NREL
NATIONAL RENEWABLE ENERGY LABORATORY

The Road to Net Zero

Bill Glover

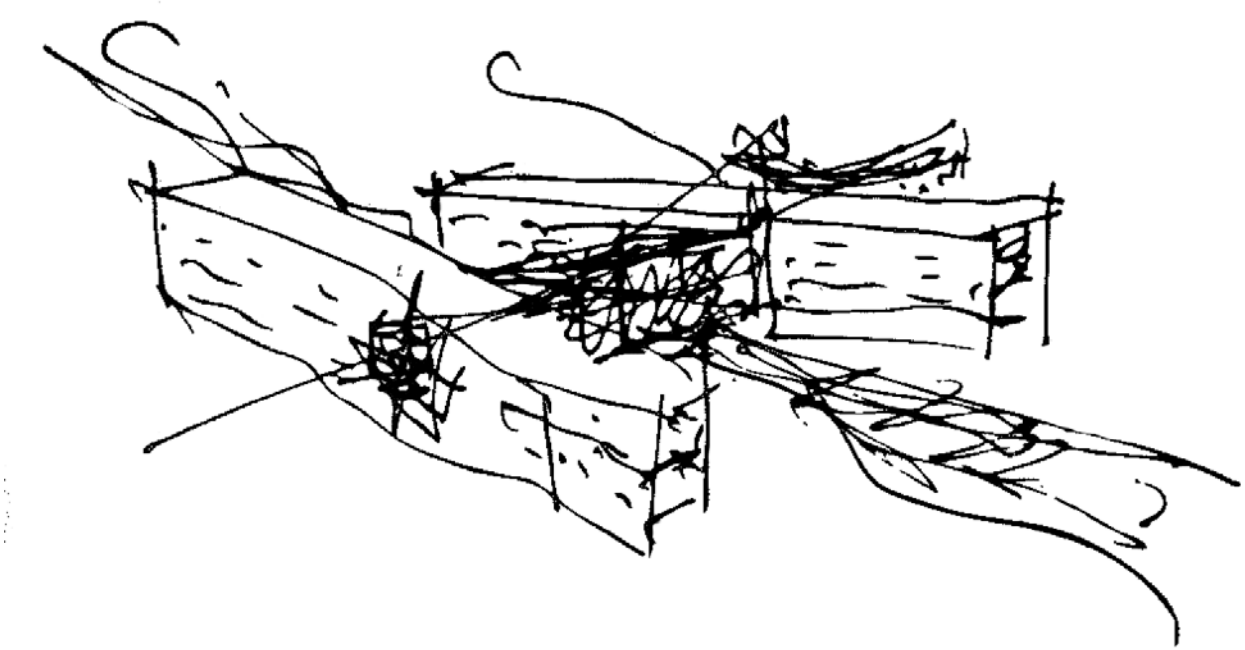
Deputy Laboratory Director and Chief Operating Officer

The Sustainable Operations Summit

May 16, 2011

Vision

Research Support Facility Vision

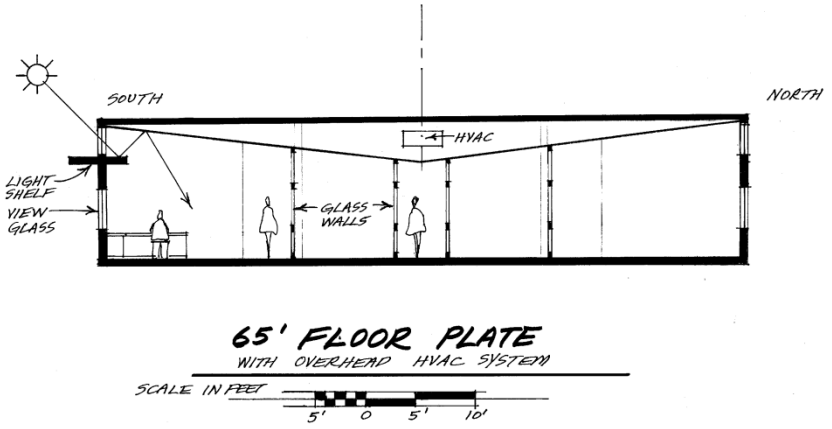


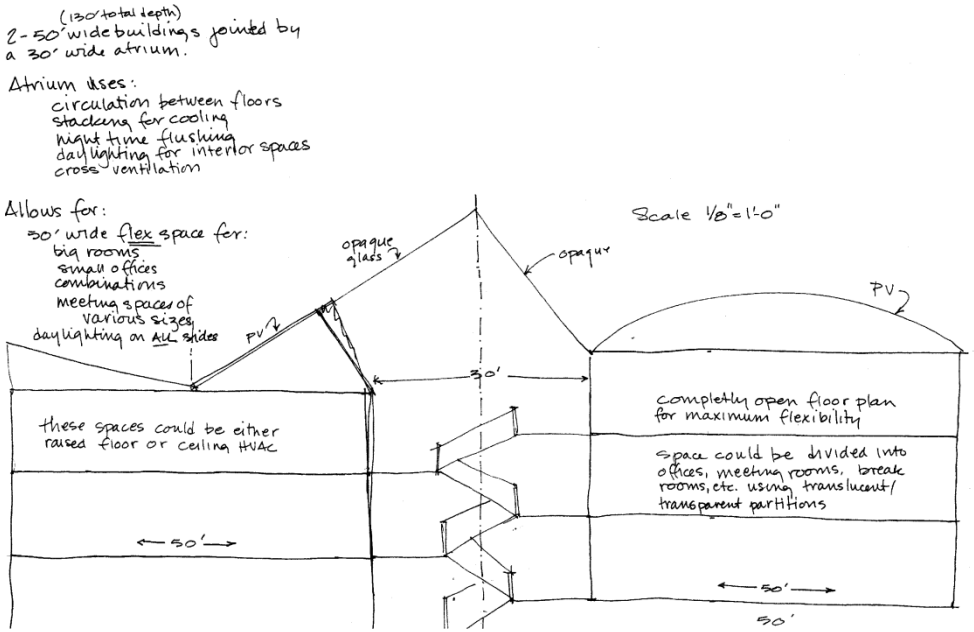
- A showcase for sustainable, high-performance design
  - Incorporates the best in energy efficiency, environmental performance, and advanced controls using a “whole building” integrated design process
- Serves as a model for cost-competitive, high-performance commercial buildings for the nation’s design construction, operation, and financing communities

Design-Build Process

Why Performance-Based Design-Build Works

- Encourages innovation
- Reduces owner's risk
- Faster construction and delivery
- Better cost control
- Makes optimal use of team members' expertise
- Establishes measurable success criteria





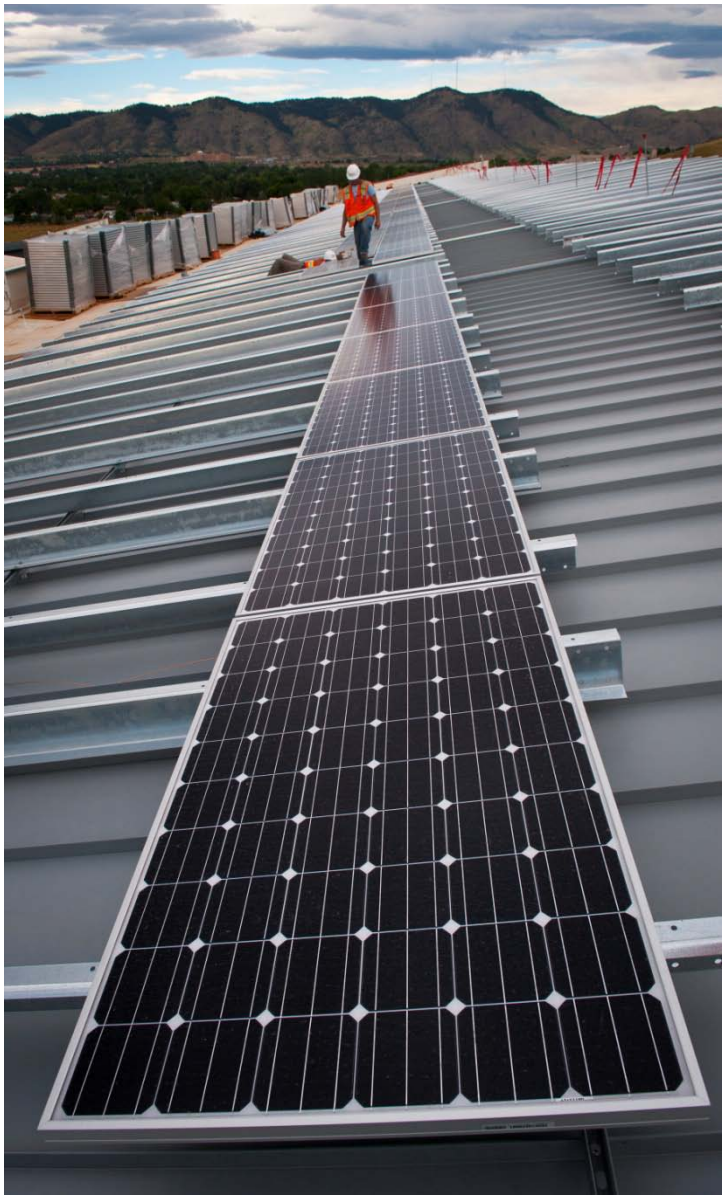
Strategy for Superior Energy Design

What Shaped Our Strategy?

- Manic focus on energy performance
- Design and culture dictate energy performance
- Whole building approach to integrate design solutions
- Owner/Subcontractor dialogue encourages creativity and trust
- Superior project definition reduces project risk and cost to all
- Traditional design-bid-build approach would not work

Key Components of Performance-Based Strategy

- Performance-based request for proposals
- National competition for conceptual design
- Design-Build acquisition strategy
- Power Purchase Agreement



Developing a Performance-Based Request for Proposals

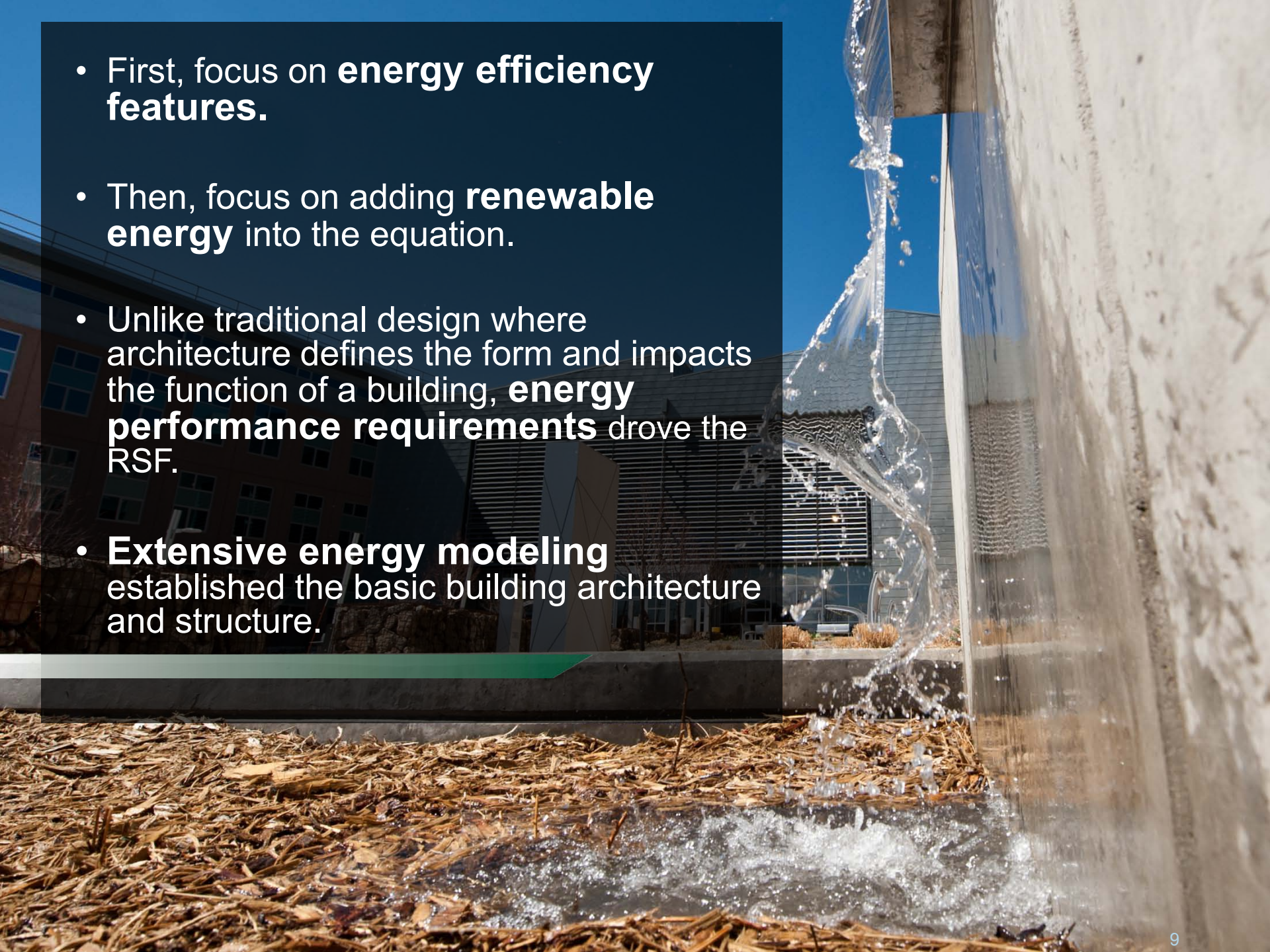
- $64M project cost limit
- Up-front planning drives success
  - Design charrettes
  - Design Build Institute of America
  - Owner's representatives
- Design challenge
  - Suite of performance goals to challenge team
  - Substantiation criteria

Tier 1: Mission Critical Goals
- Attain Safe Work/Design
- LEED Platinum
- Energy Star "Plus"

Tier 2: Highly Desirable Goals
- 800 Staff Capacity
- 25k BTU/sf/year
- Architectural Integrity
- Honor Future Staff Needs
- Measurable ASHRAE 90.1
- Support Culture and Amenities
- Expandable Building
- Ergonomics
- Flexible Workspace
- Support Future Technologies
- Documentation to Produce "How To" Manual
- Allow Secure Collaboration with Visitors
- Completion by 2010

Tier 3: If Possible Goals
- Net Zero Energy
- Most Energy Efficient Building in the World
- LEED Platinum Plus
- 50% Better than ASHRAE 90.1
- Visual Displays of Current Energy Efficiency
- Support Public Tours
- Achieve National and Global Recognition and Awards

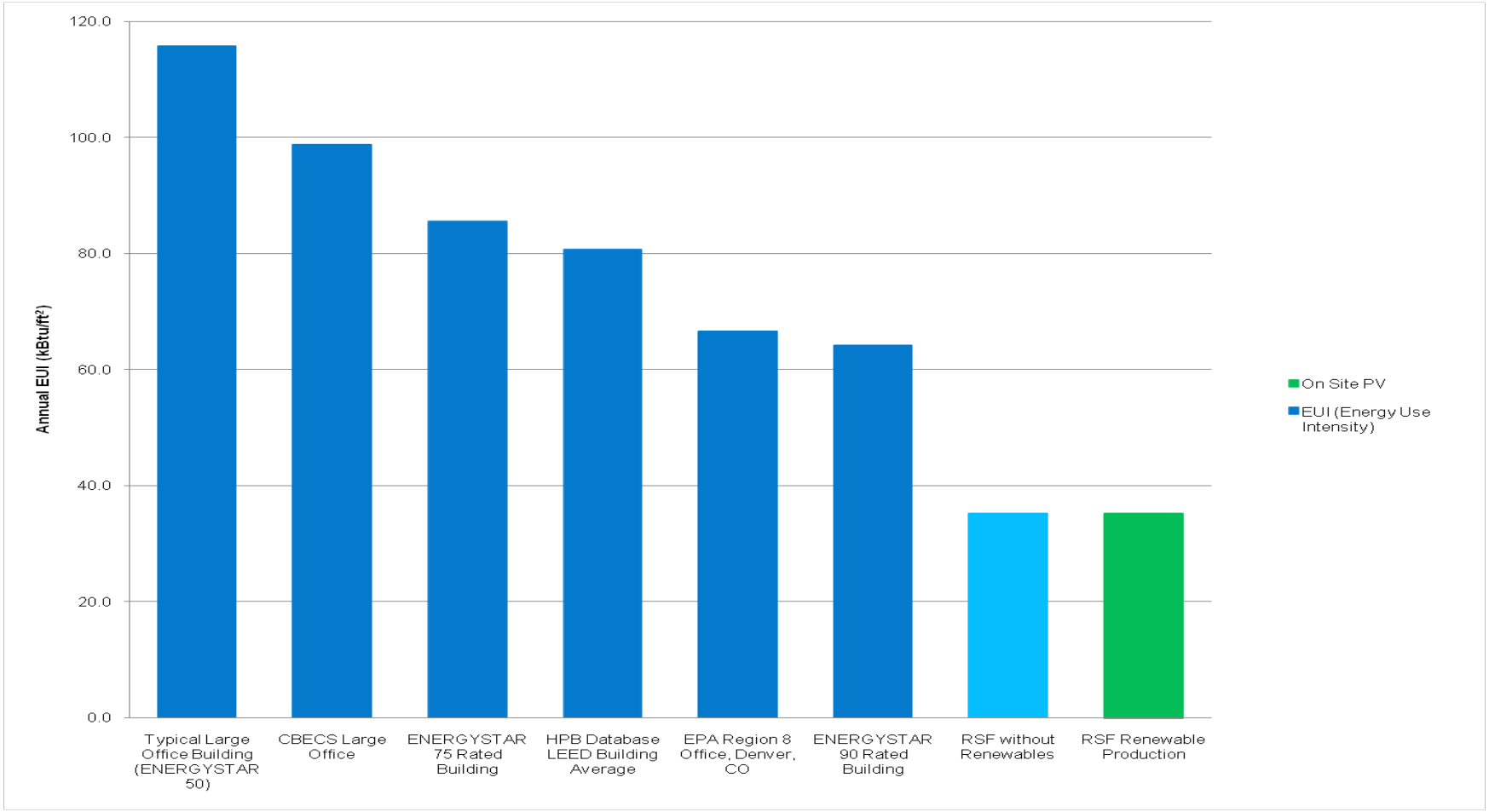
How Do You Get to Net Zero?



- First, focus on **energy efficiency features.**
- Then, focus on adding **renewable energy** into the equation.
- Unlike traditional design where architecture defines the form and impacts the function of a building, **energy performance requirements** drove the RSF.
- **Extensive energy modeling** established the basic building architecture and structure.

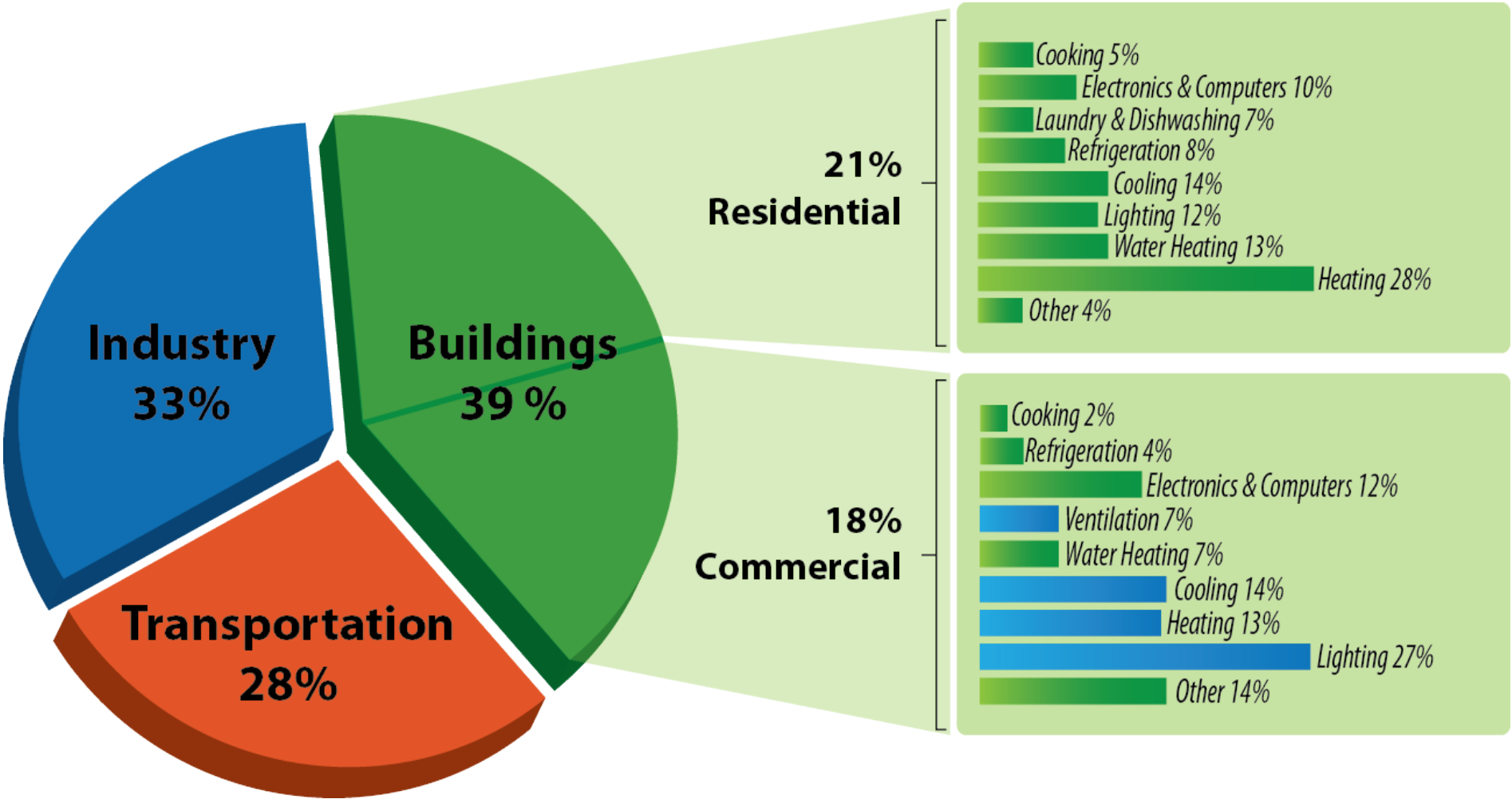
Design Requirements

- 25 kBtu/ft^2/yr for standard office space occupant density and data center loads
- Normalized up to 35.1 kBtu/ft^2/yr for better space efficiency and to account for full data center load



CBECS – Commercial Buildings Energy Consumption Survey
HPB – High Performance Building
EPA – Environmental Protection Agency

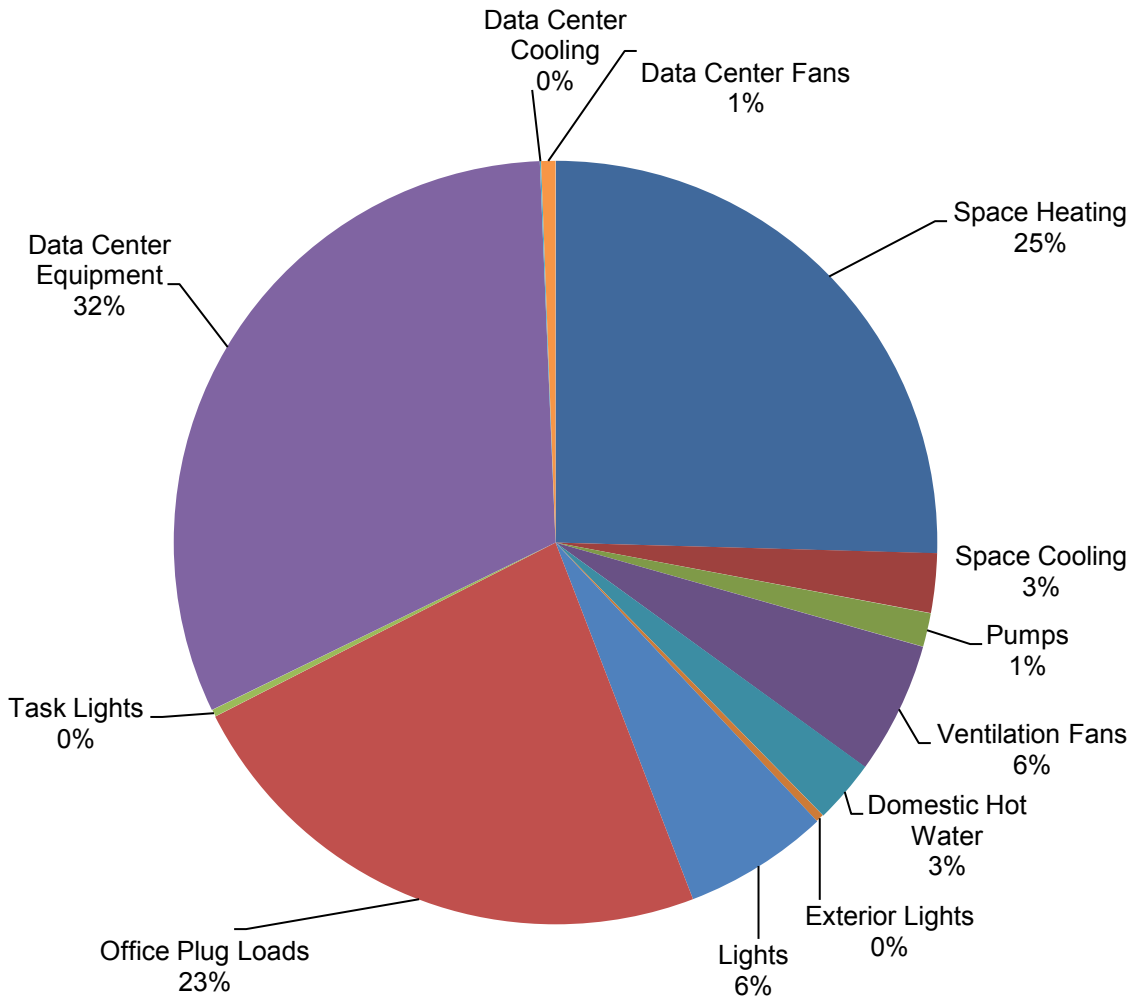
Energy Consumption in the United States

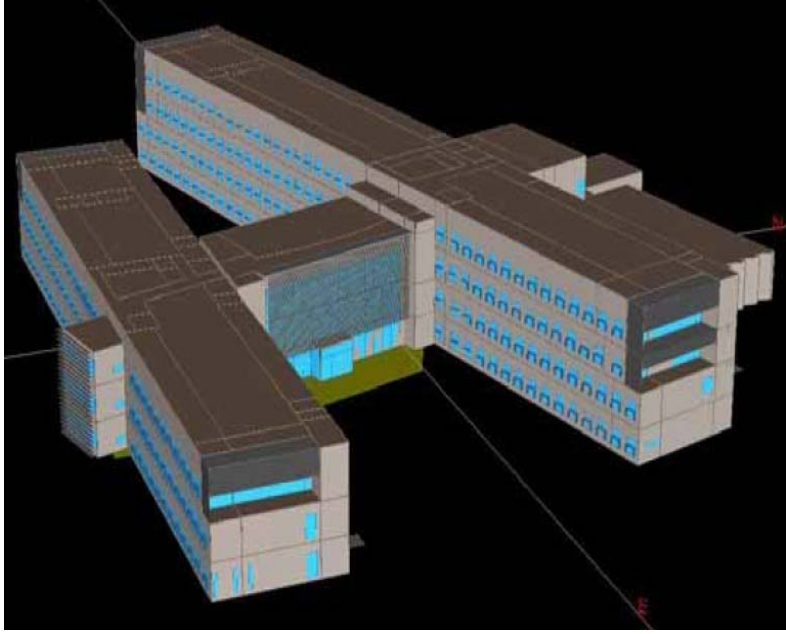


Source: U.S. Department of Energy, Buildings Energy Data Book, 2006

Energy Modeling

NREL RSF Energy Use Breakdown





End Use	kBtu/ft2
Space Heating	8.58
Space Cooling	0.85
Pumps	0.48
Ventilation Fans	1.88
Domestic Hot Water	0.90
Exterior Lights	0.12
Lights	2.07
Office Plug Loads	7.87
Task Lights	0.10
Data Center Equipment	10.65
Data Center Cooling	0.02
Data Center Fans	0.20

Key Design Strategies

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

Building Efficiency Features


Back to the Future
• Daylighting
• Thermal Mass
• Natural Ventilation

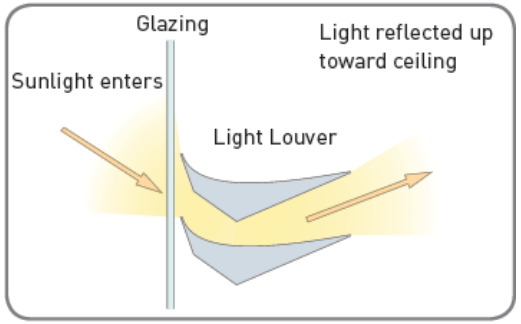
Daylighting

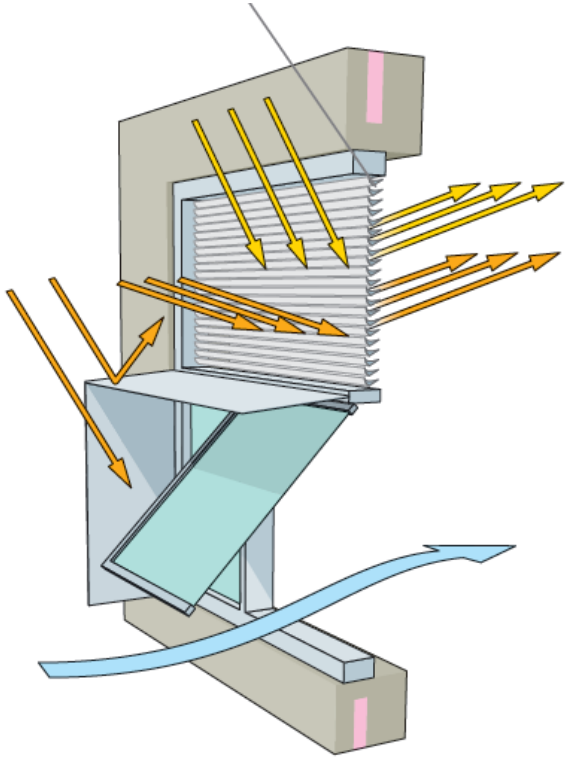
- Two long 60-foot wide wings with east-west orientation
- Design reduces electrical lighting

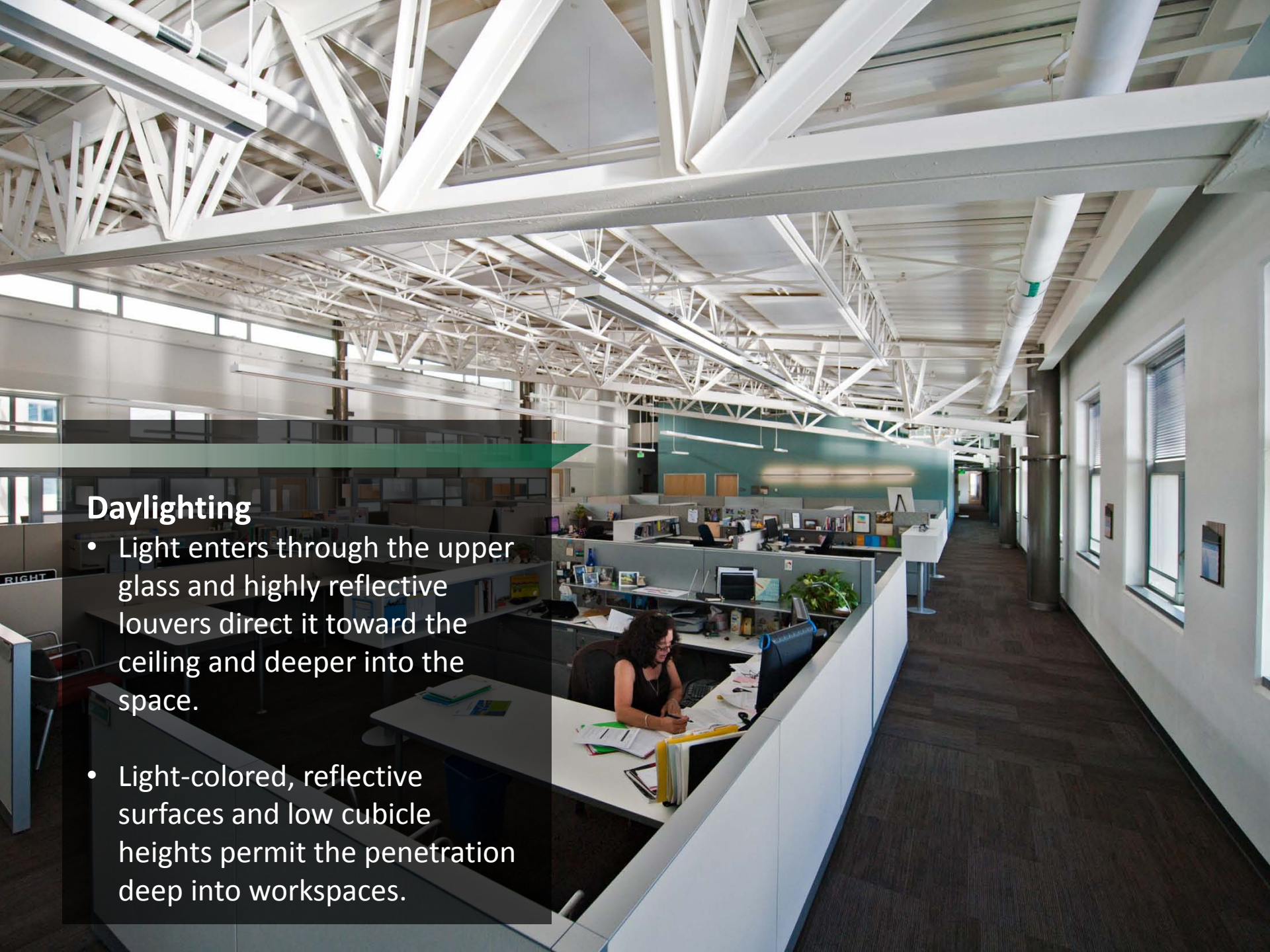
Daylighting: Light Louvers

A light louver daylighting system reflects sunlight to the ceiling, creating an indirect lighting effect.

Fixed sunshades limit excess light and glare.



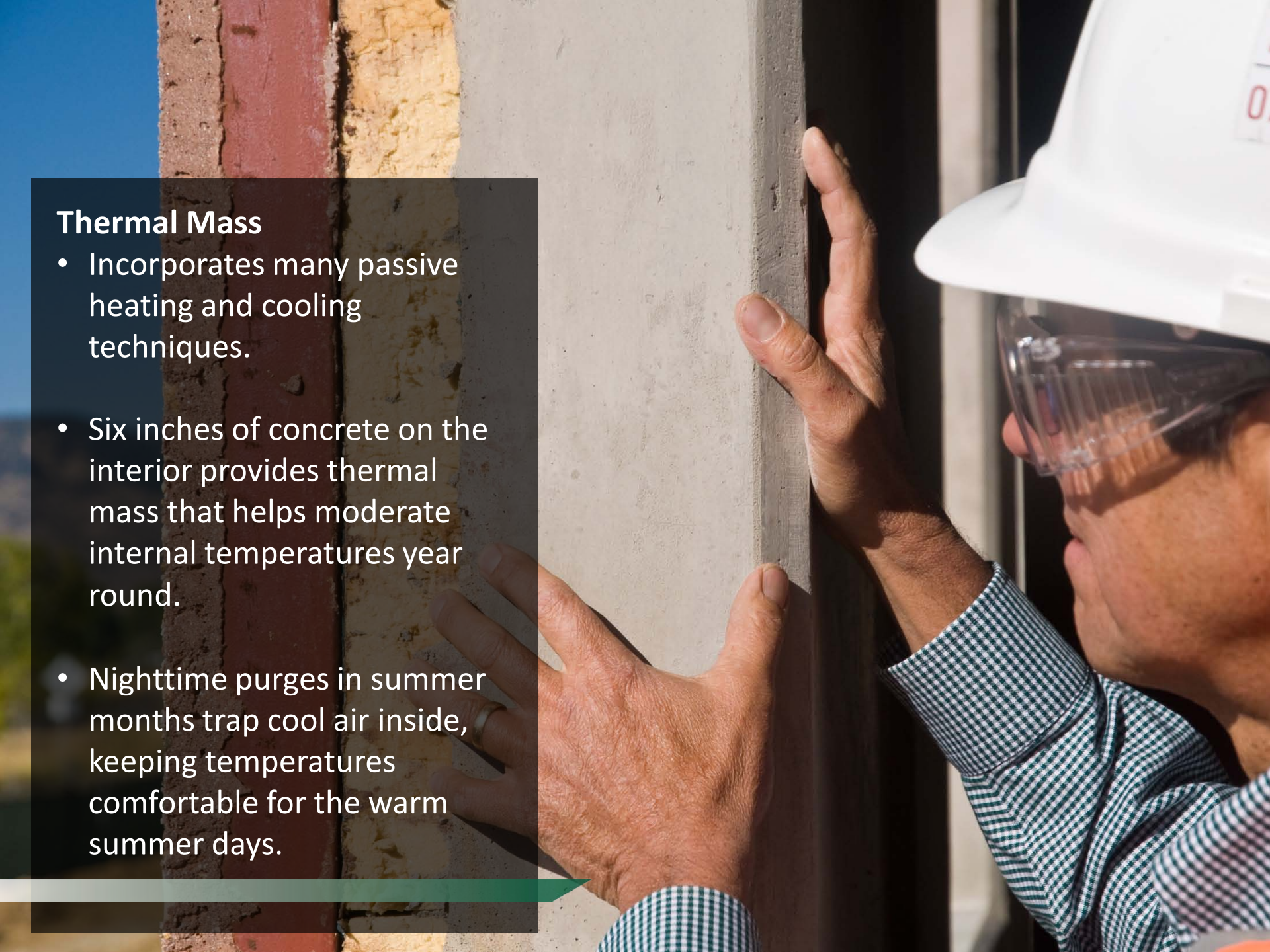




Daylighting

- Light enters through the upper glass and highly reflective louvers direct it toward the ceiling and deeper into the space.

- Light-colored, reflective surfaces and low cubicle heights permit the penetration deep into workspaces.



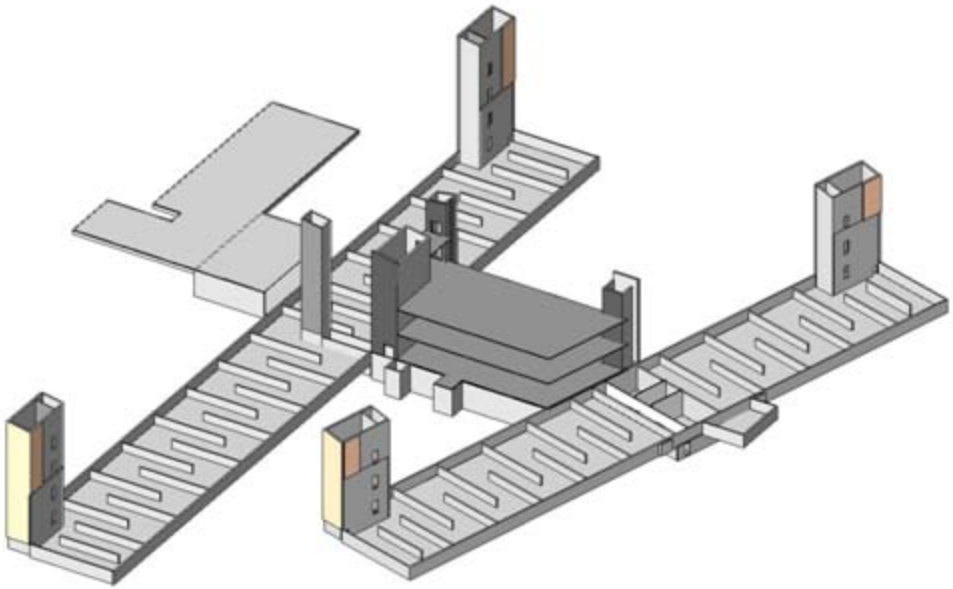
Thermal Mass

- Incorporates many passive heating and cooling techniques.
- Six inches of concrete on the interior provides thermal mass that helps moderate internal temperatures year round.
- Nighttime purges in summer months trap cool air inside, keeping temperatures comfortable for the warm summer days.

Labyrinth

Labyrinth Thermal Storage

- Massive, staggered concrete structures in the basement crawl space stores thermal energy to provide passive heating and cooling of the building.



Natural Ventilation

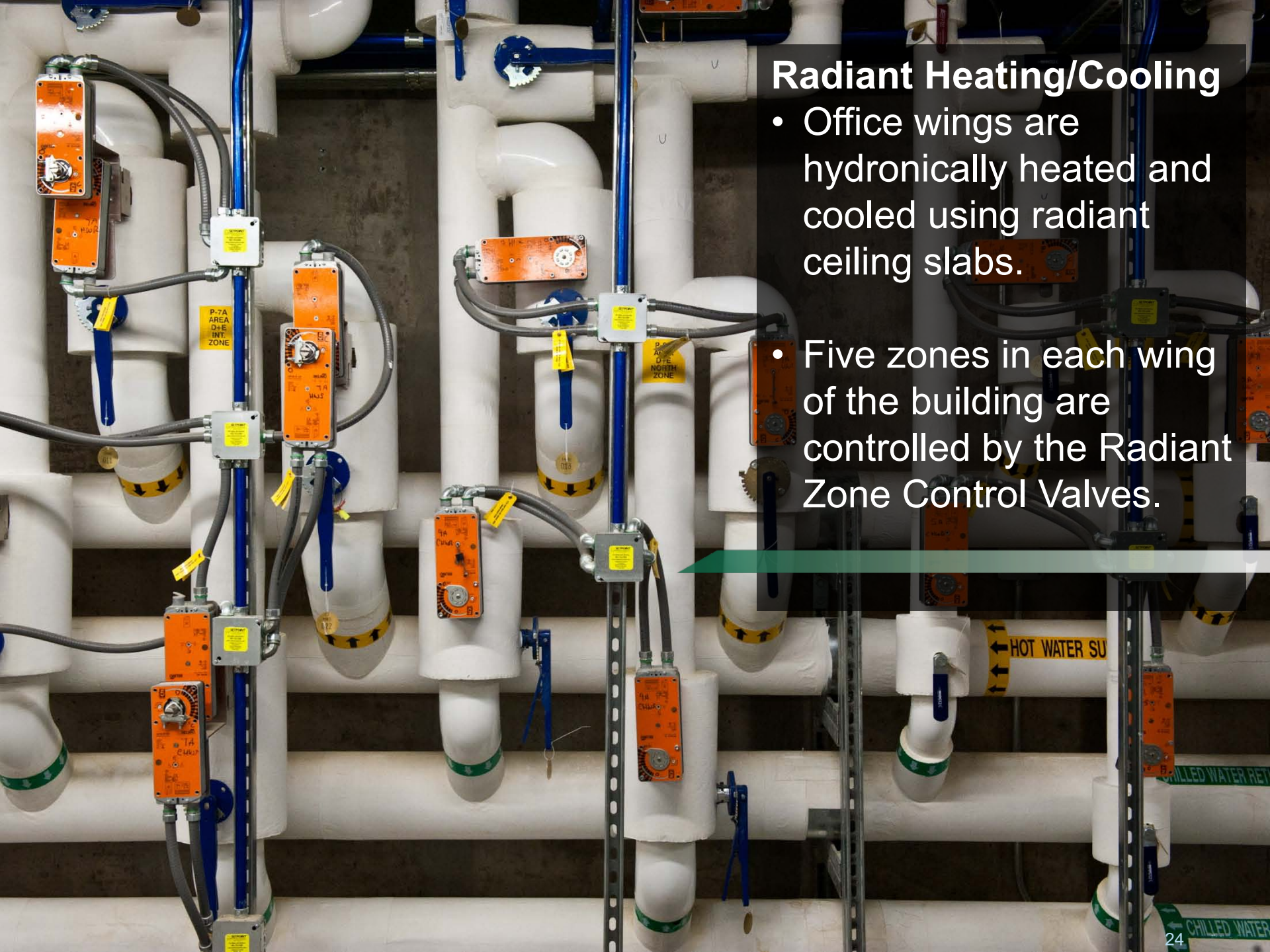
- During mild weather, operable windows allow for natural ventilation.
- Automatic windows are controlled and operated primarily to support nighttime precooling.
- Occupants are notified when conditions allow for manual windows to be opened.


Triple-glazed windows with individual overhangs maximize daylighting and minimize glare, as well as heat loss and gain.

Window Technologies

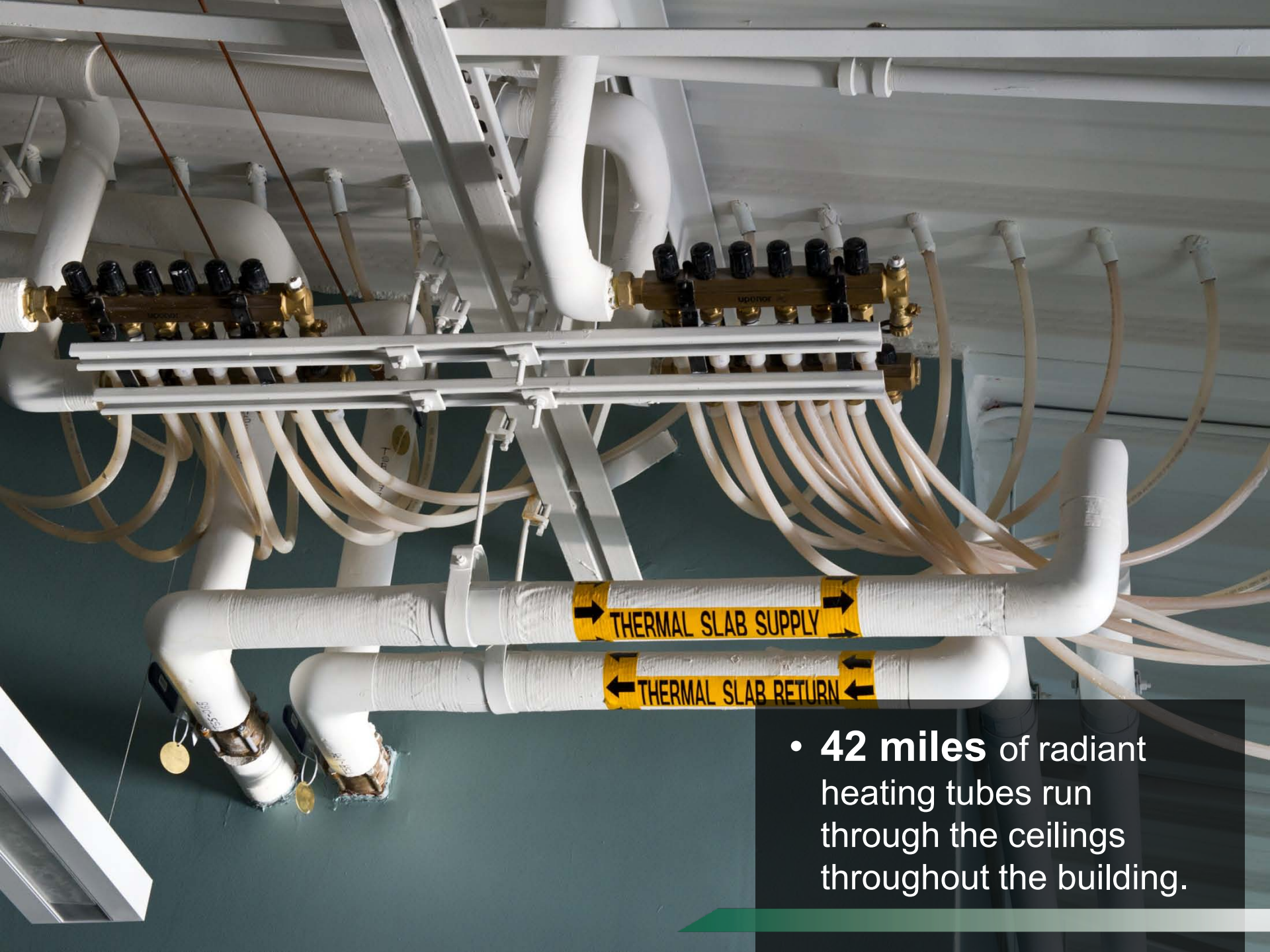
The west elevation windows feature NREL-developed **electrochromic technology** in which the windows tint in response to a small electric current, reducing heat gain in the afternoon hours.

Thermochromic windows on the eastern balcony windows react to temperature change and have glass resistant to heat transfer.



Radiant Heating/Cooling

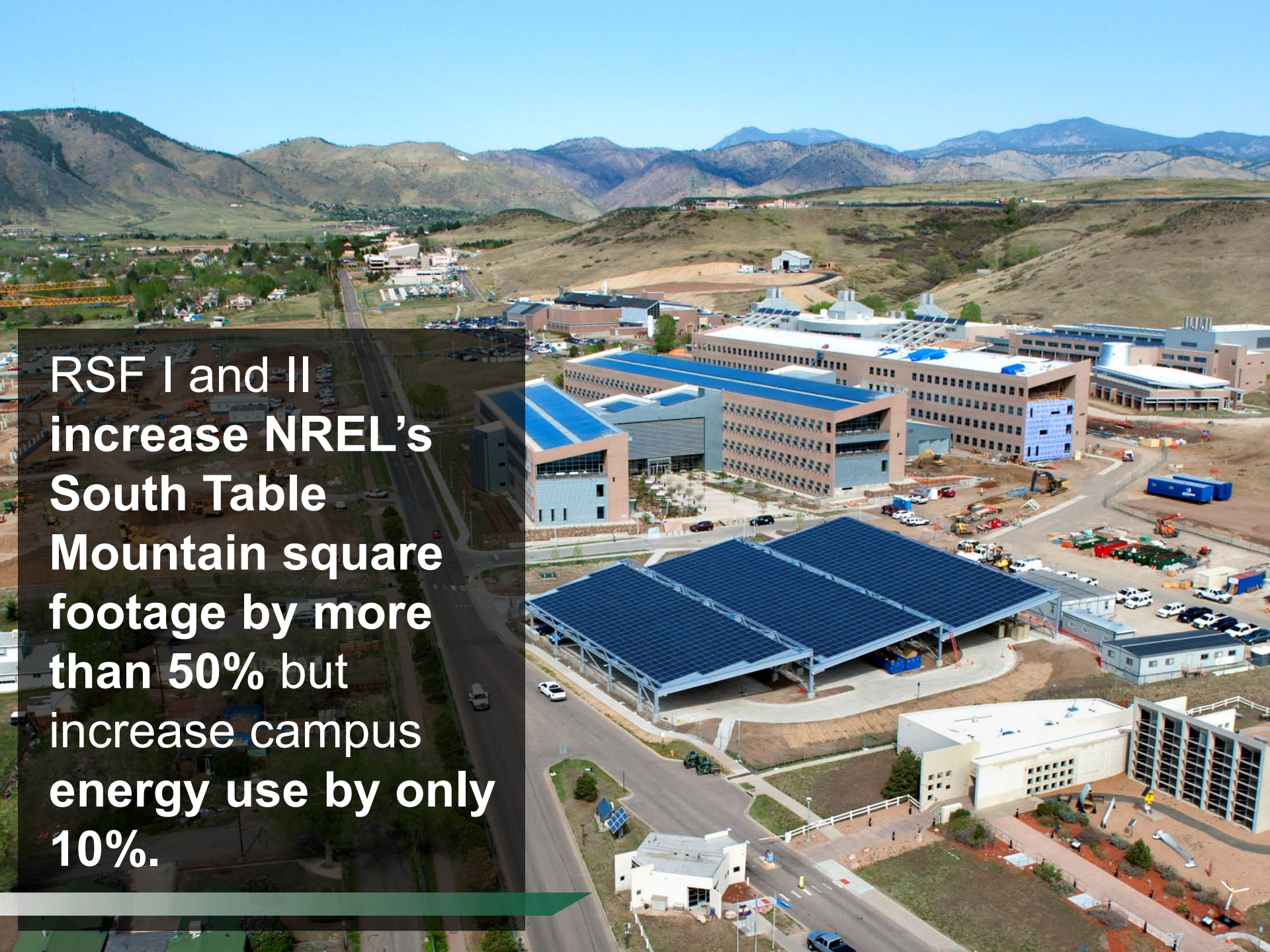
- Office wings are hydronically heated and cooled using radiant ceiling slabs.
- Five zones in each wing of the building are controlled by the Radiant Zone Control Valves.



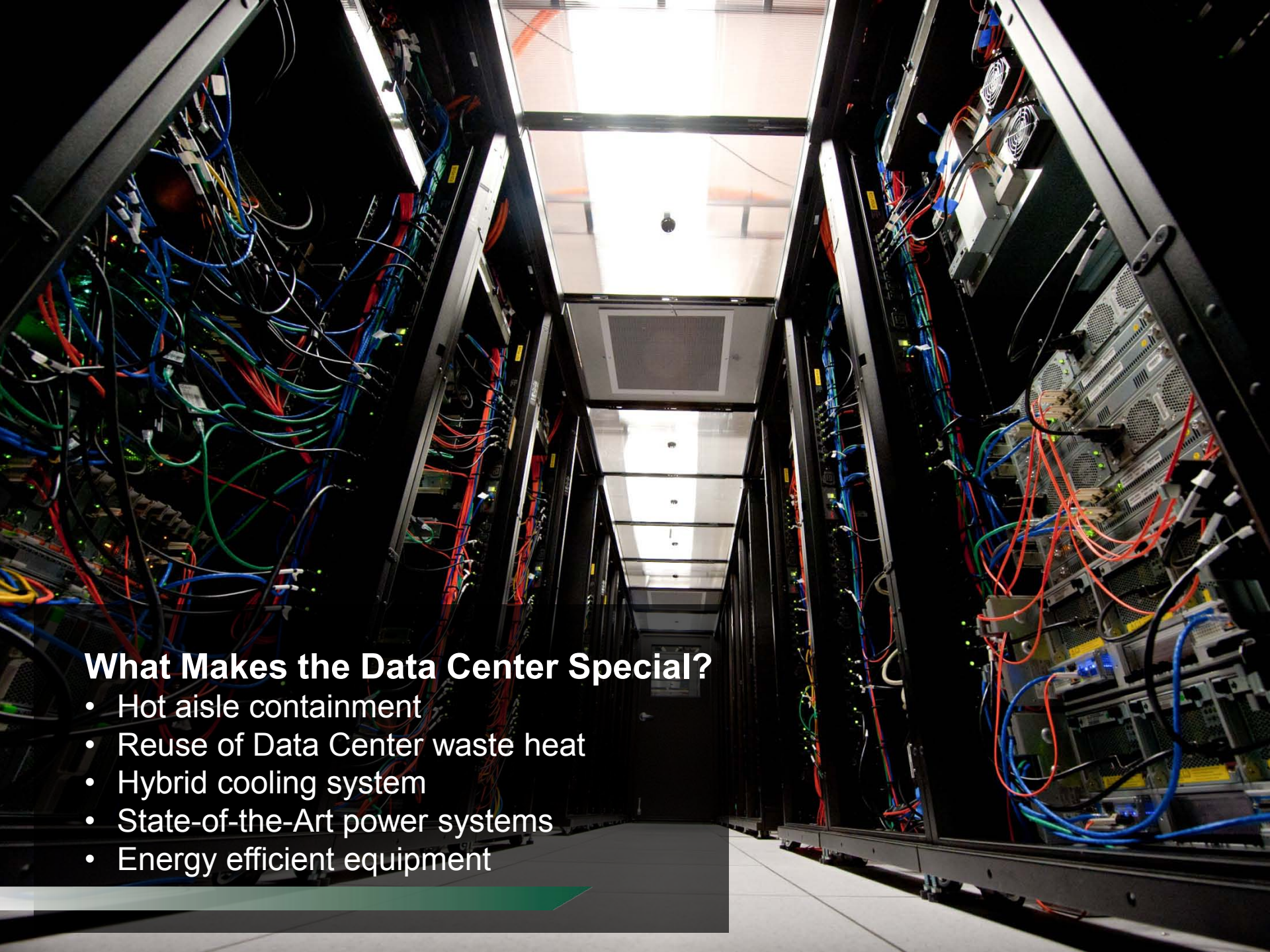
- **42 miles** of radiant heating tubes run through the ceilings throughout the building.

Ventilation system

- Ventilation air is distributed by an under-floor air distribution system
- Carbon dioxide sensors respond to occupancy and control ventilation when needed
- Evaporative coolers provide cool ventilation air when needed
- Sensible heat recovery system captures either warm or cool air from the exhaust air system to precondition the outdoor air

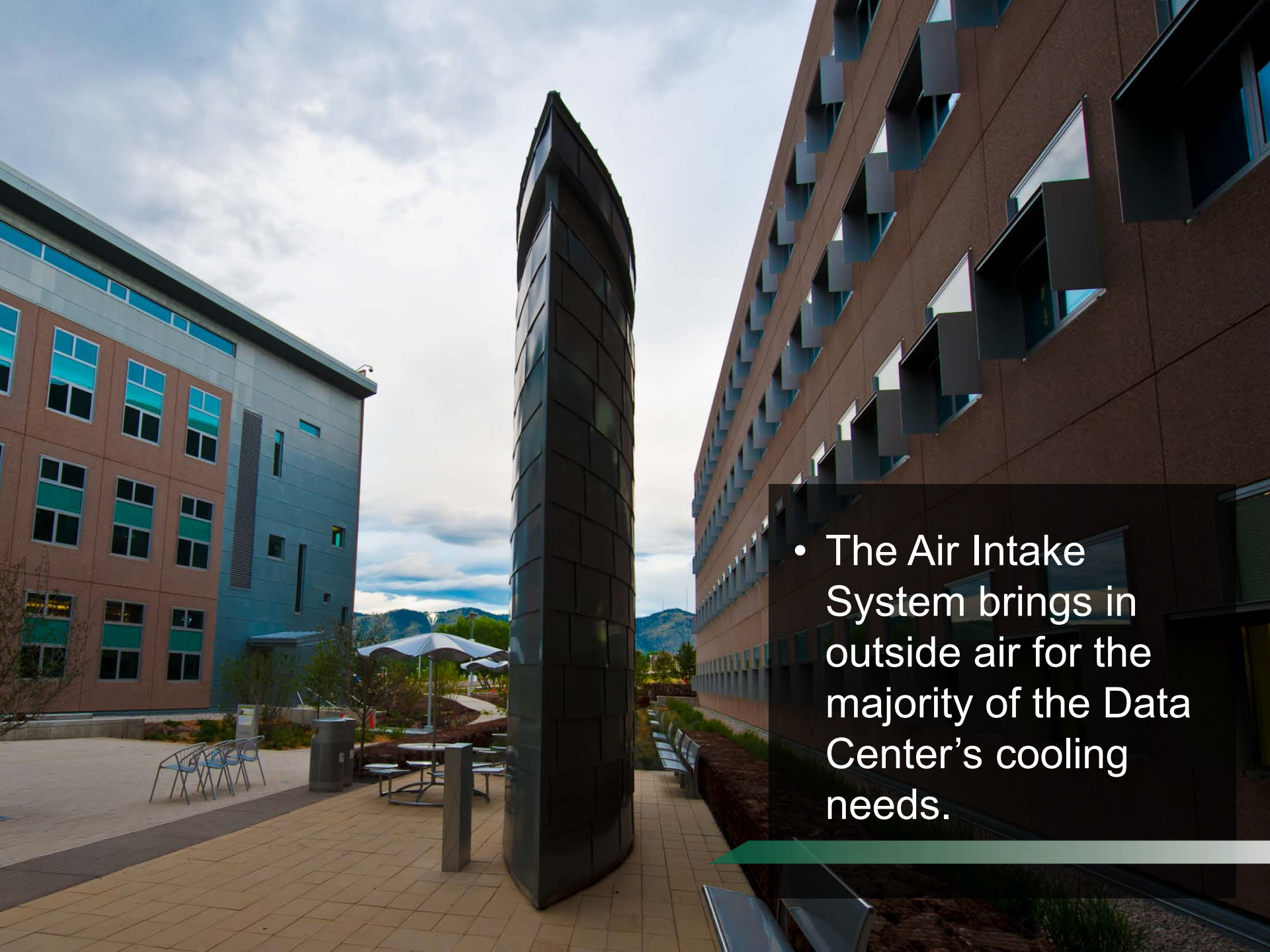

RSF I and II **increase NREL's South Table Mountain square footage by more than 50%** but increase campus **energy use by only 10%.**

Green Data Center



What Makes the Data Center Special?

- Hot aisle containment
- Reuse of Data Center waste heat
- Hybrid cooling system
- State-of-the-Art power systems
- Energy efficient equipment

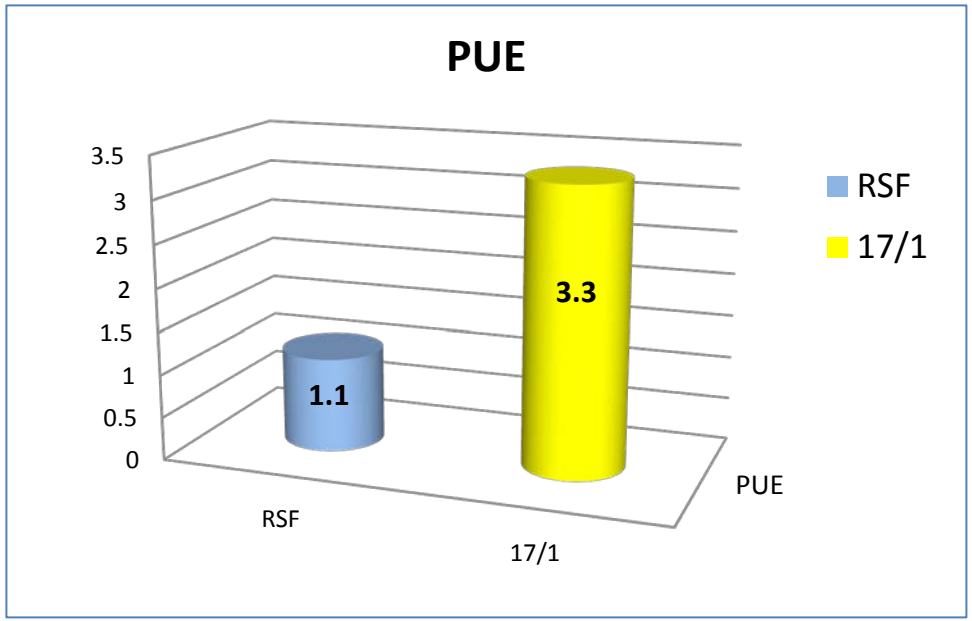


- The Air Intake System brings in outside air for the majority of the Data Center’s cooling needs.

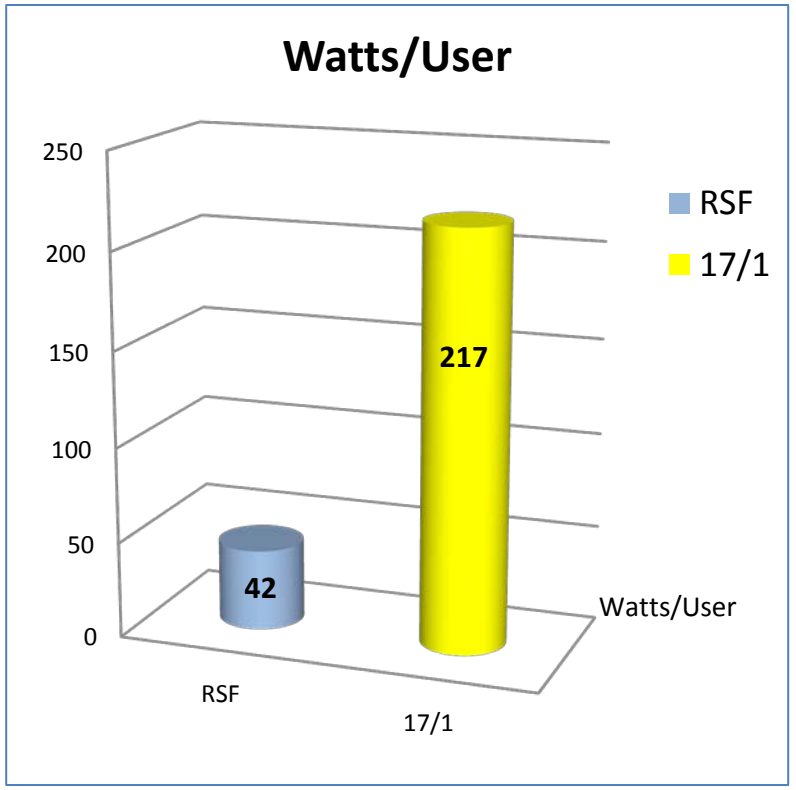
Comparison of NREL Data Centers

$$PUE = \frac{\text{Cooling + Power + Equipment}}{\text{Equipment}}$$

Power Usage Effectiveness

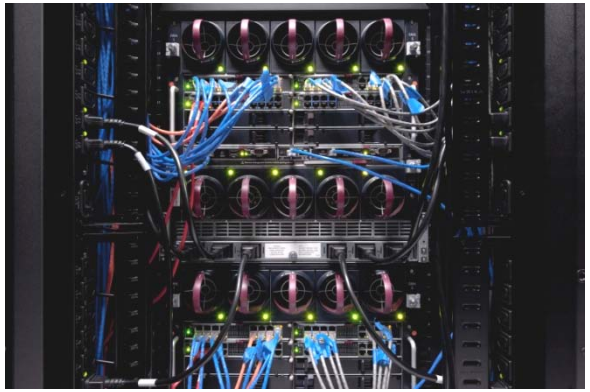


Watts Per User



Results: 81% Reduction in Power Requirements

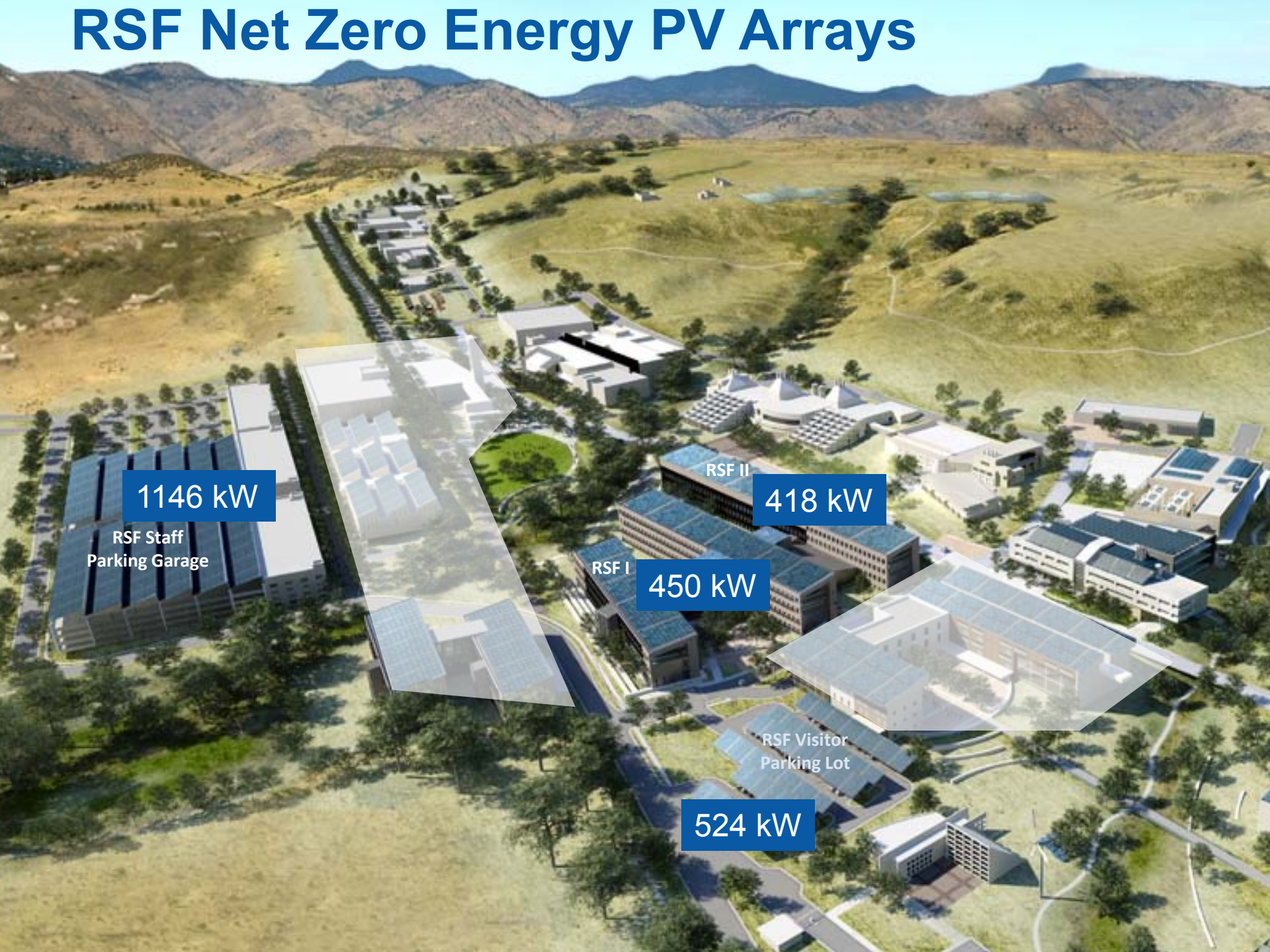
Data Center	Watts/ User	kW/ User/Yr	# Users	Data Center kW/Yr	CO_2 Emissions (in pounds)	Electricity $$
17/1	217	1,901	2,100	3,991,932	5,987,898	$ 399,193
RSF	42	368	2,100	772,632	1,158,948	$ 77,263
Diff	(175)	(1,533)		(3,219,300)	(4,828,950)	$ (321,930)



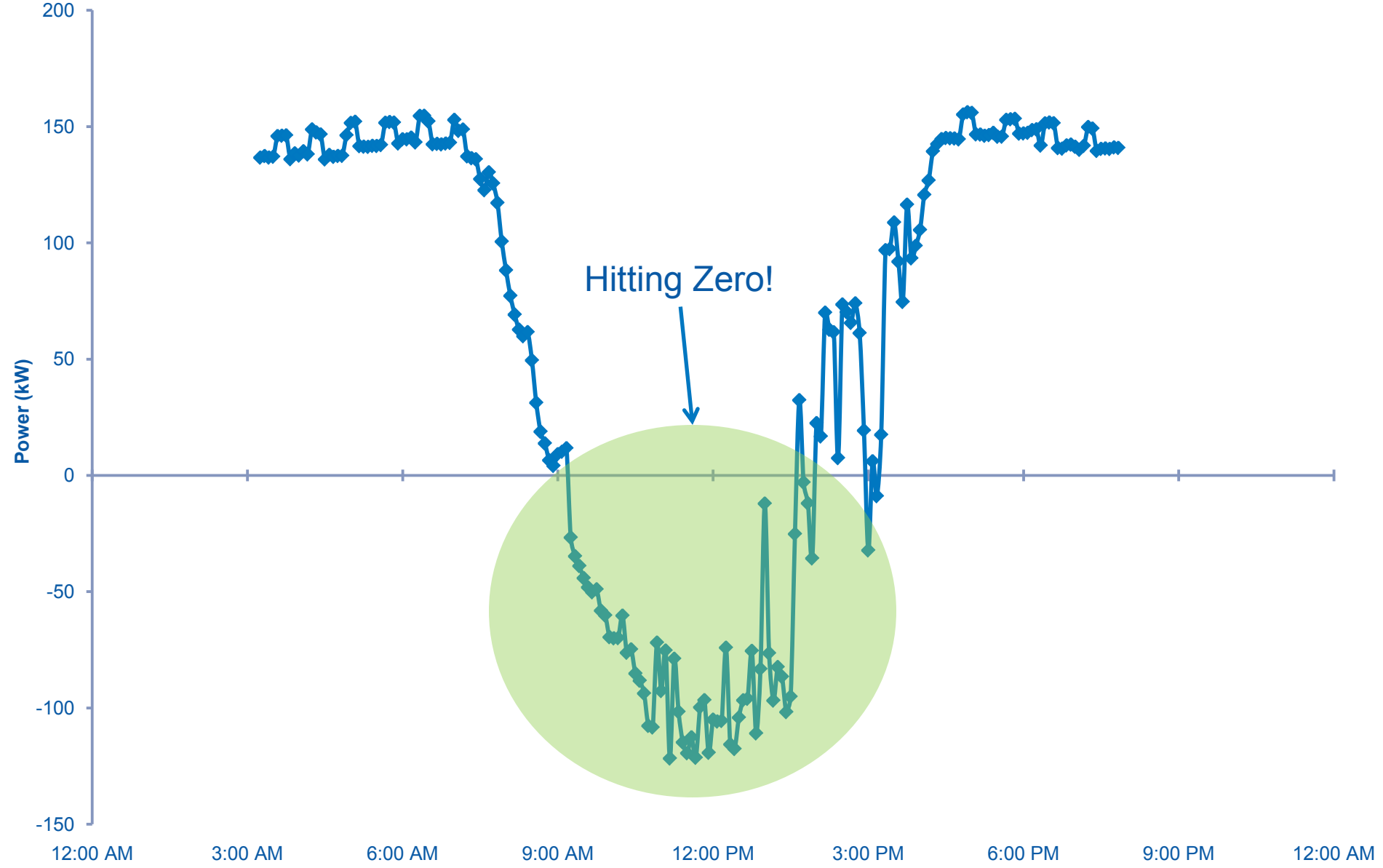
RSF Power Generation

NREL Campus

RSF Net Zero Energy PV Arrays



450-kW Roof-Mounted PV Installed and Operational December 2010




Even with high-performance, innovative building features, **we have found that 30% of building performance** is related to occupant behavior.

Energy efficient workspace….requires new occupant behavior

Workstation load – 70W;
300W continuous power draw per person (entire building)

LED task lights
6 Watts

Fluorescent task lights 35 Watts

24” LCD Energy Efficient Monitors
18 Watts

Typical 19”-24” Monitors
30-50 Watts

iGo Power Smart Towers

Reduces “vampire” energy use

VOIP phones 2 Watts

Removing personal space heater saves 1500 Watts

Laptop
30 Watts

Desktop Computer (Energy Star)
300 Watts

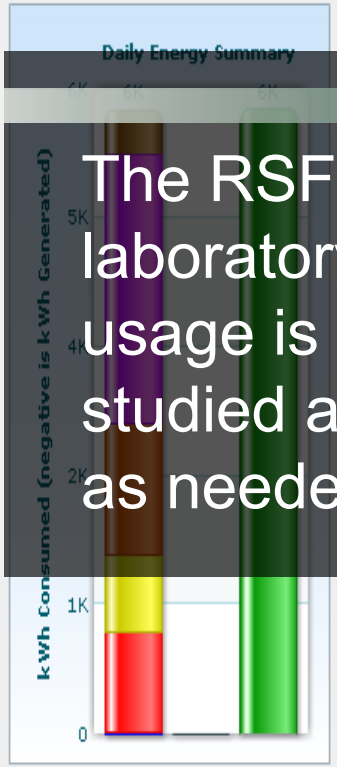
Multi-function Devices
100 Watts (continuous)

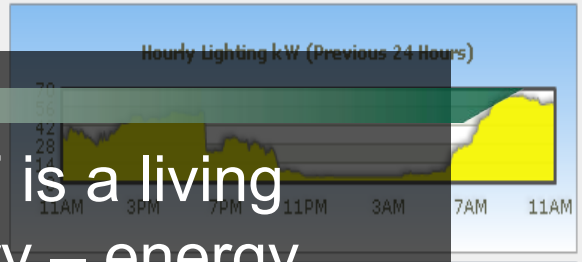
Removing desktop printers saves ~460 Watts/Printer

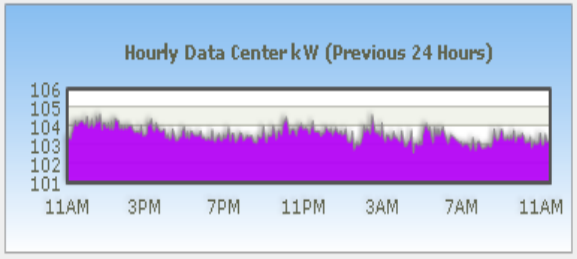
NREL
NATIONAL RENEWABLE ENERGY LABORATORY

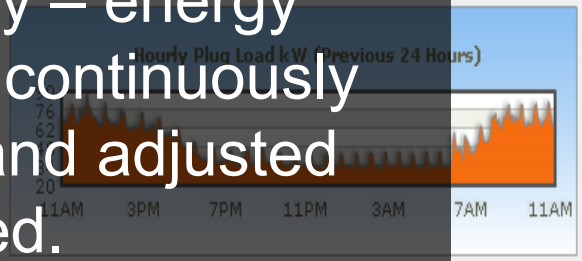
RSF Energy Monitoring

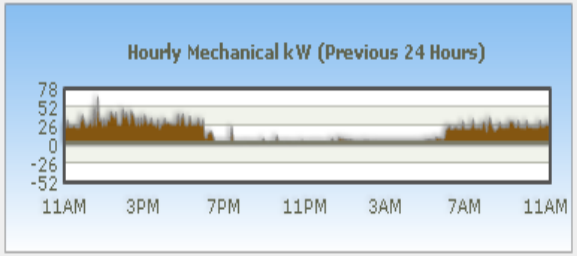
The RSF is a living laboratory – energy usage is continuously studied and adjusted as needed.

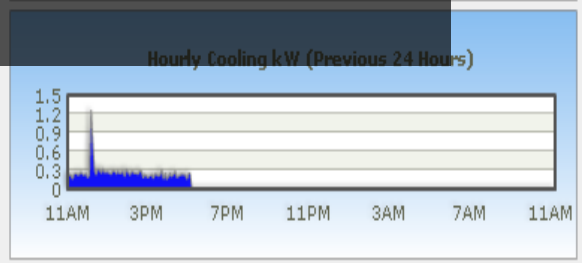


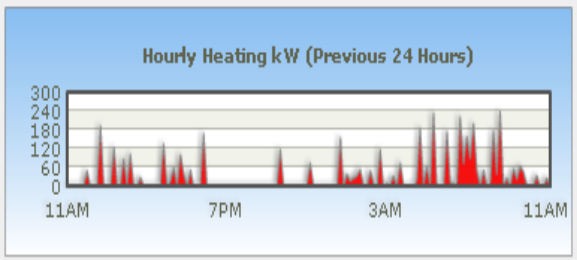


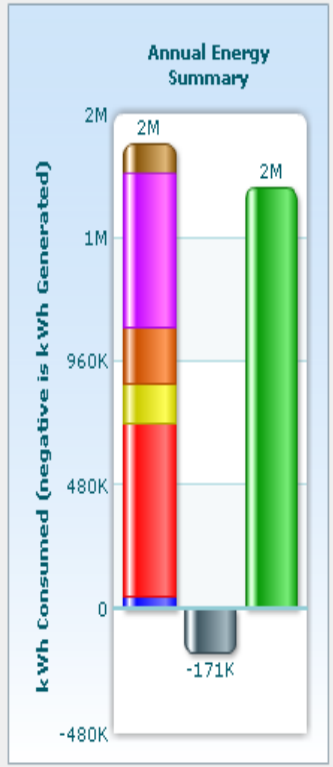


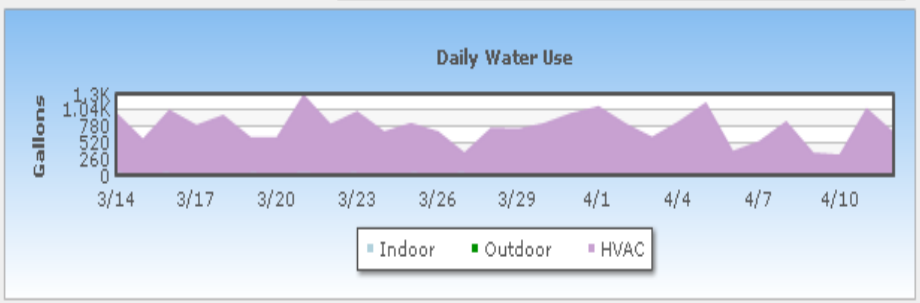


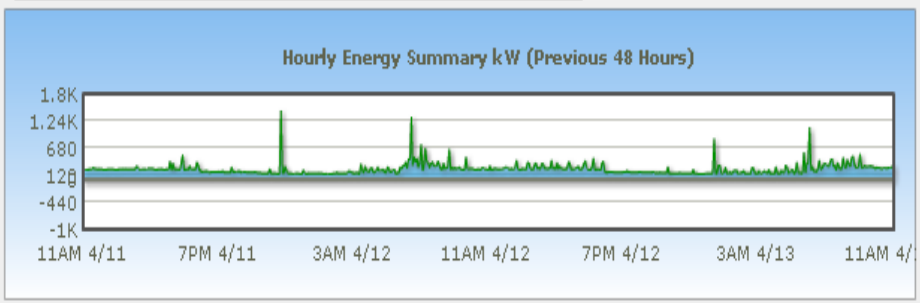












Global Energy Legend

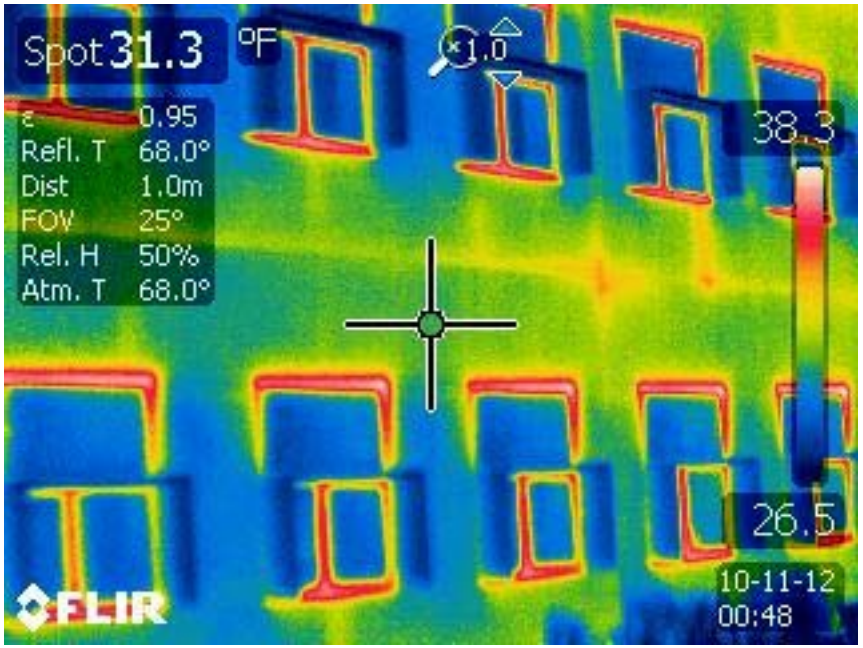
- Lighting
- Mechanical
- Total Building Load
- Data Center
- Cooling
- PV Production
- Plug Loads
- Heating
- Net Energy Use

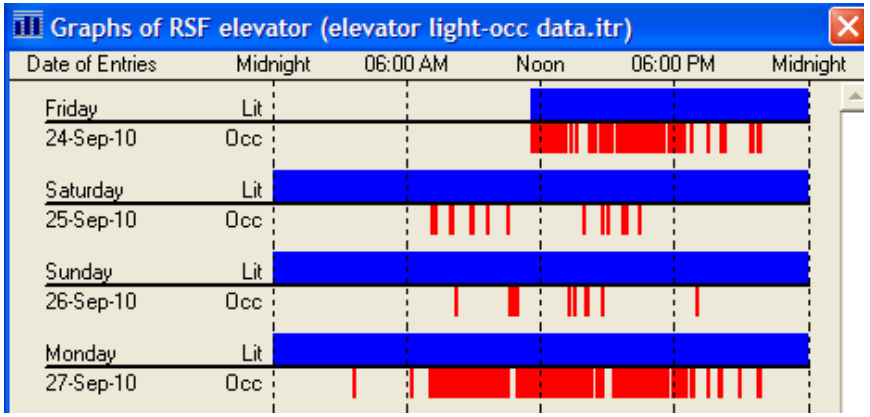
Outside Temperature: 48.7 °F
Outside Relative Humidity: 51.8 %RH
Wind Speed: 0.1 mph
Wind Direction: SE

Energy Usage and Data

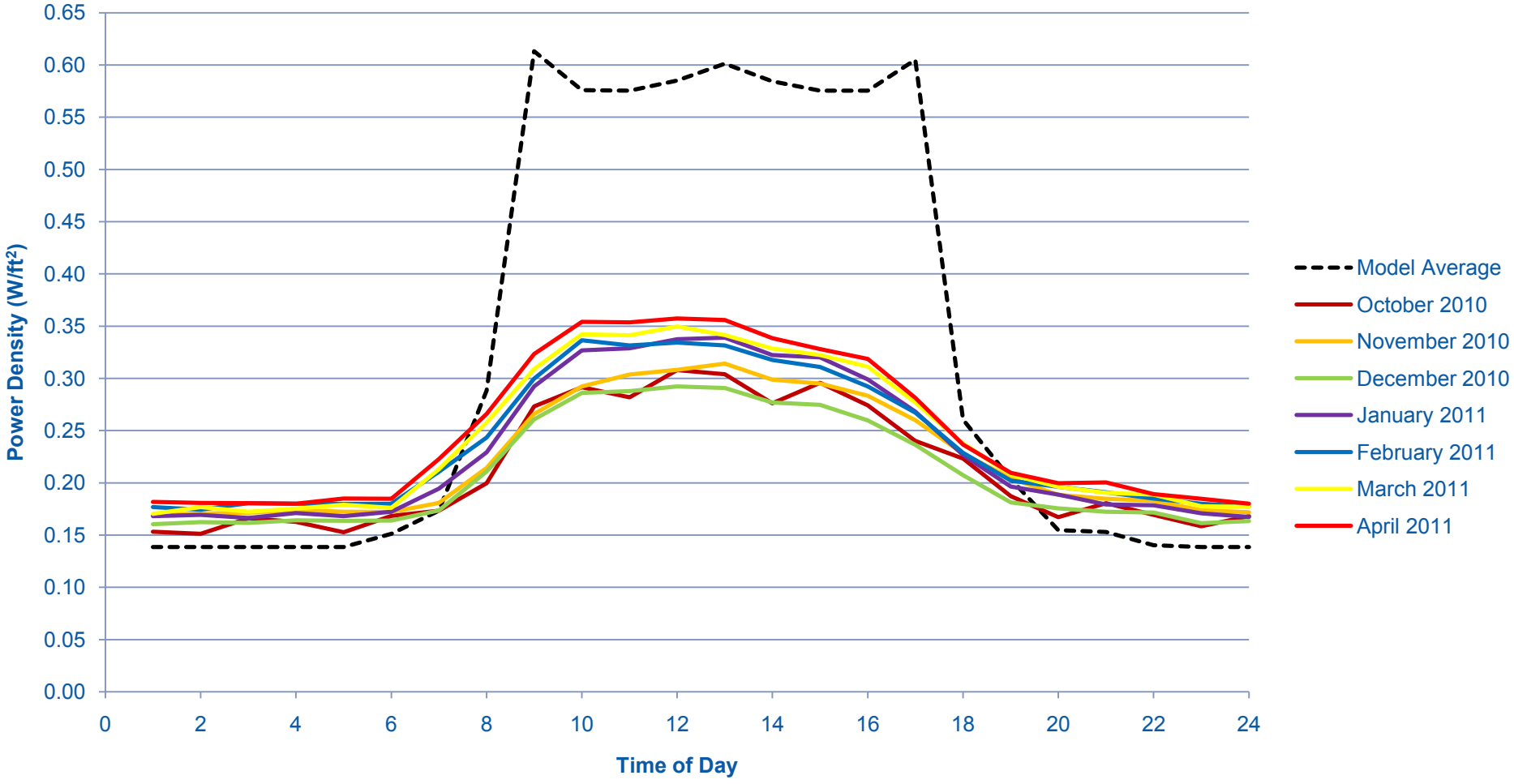
What are we monitoring?

- Everything!
  - Lighting
  - Heating
  - Cooling
  - Plug Loads
  - Data Center
  - Daylighting
  - Mechanical System Power Density
  - Outdoor Air Temperature
  - Monthly End Use Energy Consumption
  - Elevator Lighting
  - PV Output





RSF Weekday Plug Load Power Density



RSF II

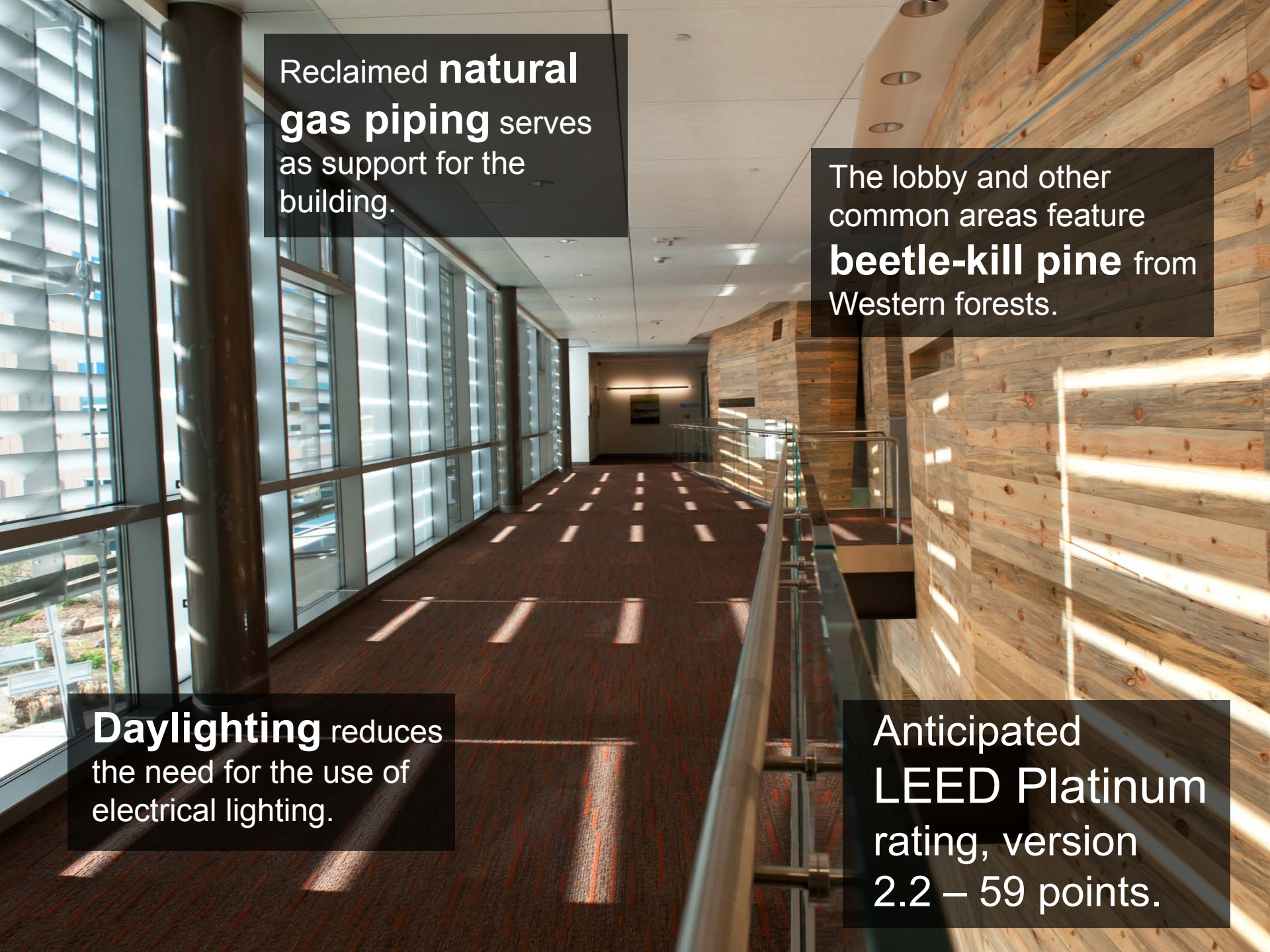
RSF II

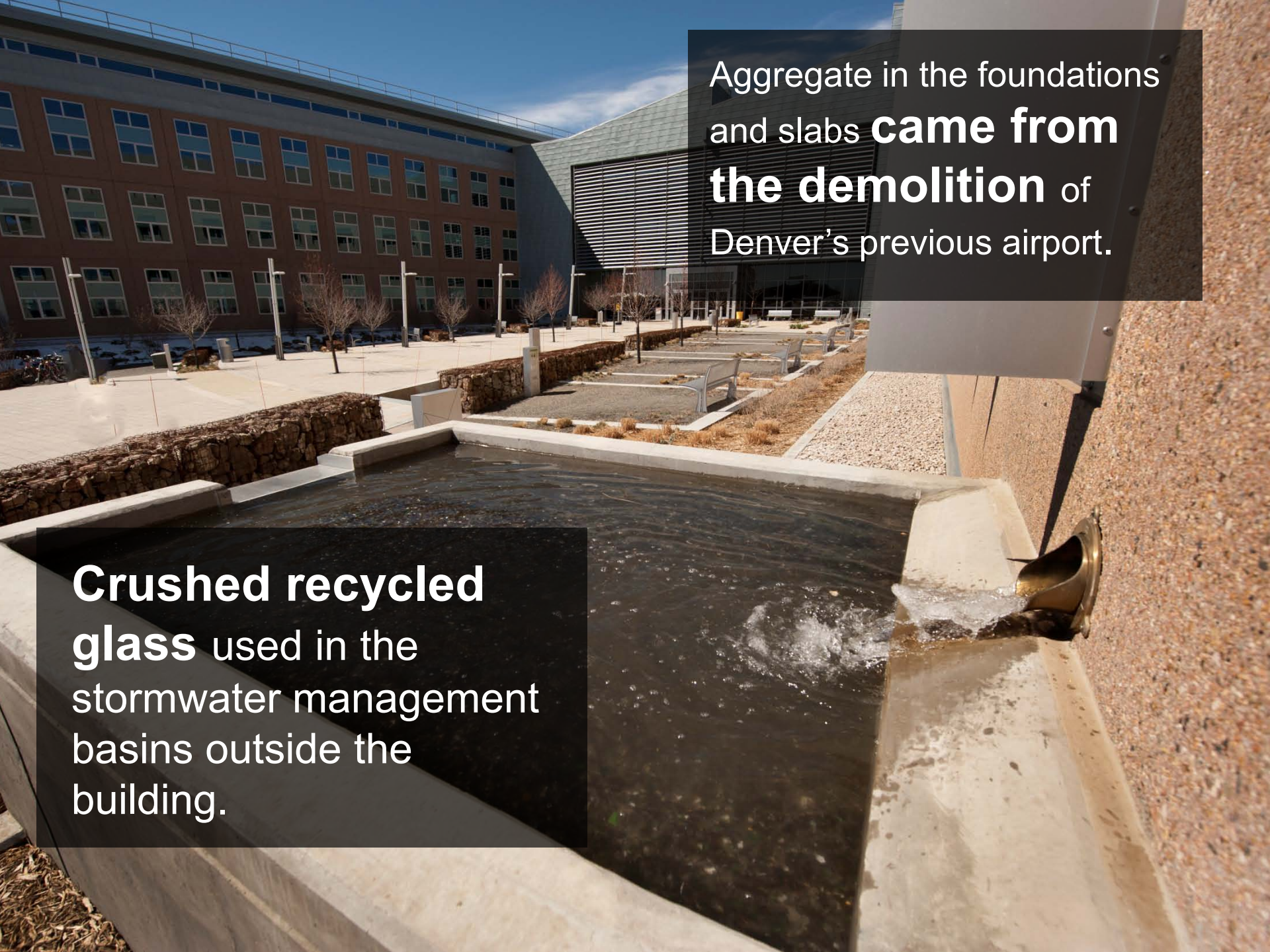
- 138,000 sq. ft.
- 525 occupants
- $39 million expansion
- Building 17% more efficient than the RSF
- Cost savings of 5%
- Completion scheduled for end of 2011

Small Improvements, Big Difference

- More efficient solar panels were purchased at a lower cost
- Less window area, while still fully daylighting office spaces
- Larger transpired collector, creating more "free" warmed air
- Better thermal breaks in the window frames, leveraging the latest in commercial windows and aluminum frames, driving down energy consumption and increasing comfort
- Displacement ventilation in conference rooms, improving thermal comfort
- Natural passive cooling in stair wells vs. mechanical ventilation in the RSF
- Daylighting controls in day-lit stairwells, allowing enhanced energy savings during the day

Sustainability and Recognition


Reclaimed **natural gas piping** serves as support for the building.
The lobby and other common areas feature **beetle-kill pine** from Western forests.
Daylighting reduces the need for the use of electrical lighting.
Anticipated LEED Platinum rating, version 2.2 – 59 points.


Aggregate in the foundations and slabs **came from the demolition** of Denver's previous airport.
Crushed recycled glass used in the stormwater management basins outside the building.

National Media and Recognition

- Major national news stories about the RSF
  - Popular Science Online (7/6/11)
  - New York Times Online (2/14/11), New York Times Online (2/15/11)
  - Associated Press Wire Story (2/23/11)
  - Wall Street Journal (2/28/11)
- Total award count – 20
  - Engineering News Record (ENR)
    - 2011 Award of Excellence
    - 2010 Newsmaker Award
  - McGraw-Hill Construction, Outstanding Green Building, 2010
  - American Institute of Architects (AIA), Top Ten Green Project

THE NEW YORK TIMES, TUESDAY, FEBRUARY 15, 2011

Soaking Up the Sun to Squeeze the Bills to Zero

From First Science Page

Office Efficiency

How Did We Do?

How Did We Do?

What We Wanted

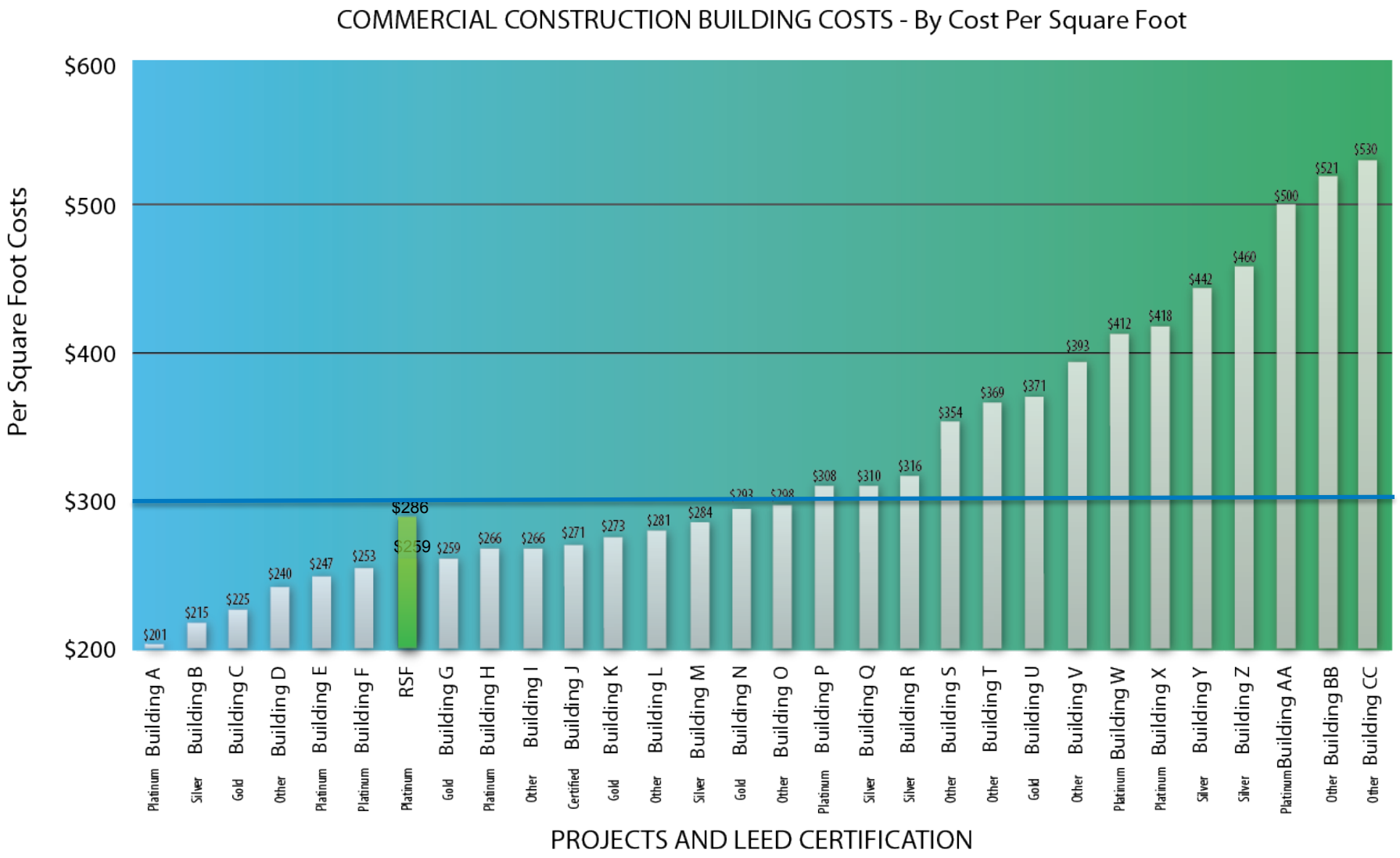
- 800 employees
- LEED Platinum
- 50% better than ASHRAE 90.1-2004
- Net zero energy goal
- Replicable whole building design process
- Competitive cost for Class A space
- As many Mission, Desirable, and If Possible goals as achievable

What We Got

- 825 employees
- LEED Platinum (59 Points)
- 50% better than ASHRAE 90.1-2007
- Net zero site energy using photovoltaics
- Documented design process
- 220K gsf @ $259/gsf of Class A space
- Every Mission Critical, Highly Desirable, and If Possible performance goal achieved

Building completed 130 days early

Construction Costs



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