**GPG FINDINGS**

The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

[www.gsa.gov/gpg](http://www.gsa.gov/gpg)

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**CAPTURE & DISPLAY CRITICAL INFORMATION IN REAL-TIME**

Operators identify ways to increase energy-efficiency.

**WIRELESS SENSOR NETWORKS FOR DATA CENTERS**

**TECHNOLOGY**

How do Wireless Sensor Networks save energy?

**CAPTURING & DISPLAYING CRITICAL INFORMATION IN REAL-TIME**

Operators identify ways to increase energy-efficiency with wireless sensor networks.

**RESULTS**

How did Wireless Sensor Networks perform in M&V?

**M&V**

Where did Measurement and Verification occur?

**DATA CENTER POWER USAGE DISTRIBUTION**

48% Cooling Load Reduction, 17% Overall Data Center Energy Reduction

**DEPLOYMENT**

Where does M&V recommend deploying Wireless Sensor Networks?

**MARCH 2012**

**OPPORTUNITY**

How much energy is used by data centers in the U.S.?

**2% OF ALL U.S. ENERGY IS CONSUMED BY DATA CENTERS**

**~50% GOES TO NON-IT LOADS**

**WSN FOR DATA CENTERS**

**17% ENERGY SAVINGS**

48% Reduction in Cooling Load

**EFFECTIVE TOOL**

For on-going optimization of data centers

3.4 YEARS

Payback at $0.045 kwh

< 50% of national average $0.11 kwh

**TECHNOLOGY**

Lawrence Berkeley National Laboratory assessed the effectiveness of a wireless sensor network provided by Synapsence at the USDA National Information Technology Center in St. Louis, Missouri.

**RESULTS**

How did Wireless Sensor Networks perform in M&V?

**M&V**

Where did Measurement and Verification occur?

**DATA CENTER POWER USAGE DISTRIBUTION**

48% Cooling Load Reduction, 17% Overall Data Center Energy Reduction

**DEPLOYMENT**

Where does M&V recommend deploying Wireless Sensor Networks?

**ALL DATA CENTERS**

Estimated $61 million in annual savings and annual decrease of 532,000 metric tons of CO2, if implemented by tenant agencies throughout the GSA portfolio.

Data center assessment kit developed during study reduces deployment time and power interruptions during installation.

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Wireless Sensor Network for Improving the Energy Efficiency of Data Centers. Rod Mahdavi, William Tschudi (LBNL), March 2012, p.27

Ibid, p.29

Ibid, p.3

Ibid, p.29

Subject to evaluation and approval by GSA-IT and Security
OCCUPANT RESPONSIVE LIGHTING

OPPORTUNITY
How much electricity is used for lighting in U.S. commercial buildings?

39% OF ELECTRICITY GOES TO LIGHTING

1% OF BUILDINGS HAVE ADVANCED LIGHTING CONTROLS

TECHNOLOGY
How does Occupant Responsive Lighting save energy?

USES 3 CONTROL STRATEGIES
OCCUPANCY SENSING, TIMER SCHEDULING, AND DIMMING

M&V
Where did Measurement and Verification occur?

LAWRENCE BERKELEY NATIONAL LABORATORY assessed the use of responsive lighting systems in 5 federal buildings in California

RESULTS
How did Occupant Responsive Lighting perform in M&V?

27%-63% ENERGY SAVINGS
SAVINGS VARY DEPENDING ON OPERATING HOURS & OCCUPANCY

IMPROVED SATISFACTION
BETTER QUALITY LIGHT WITH LESS GLARE WITHIN P100 STANDARDS

6 YEARS PAYBACK FOR CALL CENTERS
Lit 18 hours a day 7 days a week

Annual Energy Savings By Site
Energy savings ranged from 27% to 63%

LONG OPERATING HOURS
Buildings with operating hours > 14 hours Utility costs > $1.11 kWh And variable occupancy patterns

SEPTEMBER 2012

LAWRENCE BERKELEY NATIONAL LABORATORY assessed the use of responsive lighting systems in 5 federal buildings in California.

M&V
Where did Measurement and Verification occur?

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DEPLOYMENT
Where does M&V recommend deploying Occupant Responsive Lighting?

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OPPORTUNITY

How much energy is lost to plug loads in U.S. commercial buildings?

25% OF ELECTRICITY IS LOST TO PHANTOM POWER IN EFFICIENT BUILDINGS THIS CAN INCREASE TO 50%¹

TECHNOLOGY

How do Advanced Power Strips save energy?

DE-ENERGIZE CIRCUITS BASED ON A TIMER, LOAD-SENSING, OR BOTH

M&V

Where did Measurement and Verification occur?

NATIONAL RENEWABLE ENERGY LABORATORY tested the effectiveness of 3 plug load reduction strategies in buildings throughout GSA’s Mid-Atlantic Region

RESULTS

How did Advanced Power Strips perform in M&V?

SIMPLE TIMER CONTROLS MOST COST-EFFECTIVE²

26% ENERGY SAVINGS AT WORKSTATIONS with advanced computer management in place 48% IN KITCHENS & PRINTER ROOMS³

< 8 YEARS PAYBACK IN ALL APPLICATIONS < 1 year in kitchens & printer rooms⁴

Energy Reduction for Tested Control Strategies

Schedule timer controls resulted in average-energy reduction of 48%

DEPLOYMENT

Where does M&V recommend deploying Advanced Power Strips?

DEPLOY BROADLY Energy savings & low payback support deployment throughout GSA’s portfolio.*

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¹Plug Load Control and Behavioral Change Research in GSA Office Buildings. Ian Metzger, Dylan Cutler, Michael Sheppy. NREL. September 2012, p.1 ²Ibid, p.4 ³Ibid, p.4 ⁴Ibid, p.4 ⁵Subject to evaluation and approval by GSA-IT and Security

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*DEPLOY BROADLY Energy savings & low payback support deployment throughout GSA’s portfolio.
The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

**GPG FINDINGS**

**TECHNOLOGY**

CAPTURE HEAT THAT IS LOST THROUGH STEAM IN CONVENTIONAL BOILERS

95% EFFICIENCY

15% more efficient than conventional boilers

>14% SAVINGS IN NATURAL GAS CONSUMPTION

3,4 - 7 YEARS PAYBACK AT ESTIMATED TYPICAL COST

END-OF-LIFE REPLACEMENT OF CONVENTIONAL BOILERS WITH CONDENSING BOILERS

Life-cycle cost-effective even when only 3%-5% more efficient than high-efficiency boilers

Where do Condensing Boilers save energy?

CAPTURE HEAT THAT IS LOST THROUGH STEAM IN CONVENTIONAL BOILERS

**M&V**

Where did Measurement and Verification occur?

PACIFIC NORTHWEST NATIONAL LABORATORY and NATIONAL RENEWABLE ENERGY LABORATORY measured the performance of condensing boilers provided by Harsco Patterson-Kelley and Cleaver-Brooks at both the Peachtree Summit Federal Building in Atlanta, Georgia and the Denver Federal Center

**RESULTS**

How did Condensing Boilers perform in M&V?

>14% SAVINGS IN NATURAL GAS CONSUMPTION

< 130°F RETURN WATER TEMPERATURE KEY TO EFFICIENCY

4-7 YEARS PAYBACK AT ESTIMATED TYPICAL COST

Return Water Temperature Is Key to Efficiency

Lower RWT results in greater efficiencies

Where does M&V recommend deploying Condensing Boilers?

END-OF-LIFE REPLACEMENT OF CONVENTIONAL BOILERS WITH CONDENSING BOILERS

Life-cycle cost-effective even when only 3%-5% more efficient than high-efficiency boilers

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www.gsa.gov/gpg

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1 Condensing Boiler Assessment: Peachtree Summit Federal Building; Atlanta, Georgia. S.A. Parker, J. Blanchard (PNNL), November 2012, p.5
2 Ibid, p.5
3 Ibid, p.21
4 Condensing Boilers Evaluation: Retrofit and New Construction Applications. Dylan Culp, Jesse Dean, Jason Acosta, Dennis Jones (NREL), July 2014, p.26
5 Ibid, p.4
6 Ibid, p.27
7 Condensing Boiler Assessment: Peachtree Summit Federal Building; Atlanta, Georgia. S.A. Parker, J. Blanchard (PNNL), November 2012, p.24
The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

**OPPORTUNITY**

How much energy is generated by photovoltaics in GSA buildings?

1% of GSA’s energy comes from solar.

**TECHNOLOGY**

How does PV work?

CAPTURES ENERGY FROM THE SUN

CONVERTS 13-19% INTO ELECTRICITY

**M&V**

Where did Measurement and Verification occur?

Sandia National Laboratories and New Mexico State University’s College of Engineering assessed performance of 5 PV installations provided by Sunpower, Evergreen Solar, Solyndra, United Solar Ovonic, and Abound Solar at the Major General Emmett J. Bean Federal Center in Indianapolis, Indiana.

**RESULTS**

How did photovoltaics perform in M&V?

8% of site load energy generated from PV.

Parity among systems under cloudy skies.

19 year payback.

Steady decline in PV cost will further improve payback.

Laboratory systems perform similarly under cloudy skies.


**DEPLOYMENT**

Where does M&V recommend deploying photovoltaics?

PV effective even in diffuse, 4-season climates.

Price should drive PV selection.

Modeling tools produce accurate simulations for both sunny and cloudy climates.
**OPPORTUNITY**

How much energy is used for heating, ventilation and air conditioning (HVAC) in U.S. office buildings?

34% of energy goes to HVAC1

3% of U.S. office buildings rely on VRF2

**TECHNOLOGY**

How does VRF work?

Provides independent temperature control to rooms throughout building

Uses refrigerant as cooling/heating medium; substituting thin pipes for ductwork

**M&V**

Where did Measurement and Verification occur?

Pacific Northwest National Laboratory drew from a wide variety of sources to evaluate the performance of VRF for GSA buildings

**RESULTS**

How did VRF perform in M&V?

34% energy savings projected relative to code-compliant HVAC3

Thin profile advantageous in historic buildings with limited room for ductwork4

Cost-effective when the premium is < $4/sq.ft. compared to code-compliant HVAC5

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### Projected Payback for VRF vs VAV

Reasonable paybacks achievable (shown in white)

#### VRF vs VAV with Gas Reheat or Cav

<table>
<thead>
<tr>
<th>Added Cost $/ft²</th>
<th>Energy Cost Savings, $/ft²</th>
<th><strong>$1</strong></th>
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45% Projected Energy Cost Savings

#### VRF vs VAV with Electric Reheat

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34% Projected Energy Cost Savings

*Average GSA Portfolio Energy Cost Savings (based on GSA average usage of 60.7 kBtu/ft², GSA average cost of $0.89/therm, and EIA average cost of 0.10/kWh)

**Average Added Cost

**DEPLOYMENT**

Where does M&V recommend deploying VRF?

Pilot Projects

Research on field performance is limited

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1 Variable Refrigerant Flow Systems. Brian Thornton, Anne Wagner (PNNL), December 2012, p.4
2 Ibid, p.11
3 Ibid, p.4
4 Ibid, p.12
5 Ibid, p.20
6 Ibid, p.46
OPPORTUNITY

How much energy is lost through inefficient windows in commercial buildings?

23% ENERGY
USED TO HEAT & COOL BUILDINGS IS LOST THROUGH INEFFICIENT WINDOWS

TECHNOLOGY

How do Window Panel Retrofits save energy?

PRE-MANUFACTURED
LIKE STORM WINDOWS; SIMPLIFYING INSTALLATION

M&V

Where did Measurement and Verification occur?

LAWRENCE BERKELEY NATIONAL LABORATORY assessed the impact of Hi-R Low-e window panel retrofits provided by Serious Energy in a Provo, Utah federal office building.

RESULTS

How did Window Panel Retrofits perform in M&V?

41% HEATING SAVINGS IN WINTER
ESTIMATED SAVINGS FOR ENTIRE BUILDING HEATING AND COOLING: 11%

<9 YEARS PAYBACK FOR TRIPLE-PANE; DOUBLE-PANE WILL BE SHORTER

Savings Diminish with Triple-Pane Hi-R Window Panel Retrofit

COMFEN results compared to base configuration of single pane with bronze film

DEPLOYMENT

Where does M&V recommend deploying Window Panel Retrofits?

BUILDINGS IN COLD CLIMATES

WITH SINGLE-PANE WINDOWS

Double-pane retrofits recommended, as triple-pane offers diminishing returns. Site-specific evaluation is critical.
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www.gsa.gov/gpg

ON-SITE PHOTOVOLTAIC GUIDANCE

OPPORTUNITY

How is GSA meeting federal mandates for renewable energy?

7.5% Federal mandate goal for renewable energy

13.2% GSA renewable energy purchased

1% Solar energy production from GSA buildings

Additional .05% from wind & geothermal

TECHNOLOGY

How was the study conducted?

POLICY REVIEW; SURVEYS AND INTERVIEWS WITH PROJECT TEAMS

M&V

Where did Measurement and Verification occur?

NATIONAL RENEWABLE ENERGY LABORATORY collected best practices and lessons learned from 63 of the 74 GSA PV installations nationwide

RESULTS

What did we learn in M&V?

DIVERSE PORTFOLIO

SYSTEM CAPACITY RANGED FROM 10KW TO 5MW

CHALLENGES NUMEROUS & UNIVERSAL

PROJECT MANAGEMENT, SITE, INTERCONNECTION, TECHNICAL, AND ECONOMIC

RISKS MITIGATED

BY ADVANCE PLANNING AND PROJECT MANAGEMENT

Projects in NREL Study, by System Capacity

Of the 63 projects included, capacity ranges widely

FOR MORE INFORMATION

Where to find additional information?

ON-SITE PV GUIDANCE REPORT

Lessons Learned & Best Practices available at gsa.gov/gpg

*GSA. http://www.epa.gov/oaintrnt/greenpower/requirements.htm  
**GS Energy Usage Analysis System, 2013  
1 Ibid  
2 On-Site Photovoltaic Guidance. Tom Harris, Ian Metzger, Alicen Kandt, Graham Hill, Marianne Kaiser (NREL), October 2013, p.5  
3 Ibid, p.21  
4 Ibid, p.28  
5 Additional .05% from wind & geothermal

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**GPG FINDINGS**

**DECEMBER 2013**

**VARIABLE-SPEED MAGNETIC BEARING CHILLER**

**OPPORTUNITY**

How much energy is used for space cooling in U.S. office buildings?

- **10%** of energy goes to space cooling

- **32%** of commercial buildings rely on chillers to provide this cooling

**TECHNOLOGY**

How do maglev chillers save energy?

- Eliminate friction with magnetic bearings
- Improve efficiency at partial loads with variable speed drive
- **35%** more efficient than FEMP-designated high-efficiency rotary screw chillers

**M&V**

Where did Measurement and Verification occur?

PACIFIC NORTHWEST NATIONAL LABORATORY assessed the performance of a variable-speed oil-free centrifugal chiller with magnetic bearings manufactured by Danfoss at the George Howard, Jr. Federal Building in Pine Bluff, Arkansas

**RESULTS**

How did maglev chillers perform in M&V?

- **42%** energy savings as cooling loads decrease, efficiency increases
- Quiet performance allows chillers to be placed closer to occupant spaces
- **<5 years** payback after normalizing for payment structure & utility costs

Efficiency of Maglev Chiller Increases as Load Is Reduced

Maglev chiller efficiency is highest between 40 to 50 tons (27 to 33% of nominal full load)

Incumbant chiller efficiency continuously decreases as chiller load is reduced

**DEPLOYMENT**

Where does M&V recommend deploying maglev chillers?

**END-OF-LIFE REPLACEMENT**

**OF POSITIVE DISPLACEMENT CHILLERS WITH MAGLEV CHILLERS**

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*Ibid, p. 1

*Ibid, p. 3

*Ibid, p. 34

*Ibid, p. 26

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GPG FINDINGS

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REDUCE SOLAR HEAT GAIN BY TRANSITIONING DYNAMICALLY FROM CLEAR TO DARK

ELECTROCHROMIC (EC)
Use switches or automated building control systems to actively tint windows via electric current

THERMOCROMIC (TC)
Use adhesive coating to adjust tinting passively with window surface temperature

M&V

Where did Measurement and Verification occur?

LAWRENCE BERKELEY NATIONAL LABORATORY measured performance and occupant satisfaction of electrochromic and thermochromic windows provided by SageGlass and RavenBrick at the Denver Federal Center in Colorado

RESULTS

How did chromogenic windows perform in M&V compared to baseline low-e windows?

9-10% HVAC COOLING SAVINGS²
48-58% REDUCTION IN HEAT GAIN³

PRESEVERED VIEWS
EC TINTED TO DARK BLUE⁴; TC PERFORMANCE SENSITIVE TO SURROUNDING SURFACE GEOMETRY⁵

CAPTURED BENEFIT
OF NATURAL DAYLIGHTING
Provided less glare⁶

Modeled Energy Savings Comparing TC and EC vs Clear and Low-e

DEPLOYMENT

Where does M&V recommend deploying chromogenic windows?

FURTHER EVALUATION

GSA is undertaking further evaluations of EC WINDOWS in high-rise curtain wall applications with lighting that adjusts in response to daylight

1 billion MBTU OF LIGHTING ENERGY CAN BE SAVED BY TAKING ADVANTAGE OF DAYLIGHT⁷

A Pilot Demonstration of Electrochromic and Thermochromic Windows in the Denver Federal Center, Building 41, Denver, Colorado

Eleanor S. Lee (LBNL), March 2014, p.12

²Ibid, p.51
³Ibid, p.54
⁴Ibid, p.37
⁵Ibid, p.54
⁶Ibid, p.10

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OPPORTUNITY

How much energy can be saved by daylighting U.S. office buildings?

How do chromogenic windows save energy?

Technology

Electrochromic and Thermochromic Windows

GSA is undertaking further evaluations of EC WINDOWS in high-rise curtain wall applications with lighting that adjusts in response to daylight.

Lawrence Berkeley National Laboratory measured performance and occupant satisfaction of electrochromic and thermochromic windows provided by SageGlass and RavenBrick at the Denver Federal Center in Colorado.

Results

How did chromogenic windows perform in M&V compared to baseline low-e windows?

9-10% HVAC COOLING SAVINGS²
48-58% REDUCTION IN HEAT GAIN³

Preserved Views
EC tinted to dark blue⁴; TC performance sensitive to surrounding surface geometry⁵

Captured Benefit
Of natural daylighting
Provided less glare⁶

Modeled Energy Savings Comparing TC and EC vs Clear and Low-e

Deployment

Where does M&V recommend deploying chromogenic windows?

Further Evaluation

GSA is undertaking further evaluations of EC WINDOWS in high-rise curtain wall applications with lighting that adjusts in response to daylight.

1 billion MBTU of lighting energy can be saved by taking advantage of daylight⁷

A Pilot Demonstration of Electrochromic and Thermochromic Windows in the Denver Federal Center, Building 41, Denver, Colorado.

Eleanor S. Lee (LBNL), March 2014, p.12

²Ibid, p.51
³Ibid, p.54
⁴Ibid, p.37
⁵Ibid, p.54
⁶Ibid, p.10

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OPPORTUNITY

How much energy is used for heating, ventilation and air conditioning (HVAC) in U.S. office buildings?

37% OF ENERGY GOES TO HVAC

A LARGE PERCENTAGE ROUTINELY ESCAPES THROUGH THE BUILDING ENVELOPE

TECHNOLOGY

How do VIPs save energy?

R-50 INSULATION VALUE

WITHIN A THIN PROFILE, 1" COMPARED TO 15" FOR CONVENTIONAL

M&M

Where did Measurement and Verification occur?

OAK RIDGE NATIONAL LABORATORY evaluated the performance of a VIP retrofit provided by Thermal Visions, Inc. at the US Post Office and Courthouse in Camden, New Jersey

RESULTS

How did VIPs perform in M&M?

8-10% ENERGY SAVINGS WHEN COMPARED TO CODE-COMPLIANT ROOFS

ROBUST PERFORMANCE WITH PROPER PLANNING

SAVINGS FOR R-50 GREATEST IN SINGLE-STORY BUILDINGS IN EXTREME CLIMATES

Modeled Energy Use in a Single-Story Office Building

Largest savings in extreme climate zones, such as Fairbanks and Phoenix

Annual Gas Consumption

Maximum savings of $3,800 in Fairbanks—assuming $1.1/Therm

Annual Electricity Consumption

Maximum savings of $900 in Phoenix—assuming $0.1/kWh

DEPLOYMENT

Where does M&M recommend deploying VIPs?

RETROFITS

WHERE R-50 IS REQUIRED AND INSTALLING CONVENTIONAL INSULATION NECESSITATES COSTLY ALTERATIONS

*Vapor Insulated Panels in a Roofing Application Camden U.S. Post Office and Courthouse Camden, New Jersey. Dan Howett, Therese Stovall, Mahabir Bhandari, Kaushik Biswas (ORNL), March 2014, p.1

1 Ibid, p.15

2 Ibid, p.2

4 Ibid, p.2

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**GPG FINDINGS**

The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

**REDUCE FRICTION AND BENDING RESISTANCE**

By NOTCHING THE INNER SIDE OF THE BELT

SYNCHRONOUS BELTS ALSO REDUCE SLIPPAGE BY INTEGRATING TEETH WITH SLOTS ON THE MOTOR PULLEY

**FAN BELTS: SYNCHRONOUS AND COGGED**

**OPPORTUNITY**

How much energy is used for ventilation in U.S. office buildings?

**12% OF ELECTRICITY GOES TO FAN VENTILATION**

**TECHNOLOGY**

How do synchronous and cogged fan belts save energy?

**REDUCE FRICTION AND BENDING RESISTANCE**

BY NOTCHING THE INNER SIDE OF THE BELT

SYNCHRONOUS BELTS ALSO REDUCE SLIPPAGE BY INTEGRATING TEETH WITH SLOTS ON THE MOTOR PULLEY

**2-5% MORE EFFICIENT THAN STANDARD V-BELTS**

**M&V**

Where did Measurement and Verification occur?

**RESULTS**

How did synchronous and cogged fan belts perform in M&V?

**2-20% ENERGY SAVINGS FOR SYNCHRONOUS ON VFD**

2% AT 60 HZ, 20% AT 15 HZ

Cogged fan belts offered half the savings

**75% LOWER O&M FOR SYNCHRONOUS**

Cogged O&M equivalent to standard V-belts

**<4 YEARS PAYBACK FOR SYNCHRONOUS**

Repeat installations have immediate payback; Cogged payback < 1 year

**Net Present Value as a Function of Electricity Rates & Fan Runtime**

Synchronous cost-effective at $0.024/kWh or 6.8 hrs/day; Cogged cost-effective at $0.015/kWh or 4.3 hrs/day

**DEPLOYMENT**

Where does M&V recommend using synchronous and cogged fan belts?

**REPLACE V-BELTS WITH SYNCHRONOUS DRIVE BELTS ON ALL VFD FANS**

Belts on fans with high operating hours should be replaced first

**ON CV FANS, REPLACE V-BELTS AT END-OF-LIFE WITH COGGED V-BELTS**
**GPG FINDINGS**

The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

www.gsa.gov/gpg

**57-92% MORE EFFICIENT**

THAN CODE-COMPLIANT ROOF-TOP UNITS (RTU)

**MORE EFFICIENT**

REMOVE HEAT AND MOISTURE WITH UNIQUE AIR-PROCESSING TECHNOLOGY

**15% OF ENERGY GOES TO AIR CONDITIONING**

TO PEAK DEMAND, GRID FAILURES AND BLACKOUTS

**80% ENERGY SAVINGS**

INCREASED WATER USAGE (3 GALLONS/TON-HR) COMPARED TO TYPICAL RTU

**POSITIVE THERMAL COMFORT** AS DEFINED BY ASHRAE

**<15 YEARS AVERAGE PAYBACK FOR DATACENTERS**

**15% OF ENERGY GOES TO AIR CONDITIONING**

How much energy is used for air conditioning in the U.S.?

**15% OF ENERGY GOES TO AIR CONDITIONING**

How do Indirect Evaporative Coolers save energy?

**DATA CENTERS**

ASHRAE climate zones 2B - 6B

**OUTSIDE AIR PRE-CONDITIONER**

ASHRAE climate zones 2b, 3b

**ZONE COOLER**

ASHRAE climate zones 4b - 6B

**NATIONAL RENEWABLE ENERGY LABORATORY** assessed the performance of 3 multistaged IEC units provided by Coolerado and deployed at the Denver Federal Center in Colorado

**RESULTS**

How did Indirect Evaporative Coolers perform in M&V?

**80% ENERGY SAVINGS**

INCREASED WATER USAGE (3 GALLONS/TON-HR) COMPARED TO TYPICAL RTU

**POSITIVE THERMAL COMFORT**

AS DEFINED BY ASHRAE

**<15 YEARS AVERAGE PAYBACK FOR DATACENTERS**

**TOP 3 TARGET MARKETS**

Data Centers 2B - 6B

Retrofit & New Construction

Outside Air Pre-Conditioner 2B, 3B

Retrofit onto RTUs with EER ≤ 12

Zone Cooler 4B - 6B

Retrofit & New Construction

**TOP 3 TARGET MARKETS**

Data Centers 2B - 6B

Retrofit & New Construction

Outside Air Pre-Conditioner 2B, 3B

Retrofit onto RTUs with EER ≤ 12

Zone Cooler 4B - 6B

Retrofit & New Construction

**DEPLOYMENT**

Where does M&V recommend deploying Indirect Evaporative Coolers?

**TRENDY MARKETS FAVOR DRY CLIMATE ZONES (SUBTYPE B)**

Data centers in ASHRAE climate zones 2B - 6B are top target market

**DRIY CLIMATE**

Data centers: ASHRAE climate zones 2B - 6B

Outside air pre-conditioner: ASHRAE climate zones 2b, 3b

Zone cooler: ASHRAE climate zones 4b - 6B


*Ibid, p.7

*Ibid, p.3

*Ibid, p.3

*Ibid, p.3

*Ibid, p.7

*Ibid, p.27

*Ibid, p.25

*Ibid, p.30

The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance. www.gsa.gov/gpg
The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

**POWER HOT-WATER-HEATING SYSTEMS WITH SOLID WOOD FUEL**

**85%-90% EFFICIENCY RATING**

**WHERE DID MEASUREMENT AND VERIFICATION OCCUR?**

NATIONAL RENEWABLE ENERGY LABORATORY evaluated efficiency, cost-effectiveness, and operational functionality of a 1-million BTU biomass boiler provided by Advanced Climate Technologies at the Federal Building in Ketchikan, Alaska.

**PAYBACK VARIES BY SYSTEM SIZE AND PELLET COST**

Savings are greatest with larger systems and lower fuel costs.

<table>
<thead>
<tr>
<th>System Size (BTUs/hr)</th>
<th>Pellet Cost ($/ton)</th>
<th>Payback in Years</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$400</td>
<td>$500</td>
</tr>
<tr>
<td>500,000</td>
<td>30.7</td>
<td>10.7</td>
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<tr>
<td>1,000,000</td>
<td>24.1</td>
<td>8.4</td>
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<tr>
<td>1,500,000</td>
<td>20.9</td>
<td>7.3</td>
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<tr>
<td>2,000,000</td>
<td>19.9</td>
<td>6.6</td>
</tr>
<tr>
<td>2,500,000</td>
<td>17.5</td>
<td>6.1</td>
</tr>
<tr>
<td>3,000,000</td>
<td>16.4</td>
<td>5.7</td>
</tr>
<tr>
<td>3,500,000</td>
<td>15.6</td>
<td>5.4</td>
</tr>
<tr>
<td>4,000,000</td>
<td>14.8</td>
<td>5.2</td>
</tr>
</tbody>
</table>

*Diesel Price $3.63/gallon; 75% capacity factor*

*Payback varies by system size and pellet cost, savings are greatest with larger systems and lower fuel costs.*

**Where does M&V recommend deploying Biomass Boilers?**

**HOT-WATER HEATED FACILITIES USING FUEL OIL**

Most cost-effective for buildings in cold northern climates within 50 miles of a biomass pellet mill.

**What are the benefits to using Biomass Boilers?**

**Where did M&V Measurement and Verification occur?**

NATIONAL RENEWABLE ENERGY LABORATORY evaluated efficiency, cost-effectiveness, and operational functionality of a 1-million BTU biomass boiler provided by Advanced Climate Technologies at the Federal Building in Ketchikan, Alaska.

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<tr>
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<td>17.5</td>
<td>6.1</td>
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<td>16.4</td>
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<tr>
<td>4,000,000</td>
<td>14.8</td>
<td>5.2</td>
</tr>
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*Diesel Price $3.63/gallon; 75% capacity factor*

*Payback varies by system size and pellet cost, savings are greatest with larger systems and lower fuel costs.*
OPPORTUNITY
How much energy is used for lighting in U.S. commercial buildings?

TECHNOLOGY
How do Integrated Daylighting Systems save energy?

M&V
Where did Measurement and Verification occur?

RESULTS
How did Integrated Daylighting perform in M&V?

RESULTS
27% AVERAGE SAVINGS 0.84 kWh/ft²

BEST PRACTICES
UNOBSTRUCTED SKY VIEWS, LIMITED SEASONAL VARIATION, WINDOW-TO-WALL RATIO 0.5, VISIBLE TRANSMITTANCE OF 60%¹

< 6 YEARS PAYBACK WITH HIGH OCCUPANCY⁴

Lighting Energy Savings Control Strategies
Increased savings from Occupancy Control leaves little room for savings from Daylight Harvesting

DEPLOYMENT
Where does M&V recommend deploying Integrated Daylighting?

SITES WITH HIGH LIGHTING USE
New construction and retrofits with existing lighting power density greater than 1.1 W/ft² and energy use intensity greater than 3.3 kWh/ft².

Results are for fluorescent lamps, LED lamps have different performance characteristics

²Ibid, p.42
³Ibid, p.100
⁴Ibid, p.7,39

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GPG FINDINGS

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INCREASES PV PANEL EFFICIENCY

BY LOWERING PV TEMPERATURE

CAPTURES HEAT FOR OTHER USES SUCH AS DOMESTIC HOT WATER

PHOTOVOLTAIC-THERMAL HYBRID SOLAR SYSTEM

OPPORTUNITY

What are the renewable energy goals of federal mandates?

TECHNOLOGY

What is the advantage of PV-T?

INCREASES PV PANEL EFFICIENCY

BY LOWERING PV TEMPERATURE

CAPTURES HEAT FOR OTHER USES SUCH AS DOMESTIC HOT WATER

M&M

Where did Measurement and Verification occur?

NATIONAL RENEWABLE ENERGY LABORATORY measured performance of a PV-T system provided by SunDrum Solar and installed at the O’Neill Federal Building in Boston, Massachusetts

RESULTS

How did PV-T perform in M&M?

1st LARGE-SCALE INSTALLATION; NUMEROUS LESSONS LEARNED

LIMITED COST-EFFECTIVE DEPLOYMENT POTENTIAL

COMPETITIVE WITH TRADITIONAL SOLAR WHEN 30-50% LESS EXPENSIVE

Energy Savings and Economics for PV-T

Cost-effective when electricity rates are high

<table>
<thead>
<tr>
<th>City</th>
<th>Electricity Rate ($/kWh)</th>
<th>City Cost Adjustment Multiplier</th>
<th>Solar Energy Production (kWh/yr)</th>
<th>Annual Cost Savings ($)</th>
<th>Installed Cost ($)</th>
<th>Simple Payback (yrs)</th>
<th>Payback with 30% Tax Credit (yrs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Portland, OR</td>
<td>0.09</td>
<td>0.992</td>
<td>6,698</td>
<td>581</td>
<td>56,765</td>
<td>98</td>
<td>68</td>
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<tr>
<td>Boston, MA</td>
<td>0.15</td>
<td>1.172</td>
<td>6,331</td>
<td>934</td>
<td>67,065</td>
<td>72</td>
<td>50</td>
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<tr>
<td>Denver, CO</td>
<td>0.11</td>
<td>0.943</td>
<td>11,063</td>
<td>1,198</td>
<td>53,961</td>
<td>45</td>
<td>32</td>
</tr>
<tr>
<td>Honolulu, HI</td>
<td>0.34</td>
<td>1.173</td>
<td>10,097</td>
<td>3,488</td>
<td>67,123</td>
<td>19</td>
<td>13</td>
</tr>
<tr>
<td>Daggett, CA</td>
<td>0.18</td>
<td>0.996</td>
<td>11,824</td>
<td>2,144</td>
<td>56,994</td>
<td>27</td>
<td>19</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>0.10</td>
<td>0.887</td>
<td>11,783</td>
<td>1,237</td>
<td>50,757</td>
<td>41</td>
<td>29</td>
</tr>
</tbody>
</table>

DEPLOYMENT

Where does M&M recommend deploying PV-T?

HIGH ELECTRIC RATES

Small facilities, with electric rates > $0.30/kWh, in hot climates with large domestic hot water (DHW) loads and limited roof space.

Incentives can lower system costs by as much as 75%
The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

SOLAR-CONTROL FILMS

TECHNOLOGY

How do Applied Solar-Control Films work?

**REDUCE HEAT GAIN BY ABSORBING OR REFLECTING SOLAR ENERGY**

Spectrally-selective films affect only the infrared spectrum, with little impact on the visible appearance of glass.

Where did Measurement and Verification occur?

**LAWRENCE BERKELEY NATIONAL LABORATORY** assessed a liquid-applied absorbing solar-control film provided by eTime Energy at the Goodfellow Federal Center in St. Louis, Missouri. They also modeled energy performance of both spectrally-selective absorbing and reflective films in warmer climates.

**RESULTS**

How did Applied Solar-Control Films perform in M&V?

**GLAZING DEPENDENT**

COST-EFFECTIVE FOR SINGLE-PANE CLEAR; NOT RECOMMENDED FOR DOUBLE-PANE BRONZE IN MOST CLIMATES

**REFLECTIVE MORE EFFICIENT**

UP TO 29% HVAC ENERGY SAVINGS IN WARMER CLIMATES

Modeled Energy Savings For Range of Base Windows and Climates

Payback for liquid-applied absorbing @ $8/ft² (80% of current cost) and reflective @ $10/ft²

- Single Clear: 8.1 years
- Single Bronze: 10.6 years
- Double Bronze: 13.8 years

Absorbing Spectrally-Selective

- Single Clear: 9.8 years
- Single Bronze: 11.7 years
- Double Bronze: 18.0 years

Reflective Spectrally-Selective

- Single Clear: 4.9 years
- Single Bronze: 7.4 years
- Double Bronze: 14.0 years

DEPLOYMENT

Where does M&V recommend deploying Applied Solar-Control Films?

**SINGLE-PANE CLEAR WINDOWS**

Target buildings in climates with hot summers and mild winters, exposure to direct sun without exterior shading, and south, east or west orientations.

Reflective film is currently more cost-effective and more broadly recommended. Consider absorbing films for historic buildings where reflected solar radiation might damage exterior wood trim.

### Data

2. Ibid, p.10
3. Ibid, p.9
4. Ibid, p.54

**Power Calculation**

Electricity $0.08/kWh, Gas $0.85/therm

<table>
<thead>
<tr>
<th>Single Clear</th>
<th>Single Bronze</th>
<th>Double Bronze</th>
</tr>
</thead>
<tbody>
<tr>
<td>ST. LOUIS</td>
<td>PHOENIX</td>
<td></td>
</tr>
<tr>
<td>Electricity</td>
<td>Electricity</td>
<td></td>
</tr>
<tr>
<td>$0.06/kWh, Gas $0.85/therm</td>
<td>$0.06/kWh, Gas $0.85/therm</td>
<td></td>
</tr>
</tbody>
</table>
GPG FINDINGS

The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

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USE LIVE LOCAL WEATHER DATA TO CALCULATE IRRIGATION NEEDS, EITHER AS A TURNKEY SYSTEM OR CONNECTED TO A BUILDING AUTOMATION SYSTEM (BAS)

PACIFIC NORTHWEST NATIONAL LABORATORY assessed a weather station provided by Campbell Scientific and connected to a BAS at the Hart-Dole-Inouye Federal Center in Battle Creek, Michigan.

M&V

Where did Measurement and Verification occur?

66% WATER SAVINGS PROJECTED

BAS-CONNECTED WEATHER STATION

CHALLENGING TO PROGRAM AND NOT FULLY REALIZED, TURNKEY RECOMMENDED AT PRESENT

FURTHER RESEARCH

CONNECTING WEATHER STATIONS TO BAS NEEDS MORE SUPPORT

Meanwhile, turnkey weather-based systems recommended.* Areas with intermittent rain will have higher savings and should be targeted first.

Life-Cycle Cost Analysis for Smart-Irrigation Systems

<table>
<thead>
<tr>
<th>Water Rate ($/kgal)</th>
<th>$6.00</th>
<th>$7.00</th>
<th>$10,000</th>
<th>$15,000</th>
<th>$20,000</th>
<th>$25,000</th>
<th>$30,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed System Cost</td>
<td>$8.00</td>
<td>$7.00</td>
<td>$5.00</td>
<td>$4.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.0 Mgal/yr</td>
<td>20% savings</td>
<td>40% savings</td>
<td>40% savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2.0 Mgal/yr</td>
<td>20% savings</td>
<td>40% savings</td>
<td>40% savings</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

DEPLOYMENT

Where does M&V recommend deploying Weather-Stations for Irrigation Control?

FURTHER RESEARCH

CONNECTING WEATHER STATIONS TO BAS NEEDS MORE SUPPORT

*Assessment of Weather Station Used for Irrigation Control: Hart-Dole-Inouye Federal Center, Battle Creek, MI, KL McMordie, Stoughton, RS Butner, PNNL, November 2014, p. 3

OPPORTUNITY

What portion of water consumed by office buildings goes to irrigation?

TECHNOLOGY

How do Weather-Stations for Irrigation Control work?

UP TO 50% WASTED with timer-based irrigation

20-40% CAN BE SAVED with smart irrigation, depending on climate, soil, and vegetation profile

RESULTS

How did Weather-Stations for Irrigation Control perform in M&V?

Up to 50% of water in U.S. office buildings is used for irrigation.

66% of water savings projected.

Subject to evaluation and approval by GSA-IT and Security.
The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

PIPE WITH HELICAL INSERT PREVENTS CALCITE BUILDUP
BY TRANSFORMING CALCIUM AND CARBON TO FLUSHABLE ARAGONITE CRYSTALS

M&V
Where did Measurement and Verification occur?

OAK RIDGE NATIONAL LABORATORY assessed the effectiveness of catalyst-based non-chemical scale prevention provided by Fluid Dynamics at the Moss Federal Courthouse in Salt Lake City, Utah. Before installation of the technology, commercial-grade heating elements overheated and failed after only two months of operation.

RESULTS
How did Non-Chemical Scale Prevention perform in M&V?

OAK RIDGE NATIONAL LABORATORY assessed the effectiveness of catalyst-based non-chemical scale prevention provided by Fluid Dynamics at the Moss Federal Courthouse in Salt Lake City, Utah. Before installation of the technology, commercial-grade heating elements overheated and failed after only two months of operation.

Non-Chemical Scale Prevention vs. Salt-Based System in Salt Lake City
Payback for catalyst-based non-chemical scale prevention is immediate compared to a salt-based system.

<table>
<thead>
<tr>
<th></th>
<th>Salt-Based System</th>
<th>Catalyst-Based Non-Chemical Scale Prevention</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Cost</td>
<td>$2,600</td>
<td>$1,192—1&quot; diameter unit</td>
</tr>
<tr>
<td>Installation Cost</td>
<td>$500</td>
<td>$500—10 hours @ $50/hr</td>
</tr>
<tr>
<td>Maintenance Costs/year</td>
<td>$1,850—$350 chemicals, $1,500 labor</td>
<td>$100—biannual tank cleaning Required in systems without a drain.</td>
</tr>
<tr>
<td>Simple Payback</td>
<td>Immediate</td>
<td></td>
</tr>
</tbody>
</table>

DEPLOYMENT
Where does M&V recommend deploying Non-Chemical Scale Prevention?

FACILITIES WITH HARD WATER
Any heating system with calcification issues including hydronic heating systems and boilers, condensing boilers, and gas and electric water heaters. The harder the water, the more likely non-chemical scale prevention will be cost-effective.

1American Water Works Association, Public Notice Article, May 2007
2Catalyst-Based Non-Chemical Water Treatment System, Frank E. Moss U.S. Courthouse, Salt Lake City, Utah, Dan Howett (ORNL) October 2014, p. 1
3Ibid, p. 24
4Ibid, p. 25

85% OF THE UNITED STATES HAS HARD (>121 MG/L) WATER1
OPPORTUNITY
Where are pneumatic thermostats typically found?

COMMERCIAL BUILDINGS BUILT BEFORE 1999 that are >20,000 ft² and multi-story¹

TECHNOLOGY
How do Wireless Pneumatic Thermostats work?

OAK RIDGE NATIONAL LABORATORY assessed wireless pneumatic thermostats provided by Cypress Envirosystems at the Woodrow Wilson International Center for Scholars in Washington, DC

RESULTS
How did Wireless Pneumatic Thermostats perform in M&V?

Modeled Payback for Unoccupied/Occupied Control Strategy

Payback assumes an unoccupied setback of 83° for cooling and 62° for heating

<2-6 YRS PAYBACK WITH UNOCCUPIED/ OCCUPIED CONTROL STRATEGY AND LOW INSTALLATION COSTS²

DEPLOYMENT
Where does M&V recommend deploying Wireless Pneumatic Thermostats?

ANY FACILITY WITH CONVENTIONAL PNEUMATIC CONTROLS*

Deployment priority should be given to facilities with high energy costs

**OPPORTUNITY**

What is the federally mandated water reduction goal? 36% REDUCTION IN POTABLE WATER USE by 2025, compared to 2007 baseline1

37% OF UNITED STATES is experiencing drought conditions2

20-40% WATER SAVINGS with smart irrigation3

**TECHNOLOGY**

How do Wireless Moisture Sensors work?

**MEASURE SOIL MOISTURE**

TO CALCULATE IRRIGATION NEEDS, AND TRANSMIT DATA TO CENTRAL IRRIGATION CONTROLLER

**RESULTS**

INCONCLUSIVE RESULTS

COMMUNICATION AND SENSOR PROBLEMS OF PRE-COMMERCIAL TECHNOLOGY COMPROMISED ANALYSIS4 Product development continued after M&V

GREATER GRANULARITY THAN WEATHER-BASED IRRIGATION CONTROL OFFERS POTENTIAL FOR GREATER SAVINGS5

**Economic Assessment for Soil-Moisture Sensor Installation in Orlando**

Cost-effective when Savings-to-Investment Ratio (SIR) is greater than 1 Assuming installed system cost of $4,500, annual costs of $680 and 773,700 gal/yr water use

**DEPLOYMENT**

Where does M&V recommend deploying Wireless Moisture Sensors?

PACIFIC NORTHWEST NATIONAL LABORATORY assessed a pre-commercial implementation of wireless soil-moisture sensors for irrigation control provided by UgMo at the Young Federal Building in Orlando, Florida.

**FURTHER RESEARCH**

DOCUMENTING SENSOR EFFECTIVENESS Meanwhile, turnkey weather-based controllers are recommended*
GPG FINDINGS

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WIRELESS NETWORKING

ENABLES ALC FUNCTIONALITY WITHOUT THE EXPENSE OF INSTALLING DEDICATED CONTROL WIRING

M&V

Where did Measurement and Verification occur?

LAWRENCE BERKELEY NATIONAL LABORATORY assessed wireless advanced lighting controls provided by Daintree with new fluorescent lamps and dimmable ballasts at the Moss Federal Building in Sacramento, California, and with LED fixtures at the Appraisers Building in San Francisco.

RESULTS

How did Wireless Advanced Lighting Controls perform in M&V?

Payback for Advanced Lighting Controls

Savings are heavily dependent on baseline conditions

DEPLOYMENT

Where does M&V recommend deploying Wireless Advanced Lighting Controls?

INTEGRATE WITH LED FOR RENOVATIONS

Also consider for retrofits, targeting facilities with minimal lighting controls, high lighting energy use (EUI > 3.25 kWh/ft²/yr) and utility rates > $.10 kWh*
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ELECTROCHROMIC WINDOWS

FOR LAND PORTS OF ENTRY

And other facilities where window glare compromises mission-critical outdoor visibility*

PROVIDE DIRECT LINE OF SIGHT

AN UNINTERRUPTED VISUAL PATH BETWEEN THE OBSERVER AND THE AREA UNDER SURVEILLANCE

TRANSITION FROM CLEAR TO DARK

USING PHOTORECORDER READINGS AND SUN PATH CALCULATIONS

M&P

Where did Measurement and Verification occur?

LAWRENCE BERKELEY NATIONAL LABORATORY measured glare reduction and occupant satisfaction with electrochromic windows provided by SageGlass at the Donna Land Port of Entry along the Texas border with Mexico.

RESULTS

How did electrochromic windows perform in M&P?

100% USER PREFERENCE OVER CONVENTIONAL WINDOWS*

Daylight Glare Probability (DGP) in Vehicle Inspection Booths Facing West

Table with data:

<table>
<thead>
<tr>
<th>Time of day (CST)</th>
<th>Measured DGP</th>
</tr>
</thead>
<tbody>
<tr>
<td>2:00</td>
<td>0.01</td>
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<tr>
<td>2:30</td>
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<tr>
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<td>0.10</td>
</tr>
<tr>
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<tr>
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</tr>
<tr>
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<table>
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<th>DGP interpretation</th>
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<tr>
<td>&gt; 0.45</td>
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<td>0.40 to 0.45</td>
</tr>
<tr>
<td>0.35 to 0.40</td>
</tr>
<tr>
<td>&lt; 0.35</td>
</tr>
</tbody>
</table>

DEPLOYMENT

Where does M&P recommend deploying electrochromic windows?

LAND PORTS OF ENTRY

And other facilities where window glare compromises mission-critical outdoor visibility*

*Electrochromic Window Demonstration at the Donna Land Port of Entry. Eleanor S. Lee (LBNL), May 2015. p.4

Ibid, p.43

Ibid, p.4

*Subject to evaluation and approval by GSA-IT and Security

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GPG FINDINGS

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LED FIXTURES WITH ONBOARD SENSORS
DYNAMICALLY MANAGE LIGHTING
USING OCCUPANCY SENSING AND DAYLIGHT HARVESTING; INTEGRATED CONTROLS REDUCE COMPLEXITY OF INSTALLATION AND SETUP

How do LED Fixtures with Integrated Controls work?

Where did Measurement and Verification occur?

How did LED Fixtures with Integrated Controls perform in M&V?

Positive Return on Investment for Both Retrofits and Renovations

RECOMMENDED FOR RENOVATIONS

Consider for retrofits; prioritize facilities with minimal lighting controls, lighting energy use > 3.25 kWh/ft²/yr and utility rates > $.10/kWh (national average)

Opportunity

How much energy could be saved annually in the U.S. by converting recessed linear fluorescent to LED?

U.S. Avg. Lighting Baseline (EUI: 4.1 kWh/ft²/yr): 75% energy savings

Current Estimated Cost

GSA Avg. Lighting Baseline (EUI: 3.25 kWh/ft²/yr): 69% energy savings

Installed Cost ($/ft²)

Retrofit SIR

Current cost with GSA average lighting use and $.10/kWh

1.4 SIR—savings exceeds investment by 40%

Installed Cost ($/ft²)

Renovation and New Construction SIR

Current cost with GSA average lighting use and $.10/kWh

4.4 SIR—savings exceeds investment by 340%

Installed Cost ($/ft²)

LAWRENCE BERKELEY NATIONAL LABORATORY assessed plug-and-play LED fixtures with Advanced Lighting Controls (ALC) provided by Philips Lighting at the Ralph H. Metcalfe Federal Building in Chicago and the Peachtree Summit Federal Building in Atlanta.

How did LED Fixtures with Integrated Controls perform in M&V?

Where did Measurement and Verification occur?

RESULTS

Where does M&V recommend deploying LED Fixtures with Integrated Controls?*

Positive Return on Investment for Both Retrofits and Renovations

RECOMMENDED FOR RENOVATIONS

Consider for retrofits; prioritize facilities with minimal lighting controls, lighting energy use > 3.25 kWh/ft²/yr and utility rates > $.10/kWh (national average)

Opportunity

How much energy could be saved annually in the U.S. by converting recessed linear fluorescent to LED?

How do LED Fixtures with Integrated Controls work?

Where did Measurement and Verification occur?

How did LED Fixtures with Integrated Controls perform in M&V?

Positive Return on Investment for Both Retrofits and Renovations

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Consider for retrofits; prioritize facilities with minimal lighting controls, lighting energy use > 3.25 kWh/ft²/yr and utility rates > $.10/kWh (national average)

Opportunity

How much energy could be saved annually in the U.S. by converting recessed linear fluorescent to LED?

LED FIXTURES WITH ONBOARD SENSORS
DYNAMICALLY MANAGE LIGHTING
USING OCCUPANCY SENSING AND DAYLIGHT HARVESTING; INTEGRATED CONTROLS REDUCE COMPLEXITY OF INSTALLATION AND SETUP

How do LED Fixtures with Integrated Controls work?

Where did Measurement and Verification occur?

How did LED Fixtures with Integrated Controls perform in M&V?

Positive Return on Investment for Both Retrofits and Renovations

RECOMMENDED FOR RENOVATIONS

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RECOMMENDED FOR RENOVATIONS

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025
SOCIALLY DRIVEN HVAC FOR PERSONAL CONTROL

OPPORTUNITY
How is temperature typically controlled in commercial buildings?

TECHNOLOGY
How does Socially Driven HVAC Optimization work?

M&V
Where did Measurement and Verification occur?

RESULTS
How did Socially Driven HVAC Optimization perform in M&V?

DEPLOYMENT
Where does M&V recommend deploying Socially Driven HVAC Optimization?

SET TO A PREDETERMINED RANGE OR “DEADBAND”
Does not account for individual thermal preferences
Wastes energy by over-conditioning, particularly in unoccupied spaces

USES DIRECT INPUT FROM OCCUPANTS IN TEMPERATURE MANAGEMENT
TRACKS USER PREFERENCES OVER TIME, FINE-TUNES THE DEADBAND
Optimizes energy savings by widening the deadband when there is no occupant input

OAK RIDGE NATIONAL LABORATORY assessed socially driven HVAC optimization provided by Building Robotics at the Federal Building and U.S. Courthouse in Phoenix, Arizona

20% COOLING ENERGY SAVINGS
47% HEATING SAVINGS
Over typical GSA facility

59% REDUCTION IN HOT AND COLD CALLS

83% OCCUPANTS MORE SATISFIED WITH THERMAL CONDITIONS

Modeling Demonstrates Energy Cost Savings per Square Foot
Calculations do not include O&M savings, energy savings from reducing the use of personal fans and heaters, or gains in occupant productivity that may result from increased thermal comfort

<table>
<thead>
<tr>
<th>Location</th>
<th>Large Office - 400,500 ft²</th>
<th>Medium Office - 53,630 ft²</th>
<th>Small Office - 5,500 ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cost Savings ($/ft²/yr)</td>
<td>Cost Savings ($/ft²/yr)</td>
<td>Cost Savings ($/ft²/yr)</td>
</tr>
<tr>
<td>1A Miami, FL</td>
<td>$0.07</td>
<td>$0.14</td>
<td>$0.20</td>
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<tr>
<td>2B Phoenix, AZ</td>
<td>$0.07</td>
<td>$0.12</td>
<td>$0.18</td>
</tr>
<tr>
<td>3A Atlanta, GA</td>
<td>$0.08</td>
<td>$0.15</td>
<td>$0.21</td>
</tr>
<tr>
<td>3B Las Vegas, NV</td>
<td>$0.08</td>
<td>$0.15</td>
<td>$0.21</td>
</tr>
<tr>
<td>3C San-Francisco, CA</td>
<td>$0.09</td>
<td>$0.16</td>
<td>$0.23</td>
</tr>
<tr>
<td>4A Boulder, CO</td>
<td>$0.08</td>
<td>$0.12</td>
<td>$0.18</td>
</tr>
<tr>
<td>4B Albuquerque, NM</td>
<td>$0.09</td>
<td>$0.16</td>
<td>$0.22</td>
</tr>
<tr>
<td>4C Seattle, WA</td>
<td>$0.09</td>
<td>$0.16</td>
<td>$0.22</td>
</tr>
<tr>
<td>5A Chicago, IL</td>
<td>$0.09</td>
<td>$0.16</td>
<td>$0.23</td>
</tr>
<tr>
<td>5B Minneapolis, MN</td>
<td>$0.10</td>
<td>$0.17</td>
<td>$0.24</td>
</tr>
<tr>
<td>5C Anchorage, AK</td>
<td>$0.10</td>
<td>$0.17</td>
<td>$0.24</td>
</tr>
<tr>
<td>6A Boulder, CO</td>
<td>$0.10</td>
<td>$0.17</td>
<td>$0.24</td>
</tr>
<tr>
<td>6B Anchorage, AK</td>
<td>$0.10</td>
<td>$0.17</td>
<td>$0.24</td>
</tr>
</tbody>
</table>

*Current socially driven HVAC subscription fees up to $0.60/ft²/yr, depending on installation size and duration of service

Prioritize where thermal comfort is an issue
Savings will be greatest in facilities that are only intermittently occupied and have narrow deadbands and high energy costs

*Socially driven HVAC Optimization Federal Building and U.S. Courthouse Phoenix, Arizona; Dan Howell (ORNL), October 2015, p. 31
*Prioritize where thermal comfort is an issue
* Subject to evaluation and approval by GSA-IT and Security.

*Subject to evaluation and approval by GSA-IT and Security.
OPPORTUNITY

How much energy could GSA save by converting CFL downlights to LED?

TECHNOLOGY

How do direct replacement LED downlight lamps work?

M&V

Where did Measurement and Verification occur?

RESULTS

How did LED downlight lamps perform in M&V?

DEPLOYMENT

Where does M&V recommend deploying LED downlight lamps?

LED Replacement Options for CFL Downlights

Consider compatibility and controls when selecting an LED replacement

**LED Downlight Lamps for CFL Fixtures**

**APRIL 2016**

**GPG FINDINGS**

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**026**

**LED DOWNLIGHT LAMPS FOR CFL FIXTURES**

**5.7 GWH OF ELECTRICITY PER YEAR**

If all 95,000 CFL-based downlights within the portfolio were replaced

Annual savings of $600,000 at national average of $0.11/kWh

**ONE-TO-ONE LAMP REPLACEMENT**

POWERED BY THE EXISTING CFL BALLAST

Light directed down toward living and work surfaces

**PACIFIC NORTHWEST NATIONAL LABORATORY** assessed LED downlight lamps provided by Lumera in three federal buildings: GSA’s regional headquarters in Auburn, Washington; the Cabell Federal Building in Dallas, Texas; and the Veterans Administration Center in Philadelphia, Pennsylvania

**DEPENDENCY**

Where advanced lighting controls are not desired or useful

40-50% ENERGY SAVINGS¹

$6.37 ANNUAL SAVINGS³

Over typical CFL lamp at avg.

utility rate of $0.11/kWh

**< 3 YR PAYBACK**

AT AVERAGE

UTILITY RATE⁵

- LEDs APPROXIMATED CFLS

- OCCUPANTS NOTICED LITTLE DIFFERENCE⁴

Light Levels Between CFL and LED Were Comparable

**DEPLOY BROADLY**

Where advanced lighting controls are not desired or useful

**PAYBACK – 2.9 years⁴**

Cost $39

Material $22

Install $17

With ballast replacement $34

Reinstalls $15

PAYBACK – 10.4 years⁵

Cost $137

Material $81

Install $56

PAYBACK – 12.4 years⁵

Cost $165

Material $109

Install $56

**COMPATIBILITY**

**CONTROLS**

<table>
<thead>
<tr>
<th>REPLACE LAMP IF:</th>
<th>INSTALL RETROFIT KIT IF:</th>
<th>INSTALL NEW FIXTURE IF:</th>
</tr>
</thead>
<tbody>
<tr>
<td>CFL ballast is verified to work with LED replacement lamp (per manufacturer or by testing).</td>
<td>Lamp is incompatible with CFL ballast (consult manufacturer specifications).</td>
<td>Now construction or renovation.</td>
</tr>
<tr>
<td>No controls are necessary.</td>
<td>Dimming is desired and CFL ballast does not support it.</td>
<td>Integrated advanced lighting controls are desired (tuning, occupancy sensing, daylighting).</td>
</tr>
</tbody>
</table>

**PAYBACK – 2.9 years⁴**

Cost $39

Material $22

Install $17

With ballast replacement $34

Reinstalls $15

PAYBACK – 10.4 years⁵

Cost $137

Material $81

Install $56

PAYBACK – 12.4 years⁵

Cost $165

Material $109

Install $56

**Key**

- **CFL**

- **LED**

- **Installing New LED Fixtures**

- **Testing LED Compatibility**

- **Ballast Replacement**

- **Controls**

- **No Controls**

- **Dimming**

- **Full Controls**

- **Reinstalls**

- **Labor**

- **Additional Material**

- **Electricity**

A difference of less than 100 Lux is typically not noticeable by the human eye.

**REFERENCES**

¹ LED Downlight Lamps for CFL Fixtures, EE Richman, JJ McCullough, TA Beeson, SA Loper (PNNL), March 2016, p.17

² Ibid, p.12

³ Ibid, p.11

⁴ Ibid, p.12

⁵ Ibid, p.12

*Assumes maintenance savings included; exchange material cost; RSMeans derived labor estimates; national average energy rate $0.11; 4000-hr/yr operation

Such as maintenance savings included; exchange material cost; RSMeans derived labor estimates; national average energy rate $0.11; 4000-hr/yr operation

*April 2016 — updated material cost of $15, provided by the vendor, reduces payback to 2.4 years

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**Opportunity**

Why is GSA interested in the Honeycomb Solar Thermal Collector (HSTC)?

**Technology**

How does HSTC differ from typical flat-plate collectors?

**Minimizes Heat Loss**

Honeycomb insulating layer allows solar energy to enter the collector while reducing heat loss from the energy collecting surface.

**M&V**

Where did Measurement and Verification occur?

**Results**

How did HSTC perform in M&V?

**Comparable to Other Flat Plates for Standard DHW**

In SHW systems without a storage tank, HSTC should outperform other flat plates, particularly in cold climates.

**Trained SHW Installer is Critical**

To address unique features of SHW systems.

**Overheating Protection Worked**

May decrease maintenance costs over time.

**Modeled Energy Savings for HSTC in Locations with Different Solar Resources**

Large loads are critical for positive ROI.

<table>
<thead>
<tr>
<th>City</th>
<th>Hot Water Load (gal/day)</th>
<th>System Unit Cost ($/ft²)</th>
<th>Collector Area (ft²)</th>
<th>Solar Fraction*</th>
<th>Annual Energy Savings (kWh/yr)</th>
<th>Payback (years)</th>
<th>SIR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Seattle, WA</td>
<td>125</td>
<td>$102</td>
<td>88</td>
<td>0.44</td>
<td>3,154</td>
<td>40.0</td>
<td>0.26</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>$102</td>
<td>175</td>
<td>0.32</td>
<td>8,937</td>
<td>26.8</td>
<td>0.56</td>
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<tr>
<td></td>
<td>500</td>
<td>$46</td>
<td>175</td>
<td>0.32</td>
<td>8,937</td>
<td>13.0</td>
<td>1.15</td>
</tr>
<tr>
<td>Indianapolis, IN</td>
<td>125</td>
<td>$102</td>
<td>88</td>
<td>0.51</td>
<td>3,638</td>
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<td></td>
<td>500</td>
<td>$102</td>
<td>175</td>
<td>0.38</td>
<td>10,448</td>
<td>19.2</td>
<td>0.81</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>$46</td>
<td>175</td>
<td>0.38</td>
<td>10,448</td>
<td>9.3</td>
<td>1.68</td>
</tr>
<tr>
<td>Denver, CO</td>
<td>125</td>
<td>$102</td>
<td>88</td>
<td>0.60</td>
<td>4,291</td>
<td>24.5</td>
<td>0.54</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>$102</td>
<td>175</td>
<td>0.44</td>
<td>12,343</td>
<td>16.2</td>
<td>0.98</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>$46</td>
<td>175</td>
<td>0.44</td>
<td>12,343</td>
<td>7.8</td>
<td>2.03</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>125</td>
<td>$102</td>
<td>88</td>
<td>0.54</td>
<td>2,757</td>
<td>21.4</td>
<td>0.50</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>$102</td>
<td>175</td>
<td>0.71</td>
<td>13,556</td>
<td>15.0</td>
<td>1.06</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>$46</td>
<td>175</td>
<td>0.71</td>
<td>13,556</td>
<td>7.3</td>
<td>2.23</td>
</tr>
</tbody>
</table>

*The solar fraction represents the fraction of the total hot water energy load that is displaced by the solar hot water system.

**Deployment**

Where does M&V recommend deploying SHW?

**Electric Water Heaters Large Consistent Loads**

Natural gas prices in the U.S. are generally too low to make SHW cost-effective. Life-cycle cost, rather than efficiency, should drive system selection.

---

2. Ibid, p.7
3. Ibid, p.11
4. Ibid, p.8
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**GPG FINDINGS**

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**CHILLER PLANT CONTROL OPTIMIZATION SYSTEM**

**TECHNOLOGY**

How does the Control Optimization System for Chiller Plants work?

**RESULTS**

How did the Control Optimization System perform in M&V?

- **35% COOLING SAVINGS**
  - +/- 10% uncertainty due to estimated baseline

- **5 YR PAYBACK**
  - At avg. cost of $0.11/kWh

- **BETTER VISIBILITY & CONTROL FOR PLANT OPERATIONS**

**M&V**

Where did Measurement and Verification occur?

**PACIFIC NORTHWEST NATIONAL LABORATORY** assessed a control optimization system for chiller plants provided by Siemens at the Frank M. Johnson Jr. Federal Building and U.S. Courthouse in Montgomery, Alabama.

**OPPORTUNITY**

What is the impact of improved chiller operations on GSA?

80% OF GSA FLOOR SPACE IS IN LARGE BUILDINGS

The majority of which is cooled by chillers.

**DEPLOYMENT**

Where does M&V recommend deploying the Control Optimization System?

**CENTRIFUGAL CHILLERS WITH LOADS > 3 MILLION TON-HRS/YR**

Also consider for incorporation into new all-variable-speed chiller plants, where both installation costs and energy savings may be lower.

---

2 Ibid, p. 7
3 Ibid, p. 38
4 Ibid, p. 7

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OPPORTUNITY

How much electricity could be saved by raising cooling setpoints across the GSA-owned portfolio?

18.7 MILLION kWh ANNUALLY

$2 MILLION @ GSA AVERAGE OF $0.11 kWh²

by raising cooling setpoints 2°F

TECHNOLOGY

How do Smart Ceiling Fans work?

SENSORS MEASURE TEMPERATURE AND INCREMENTALLY ADJUST FAN SPEED

TURN ON AND OFF AUTOMATICALLY BASED ON OCCUPANCY OR PREDETERMINED TEMPERATURES

M&V

Where did Measurement and Verification occur?

NATIONAL RENEWABLE ENERGY LABORATORY modeled energy savings and assessed the deployment potential for ceiling fans provided by Big Ass Solutions

RESULTS

What did modeling of Smart Ceiling Fans reveal?

4-11% ENERGY SAVINGS

WITH 4°F SETPOINT INCREASE

From 74°F to 78°F²

SAVINGS <$1.50/ft² INSTALLED COST

For < 10-year payback¹

CONSIDER FOR OPEN OFFICES

Where does the white paper recommend deploying Smart Ceiling Fans?

CONSIDER FOR OPEN OFFICES

Target facilities with:

• Ceilings at least 9 feet high and interior/desk partitions less than 54 inches tall

• At least 2,000 cooling degree days and full daytime business hours

• No features, such as lighting or air conditioning, that will interfere with fan blades

• Cooling setpoint lower than 75°F, and no prohibitions against raising it

 Modeled Savings for Smart Fans

Energy savings for ENERGY STAR certified fans will be roughly equivalent

<table>
<thead>
<tr>
<th>Location</th>
<th>Energy Savings kWh²/yr</th>
<th>Energy Cost Savings $/yr</th>
<th>Installed Cost for 10-year Payback $/ft²</th>
</tr>
</thead>
<tbody>
<tr>
<td>Miami, FL</td>
<td>1.19</td>
<td>$0.117</td>
<td>$1.17</td>
</tr>
<tr>
<td>Houston, TX</td>
<td>1.41</td>
<td>$0.115</td>
<td>$1.15</td>
</tr>
<tr>
<td>Phoenix, AZ</td>
<td>1.47</td>
<td>$0.149</td>
<td>$1.49</td>
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<tr>
<td>Atlanta, GA</td>
<td>1.26</td>
<td>$0.131</td>
<td>$1.31</td>
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<tr>
<td>Las Vegas, NV</td>
<td>1.26</td>
<td>$0.119</td>
<td>$1.19</td>
</tr>
<tr>
<td>San Francisco, CA</td>
<td>1.39</td>
<td>$0.318</td>
<td>$2.18</td>
</tr>
<tr>
<td>Baltimore, MD</td>
<td>1.26</td>
<td>$0.140</td>
<td>$1.40</td>
</tr>
<tr>
<td>Albuquerque, NM</td>
<td>1.02</td>
<td>$0.105</td>
<td>$0.95</td>
</tr>
<tr>
<td>Seattle, WA</td>
<td>1.19</td>
<td>$0.095</td>
<td>$0.95</td>
</tr>
<tr>
<td>Chicago, IL</td>
<td>0.81</td>
<td>$0.075</td>
<td>$0.75</td>
</tr>
<tr>
<td>Denver, CO</td>
<td>0.84</td>
<td>$0.084</td>
<td>$0.84</td>
</tr>
<tr>
<td>Minneapolis, MN</td>
<td>0.71</td>
<td>$0.070</td>
<td>$0.70</td>
</tr>
</tbody>
</table>

Savings are greatest in San Francisco.

DEPLOYMENT

Where does the white paper recommend deploying Smart Ceiling Fans?


SENSORS MEASURE TEMPERATURE AND INCREMENTALLY ADJUST FAN SPEED

TURN ON AND OFF AUTOMATICALLY BASED ON OCCUPANCY OR PREDETERMINED TEMPERATURES

Savings are greatest in San Francisco.

Energy Savings Across Climate Zones

Installed Cost Needed for a 10-year Payback

Assuming a 4°F increase in cooling setpoint
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TLED LIGHTING RETROFITS WITH DEDICATED DRIVERS

OPPORTUNITY

How much energy could GSA save by converting LFLs to LEDs?

134 GWH ELECTRICITY/YEAR

TECHNOLOGY

How do these LED Retrofits work?

REPLACE LAMP AND LED DRIVER
USING EXISTING LENS & FIXTURE; NO NEED TO ALTER CEILING GRID
Compatible with advanced lighting controls (ALCs)

M&V

Where did Measurement and Verification occur?

PACIFIC NORTHWEST NATIONAL LABORATORY assessed two LED retrofits (“LED-A” and “LED-B”) provided by NEXT Lighting and Cree in three federal buildings: GSA’s regional headquarters in Auburn, Washington; the Cabell Federal Building in Dallas, Texas; and the Veterans Administration Center in Philadelphia, Pennsylvania

RESULTS

How did LED Retrofits perform in M&V?

27-29% ENERGY SAVINGS
ADDITIONAL SAVINGS POSSIBLE WITH ALC

6 YR PAYBACK AT NAT'L AVG. UTILITY RATE ($0.11/kWh) & $50 FIXTURE COST

GROUNDWORKS

Where does M&V recommend deploying LED Retrofits?

FIXTURES WITH LENSES AND SOCKETS IN GOOD CONDITION
Where and ALC is desired or useful. To assess fit, light levels, color temperature and glare, test a small number of lights before committing to purchase.

LED Retrofit Options Assessed During M&V

Consider compatibility and controls when selecting an LED replacement

LED A
Replacement lamp uses alternative mounting, LED driver

• Lamps can be repositioned in the fixture
• Dimming & ALC possible
• Performance depends on optics & lens of existing fixture
• Self-tapping screws could cause electrical problems
• Wire harnesses won’t always fit legacy situations
• Not compatible with master/remote configurations or shunted lamp holders

Equipment: $40–$70
Installation: $34–$68

LED B
Replacement lamp uses existing socket, LED driver

• Familiar installation process
• Compatible with shunted and unshunted lamp holders
• Dimming & ALC possible
• Performance depends on optics & lens of existing fixture

Equipment: $40–$70
Installation: $34–$68

* 90% and 100% RS Means derived labor estimates; similar cost to lamp + ballast replacement

Average Light Levels Across Test-Bed Sites
LED retrofits had similar illuminance levels but different light output (LED-A, 4500 lumens; LED-B, 4400 lumens)

Key

LFL
LFL AVERAGE
LED A
LED A AVERAGE
LED B
LED B AVERAGE

A difference of less than 100 Lux is typically not noticeable by the human eye.

1Linear LED Lighting Retrofit Assessment, EE Richman, JJ McCullough, TA Beeson (PNNL), September, 2016, p. 2
2Ibid, p.5
3Ibid, p.61
4Ibid, p.10
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031
VARIEABLE-SPEED DIRECT-DRIVE SCREW CHILLER

OPPORTUNITY
What is the impact of improved chiller operations on GSA?

TECHNOLOGY
How does this Variable-Speed Screw (VSS) Chiller work?

CAPACITY CONTROLLED BY REGULATING MOTOR SPEED ALONE
THREE SCREW ROTORS AND A VARIABLE-SPEED MOTOR ARE THE ONLY MOVING PARTS; THERE ARE NO UNLOADERS

M&V
Where did Measurement and Verification occur?

OAK RIDGE NATIONAL LABORATORY assessed a variable-speed direct-drive screw (VSS) chiller against a baseline variable-speed magnetic bearing chiller (MBC). The chillers were installed at the Sidney R. Yates Building in Washington, D.C. and connected to the same chilled water and condenser water loops, creating operating conditions as close to identical as possible within a real-world environment.

RESULTS
How did the Variable-Speed Screw Chiller perform in M&V at the test bed location?

High EFFICIENCY
ENERGY PERFORMANCE COMPARED TO BASELINE MBC

Range OF OPERATING CONDITIONS MET
Condenser water temperature ranged from 55°F to over 95°F

Quiet PERFORMANCE
77-83 DECIBELS
For both VSS & MBC

Average Energy Consumption at the Yates Building
VSS savings over baseline MBC could range from +24% to -4% due to field measurement uncertainty.

CONSIDER VSS & MBC FOR END-OF-LIFE REPLACEMENT
Both chillers performed effectively and have rated energy consumption that is more than 35% better than FEMP standards for water-cooled chillers. Individual site characteristics will determine the most cost-effective chiller for the application.

Combined Chillers/ Total Building % of full load

% of Full Year’s Profile VSS kW/ton (weighted) MBC kW/ton (weighted)

20-30% 3.6% 0.020 0.021
30-40% 8.3% 0.044 0.049
40-50% 11.3% 0.062 0.070
50-60% 13.1% 0.075 0.086
60-70% 25.1% 0.154 0.176
70-80% 24.3% 0.183
80-90% 13.0% 0.097 0.106
90-100% 1.1% 0.009 0.010

0.623 0.699

DEPLOYMENT
Where does M&V recommend deploying the Variable-Speed Screw Chiller?

OAK RIDGE NATIONAL LABORATORY assessed a variable-speed direct-drive screw (VSS) chiller against a baseline variable-speed magnetic bearing chiller (MBC). The chillers were installed at the Sidney R. Yates Building in Washington, D.C. and connected to the same chilled water and condenser water loops, creating operating conditions as close to identical as possible within a real-world environment.

Where did Measurement and Verification occur?

Average Energy Consumption at the Yates Building
VSS savings over baseline MBC could range from +24% to -4% due to field measurement uncertainty.

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GPG FINDINGS

The GPG program enables GSA to make sound investment decisions in next generation building technologies based on their real world performance.

LOW-E WINDOW FILM

ACROSS ALL CLIMATE ZONES

Biggest efficiency gain and fastest payback will be in buildings with either single glazing or existing applied film that is low performing or nearing the end of its (~15 year) service life. Also consider for lower-performing double glazing that does not already have a low-e coating between panes.

LAWRENCE BERKELEY NATIONAL LABORATORY assessed a low-e film provided by the Eastman Chemical Company at two sites, the Hansen Federal Building in Ogden, Utah, and the Cabell Federal Building in Dallas, Texas. They also modeled energy performance in seven climates with four different base window configurations.

Where did Measurement and Verification occur?

MODELED PERIMETER ENERGY SAVINGS FOR RANGE OF CLIMATES

Whole building energy savings is estimated to be at least 1/3 of perimeter savings

<table>
<thead>
<tr>
<th>Location</th>
<th>Heating kBtu/ft²/yr</th>
<th>Cooling kBtu/ft²/yr</th>
<th>Total kBtu/ft²/yr</th>
<th>% Heating</th>
<th>% Cooling</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1A Miami, FL</td>
<td>0.01</td>
<td>12.16</td>
<td>33</td>
<td>0.03</td>
<td>8.08</td>
<td>25</td>
</tr>
<tr>
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<td>0.47</td>
<td>10.94</td>
<td>33</td>
<td>1.52</td>
<td>7.12</td>
<td>26</td>
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<tr>
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<tr>
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<td>26</td>
<td>3.24</td>
<td>3.74</td>
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<tr>
<td>5A Chicago, IL</td>
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<td>24</td>
<td>5.79</td>
<td>3.23</td>
<td>22</td>
</tr>
<tr>
<td>5B Ogden, UT</td>
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<td>7.13</td>
<td>30</td>
<td>4.97</td>
<td>4.12</td>
<td>27</td>
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<tr>
<td>6A Minneapolis, MN</td>
<td>2.97</td>
<td>5.45</td>
<td>22</td>
<td>7.53</td>
<td>5.06</td>
<td>21</td>
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AVERAGE PERIMETER SAVINGS

<table>
<thead>
<tr>
<th>Location</th>
<th>Average kBtu/ft²/yr</th>
<th>% Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.08</td>
<td>9.00</td>
<td>25</td>
</tr>
</tbody>
</table>

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TECHNOLOGY

How does Low-e film work?

REduces Solar Heat Gain and Insulates

By Selectively Absorbing and Reflecting Heat

Blocks direct solar heat to reduce summer cooling demand. Improves window insulation to reduce summer and winter energy use and improve occupant comfort.

M&M

Where did Measurement and Verification occur?

RESULTS

How did Low-e film perform in M&M?

29% AVERAGE PERIMETER HVAC SAVINGS with single-pane clear glass²

BETTER THERMAL COMFORT

Occupants reported superior comfort in both summer and winter³

2-6 YR PAYBACK with single-pane glass; installed cost of $7.75 sq. ft.⁴

Table: Modeled Perimeter Energy Savings for Range of Climates

<table>
<thead>
<tr>
<th>Location</th>
<th>Single Clear Glazing to VT35 Film</th>
<th>Single Bronze Glazing to VT35 Film</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heating kBtu/ft²/yr</td>
<td>Heating kBtu/ft²/yr</td>
<td>Heating kBtu/ft²/yr</td>
</tr>
<tr>
<td>Cooling kBtu/ft²/yr</td>
<td>Cooling kBtu/ft²/yr</td>
<td>Cooling kBtu/ft²/yr</td>
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<tr>
<td>Total kBtu/ft²/yr</td>
<td>Total kBtu/ft²/yr</td>
<td>Total kBtu/ft²/yr</td>
</tr>
<tr>
<td>% Heating</td>
<td>% Cooling</td>
<td>% Total</td>
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<td>Miami, FL</td>
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<td>5.66</td>
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OPPORTUNITY

Windows are responsible for how much energy use?

34% OF COMMERCIAL BUILDING HVAC ENERGY IS LOST TO WINDOWS³
OPPORTUNITY
What have previous studies demonstrated about the potential for electrochromic (EC) windows?

TECHNOLOGY
How do EC windows work?

WINDOWS TINT IN RESPONSE TO EXTERNAL CONDITIONS OR USER OVERRIDE

M&V
Where did Measurement and Verification occur?

RESULTS
How did EC windows perform in M&V?

63–92% OCCUPANT PREFERENCE OVER EXISTING LOW-E4
However, implementations that both satisfy occupants and meet competing performance requirements are challenging and take time.3

CONTROL
BASELINE CONDITIONS AND OCCUPANT BEHAVIOR DETERMINE SAVINGS
In Sacramento, most blinds remained lowered and darker tint levels predominated, resulting in a 62% increase in lighting energy. In Portland, 40% more blinds were left raised and lighter tint levels predominated, resulting in 36% lighting energy savings but a 2% HVAC increase.5

NOT COST-EFFECTIVE FOR GENERAL OFFICE SPACE BASED ON ENERGY SAVINGS ALONE7
Energy savings did not cover increased costs—in Portland, the incremental difference between installing spectrally selective low-e windows and EC windows was $37/ft².

DEPLOYMENT
Where does M&V recommend deploying EC windows?

FACILITIES WHERE OUTSIDE VIEWS ARE CRITICAL
A previous GPG study recommended EC windows where glare control is required but blinds would interfere with mission, such as Land Ports of Entry. EC windows also could enhance architectural features that provide a connection with the outdoors, such as skylights and atriums, though this has not been evaluated.

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**OPPORTUNITY**

RTUs condition how much floor space nationwide?

>50% OF COMMERCIAL FLOOR SPACE IN THE U.S. IS CONDITIONED BY ROOFTOP UNITS (RTUS)

**TECHNOLOGY**

How do advanced RTUs work?

VARIABLE SPEED INVERTER COMPRESSOR MAINTAINS AIR TEMPERATURE SETPOINT

VARIABLE SPEED SUPPLY FAN Responds to zone conditions

**M&V**

Where did Measurement and Verification occur?

PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL) assessed the first RTU to meet the Department of Energy’s High Performance RTU Challenge. The RTU was provided by Daikin Applied and installed in a GSA warehouse in Fort Worth, Texas. PNNL also conducted a concurrent study of the advanced RTU at two Florida supermarkets.

**RESULTS**

How did the advanced RTU perform in M&V?

26% ENERGY SAVINGS

Models predicted 40% savings compared to a standard RTU

COSTS FOR INSTALLATION VARY

Heavier unit and different footprint may require infrastructure reinforcement or duct changes

3.8 YR PAYBACK demonstrated at two Florida supermarkets

Energy Efficiency Ratio as a Function of Outdoor Air Temperature

Advanced RTU exceeds baseline efficiency, particularly at higher outdoor air temperatures

**DEPLOYMENT**

Where does M&V recommend deploying advanced RTUs?

END-OF-LIFE REPLACEMENT

Modeling indicates that savings will be greatest in hot, humid climates
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SMALL CIRCULATOR PUMPS WITH AUTOMATED CONTROL

TECHNOLOGY

< 2.5 HORSEPOWER PUMPS
VARIABLE SPEED ELECTRONICALLY COMMUTED MOTORS
ONBOARD CONTROL ALGORITHMS

WHERE did Measurement and Verification occur?
NATIONAL RENEWABLE ENERGY LABORATORY (NREL) measured performance of two common pump applications at two buildings within the Denver Federal Center—a domestic hot water (DHW) system and an air handler unit (AHU).

RESULTS

How much energy can high-performance circulator pumps save?

Payback and Savings Compared to Baseline Standard Pumps

Higher flow rates combined with smaller pump sizes offered the best return on investment.

END-OF-LIFE REPLACEMENT FOR CONSTANT-SPEED PUMPS

Pumps used for DHW recirculation, small heating systems, small chilled water systems, solar hot water systems and small geothermal heat pump applications are all candidates for replacement.

*High-Performance Circulator Pump Demonstration, Jessie Dean, Anoop Honnekeri, Greg Barker, National Renewable Energy Laboratory (NREL), September 2018, p. 4 • Ibid, p. 30, 42 • Ibid, p. 5 • Ibid, p. 6

How do high-performance circulator pumps with automated control perform in M&V?

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GPG FINDINGS

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DUAL-ZONE INDOOR SHADES

OPPORTUNITY
How much energy can window technologies save in U.S. commercial buildings?

11% REDUCTION IN PRIMARY ENERGY USE WITH SOLAR CONTROL & DAYLIGHTING TECHNOLOGIES

TECHNOLOGY
How do dual-zone indoor shades work?

UPPER ZONE FOR DAYLIGHT
WITH AUTOMATICALLY- OR MANUALLY-CONTROLLED LOUVERS
LOWER ZONE CONTROLS GLARE & PRESERVES VIEWS

LAWRENCE BERKELEY NATIONAL LABORATORY measured performance of a dual-zone indoor shade provided by LouverShade at the Advanced Windows Testbed in Berkeley, CA against roller shades and venetian blinds. LBNL assessed facility manager and occupant satisfaction at the Ronald V. Dellums Federal Building in Oakland, CA, where the dual-zone shades replaced vertical blinds.

M&V
Where did Measurement and Verification occur?

RESULTS
How did the dual-zone indoor shades perform in M&V?

DECREASE IN ENERGY USE
Compared to fabric roller shades (25% to 51% for lighting, -4% to 15% for cooling); increase compared to venetian blinds (150% to 300% for lighting, 5% to 36% for cooling)²

ROI NEGATIVE
Compared to both fabric roller shades and venetian blinds³

80% OCCUPANT PREFERENCE
Over baseline vertical blinds⁴

Measured Energy Use at the Advanced Windows Testbed
Compared to venetian blinds; points above diagonal line indicate that energy use is greater than venetian blinds

DEPLOYMENT
Where does M&V recommend deploying dual-zone indoor shades?

CONSIDER FOR REPLACEMENT OF ROLLERSHADES
Manual upper shades provided the best balance between financial performance and occupant response. Not broadly recommended to replace venetian blinds from a cost-savings standpoint.


SEPTEMBER 2018

REDUCTION IN PRIMARY ENERGY USE
WITH SOLAR CONTROL & DAYLIGHTING TECHNOLOGIES

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ADVANCED LIGHTING CONTROLS AND LED

OPPORTUNITY

How can advanced lighting controls (ALC) support LED?

MAKING ALC MORE EFFECTIVE

LED’S DIGITAL NATURE PROVIDES MORE PRECISE DIMMING

TECHNOLOGY

What advanced lighting control strategies were assessed?

3 CONTROL STRATEGIES

LIGHT-LEVEL TUNING, OCCUPANCY SENSING, DAYLIGHT HARVESTING

M&V

Where did Measurement and Verification occur?

PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL) assessed five different LED and advanced-control systems in open-plan offices at the Fort Worth Federal Center, Fort Worth, Texas

RESULTS

How did the advanced lighting controls perform in M&V?

43% CONTROL SAVINGS

from LED baseline, even with minimal daylight availability

TUNING IS CRITICAL

The ability to dim initial light levels significantly increased occupant satisfaction

ROI VARIABLE

Can be cost-effective when the added cost of controls is <$70 per fixture @ GSA avg. utility $0.11/kW

PACIFIC NORTHWEST NATIONAL LABORATORY (PNNL) assessed five different LED and advanced-control systems in open-plan offices at the Fort Worth Federal Center, Fort Worth, Texas

Where did Measurement and Verification occur?


2 Ibid, p.26

3 Ibid, p.35

ALC Costs Needed for a 10-Year Payback*

The more efficient the lighting, the more challenging for ALC to achieve positive ROI

ALC calculator at gsa.gov/gpg can help determine site-specific payback

*Assuming a 10-hour, 5-day work week and 43% ALC savings

DEPLOYMENT

Where does the study recommend deploying advanced lighting controls?

FACILITIES WITH HIGH UTILITY RATES

Full-featured ALC will be most cost-effective for facilities with high utility rates and/or rebate opportunities and in open offices where occupants are engaged in a variety of tasks.

If ALC is not cost-effective, choose LED systems with dedicated 0-10V drivers that provide dimming. Tuning can be key to occupant satisfaction.


**Ibid, p.26 

***Ibid, p.35

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OPPORTUNITY
How much water do cooling towers use?

28% of water in commercial buildings is used by cooling towers or other heating and cooling systems.

TECHNOLOGY
How does electrochemical water treatment work?

ELECTROLYSIS SEQUESTERS SCALE IN REACTOR TUBES
AND CREATES CHLORINE, A NATURAL BIocide

M&V
Where did Measurement and Verification occur?

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) assessed an alternative water treatment (AWT) system provided by Dynamic Water Technology for two 150-ton cooling towers in Savannah, Georgia.

RESULTS
How did electrochemical water treatment perform in M&V?

32% WATER SAVINGS
98.6% reduction in blowdown

50% MAINTENANCE REDUCTION
Small cost increase in annual O&M contract

100% CHEMICAL SAVINGS
Technology generates chlorine; reduced slime

2.5 YEAR PAYBACK
@ GSA avg. water/sewer $16.76/kgal

Electrochemical Water Treatment Return-On-Investment
Rebates for AWT systems are available through some local water utilities

<table>
<thead>
<tr>
<th></th>
<th>Testbed (Before)</th>
<th>Testbed (After)</th>
<th>GSA Normalized (After)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment ($)</td>
<td>N/A</td>
<td>$30,340</td>
<td>$30,340</td>
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<tr>
<td>Installation ($)</td>
<td>N/A</td>
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<td>$15,000</td>
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<td>Maintenance (yr)</td>
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<td>Maintenance Savings (yr)</td>
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<td>$720</td>
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<td>Water Consumption (Gallons/yr)</td>
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<tr>
<td>Water Savings (Gallons/yr)</td>
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<tr>
<td>Water Savings ($)</td>
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<td>$7,529</td>
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<tr>
<td>Simple Payback (yr)</td>
<td>8.7</td>
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<tr>
<td>Savings to Investment Ratio</td>
<td>1.7</td>
<td>0.8</td>
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</tr>
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</table>

* Savannah testbed water/sewer $6.64/kgal  * GSA average water/sewer $16.76/kgal, normalized installation cost

DEPLOYMENT
Where does the study recommend deploying electrochemical water treatment?

CONSIDER FOR ALL COOLING TOWERS
Most cost-effective in areas with high water costs or where water is excessively hard, has high pH values and/or large amounts of total dissolved solids.
ADVANCED OXIDATION PROCESS FOR COOLING-TOWER WATER

OPPORTUNITY
How much water do cooling towers routinely blow down?

UP TO 50% COOLING WATER IS FLUSHED TO MINIMIZE SCALE BUILD-UP

TECHNOLOGY
How does the advanced oxidation process (AOP) for cooling towers work?

PHOTOCHEMICAL TREATMENT
OXIDIZES MINERALS AND CONTAMINANTS

Air drawn into the ultraviolet reactor generates a mixed oxidant gas that is diffused into the water. Hydroxyl radicals and peroxides form to attack contaminants and oxidize minerals.

M&V
Where did Measurement and Verification occur?

RESULTS
How did the advanced oxidation process perform in M&V?

26% WATER SAVINGS
Estimated savings from 23% to 30%2

50% MAINTENANCE REDUCTION
Reduced scaling might also save energy, though this was not assessed3

MET GSA WATER STANDARDS
No additional chemicals were needed4

2 YEAR PAYBACK
@ GSA avg. water/sewer $16.76/kgal5

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) assessed an advanced oxidation process system provided by Silver Bullet Water Treatment Company in two 250-ton cooling towers at the Denver Federal Center (DFC)

Measurement and Verification occurred in JANUARY 2019

Advanced Oxidation Process Return-On-Investment
© GSA average cost of water/sewer of $16.76/kgal

<table>
<thead>
<tr>
<th>Baseline (Before)</th>
<th>AOP System (After)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Equipment (two 250-ton cooling towers)* N/A</td>
<td>$22,487</td>
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<tr>
<td>Annual Maintenance</td>
<td>$5,855</td>
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<tr>
<td>Annual Water Consumption (gal/yr)</td>
<td>2,003,270 gal</td>
</tr>
<tr>
<td>Annual Energy Costs ($0.08/kWh) ($416,578)</td>
<td>$0</td>
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<tr>
<td>Annual Water Costs (@$16.76 kgal/yr)</td>
<td>$14,303</td>
</tr>
<tr>
<td>Payback (yrs)</td>
<td>2.1</td>
</tr>
<tr>
<td>Savings-to-Investment Ratio</td>
<td>7.2</td>
</tr>
</tbody>
</table>

*Normalized installation cost of one unit

DEPLOYMENT
Where does the study recommend deploying the AOP system?

CONSIDER FOR ALL COOLING TOWERS
Anticipate changes needed to O&M contracts to transition from traditional chemical treatment to alternative water treatment systems

OPPORTUNITY

Why is GSA interested in alternative water treatments?

41% INCREASE IN GSA WATER RATES 2014-2017

TECHNOLOGY

How do these alternative water treatments work?

SALT-BASED ION EXCHANGE
REMOVES HARDNESS WITHOUT ADDITIONAL CHEMICALS

CHEMICAL SCALE INHIBITION
PROPRIETARY CHEMICALS INHIBIT SCALING AND CORROSION

M&V

Where did Measurement and Verification occur?

RESULTS

How did these alternative water treatments perform in M&V?

23% WATER SAVINGS
94%-99% reduction in blowdown

0&M VARIABLE
Chemical scale inhibition increased O&M costs, salt-based reduced them

IMPROVED CHILLER OPERATIONS
Cleaner condenser tubes, increased heat exchanger effectiveness

<3 YEAR PAYBACK
@ GSA average water/sewer cost of $16.76/kgal

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) assessed three alternative water treatment (AWT) systems at the Denver Federal Center. Two out of the three systems maintained adequate water quality.

Modeled Cost Savings per Cycles of Concentration (CoC)

Most water savings are achieved by a CoC of 10; both systems achieved CoCs greater than 12

CONSIDER FOR ALL COOLING TOWERS

Both salt-based and chemical-scale inhibition systems can be retrofitted to any cooling tower.

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The GPG program enables GSA to make sound investment decisions in next-generation building technologies based on their real-world performance.

MONITOR AND ANALYZE INDIVIDUAL CIRCUITS FOR GRANULAR ELECTRIC CONSUMPTION

How is GSA interested in circuit-level submetering and analytics?

How does the full-panel submetering and analytics system work?

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) assessed the full-panel submetering and analytics system at the Salt Lake City Courthouse. Technology was provided by Enertiv.

<3% ERROR IN MEASUREMENT

using high-accuracy current transformers (CTs) which are critical for low power circuits

10% HVAC LOAD SAVINGS

by utilizing submeter data that identified lead/lag programming issue

1 YR PAYBACK

based on accurate costs for overtime tenant billing. Metered energy use was double calculated estimate

High-Accuracy CTs Tracked with Revenue-Grade Reference Submeter

Standard-accuracy CTs did not meet requirements for tenant billing

ACCURATE TENANT BILLING

Most value when monitoring overtime utilities or devices that have high power consumption. Pilot project recommended to determine best practices, including changes to GSA billing practices.
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**TECHNOLOGY**

What are wireless current-transformers (CT)?

**OPPORTUNITY**

Why is GSA interested in submetering and analytics?

- TENANT OR EQUIPMENT-LEVEL BILLING
- FAULT DETECTION & DIAGNOSTICS (FDD)
- ENERGY CONSERVATION MEASURES (ECMS)

**RESULTS**

How did wireless CTs perform in M&V?

**M&V**

Where did Measurement and Verification occur?

National Renewable Energy Laboratory (NREL) assessed wireless CTs at the Cesar Chavez Memorial Building in Denver, Colorado. Technology was provided by Centrica.

Where does the study recommend deploying wireless CTs?

**DEPLOYMENT**

Fault Detection & Diagnostics

Wireless CTs can monitor systems not typically monitored by a building automation system and can be integrated into GSA’s smart building platform, GSALink. Pilot project recommended to determine best practices, cost-benefit analysis and site selection.

Accurately Tracks Load Profile Trends

Precisely tracks on/off state of equipment, supporting FDD

- **FDD ACTIONABLE**
  - Insights included short-cycling, on/off issues, and seasonal trends

- **1 DAY INSTALLATION**
  - for 144 individual circuits in 13 panels and 4 HVAC equipment disconnects.
  - Configuration software streamlined the process with real-time feedback

- **7% AVG. ERROR IN MEASUREMENT**
  - up to 52% measured error with VAV & loads with heavy cycling; not accurate enough for tenant billing

- **CLIP-ON SENSORS POWERED BY CURRENT IN ELECTRICAL WIRE**
  - No meter, wiring or conduit required; data sent to the cloud

- **VEN. ERROR IN MEASUREMENT**
  - Tenant or equipment-level billing
  - Fault detection & diagnostics (FDD)
  - Energy conservation measures (ECMS)

- **Where**
  - National Renewable Energy Laboratory (NREL)
  - Cesar Chavez Memorial Building in Denver, Colorado
  - centrica.com

Case Study:

Laboratory and Field Evaluation of Circuit-level Electrical Submetering with Wireless Current Transformers

Willy Bernal Heredia, Dylan Cutler, Jesse Dean (NREL), June 2019, p.32

Ibid, p.31

Ibid, p.28

3 day installation for 144 individual circuits in 13 panels and 4 HVAC equipment disconnects.

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GPG FINDINGS
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MORE EFFICIENT UNDER ALL CIRCUMSTANCES
4% avg. savings compared to a premium-efficient motor & VFD.3
33% for 1.5 hp motor compared to a standard-efficient motor & VFD (NREL assessment)4

SOFTWARE-CONTROLLED SWITCHED RELUCTANCE MOTOR WITH VARIABLE-FREQUENCY DRIVE (VFD)
REAL-TIME CLOUD-BASED MONITORING AND CONTROL

OAK RIDGE NATIONAL LABORATORY (ORNL) assessed a 10 hp smart motor on a chilled water pump application at the Land Port of Entry in San Ysidro, California. A concurrent National Renewable Energy Laboratory (NREL) assessment of a 1.5 hp motor took place on condenser fans in a refrigeration system at a Walmart in Lakeside, Colorado. Technology was provided by Software Motor Company.

Where did Measurement and Verification occur?

Why is GSA interested in smart motors?
What are smart motors?
How did the 10 hp smart motor perform in M&V?
When does the study recommend deploying smart motors?

END-OF-LIFE REPLACEMENT
Also consider retrofits for: fixed-speed motors; motors < 5 hp; and applications with lower installation costs, such as motors that control fans

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56% OF MOTORS ARE < 5 HP2
ALTERNATIVE WATER TREATMENT FOR COOLING TOWERS

GPG FINDINGS

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ALTERNATIVE WATER TREATMENT

FOR COOLING TOWERS

ALL COOLING TOWERS

Anticipate changes needed to O&M contracts to transition from traditional chemical treatment to alternative water treatment systems.

TECHNOLOGY

How do Alternative Water Treatment (AWT) systems work?

INCREASE CoC (CYCLES OF CONCENTRATION) WHILE CONTROLLING SCALE & CORROSION

AWT systems hold minerals in suspension at increased CoCs.

MAKING WATER SAVINGS

Savings ranged from 23% to 32%; blowdown reduced 94% to 99%.

Increased CoCs

BEFORE AWT

3 to 4 CoCs

BLOWDOWN

MAKE-UP WATER

AFTER AWT

11 to 20+ CoCs

BLOWDOWN

MAKE-UP WATER Reduced by ~94%

M&E

Where did Measurement and Verification (M&E) occur?

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) has assessed four AWT systems, three at the Denver Federal Center and one in Savannah, Georgia. Two more assessments are underway with results due by 2021.

RESULTS

How did the four AWT systems perform in M&E?

26% AVG. WATER SAVINGS

Savings ranged from 23% to 32%; blowdown reduced 94% to 99%.

50% REDUCTION IN TOWER CLEANING due to less scale and corrosion.

MET GSA WATER STANDARDS including controlling for legionella.

2-3 YEAR PAYBACK

@ 2017 GSA avg. water/sewer cost of $16.76/kgal.

Positive Return on Investment for all Systems

@ 2017 GSA average water/sewer cost of $16.76/kgal.

PAYBACK (yrs)

3.8

2.2

2.2

2.7

Savings-to-Investment Ratio

5.6

6.9

6.7

5.5

Electrochemical Advanced Oxidation Salt-Based Chemical-Scale

<table>
<thead>
<tr>
<th>Cooling Tower Size (tons)</th>
<th>Electrochemical Cost ($)</th>
<th>Advanced Oxidation Cost ($)</th>
<th>Salt-Based Cost ($)</th>
<th>Chemical-Scale Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Installed Cost</td>
<td>$45,340</td>
<td>$32,435</td>
<td>$22,689</td>
<td>$13,511</td>
</tr>
<tr>
<td>Installed Cost Per Ton</td>
<td>$151</td>
<td>$47</td>
<td>$30</td>
<td>$27</td>
</tr>
<tr>
<td>Annual Maintenance Change</td>
<td>+$720</td>
<td>-$2,522</td>
<td>-$6,445</td>
<td>+$1,883</td>
</tr>
<tr>
<td>Annual Electricity Increase (MWh)</td>
<td>$1,049</td>
<td>$562</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Water Savings Per Ton-Hour of Cooling</td>
<td>0.64</td>
<td>not measured</td>
<td>0.58</td>
<td>0.42</td>
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<tr>
<td>Annual Water Savings (MWh16.76 kgal)</td>
<td>$11,615</td>
<td>$8,046</td>
<td>$3,724</td>
<td>$13,818</td>
</tr>
</tbody>
</table>

Payback (yrs)

3.8

2.2

2.2

2.7

Savings-to-Investment Ratio

5.6

6.9

6.7

5.5

DEPLOYMENT

Where do the assessments recommend deploying AWT systems?

ALL COOLING TOWERS

Anticipate changes needed to O&M contracts to transition from traditional chemical treatment to alternative water treatment systems.

*Demonstration and Evaluation of an Advanced Oxidation Technology for Cooling Tower Water Treatment, Jesse Dean, Dylan Cutler, Gregg Tomberlin, James Elsworth (NREL), December 2018, p.1  • GSA Guidance—Alternative Water Treatment Systems for Cooling Towers, Jesse Dean (NREL), Gregg Tomberlin (NREL), Andrea Silvestri (Contex Information Design), January 2020, p.6  • Ibid, p.9  • Ibid, p.7  • Ibid, p.11

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AWT: CONTINUOUS MONITORING AND PARTIAL WATER SOFTENING

OPPORTUNITY

Why is GSA interested in alternative water treatments (AWT)?

UP TO 50% COOLING WATER IS FLUSHED TO MINIMIZE SCALE BUILD-UP

TECHNOLOGY

How does the continuous monitoring and partial water softening system work?

PARTIAL SOFTENING INCREASES BLOWDOWN SETPOINT

SUPPLEMENTAL TREATMENT SYSTEM DETERMINES OPTIMAL BLOWDOWN TO SATISFY WATER CHEMISTRY TARGETS; SIDESTREAM FILTRATION FILTERS DEBRIS

Real-time monitoring sends system alarms via built-in display or integrated with building management system

M&V

Where did Measurement and Verification occur?

RESULTS

How did the monitoring and partial-softening system perform in M&V?

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) assessed a continuous monitoring and partial-water softening system provided by Aqualogix in three cooling towers at the Lloyd D. George Courthouse in Las Vegas, Nevada

15% WATER SAVINGS

52% reduction in blowdown

MET GSA WATER STANDARDS

Monitors performance and sends alarms

O&M UNCHANGED

Works alongside traditional chemical treatment

3 YEAR PAYBACK @ GSA avg. water/sewer $16.76/kgal

Monitoring and Partial-Softening Return-On-Investment

© 3-million ton target load and GSA average water/sewer cost of $16.76/kgal

<table>
<thead>
<tr>
<th>Monitoring &amp; Partial Softening</th>
<th>Installed Equipment (200–1000 ton load)*</th>
<th>$38,371</th>
</tr>
</thead>
<tbody>
<tr>
<td>Annual Maintenance*</td>
<td>$743</td>
<td></td>
</tr>
<tr>
<td>Annual Energy Increase (0.7,750 kWh/year; $0.11/kWh)</td>
<td>$851</td>
<td></td>
</tr>
<tr>
<td>Water Savings (938,273 kgal @ $16.76/kgal)</td>
<td>$16,480</td>
<td></td>
</tr>
<tr>
<td>GSA Average Payback (yr)**</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>GSA Average Savings-to-Investment Ratio</td>
<td>5.8</td>
<td></td>
</tr>
</tbody>
</table>

*GSA discounted pricing
**$250 for annual calibration, $533 for salt
***Payback assumes target load of 3 million ton hours and GSA utility rates. Payback at the testbed was 7.5 years based on the measured 1.6 million ton hour load and utility rate of $12.59/kgal

Where does the assessment recommend deploying this AWT system?

CONSIDER FOR ALL COOLING TOWERS

Continues standard and familiar water treatment practices and may offer an easier and more failsafe deployment opportunity for GSA facilities.

*Continuous Monitoring and Partial Water Softening for Cooling Tower Water Treatment; Gregg Tomberlin, Jesse Dean, Michael Deru (NREL), October 2020, p.9
**Ibid, p.24
***Ibid, p.28
****Ibid, p.26
*****Ibid, p.31
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COMPARED TO REFERENCE

Captured load profile trends accurately, even for high-variability loads.

SUBMETERS AND ANALYTICS: SINGLE-CIRCUIT METER

OPPORTUNITY

Why is GSA interested in submetering and analytics?

TECHNOLOGY

What are single-circuit meters?

MONITOR SINGLE OR 3-PHASE CIRCUITS INCLUDING PANEL MAINS

Combines a meter, a wireless communication gateway that collects data from multiple meters, non-proprietary current transformers and cloud-based analytics.

M&E

Where did Measurement and Verification occur?

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) assessed single-circuit meters at the Cesar Chavez Memorial Building in Denver, Colorado. Technology was provided by Meazon.

RESULTS

How did single-circuit meters perform in M&V?

<2% ERROR COMPARED TO REFERENCE

Captured load profile trends accurately, even for high-variability loads.

1 DAY INSTALLATION

for 6 measured loads: $470 equipment and $431 installation per load; equipment bulk purchase estimate $132/load.

FDD/ECM

Provides basic fault-detection and energy conservation measures for facilities without a BAS; can also be integrated into GSA’s smart building platform, GSALink.

ACCURATELY TRACKS ENERGY CONSUMPTION

<2% measurement error, except when chillers were online but idling.

DEPLOYMENT

Where does the study recommend deploying single-circuit meters?

TENANT BILLING

Most value for monitoring devices with high power consumption.

Low-cost submetering can also provide FDD for facilities without GSALink and support ECM identification and M&V.

*Case Study: Field Evaluation of a Low Cost Circuit-Level Electrical Submetering System, Willy Bernal Heredia, Dylan Cutler, Jesse Dean (NREL), January 2021, p.23

**Ibid, p.25

*** Ibid, p.29

The decrease in measurement accuracy for low-power loads is consistent with previous GPG submetering evaluations. New meter design & high accuracy CTs may mitigate measurement errors for low-power loads.

Accurately Tracks Energy Consumption

<2% measurement error, except when chillers were online but idling.

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