Radiant Cooling and Heating Systems Case Study

Photo: Stantec

OVERVIEW

Location: Golden, CO

Project Size: 222,000 ft^2

Construction Type: New Construction

Completion Date: June 2010

Fully Occupied: Yes

Building Type: Office

Climate Zone: ASHRAE 5B

Total Building Cost: $57.4 million / $259/ft^2

NATIONAL RENEWABLE ENERGY LABORATORY (NREL) RESEARCH SUPPORT FACILITY (RSF)

The Research Support Facility (RSF) is a 222,000 square foot, 4-story office building located on the campus of the U.S. Department of Energy's (DOE) National Renewable Energy Laboratory (NREL). Built in 2010, the building is one of the largest LEED Platinum certified buildings in the nation and was designed to be a zero net energy (ZNE) building. The project serves to align with DOE and NREL's long-term goals of clean energy and resource minimization.

The office building housing 800 staff was designed to meet NREL's ZNE goals by adapting an integrated approach to climate-responsive design and high performance building systems. The building integrates passive strategies by optimizing the building form and design to incorporate natural ventilation, daylight and thermal mass. A low energy HVAC system supports the passive strategies. Open office spaces are served by hydronic radiant slab ceilings paired with a dedicated outdoor air system (DOAS) for ventilation and dehumidification. A traditional VAV reheat system serves non-office spaces.

Planning and Design Approach

An integrated whole building design-build strategy was used to meet the stringent construction schedule and performance goals. The performance based design-build approach focused on extensive up-front planning, identifying and allocating risks, encouraging performance cost tradeoffs and maximizing collaboration between interdisciplinary teams. The design-build strategy employed at the RSF demonstrates cost-effective, feasible solutions that other commercial buildings can easily replicate and adapt.

The building leverages the landscape and climate characteristics of the site. Daylighting and natural ventilation enhance both energy performance and occupant productivity. The radiant slabs make use of the thermal mass and ensure thermal comfort through a night purging strategy.

STATE OF CALIFORNIA ENERGY COMMISSION

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CBE CENTER FOR THE BUILT ENVIRONMENT

Team/Owner Details

Owner: U.S. DOE and NREL

Architect: RNL

Structural Engineer: KL&A, Inc.

MEP Engineering: Stantec

Landscape Architect: RNL

General Contractor: Haselden Construction

The RSF provides a new type of office environment, encouraging collaboration and employee engagement in the functioning of the building through operable windows, integrated workstations with occupant controls and a display providing real-time and annual energy performance, emphasizing the living laboratory aspect of the building.

Radiant System

The project uses Thermally Activated Building System (TABS) as a viable heating and cooling strategy. 42 miles of radiant tubing routes through the ceiling slabs on each level of the RSF, covering over 75% of the conditioned floor area.

The mechanical contractor, Trautman & Shreve, innovatively designed a customized, cost-effective and time-saving solution by using radiant mats instead of conventional radiant tubing. These rollout radiant mats were custom-designed and pre-fabricated for each zone to comply with the condensed construction timeline, ultimately saving 85% of the time required for conventional radiant tubing methods.

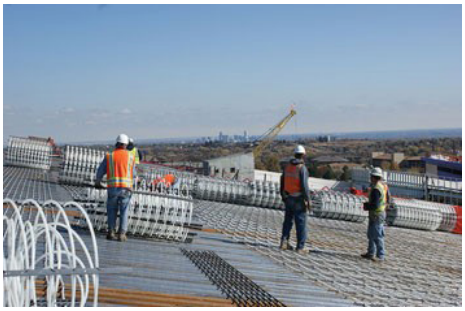
The chilled water for the radiant cooling system is provided from the campus' central cooling plant, consisting of water-cooled centrifugal chillers with a water side economizer. Hot water is provided by a central woodchip boiler at NREL's Renewable Fuels Heating Plant. Non-office spaces are conditioned with a traditional VAV reheat system, supported by perimeter heating units to accommodate quick response to changes in occupancy levels. Thermal comfort is also provided by desktop fans and windows, allowing occupant control and mixed mode ventilation.

Ventilation – Supplemental Cooling

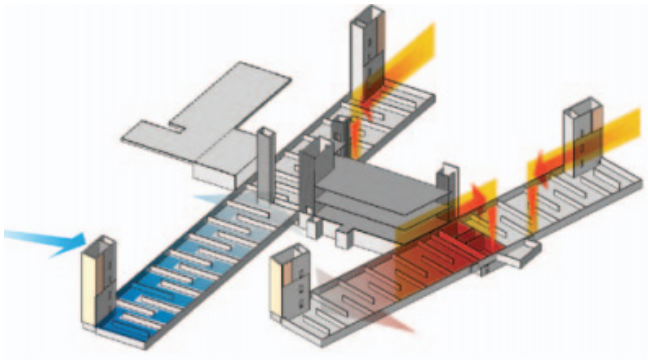
The RSF predominantly uses underfloor air distribution in all open office spaces. The building has four radiant thermal zones, and the radiant heating and cooling in each zone is supplemented by a dedicated outdoor air system for ventilation and dehumidification. Each zone is equipped with a thermostat and demand control ventilation to regulate fan and cooling energy. The lower level of the building is designed as a ventilation heat exchanger termed "the labyrinth" with custom designed concrete airflow partitions. These partitions increase the air's contact with concrete as the labyrinth acts as a thermal battery, storing the chill of the night during summer to pre-cool ventilation air, thereby reducing the cooling load.

"It's important to get the operational side of the building integrated with the design and construction side. Transparency and communication are critical through the entire process."

–Tom Hootman, Director of Sustainability, RNL



Custom-designed, rollout radiant tubing installation on site.
Photo: Uponor

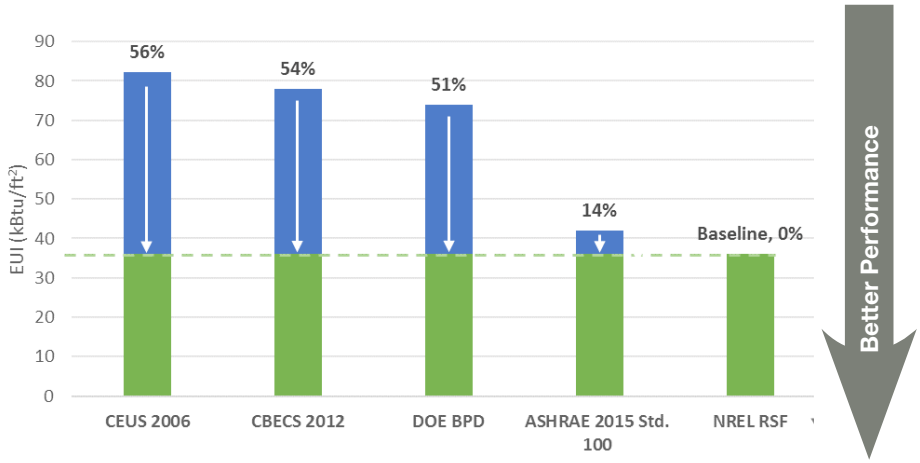


The lower floor labyrinth as a thermal battery.
Photo: NREL

In the winter, the labyrinth draws heat from the data center discharge and the perforated sheet metal attached to the south façade that acts as a transpired solar collector.

Building Energy Use

The RSF has a whole building site Energy Use Intensity (EUI) of 36 kBtu/ft², which includes the RSF datacenter. This low energy use is 51-56% less than the average office EUI performance of the national CBECS and California CEUS datasets and of offices in the same climate zone within the Building Performance Dataset (BPD), as seen below. While those datasets include a mix of construction ages, the RSF is also performing better than ASHRAE's best-practice energy efficiency standard 100 targets by 14%.



Energy Use Intensity (EUI)[1]: 36

Percent difference of office energy use intensity benchmarks compared to the RSF measured performance.

"This building represents a turning point in American architecture and construction. It's something like the creation of the Model T; it's not only a brilliant manufacturing concept, it's the ability to replicate it. The RSF represents an ability to replicate deep sustainability in practically any climate."

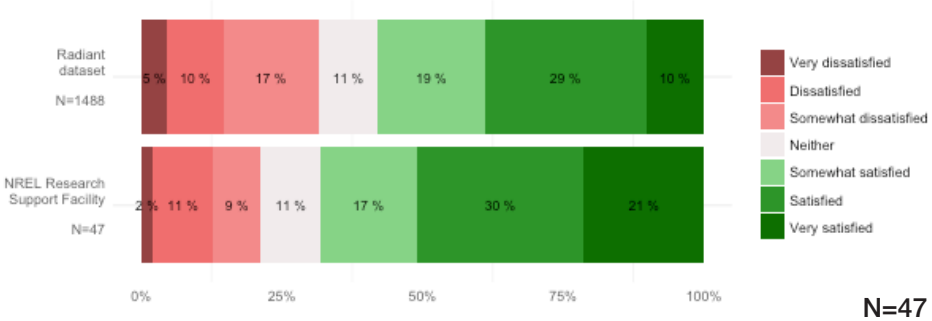
–Philip Macey, Project Manager, Haselden Construction

"This building demonstrates that the energy performance of commercial buildings can be substantially improved using an integrated design process. Through this innovative approach—combined with a relentless focus on the energy model—our team has created a new national building performance standard for large-scale commercial buildings that is achievable and marketable now."

–Jeff Baker, Director of Laboratory Operations, DOE's Office of Energy Efficiency and Renewable Energy

Thermal Comfort Feedback

Overall, the thermal comfort of the occupants in the RSF is very good. 68% of the occupants reported that they were satisfied, 11% reported that they were neither satisfied nor dissatisfied and 22% reported that they were dissatisfied. The satisfaction reported at the RSF was higher than the sample dataset overall and higher than comparable all-air buildings.



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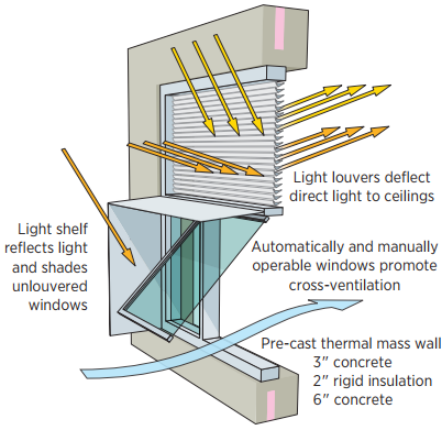
Occupant thermal comfort feedback for the RSF.



Light louver daylight system with operable view window. Photo: NREL

This case study is part of a project focused on energy and occupant factors within the larger study Optimizing Radiant Systems for Energy Efficiency and Comfort. Additional case studies and the full research findings on energy use and occupant perceptions of the indoor environment will be available in Fall 2017 at cbe.berkeley.edu/research/optimizing-radiant-systems.htm and at newbuildings.org. The larger study will include design optimization, cost assessment and savings opportunities and will be available on the CEC EPIC site in 2018 at energy.ca.gov/research/new_reports.html.

Funder: California Energy Commission (EPIC Project 14-009)

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Additional Team: TRC–G. Paliaga | CBE–S. Schiavon, P. Raftery, L. Graham

Additional Efficiency Strategies and Features

Mixed Mode Ventilation

The RSF incorporates mixed mode ventilation by using automated and manually operable windows, allowing natural ventilation through each zone. The automated window programming facilitates night cooling and cross ventilation by opening lower level windows on the south façade and higher level windows on the north façade. The CO_2 based demand control ventilation turns down the mechanical system during low occupancy or when natural ventilation is used.

High Performance Windows

High performance fenestration further improves the thermal performance of the building. Windows are triple pane low-e glazing with a 0.17 U-value and a 0.23 Solar Heat Gain Coefficient (SHGC). The north and south façade have distinct windows: the upper halves of the windows are fixed closed and have light re-directing louvers for enhanced daylighting, while the lower halves are shaded with overhangs and openings are controlled either automatically or manually. Automatic window controls primarily support nighttime precooling. A workstation based application alerts occupants to operate the manually controlled windows when optimal conditions exist for natural ventilation.

Plug Load Management

The RSF uses an energy management and control system to monitor and regulate energy consumption. The project demonstrated major plug load savings through a detailed analysis of their existing inventory and needs, eliminating unnecessary equipment and encouraging multi-function systems and plug-load controls. These factors contributed to saving at least 50% of the typical plug load use for the NREL campus.

Role of Radiant in High Performance

Although a radiant system is not the sole driver of good energy performance, it can be an important part of an integrated approach from design and technology selection through to occupancy and operations. In California, low energy outcomes rely on strategies to address the HVAC system, which represents the highest proportion of commercial building energy use (32%)[1].

This research found the majority of the study set buildings (96%) were pursuing high levels of LEED certification, where reduced energy is a requirement. This mirrors the findings in the largest database of ZNE buildings, where more than half of ZNE buildings in North America use a radiant system[2], and in a survey of 29 advanced ZNE and near ZNE buildings in California, where 11 include radiant systems[3]. The RSF building energy use is exemplary and the radiant system is part of the integrated approach that achieved that performance.

[1] California Commercial Energy Use Survey (CEUS) 2006 http://www.energy.ca.gov/ceus/
[2] New Buildings Institute Getting to Zero Database http://newbuildings.org/resource/getting-to-zero-database/
[3] TRC and PG&E, ACEEE 2016 http://aceee.org/files/proceedings/2016/data/papers/3_636.pdf