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
  o Design charrettes
  o Design Build Institute of America
  o Owner’s representatives
• Design challenge
  o Suite of performance goals to challenge team
  o 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/ft²/yr for standard office space occupant density and data center loads
- Normalized up to 35.1 kBtu/ft²/yr for better space efficiency and to account for full data center load

**Diagram:**
- Categories: Typical Large Office Building (ENERGY STAR 50), CBEC Large Office, ENERGY STAR 75 Rated Building, HPB Database LEED Building Average, EPA Region 8 Office, Denver, CO, ENERGY STAR 90 Rated Building, RSF without Renewables, RSF Renewable Production
- Legend:
  - Green: On Site PV
  - Blue: EUI (Energy Use Intensity)

**Abbreviations:**
- CBECS – Commercial Buildings Energy Consumption Survey
- HPB – High Performance Building
- EPA – Environmental Protection Agency
Energy Consumption in the United States

- **Industry**: 33%
- **Buildings**: 39%
- **Transportation**: 28%

**Residential**: 21%
- Cooking 5%
- Electronics & Computers 10%
- Laundry & Dishwashing 7%
- Refrigeration 8%
- Cooling 14%
- Lighting 12%
- Water Heating 13%
- Other 4%
- Heating 28%

**Commercial**: 18%
- Cooking 2%
- Refrigeration 4%
- Electronics & Computers 12%
- Ventilation 7%
- Water Heating 7%
- Cooling 14%
- Heating 13%
- Lighting 27%
- Other 14%

Energy Modeling

NREL RSF Energy Use Breakdown

End Use

<table>
<thead>
<tr>
<th>End Use</th>
<th>kBtu/ft²</th>
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<tbody>
<tr>
<td>Space Heating</td>
<td>8.58</td>
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<tr>
<td>Space Cooling</td>
<td>0.85</td>
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<tr>
<td>Pumps</td>
<td>0.48</td>
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<tr>
<td>Ventilation Fans</td>
<td>1.88</td>
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<tr>
<td>Domestic Hot Water</td>
<td>0.90</td>
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<tr>
<td>Exterior Lights</td>
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<tr>
<td>Lights</td>
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<tr>
<td>Office Plug Loads</td>
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<tr>
<td>Task Lights</td>
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<tr>
<td>Data Center Equipment</td>
<td>10.65</td>
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<tr>
<td>Data Center Cooling</td>
<td>0.02</td>
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<tr>
<td>Data Center Fans</td>
<td>0.20</td>
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</table>
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 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

Power Usage Effectiveness

\[ \text{PUE} = \frac{\text{Cooling + Power + Equipment}}{\text{Equipment}} \]

Watts Per User

- RSF
- 17/1

- PUE
- Watts/User

- 1.1
- 3.3
- 42
- 217
### Results: 81% Reduction in Power Requirements

<table>
<thead>
<tr>
<th>Data Center</th>
<th>Watts/ User</th>
<th>kW/ User/Yr</th>
<th># Users</th>
<th>Data Center kW/Yr</th>
<th>CO₂ Emissions (in pounds)</th>
<th>Electricity $$</th>
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<tr>
<td>17/1</td>
<td>217</td>
<td>1,901</td>
<td>2,100</td>
<td>3,991,932</td>
<td>5,987,898</td>
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<td>RSF</td>
<td>42</td>
<td>368</td>
<td>2,100</td>
<td>772,632</td>
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<td>Diff</td>
<td>(175)</td>
<td>(1,533)</td>
<td></td>
<td>(3,219,300)</td>
<td>(4,828,950)</td>
<td>$(321,930)</td>
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RSF Power Generation
NREL Campus
RSF Net Zero Energy PV Arrays

- RSF Staff Parking Garage: 1146 kW
- RSF I: 450 kW
- RSF II: 418 kW
- RSF Visitor Parking Lot: 524 kW
450-kW Roof-Mounted PV Installed and Operational December 2010

Hitting Zero!
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

- Removing desktop printers saves ~460 Watts/Printer
- LED task lights 6 Watts
- Fluorescent task lights 35 Watts
- Desktop Computer (Energy Star) 300 Watts
- 24” LCD Energy Efficient Monitors 18 Watts
- Typical 19”-24” Monitors 30-50 Watts
- Laptop 30 Watts
- 24” LCD Energy Efficient Monitors 18 Watts
- 24” LCD Energy Efficient Monitors 18 Watts
- Workstation load – 70W; 300W continuous power draw per person (entire building)
- iGo Power Smart Towers Reduces “vampire” energy use
- VOIP phones 2 Watts
- Multi-function Devices 100 Watts (continuous)
- Removing personal space heater saves 1500 Watts
- Removing desktop printers saves ~460 Watts/Printer
- Energy efficient workspace….requires new occupant behavior
The RSF is a living laboratory – energy usage is continuously studied and adjusted as needed.
Energy Usage and Data

What are we monitoring?
• Everything!
  o Lighting
  o Heating
  o Cooling
  o Plug Loads
  o Data Center
  o Daylighting
  o Mechanical System Power Density
  o Outdoor Air Temperature
  o Monthly End Use Energy Consumption
  o Elevator Lighting
  o PV Output
RSF Weekday Plug Load Power Density

![Graph showing power density by time of day with different months and years represented with different colors.]

- Model Average
- October 2010
- November 2010
- December 2010
- January 2011
- February 2011
- March 2011
- April 2011

Power Density (W/ft²) vs. Time of Day
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
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