WHEN THE U.S. DEPARTMENT OF ENERGY’S National Renewable Energy Laboratory (NREL) decided to move 800 staff out of leased space into a new office building on its Golden, Colo., campus, it used that opportunity to build a living lab for best practices in net zero energy performance based on DOE and NREL research. The Research Support Facility (RSF) also provided a chance to develop and advance a replicable model for the next generation of high performance buildings. The result is a LEED Platinum facility built for $259/ft² (comparable to other government and institution office construction costs) with an energy use intensity (EUI) of 35.4 kBtu/ft²·yr.

This article presents the process used for delivering the RSF as a replicable blueprint to achieve a large reduction in building energy use and to adopt a net zero energy approach for large-scale commercial buildings without increasing cost. Net Zero Energy Procurement

The foundation to this blueprint is writing performance requirements into the contract. NREL developed a performance-based design-build approach to procurement. The goals of this approach are unleashing the creativity of the designers and builders, maximizing collaboration, and reducing overall risk by shifting responsibility and control to the design-build team. (See Key Provisions Included.) These provisions filtered into the design-build team’s contractual relationships and reinforced a performance-centered, integrated delivery process. The investment NREL made in clearly and thoroughly defining its objectives was critical to simultaneously meet the aggressive performance, cost and schedule requirements. (See Primary Project Objectives and Requirements.) The design-build team realized that by focusing on net zero energy, many of the other objectives would fall into place. The project is pursuing three of NREL’s four definitions of net zero energy: site energy, source energy, and energy content of embodied materials.
Climate Responsive Design
The most cost-effective way to save energy is to not need it. Building the architectural concept around climate responsive strategies reduces demand on active lighting and HVAC systems.

The primary building section design addresses strategies such as a 100% daylit footprint, effective cross ventilation and solar and glare control. The resulting section is 60 ft deep. The narrow depth and campus constraints led to the H-shaped plan that positions the office program in long, thin, east-west-oriented wings.

The building envelope also is key in integrating passive strategies. The façades have low average window-to-wall ratios of 27%, but the design still provides a fully daylit interior.

The two primary exterior wall assemblies include a precast concrete assembly and a steel stud assembly. The precast concrete walls include continuous rigid insulation and use a low-conductivity connector between the interior and exterior concrete layers.

In addition to high R-value wall and roof assemblies, careful attention was paid to the building envelope. Below Site walls and retaining walls use large rocks that were found during the building excavation and built into gabion cages.

ENERGY AT A GLANCE
- Annual Energy Use Intensity (Site, Not Including PV): 35.4 kBtu/ft²
- Electricity (From Grid): 1.01 kBtu/ft²
- Electricity (From PV): 24.2 kBtu/ft²
- Natural Gas for District Heated Water: 9.68 kBtu/ft²
- Electricity for District Chilled Water: 0.46 kBtu/ft²
- Annual Energy Use Intensity (Site, Not Including PV or Data Center): 20.9 kBtu/ft²
- Annual Net Energy Use Intensity: 11.2 kBtu/ft²
- Annual Energy Use Intensity (Site, Not Including PV or Data Center): 11.2 kBtu/ft²
- Annual Energy Cost Index (ECI): $0.55/ft²
- Annual Source Energy: 17 kBtu/ft²
- Annual Energy Use Intensity (Site, Not Including PV or Data Center): 20.9 kBtu/ft²
- ENERGY STAR Rating: 100
- Heating Degree Days: 6,220
- Cooling Degree Days: 1,154

WATER AT A GLANCE
- Annual Water Use: Irrigation: 48,445 gallons (modeled); Building: 742,757 gallons (modeled)
- Note: Actual water use data unavailable due to meter problems.

Net Zero Energy Procurement
- Firm fixed price and schedule
- Complete and detailed energy performance goals and requirements
- No prescribed solutions (such as bridging documents) provided for meeting requirements
- Full design-build team control of design variables related to documented goals
- Regular energy modeling checks to substantiate the project was on track to meet goals
- Financial incentives for superior performance

PRIMARY PROJECT OBJECTIVES AND REQUIREMENTS
- LEED Platinum
- Absolute EUI target of 35.1 kBtu/ft²
- Accommodate at least 800 staff (922 accommodated)
- High performance workspace (support culture, collaboration, amenities, flexibility, ergonomics)
- Architectural quality and design to enhance NREL’s identity and mission
- Net zero energy approach
- Share process and lessons learned so they can be replicated by the industry
- $64.3 million firm fixed price ($57.4 million construction cost)
- Substantial completion by June 2010

Key Provisions Included
- Net Zero Energy Procurement
- Firm fixed price and schedule
- Complete and detailed energy performance goals and requirements
- No prescribed solutions (such as bridging documents) provided for meeting requirements
- Full design-build team control of design variables related to documented goals
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Energy and water use data unavailable due to meter problems.
paid to the intersections of assemblies to reduce thermal bridging. The primary windows repeated across the south façade are the workhorse of the climate responsive architecture. This window has a distinct upper daylight section, which is fixed, shade-free, has double pane low-e glazing for daylight performance and has a high visible light transmittance. A reflective daylighting device (louver system) redirects sunlight up onto the ceiling deep into the space. The south window also has a distinct lower view window section, which has a low U-value, solar heat gain coefficient and visible transmittance. This lower view section’s triple pane, low-e glazing contributes to improved thermal performance. The view section’s external three-sided shade provides solar and glare control most of the year, so no interior window covering is needed. The view portion of the window also has an operable window section, with two-thirds of the operable windows being manual and one-third automated. Occupants receive notifications on their computers when conditions are favorable for opening the windows. The Colorado daylighting device (louver system) redirects sunlight up onto the ceiling deep into the space.

Left: The open office environment and narrow floor plate allow for effective cross ventilation and daylighting.

Above: The RSF’s adjacent visitor’s parking lot is shaded with a sawtooth roof supporting one of the facility’s photovoltaic systems.

Note: The annual EUI values are demand side values and do not include the PV generation.
climate is well suited for natural ventilation, particularly in spring and fall. During the summer, hot days are followed by cooler nights. In this scenario, the automated operable low level view windows on the north façade and high level automated windows on the south façade open to perform a night purge. The building’s interior has a significant amount of exposed thermal mass, which can absorb much of the internal summer heat gains. The cool night air allows the thermal mass to purge this heat.

The RSF includes additional architectural elements to capture and store free heat when integrated with the building’s ventilation system. Perforated sheet metal attached to the south façade functions as a solar collector, capturing heat when air is drawn through by fans located in the building’s crawl space. The heated air behind the dark corrugated metal cladding of the transpired solar collector is pulled into the building’s crawl space thermal mass labyrinth. The crawler space functions as a thermal battery, storing thermal energy and allowing the ventilation air for the building to be passively preheated later.

**Plug Loads and Occupancy Engagement**

Even with close attention, plug load equipment typically consumes more than half of the energy use in a net zero energy building. The heat released by this equipment must be removed by the HVAC system, affecting cooling equipment size, cost and energy consumption. The data center accounts for more than 40% of the RSF’s total energy use. It runs continuously, but benefits from energy-efficient equipment, consolidating and virtualizing servers, and best practices for power and cable management.

Office plug loads represent over one-quarter of the energy use when excluding the data center energy. Plug loads have been largely reduced compared to NREL’s previous leased office and data center. NREL conducted a detailed inventory of existing plug loads and then a critical assessment of plug load needs and policies. The agency implemented new equipment standards for RSF that eliminate unneeded equipment, favor shared multi-function printers, use “best of class” energy-efficient equipment and keep equipment off when not in use. Based on the measured plug loads end uses, NREL is saving approximately 50% in plug load energy compared to its previous typical practices.

The typical daytime plug load power density (not including the data center) is 0.35 W/ft², significantly below the predicted 0.55 W/ft². Night and weekend measured plug loads have been slightly higher than predicted due to challenges implementing robust computer power management settings and “surprise” plug loads such as the backup diesel generator fuel tank heaters.

Efforts to engage occupants in energy efficiency began during design-build and have included occupant training, feedback and the use of real-time energy displays. The design was posted on NREL’s internal Web site and included in newsletters. Since the open office environment was such a significant departure from the staff’s previous work environment, the previous leased space was reconfigured to test-drive the new open workstations and help build wider acceptance across all of NREL’s staff.

NREL developed a prototype computer network-based application called “Building Occupant Agent” to provide a two-way flow of information and feedback between

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**KEY SUSTAINABLE FEATURES**

**Water Conservation**
- Dual flush water closets
- Waterless urinals
- Low-flow lavatories and showers
- Native and adaptive landscaping
- Drip irrigation
- Irrigation zones based on exposure and water frequency
- Satellite-based smart irrigation controller
- Roof drainage irrigates rain gardens

**Recycled Materials**
- 34% recycled content for building materials (per LEED)

**Daylighting**
- 92% of regularly occupied spaces daylit (per LEED)
- Narrow floor plate (60 ft)
- Louvers designed for daylighting in south facing daylight windows
- Daylight controls

**Individual Controls**
- Operable windows
- Underfloor ventilation air
- Individual task lights
- Occupant accessible lighting control

**Other Major Sustainable Features**
- Building massing and open plan for passive energy optimization
- Thermal mass interiors
- Natural ventilation and night purging
- Transpired solar collectors
- Thermal labyrinth crawl space
- Radiant heating and cooling
- Green data center
- 75% of construction waste diverted
- Recycled natural gas pipe used as structural columns
- Bottle kiln pine harvested wood used in interior
- 59% certified wood
- Office recycling/composting program

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**B U I L D I N G T E A M**

**Building Owner/Operator**
Department of Energy/National Renewable Energy Laboratory

**Architect, Interior Design, Landscape Architecture, Lighting Design**
RNL

**General Contractor**
Hawesdon Construction

**Mechanical, Electrical Engineer; Energy Modeling**
Stantec

**Structural Engineer**
KL&A

**Civil Engineer**
Martin/Martin

**LEED Consultant, Daylight Modeling**
AEC

**Architect, Lighting Design**
RNL

**Architect, Interior Design, Landscape Architecture, Lighting Design**
AEC

**Renewable Energy Laboratory Consultant**
RNL

**General Contractor**
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**SOUTH WINDOW**

**TRANSPRIED SOLAR COLLECTOR**

- Sun Warms Dark Colored Metal Panel
- Cold Air Drawn into Collector Through Perforations
- Passively Heated Air Stored in Thermal Labyrinth for Preheating Ventilation Air
- Air is Passively Heated in Cavity Between Metal Panel and Precast Wall

**ENERGY USE BREAKDOWN**

<table>
<thead>
<tr>
<th>O C T. 2010 – S E P T. 2011</th>
<th>K B T U / F T ²</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cooling</strong></td>
<td>0.40</td>
</tr>
<tr>
<td><strong>Heating</strong></td>
<td>9.68</td>
</tr>
<tr>
<td><strong>Mechanical Systems</strong></td>
<td>2.19</td>
</tr>
<tr>
<td><strong>Lighting</strong></td>
<td>2.83</td>
</tr>
<tr>
<td><strong>Plug Loads</strong></td>
<td>5.76</td>
</tr>
<tr>
<td><strong>Data Center</strong></td>
<td>14.43</td>
</tr>
<tr>
<td><strong>Building Total</strong></td>
<td>35.35</td>
</tr>
</tbody>
</table>
occupants, facility management and the building management system. The lobby features two displays of real-time and annual energy performance as a reminder that the building is a living laboratory.

**Low Energy Active Systems**
Smart architecture and plug load choices set the stage for low energy active systems. Lighting, HVAC and plumbing systems all have opportunities for energy reduction.

**Lighting**
The lighting design focuses on using controls to keep lights off when not needed and minimizing lighting power density (LPD). The RSF is designed with daylighting as the primary

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**MECHANICAL POWER DENSITY**

![Graph showing mechanical power density comparison between actual vs. model for Oct. 2011.]

**DAILY HEATING ENERGY**

![Graph showing daily heating energy comparison between actual vs. model for Oct. 2010 – Oct. 2011.]

**LIGHTING POWER DENSITY**

![Graph showing lighting power density comparison between actual vs. model for Oct. 2011.]

**DAILY COOLING ENERGY**

![Graph showing daily cooling energy comparison between actual vs. model for Oct. 2010 – Oct. 2011.]

**PLUG LOAD POWER DENSITY**

![Graph showing plug load power density comparison between actual vs. model for Oct. 2011.]

**PV OUTPUT**

![Graph showing PV output comparison between actual vs. model for Oct. 2011.]

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**INNOVATION**

**INFORMATION**

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lighting source with an ambient light level for office areas at 25 footcandles. The primary fluorescent fixture, a two lamp, 25-watt T-8, supplements daylight levels. All workstations include a 6-watt LED task lamp. The control philosophy for lights is manual, on-off, with automatic-off backup. It is up to the occupants to turn lights on as lights do not turn on automatically. When manually switched on, lights are automatically dimmed and turned off based on photosensors and a time clock. In private offices and conference rooms, vacancy sensors also shut off lights when the space is unoccupied. The RSF is realizing up to 85% savings in lighting energy use during sunny midday hours. During a typical sunny day, the LPD is often at or below 0.15 W/ft², a significant savings compared to a typical code-minimum office building with an LPD of 1 W/ft², and to the installed LPD of 0.63 W/ft².

HVAC

With heating and cooling loads reduced by climate-responsive architecture, low energy HVAC systems can condition the space when needed. Strategies include:

- decoupled ventilation and space conditioning to reduce fan and reheat energy, low pressure drop design, equipment efficiency, and leveraging free sources of heating (and cooling) like air-to-air heat recovery and IT equipment.
- Advanced controls can be the Achilles’ heel of real-world HVAC performance, and as such, should be well developed.
- HVAC system serving the majority of the RSF decouples ventilation air from temperature control using hydronic radiant slab ceilings and a dedicated outdoor air system for ventilation and dehumidification. The hydronic radiant tubing is intersected by the structural floor and roof decks to condition the space below. Ventilation air is distributed via 12 in. raised access floors. This decoupled approach eliminates reheat energy and much of the fan power associated with a more conventional all-air variable air volume (VAV) reheat system.
- This system was selected to pair well with the passive strategies for the building, including natural ventilation and night purging. CO₂ sensors allow the active ventilation system to ramp down when occupancy is low or natural ventilation is in use. Nonoffice spaces such as conference rooms are conditioned with a more traditional VAV reheat system to provide quick response to large changes in occupancy and to accommodate high occupant densities. CO₂-based demand control ventilation is provided to minimize fan, cooling and reheat energy. Hydronic radiant panels provide heat during unoccupied hours without engaging air handlers and reheat energy during periods of low use.

The data center’s dedicated cooling system is built around free cooling that exports useful heat to the rest of the building. This system operates at room temperatures in the mid-70°F (17°C), which is well within the limits of manufacturers’ recommendations and current industry standards, but higher than conventional industry practice.

The cooling strategy also includes capturing the hot air discharged from equipment so that waste heat can be removed from the space without mixing with the cool air supplied to the space. These provisions allow a relatively warm supply air temperature. Free cooling provided by either direct outside air or evaporative cooling can meet this requirement most of the year.

The hot air discharged from the server racks above 90°F is used directly as transfer air for ventilating other parts of the building when outside conditions are cool. The data center air handlers include chilled-water coils as backup to provide cooling for a handful of hours each summer. The free cooling and IT efficiency measures make the data center one of the most efficient in the world. During the cooler months, the data center has been running a power utilization effectiveness (PUE) of 1.1 to 1.15 and an average of 1.21 during the summer months. The theoretical best possible PUE is 1.

The ventilation air for all parts of the building is tempered using a variety of “free” sources. Ventilation is heated by using air discharged from the data center, air warmed by the transpired collector and thermal mass labyrinth, and more conventional runaround loop heat recovery.

Evaporative cooling is used to temper ventilation air most warm days.

The remaining heating and cooling requirements for the building are satisfied by drawing heated and cooled air from an energy efficiency and thermal comfort perspective. Another improvement comes with the HVAC system selection for conference room areas. The original facility used a VAV-reheat system. The third wing addresses the need for high occupant density and faster thermal response with a displacement ventilation system, which provides greater ventilation effectiveness, while eliminating reheat.

A simpler thermal labyrinth. The thermal labyrinth plays a role in tempering ventilation air. However, based on performance and more refined analysis, the labyrinth structure itself can be much simpler. The crawl space for the third wing still functions as a thermal return, but is constructed as a more typical concrete crawl space. The exposed foundation walls and floors provide ample thermal mass without the additional staggered interior labyrinth walls.

Domestic water from recovered heat. The reliability and energy efficiency of the hot water system in the third wing were enhanced by switching to a heat pump-type water heater for heating domestic water. Though this approach introduces energy loss from storage, distribution and recirculation pumping, the system provides heat three times as efficiently and provides free cooling to adjacent telecom and electrical rooms.
chilled water from the NREL central plant loop. The campus district hot water is heated with large condensate loops. The campus district hot water is used as a buffer, based on a site energy definition of net zero.

**Aligning Performance**

No building can be expected to operate at its potential without paying attention to performance and addressing issues that arise. The operation of the RSF building includes a thorough measurement and verification process.

All energy end uses and on-site renewable energy systems are metered. A rich set of actual energy use data has been gathered, analyzed, and compared to the predicted performance from the final as-built energy model. Accounting for modest differences in weather and actual building use, overall building energy use and end use energy consumption has tracked closely with predictions.

**Conclusion**

NREL’s RSF is successfully pursuing its objective of being a next generation high performance commercial building. While the specific strategies implemented on the RSF will vary in applicability to other projects, the overall approach to achieving large energy savings without additional cost is repeatable and can serve as a blueprint for taking net zero energy to scale.

**Additional Resources**

- Request For Proposals: [www.nrel.gov/rsf](http://www.nrel.gov/rsf)
- Contracting Costs In High Performance Office Buildings: [http://tinyurl.com/nrel-costs](http://tinyurl.com/nrel-costs)
- Plug Load Management: [http://tinyurl.com/blg-loads](http://tinyurl.com/blg-loads)
- Technology Data: [http://tinyurl.com/nrel-dataatr](http://tinyurl.com/nrel-dataatr)
- Full Set Of Predicted Vs. Actual Performance: [http://tinyurl.com/rsf-update](http://tinyurl.com/rsf-update)

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