Vision
Research Support Facility Vision

• A showcase for sustainable, high-performance design
  o 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
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%
- Heating: 28%
- Other: 4%

**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 | 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

Cooling + Power + Equipment

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

Power Usage Effectiveness

Watts Per User

<table>
<thead>
<tr>
<th>PUE</th>
<th>Watts/User</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1 (RSF)</td>
<td>42</td>
</tr>
<tr>
<td>3.3 (17/1)</td>
<td>217</td>
</tr>
</tbody>
</table>

Watts Per User Chart:

- RSF: 42 Watts/User
- 17/1: 217 Watts/User
### 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>
</tr>
</thead>
<tbody>
<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>
<td>$399,193</td>
</tr>
<tr>
<td>RSF</td>
<td>42</td>
<td>368</td>
<td>2,100</td>
<td>772,632</td>
<td>1,158,948</td>
<td>$77,263</td>
</tr>
<tr>
<td>Diff</td>
<td>(175)</td>
<td>(1,533)</td>
<td></td>
<td>(3,219,300)</td>
<td>(4,828,950)</td>
<td>$(321,930)</td>
</tr>
</tbody>
</table>
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
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

<table>
<thead>
<tr>
<th>Equipment</th>
<th>Watts</th>
</tr>
</thead>
<tbody>
<tr>
<td>24” LCD Energy Efficient Monitors</td>
<td>18 Watts</td>
</tr>
<tr>
<td>Typical 19”-24” Monitors</td>
<td>30-50 Watts</td>
</tr>
<tr>
<td>Laptop</td>
<td>30 Watts</td>
</tr>
<tr>
<td>Desktop Computer (Energy Star)</td>
<td>300 Watts</td>
</tr>
<tr>
<td>LED task lights</td>
<td>6 Watts</td>
</tr>
<tr>
<td>Fluorescent task lights</td>
<td>35 Watts</td>
</tr>
<tr>
<td>iGo Power Smart Towers</td>
<td></td>
</tr>
<tr>
<td>VOIP phones</td>
<td>2 Watts</td>
</tr>
<tr>
<td>Workstation load</td>
<td>70W; 300W continuous power draw per person (entire building)</td>
</tr>
<tr>
<td>Removing personal space heater</td>
<td>saves 1500 Watts</td>
</tr>
<tr>
<td>Multi-function Devices</td>
<td>100 Watts (continuous)</td>
</tr>
<tr>
<td>Removing desktop printers saves</td>
<td>~460 Watts/Printer</td>
</tr>
</tbody>
</table>
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 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
  o Popular Science Online (7/6/11)
  o New York Times Online (2/14/11), New York Times Online (2/15/11)
  o Associated Press Wire Story (2/23/11)
  o Wall Street Journal (2/28/11)

• Total award count – 20
  o Engineering News Record (ENR)
    – 2011 Award of Excellence
    – 2010 Newsmaker Award
  o McGraw-Hill Construction, Outstanding Green Building, 2010
  o 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
Construction Costs

COMMERCIAL CONSTRUCTION BUILDING COSTS - By Cost Per Square Foot

Per Square Foot Costs

- $600
- $500
- $400
- $300
- $200

Projects and LEED Certification

- Platinum Building A
- Silver Building B
- Gold Building C
- Other Building D
- Platinum Building E
- Platinum Building F
- RSF
- Gold Building G
- Platinum Building H
- Other Building I
- Building J
- Building K
- Building L
- Building M
- Building N
- Building O
- Building P
- Building Q
- Building R
- Other Building S
- Building T
- Building U
- Building V
- Platinum Building W
- Platinum Building X
- Silver Building Y
- Silver Building Z
- Platinum Building AA
- Other Building BB
- Other Building CC