



# Main Street Net-Zero Energy Buildings: The Zero Energy Method in Concept and Practice

## Preprint

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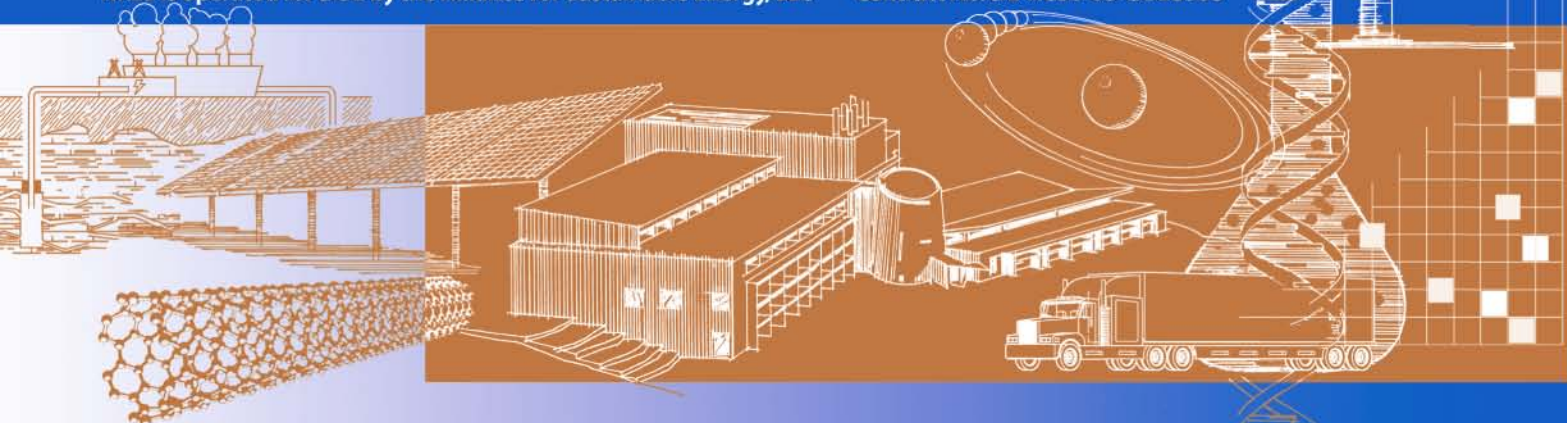
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**MAIN STREET NET-ZERO ENERGY BUILDINGS:  
THE ZERO ENERGY METHOD IN CONCEPT AND PRACTICE**

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**ABSTRACT**

Until recently, large-scale, cost-effective net-zero energy buildings (NZEBs) were thought to lie decades in the future. However, ongoing work at the National Renewable Energy Laboratory (NREL) indicates that NZEB status is both achievable and repeatable today. This paper presents a definition framework for classifying NZEBs and a real-life example that demonstrates how a large-scale office building can cost-effectively achieve net-zero energy.

The vision of NZEBs is compelling. In theory, these highly energy-efficient buildings will produce, during a typical year, enough renewable energy to offset the energy they consume from the grid. The NREL NZEB definition framework classifies NZEBs according to the criteria being used to judge net-zero status and the way renewable energy is supplied to achieve that status. We use the new U.S. Department of Energy/NREL 220,000-ft<sup>2</sup> Research Support Facilities (RSF) building to illustrate why a clear picture of NZEB definitions is important and how the framework provides a methodology for creating a cost-effective NZEB. The RSF, scheduled to open in June 2010, includes contractual commitments to deliver a Leadership in Energy Efficiency and Design (LEED) Platinum Rating, an energy use intensity of 25 kBtu/ft<sup>2</sup> (half that of a typical LEED Platinum office building), and net-zero energy status.

We will discuss the analysis method and cost tradeoffs that were performed throughout the design and build phases to meet these commitments and maintain construction costs at \$259/ft<sup>2</sup>. We will discuss ways to achieve large-scale, replicable NZEB performance. Many passive and renewable energy strategies are utilized, including full daylighting, high-performance

lighting, natural ventilation through operable windows, thermal mass, transpired solar collectors, radiant heating and cooling, and workstation configurations to maximize daylighting.

This paper was prepared by the client and design teams, including Paul Torcellini, PhD, PE, Commercial Building Research Group Manager with NREL; Shanti Pless and Chad Lobato, Building Energy Efficiency Research Engineers with NREL; David Okada, PE, LEED AP, Associate with Stantec; and Tom Hootman, AIA, LEED AP, Director of Sustainability with RNL.

**INTRODUCTION**

Buildings have a significant impact on energy use and the environment. Commercial and residential buildings use almost 40% of the primary energy and approximately 70% of the electricity in the United States. The energy used by the building sector continues to increase, primarily because new buildings are constructed faster than old ones are retired. Electricity consumption in the commercial building sector doubled between 1980 and 2000 and is expected to increase another 50% by 2025 [1]. To address the growing energy use in the commercial building sector, an influential community of industry leaders and researchers has committed to pushing the boundaries of building performance to develop net-zero energy buildings (NZEBs).

The vision of NZEBs is compelling. These highly energy-efficient buildings will use renewable energy technology to produce (and export) as much energy as they consume from the grid annually. And, although today's buildings are our nation's highest energy-consuming and carbon-emitting sector, NZEBs enable us to build a network of clean domestic energy assets.

The U.S. Department of Energy (DOE) was authorized by Congress in the Energy Independence and Security Act of 2007 to develop the Net-Zero Energy Commercial Building Initiative to support the goal of net-zero energy for all new commercial buildings by 2030. The initiative specifies a net-zero energy target for 50% of U.S. commercial buildings by 2040 and net-zero energy for all U.S. commercial buildings by 2050.

Building design professional societies also recognize the vision of NZEBs. For example:

- The ASHRAE Vision 2020 report [2] sets out requirements for developing the tools by 2020 to enable commercially viable NZEBs by 2030. ASHRAE’s recent conference on NZEBs featured more than 25 posters [3] of NZEBs, some of which operate close to or at net zero. Others are in various stages of design or construction.
- The AIA 2030 Challenge [4] calls for incrementally reducing energy use, starting with a 50% reduction over existing buildings and increasing savings up to 2030, when new buildings will be carbon neutral. Some architecture firms are voluntarily committing to adopt energy-saving design targets and to implement steps toward carbon neutrality.

Policymakers also are embracing NZEBs as a key strategy for meeting energy and carbon goals. On October 5, 2009, President Obama signed an Executive Order that sets sustainability goals for federal agencies. The Order requires that all new federal facilities that enter the planning process by 2020 be designed as NZEBs [5]. The California Public Utilities Commission has an energy action plan to achieve net-zero energy for all new residential construction by 2020 and for all new commercial construction by 2030. NZEB goals also were recently announced by the European Parliament in a March 2009 press release [6]. All European Union Member States are to ensure that all newly constructed buildings produce as much energy as they consume on site no later than December 31, 2018.

However, as evidenced by the U.S. stock of NZEBs in the DOE Zero Energy Buildings Database [7], we have only a small set of early-adopter commercial NZEBs. Until recently, large-scale, cost-effective NZEBs were thought to lie decades in the future. The early examples of NZEBs have shown that achieving net-zero energy is technically possible, but have not necessarily focused on cost-effective, large-scale, replicable NZEBs. This paper presents a definition framework for classifying NZEBs and a real-life example that demonstrates how a large-scale office building can cost-effectively achieve net-zero energy.

### WHAT IS A NET-ZERO ENERGY BUILDING?

In the broadest sense, an NZEB is a residential or commercial building with greatly reduced energy needs. In such a building, efficiency gains enable the balance of energy needs to be offset with renewable energy technologies. But this broad definition

leaves room for interpretation—and for misunderstanding among owners, architects, and other players. Agreeing to a common definition of NZEB boundaries and metrics is essential to developing design goals and strategies.

To clarify the definitions for the industry and the National Renewable Energy Laboratory’s (NREL) recent projects, NREL has published two foundational references:

- *Zero Energy Buildings: A Critical Look at the Definition* [8], which documents four NZEB definitions: net-zero site energy, net-zero source energy, net-zero energy costs, and net-zero energy emissions.
- *Getting to Net Zero* [9], which classifies NZEBs based on the renewable energy sources used. At the top of the classification system is the NZEB:A—a building that offsets all its energy use from renewable energy resources available within the footprint. At the lowest end is the NZEB:D—a building that achieves an NZEB definition through a combination of on-site renewables and off-site purchases of renewable energy credits.

Table 1 and the “Net-Zero Energy Building Definitions” section summarize the four NZEB definitions and four energy use classifications. All NZEBs must reduce site energy through energy efficiency and demand-side renewable energy technologies such as daylighting, insulation, passive solar heating, high-efficiency HVAC equipment, natural ventilation, evaporative cooling, ground-source heat pumps, and ocean water cooling. They must also use supply-side renewable energy according to one of the four NZEB classifications. Column 3 discusses the ability of each classification to meet the site, source, emissions, and cost definitions of NZEBs.

There is no “best” definition or energy use accounting method; each has merits and drawbacks, and each project’s approach should be selected to align with the owner’s goals. But across all NZEB definitions and classifications, one design rule remains constant: tackle *demand* first, then *supply*.

### NET-ZERO ENERGY BUILDING DEFINITIONS

- **Net Zero Site Energy:** A site NZEB produces (and exports) at least as much renewable energy as it uses in a year, when accounted for at the site.
- **Net Zero Source Energy:** A source NZEB produces and exports (or purchases) at least as much renewable energy as it uses in a year, when accounted for at the source. Source energy refers to the primary energy used to extract, process, generate, and deliver the energy to the site. To calculate a building’s total source energy, imported and exported energy is multiplied by the appropriate site-to-source conversion multipliers based on the utility’s source energy type.
- **Net Zero Energy Costs:** In a cost NZEB, the amount of money the utility pays the building owner for the

renewable energy the building exports to the grid is at least equal to the amount the owner pays the utility for the energy services and energy used over the year.

- **Net Zero Emissions:** A net zero emissions building produces (or purchases) enough emissions-free renewable energy to offset emissions from all energy used in the building annually. Carbon, nitrogen oxides, and sulfur oxides are common emissions that NZEBs offset. To calculate a building's total emissions, imported and exported energy is multiplied by the appropriate emission multipliers based on the utility's emissions and on-site generation emissions (if there are any).

many staff to move to a central location. Figure 1 shows an architectural rendering of the completed RSF.



NREL/PIX 16250  
Credit: RNL Design

**Figure 1** Architectural rendering of the RSF's eastern façade

## ENERGY-DRIVEN DESIGN AND CONTRACTURAL REQUIREMENTS

A performance based design-build process was used to construct the RSF with energy as a primary design consideration. An NZEB requires thorough planning from its inception and the interactions of all building systems have to be accounted for. Rather than specifying key building characteristics such as size, configuration, and construction, DOE and NREL wrote the Request for Proposals (RFP) with three categories of building performance parameters:

- **Mission Critical.** Performance items that were required in the final design. The RSF design must be safe for all workers and occupants during construction, normal occupancy, operations and maintenance, and deconstruction. The building had to receive a LEED Platinum rating and meet ENERGY STAR requirements.
- **Highly Desirable.** Performance items that were ranked in order of preference. The design had to be able to house 800 staff, have an annual energy use intensity (EUI) (not including photovoltaics [PV]) of 25 kBtu/ft<sup>2</sup>, have architectural integrity, be flexible enough to accommodate future staffing needs, exceed ASHRAE 90.1-2004 by at least 50%, and be completed in 2010.
- **If Possible.** Performance items that we would like to have if the budget allowed. These included performance requirements such as the building should be an NZEB, be one of the most energy-efficient buildings in the world, and exceed LEED Platinum status.

During the proposal stage, Haselden Construction and RNL Design committed to meeting all of the project's performance items within the project's firm fixed price, and were selected as the design-build team. The team worked closely with NREL and DOE in an integrated design approach to fully understand and define the project.

As with all NZEBs, energy efficiency is top priority. The RSF had to be as energy efficient as possible to achieve NZEB status. The original RFP required an annual EUI of 25 kBtu/ft<sup>2</sup>. This requirement was based on standard government building occupant density of 650 employees, 220,000 ft<sup>2</sup>, and a data center to service the RSF occupants. Current design has

**Table 1** Classifying ZEBs by Renewable Energy Supply

ZEB Classification	ZEB Supply-Side Options	ZEB Definitions
<b>On-Site Supply Options</b>		
A	Use renewable energy sources available within the building's footprint and dedicated to the building (Examples: Photovoltaic, solar hot water, and wind located on the building.)	YES: Site, Source, Emissions Difficult: Cost
B	Use renewable energy sources as described in ZEB:A And/or Use renewable energy sources available at the building site and dedicated to the building (Examples: Photovoltaic, solar hot water, low-impact hydroelectric, and wind located on parking lots, adjacent open space, but not physically mounted on the building.)	YES: Site, Source, Cost, Emissions Difficult: Cost
<b>Off-Site Supply Options</b>		
C	Use renewable energy sources as described in ZEB:A; and/or ZEB:B And Use renewable energy sources available off site to generate energy on site and dedicated to the building (Examples: Biomass, wood pellets, ethanol, or biodiesel that can be imported from off site, or collected from waste streams from on-site processes that can be used on site to generate electricity and heat.)	YES: Site, Source, Cost, Emissions
D	Use renewable energy sources as described in ZEB:A, ZEB:B, and/or ZEB:C And Purchase recently added off-site renewable energy sources, as certified from Green-E (2009) or other equivalent renewable energy certification programs. Continue to purchase the generation from this new resource to maintain ZEB status. (Examples: Utility-based wind, photovoltaic, emissions credits, or other "green" purchasing options. All off-site purchases must be certified as recently added renewable energy (Green-E 2009). A building could also negotiate with its power provider to install dedicated wind turbines or PV panels at a site with good solar or wind resources off-site. In this approach, the building might own the hardware and receive credits for the power. The power company or a contractor would maintain the hardware.)	YES: Source, Emissions NO: Site, Cost

## REAL-LIFE NET-ZERO ENERGY BUILDING: NREL'S RESEARCH SUPPORT FACILITIES

Scheduled to open in June 2010, NREL's new Research Support Facilities (RSF) will be one of the world's most energy-efficient office buildings. It is designed to be one of the first large-scale NZEBs and will achieve the U.S. Green Building Council's (USGBC) Leadership in Energy and Environmental Design (LEED) highest rating, LEED Platinum. The 220,000-ft<sup>2</sup> building will house 824 employees on NREL's Golden, Colorado, campus. NREL is currently leasing office space in a nearby office complex, and the RSF will enable

increased the number of occupants to 824 in the same floor area. With the increase in employee density and space efficiency, the RFP allowed for a per-person EUI goal normalization. The required EUI has thus been normalized to 32 kBtu/ft<sup>2</sup> with the prorated data center for 824 occupants, or 35 kBtu/ft<sup>2</sup> with the full data center.

The EUI requirement was developed based on NREL’s desire to design, build, and operate one of the most efficient office buildings in the United States. NREL researchers performed computer simulations and collected data from high-performing buildings nationwide to create an energy specification that could be met within the project’s budget, yet set an ambitious new national energy efficiency benchmark.

The requirements are based on a whole-building annual energy use metric. Stating energy consumption on a per-square-foot basis enables energy performance to be compared directly between buildings of different sizes and uses. Figure 2 compares the RSF’s annual EUI and renewable energy generation to buildings with varying levels of energy performance. The RSF is expected to operate at an EUI that is 74% lower than the typical office building.

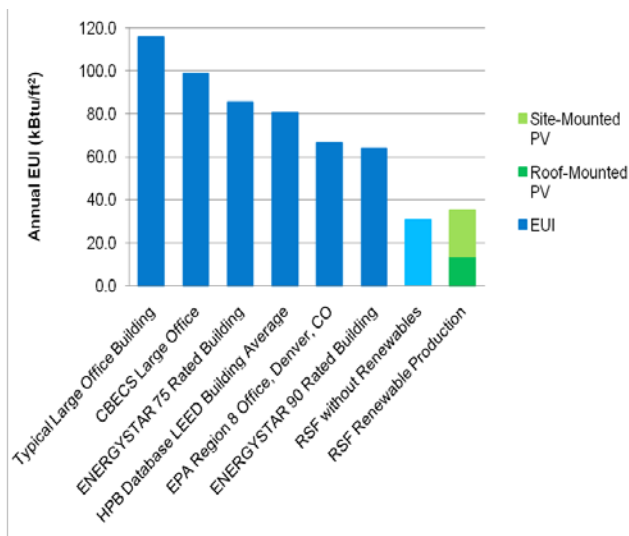


Figure 2 Whole-building EUI comparison

**ENERGY MODELING AS A DESIGN TOOL**

The energy use and costs of a building depend on the complex interactions of many parameters and variables. Whole-building energy simulation software can thoroughly evaluate all interactions between the envelope, HVAC system, and design features. The best time for energy modeling to inform the design process is in the conceptual design stages, before any design concepts have been developed. Yet energy analysis, if done at all, typically starts at about the time of design development and is used for LEED compliance or selection of HVAC type—not for designing the building orientation, massing, section, or envelope.

For the RSF design/build team, early conceptual design energy modeling was required as part of the design completion so the design/build team could commit to meeting the energy goals. During conceptual design, the design team first considered the building section to determine the optimal width that could be fully daylight. In addition to whole-building energy models, the design team performed early daylighting modeling to determine optimal glazing orientation, sizes, and shading. Energy and daylighting models were updated throughout the design process to ensure the design met the required energy use goals. The design/build team is required to update the energy models based on what was actually built and still meet the 35 kBtu/ft<sup>2</sup> EUI goal at the point of building turnover. After the first year of operation, the energy models will be calibrated based on measured end use data to verify performance. The EUI by end use based on the final RSF design is shown in Figure 3.

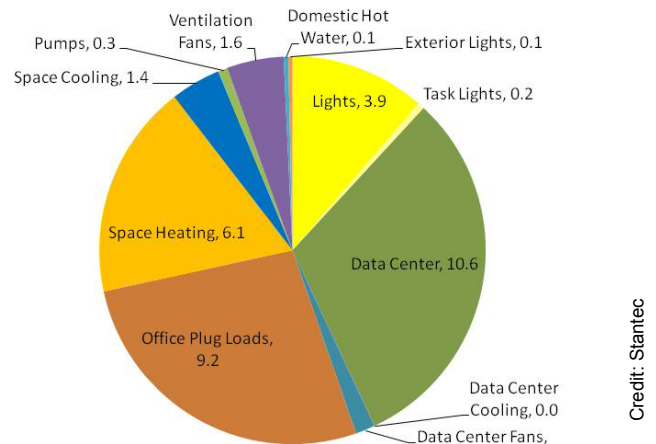


Figure 3 Final design energy model by end use, kBtu/ft<sup>2</sup>

**ENVELOPE DESIGN**

**Orientation**

The design/build team first developed a simple modular envelope to meet the aggressive cost and energy performance contractual requirements. The RSF features a “lazy H” layout; the legs have a long east-west axis. The orientation enables the building to take advantage of the Colorado environment. The occupied zones are 60 feet wide, which enables every occupant to be within 30 feet of windows. It also includes an open floor plan without obstruction from columns or interior supports. Figure 4 shows a construction photo taken in December 2009.

The north wing is four stories; the south wing is three stories. The two wings are designed for office space; the connection between the two will house common areas such as conference rooms, a library, and a media area.

The high aspect ratio of 13 results in a narrow floor plate, which offers daylighting and natural ventilation to a significant portion of the building area. To balance the advantages of daylighting, natural ventilation, and views with the

disadvantages of heat loss or gain and additional envelope costs, the window to wall ratios (WWRs) are optimized to maximize daylighting and provide views, but are not overglazed. The south façade WWR is about 28%; the north façade WWR is about 26%.



NREL/PIX 16772  
Credit: Haselden Construction

**Figure 4** The “lazy H” configuration of two narrow multistory office wings (connected by an enclosed bridge and courtyards) allows daylight to penetrate the work spaces.

### Façade

The exterior façade is constructed with modular precast concrete panels that provide insulation and thermal mass and temper interior air temperature fluctuations. They consist of layered 3-inch exterior concrete, R-14 rigid foam insulation, and 6-inch interior concrete. The roof is an R-33 poured 3-inch concrete slab on 2-inch composite decking.

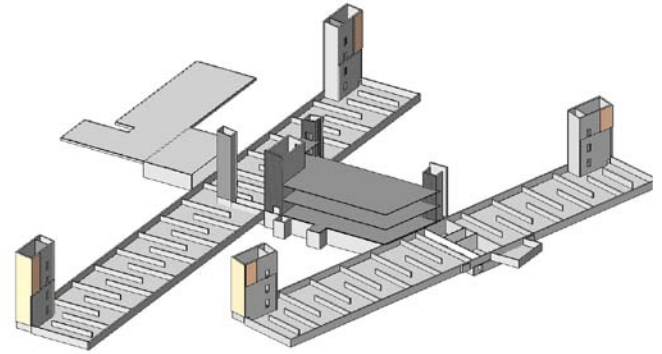
### Windows

The window glazing is tuned to their functions. The vision glass is triple-glazed. Its low-e glazing has a U-value of 0.17 and a solar heat gain coefficient of 0.22. Insulated framing increases the assembly U-value to 0.34. The upper daylighting glass is double glazed. Its low-e glazing has a U-value of 0.27, a solar heat gain coefficient of 0.38, and a visible light transmittance of 65%. Insulated framing increases the assembly U-value to 0.44. The spandrel glass is triple glazed. Its low-e glazing has a U-value of 0.25 and an assembly U-value of 0.38.

### Labyrinth

The below-grade labyrinth (see Figure 5) provides additional thermal mass. The lower floor had to be constructed above grade because of Colorado’s expansive soil. The elevated lower level resulted in a large crawl space. A labyrinth of concrete walls was poured into the crawl space to add significant thermal mass to the dedicated outdoor air system (DOAS).

The labyrinth’s thermal mass will be used as a heat sink to preheat the outdoor air. During cold weather, heated air from transpired solar collectors will heat the thermal mass, which will preheat ventilation air.



Credit: RNL Design

**Figure 5** Architectural rendering of the below-grade labyrinth

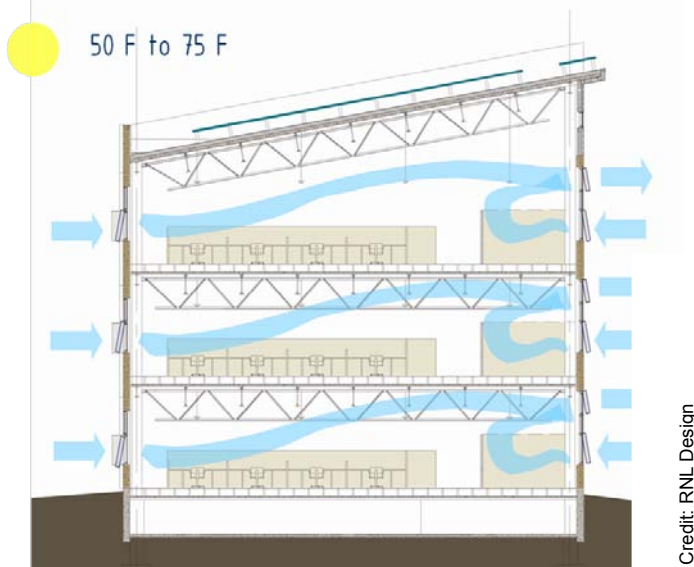
### HVAC DESIGN

To meet the project’s aggressive energy efficiency requirement, every aspect of the RSF’s HVAC system was designed to be energy efficient without sacrificing comfort. The office wings will be heated and cooled by a radiant ceiling slab, and are designed to maintain ASHRAE Standard 55 comfort levels [10]. The NREL campus has a central woodchip boiler and high-efficiency water-cooled chillers that provide district hot and cool water. The RSF’s radiant system will use this water for heating and cooling. The 42 miles of radiant tube heat exchanger are run through the ceilings on each level.

Data centers in large office buildings typically use significant energy. By adopting the newest data center cooling temperature guidelines, and fully utilizing hot aisle containment, the data center can be cooled by efficient evaporative cooling and single-pass outdoor air 99% of the year. This strategy also allows the building to use the waste heat from the data center.

Ventilation will be provided by a DOAS and natural ventilation, which are distributed by an under-floor air distribution (UFAD) system with swirl diffusers. The mechanic ventilation system is sized to provide 30% additional outdoor air over ASHRAE Standard 62.1-2004 requirements [11]. During mild weather, operable windows will provide natural ventilation. The southern lower windows feature a manual and an automatic operable system; the northern windows feature a low-level manual and an upper automatic system. The manual windows will operate as needed to suit the occupants. A workstation-based task manager interface will notify occupants when conditions are optimal for natural ventilation and windows may be opened. The actuated windows will be controlled and operated primarily to support nighttime precooling. Figure 6 shows the natural ventilation scheme used in the office wings.

When conditions do not permit natural ventilation, the DOAS will provide mechanical ventilation. The DOAS is coupled with the UFAD system, which will provide ventilation air at low pressure and velocity and result in lower ventilation fan energy consumption. Separating the space conditioning and ventilation functions allows the air systems to be downsized relative to a standard forced air system. Demand control ventilation further reduces energy consumption. Carbon dioxide sensors respond to occupancy and control ventilation when needed. When dry Colorado summer conditions permit, evaporative cooling will also be used to cool ventilation air. Finally, a sensible heat recovery system captures either warm or cool air from the exhaust air system to precondition the outdoor air.

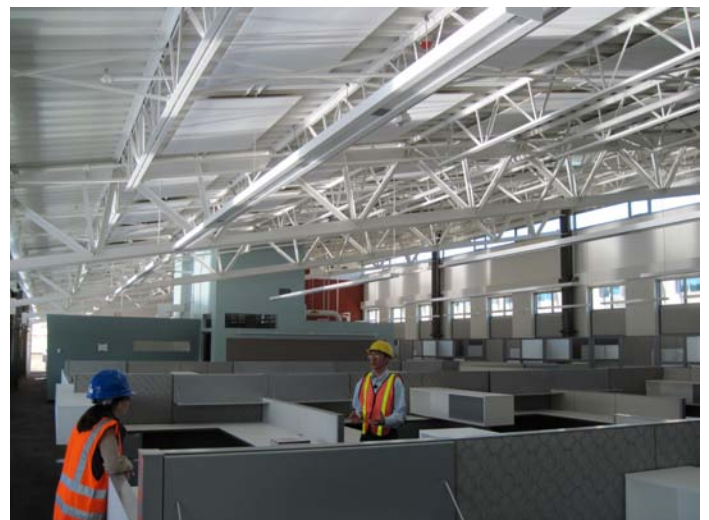


**Figure 6** Rendering of the natural ventilation in the RSF

## LIGHTING DESIGN

Lighting is typically the largest energy end use in an office building, so reducing it is a primary design consideration. The lighting and daylighting design in the RSF begins with orientation. The long east-west axis grants most occupants access to natural light. The north and south glazings feature vision and daylighting glass. On the south façade, overhangs shade the lower vision glass. Light enters through the upper daylighting glass and is reflected by highly reflective louvers toward the ceiling and deeper into the space. The north glazing is not shaded and permits indirect natural light to enter. Advanced daylighting modeling tools were used to develop an optimally designed narrow floor plate, window sizes and performance characteristics, and louvers to allow daylighting in 100% of the office wings during most of the year. Figure 7 shows the daylit interior of the top floor of one office wing. As this picture shows, daylighting provides all required lighting during sunny sky conditions, exceeding 30 foot candles at all workstations. When daylighting does not meet the RSF's lighting needs, energy-efficient, 25-W, T-8 electrical lighting,

which is designed at a weighted average of  $0.63\text{W}/\text{ft}^2$ , provides a minimum of 30 foot candles at the desktop. The lighting control concept was developed to be as simple as possible and still respond to available daylight. Manual switches, photosensors, and occupancy sensors ensure electric lighting is provided only when daylighting cannot supply adequate light. Open offices are controlled with local daylight dimming sensors and a building occupancy schedule. LED task lighting provides localized electric lighting control to office spaces; each consumes only 13 W. For all the enclosed daylit spaces, such as the north offices, huddle rooms, and conference rooms, vacancy sensors are used to encourage appropriate occupant interaction with the lighting controls. The control concept is to encourage occupants to turn their lights on if daylighting is not sufficient, and to turn them off when they leave the space. Vacancy sensors will turn the lights off if the occupants do not.



**Figure 7** Example of the RSF's daylit interior

The interior acoustical treatments, furniture, and paints were selected as key components of the daylighting design. Interior wall surfaces and ceilings are painted with white paint of the highest possible reflectance (exceeds 80%) to reflect light into the office space. Highly reflective acoustical ceiling panels will maximize daylight distribution. The low wall cubicles and office furniture are covered in light colors to reflect light. The cubicle walls are only 42 inches tall, so the daylight can reach deep into the spaces.

## PLUG AND MISCELLANEOUS LOADS

When a building approaches a high level of energy efficiency, plug and miscellaneous loads form a significant portion of the total EUI. In a minimally code-compliant building, plug loads may account for 25% or less of the total EUI, but compared to the RSF's goal, baseline plug loads consume nearly the whole energy budget. At reduced levels, plug loads will account for more than 50% of the total energy use. To achieve net-zero energy status, the design team, owners, and operators must identify opportunities to address plug and process loads.



## Equipment

Because plug loads have considerable impact on the energy budget, great effort was expended to reduce them as much as possible. ENERGY STAR equipment must be used whenever possible, and its use must be accurately scheduled. The RSF (similar to a typical office building) will be occupied only about one-third of the time in a given year. To achieve a plug load EUI that does not surpass its overall energy goal, unused equipment must be turned off.

## Computers, Monitors, and Telephones

At the workstation level, plug loads will be reduced by transitioning from desktop to laptop computers. A plug load audit performed on the NREL campus during the initial stages of the project showed that an in-use desktop computer consumes an hourly average of 100 W compared to an in-use laptop on a docking station that consumes an hourly average of 30 W. In both cases, a 19-inch LCD monitor consumes an additional hourly average of 30 W. Switching from desktops to laptops will save approximately 70 W per occupant (57 kW for the full building). Task lighting will be 13-W LED instead of 35-W fluorescent. Telephones have been changed from standard units that consume approximately 15 W each to voice over internet protocol units that consume 4 W each.

## Copiers and Printers

Shared all-in-one copying and printing stations will reduce or eliminate the use of printers in individual cubicles. The approximate number of occupants who use a shared copying station has been increased from 15 to 20.

## Elevators

The RSF will employ energy-efficient traction regenerative elevators rather than the standard hydraulic elevators that typically operate in low-rise office buildings. The elevators are equipped with energy-efficient fluorescent lighting. Unlike typical elevator lighting, the RSF elevator lighting and fan will be turned off when the elevator car is unoccupied.

## Appliances

A key design team contribution to reducing plug loads included maximizing space efficiency in shared spaces. The current NREL office building inventory provides break rooms with refrigerators, microwaves, coffee pots, drinking fountains, and vending machines. The RSF will feature the same amenities, but each break room will accommodate approximately 20 occupants compared to those in the existing buildings that accommodate 15 occupants each. This increase will reduce the number of energy-consuming appliances. Further savings are accomplished in the break rooms by delamping vending machines [10], identifying and purchasing the most efficient possible refrigerators, and by provided filtered water to all kitchen sinks so that drinking fountain coolers and water clubs can be eliminated.

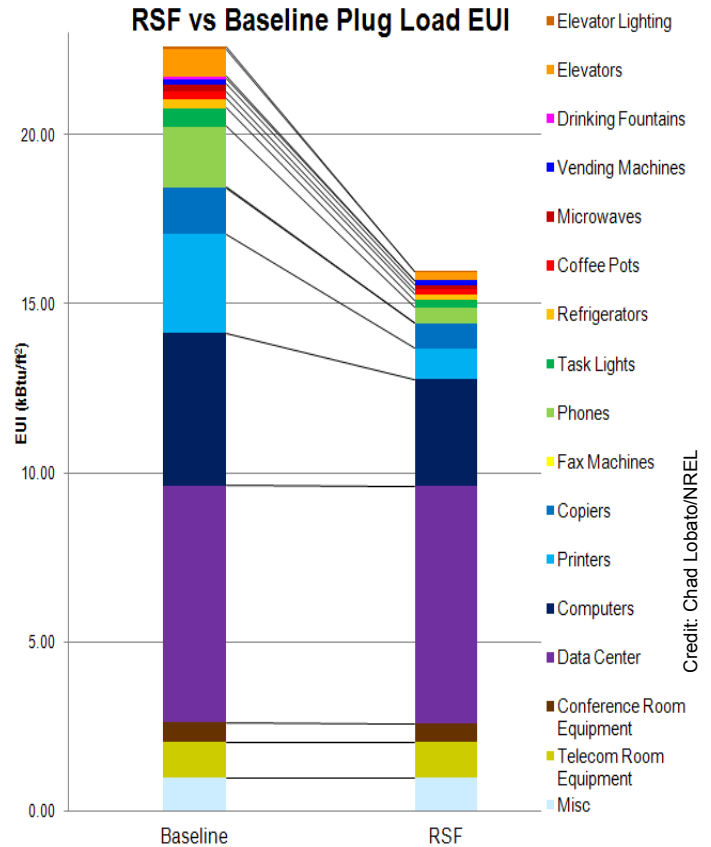


Figure 8 Plug load reductions

## Turning It All Off

To ensure unused office space equipment is turned off, the design and owner team is working to ensure plug loads are truly off. One promising strategy includes equipping each workspace with plug load management systems that provide easy switching and monitoring-based feedback. Enabling and verifying the power management settings in each computer will increase laptop and monitor standby functionality.

In net-zero energy projects, even the smallest plug loads should be identified, modeled, and considered. For example, the plug load distribution transformers were included in the models. To minimize their inefficiencies, the design team attempted to minimize the number of distribution transformers, and then specified high-efficiency models. For the RSF, every watt counts, as PV needs to be provided to offset all energy uses. Therefore, any strategy is considered cost effective if it is cheaper than purchasing PV.

Figure 8 compares the plug load EUIs in NREL's existing office buildings to those in the RSF. Without including the possible savings from more efficient data center operations, we expect approximately 30% energy savings from plug and process loads.

## RENEWABLES

The RSF's energy efficiency level is expected to be world class, but the building will also stand out as one of the first large-scale NZEBs with on-site renewable energy generation that will offset all the energy that is consumed annually. Energy end uses include all HVAC loads (including campus hot and chilled water), lighting, plug loads, and the data center. Compared to NREL's NZEB definitions and classifications, the RSF will be a zero site, source, cost, and emissions NZEB:B. Enough renewable energy will be generated on site to offset site energy, source energy, energy costs, and emissions.

The roof is built with a south-facing 10-degree slope. A standing seam metal roof construction offers an optimal mounting surface for a rooftop PV system. The roof will be covered with 594 kW of PV panels that are more than 17% efficient.

The rooftop array alone will not generate enough energy to meet the RSF's needs, so a parking structure will be covered with 1,100 kW of PV. The combination rooftop array and parking structure array will provide nearly 1.7 MW of PV to offset all the RSF's annual energy end uses.

## COSTS

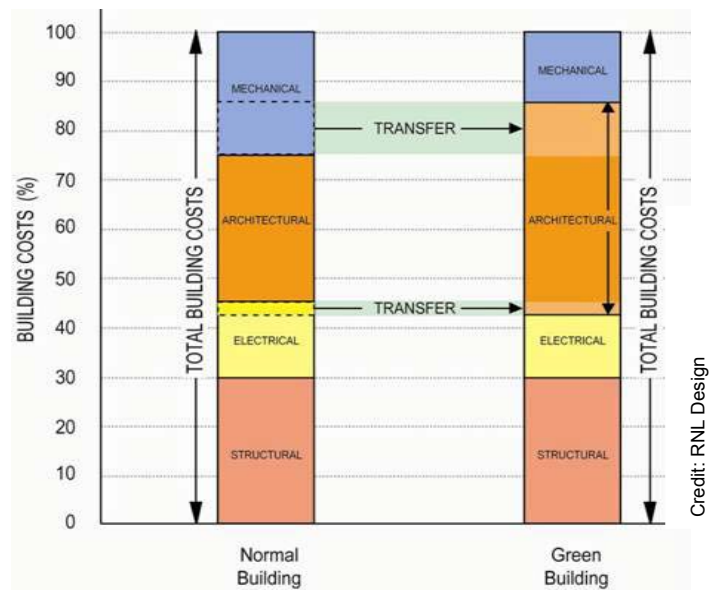
The construction cost goal was to design and build the RSF to be comparable to other new construction institutional office buildings. The RSF met or exceeded all project objectives on budget with a firm fixed price. The construction costs for the RSF building, interiors, site, and infrastructure were \$259/ft<sup>2</sup>, including the interiors and some furniture and cabling. The PV system is partially financed through a third-party power purchase agreement and American Recovery and Reinvestment Act funding. If it had been purchased outright without tax breaks or subsidies at an installed cost of \$5/W, the RSF would have cost \$34/ft<sup>2</sup> more.

The contract required the building to be replicable at a firm fixed price, so costs had to be kept at levels similar to those of typical buildings. The project thus devoted larger portions of the budget to certain design aspects of the design to reduce the sizes and costs in other areas. The long narrow floor plate forces an increased envelope area. This area, as well as increased insulation, cost more than a typical building, but enabled the design team to reduce the sizes and costs of the mechanical and electrical systems. The floor plate allows increased daylighting, which reduces the need for electrical lighting. It also permits natural ventilation for a larger percentage of the area, which reduces the HVAC system load. The increased insulation lowers the heating and cooling loads and enables the heating and cooling equipment to be downsized. Figure 9 illustrates the transfer of costs from the areas that are downsized because of the other areas that are improved over standard practices. Overall, a key cost reduction strategy has been to successfully integrate numerous energy efficiency strategies with the architectural design and

building shell—strategies such as daylighting, passive solar heating, high building thermal mass, and natural ventilation are all considered architectural elements that do not necessarily have to have higher capital costs.

No unique technologies were used to construct the RSF. Standard technologies keep costs low and repeatability high. Exterior walls are constructed of modular precast panels that require minimal finishing. These panels combine with open repeatable office space configurations—which eschew complicated curved surfaces or finishes—to offer straightforward installations that keep costs down.

In addition to allowing energy efficiency to be well integrated in a cost effective manner, the design-build process used in the RSF has reduced the project schedule significantly compared to similar office buildings. A typical design-bid-build DOE project takes four to five years to complete from conception to occupancy; the RSF process will take three years.



**Figure 9** The transfer of costs from HVAC capacity to architectural elements allows energy efficiency with little to no incremental cost increase.

## CONCLUSIONS

NZEBs are vital to the nation's energy-efficient future. They will provide the space needed to perform basic day-to-day operations, but will have a far lesser environmental impact. To design and build an NZEB, energy efficiency and renewable energy generation must be requirements from the beginning. A clear and comprehensive RFP that includes specific and measurable EUI goals is critical to ensure energy goals are cost-effectively met. This paper has shown how clear NZEB goals have been successfully applied to a large-scale office building. Well-established contractual energy goals enabled the team to integrate every design feature to achieve a balance between optimal building performance and cost.

A cost-effective NZEB is a realistic possibility that uses today's technologies combined with an integrated design process. To achieve NZEB status, everyone involved must strive for the same goal. The design and construction teams, building owners, and occupants must be involved. Including EUI goals in the procurement and contractual processes helps ensure energy goals are considered throughout the design, build, and operations processes. Internal loads are a driving force that in many cases are beyond the design team's control. The occupants generally control internal loads and must work to understand and develop energy efficiency strategies to reduce this ever-growing portion of the total building EUI. Load reduction takes a combination of equipment, program, information technology institutional changes, and occupant behavior awareness. For NZEBs, every watt counts, as saving a single continuous watt with energy efficiency equates to avoiding \$33 in PV capital costs.

The RSF was designed and built to be one of the world's most energy-efficient buildings. Its design strategies are readily available and are not unique technologies. As the project is completed, a full end-use data monitoring system will be used to demonstrate measured energy performance.

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