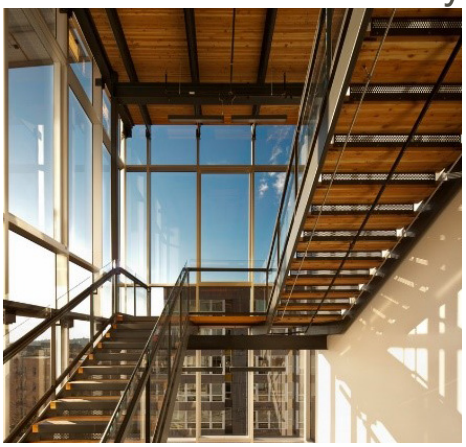
# Radiant Cooling and Heating Systems Case Study



Photos: Miller Hull Partnership

## OVERVIEW

**Location:** Seattle, WA

**Project Size:** 52,000 square feet (SF)

**Construction Type:** New Construction

**Completion Date:** 2013

**Fully Occupied:** Yes

**Building Type:** Office

**Climate Zone:** 4C

**Total Building Cost:** $32.5 Million | $625/SF

## BULLITT CENTER

The Bullitt Center in Seattle, Washington is a six-story, 44,700 square foot (SF) office building. The Bullitt Foundation, a nonprofit philanthropic organization with a focus on the environment, worked with local real estate firm Point32 to develop the $32.5 million building. The building was the vision of Denis Hayes to create “the greenest urban office building in the world” and it received the Sustainable Building of the Year award from World Architecture News in 2013 and many subsequent green building awards.

The Bullitt building was studied under a California Energy Commission EPIC research project on radiant heating and cooling systems in 2016-2017. While forced-air distribution systems remain the predominant approach to heating and cooling in U.S. commercial buildings, radiant systems are emerging as a part of high performance buildings. Radiant systems transfer energy via a surface that contains piping with warmed or cooled water, or a water/glycol mix; this study focused on radiant floor and suspended ceiling panel systems[1]. These systems can contribute to significant energy savings due to relatively small temperature differences between the room set-point and cooling/heating source, and the efficiency of using water rather than air for thermal distribution[2]. The full research study included a review of the whole-building design characteristics and site energy use in 23 buildings and surveys of occupant perceptions of indoor environmental quality in 26 buildings with 1645 individuals.

### Planning and Design Approach

The goals for the Bullitt Center had never been attempted on a commercial scale, and thus an integrated design process from the very beginning was essential to the success of the project. The building itself is an irregularly shaped, five-sided, six-story building with a footprint that covers about 98 percent of the site. The design of the building was influenced by the neighborhood, city, and region which was

1 Thermally Activated Building Systems (TABS) and Embedded Surface Systems (ESS) are located in the floor. Note: Chilled beams also use water distribution but typical ‘active’ beams provide cooling predominantly by convection by blowing building ventilation air across cooling coils, and were not the study focus.

2 Water transfers thermal energy about 7 times more effectively than air. CBE Brower Study, CEC EPIC 2011 http://escholarship.org/uc/item/7tc0421f#page-1

nbi new buildings institute

CBE CENTER FOR THE BUILT ENVIRONMENT

### *Team/Owner Details*

**Owner:** Bullitt Foundation

**Architect:** Miller Hull Partnership

**Development Partner:** Point32

**General Contractors:** Schuchart, Foushee

**Structural Engineer:** DCI Engineers

**MEP Engineering:** PAE

**Civil Engineer:** Stantec

**Commissioning:** Keithly Barber Associates

**Solar Team:** Northwest Wind and Solar, Solar Design Associates

**Water Systems:** 2020 Engineering

**Landscape Architect:** Berger Partnership

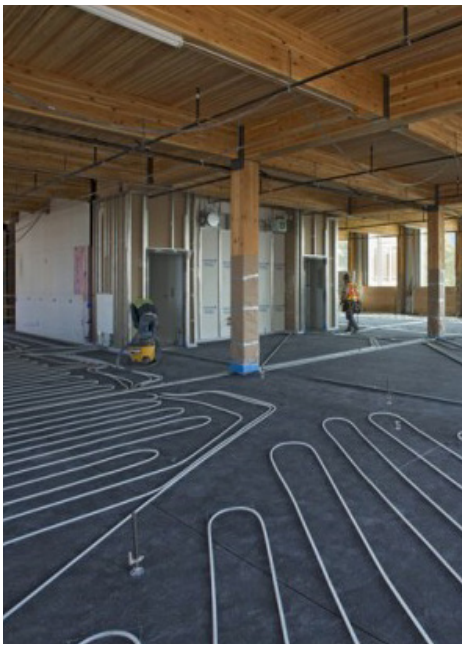


Photo: Earth Techling

Radiant Slab Coils

**Energy Use Intensity (EUI)[1]:** 12

**Figure 1:** Percent difference of energy use intensity benchmarks compared to the Bullitt Building measured performance.

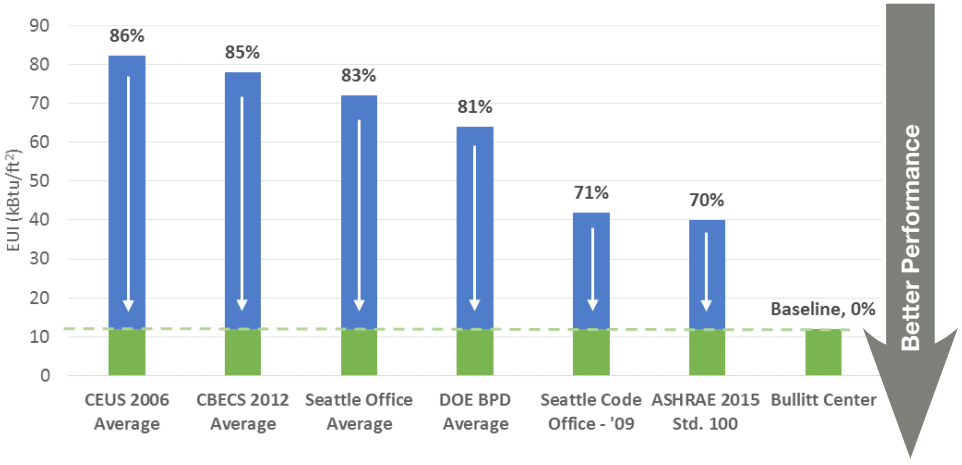
emerging as a leader for sustainable development. Hayes chose the requirements of the Living Building Challenge (LBC) including a zero net energy (ZNE)[3] outcome to guide his design and performance outcomes. Even the stairway, designed to attract use, reduces energy typically used by elevators.

## Radiant and Ventilation System

Bullitt uses a mixed-mode cooling, heating and ventilation strategy to optimize fresh air and greatly reduce energy use. Controls and sensors measure the indoor air temperature and humidity to control air flow through the building and respond to thermal comfort set points. For cooling and improved air movement low-velocity ceiling fans are combined with automated windows that open first for passive cooling and to provide natural ventilation and fresh air. If outside temperatures are not effective the windows remain closed and the dedicated outside air system (DOAS) provides 100% outside air, tempered during the heating season by energy recovered from the exhaust air leaving the building. This system was estimated to offset about 750 hours of annual cooling that would otherwise be needed without operable windows. Automated windows and the DOAS are also employed in the evenings as part of the nightly flushing to cool the thermal mass of the building envelope by 30–50°F prior to morning occupancy. The third level of the strategy is the radiant system which heats and cools the building through hydronic radiant tubing that coil a few inches beneath the concrete overlay of each floor.[4] A mix of water and glycol run inside the tubes warming or cooling the concrete slab, which efficiently radiates into the occupied spaces. This system is closed-loop and cyclical, and the only energy input is to run the pumps and compressors.

### Cooling and Heating Plant

Bullitt hosts a geothermal heat exchange system as their heating and cooling source system. The mix of water and glycol is pumped through 26 on-site wells that are 400 feet deep each. At that depth, the ground retains an ambient temperature of about 53°F in the Seattle area. This warms the fluid returning from the building in the winter and cools it in the summer. In the winter, heat pumps extract energy from this fluid before returning it to the ground a few degrees cooler. The geothermal well field is in an area with a constant lens of groundwater moving slowly toward Puget Sound. As a result, any “heat pollution” from the wells dissipates within approximately 12 inches of the well.




1 Energy Use Intensity (EUI) is a common metric to measure energy consumption in kBtu/square foot/year

3 ZNE buildings annually produce onsite energy from renewables equal to or greater than their annual energy use.
4 This radiant approach is an Embedded Surface Systems (ESS)

Photo: Miller Hull Partnership

"The Bullitt Center is an example of biomimicry in the built environment. It more or less functions like an organism. For example, it has a nervous system that senses what the temperature is outside, what the temperature is inside, whether the wind is blowing, what direction it's blowing from, how fast it's blowing, whether or not it's raining, how intense the sunlight is and how much carbon dioxide is built up inside."

*Denis Hayes, CEO of the Bullitt Foundation*

## Building Energy Use

The Bullitt Center building has a whole building site Energy Use Intensity (EUI) of just 12 kBtu/ft$^2$. This is an exceptionally low energy use and aligned with the zero net energy and LBC goals whereby 100% or more of the building's annual energy use is offset by the rooftop photovoltaics (PVs). This low-energy use is 80-86% less than the average office EUI performance of the national CBECS[5] and California CEUS[6] datasets and offices in the same climate zone within the Building Performance Dataset (BPD)[7] as seen in Figure 1. While those datasets include a mix of construction age the Bullitt building's energy use is also significantly lower than a new code building in the same year and ASHRAE's best-practice energy efficiency standard 100 targets by 70-71%.

## Research Data Set Energy Use

The Bullitt building is part of 23 radiant buildings in the full CEC research study where the bulk of the buildings were clear leaders compared to peers in both CBECS and the BPD. Two thirds receiving an EnergyStar score of 90 or above, signifying that these buildings outperform 90% of comparable buildings. The research study set is on par with the high efficiency target set by ASHRAE in Standard 100 and several of the full research dataset buildings even reached ZNE performance levels (~25 EUI) demonstrating the use of radiant as a path to high performance buildings.

## Thermal Comfort Feedback

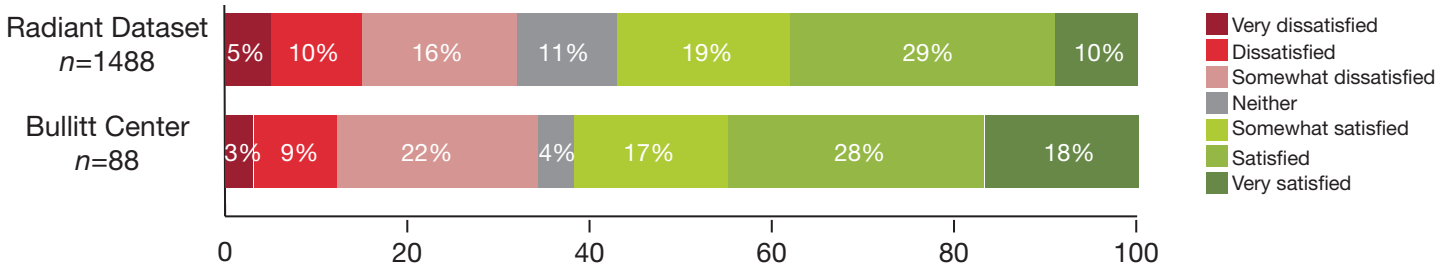
The satisfaction reported at the Bullitt Center was lower than expected for a radiant building in this climate zone. Continued studies will work to refine the reasons for the modest satisfaction rate in this otherwise renowned building design. In the Bullitt Center 63% of the occupants reported that they were satisfied, 4% reported that they were neither satisfied nor dissatisfied and 34% reported that they were dissatisfied.

## Additional Efficiency Strategies and Features

### Envelope

The design team began with a tight envelope and high performance windows to reduce energy loads. In design studies, with simplified building geometry, moving wall insulation from R-19 up to R-25, and roof insulation from R-30 up to R-39, plus improving windows U-factors from 0.60 (insulated glass) to 0.14 (multi-pane/film assembly), resulted in a 62% reduction in the heating load.[8] A super-insulated Schuco curtain wall system was selected with triple pane 2" thick glazing. A customized mullion eliminates thermal bridging and the glass rests against foam along the aluminum frame extrusion. Around the entire window frame a 4"-5" wide "flap" adds to the high performance of the envelope and is sealed to the wall assembly reducing infiltration of the cold Puget Sound winter air.

**Figure 2:** Results on thermal comfort question within the CBE occupant satisfaction survey. *Credit: Caroline Karmann*




5 U.S. Energy Information Agency Commercial Buildings Energy Consumption Survey (CBECS)
6 California Commercial Energy Use Survey (CEUS)
7 U.S. Department of Energy Building Performance Dataset (BPD)
8 University of Washington Integrated Design Lab Study x year

Photo: John Stamets

The windows have external blinds that are automatically controlled by sensors and timers that work in tandem with the automated windows to regulate the amount of light, heat and air in the building. The blinds may also be lowered or raised and tilted at various angles by occupants to minimize or maximize the building's heat gain and eliminate glare. High efficiency fluorescent fixtures were selected rather than LEDs due in part to the cost of LEDs at the time of construction and in part because the electric lighting was projected for very little use.

### Controls

A Building Management System (BMS) integrates the passive and active systems to help maintain a comfortable office setting with net zero consumption of energy and water. The BMS is responsible for the control of the heating system, cooling system, passive and active ventilation systems, daylight control, composters and grey water metabolism and works by sensing the internal and external conditions to engage the appropriate systems. All of these systems are carefully monitored at the main control room in the core of the building to ensure maximum efficiency.

### Renewables

The Bullitt Center has 244 kW 12,400 SF photovoltaic array comprised of 575 individual panels fastened to a steel substructure that parallels the western slope of the site. To meet 100% of the building's energy use the Bullitt Center got a permit variance that allows the array to extend beyond the edge of the building and over the sidewalk creating a flying illusion of the rooftop and capturing attention for this innovative building design.

### Composting Toilet & Water Efficiency

The LBC requires all water to be harvested and treated on site. To meet this requirement with the unique problem of managing human waste on site, the Bullitt Center used Phoenix Composting Toilets from Advanced Composting Systems. This system uses a minimal amount of water where after a complicated treatment system, compost is the end result, saving water, saving the energy of treating wastewater, and eliminating nutrient release into the watershed.

## Role of Radiant in High Performance

Although a radiant system is not solely the 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%).[9] 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,[10] and in a survey of 29 advanced ZNE and near ZNE buildings in California where 11 include radiant systems.[11] The Bullitt building energy use is exemplary and the radiant system is part of the integrated approach that achieved that performance.

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