GPG FINDINGS 001

MARCH 2012

WIRELESS SENSOR NETWORKS FOR DATA CENTERS

OPPORTUNITY

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

2%

OF ALL U.S. ENERGY

IS CONSUMED BY DATA CENTERS[1]

~50%

GOES TO NON-IT LOADS[2]

TECHNOLOGY

How do Wireless Sensor Networks save energy?

CAPTURE & DISPLAY CRITICAL INFORMATION IN REAL-TIME

OPERATORS IDENTIFY WAYS TO INCREASE ENERGY- EFFICIENCY

M&V

Where did Measurement and Verification occur?

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?

17%

ENERGY SAVINGS

48% REDUCTION IN COOLING LOAD[3]

EFFECTIVE

TOOL

FOR ON-GOING OPTIMIZATION OF DATA CENTERS[4]

3.4

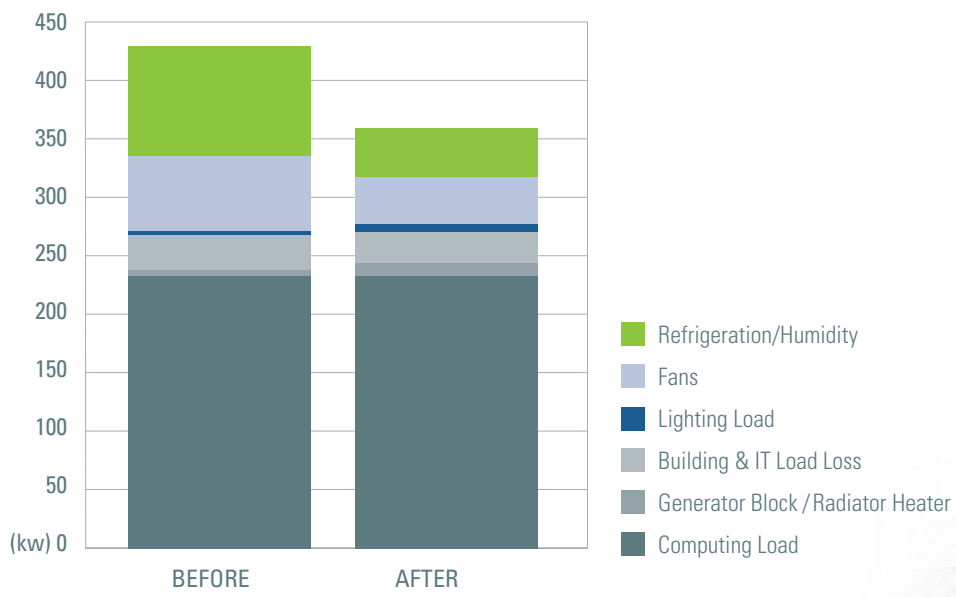
YEARS

PAYBACK AT $0.045 kWh

< 50% of national average $0.11 kWh[5]

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

[1]McKinsey & Company, "Revolutionizing Data Center Efficiency", 2008 [2]Wireless Sensor Network for Improving the Energy Efficiency of Data Centers. Rod Mahdavi, William Tschudi (LBNL), March 2012, p.27 [3]Ibid, p.29 [4]Ibid, p.7 [5]Ibid, p.29 *Subject to evaluation and approval by GSA-IT and Security

GSA

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**

GPG FINDINGS 002

SEPTEMBER 2012

OCCUPANT RESPONSIVE LIGHTING

OPPORTUNITY

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

39%
OF ELECTRICITY
GOES TO LIGHTING[1]

1%
OF BUILDINGS
HAVE ADVANCED LIGHTING CONTROLS[2]

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?

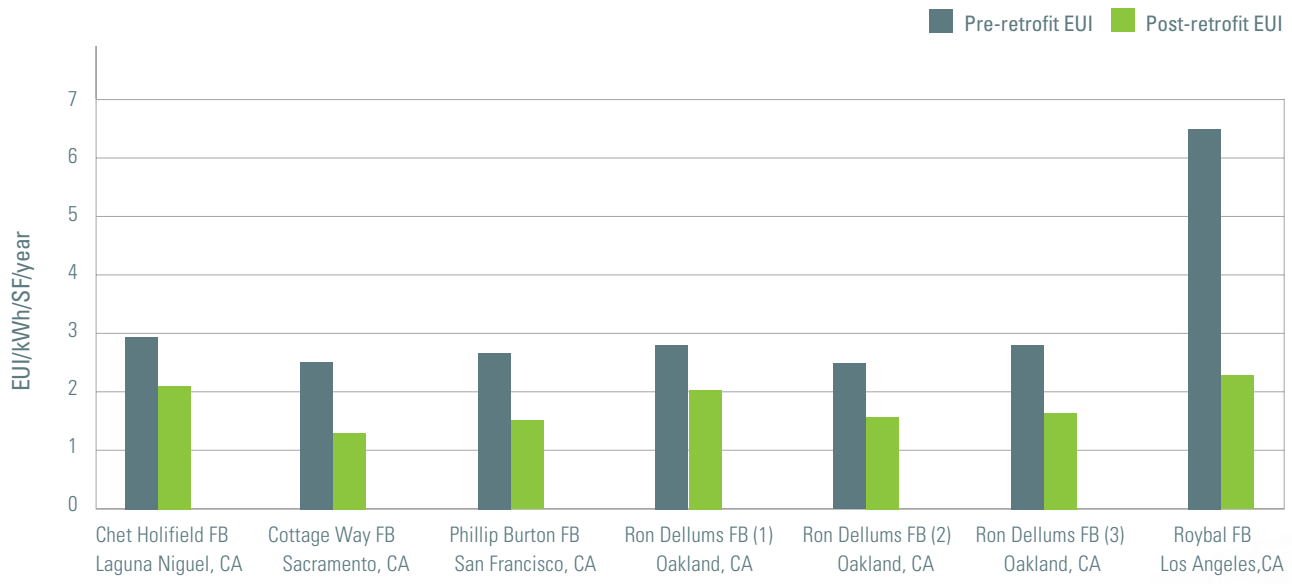
27%-63%
ENERGY SAVINGS[3]
SAVINGS VARY DEPENDING ON OPERATING HOURS & OCCUPANCY[4]

IMPROVED
SATISFACTION
BETTER QUALITY LIGHT WITH LESS GLARE WITHIN P100 STANDARDS[5]

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

Annual Energy Savings By Site

Energy savings ranged from 27% to 63%



DEPLOYMENT

Where does M&V recommend deploying Occupant Responsive Lighting?

LONG OPERATING HOURS

Buildings with operating hours > 14 hours
Utility costs > $.11 kwh
And variable occupancy patterns

[1]Responsive Lighting Solutions. Joy Wei, Abby Enscoe, Francis Rubenstein (LBNL), September 2012, p.17 [2]Ibid, p.17 [3]Ibid, p.34 [4]Ibid, p.12 [5]Ibid, p.13 [6]Ibid, p.12

GSA

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GPG FINDINGS 003

SEPTEMBER 2012

ADVANCED POWER STRIPS FOR PLUG LOAD CONTROL

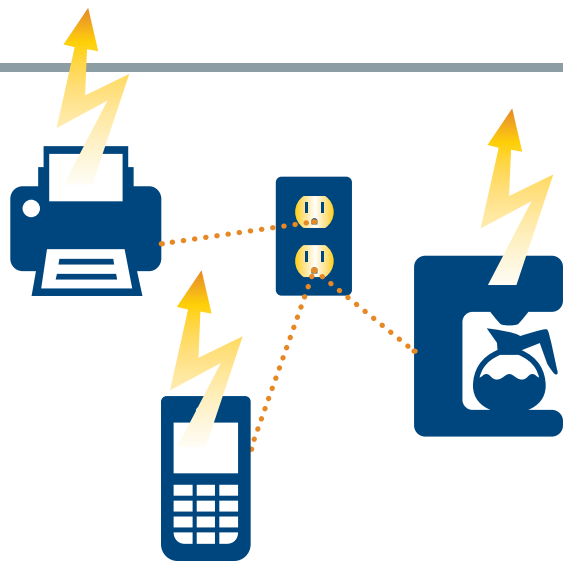
OPPORTUNITY

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-EFFECTIVE[2]

26%

ENERGY SAVINGS

AT WORKSTATIONS with advanced computer management in place

48% IN KITCHENS & PRINTER ROOMS[3]

<8

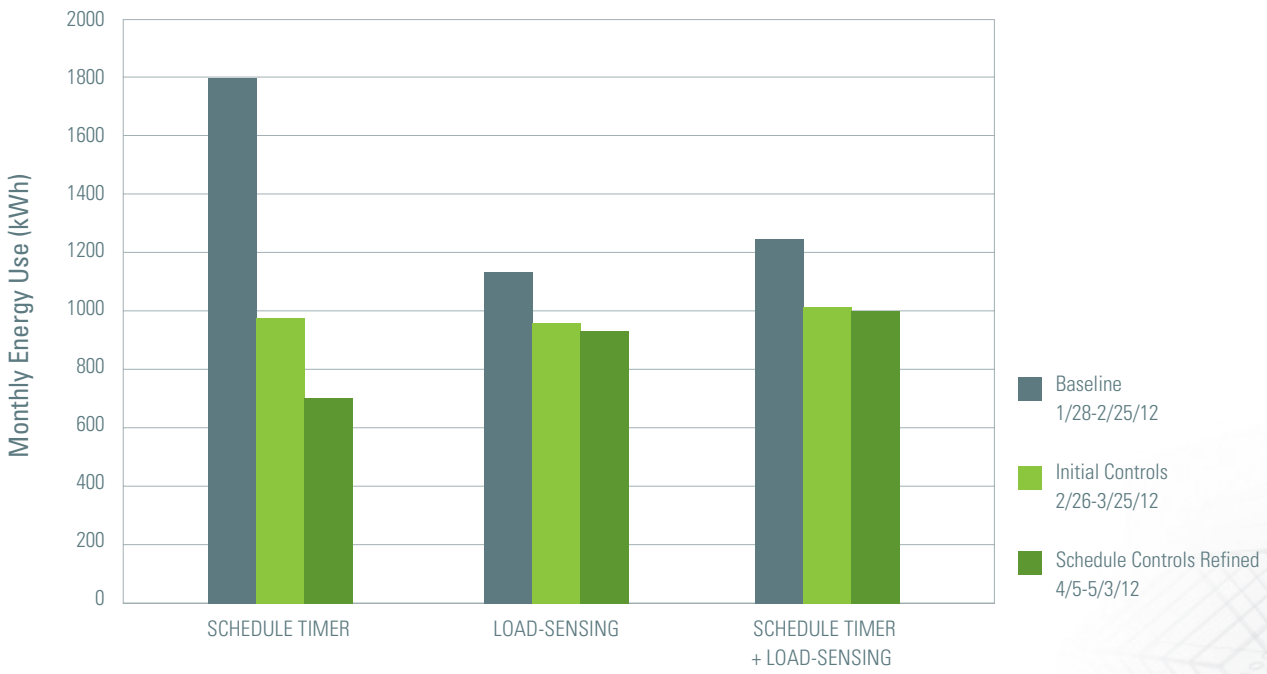
YEARS

PAYBACK IN ALL APPLICATIONS

< 1 year in kitchens & printer rooms[4]

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.*

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

GPG FINDINGS

004 CONDENSING BOILERS

UPDATED JULY 2014

OPPORTUNITY

How much energy is used for heating in U.S. commercial buildings?

35%
OF ENERGY
GOES TO HEATING[1]

32%
OF COMMERCIAL BUILDINGS
RELY ON BOILERS TO SUPPLY THIS HEAT[2]

TECHNOLOGY

How do Condensing Boilers save energy?

CAPTURE HEAT
THAT IS LOST THROUGH STEAM
IN CONVENTIONAL BOILERS

95%
EFFICIENCY
15% more efficient than 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?

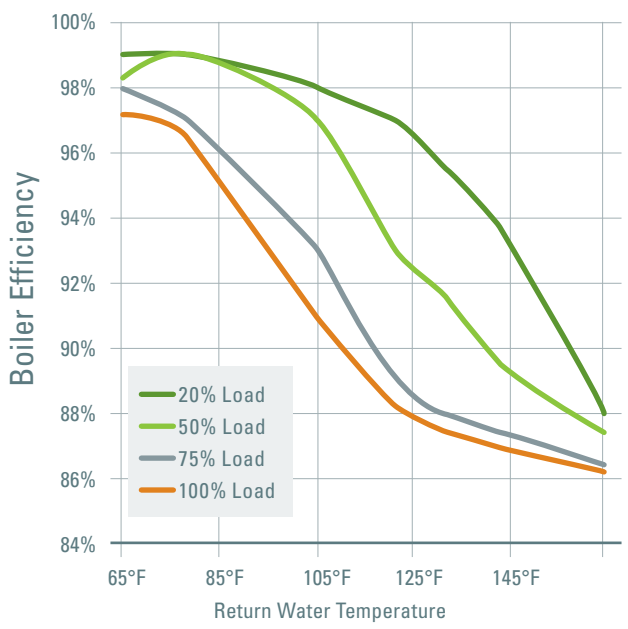
>14%
SAVINGS
IN NATURAL GAS CONSUMPTION[3,4]

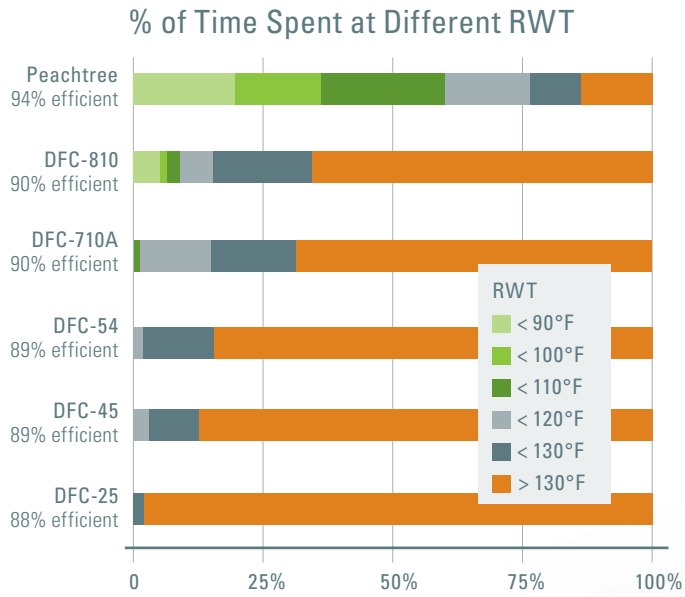
<130°F
RETURN WATER TEMPERATURE
KEY TO EFFICIENCY[5]

4-7
YEARS
PAYBACK AT ESTIMATED TYPICAL COST[6,7]

Return Water Temperature Is Key to Efficiency

Lower RWT results in greater efficiencies





DEPLOYMENT

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

[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 Cutler, 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

GSA

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GPG FINDINGS 005

DECEMBER 2012

PHOTOVOLTAIC SYSTEM PERFORMANCE

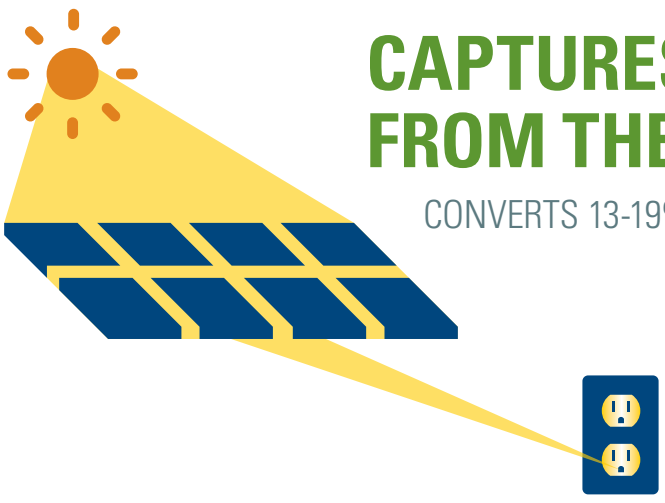
OPPORTUNITY

How much energy is generated by photovoltaics in GSA buildings?

1% OF GSA'S ENERGY COMES FROM SOLAR[1]

TECHNOLOGY

How does PV work?



CAPTURES ENERGY FROM THE SUN

CONVERTS 13-19% INTO ELECTRICITY[2]

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[3]

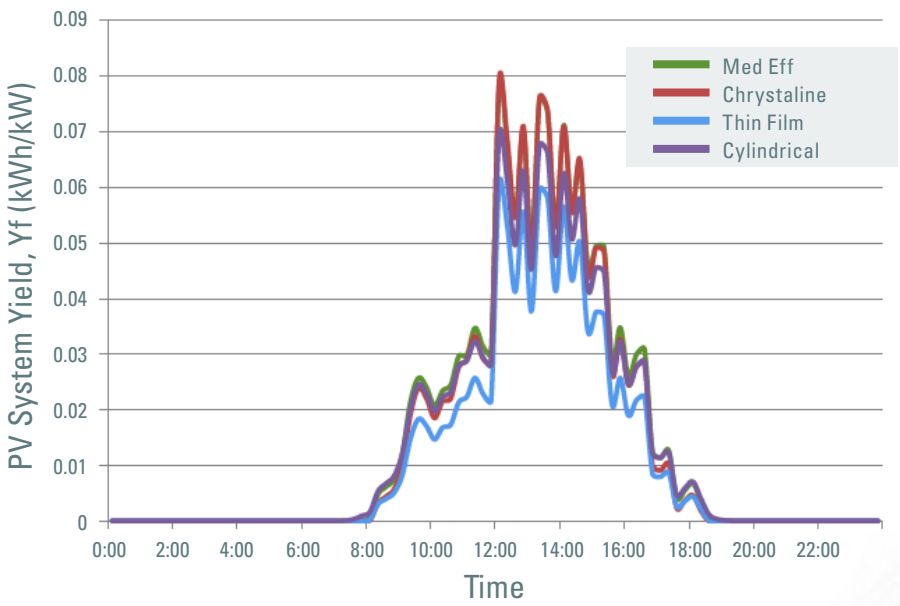
PARITY AMONG SYSTEMS UNDER CLOUDY SKIES[4]

19 YEAR PAYBACK[5]

Steady decline in PV cost will further improve payback[6]

Laboratory Systems Perform Similarly Under Cloudy Skies

PV System Yield on Cloudy Day, March 3, 2012



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

[1]GSA Energy Usage Analysis System, 2013 [2]Photovoltaic System Performance. Andrew L. Rosenthal (USDOE, NMSU, SNL) December 2012, p.5 [3]Ibid, p.12 [4]Ibid, p.1 [5]Ibid, p.12 [6]Ibid, p.3

GPG FINDINGS 006

DECEMBER 2012

VARIABLE REFRIGERANT FLOW

OPPORTUNITY

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

34%
OF ENERGY
GOES TO HVAC[1]

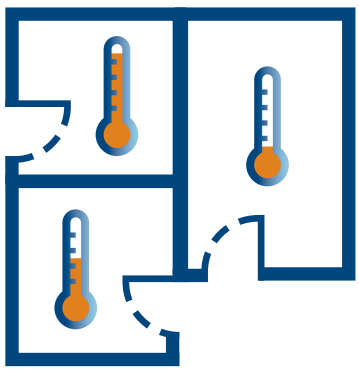
3%
OF U.S. OFFICE BUILDINGS RELY ON VRF[2]
PRIMARY HVAC SYSTEM IN EUROPE, JAPAN AND CHINA[3]

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 HVAC[4]

THIN
PROFILE
ADVANTAGEOUS IN HISTORIC BUILDINGS WITH LIMITED ROOM FOR DUCTWORK[5]

COST-
EFFECTIVE
WHEN THE PREMIUM IS < $4/SQ.FT. COMPARED TO CODE-COMPLIANT HVAC[6]

Projected Payback for VRF vs VAV

Reasonable paybacks achievable (shown in white)

VRF vs VAV with Gas Reheat or Cav

34% Projected Energy Cost Savings

Added Cost $/ft² \ Energy Cost Savings, $/ft²	$.10	$.14	*$.18	$.22	$.26	$.30	$.34	$.38
$1	10	7	6	5	4	3	3	3
$2	20	14	11	9	8	7	6	5
$3	30	21	17	14	12	10	9	8
**$4	40	29	22	18	15	13	12	11
$5	50	36	28	23	19	17	15	13
$6	60	43	33	27	23	20	18	16

VRF vs VAV with Electric Reheat

45% Projected Energy Cost Savings

Added Cost $/ft² \ Energy Cost Savings, $/ft²	$.13	$.19	*$.24	$.29	$.34	$.40	$.45	$.50
$1	8	5	4	3	3	3	2	2
$2	15	11	8	7	6	5	4	4
$3	23	16	13	10	9	8	7	6
**$4	30	22	17	14	12	10	9	8
$5	38	27	21	17	15	13	11	10
$6	45	32	25	21	17	15	13	12

* 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

[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.13 [5]Ibid, p.24 [6]Ibid, p.46

GSA

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GPG FINDINGS 007

DECEMBER 2013

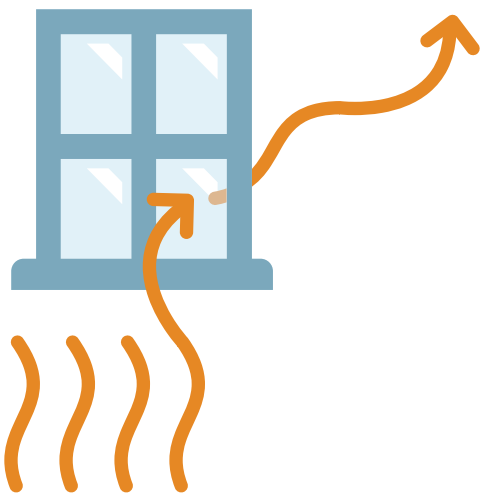
HI-R LOW-E WINDOW RETROFIT SYSTEM

OPPORTUNITY

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

23% ENERGY

USED TO HEAT & COOL BUILDINGS IS LOST THROUGH INEFFICIENT WINDOWS[1]



TECHNOLOGY

How do Window Panel Retrofits save energy?

IMPROVE THERMAL PERFORMANCE

WITH LOW-E WINDOW PANELS

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[2]

ESTIMATED SAVINGS FOR ENTIRE BUILDING HEATING AND COOLING: 11%[3]

QUICK

INSTALLATION[4]

IMPROVED VISUAL AND THERMAL COMFORT[5]

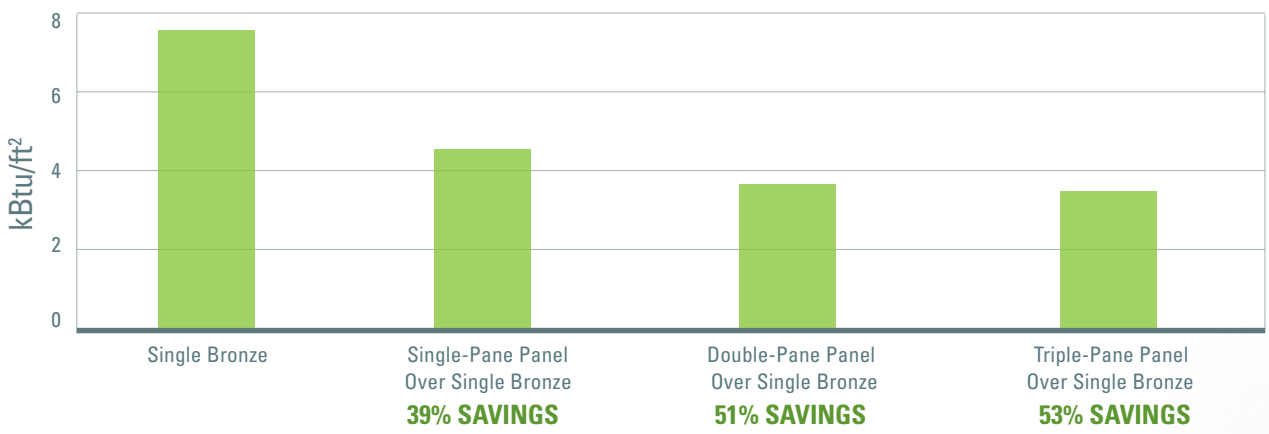
<9

YEARS

PAYBACK FOR TRIPLE-PANE; DOUBLE-PANE WILL BE SHORTER[6]

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

[1]Highly Insulating Window Panel Attachment Retrofit. Charlie Curcija, Howdy Goudey, Robin Mitchell, Erin Dickerhoff (LBNL), December 2013, p.3 [2]Ibid, p.26 [3]Ibid, p.39 [4]Ibid, p.7 [5]Ibid, p.26,35 [6]Ibid, p.2

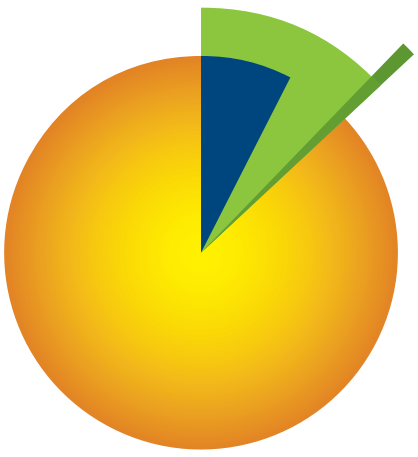
GPG FINDINGS 008

DECEMBER 2013

ON-SITE PHOTOVOLTAIC GUIDANCE

OPPORTUNITY

How is GSA meeting federal mandates for renewable energy?



7.5% Federal mandate goal for renewable energy[1]

13.2% GSA renewable energy purchased[2]

1% Solar energy production from GSA buildings[3]

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[4]

CHALLENGES NUMEROUS & UNIVERSAL[5]

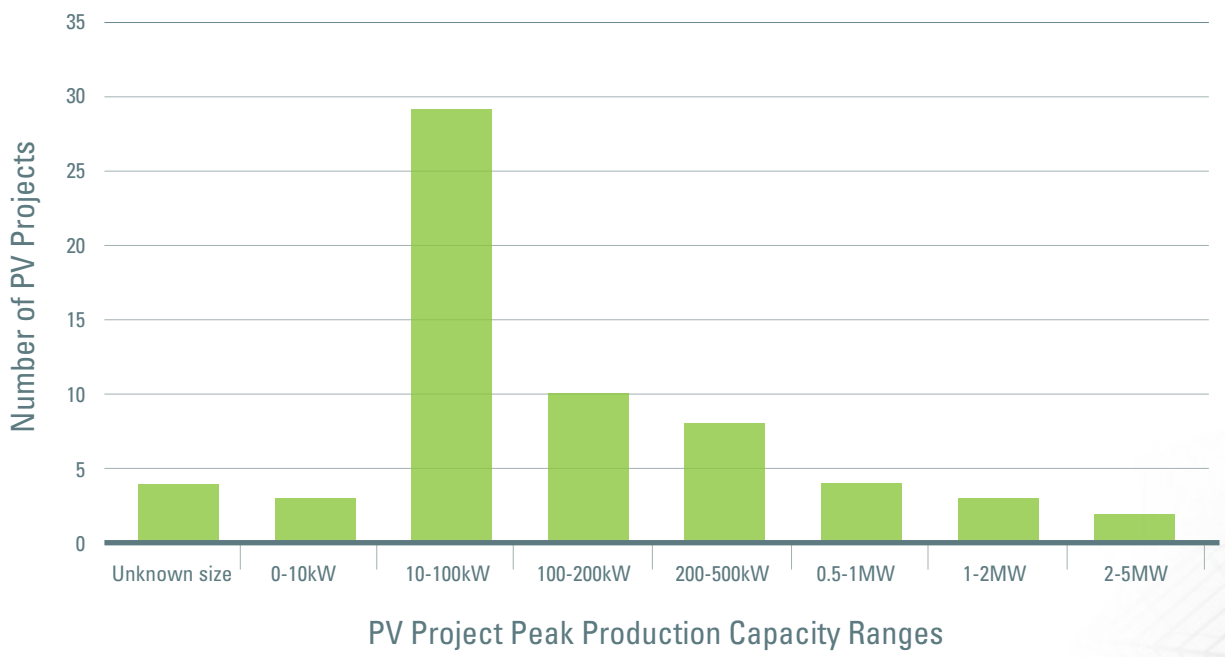
PROJECT MANAGEMENT, SITE, INTERCONNECTION, TECHNICAL, AND ECONOMIC

RISKS MITIGATED

BY ADVANCE PLANNING AND PROJECT MANAGEMENT[6]

Projects in NREL Study, by System Capacity

Of the 63 projects included, capacity ranges widely



FOR MORE INFORMATION

Where to find addtional information?

ON-SITE PV GUIDANCE REPORT

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

[1]EPA, http://www.epa.gov/oaintrnt/greenpower/requirements.htm [2]GSA Energy Usage Analysis System, 2013 [3]ibid
[4]On-Site Photovoltaic Guidance. Tom Harris, Ian Metzger, Alicen Kandt, Graham Hill, Marianne Kaiser (NREL), October 2013, p.5
[5]Ibid, p.21 [6]Ibid, p.28

GSA

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GPG FINDINGS 009

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[1]

32%
OF COMMERCIAL BUILDINGS
RELY ON CHILLERS TO PROVIDE THIS COOLING[2]

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?

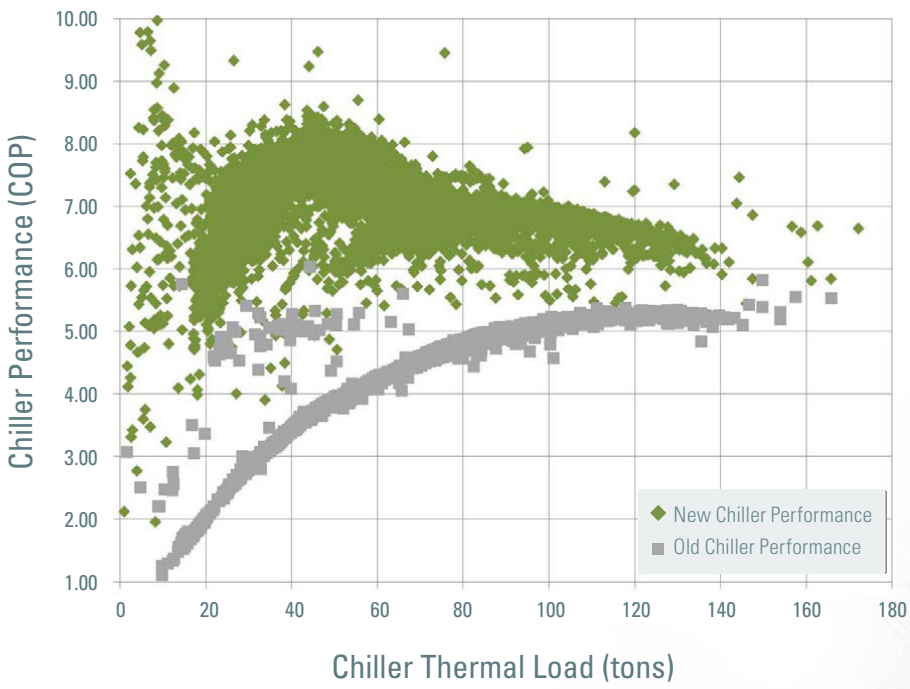
42%
ENERGY SAVINGS
AS COOLING LOADS DECREASE, EFFICIENCY INCREASES[3]

QUIET
PERFORMANCE
ALLOWS CHILLERS TO BE PLACED CLOSER TO OCCUPANT SPACES[4]

<5
YEARS
PAYBACK
after normalizing for payment structure & utility costs[5]

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

[1]Variable-speed Oil-free Centrifugal Chiller with Magnetic Bearings Assessment; George Howard, Jr. Federal Building and U.S.Courthouse, Pine Bluff, Arkansas. S.A.Parker, J.Blanchard (PNNL), December 2013, p.1 [2]Ibid, p.1 [3]Ibid, p.3 [4]Ibid, p.34 [5]Ibid, p.26

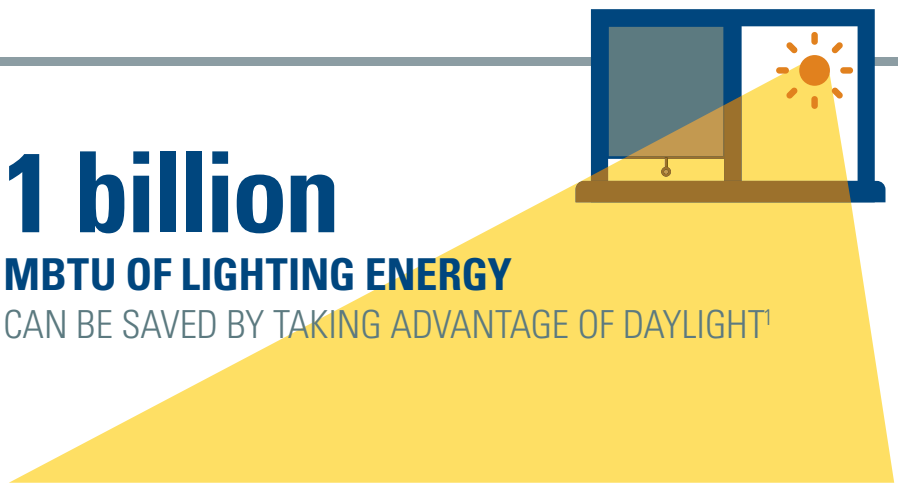
GPG FINDINGS 010

MARCH 2014

ELECTROCHROMIC AND THERMOCHROMIC WINDOWS

OPPORTUNITY

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



1 billion

MBTU OF LIGHTING ENERGY

CAN BE SAVED BY TAKING ADVANTAGE OF DAYLIGHT[1]

TECHNOLOGY

How do chromogenic windows save energy?

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

THERMOCHROMIC (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 SAVINGS[2]

48-58% REDUCTION IN HEAT GAIN[3]

PRESERVED VIEWS

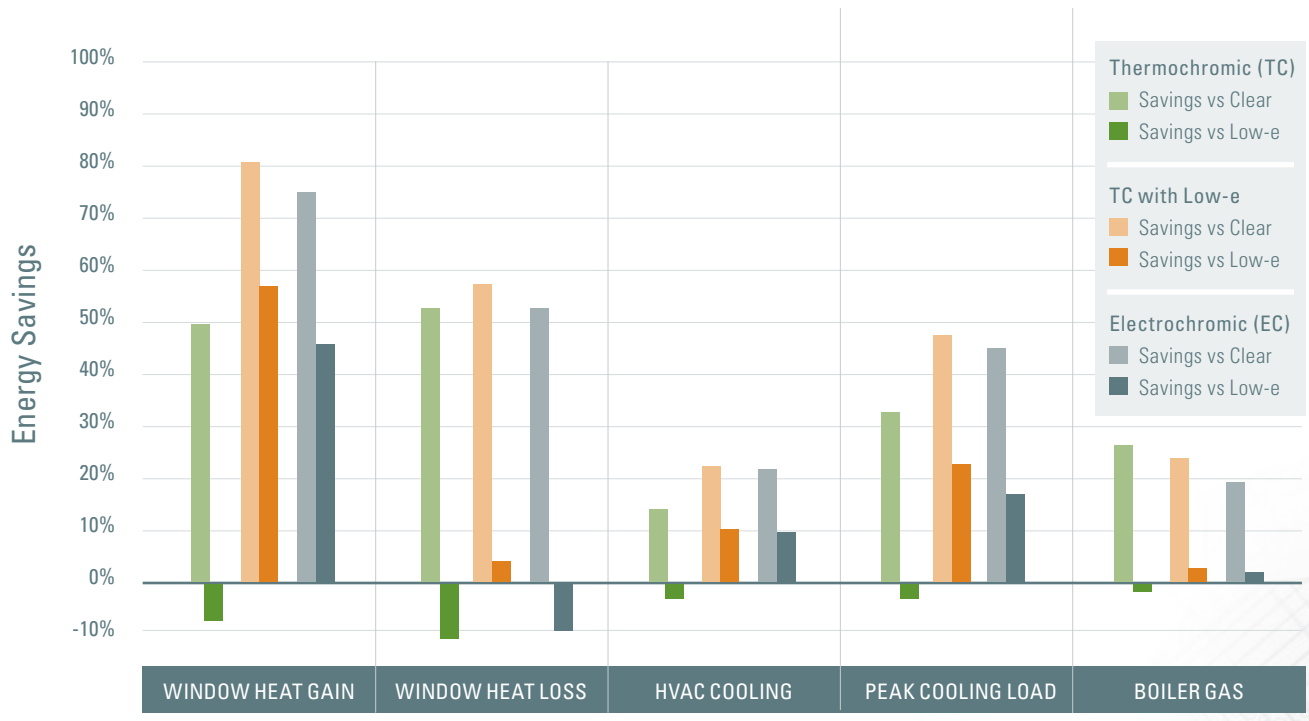
EC TINTED TO DARK BLUE[4]; TC PERFORMANCE SENSITIVE TO SURROUNDING SURFACE GEOMETRY[5]

CAPTURED BENEFIT

OF NATURAL DAYLIGHTING

Provided less glare[6]

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]A Pilot Demonstration of Electrochomic and Thermochromic Windows in the Denver Federal Center, Building 41, Denver, Colorado. Eleanor S. Lee (LBNL), March 2014, p.12 [2]Ibid, p.51 [3]Ibid, p.54 [4]Ibid, p.17 [5]Ibid, p.50 [5]Ibid, p.10

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GPG FINDINGS 011

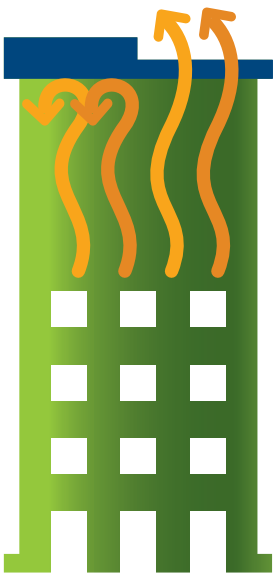
MARCH 2014

VACUUM INSULATED PANELS IN ROOFING APPLICATIONS

OPPORTUNITY

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

37%
OF ENERGY
GOES TO HVAC[1]



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&V

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&V?

8-10%
ENERGY SAVINGS
WHEN COMPARED TO CODE-COMPLIANT ROOFS[2]

ROBUST
PERFORMANCE
WITH PROPER PLANNING[3]

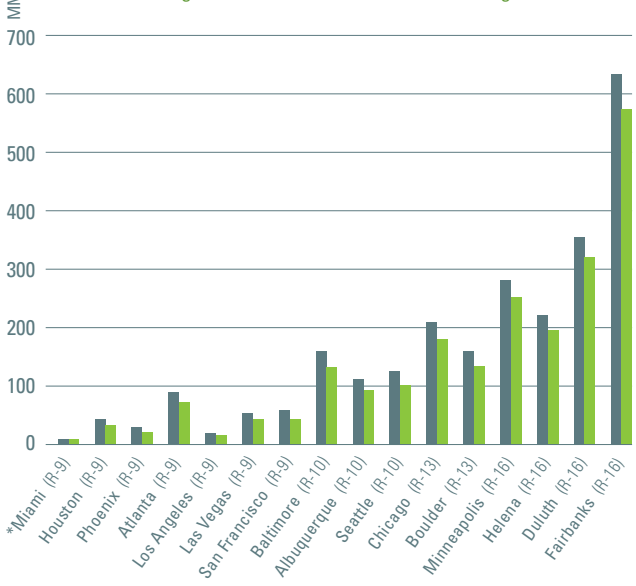
SAVINGS FOR R-50
GREATEST IN SINGLE-STORY BUILDINGS IN EXTREME CLIMATES[4]

Modeled Energy Use in a Single-Story Office Building

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

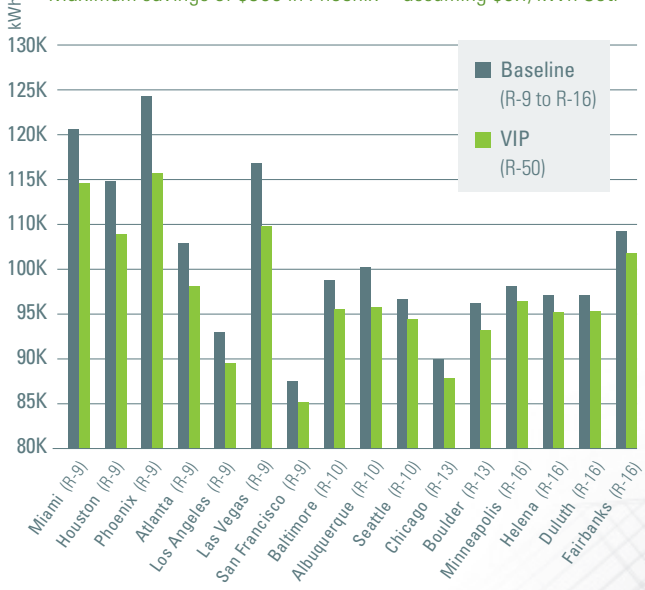
Annual Gas Consumption

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



Annual Electricity Consumption

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



*Cities listed by climate zone from Hot-Humid (1A) to Subarctic (8A)[1]

DEPLOYMENT

Where does M&V recommend deploying VIPs?

RETROFITS

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

[1]Vacuum 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 [2]Ibid, p.15 [3]Ibid, p.2 [4]Ibid, p.2

GSA

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GPG FINDINGS 012

MARCH 2014

FAN BELTS: SYNCHRONOUS AND COGGED

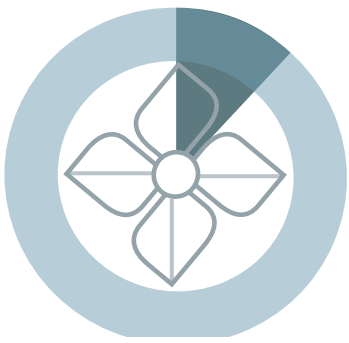
OPPORTUNITY

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

12%

OF ELECTRICITY

GOES TO FAN VENTILATION[1]



ADDITIONAL SAVINGS POSSIBLE

Belt-driven fans are also used in non-ventilation applications

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?

NATIONAL RENEWABLE ENERGY LABORATORY measured the performance of cogged V-belts and synchronous drive belts provided by the Gates Corporation at the Byron G. Rodgers Federal Building and U.S. Courthouse in Denver, Colorado

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[2]

75%

LOWER O&M

FOR SYNCHRONOUS

Cogged O&M equivalent to standard V-belts[3]

<4

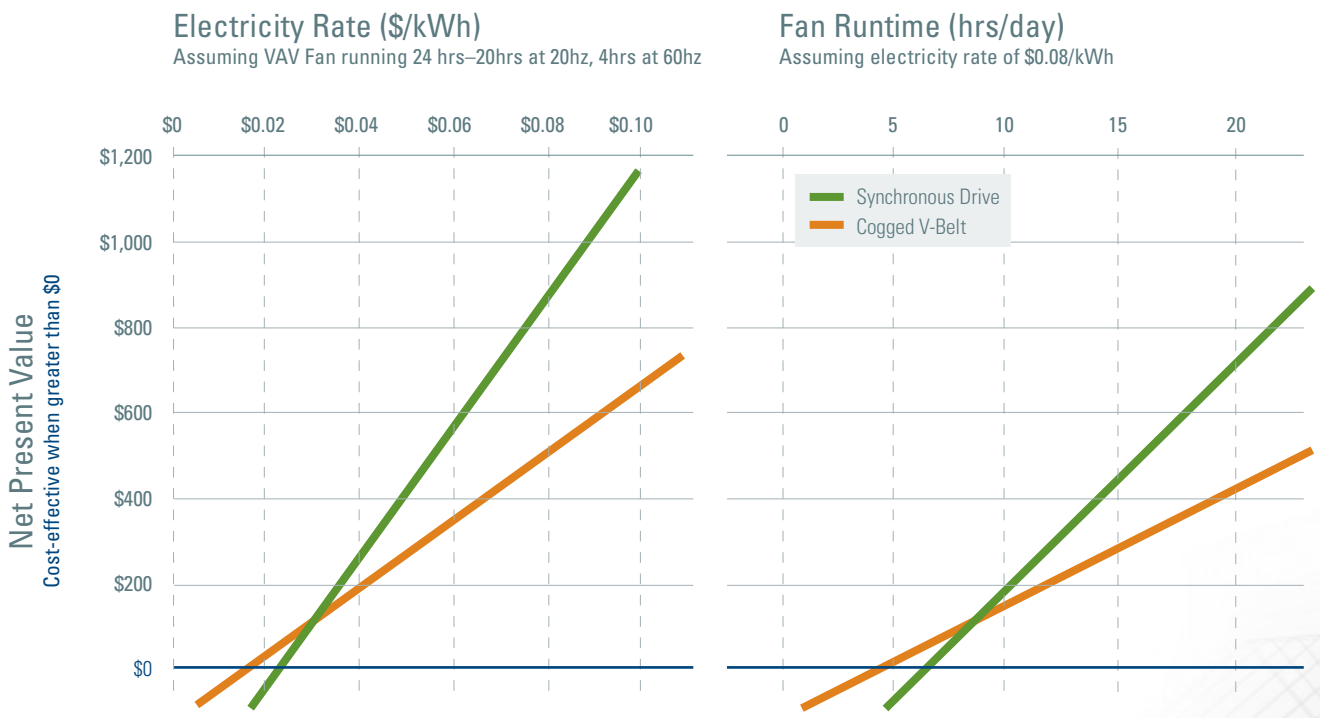
YEARS

PAYBACK FOR SYNCHRONOUS[4]

Repeat installations have immediate payack; Cogged payback < 1 year [5]

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

[1]Synchronous and Cogged Fan Belt Assessment. Dylan Cutler, Jesse Dean, Jason Acosta (NREL), March 2014, p.1 [2]Ibid, p.2 [3]Ibid, p.3 [4]Ibid, p.5 [5]Ibid, p.4

GPG FINDINGS 013

MARCH 2014

INDIRECT EVAPORATIVE COOLER

OPPORTUNITY

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

15%
OF ENERGY
GOES TO AIR CONDITIONING[1]

LARGEST CONTRIBUTOR
TO PEAK DEMAND, GRID FAILURES AND BLACKOUTS[2]

TECHNOLOGY

How do Indirect Evaporative Coolers save energy?

REMOVE HEAT AND MOISTURE
WITH UNIQUE AIR-PROCESSING TECHNOLOGY

57-92% MORE EFFICIENT
THAN CODE-COMPLIANT ROOF-TOP UNITS (RTU)[3]

M&V

Where did Measurement and Verification occur?

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[4]
INCREASED WATER USAGE (3 GALLONS/ TON-HR) COMPARED TO TYPICAL RTU[5]

POSITIVE
THERMAL COMFORT
AS DEFINED BY ASHRAE[6]

<15
YEARS
AVERAGE PAYBACK FOR DATACENTERS[7]

Tarket Markets Favor Dry Climate Zones (Subtype B)

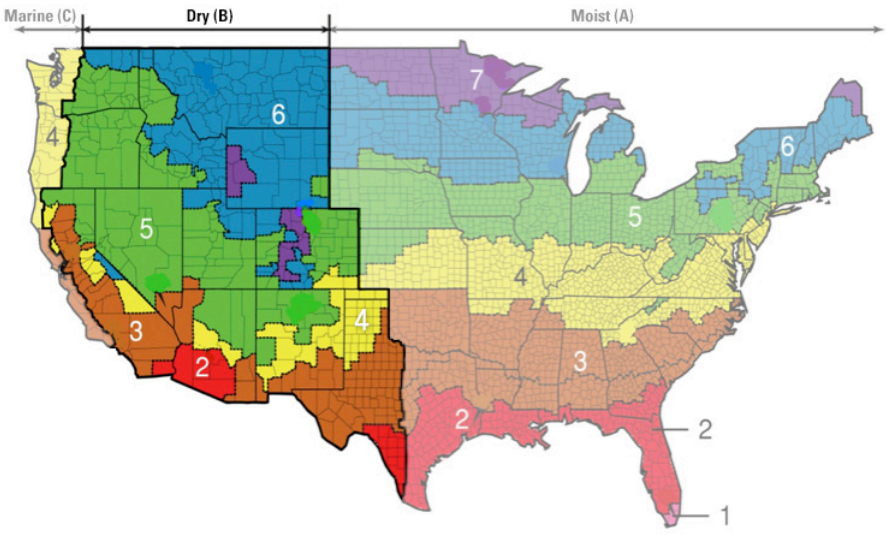
Data centers in ASHRAE climate zones 2B - 6B are top target market

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?

DRY CLIMATES

Data centers : ASHRAE climate zones 2B - 6B
Outside air pre-conditioner : ASHRAE climate zones 2b, 3b
Zone cooler : ASHRAE climate zones 4b- 6B

[1]Multistaged Indirect Evaporative Cooler Evaluation. Jesse Dean, Ian Metzger (NREL), March 2014, p.7 [2]Ibid, p.7 [3]Ibid, p.3 [4]Ibid, p.5 [5]Ibid, p.27 [6]Ibid, p.25 [7]Ibid, p.30

GPG FINDINGS 014

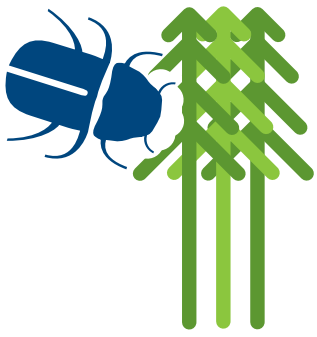
JUNE 2014

WOOD-PELLET BIOMASS BOILERS

OPPORTUNITY

What are the benefits to using Biomass Boilers?

DRIVE USE OF LOCALLY SOURCED RENEWABLE ENERGY



TAKE ADVANTAGE OF WASTE WOOD

PINE-BEETLE INFESTATION HAS KILLED 17.7 MILLION ACRES OF U.S. FOREST[1]

TECHNOLOGY

How do Biomass Boilers work?

POWER HOT-WATER-HEATING SYSTEMS

WITH SOLID WOOD FUEL

85%-90%

EFFICIENCY RATING

M&V

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

RESULTS

How did Biomass Boilers perform in the M&V?

85.6%

BOILER EFFICIENCY

AT 45% PARTIAL LOAD[2]; INCREASED LOAD WILL INCREASE EFFICIENCY[3]

HIGH

FUNCTIONALITY

LOW O&M COSTS[4]

<5

YEARS

PAYBACK OPERATING AT 75% CAPACITY WITH AVERAGE PELLET COSTS[5]

Payback Varies by System Size and Pellet Cost

Savings are greatest with larger systems and lower fuel costs

Pellet Cost ($/ton)

System Size (BTUs/hr)	$400	$350	$300	$250	$200
	PAYBACK IN YEARS				
500,000	30.7	10.7	6.5	4.7	3.6
1,000,000	24.1	8.4	5.1	3.6	2.8
1,500,000	20.9	7.3	4.4	3.2	2.5
2,000,000	18.9	6.6	4.0	2.9	2.2
2,500,000	17.5	6.1	3.7	2.6	2.1
3,000,000	16.4	5.7	3.5	2.5	1.9
3,500,000	15.6	5.4	3.3	2.4	1.8
4,000,000	14.8	5.2	3.1	2.2	1.8

< 2
< 3
< 5
< 10
10+

Diesel Price $3.63/gallon; 75% capacity factor

(At a 50% capacity factor, the payback period increases 30%)

DEPLOYMENT

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

[1]US Forest Service, Western Bark Beetle Strategy, Human Safety, Recovery and Resiliency, 7/11/2011 [2]Wood-Pellet-Fired Biomass Boiler Project at the Ketchikan Federal Building. Gregg Tomberlin (NREL), June 2014, p3 [3]Ibid, p.12 [4]Ibid, p.23 [5]Ibid, p.29

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GPG FINDINGS 015

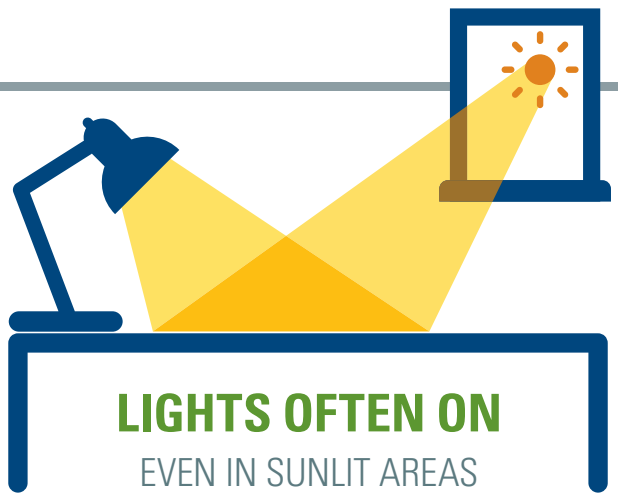
JULY 2014

INTEGRATED DAYLIGHTING SYSTEMS

OPPORTUNITY

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

26%
OF ELECTRICITY
GOES TO LIGHTING[1]



LIGHTS OFTEN ON
EVEN IN SUNLIT AREAS

TECHNOLOGY

How do Integrated Daylighting Systems save energy?

AVAILABLE NATURAL LIGHT
OFFSETS USE OF ELECTRIC LIGHT

EFFECTIVE WHERE PERIMETER DEPTH IS TWO TIMES THE MAXIMUM WINDOW HEIGHT

M&V

Where did Measurement and Verification occur?

LAWRENCE BERKELEY NATIONAL LABORATORY measured IDS performance at 5 federal buildings to evaluate incremental savings from daylight harvesting

RESULTS

How did Integrated Daylighting perform in M&V?

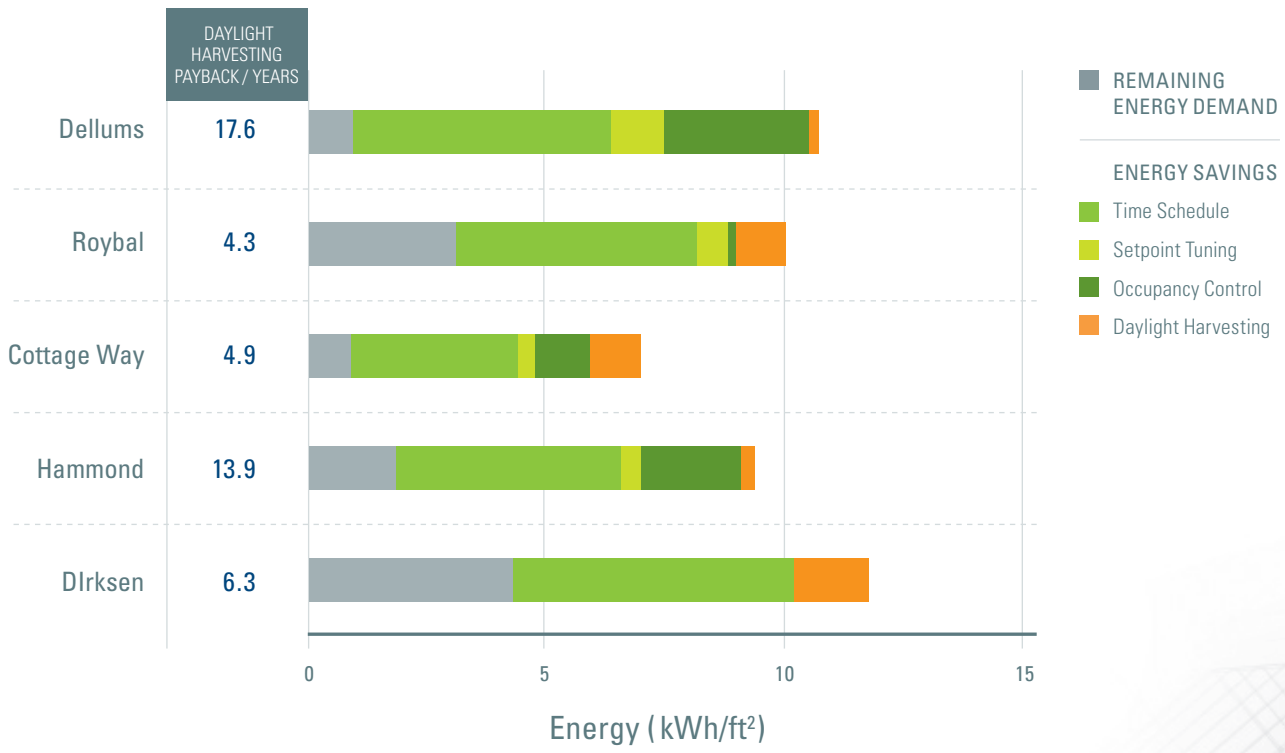
27%
AVERAGE SAVINGS
0.84 KWH/FT^2

BEST PRACTICES
UNOBSTRUCTED SKY VIEWS, LIMITED SEASONAL VARIATION, WINDOW-TO-WALL RATIO 0.5, VISIBLE TRANSMITTANCE OF 60%[3]

<6
YEARS PAYBACK
WITH HIGH OCCUPANCY[4]

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/ft^2 and energy use intensity greater than 3.3 kWh/ft^2

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

[1]Integrated Daylighting Systems. Alastair Robinson, Claudine Custodio, Steven Selkowitz (LBNL), July 2014, p.13 [2]Ibid, p.42
[3]Ibid, p.100 [4]Ibid, p.7,39

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GPG FINDINGS 016

JANUARY 2015

PHOTOVOLTAIC-THERMAL HYBRID SOLAR SYSTEM

OPPORTUNITY

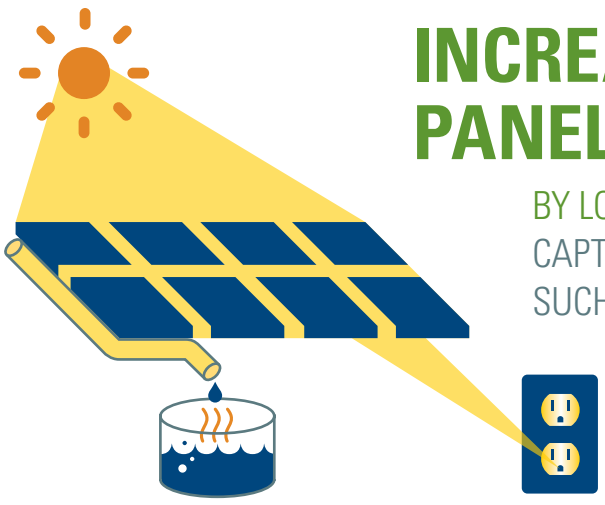
What are the renewable energy goals of federal mandates?

7.5%
OF ELECTRICITY
GENERATED BY RENEWABLES[1]

30%
OF HOT WATER
HEATED WITH SOLAR[2]

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&V

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&V?

1st
LARGE-SCALE INSTALLATION; NUMEROUS LESSONS LEARNED[3]

LIMITED
COST-EFFECTIVE DEPLOYMENT POTENTIAL[4]

COMPETITIVE
WITH TRADITIONAL SOLAR WHEN 30-50% LESS EXPENSIVE[5]

Energy Savings and Economics for PV-T

Cost-effective when electricity rates are high

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

DEPLOYMENT

Where does M&V recommend deploying PV-T?

HIGH ELECTRIC RATES

Small facilities, with electric rates > $.30 k/Wh, in hot climates with large domestic hot water (DHW) loads and limited roof space.

Incentives can lower system costs by as much as 75%

[1]Photovoltaic-Thermal New Technology Demonstration. Jesse Dean, Peter McNutt, Lars Lisell, Jay Burch, Dennis Jones, David Heinicke (NREL), January 2015 p.1 [2]Ibid, p.1 [3]Ibid, p.58 [4]Ibid, p.8 [5]Ibid, p.47

GPG FINDINGS 017

JANUARY 2015

SOLAR-CONTROL FILMS

OPPORTUNITY

Windows in U.S. office buildings are responsible for how much cooling energy demand?

28%

OF COOLING ENERGY DEMAND IS DUE TO HEAT GAIN IN WINDOWS[1]

10 MILLION HOUSEHOLDS

equivalent energy use[2]

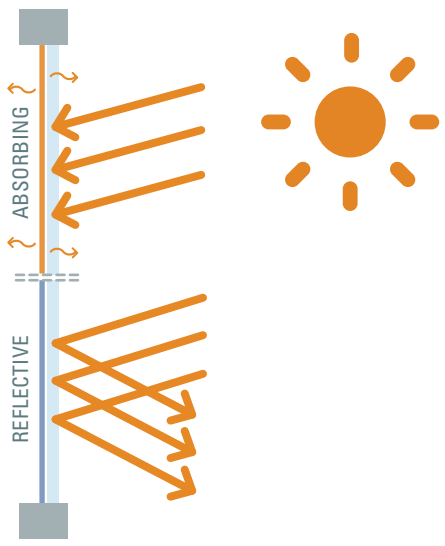
TECHNOLOGY

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

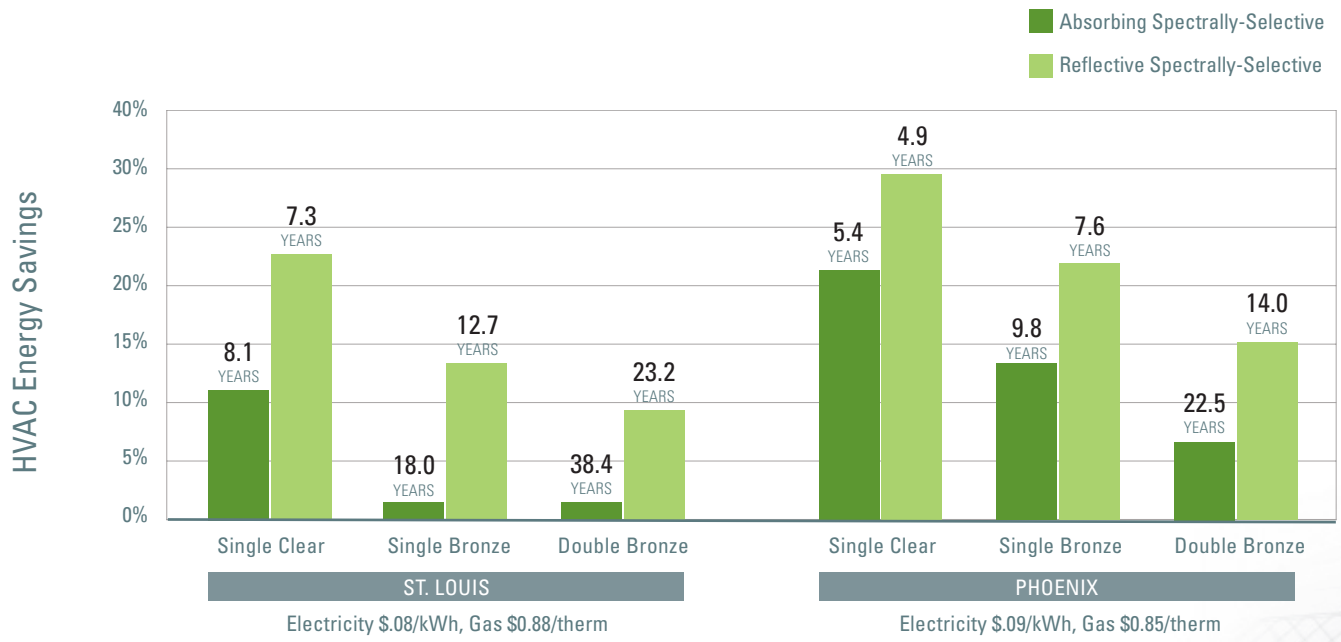
COST-EFFECTIVE FOR SINGLE-PANE CLEAR; NOT RECOMMENDED FOR DOUBLE-PANE BRONZE IN MOST CLIMATES[3]

REFLECTIVE MORE EFFICIENT

UP TO 29% HVAC ENERGY SAVINGS IN WARMER CLIMATES[4]

Modeled Energy Savings For Range of Base Windows and Climates

Payback for liquid-applied absorbing @ $8/ft^2 (80% of current cost) and reflective @ $10/ft^2



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.

[1]Liquid-Applied Absorbing Window Film Retrofit, Charlie Curcija, Howdy Goudey, Robin Mitchell, Leandro Manes, Stephen Selkowitz, LBNL, November 2014, p. 10 [2]Ibid, p.10 [3]Ibid, p.9 [4]Ibid, p.54

GPG FINDINGS 018

JANUARY 2015

WEATHER STATION FOR IRRIGATION CONTROL

OPPORTUNITY

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

20%

OF WATER IN U.S. OFFICE BUILDINGS IS USED FOR IRRIGATION[1]

UP TO 50% WASTED

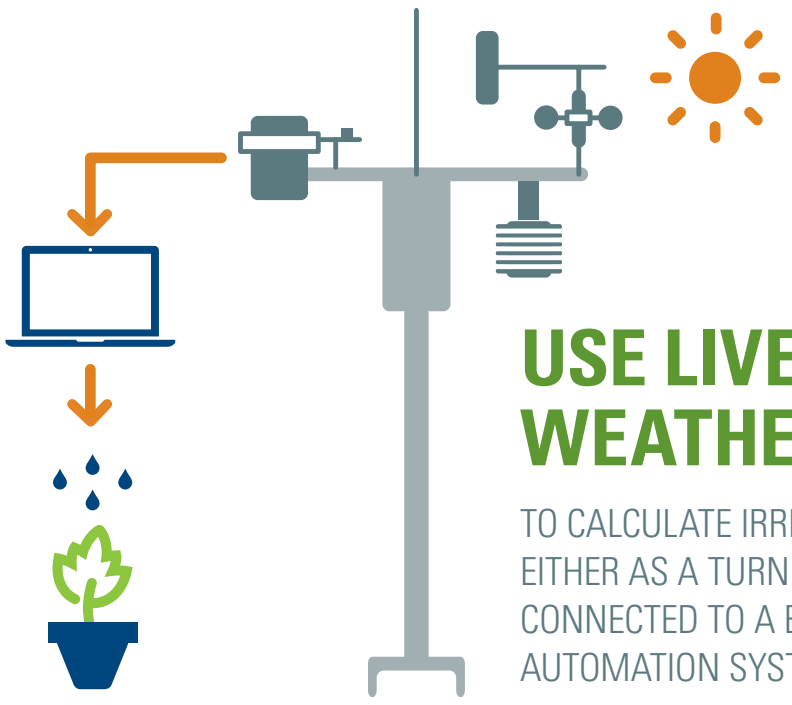
with timer-based irrigation[2]

20-40% CAN BE SAVED

with smart irrigation, depending on climate, soil, and vegetation profile[3]

TECHNOLOGY

How do Weather-Stations for Irrigation Control work?



USE LIVE LOCAL WEATHER DATA

TO CALCULATE IRRIGATION NEEDS, EITHER AS A TURNKEY SYSTEM OR CONNECTED TO A BUILDING AUTOMATION SYSTEM (BAS)

M&V

Where did Measurement and Verification occur?

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.

RESULTS

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

66%

WATER SAVINGS

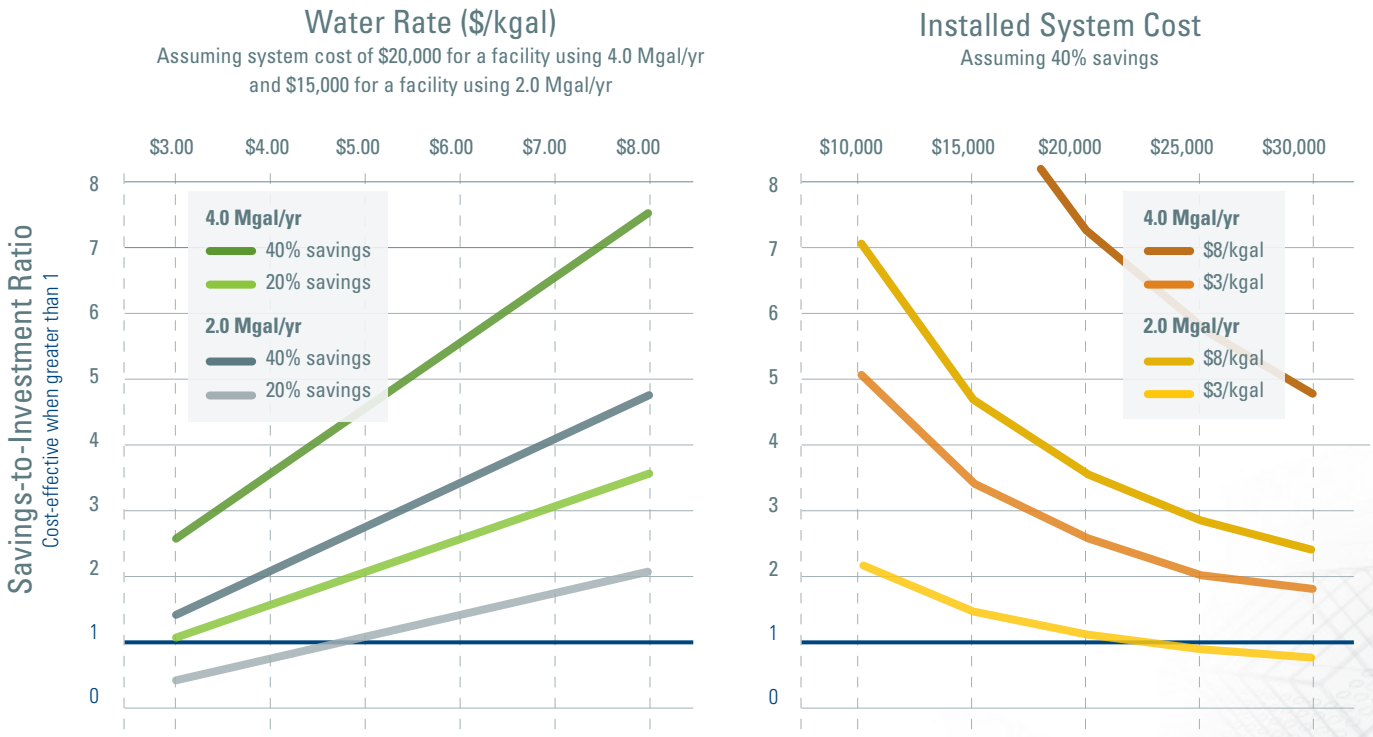
PROJECTED[4]

BAS-CONNECTED

WEATHER STATION

CHALLENGING TO PROGRAM AND NOT FULLY REALIZED, TURNKEY RECOMMENDED AT PRESENT[5]

Life-Cycle Cost Analysis for Smart-Irrigation Systems



DEPLOYMENT

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

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.

[1]Assessment of Weather Station Used for Irrigation Control: Hart-Dole-Inouye FederalCenter, Battle Creek, MI, KL McMordie Stoughton, RS Butner, PNNL, November 2014, p. 3 [2]Ibid, p.3 [3]Ibid, p.3 [4]Ibid, p.6 [5]Ibid, p.10 Subject to evaluation and approval by GSA-IT and Security

GSA

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GPG FINDINGS 019

FEBRUARY 2015

CATALYST-BASED SCALE PREVENTION

OPPORTUNITY

What percentage of the U.S. has hard water?

85%

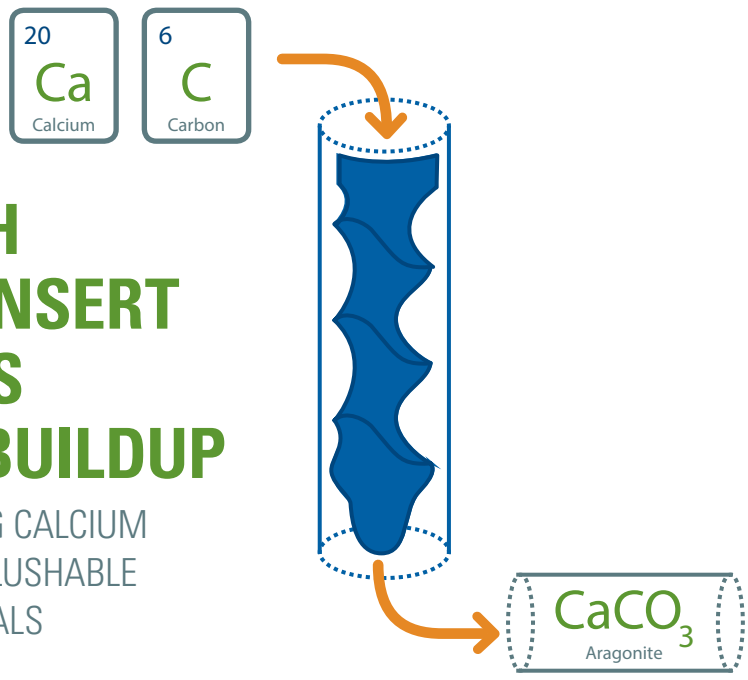
OF THE UNITED STATES HAS HARD (>121 MG/L) WATER[1]

CALCITE BUILDUP

due to hard water restricts water flow and causes heating systems to overheat and fail

TECHNOLOGY

How does Non-Chemical Scale Prevention work?



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?

EFFECTIVE

REDUCTION OF CALCITE

NO BUILDUP AFTER 18 MONTHS[2]

O&M

MINIMAL

NO MOVING PARTS OR CHEMICALS[3]

<2 yrs

PAYBACK; IMMEDIATE WHEN COMPARED TO CHEMICAL SYSTEMS[4]

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

	Salt-Based System	Catalyst-Based Non-Chemical Scale Prevention
Equipment Cost	$2,600	**$1,192— ¾" diameter unit** Unit pricing ranges between $798 for a ⅜" pipe and $96,360 for a 16" pipe.
Installation Cost	$600	**$500 —10 hours @ $50/hr** Installation for new construction is $0, as it incurs no additional costs over baseline.
Maintenance Costs/year	**$1,850—$350 chemicals, $1,500 labor**	**$100—biannual tank cleaning** Required in systems without a drain.
Simple Payback		**Immediate**

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 sacle prevention will be cost-effective

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

GPG FINDINGS 020

MARCH 2015

WIRELESS THERMOSTATS FOR PNEUMATIC SYSTEMS

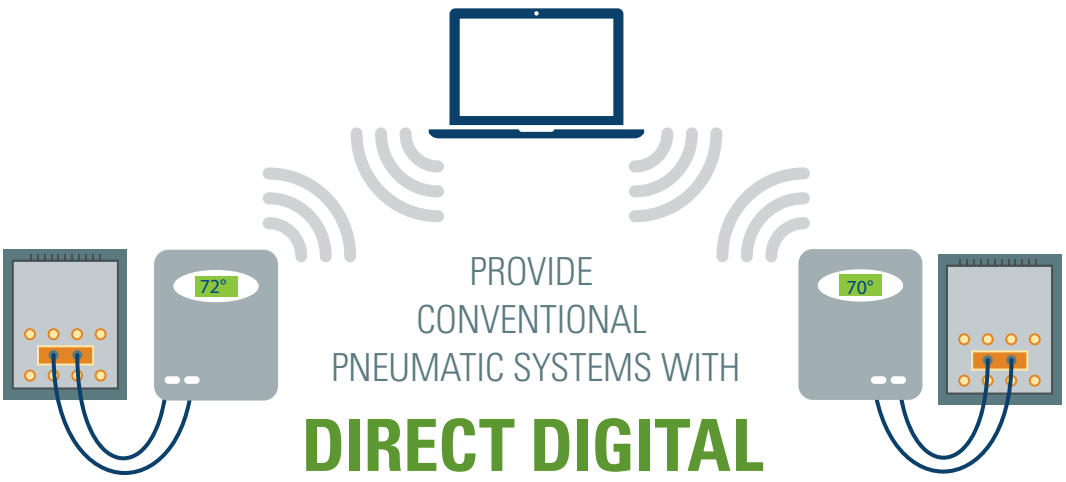
OPPORTUNITY

Where are pneumatic thermostats typically found?

COMMERCIAL BUILDINGS BUILT BEFORE 1999 that are > 20,000 ft^2 and multi-story[1]

TECHNOLOGY

How do Wireless Pneumatic Thermostats work?



PROVIDE CONVENTIONAL PNEUMATIC SYSTEMS WITH

DIRECT DIGITAL CONTROL (DDC) FUNCTIONALITY

M&V

Where did Measurement and Verification occur?

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?

EFFECTIVE APPLICATION OF ENERGY-SAVING CONTROL STRATEGIES[2]

ENERGY SAVINGS ACROSS CLIMATE ZONES AND OFFICE SIZES[3]

<2-6 YRS PAYBACK WITH UNOCCUPIED/OCCUPIED CONTROL STRATEGY AND LOW INSTALLATION COSTS[4]

Modeled Payback for Unoccupied/Occupied Control Strategy

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

Location		Large Office - 498,500 ft^2 Payback (years)		Medium Office - 53,630 ft^2 Payback (years)		Small Office - 5,500 ft^2 Payback (years)	
CLIMATE ZONE	CITY	LOW[1]	HIGH[2]	LOW[3]	HIGH[4]	LOW[5]	HIGH[6]
1A	Miami, FL	3.6	6.5	3.7	6.8	1.9	3.3
2A	Houston, TX	3.7	6.7	4.5	8.2	2.9	5.0
2B	Phoenix, AZ	4.6	8.2	4.0	7.3	2.5	4.3
3A	Atlanta, GA	3.0	5.4	3.5	6.4	2.6	4.5
3B-coast	Los Angeles, CA	2.8	5.1	3.7	6.8	3.7	6.3
3B	Las Vegas, NV	5.3	9.5	5.0	9.2	3.1	5.4
3C	San Francisco, CA	3.0	5.5	3.8	7.0	3.2	5.5
4A	Baltimore, MD	2.8	5.0	3.3	6.0	2.7	4.7
4B	Albuquerque, NM	5.4	9.7	6.0	10.9	3.5	5.9
4C	Seattle, WA	3.6	6.5	4.5	8.2	4.3	7.4
5A	Chicago, IL	3.1	5.6	3.8	7.0	2.8	4.8
5B	Boulder, CO	5.0	8.9	5.7	10.5	3.7	6.4
6A	Minneapolis, MN	4.6	8.3	5.7	10.5	3.7	6.3
6B	Helena, MT	3.9	7.1	4.6	8.4	3.3	5.7
7	Duluth, MN	4.3	7.8	5.3	9.7	3.7	6.3
8	Fairbanks, AK	4.2	7.6	5.2	9.5	3.1	5.3

Installation Costs: [1] \$0.50/ft^2 [2] \$0.90/ft^2 [3] \$0.60/ft^2 [4] \$1.10/ft^2 [5] \$0.70/ft^2 [6] \$1.20/ft^2

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

[1]Wireless Pneumatic Thermostat Evaluation, Ronald Reagan Building and International Trade Center, Washington, DC, Dan Howett, P.E., Mahabir Bhandari, PhD ORNL, March 2015, p. 2 [2]Ibid, p.3 [3]Ibid, p.4 [4]Ibid, p.4 *Subject to evaluation and approval by GSA-IT and Security

GPG FINDINGS 021

APRIL 2015

WIRELESS SOIL-MOISTURE SENSORS FOR IRRIGATION CONTROL

OPPORTUNITY

What is the federally mandated water reduction goal?

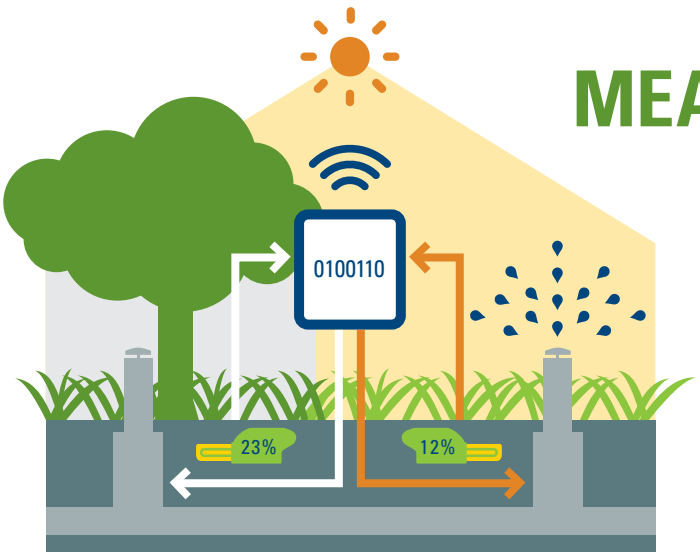
36%
REDUCTION IN POTABLE WATER USE
by 2025, compared to 2007 baseline[1]

37% OF UNITED STATES
is experiencing drought conditions[2]

20-40% WATER SAVINGS
with smart irrigation[3]

TECHNOLOGY

How do Wireless Moisture Sensors work?



MEASURE SOIL MOISTURE

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

M&V

Where did Measurement and Verification occur?

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

RESULTS

How did Wireless Moisture Sensors perform in M&V?

INCONCLUSIVE RESULTS

COMMUNICATION AND SENSOR PROBLEMS OF PRE-COMMERCIAL TECHNOLOGY COMPROMISED ANALYSIS[4]

Product development continued after M&V

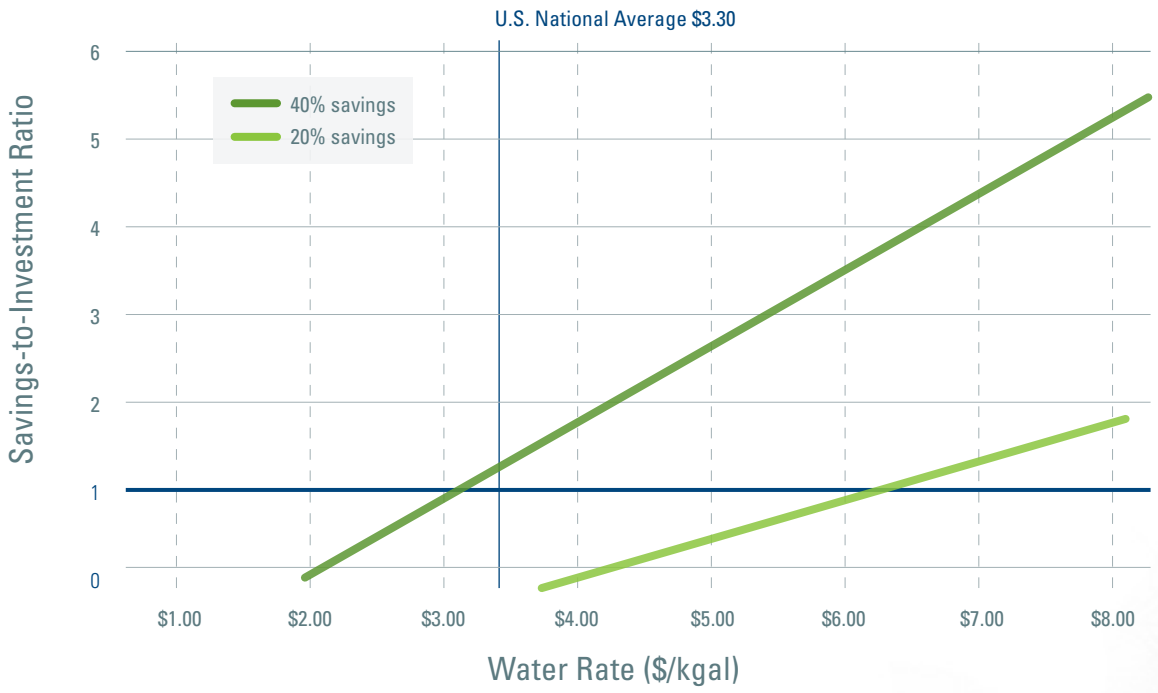
GREATER GRANULARITY

THAN WEATHER-BASED IRRIGATION CONTROL OFFERS POTENTIAL FOR GREATER SAVINGS[5]

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?

FURTHER RESEARCH

DOCUMENTING SENSOR EFFECTIVENESS

Meanwhile, turnkey weather-based controllers are recommended*

[1]Executive Order 13693, https://www.whitehouse.gov/the-press-office/2015/03/19/executive-order-planning-federal-sustainability-next-decade [2] *The New York Times*, Mapping the Spread of Drought Across the U.S., Accessed 4/6/2015. [3]Irrigation Controls Based on Wireless Soil Moisture Technology Assessment: George C. Young Federal Building and U.S. Courthouse, Orlando, FL, KL McMordie Stoughton, RS Butner, PNNL, March 2015, p. 1 [4]Ibid, p.1 [5]Ibid, p.3 *Subject to evaluation and approval by GSA-IT and Security

GPG FINDINGS

022

MAY 2015

WIRELESS ADVANCED LIGHTING CONTROLS

OPPORTUNITY

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

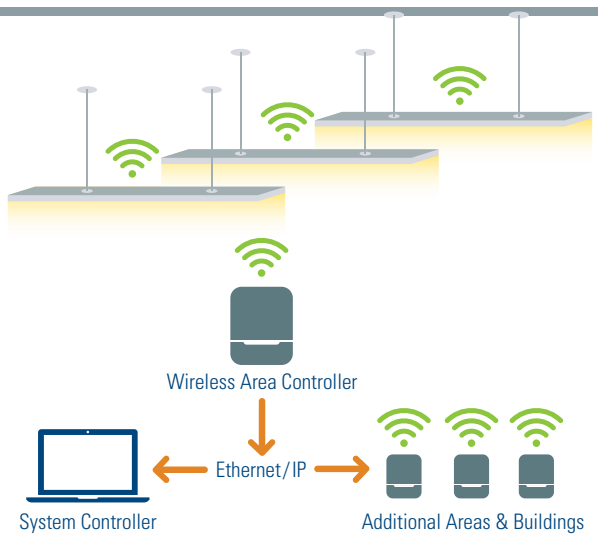
26%
OF ELECTRICITY
GOES TO LIGHTING[1]

>30%
DEMONSTRATED SAVINGS
WITH ADVANCED LIGHTING CONTROLS (ALC)[2]
Compared to national average EUI of 4.1 kWh/ft²/yr

ONLY 2% OF U.S. COMMERCIAL BUILDINGS IMPLEMENT ALC[3]

TECHNOLOGY

How do Wireless Advanced Lighting Controls work?



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?

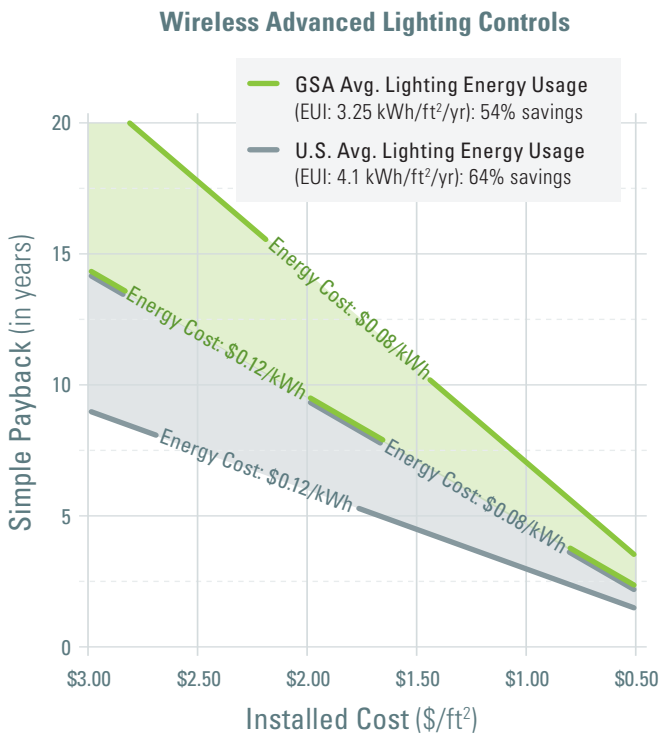
54%
SAVINGS
78% SAVINGS INCLUDING LED[4]
Normalized for GSA

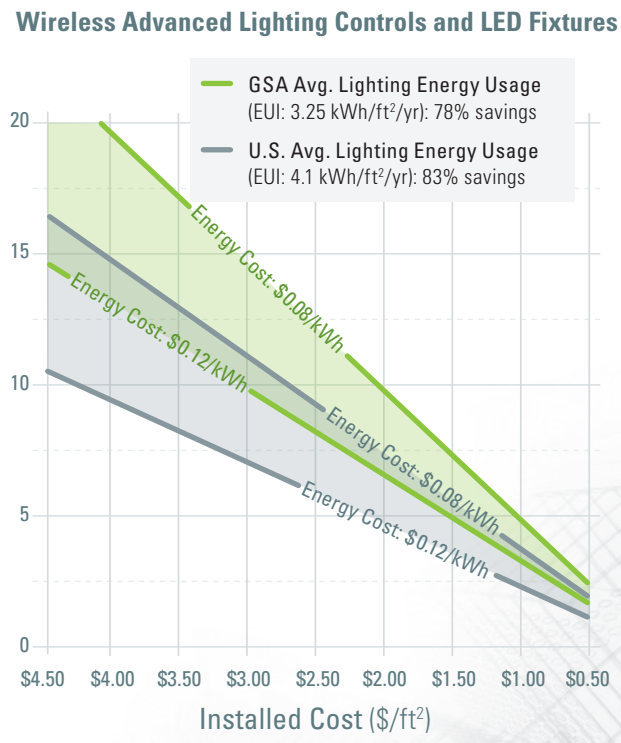
INCREASED
FLEXIBILITY
IN LIGHT LEVELS TO SUIT USER PREFERENCES[5]

3-6 yr
INCREMENTAL PAYBACK
FOR RENOVATIONS[6]

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*

[1]Wireless Advanced Lighting Controls Retrofit Demonstration. Francis Rubinstein (LBNL), April 2015, p.7 [2]Ibid, p.23 [3]Ibid, p.23 [4]Ibid, p.7,39 [5]Ibid, p.7,39 [6]Ibid, p.7,39 *Subject to evaluation and approval by GSA-IT and Security

GSA

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GPG FINDINGS 023

MAY 2015

ELECTROCHROMIC WINDOWS FOR LAND PORTS OF ENTRY

OPPORTUNITY

What is the potential benefit to Land Ports of Entry?

PROVIDE DIRECT LINE OF SIGHT

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

TECHNOLOGY

How do electrochromic (EC) windows work?

TRANSITION FROM CLEAR TO DARK

USING PHOTOSENSOR READINGS AND SUN PATH CALCULATIONS

M&V

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&V?

GLARE REDUCTION

BELOW PERCEPTIBLE GLARE THRESHOLD[2]

NIGHTTIME VISIBILITY REDUCED

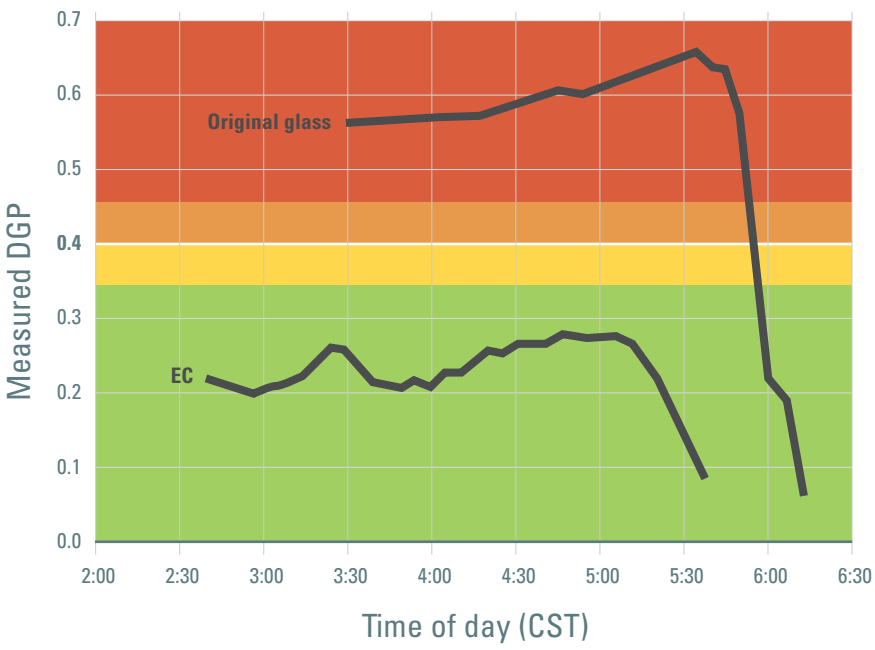
WITH INCREASED INTERIOR REFLECTION[3]

100% USER PREFERENCE

OVER CONVENTIONAL WINDOWS[4]

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

Booth with EC windows has much lower glare throughout a sunny afternoon



DGP	Qualitative Interpretation
> 0.45	Intolerable glare
0.40 to 0.45	Disturbing glare
0.35 to 0.40	Perceptible glare
< 0.35	Imperceptible glare

DGP is a metric for visual comfort, with values from 0 to 1, representing the probability that a person would experience disturbing glare in a particular situation.

DEPLOYMENT

Where does M&V recommend deploying electrochromic windows?

LAND PORTS OF ENTRY

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

[1]Electrochromic Window Demonstration at the Donna Land Port of Entry. Eleanor S. Lee (LBNL), May 2015, p.4 [2]Ibid, p.43
[3]Ibid, p.4 *Subject to evaluation and approval by GSA-IT and Security

GSA

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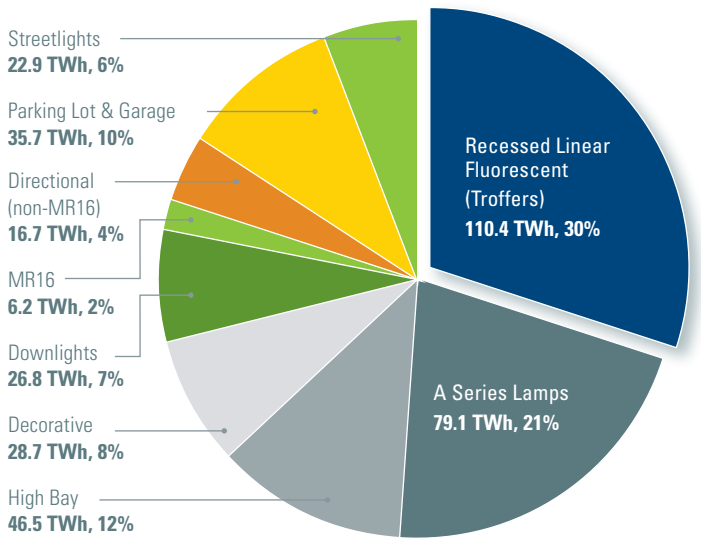
GPG FINDINGS 024

AUGUST 2015

LED FIXTURES WITH INTEGRATED ADVANCED LIGHTING CONTROLS

OPPORTUNITY

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



110.4

TWh SAVED[1]

EQUIVALENT TO 10 MILLION HOMES

1 TWh = average annual energy use of approximately 92,000 U.S. households

TECHNOLOGY

How do LED Fixtures with Integrated Controls work?

LED FIXTURES WITH ONBOARD SENSORS DYNAMICALLY MANAGE LIGHTING

USING OCCUPANCY SENSING AND DAYLIGHT HARVESTING; INTEGRATED CONTROLS REDUCE COMPLEXITY OF INSTALLATION AND SETUP

M&V

Where did Measurement and Verification occur?

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.

RESULTS

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

69%

ENERGY SAVINGS

OVER GSA AVERAGE

41% from LED
28% from ALC[2]

40%

RETURN ON INVESTMENT

FOR GSA RETROFITS

1.4 SIR at current estimated cost and utility rate of $.10 kWh[3]

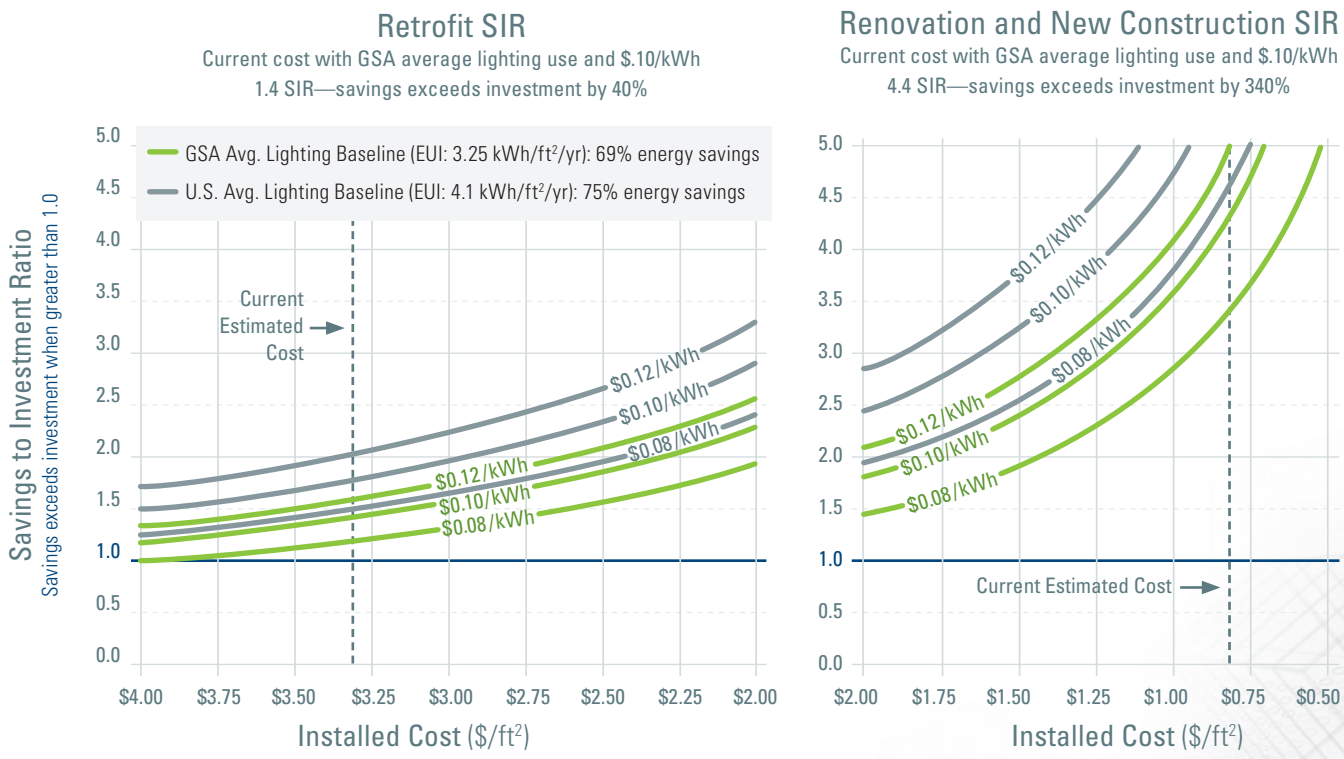
25%

OF COST SAVINGS

DUE TO REDUCED MAINTENANCE

LEDs last twice as long as fluorescent lamps[4]

Positive Return on Investment for Both Retrofits and Renovations



DEPLOYMENT

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

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)

[1]Navigant Consulting Inc. April 2013 (Revised May 2013). *Adoption of Light-Emitting Diodes in Common Lighting Applications.*
[2]*Retrofit Demonstration of LED Fixtures with Integrated Sensors and Controls,* Francis Rubinstein (LBNL), July 2015, p.77 [3]Ibid, p.16
[4]Ibid, p.18 *Subject to evaluation and approval by GSA-IT and Security.

GSA

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GPG FINDINGS 025

DECEMBER 2015

SOCIALLY DRIVEN HVAC FOR PERSONAL CONTROL

OPPORTUNITY

How is temperature typically controlled in commercial buildings?

SET TO A PREDETERMINED RANGE OR "DEADBAND"

Does not account for individual thermal preferences

Wastes energy by over-conditioning, particularly in unoccupied spaces

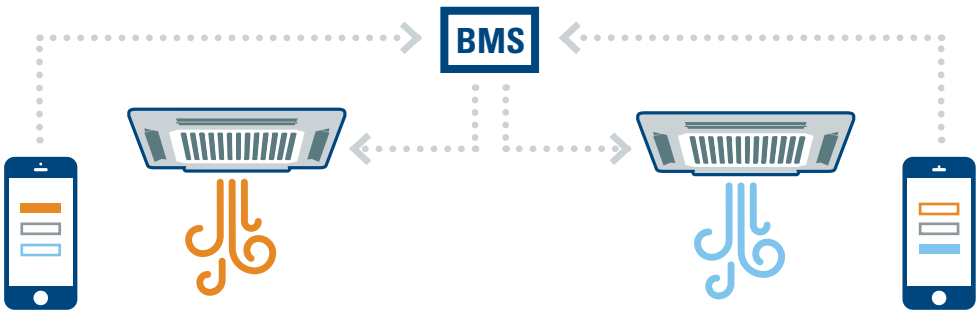
TECHNOLOGY

How does Socially Driven HVAC Optimization work?

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



M&V

Where did Measurement and Verification occur?

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

RESULTS

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

20%
COOLING ENERGY SAVINGS
47% HEATING SAVINGS
Over typical GSA facility[1]

59%
REDUCTION
IN HOT AND COLD CALLS[2]

83%
OCCUPANTS
MORE SATISFIED WITH THERMAL CONDITIONS[3]

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

Location		Large Office - 498,500 ft² Cost Savings ($/ft²/yr)		Medium Office - 53,630 ft² Cost Savings ($/ft²/yr)		Small Office - 5,500 ft² Cost Savings ($/ft²/yr)	
CLIMATE ZONE	CITY	2° Shift[1]	4° Shift[2]	2° Shift[1]	4° Shift[2]	2° Shift[1]	4° Shift[2]
1A	Miami, FL	$0.06	$0.13	$0.14	$0.30	$0.23	$0.48
2A	Houston, TX	$0.06	$0.12	$0.10	$0.20	$0.16	$0.32
2B	Phoenix, AZ	$0.07	$0.13	$0.12	$0.24	$0.18	$0.38
3A	Atlanta, GA	$0.08	$0.15	$0.12	$0.23	$0.18	$0.35
3B-coast	Los Angeles, CA	$0.11	$0.15	$0.15	$0.27	$0.22	$0.50
3B	Las Vegas, NV	$0.06	$0.15	$0.09	$0.21	$0.16	$0.29
3C	San Francisco, CA	$0.09	$0.16	$0.11	$0.19	$0.17	$0.34
4A	Baltimore, MD	$0.09	$0.16	$0.12	$0.22	$0.15	$0.30
4B	Albuquerque, NM	$0.05	$0.10	$0.08	$0.15	$0.13	$0.27
4C	Seattle, WA	$0.09	$0.16	$0.10	$0.16	$0.12	$0.18
5A	Chicago, IL	$0.06	$0.10	$0.07	$0.12	$0.10	$0.19
5B	Boulder, CO	$0.06	$0.10	$0.07	$0.13	$0.11	$0.18
6A	Minneapolis, MN	$0.05	$0.09	$0.06	$0.11	$0.10	$0.18
6B	Helena, MT	$0.06	$0.10	$0.07	$0.11	$0.09	$0.15
7	Duluth, MN	$0.06	$0.10	$0.06	$0.10	$0.09	$0.15
8	Fairbanks, AK	$0.09	$0.12	$0.09	$0.14	$0.11	$0.19

[§]Current socially driven HVAC subscription fees up to $0.60/ft²/yr, depending on installation size and duration of service [1] 70°-75° to 68°-77° [2] 70°-73° to 68°-77°

DEPLOYMENT

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

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

[1]*Socially Driven HVAC Optimization Federal Building and U.S. Courthouse Phoenix, Arizona*, Dan Howett (ORNL), October 2015, p. 17
[2]Ibid, p. 41 [3]Ibid, p. 22 *Subject to evaluation and approval by GSA-IT and Security.

GSA

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GPG FINDINGS 026

APRIL 2016

LED DOWNLIGHT LAMPS FOR CFL FIXTURES

OPPORTUNITY

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

5.7 GWH OF ELECTRICITY PER YEAR

If all 95,000 CFL-based downlights within the portfolio were replaced[1]

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

TECHNOLOGY

How do direct replacement LED downlight lamps work?

ONE-TO-ONE LAMP REPLACEMENT

POWERED BY THE EXISTING CFL BALLAST

Light directed down toward living and work surfaces

M&V

Where did Measurement and Verification occur?

PACIFIC NORTHWEST NATIONAL LABORATORY assessed LED downlight lamps provided by Lunera 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 downlight lamps perform in M&V?

40-50%
ENERGY SAVINGS[2]
$6.37 ANNUAL SAVINGS[3]
Over typical CFL lamp at avg. utility rate of $0.11/kWh

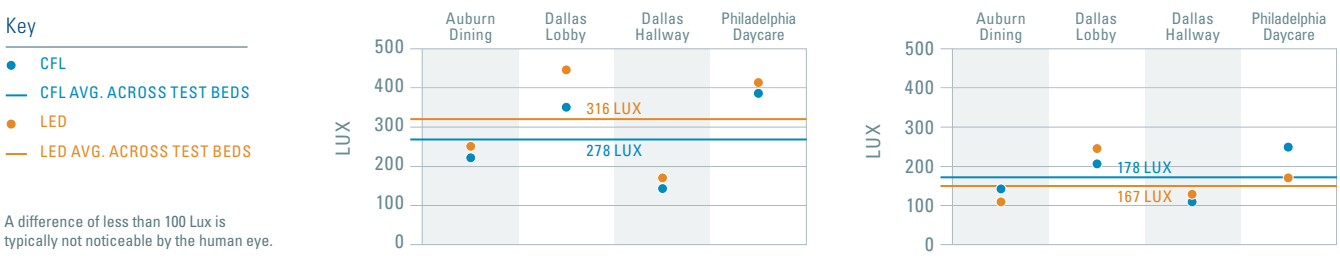
LEDs
APPROXIMATED CFLS
OCCUPANTS NOTICED LITTLE DIFFERENCE[4]

< 3
YR PAYBACK
AT AVERAGE UTILITY RATE[5]

Light Levels Between CFL and LED Were Comparable

Average Horizontal Light Levels
Work Surface or Floor

Average Vertical Light Levels
Wall



DEPLOYMENT

Where does M&V recommend deploying LED downlight lamps?

DEPLOY BROADLY

Where advanced lighting controls are not desired or useful

LED Replacement Options for CFL Downlights

Consider compatibility and controls when selecting an LED replacement

	REPLACE LAMP IF :	INSTALL RETROFIT KIT IF :	INSTALL NEW FIXTURE IF :
COMPATIBILITY	CFL ballast is verified to work with LED replacement lamp (per manufacturer or by testing).	Lamp is incompatible with CFL ballast (consult manufacturer specifications).	New construction or renovation.
CONTROLS	No controls are necessary.	Dimming is desired and CFL ballast does not support it.	Integrated advanced lighting controls are desired (tuning, occupancy sensing, daylighting).
	PAYBACK–2.9 years* Cost $39 Material $22§, Install $17 With ballast replacement $94 (Material $38, Install $56) PAYBACK 7.1 years	**PAYBACK –10.4 years*** Cost $137 Material $81, Install $56	**PAYBACK–12.4 years*** Cost $165 Material $109, Install $56

*Assumes maintenance savings included; midrange 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

[1] *LED Downlight Lamps for CFL Fixtures*, EE Richman, JJ McCullough, TA Beeson, SA Loper (PNNL), March 2016, p.17 [2] Ibid, p.10 [3] Ibid, p.12 [4] Ibid, p.11 [5] Ibid, p.12

GPG FINDINGS 027

AUGUST 2016

HONEYCOMB SOLAR THERMAL COLLECTOR

OPPORTUNITY

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

30% **SOLAR HOT WATER (SHW) REQUIRED**

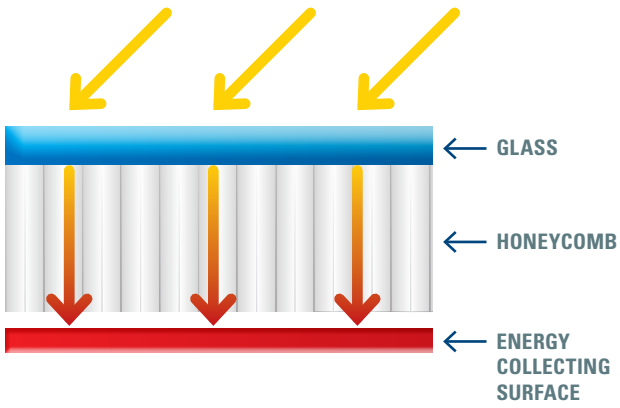
TO COMPLY WITH EISA[1]

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?

NATIONAL RENEWABLE ENERGY LABORATORY measured performance of an HSTC system provided by Tigi Solar at two demonstration sites: the Major General Emmett J. Bean Federal Center in Indianapolis; and the GSA Regional Headquarters Building in Auburn, Washington

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[2]

TRAINED

SHW INSTALLER IS CRITICAL

To address unique features of SHW systems[3]

OVERHEATING PROTECTION WORKED

May decrease maintenance costs over time[4]

Modeled Energy Savings for HSTC in Locations with Different Solar Resources

Large loads are critical for positive ROI

City	Hot Water Load (gal/day)	System Unit Cost ($/ft²)	Collector Area (ft²)	Solar Fraction*	Annual Energy Savings (kWh/yr)	Payback (years)	SIR
Seattle, WA cold/cloudy annual solar radiation 5.0 gigajoule/m²/yr	125	$102	88	0.44	3,154	40.0	0.26
	500	$102	175	0.32	8,937	26.8	0.56
	500	$46	175	0.32	8,937	13.0	1.15
Indianapolis, IN cold/partly cloudy annual solar radiation 5.9 gigajoule/m²/yr	125	$102	88	0.51	3,638	29.0	0.42
	500	$102	175	0.38	10,448	19.2	0.81
	500	$46	175	0.38	10,448	9.3	1.68
Denver, CO cold/sunny annual solar radiation 6.8 gigajoule/m²/yr	125	$102	88	0.60	4,291	24.5	0.54
	500	$102	175	0.44	12,343	16.2	0.98
	500	$46	175	0.44	12,343	7.8	2.03
Phoenix, AZ warm/sunny annual solar radiation 8.5 gigajoule/m²/yr	125	$102	88	0.54	2,757	21.4	0.50
	500	$102	175	0.71	13,556	15.0	1.06
	500	$46	175	0.71	13,556	7.3	2.20

* 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.

[1]High Performance Flat Plate Solar Thermal Collector Evaluation. Caleb Rockenbaugh, Jesse Dean, David Lovullo, Lars Lisell, Greg Barker, Ed Hanckock, Paul Norton (NREL), July 2016 p.8 [2]Ibid, p.7 [3]Ibid, p.11 [4]Ibid, p.8

GPG FINDINGS 028

SEPTEMBER 2016

CHILLER PLANT CONTROL OPTIMIZATION SYSTEM

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[1]

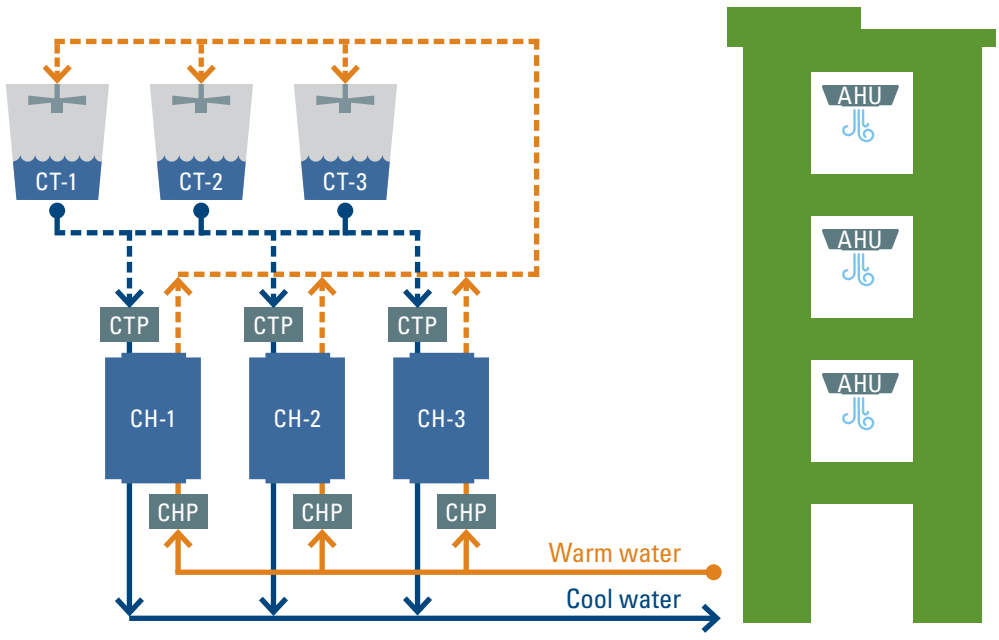
TECHNOLOGY

How does the Control Optimization System for Chiller Plants work?

OPTIMIZES SYSTEM PRESSURE AND TEMPERATURE DIFFERENCE (DELTA T)

MANAGES CHILLER LIFT AND FLOW BY MONITORING AND CONTROLLING FIVE INTERDEPENDENT SYSTEMS

Cooling Towers (CT), Chillers (CH), Condenser Pumps (CTP), Chilled Water Pumps (CHP), and Air Handler Units (AHU)



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

RESULTS

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

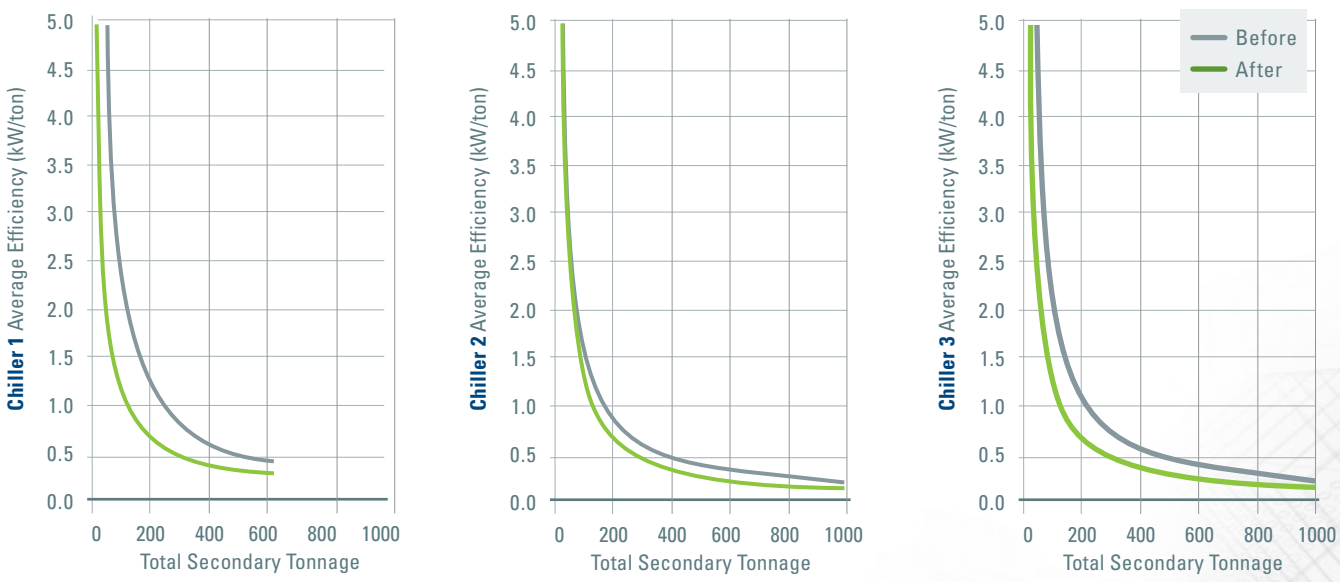
35%
COOLING SAVINGS
+/- 10% uncertainty
due to estimated baseline[1]

5 YR
PAYBACK
At avg. cost of $0.11/kWh[3]

BETTER
VISIBILITY & CONTROL
FOR PLANT OPERATIONS[2]

Increased Efficiency, Especially at Part Loads

Performance averaged 0.64 kW/ton after control optimization



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.

[1]*Optimization of Variable Speed Chiller Plants: Frank M. Johnson Jr. Federal Building and U.S. Courthouse, Montgomery, Alabama,* JC Hail, DD Hatley, RM Underhill (PNNL), August 2016, p.13 [2]Ibid, p.7 [3]Ibid, p.38 [4]Ibid, p.7

GSA

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**

GPG FINDINGS 029

SEPTEMBER 2016

SMART CEILING FANS

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 kWh[1]

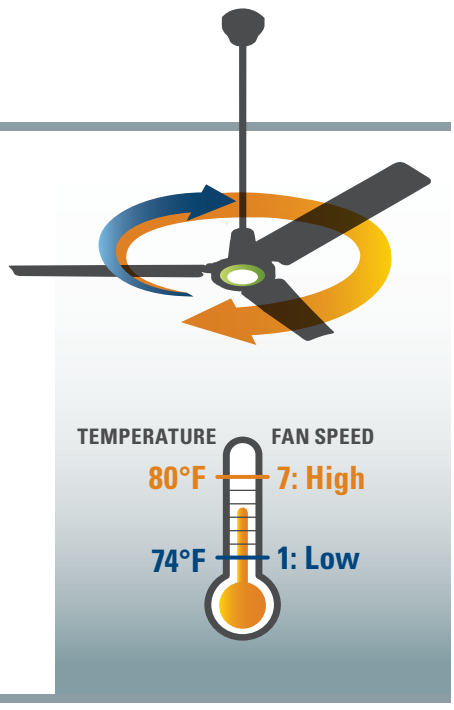
by raising cooling setpoints 2°F

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°F[2]

SAVINGS
GREATEST IN
FIRST 4 DEGREES OF SETPOINT CHANGE[3]

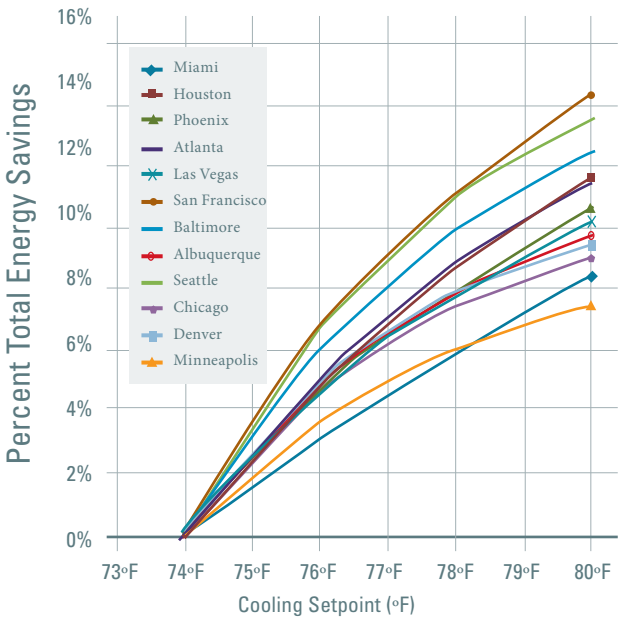
<$1.50/ft²
INSTALLED COST
For < 10-year payback[4]

Modeled Savings for Smart Fans

Energy savings for ENERGY STAR certified fans will be roughly equivalent

Energy Savings Across Climate Zones

Savings are greatest in San Francisco



Installed Cost Needed for a 10-year Payback

Assuming a 4°F increase in cooling setpoint

Location	Energy Savings kWh/ft²/yr	Energy Cost Savings $/ft²/yr	Installed Cost for 10-year Payback $/ft²
Miami, FL	1.19	$0.117	$1.17
Houston, TX	1.41	$0.115	$1.15
Phoenix, AZ	1.47	$0.149	$1.49
Atlanta, GA	1.26	$0.131	$1.31
Las Vegas, NV	1.26	$0.119	$1.19
San Francisco, CA	1.39	$0.218	$2.18
Baltimore, MD	1.26	$0.140	$1.40
Albuquerque, NM	1.02	$0.105	$1.05
Seattle, WA	1.19	$0.095	$0.95
Chicago, IL	0.81	$0.075	$0.75
Denver, CO	0.84	$0.084	$0.84
Minneapolis, MN	0.71	$0.070	$0.70

DEPLOYMENT

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°, and no prohibitions against raising it

[1] *GSA Green Proving Ground, Smart Ceiling Fan – White Paper*, K. Kiatreungwattana, M. Deru, J. DeGraw (NREL), August 2016, p.13
[2] Ibid, p.7 [3] Ibid, p.38 [4] Ibid, p.7

GPG FINDINGS 030

SEPTEMBER 2016

TLED LIGHTING RETROFITS WITH DEDICATED DRIVERS

OPPORTUNITY

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

134 GWH ELECTRICITY/YEAR

REPLACING 1.53 MILLION LINEAR FLUORESCENT LAMPS (LFLS)
$15 MILLION ANNUAL SAVINGS
at national average utility rate of $0.11/kWh[1]

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[2]
ADDITIONAL SAVINGS POSSIBLE WITH ALC

EASY
INSTALLATION
SIMILAR TO LFL LAMP AND BALLAST REPLACEMENT[3]

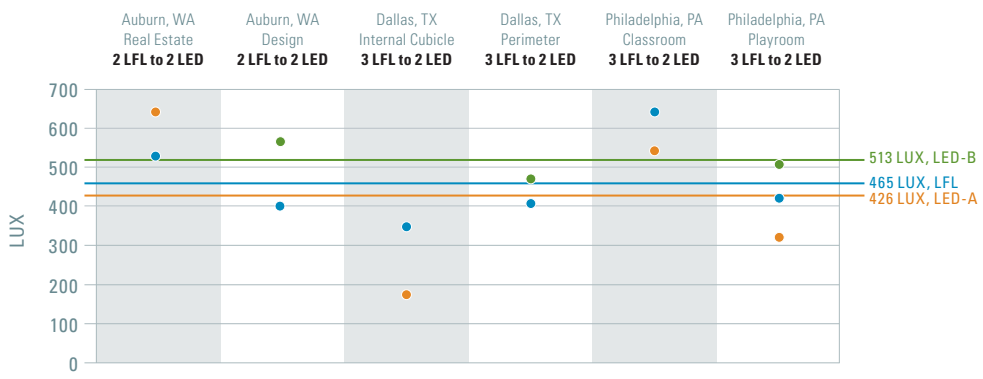
6
YR PAYBACK
AT NAT'L AVG. UTILITY RATE ($0.11/kWh) & $50 FIXTURE COST[4]

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.



DEPLOYMENT

Where does M&V recommend deploying LED Retrofits?

FIXTURES WITH LENSES AND SOCKETS IN GOOD CONDITION

And where 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

	PROS	CONS	COST*
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

* 50% and 100% RS Means derived labor estimates; similar cost to lamp + ballast replacement

[1] *Linear LED Lighting Retrofit Assessment*, EE Richman, JJ McCullough, TA Beeson (PNNL), September, 2016, p.2 [2] Ibid, p.5
[3] Ibid, p.61 [4] Ibid, p.10

GPG FINDINGS 031

UPDATED NOVEMBER 2017

VARIABLE-SPEED DIRECT-DRIVE SCREW CHILLER

OPPORTUNITY

What is the impact of improved chiller operations on GSA?

MOST LARGE COMMERCIAL BUILDINGS (> 100,000 FT²) USE WATER-COOLED CHILLERS

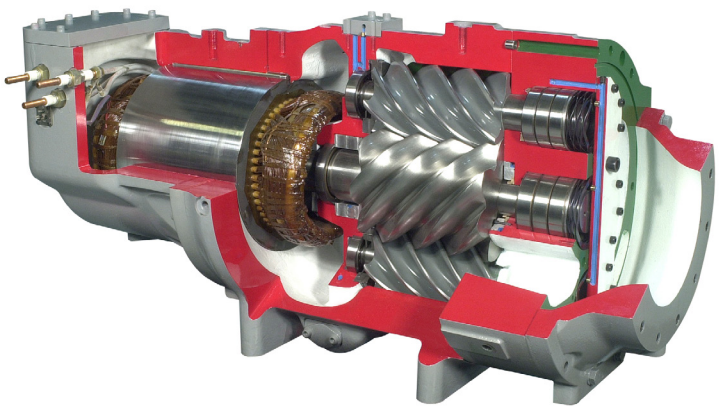
80% of GSA floor space is in large buildings[1]

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[2]



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[3]

Range OF OPERATING CONDITIONS MET

Condenser water temperature ranged from 55°F to over 95°F[4]

Quiet PERFORMANCE

77-83 DECIBELS For both VSS & MBC[5]

Average Energy Consumption at the Yates Building

VSS savings over baseline MBC could range from +24% to -4% due to field measurement uncertainty[6]

Combined Chillers/ Total Building % of full load	% of Full Year's Profile	VSS kW/ton (weighted)	MBC kW/ton (weighted)
20-30%	3.8%	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%	0.163	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?

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.

[1] *Variable-Speed Screw Chiller, Sidney Yates Building, Washington, DC*, Dan Howett (PE), Mark Adams (ORNL), George Ostrouchov PhD, revised August 2017, p.4 [2] Image courtesy of Carrier, used with permission [3] *Variable-Speed Screw Chiller, Sidney Yates Building, Washington, DC*, Dan Howett (PE), Mark Adams (ORNL), George Ostrouchov PhD, revised August 2017 p.3 [4] Ibid, p.186 [5] Ibid, p.25, 281 (as measured in a lab setting) [6] Ibid, p.9

GPG FINDINGS 032

FEBRUARY 2017

LOW-E WINDOW FILM

OPPORTUNITY

Windows are responsible for how much energy use?

34% OF COMMERCIAL BUILDING HVAC ENERGY IS LOST TO WINDOWS[1]

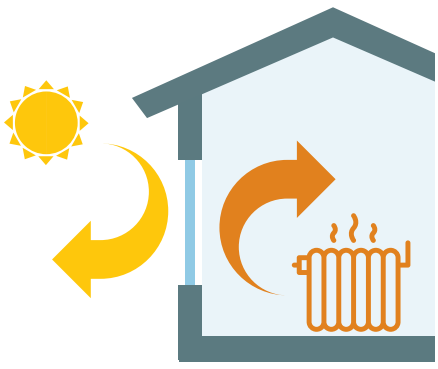
TECHNOLOGY

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&V

Where did Measurement and Verification occur?

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.

RESULTS

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

29%
AVERAGE PERIMETER HVAC SAVINGS
with single-pane clear glass[2]

BETTER
THERMAL COMFORT
Occupants reported superior comfort in both summer and winter[3]

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

Modeled Perimeter Energy Savings for Range of Climates

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

Location		Single Clear Glazing to VT35 Film			Single Bronze Glazing to VT35 Film		
CLIMATE ZONE	CITY	HEATING kBtu/ft2/yr	COOLING kBtu/ft2/yr	TOTAL %	HEATING kBtu/ft2/yr	COOLING kBtu/ft2/yr	TOTAL %
1A	Miami, FL	0.01	12.16	33%	0.03	8.08	25%
2A	Dallas, TX	0.47	10.94	33%	1.52	7.12	26%
2B	Phoenix, AZ	0.20	15.24	38%	0.45	10.40	30%
4A	Washington, D.C.	0.51	6.40	26%	3.24	3.74	23%
5A	Chicago, IL	1.97	5.66	24%	5.79	3.23	22%
5B	Ogden, UT	1.45	7.13	30%	4.97	4.12	27%
6A	Minneapolis, MN	2.97	5.45	22%	7.51	3.06	21%
AVERAGE PERIMETER SAVINGS		**1.08**	**9.00**	**29%**	**3.36**	**5.68**	**25%**

DEPLOYMENT

Where does M&V recommend deploying Low-e 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.

[1]Low-e Applied Film Window Retrofit for Insulation and Solar Control, Charlie Curcija, Howdy Goudey, Robin Mitchell, LBNL, February 2017, p. 10 [2]Ibid, p. 62-131 [3]Ibid, p.43 [4]Ibid, p.42

GPG FINDINGS 033

NOVEMBER 2017

ELECTROCHROMIC WINDOWS FOR OFFICE SPACE

OPPORTUNITY

What have previous studies demonstrated about the potential for electrochromic (EC) windows?

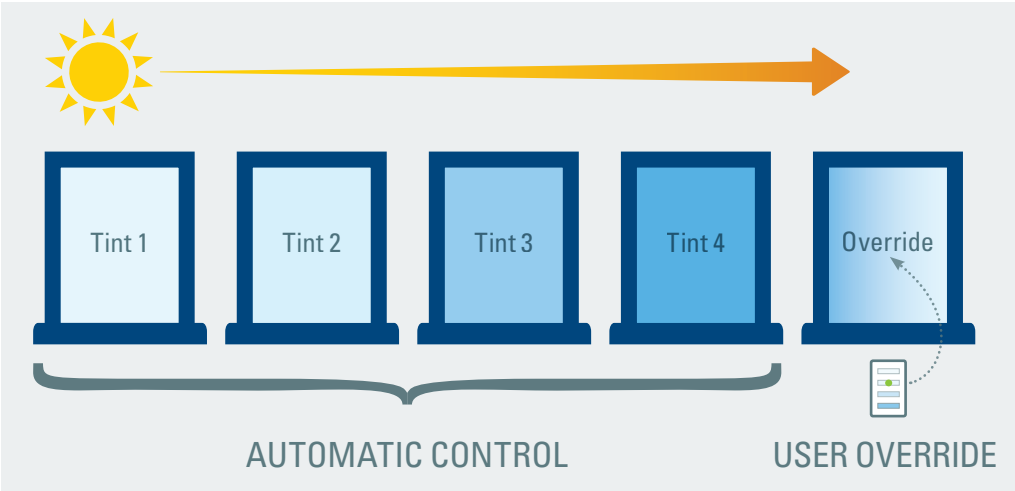
REDUCED

- **HEAT GAIN AND COOLING ENERGY[1]**
- **LIGHTING ENERGY[2]**
- **GLARE[3]**

TECHNOLOGY

How do EC windows work?

WINDOWS TINT IN RESPONSE TO EXTERNAL CONDITIONS OR USER OVERRIDE



M&V

Where did Measurement and Verification occur?

LAWRENCE BERKELEY NATIONAL LABORATORY assessed occupant satisfaction with EC windows in two buildings with curtain-wall construction—the 911 Federal Building in Portland, Oregon and the John E. Moss Federal Building in Sacramento, California.

RESULTS

How did EC windows perform in M&V?

63-92%

OCCUPANT PREFERENCE OVER EXISTING LOW-E[4]

However, implementations that both satisfy occupants and meet competing performance requirements are challenging and take time.[5]

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.[6]

NOT COST-EFFECTIVE FOR GENERAL OFFICE SPACE BASED ON ENERGY SAVINGS ALONE[7]

Energy savings did not cover increased costs—in Portland, the incremental difference between installing spectrally selective low-e windows and EC windows was $37/ft^2$.

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.

[1] *A Pilot Demonstration of Electrochromic and Thermochromic Windows in the Denver Federal Center*, Eleanor S. Lee (LBNL), March 2014, p.4 [2] Ibid, p.1 [3] *Electrochromic Window Demonstration at the Donna Land Port of Entry*. Luís L. Fernandes (LBNL), May 2015, p.37 [4] *Electrochromic Window Demonstration at the John E. Moss Federal Building. Sacramento*, Luís L. Fernandes (LBNL), August 2017, p.54 and *Electrochromic Window Demonstration at the 911 Federal Building, Portland Oregon*, Eleanor S. Lee (LBNL), August 2017, p.8 [5] Ibid, p.8 and p.136 [6] Ibid, p.3 and p.7 [7] Ibid, p.101 and p.7

GPG FINDINGS 034

APRIL 2018

HIGH-PERFORMING COMMERCIAL ROOFTOP UNITS

OPPORTUNITY

RTUs condition how much floor space nationwide?

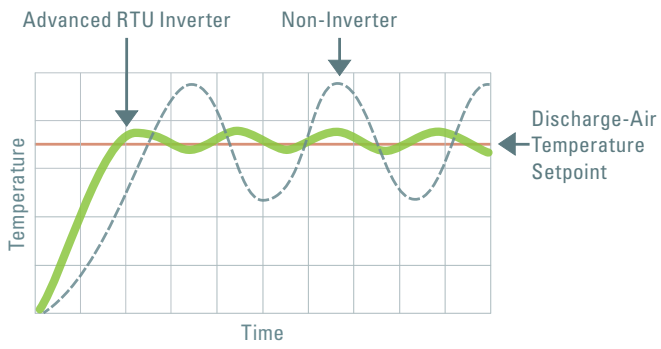
>50% OF COMMERCIAL FLOOR SPACE IN THE U.S. IS CONDITIONED BY ROOFTOP UNITS (RTUS)[1]

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?

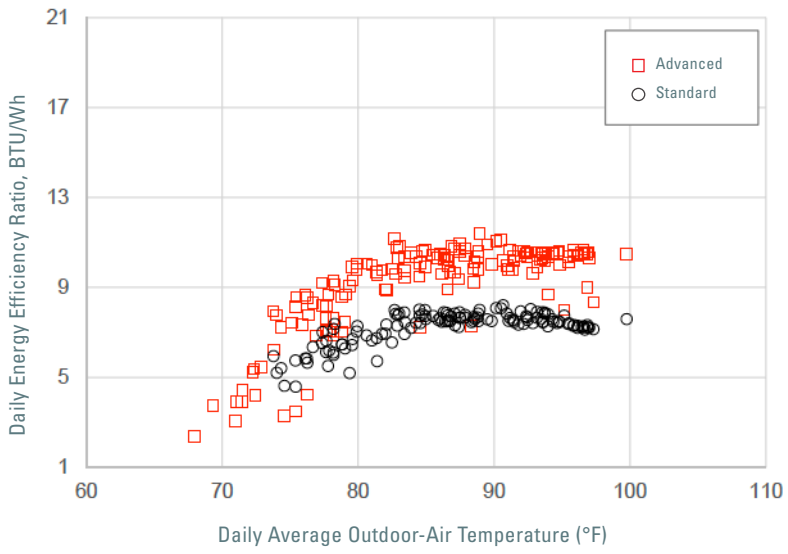
26%
ENERGY SAVINGS
Models predicted 40% savings compared to a standard RTU[2]

COSTS
FOR INSTALLATION VARY
Heavier unit and different footprint may require infrastructure reinforcement or duct changes[3]

3.8 YR
PAYBACK
demonstrated at two Florida supermarkets[4]

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

[1]Field Evaluation of the Performance of the RTU Challenge Unit: Daikin Rebel, S. Katipaumla, W. Wang, H. Ngo, RM Underhill, Pacific Northwest National Laboratory, PNNL-26279, May 2017, p. 10 [2]Ibid, p. 25 [3]Ibid, p. 4 [4]Field Evaluation of the Performance of the RTU Challenge Unit: Daikin Rebel, S. Katipamula, W. Wang, H. Ngo, RM. Underhill, Pacific Northwest National Laboratory, PNNL-23672, March, 2015, p. 4

GSA

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GPG FINDINGS 035

SEPTEMBER 2018

SMALL CIRCULATOR PUMPS WITH AUTOMATED CONTROL

OPPORTUNITY

How much energy can high-performance circulator pumps save?

4.75 TWh

REPLACING 30 MILLION U.S. CIRCULATOR PUMPS

WITH 50% HIGHER EFFICIENCY[1]

TECHNOLOGY

How do high-performance circulator pumps with automated control work?

< 2.5 HORSEPOWER PUMPS

VARIABLE SPEED

ELECTRONICALLY COMMUTED MOTORS

ONBOARD CONTROL ALGORITHMS

M&V

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 did the small circulator pumps with automated control perform in M&V?

96%

ENERGY SAVINGS

for DHW pump, 60% savings for AHU pump[2]

MORE

OPERATIONAL VISIBILITY

and reduced maintenance, no greasing of bearings or replacing pump seals [3]

<6

YEAR PAYBACK

@ 0.11/kWh GSA average utility rate and including annual maintenance savings[4]

Payback and Savings Compared to Baseline Standard Pumps

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

	% Savings	Annual Energy Savings (kWh/yr)	Annual Energy Cost Savings @ 0.11 kWh ($)	Annual O&M Savings ($)	Incremental Cost ($) over market standard pump	Simple Payback	Savings-to-Investment Ratio (SIR)
DHWP #1: ¼ HP, 77 watts (duty point) **Baseline:** ¼ HP, 280 watts (duty point)	96%	587 kW	$65	$75	$575	4.1	3.6
DHWP #2: ¼ HP, 97 watts (duty point) **Baseline:** ½ HP, 370 watts (duty point)	96%	1,039 kW	$114	$75	$575	3.0	4.9
AHU 19 : 0.36 HP, 186 watts (duty point) **Baseline:** ½ HP, 223 watts (duty point) 4 hrs/day run-time	26%	45 kW	$5	$75	$500	6.3	2.4
AHU 19: 0.36 HP, 186 watts (duty point) **Baseline:** ½ HP, 330 watts (duty point) 20 hrs/day run-time	60%	688 kW	$76	$75	$500	3.3	4.5

DEPLOYMENT

Where does M&V recommend deploying small circulator pumps with automated control?

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.

[1]High-Performance Circulator Pump Demonstration, Jesse Dean, Anoop Honnekeri, Greg Barker, National Renewable Energy Laboratory (NREL), September 2018, p.4 [2]Ibid, p.30, 42 [3]Ibid, p.v [4]Ibid, p.v

GPG FINDINGS 036

SEPTEMBER 2018

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[1]

TECHNOLOGY

How do dual-zone indoor shades work?

UPPER ZONE FOR DAYLIGHT
WITH AUTOMATICALLY- OR MANUALLY-CONTROLLED LOUVERS

LOWER ZONE CONTROLS GLARE & PRESERVES VIEWS

M&V

Where did Measurement and Verification occur?

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.

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]

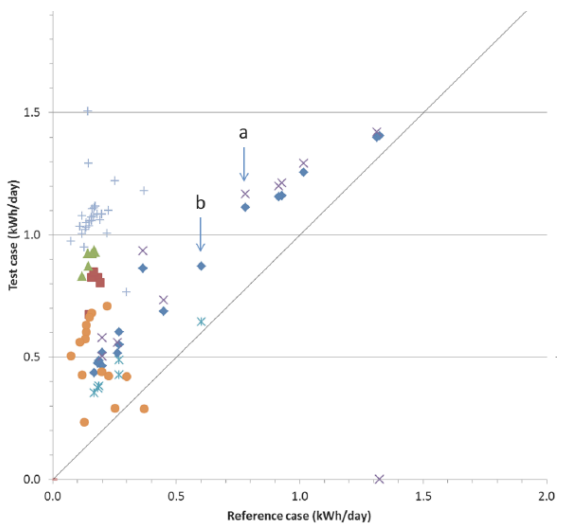
ROI NEGATIVE
Compared to both fabric roller shades and venetian blinds[3]

80% OCCUPANT PREFERENCE
Over baseline vertical blinds[4]

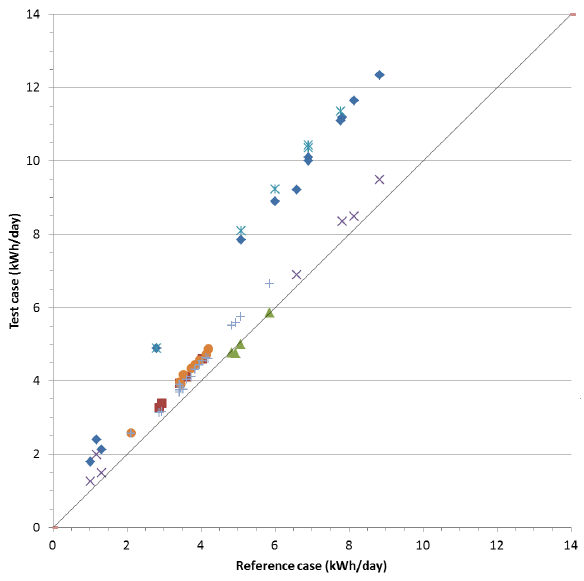
Measured Energy Use at the Advanced Windows Testbed

Compared to venetian blinds; points above diagonal line indicate that energy use is greater than venetian blinds

Lighting Energy
with Dimmable Fluorescent



Cooling Energy
Daily Cooling Load



Man-GG-W Man-GG-S Man-GS-W Man-GS-S Auto-GG-W Auto-GG-S RS-S Series8 Linear (Series8)

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.

[1]Dual-Zone Solar Control Indoor Shade, Eleanor S. Lee, Christoph Gehbauer, Anothai Thanachareonkit, Luís L. Fernandes, Taoning Wang, Lawrence Berkeley National Laboratory (LBNL), January 2018, p.7 [2]Ibid, p.30 [3]Ibid, p.47 [4]Ibid, p.44

GPG FINDINGS 037

NOVEMBER 2018

ADVANCED LIGHTING CONTROLS AND LED

OPPORTUNITY

How can advanced lighting controls (ALC) support LED?

LED'S DIGITAL NATURE PROVIDES MORE PRECISE DIMMING

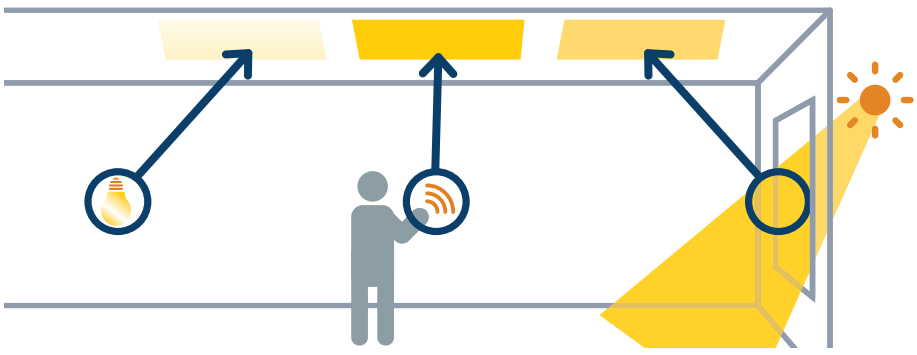
MAKING ALC MORE EFFECTIVE

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[1]

TUNING

IS CRITICAL

The ability to dim initial light levels significantly increased occupant satisfaction[2]

ROI

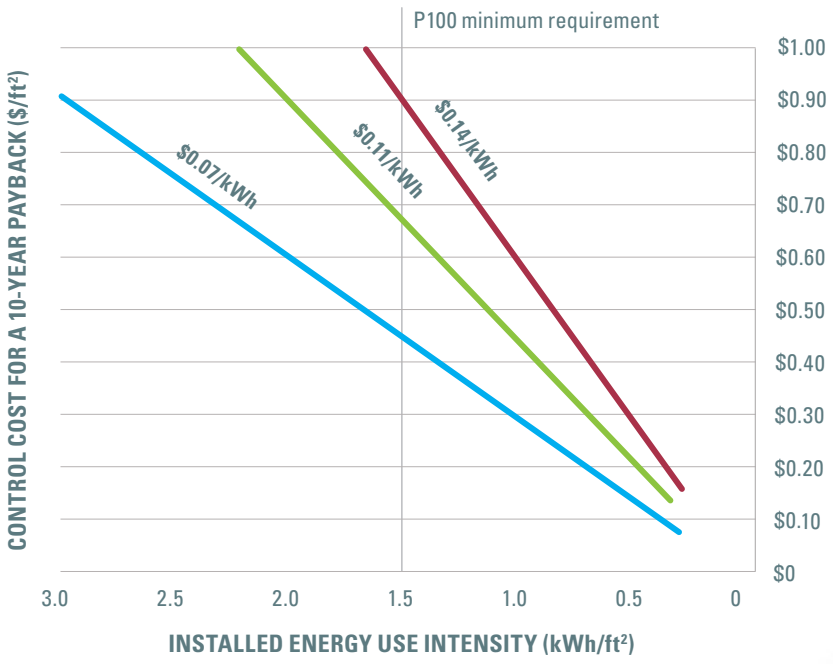
VARIABLE

Can be cost-effective when the added cost of controls is <$70 per fixture @ GSA avg. utility $0.11/kW[3]

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.

[1]Evaluation of Advanced Lighting Control Systems in a Working Office Environment, M. Myer, Pacific Northwest National Laboratory, (PNNL-27619), September 2018, p.3 [2]Ibid, p.26 [3]Ibid, p.35

GPG FINDINGS 038

DECEMBER 2018

ELECTROCHEMICAL WATER TREATMENT

OPPORTUNITY

How much water do cooling towers use?

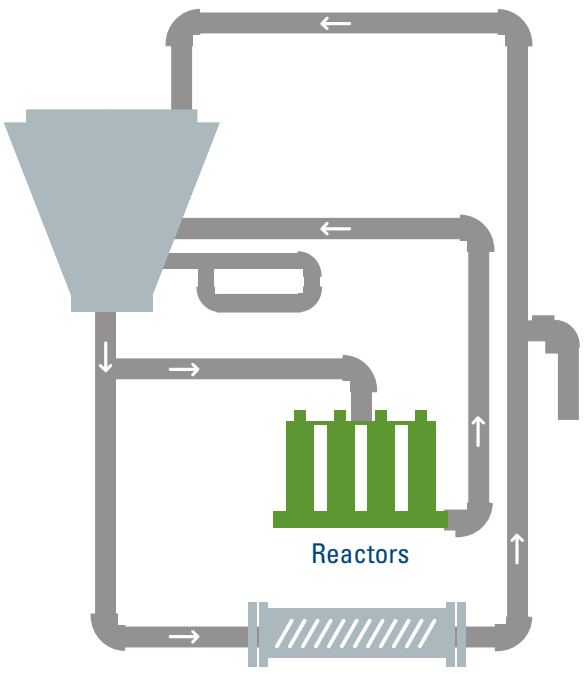
28% OF WATER IN COMMERCIAL BUILDINGS IS USED BY COOLING TOWERS OR OTHER HEATING AND COOLING SYSTEMS[1]

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
99.8% reduction in blowdown[2]

50% MAINTENANCE REDUCTION
Small cost increase in annual O&M contract[3]

100% CHEMICAL SAVINGS
Technology generates chlorine; reduced slime[4]

2.5 YEAR PAYBACK
@ GSA avg. water/sewer $16.76/kgal[5]

Electrochemical Water Treatment Return-On-Investment

Rebates for AWT systems are available through some local water utilities

	Testbed (Before)	Testbed (After)+	GSA Normalized (After)*
Equipment ($)	N/A	$30,340	$30,340
Installation ($)	N/A	$29,029	$15,000
Maintenance (yr)	$5,280	$6,000	$6,000
Maintenance Savings (yr)	N/A	-$720	-$720
Water Consumption (Gallons/yr)	3,588,156	2,454,299	2,454,299
Water Savings (Gallons/yr)	N/A	1,133,857	1,133,857
Water Savings ($/yr)	N/A	$7,529	$19,003
Simple Payback (yrs)		**8.7**	**2.5**
Savings to Investment Ratio		**1.7**	**6.0**

+ 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

[1]Electrolysis Water Treatment for Cooling Towers, Gregg Tomberlin, Jesse Dean, Jimmy Salasovich (NREL), December 2018, p.9
[2]Ibid, p.21 [3]Ibid, p.23 [4]Ibid, p.24 [5]Ibid, p.26

GPG FINDINGS 039

JANUARY 2019

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[1]

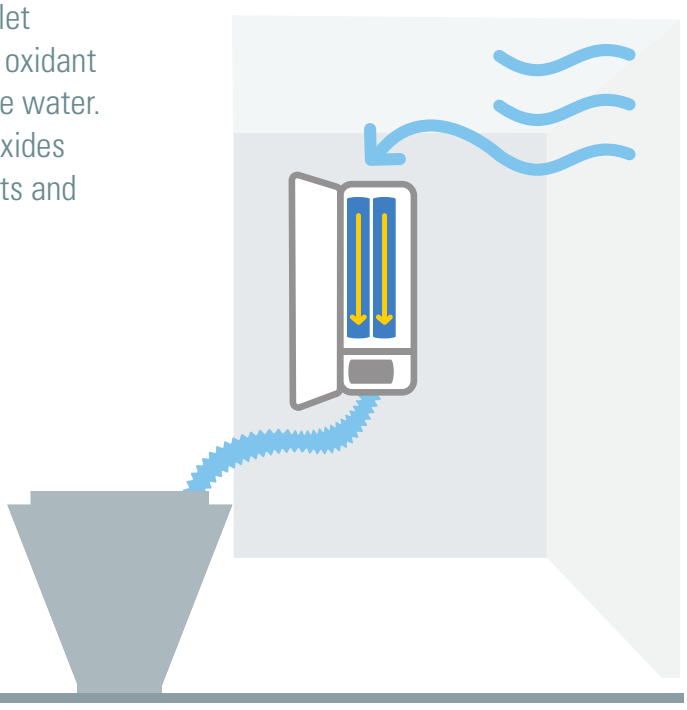
TECHNOLOGY

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?

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)

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 assessed[3]

MET GSA WATER STANDARDS
No additional chemicals were needed[4]

2 YEAR PAYBACK
@ GSA avg. water/sewer $16.76/kgal[5]

Advanced Oxidation Process Return-On-Investment

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

	Baseline (Before)	AOP System (After)
Installed Equipment (two 250-ton cooling towers)*	N/A	$22,487
Annual Maintenance	$5,855	$3,333
Annual Water Consumption (gal/yr)	2,003,273 gal	1,475,482 gal
Annual Energy Costs (5,250 kWh/yr @$0.11/kWh)	$0	$578
Annual Water Costs (@$16.76 kgal/yr)	$14,303	$5,457
Payback (yrs)		**2.1**
Savings-to-Investment Ratio		**7.2**

*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

[1]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 [2]Ibid, p.17 [3]Ibid, p.20,21 [4]Ibid, p.17 [5]Ibid, p.20

GPG FINDINGS 040

FEBRUARY 2019

ALTERNATIVE WATER TREATMENTS FOR COOLING TOWERS

OPPORTUNITY

Why is GSA interested in alternative water treatments?

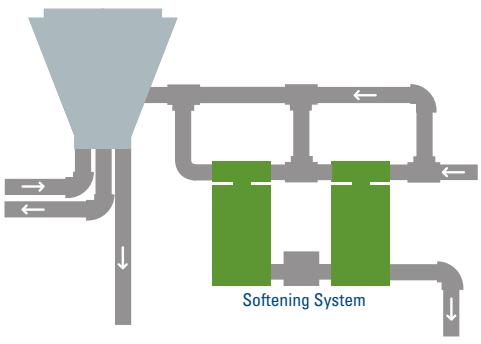
41% INCREASE IN GSA WATER RATES 2014-2017[1]

TECHNOLOGY

How do these alternative water treatments work?

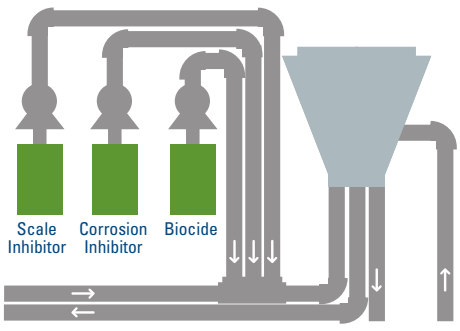
SALT-BASED ION EXCHANGE

REMOVES HARDNESS WITHOUT ADDITIONAL CHEMICALS



CHEMICAL SCALE INHIBITION

PROPRIETARY CHEMICALS INHIBIT SCALING AND CORROSION



M&V

Where did Measurement and Verification occur?

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.

RESULTS

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

23%
WATER SAVINGS
94%-99% reduction in blowdown[2]

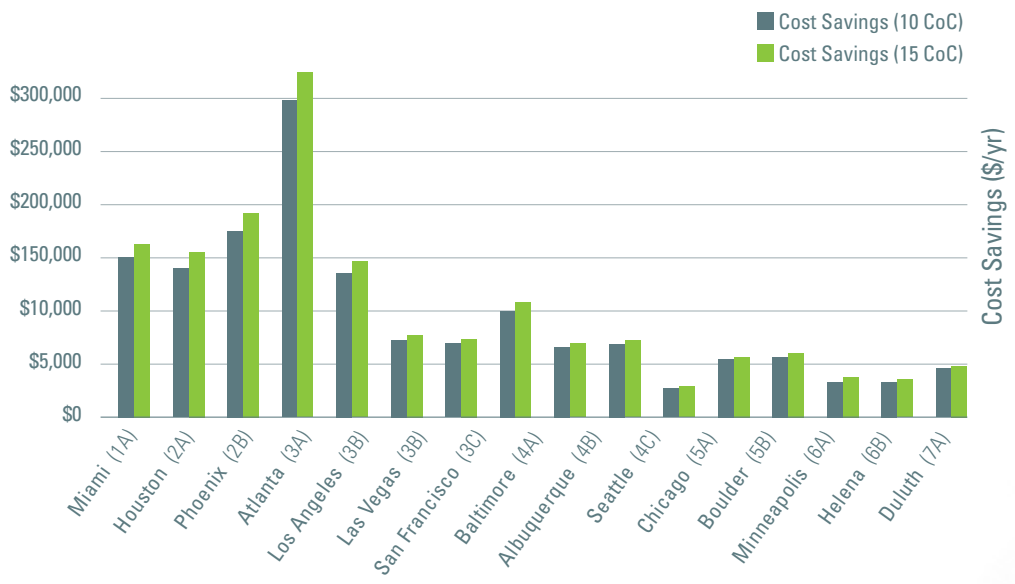
O&M
VARIABLE
Chemical scale inhibition increased O&M costs, salt-based reduced them[3]

IMPROVED CHILLER OPERATIONS
Cleaner condenser tubes, increased heat exchanger effectiveness[4]

<3 YEAR
PAYBACK
@ GSA average water/sewer cost of $16.76/kgal[5]

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



DEPLOYMENT

Where does the study recommend deploying alternative water treatments?

CONSIDER FOR ALL COOLING TOWERS

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

[1]Electrochemical Water Treatment for Cooling Towers, Gregg Tomberlin, Jesse Dean, Michael Deru (NREL), February 2019, p.26
[2]Alternative Water Treatment Technologies for Cooling Tower Applications, Dylan Cutler, Jennifer Daw, P.E., Dan Howett, P.E. Jesse Dean (NREL), February 2019, p.6 [2]Ibid, p.31, 33 [3]Ibid, p.35 [4]Ibid, p.6 [5]Ibid, p.6

GSA

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**