

## Emerging Technologies: *Exploring Green Commercial Buildings of the Future*



NREL

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03/02/2011

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

## Recent Technological Advances

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Just because you are an expert today doesn't mean you will be an expert tomorrow!!

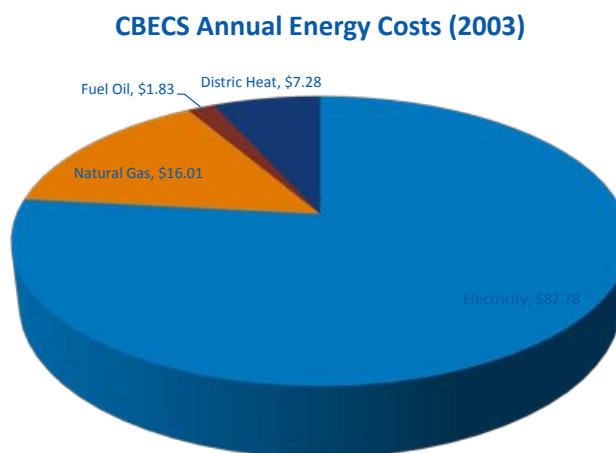
Some highlights from ~2009

- Cost of polysilicon ingots dropped from \$500/kg to below \$100/kg
  - PV panel prices dropped 30%-40%, resulting in installation costs as low as \$4.00-\$5.00/DC-Watt and 5-10 year payback periods (with subsidies)
- Significant improvements in solid state lighting color quality, efficacy, and cost reductions
  - Philips introduced an LED replacement to incandescent lamps with an efficacy > 90 lm/Watt, lifetime > 25,000 hrs, and energy consumption < 10 Watts
- A new multi stage indirect evaporative cooling technology with a part load EER above 100
- A new 5 ton packaged rooftop unit with EER's ranging from 30 -50
- New desktop computers were introduced that uses 60% less energy than a standard Energy Star Desktop
- Cost effective net zero energy buildings

# Commercial Buildings Energy Consumption Survey

## CBECS 2003 Statistics

- 4,859,000 buildings
- 71.66 billion ft<sup>2</sup>
  - 100.8 billion ft<sup>2</sup> (projected in 2030)
- 890 billion kwh (elec)
- 1870 billion ft<sup>3</sup> (nat gas)
- 1602 million gal (fuel oil)
- 634 trillion btu (dist heat)
- \$107.89 billion/yr



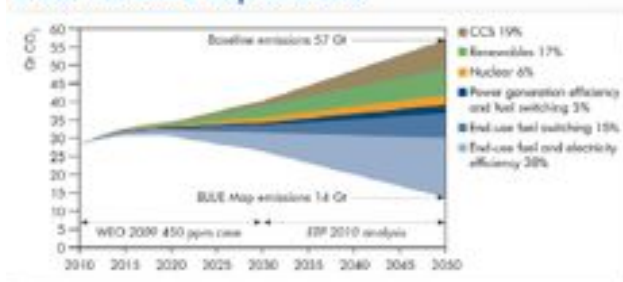
Source: [http://www.eia.doe.gov/emeu/cbecs/cecs2003/detailed\\_tables\\_2003/detailed\\_tables\\_2003.html](http://www.eia.doe.gov/emeu/cbecs/cecs2003/detailed_tables_2003/detailed_tables_2003.html)

# US Climate Change Policy

Target of 80% reduction in GHG emissions by 2050

- Mid-term reduction of 45% by 2020

## Key Technologies for Reducing CO<sub>2</sub> Emissions Under the BLUE Map Scenario



Source: International Energy Agency, Energy Technologies Perspectives 2010

**2050 national goal:**  
Oil use reduced to <15% of current levels,  
CO<sub>2</sub> emissions cut by >80%

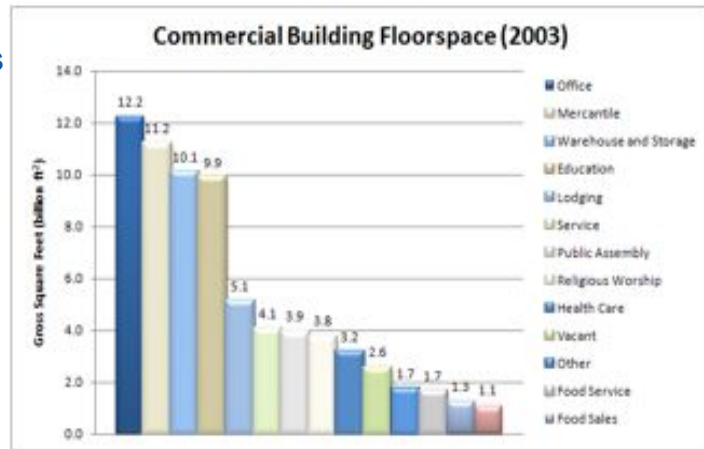
[http://www.nrel.gov/director/pdfs/20110105\\_nsf.pdf](http://www.nrel.gov/director/pdfs/20110105_nsf.pdf)

# Commercial Buildings Energy Consumption Survey

## Status of U.S. Buildings:

- 39% of primary energy
- 71% of electricity
- 38% of carbon emissions

71.7 billion ft<sup>2</sup>



“A journey of a thousand miles begins with a single step”

- Lao-tzu, *Chinese philosopher (604 BC - 531 BC)*

Source: [http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed\\_tables\\_2003/detailed\\_tables\\_2003.html](http://www.eia.doe.gov/emeu/cbecs/cbecs2003/detailed_tables_2003/detailed_tables_2003.html)

## DOE EERE Program

EERE programmatic budget \$2.24 billion (2010)

DOE Appropriations and Requests for Energy Efficiency and Renewable Energy (Dollars in thousands)			
EE and RE Technology Area	FY 2009 Current Appropriations	FY 2010 Current Appropriations	FY 2011 Congressional Request
Hydrogen technology	164,638	174,000	0
Hydrogen and fuel cell technologies	0	0	0
Biomass and refinery systems R&D	214,245	220,000	220,000
Solar energy	172,414	247,000	302,398
Wind energy	54,370	80,000	122,500
Geothermal technology	43,322	44,000	55,000
Water power	39,082	50,000	40,488
Vehicle technologies	267,143	311,365	325,302
<b>Building technologies</b>	<b>138,113</b>	<b>222,000</b>	<b>230,698</b>
Industrial technologies	88,196	32,000	42,272
Federal energy management program	22,000	32,000	42,272

[www.mbe.doe.gov/budget/11budget/Content/Approstat.pdf](http://www.mbe.doe.gov/budget/11budget/Content/Approstat.pdf)

# Building Technologies Program R&D

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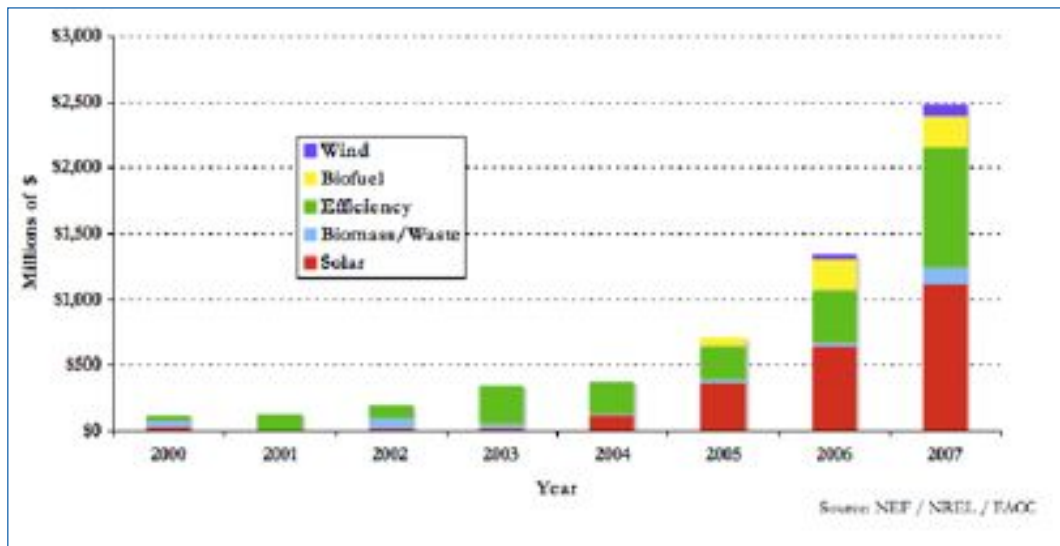
## Program Areas:

- Appliances R&D
- Building Envelope
- Whole Building Design
- Indoor Air Quality
- Lighting
- Water Heating
- Advanced Controls, Commissioning
- Geothermal/Ground-Source Heat Pumps

*The total building technologies R&D funding was approximately 39% of the 2010 budget, or \$86.58 million*

## Global Venture Capital Investments in Clean Energy

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Reference: *A Historical Analysis of Investment in Solar Energy Technologies (2000-2007)*, NREL 2008

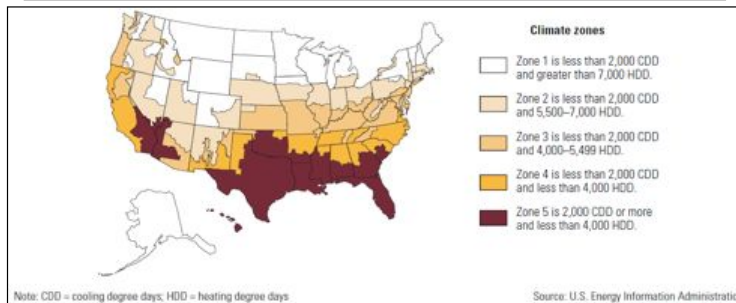
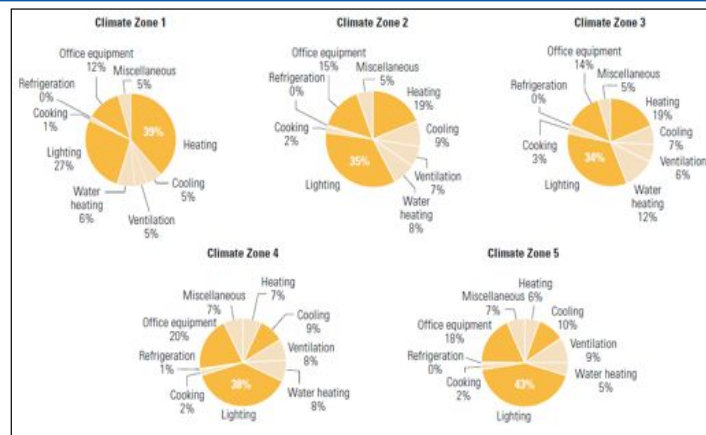
# 2010 Venture Capital Invest in Cleantech

The total venture capital investment in energy efficiency R&D in the United States in 2010 is estimated to be \$703 million.

<http://www.cleanenergypipeline.com/Resources/CleantechOpen2010-Report.pdf>; accessed December 2010.

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## Energy Consumption in Office Buildings by End Use



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## R-5 Highly-Insulating Windows and Low-e Storm Windows Volume Purchase Program

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### Goal :

- Affordable R-5 (U-factor of 0.22 or less for operable window and 0.20 or less for fixed window) with price premium less than \$4/ft<sup>2</sup> compared to conventional double-pane low-e windows
- More than 40 qualified vendors were selected to provide R-5 and low-e storm windows at a competitive price



Reference:

[http://apps1.eere.energy.gov/buildings/building\\_e2\\_news/detail.cfm/articleId=13](http://apps1.eere.energy.gov/buildings/building_e2_news/detail.cfm/articleId=13)

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## R-5 Highly-Insulating Windows and Low-e Storm Windows Volume Purchase Program

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- Whole-window R-value of 5 (a U-factor of 0.22 or less)
- Currently triple pane (sometimes includes suspended film), but other future options are conceivable
- Current ENERGY STAR qualified windows have an U-factor of around 0.3
- Increasing the R-value from 3 to 5 reduces average heat loss through the window by 40% and improves occupant comfort

Reference:

[http://www1.eere.energy.gov/buildings/windowsvolumepurchase/pdfs/glassbuild\\_presentation\\_10-01-09.pdf](http://www1.eere.energy.gov/buildings/windowsvolumepurchase/pdfs/glassbuild_presentation_10-01-09.pdf)

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## Aerogel-Based Spaceloft Insulation for General Building Applications

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### ***Description :***

- Highest R value of any building material

Reference: Spaceloft [http://www.aerogel.com/Aspen\\_Aerogels\\_Spaceloft.pdf](http://www.aerogel.com/Aspen_Aerogels_Spaceloft.pdf) 3

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## R-5 Highly-Insulating Windows and Low-e Storm Windows Volume Purchase Program

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- The number one application of the technology in its current state is in space-constrained commercial building renovations over existing concrete construction
- Significantly better thermal performance than any other building insulation material
- Reduced space volume and insulation density
- Hydrophobic and breathable at the same time
- Thermal conduction 96% of air

Reference: Spaceloft [http://www.aerogel.com/Aspen\\_Aerogels\\_Spaceloft.pdf](http://www.aerogel.com/Aspen_Aerogels_Spaceloft.pdf) 3

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## Electrochromic and Thermochemical Windows

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### **Description :**

- Electrical signal will tint the window
- Daylight sensor activates window - within 5–10 minutes, glass darkens to a pre-set level
- This electrochromic glass modulates light transmission and solar heat gain by sending an electrical charge through the glass
- The electricity used to operate 1,500 square feet of SageGlass window is less than a 60-W light bulb



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## Electrochromic and Thermochemical Windows

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### **Description :**

- Reversibly change light transmission based on thermochemical materials activated by heating effect of the sun
- The window design allows for
  - Good daylighting
  - A low solar heat gain coefficient
  - A low U-value
  - High insulation value
  - Energy savings up to 30% are estimated compared with traditional window systems

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# DOE – Dollar a Watt Vision

## Description :

- Goal to achieve \$1/watt installed costs by 2017



DOE PPT

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# Integrated Roof Systems

## Description :

- Fully *integrate PV into standard building materials and components*
- Combine thermal and electrical generation
- Reduce solar heat gain
- Utilize water catchment
- Design roofs with no roofing objects (solar ready)
- Integrate PV systems into fully adhered thermoplastic olefin or polyolefin membrane roof in factory
- ‘Plug in’ device – no permitting / inspection
- Close to \$0 installation costs



NREL Pix 15779

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# Building Envelope Systems of the Future

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- Triple paned windows (R5 or better)
- Potential for new insulation materials
- Higher R value walls, roofs, etc
- Electrochromic or thermochromic windows in specialty applications
- Phase change materials in common bldg materials

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## Next Generation – Energy Efficient Desktop Computers

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***Typical desktop uses 80-120 Watts when active!!***

### **Energy Efficient Desktops:**

Advent Eco PC	(50 Watts)
Asus Eee Box B202	(20 Watts)
Apple Mac mini	(20 – 28 Watts)
Dell Studio Hybrid	(65 Watts)
Very PC Fulwood	(27 Watts)
Tranquil T2e Atom	(29 Watts)
Shuttle X27	(26 Watts)
RM EcoQuiet One 50	(58 Watts (including monitor))

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## Thin Clients

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- Solid state device that access a local network server
- Majority of processing and data storage takes place on the server
- Provide for more security, lower maintenance costs, and longer life
- ***Require about 40 Watts including server***
- ***Isolate heating load from the space***

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## Plug Loads of the Future

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- Low Energy Use Computers (<20 watts)
- LED Monitors
- LED Task Lighting
- Centralized Plug Load Power Management
- Plug Load Occupancy Sensors

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# Hybrid Packaged Rooftop Unit

## Goal :

- Western Cooling challenge - set forth as a challenge to manufacturers to improve the state-of-the-art space cooling products
- NREL is to verify these criteria through laboratory testing at its HVAC test facility
- Coolerado H-80 unit won the competition unit, an advanced ultra-cooler that uses the patented “M-cycle” process, is a hybrid indirect evaporative cooling and refrigeration direct expansion system

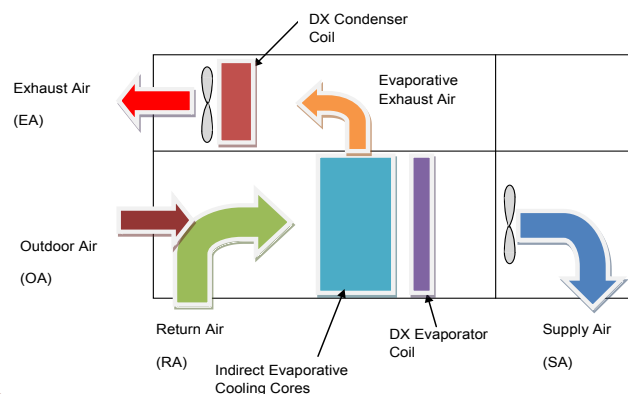


Reference: <http://www.nrel.gov/docs/fy11osti/46524.pdf>

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# Hybrid Packaged Rooftop Unit

- Return air and outdoor air cooled by an indirect evaporative medium
- Between 43% and 46% of this air is used as an indirect evaporative cooling stream
- The balance is then passed through a refrigerant evaporator coil
- The exhaust air from the evaporative process is used for the heat sink air flow going through the refrigerant condenser coil



Reference: <http://www.nrel.gov/docs/fy11osti/46524.pdf>

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# Hybrid Packaged Rooftop Unit

		Specification	Performance	Units
Peak Conditions (105°F/73°F)	Sensible Cooling	–	56.9	kBtu/h
	Sensible EER	≥14.0	20.1	Btu/Wh
	* Water Use	–	1.83	gal/ton-h (sensible)
Surrogate Annual Conditions (90°F/64°F)	Sensible Cooling	–	45.6	kBtu/h
	Sensible EER	≥17.0	41.1	Btu/Wh
	* Water Use	≤4.0	1.85	gal/ton-h (sensible)

Reference: <http://www.nrel.gov/docs/fy11osti/46524.pdf>

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## Dewpoint Evaporative Comfort Cooling

Demonstrate the ability of new high performance indirect evaporative cooling technology to:

- Enhance cooling efficiency and comfort in dry climates
- Substantially reduce peak power demand relative to conventional air-conditioning
- Installed 24 units on five different buildings at Ft. Carson

Source NREL



<http://www.serdp.org/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-200821>

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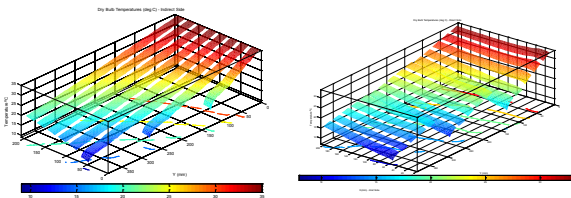
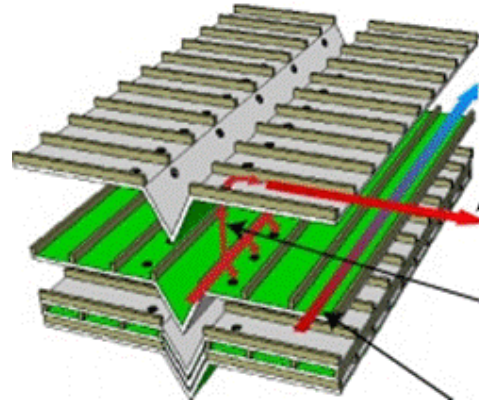
# Technology Description

Innovative indirect evaporative cooling technology developed by Coolerado Corporation

Staged cooling with wet-bulb effectiveness from 90% to 125%

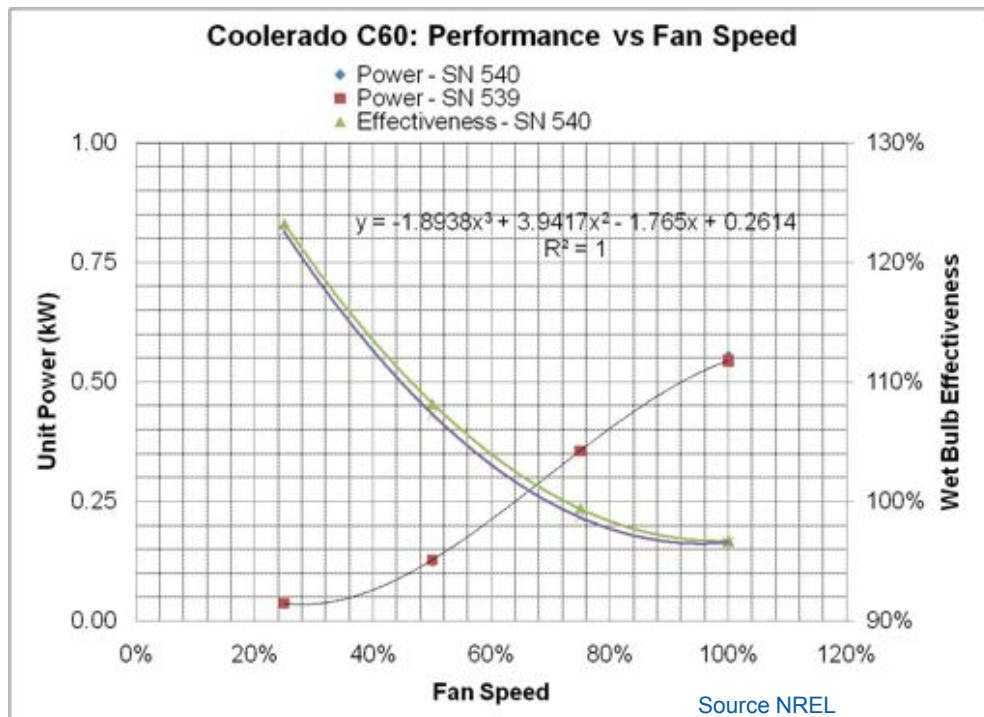
No moisture added to the product airstream.

Fan is the only major energy input.

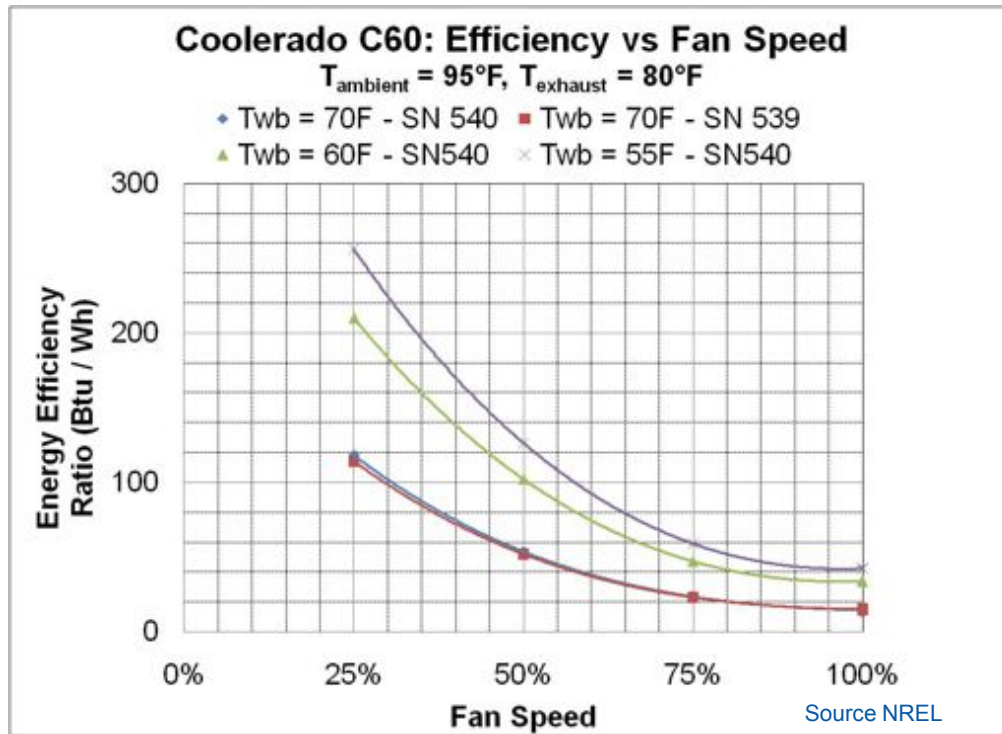


[http://www1.eere.energy.gov/femp/pdfs/tir\\_coolerado.pdf](http://www1.eere.energy.gov/femp/pdfs/tir_coolerado.pdf)

# Dewpoint Evaporative Comfort Cooling



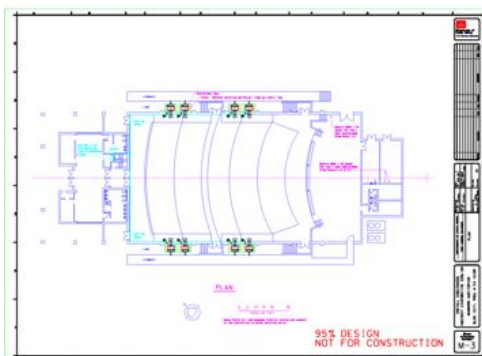
# Dewpoint Evaporative Comfort Cooling



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## McMahon Theater (Auditorium)

8 units supply air above audience  
4 units on each side of audience  
6,700 SF facility



NREL Pic

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# Colorado Springs Weather Data (TMY3)

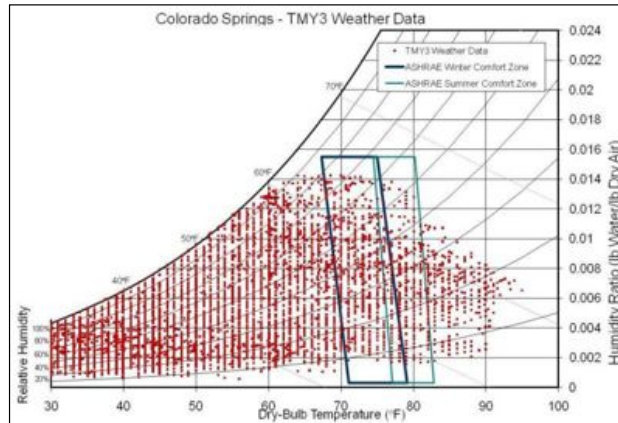
## Design Days for Cooling:

Cooling Design Day (0.4%)

- $T_{db}$ : 90.3 °F
- Mean Coincident  $T_{wb}$ : 58.8 °F

Evaporative Design Day (0.4%)

- $T_{wb}$ : 63.3 °F
- Mean Coincident  $T_{db}$ : 78.3 °F



Source NREL

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# Colorado Springs Actual Weather Data Summer 2010

## Measured at Site:

Max Conditions July – September

- $T_{db}$ : 97.8 °F, MC  $T_{wb}$ : 62.9 °F
- Maximum  $T_{wb}$ : 70.79 °F

Total of 113 hours above 0.4% design conditions

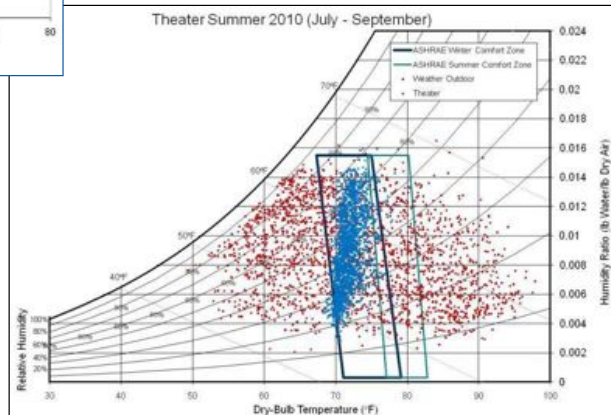
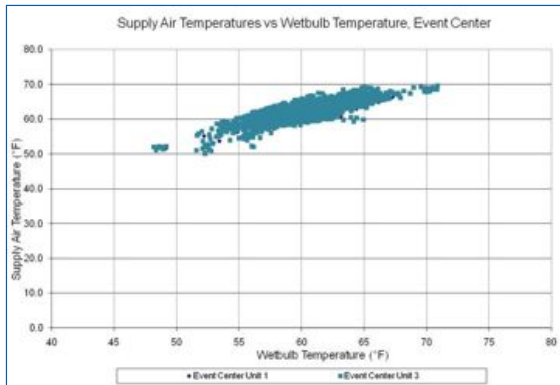
- 1.3% on an annual basis

Maximum Outside Air Temperature (F)	Maximum Outside Air Wet-bulb Temperature (F)	Number of Hours Above 0.4% Design	Percent of Hours Above 0.4% Design (%)
97.86	70.79	113	1.3%

Source NREL

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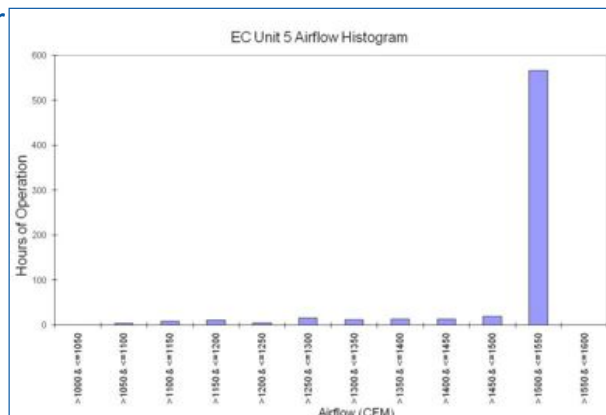
# Dewpoint Evaporative Comfort Cooling



Source NREL

## Energy Analysis

- Monthly average EER = 40 - 54
- Minimum efficiency packaged DX EER = 13
- Thus, 67.5% reduction in energy use not accounting for fan energy savings



Source NREL

# Applications / Design Considerations

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## Design Considerations:

- Install return air to reduce water use / OA load
- Install French drain to use waste water for landscape
- Retrofit – install as pre-conditioner for packaged unit

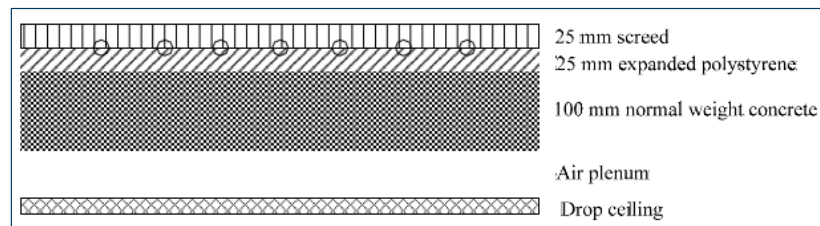
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# Radiant Heating and Cooling w/ DOAS

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## Energy Benefits

- Significantly reduces fan/pump energy use
- Operate at higher chilled water temp (can run on cooling tower)
- Operate on lower hot water temperatures
- Use air pre-conditioner w/DOAS in climates as needed



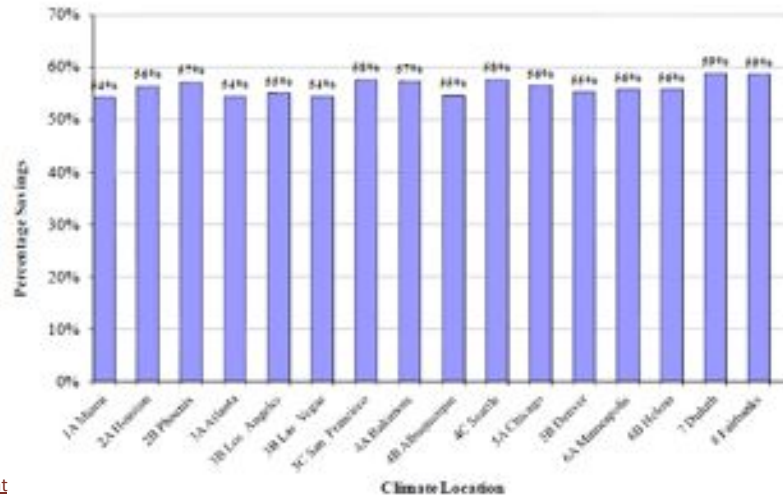
[http://www.pnl.gov/main/publications/external/technical\\_reports/PNNL-18773.pdf](http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18773.pdf)

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# Radiant Heating and Cooling w/ DOAS

## Energy Benefits

- ASHRAE AEDG 50% savings over 90.1 recommend radiant in all climates



[http://www.pnl.gov/main/publications/external/technical\\_reports/PNNL-18773.pdf](http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18773.pdf)

Figure 6.1. Percentage Energy Savings by Climate Zone (Radiant System)

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# Ground Based Heating/Cooling

## Technology Applications

- Ground based air pre-conditioner
- Ground Source Heat Pumps
  - Thermally active foundations
  - Installation cost reduction measures



[http://bechtel.colorado.edu/~jmccartn/GSHPs/Files/2006\\_Brandt\\_ThermallyActive.pdf](http://bechtel.colorado.edu/~jmccartn/GSHPs/Files/2006_Brandt_ThermallyActive.pdf)

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# HVAC Systems

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- Motors and Pumps are close to theoretical max
- Move to toward radiant heating and cooling with DOAS
- GSHP and District Heating/Cooling
- Advanced evaproative cooling technologies for small commercial

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# Solid State Lighting: Light Emitting Diodes

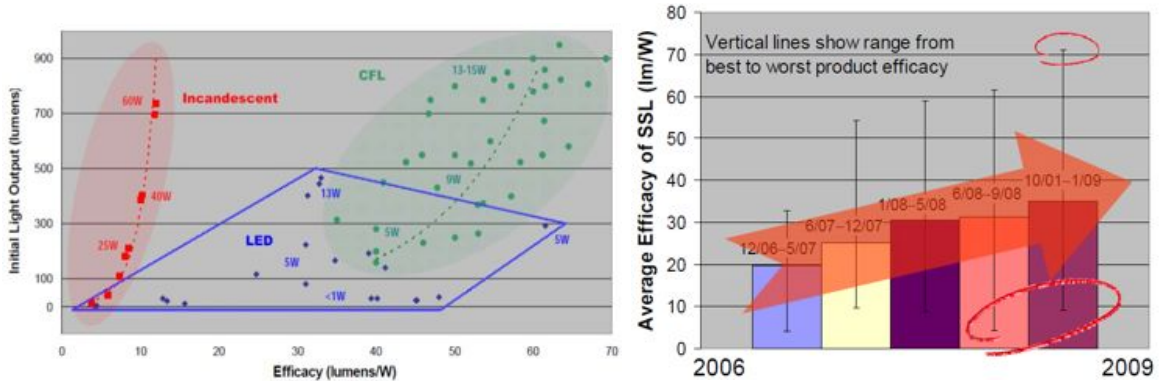
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- Very compact, low profile, low energy
- No breakable glass or filaments
- Require no “warm-up” time
- 50,000 hrs life time rating
  - Life time not affected by frequent switching
- No UV or IR light emitted
- Can produce 30 to 150 lumens each
- Can be used separately or in arrays
- Emit light in a highly directional manner rather than spherically
  - Reduces wasted light

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# Solid State Lighting: Light Emitting Diodes

LED's are improving rapidly but are not the best choice in all applications



Source: Pacific Northwest National Laboratory

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# Solid State Lighting: Light Emitting Diodes

DOE's long-term R&D goal calls for white-light LEDs producing 160 lm/W in cost-effective, market-ready systems by 2025.

Currently, LEDs can only perform similarly to fluorescent lamps and only make sense for specific retrofit applications.

Light Source	Typical Luminous Efficacy Range in lm/W (varies depending on wattage and lamp type)
Incandescent (no ballast)	10-18
Halogen (no ballast)	15-20
Compact fluorescent (CFL) (incl. ballast)	35-60
Linear fluorescent (incl. ballast)	50-100
Metal halide (incl. ballast)	50-90
Cool white LED >4000K (incl. driver)	60-92*
Warm white LED <4000K (incl. driver)	27-54*

\*As of Spring 2009

Source: Pacific Northwest National Laboratory

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# Solid State Lighting

## Current Applications

- Exit signs
- Recessed can lighting
- Desk Lamps
- Exterior lighting

## Future Applications

- Replacement for fluorescent in interior lighting
- Replace CFL in screw in lamps



Source NREL

## 50% Energy Savings over ASHRAE 90.1 – 2004 for Lighting

**Table 6.2 Final Energy Savings Recommendations – Lighting**

Item	Component	All Climate Zone Locations					
		W/ft <sup>2</sup>		ft <sup>2</sup> /m <sup>2</sup>			
Interior Lighting	Lighting power density	Office, open plan	0.68	7.3	Office, enclosed	0.8	8.6
		Conference/meeting	0.77	8.3	Active storage	0.64	6.9
		Corridor/transit	0.50	5.4	Restroom	0.82	8.8
		Lounge/recreation	0.73	7.9	Stair	0.6	6.5
		Electrical/mechanical	1.24	13.3	Lobby	1.09	11.7
		Other	0.82	8.8	OVERALL	0.75	8.1
		Fluorescent lamps	T1HO or T8 high-performance with high-performance electronic ballast and compact fluorescent (CFL) with electronic ballast.				
	Occupancy controls	Added for open-office task lights, enclosed office ambient lighting, active storage, restrooms and electrical/mechanical spaces.					
	Flag load lighting	Compact fluorescent (CFL) with electronic ballast					
	Exterior Lighting Power Density	Base allowance	750 W				
Parking areas and drives		0.100	1.08				
Walkways		0.160	1.72				
Entry canopies		0.400	4.31				
Façade (see wattage only for façade)		0.075	0.81				

[http://www.pnl.gov/main/publications/external/technical\\_reports/PNNL-18773.pdf](http://www.pnl.gov/main/publications/external/technical_reports/PNNL-18773.pdf)

## Future of EE Lighting: Individualized Lighting Controls

### Work station specific luminaires:

- One independently controllable luminaire per workstation
- One dimmable ambient lamp per fixture
- Two dimmable baffled down lights
- Occupancy sensors and/or photocells built directly into the body of the fixture as well as all associated control circuitry required to commission and operate the system
- Networked together using a microcontroller
- Use of a PC to run application-specific control software and collect real time energy data

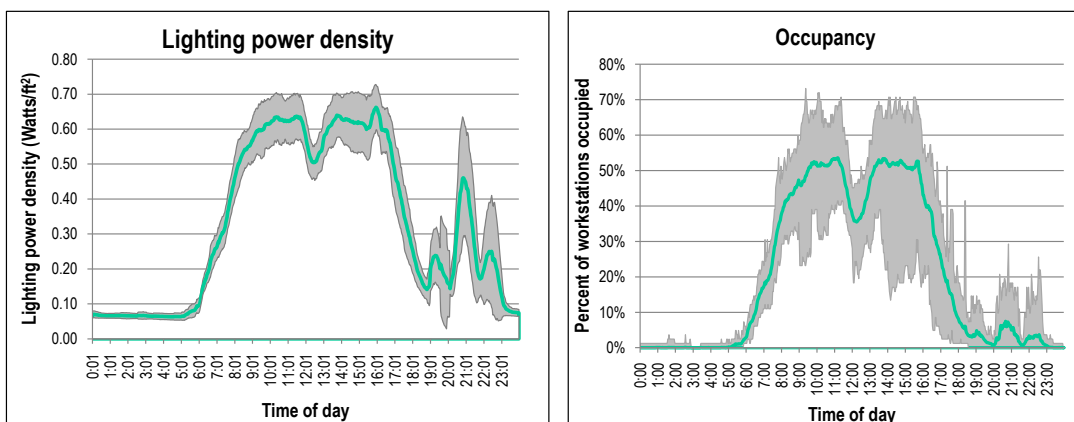


Cubicles lit with workstation-specific luminaires during the pilot study at the Philip Burton Federal Building.

[www.osti.gov/bridge/servlets/purl/986324-LKIY1S/](http://www.osti.gov/bridge/servlets/purl/986324-LKIY1S/)

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## Future of EE Lighting: Individualized Lighting Controls



[www.osti.gov/bridge/servlets/purl/986324-LKIY1S/](http://www.osti.gov/bridge/servlets/purl/986324-LKIY1S/)

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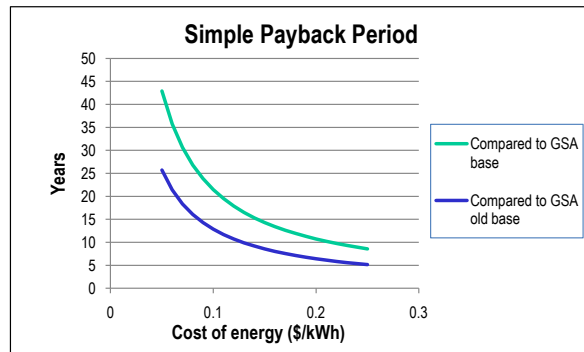
## Future of EE Lighting: Individualized Lighting Controls

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### Installed Cost and Payback:

- Overall energy savings 40% versus low power density baseline
- Installed cost ~ \$450/fixture

[www.osti.gov/bridge/servlets/purl/986324-LKIY1S/](http://www.osti.gov/bridge/servlets/purl/986324-LKIY1S/)



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## Optical Louvers/Integrated Daylighting

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- Consider Install Light Louvers on upper windows
- LightLouver website:  
<http://www.lightlouver.com/Info/Design%20Features/Design%20Features.html>



Source: NREL

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# NREL – Image Processing-Based Occupancy Sensor

## Need to Address:

Motion sensors are a poor surrogate for occupancy measurement for occupancy. Performance deficiencies impact occupant comfort, resulting in related controls being disabled or severely undertuned.

## Project Goal:

Cost-effective, embedded image processing techniques will be developed to better match occupancy with control signal resulting in applications for temperature, ventilation, and daylighting control for retrofit or new construction at less cost and higher robustness. A broader value proposition including integration with building security systems is also possible.

RSF installation and performance evaluation (8/31/2011)

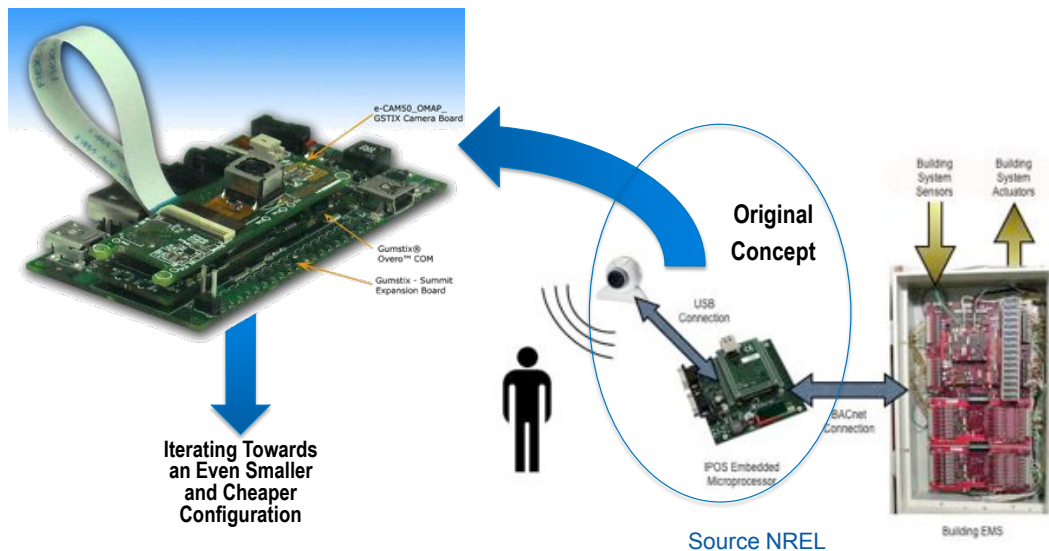
### PI & Key Staff:

Larry Brackney – Project and subcontract manager, architecture, algorithm development, and testing (15%)

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# NREL – Image Processing-Based Occupancy Sensor

Focus on cost-effectiveness and manufacturability at the outset



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# Lighting / Daylighting

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- Revolutionary automated controls
- Solid State Lighting in all applications
- Integrated building design /daylighting

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## DOE/NREL RSF: Project Goals

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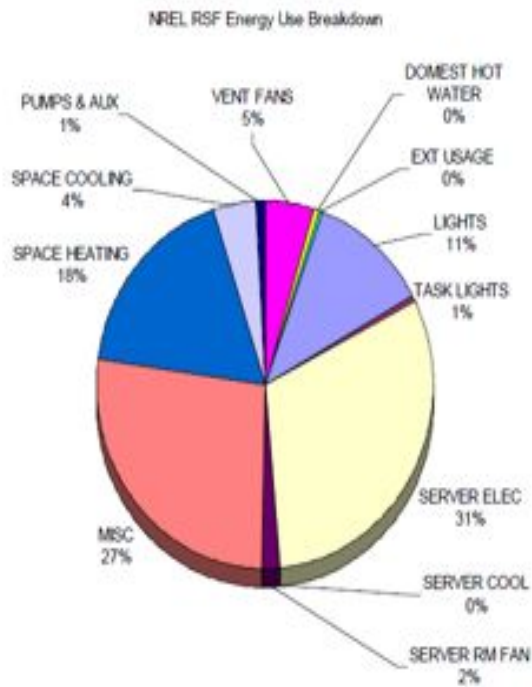
- 800+ people in DOE office space on NREL's campus
- 220,000 ft<sup>2</sup>
- Design/Build Process with required energy goals
  - 25 kBtu/ft<sup>2</sup>
  - 50% energy savings
  - LEED Platinum
- Replicable
  - Process
  - Technologies
  - Cost
- Site, source, carbon, cost ZEB:B
  - Includes plugs loads and datacenter
- Firm fixed price of ~\$64 million
  - \$259/ft<sup>2</sup> construction cost (not including \$27/ft<sup>2</sup> for PV)
- Open first phase June 10, 2010



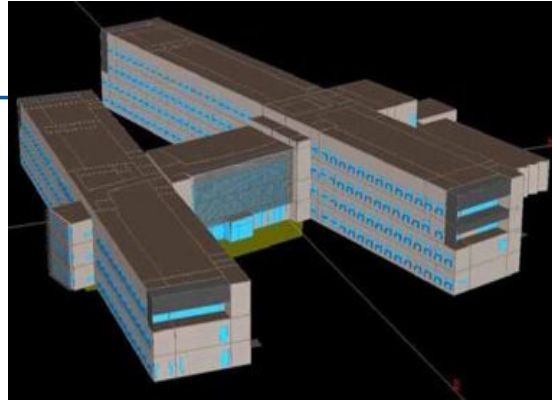
Source NREL

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# Energy Modeling



Source NREL



End Use	kBtu/ft2
Lights	3.85
Task Lights	0.19
Data Center	10.60
Data Center Cooling	0.01
Data Center Fans	0.55
Office Plug Loads	9.16
Space Heating	6.11
Space Cooling	1.42
Pumps	0.27
Ventilation Fans	1.61
Domestic Hot Water	0.13
Exterior Lights	0.12

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## Key Design Strategies

1. Optimal orientation and office space layout
2. Fully daylit office wings with high performance electrical lighting
3. Continuous insulation precast wall panels with thermal mass
4. Operable windows for natural ventilation
5. Radiant heating and cooling
6. Outdoor air preheating
  - Transpired solar collector
  - Datacenter waste heat
  - Exhaust air energy recovery
  - Crawl space thermal storage
7. Aggressive plug load control strategies
8. Data center outdoor air economizer with hot aisle containment
9. Roof top and parking lot based PV

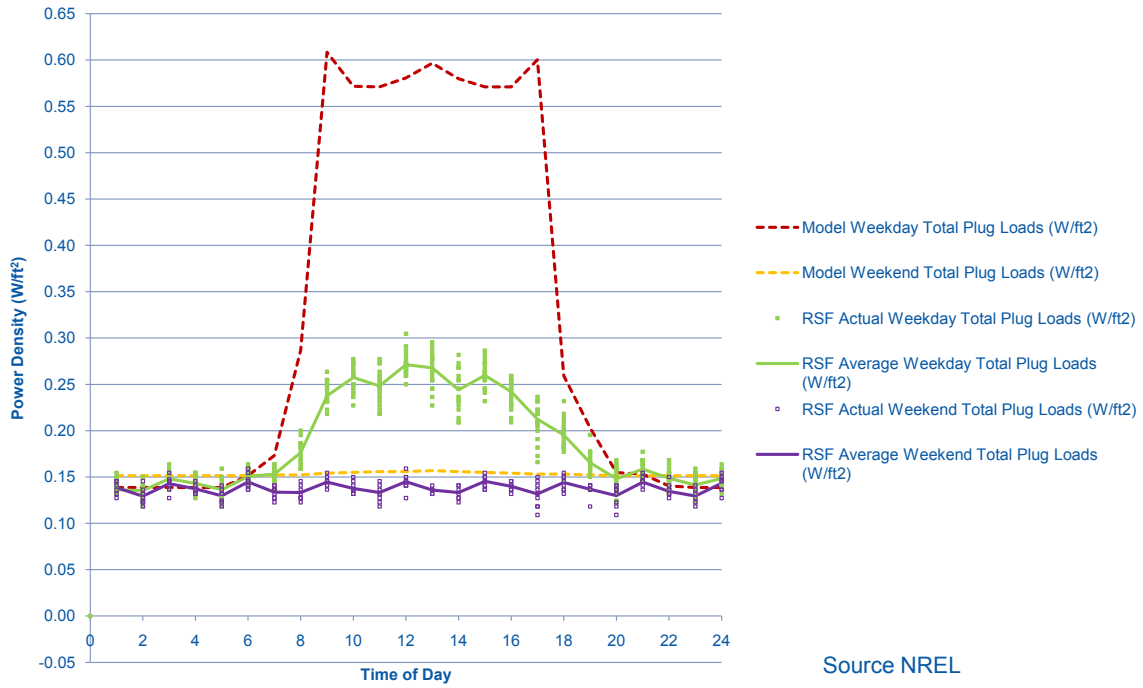
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# October 2010 Plug Loads

## October Actual vs Model Total Plug Loads Power Density



Source NREL

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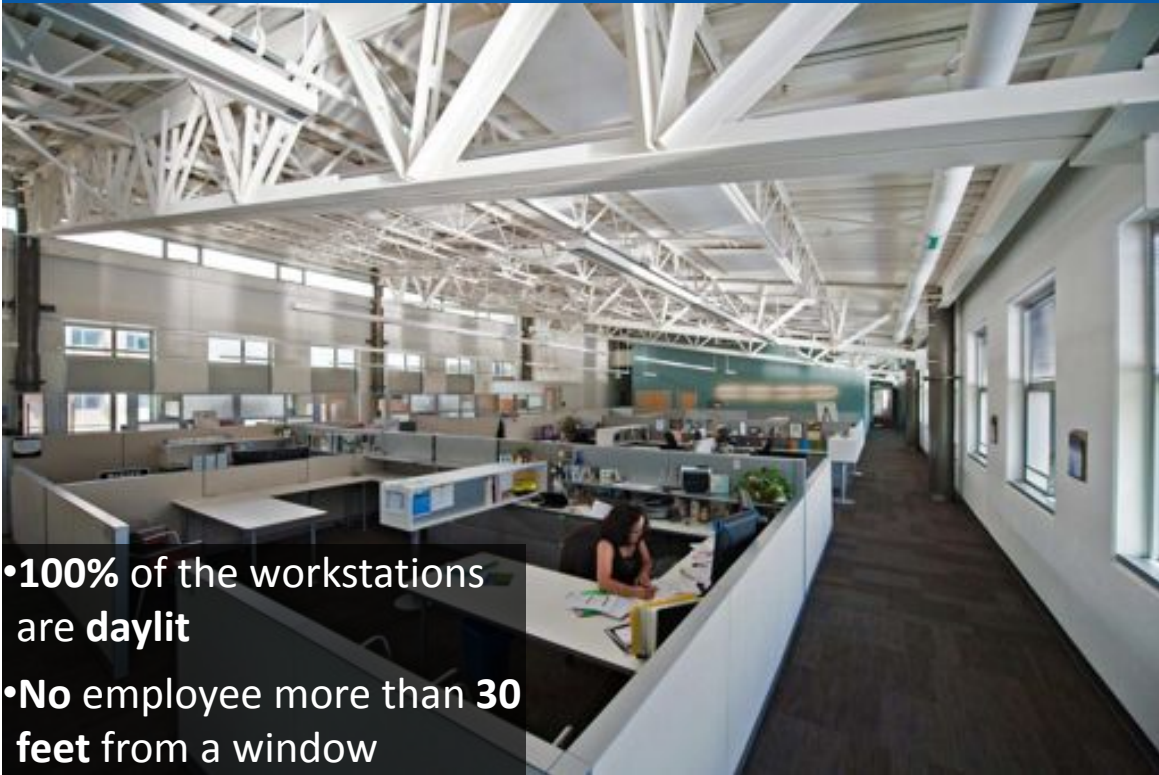
# Daylighting Elements



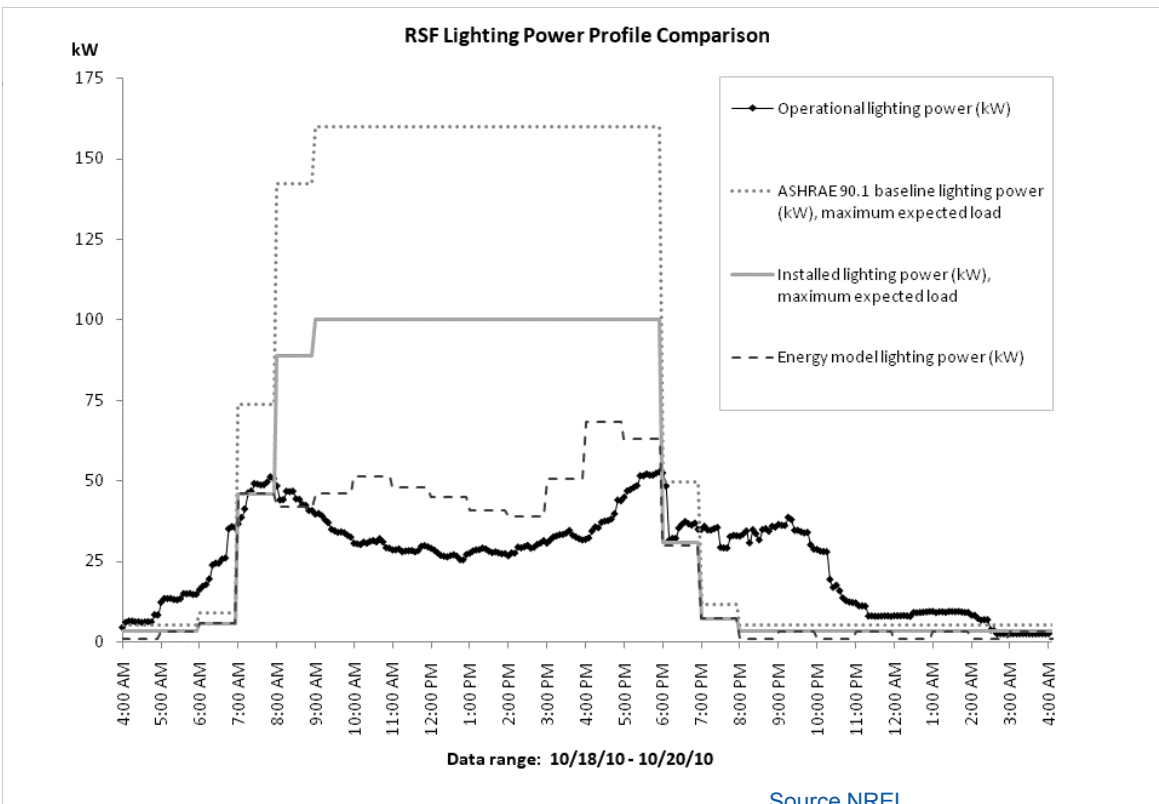
Source NREL



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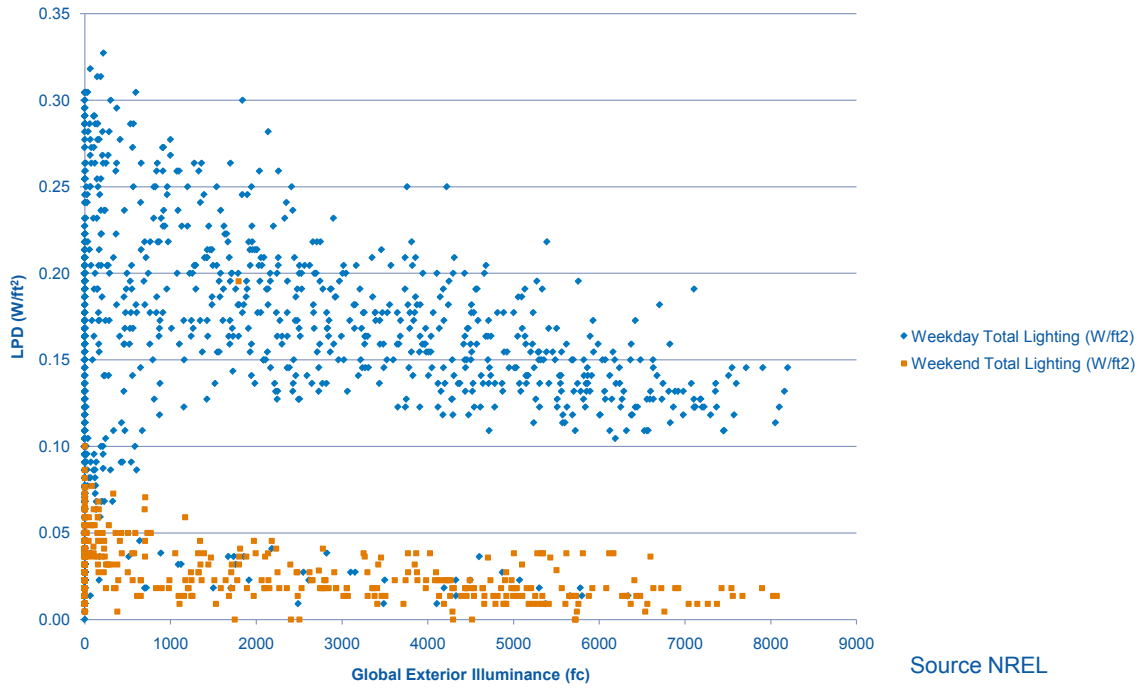


- 100% of the workstations are daylight
- No employee more than 30 feet from a window



# RSF Lighting

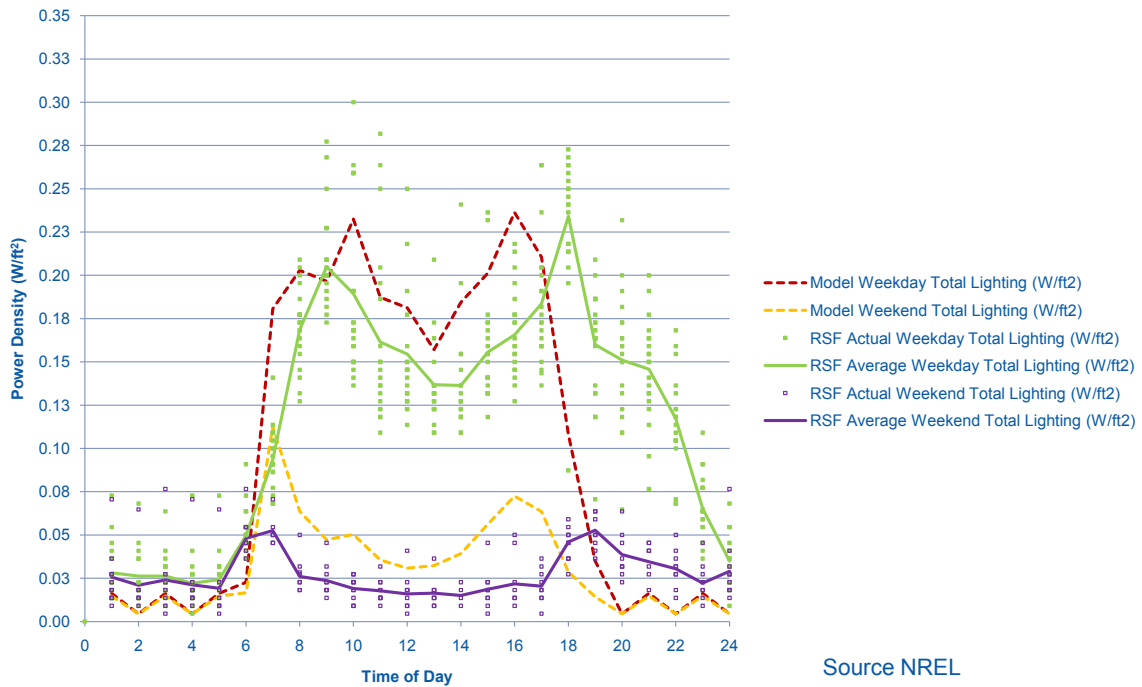
## RSF LPD vs Solar Illuminance



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# October 2010 Lighting

## October Actual vs Model Total Lighting Power Density



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# Commercial Buildings of The Future

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- Well Insulated Envelope
- Triple paned & electrochromic windows
- Integrated cool/generation roof
- Lighting Power Densities <0.3 watt/ft<sup>2</sup>
- Equipment Power Densities <0.35 Watt/ft<sup>2</sup>
- Radiant heating /cooling w/DOAS
- Ground based Heating/Cooling
- Self Optimizing HVAC, Lighting



## Emerging Technology Demonstrations

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- California Energy Commission – Public Interest Energy Research (PIER) Program

<http://www.energy.ca.gov/pier/portfolio/PIERwrite-ups.htm>

- DoD's environmental technology demonstration and validation program

<http://www.serdp.org/Program-Areas/Energy-and-Water>

- Dewpoint Evaporative Comfort Cooling

<http://www.serdp.org/Program-Areas/Energy-and-Water/Energy/Conservation-and-Efficiency/EW-200821>

- Solid State Lighting GATEWAY Demonstration Results

[http://www1.eere.energy.gov/buildings/ssl/gatewaydemos\\_results.html](http://www1.eere.energy.gov/buildings/ssl/gatewaydemos_results.html)

## Resources

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- Illumination Engineering Society <http://www.iesna.org/>
- Energy Star Compact Fluorescent Lighting Program [http://www.energystar.gov/index.cfm?c=cfls.pr\\_cfls](http://www.energystar.gov/index.cfm?c=cfls.pr_cfls)
- DOE Solid State Lighting Program <http://www1.eere.energy.gov/buildings/ssl/>
- Caliper Program <http://www1.eere.energy.gov/buildings/ssl/caliper.html>
- Solid State Lighting Gateway Demonstrations <http://www1.eere.energy.gov/buildings/ssl/gatewaydemos.html>

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## Resources

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### **Next Generation Luminaries**

<http://www.ngldc.org/>

### **Lighting for Tomorrow**

<http://www.lightingfortomorrow.com/>

### **Achieving Energy Savings with Highly-Controlled Lighting in an Open-Plan Office**

<http://www.osti.gov/bridge/purl.cover.jsp;jsessionid=18BDB13F214DBF3D941528DCD7C8075D?purl=/986324-LKIY1S/>

### **Advanced Lighting Control Vendors**

<http://www.daintree.net/index.php>

<http://www.lutron.com/Pages/Default.aspx>

<http://www.encelium.com/>

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# Resources

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## Technical Support Document: 50% Energy Savings Design Technology Packages for Medium Office Buildings

[http://www.pnl.gov/main/publications/external/technical\\_reports/PNNL-19004.pdf](http://www.pnl.gov/main/publications/external/technical_reports/PNNL-19004.pdf)

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# Questions

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