- Refrigerators are replaced at the end of their useful life. Labor costs are not included for incremental replacements.
- Incremental costs of ENERGY STAR model compared to standard model was estimated to be $30.
- O&M cost increase was estimated to be $0/year.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the overall cost.

Activate Computer Power Management

Current Condition: The facility has approximately 248 desktop computers. Many desktop computers are left running around the clock. There are several commercial computer power management software vendors, such as Surveyor, EZ Save, EZ GPO, Energy Saver Pro, and Night Watchman. These software programs are centrally administered programs that perform the following functions: (1) poll computers on a network to determine each monitor and computer's power management settings; (2) generate reports on the result of the polling; (3) set appropriate power management settings on monitors and computers on the network; and (4) set appropriate screen-saver settings on monitors on the network so that users retain screen-saver images.

Recommended Action: Select a vendor to meet site-specific needs. Once a vendor is selected, the computer power management software should be centrally administered to all network computers. Although the assessment team cannot endorse a specific vendor, for this analysis, it is assumed the site would implement the Surveyor software program.

Table 33. Energy and Cost Savings Summary for Activating Computer Power Management

Energy and Cost Savings	
Electricity Savings (kWh/yr)	49,784
Cost Savings ($/yr)	$13,940
Implementation Costs ($)	$12,545
Simple Payback (years)	2.4
CO_2 Savings (metric tons/yr)	39.5

Assumptions:

- It was assumed 20% of the computers were already using computer power management.
- It was assumed that computers are not in use 58% of the time.
- Labor costs were estimated at $75/hr x 0.25 hrs/computer x 248 computers.
- Computer power management software costs were estimated at $13,940 with license renewal costs of $8,680/year. Management software costs were calculated from a general installation cost $5,000 and an additional $25 per computer for licenses.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the overall cost.

Replace Desktop Computers with Low-Energy Desktops at Technology Refresh

Current Condition: The assessment team observed approximately 248 desktop computers in the building. Desktop computers use significantly more energy than low-energy desktops with the same processing capabilities. The typical office desktop computer has the following energy characteristics: active/on mode = 104 W, suspended mode = 15 W, off mode = 3 W.

Recommended Action: Convert all desktop computers to low-energy desktops. A typical low-energy desktop computer has the following energy characteristics: active/on mode = 19 W, suspended mode = 3 W, off mode = 2 W.

The analysis for an immediate replacement was found to have an unreasonable payback period; therefore, the desktops should be replaced incrementally at their scheduled time of replacement during the normal technology refresh cycle. The implementation cost incurred with this approach will be the incremental cost of purchasing a low-energy desktop instead of a standard desktop computer.

Table 34. Energy and Cost Savings Summary for Low-Energy Desktops

Energy and Cost Savings	
Electricity Savings (kWh/yr)	59,431
Cost Savings ($/yr)	$21,051
Implementation Costs ($)	$161,200
Simple Payback (years)	7.7
CO_2 Savings (metric tons/yr)	47.1

Assumptions:

- Computers are replaced at the end of their useful life. Labor costs are not included for incremental replacements.
- It was assumed that 20% of the computers were already using computer power management.
- It was assumed that computers are not in use 58% of the time.
- Incremental cost for low-energy desktop compared to standard model is $500/computer.
- Cost savings does not include disposal.
- Energy savings take into account interactions with the cooling systems.
- A 30% contingency was added to the overall cost.

Additional Plug-Load ECMs

Remove Personal Printers and Utilize Network Printers

Considering the nature of work being done at the Hawaii State Capitol building, certain personal printers are required. Personal printers that are in place but not required for security or data-sensitivity reasons should be removed. Removal of each personal printer could result in a savings of 150 kWh/yr.

Install Occupancy-Sensing Power Strips

Additional energy savings can be obtained by using occupancy-controlled power strips to power the under-cabinet fixtures and any additional equipment that employees might have at their desks. The occupancy sensors detect when the office is vacant and will shut off the equipment powered by the strip.

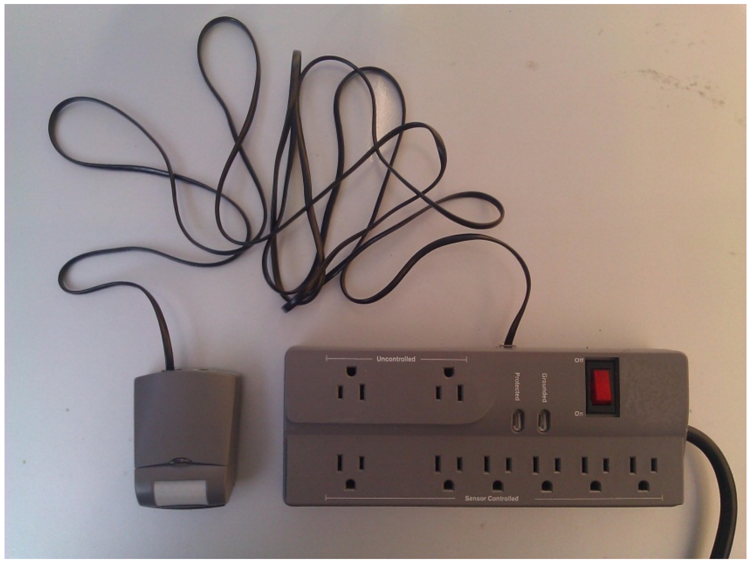


Figure 27. Plug-load occupancy sensor

Photo by Caleb Rockenbaugh, NREL

Typical occupancy-controlled power strips have five receptacles controlled by the occupancy sensor and three standard receptacles. The cost of the occupancy controlled power strips is approximately $50–$70 per device. Given the high variation of occupancy depending on whether the legislature is in session, these devices could significantly reduce standby plug loads.

Renewable Energy Measures

Install Photovoltaic System on the Southeast Lawn

Photovoltaic Systems[4]

Photovoltaics are semiconductor devices that convert sunlight directly into electricity. They do so without any moving parts and without generating any noise or pollution. They must be mounted in an unshaded location; rooftops, carports, and ground-mounted arrays are common mounting locations.

The amount of energy produced by a panel depends on several factors. These factors include the type of collector, the tilt and azimuth of the collector, the temperature, and the level of sunlight and weather conditions. An inverter is required to convert the direct current (DC) to alternating current (AC) of the desired voltage compatible with building and utility power systems. The balance of the system consists of conductors/conduit, switches, disconnects, and fuses. Grid-connected PV systems feed power into the facility's electrical system and do not include batteries.

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[4] Lisell, L.; Mosey, G. *Feasibility Study of Economics and Performance of Solar Photovoltaics in Nitro, West Virginia.* NREL/TP-6A2-48594. Golden, CO: NREL (2010). Accessed June 6, 2012: http://www.nrel.gov/docs/fy10osti/48594.pdf.

The PV systems have the following components:

- PV arrays, which convert light energy to DC electricity
- Inverters, which convert DC to AC and provide important safety, monitoring, and control functions
- Various wiring, mounting hardware, combiner boxes
- Monitoring equipment

Figure 28 below shows the major components of a grid-connected PV system and illustrates how these components are interconnected.

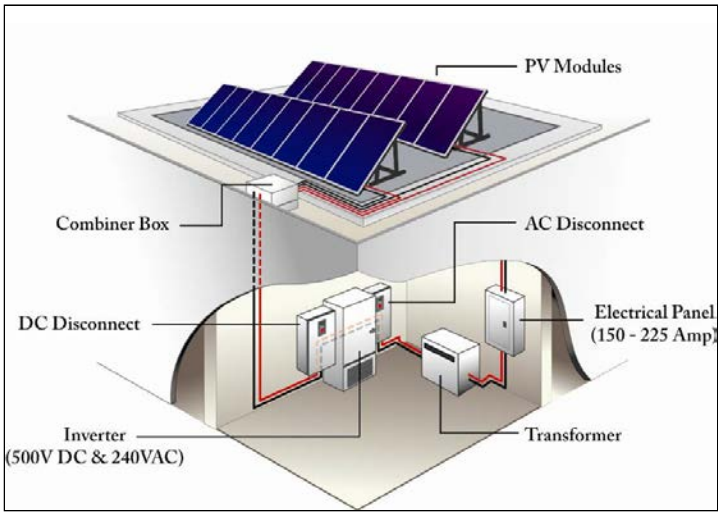

Figure 28. Major components of grid-connected PV system
Illustration by Jim Leyshon, NREL

PV panels are very sensitive to shading. When shade falls on a panel, that portion of the panel is no longer able to collect the high-energy beam radiation from the sun. PV panels are made up of many individual cells that all produce a small amount of current and voltage. These individual cells are connected in series to produce a larger current. If an individual cell is shaded, it will act as a resistance to the whole series circuit, impeding current flow and dissipating power rather than producing power.

Ground-Mounted Systems: In many cases, the ground is the best location for a PV system. Ground-mounted systems are usually less expensive than roof-mounted systems. Large areas with minimal shading obstructions such as trees or other buildings are preferred. A typical ground-mounted rack system can achieve power densities on the order of 8 DC watts/ft^2, for a crystalline silicon panel.

PV Array: The primary component of a PV system, the PV array, converts sunlight to electrical energy; all other components simply condition or control energy use. Most PV arrays consist of interconnected PV modules that range in size from 50 to 300 peak DC watts. Peak watts are the rated output of PV modules at standard operating conditions of 25°C (77°F) and insolation of 1,000 w/m^2. Because these standard operating conditions are nearly ideal, the actual output will be less under typical environmental conditions. PV modules are the most reliable components in any PV system. They have been engineered to withstand extreme temperatures, severe winds, and impacts. ASTM E 1038-93 subjects modules to impacts from 1-inch hail balls at terminal velocity (55 mph) at various parts of the module. PV modules have a life expectancy of 20–30 years, and manufacturers warranty them against power degradation for 25 years. The array is usually the most expensive component of a PV system; it accounts for approximately two-thirds of the cost of a grid-connected system. There is a large choice of PV manufacturers, although it is recommended that the PV be approved by Go Solar California.[5]

Inverters: PV arrays provide DC power at a voltage dependent on the configuration of the array. This power is converted to AC at the required voltage and number of phases by the inverter. Inverters enable the operation of commonly used equipment such as appliances, computers, office equipment, and motors. Current inverter technology provides true sine wave power at a quality often better than that of the serving utility. A location for the inverter along with the balance of the system equipment should be considered.

Inverters are available that include most or all of the control systems required for operation, including some metering and data-logging capability. Inverters must provide several operational and safety functions for interconnection with the utility system. The Institute of Electrical and Electronic Engineers Inc. (IEEE) maintains standard "P929 Recommended Practice for Utility Interface of Photovoltaic (PV) Systems," which allows manufacturers to write "Utility-Interactive" on the listing label if an inverter meets the requirements of frequency and voltage limits, power quality, and nonislanding inverter testing. Underwriters Laboratory maintains "UL Standard 1741, Standard for Static Inverters and Charge Controllers for Use in Photovoltaic Power Systems," which incorporates the testing required by IEEE 929 and includes design (type) testing and production testing. There is a large choice of inverter manufacturers, although it is recommended that the inverter be approved by Go Solar California.[6]

Operations and Maintenance (O&M): The PV panels will come with a 25-year performance warranty; the inverters come standard with a 5- or 10-year warranty (extended warranties available) and would be expected to last 10–15 years. System performance should be verified on a vendor-provided website. Wire and rack connections should be checked. For this economic analysis, an annual O&M cost of $12.50/kW is based on O&M cost of other fixed-axis, grid-tied PV systems.

Simulation Methodology

The PV system is assumed to be a standard crystalline silicon panel. Panel and rack manufacturers should be consulted to confirm the rated wind load for mounting systems. Also, the roof condition should be examined. Figure 29 shows a Google Earth image of the available ground area at the most plausible site for a solar system.

[5] Go Solar California: http://www.gosolarcalifornia.org/equipment/pvmodule.php

[6] Go Solar California: http://www.gosolarcalifornia.org/equipment/inverter.php

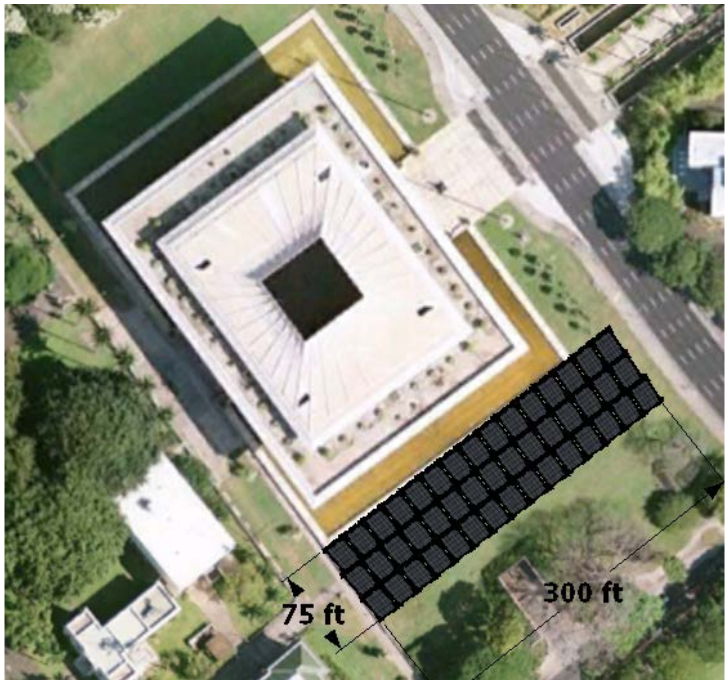

Figure 29. Available ground area for a PV system at the Hawaii State Capitol building

Photo © Google Earth 2012 (edited by Ian Metzger, NREL)

Total available roof area for solar PV observed at the Hawaii State Capitol building was 22,500 ft^2 with an azimuth angle of approximately 30^o east of south. No major shading obstructions were observed, and greater than 90% solar availability was maintained for the available area.

Results: Table 35 shows the simulation results for the ground-mounted PV system that maximizes area for PV. Results show a simple payback period of 6.7 years, which includes the federal ITC of 30% and the state of Hawaii tax credit of 35% for a maximum of $500,000. The resulting system size is estimated to be 180 kW. PV systems visible from outside of the Hawaii State Capitol building could have the added benefits of good public relations and high visibility.

Table 35. PV System Specifications and Results

Metric	Value
System Size	22,500 ft^2
Number of Panels	1,031 (14 ft^2 each)
Panel Tilt	20^o
Estimated Unit Cost	$6.24/w
Capacity	180 kW
Electricity Production	285,434 kWh/yr
Cost Savings	$79,922
Implementation Costs	$1,150,766
Federal Incentives (30% ITC)	$345,230
State Incentive (35% ITC)	$281,937
Total Incentives	$627,167
Implementation Cost with Incentives	$523,598
Simple Payback (without Incentives)	14.5 years
Simple Payback (with Incentives)	6.7 years
CO_2 Savings	226 metric tons

Assumptions:

- Energy savings were calculated using SolOpt simulation software developed at NREL.
  - Weather data for Honolulu, Hawaii, was used for the simulation.
- A blended electric rate of $0.28 /kWh was assumed.
- Incentives included the federal ITC of 30%.
- Incentives included the State of Hawaii tax credit of 35% for a maximum of $500,000.
- System costs were estimated based on costs curves developed by NREL.
- A 30% contingency was added to the implementation cost.

Incentives, Net Metering, and Financing

The Database of State Incentives for Renewables and Efficiency (DSIRE)[7] provides a summary of interconnection, net metering, and other incentives. Identifying and leveraging federal, state, and local utility incentives and grants are important factors in making PV systems cost effective. A private, tax-paying entity that owns PV a system can qualify for a 30% federal business energy ITC and accelerated depreciation on the PV system, which are

[7] http://www.dsireusa.org

worth about 15%. The total potential tax benefits to the tax-paying entity are about 45% of the system cost.

When a utility customer has the ability to generate electricity, the practice of net metering allows power to flow both to the utility and from the utility depending on the level of the customer's electricity generation and use. When the customer's electricity generation is greater than electricity use, the extra electricity will flow back onto the utility grid for use by other customers. When the customer is generating less electricity than the customer is using, the electricity from the grid will flow to the customer to account for the difference. The practice is particularly well-suited to small renewable energy systems due to their inherent variability in power output and inability to consistently match a customer's instantaneous energy use. There are various ways that net metering can be implemented, but in most cases the customer is compensated for the power provided to the grid, essentially offsetting the power that the customer must draw from the grid when necessary.[8, 9]

Federal and state agencies can still take advantage of these incentives through different financing and ownership agreements. Power purchase agreements (PPAs) structure agreements so that commercial tax-paying entities own and operate the system and agree to sell the power to federal or state agencies at a predetermined price. By doing so, the commercial entity can capture the tax credits and pass the savings on to federal and state agencies through discounted electricity rates.

Additional Renewable Energy Measures

Consider Solar Water Heating System

Solar hot water (SHW) systems provide the most favorable payback in buildings with relatively high hot water use. Office buildings typically have relatively low hot water use, as water is primarily used for hand washing. A SHW system can be installed on the flat portion of the roof to meet up to roughly 80% of the hot water demand. There are three types of solar water heating collectors: unglazed plastic collectors for low temperatures such as swimming pool heating; glazed, insulated flat-plate collectors for mid-temperature service hot water; and evacuated tube collectors with reflectors for high-temperature applications. The suggested system would use either flat-plate or evacuated tube collectors. Site staff indicated concern that an SHW system would change the appearance of the historic building. Therefore, a more detailed study is required to determine feasibility.

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[8] Elements of a Sustainable Solar City (2008). July 28, 2009. Accessed August 2012. http://www.solaramericacities.energy.gov/PDFs/Elements_of_a_Sustainable_Solar_City.pdf

[9] Freeing the Grid (2008). July 29, 2009. Accessed August 2012 http://www.newenergychoices.org/uploads/FreeingTheGrid2008_report.pdf