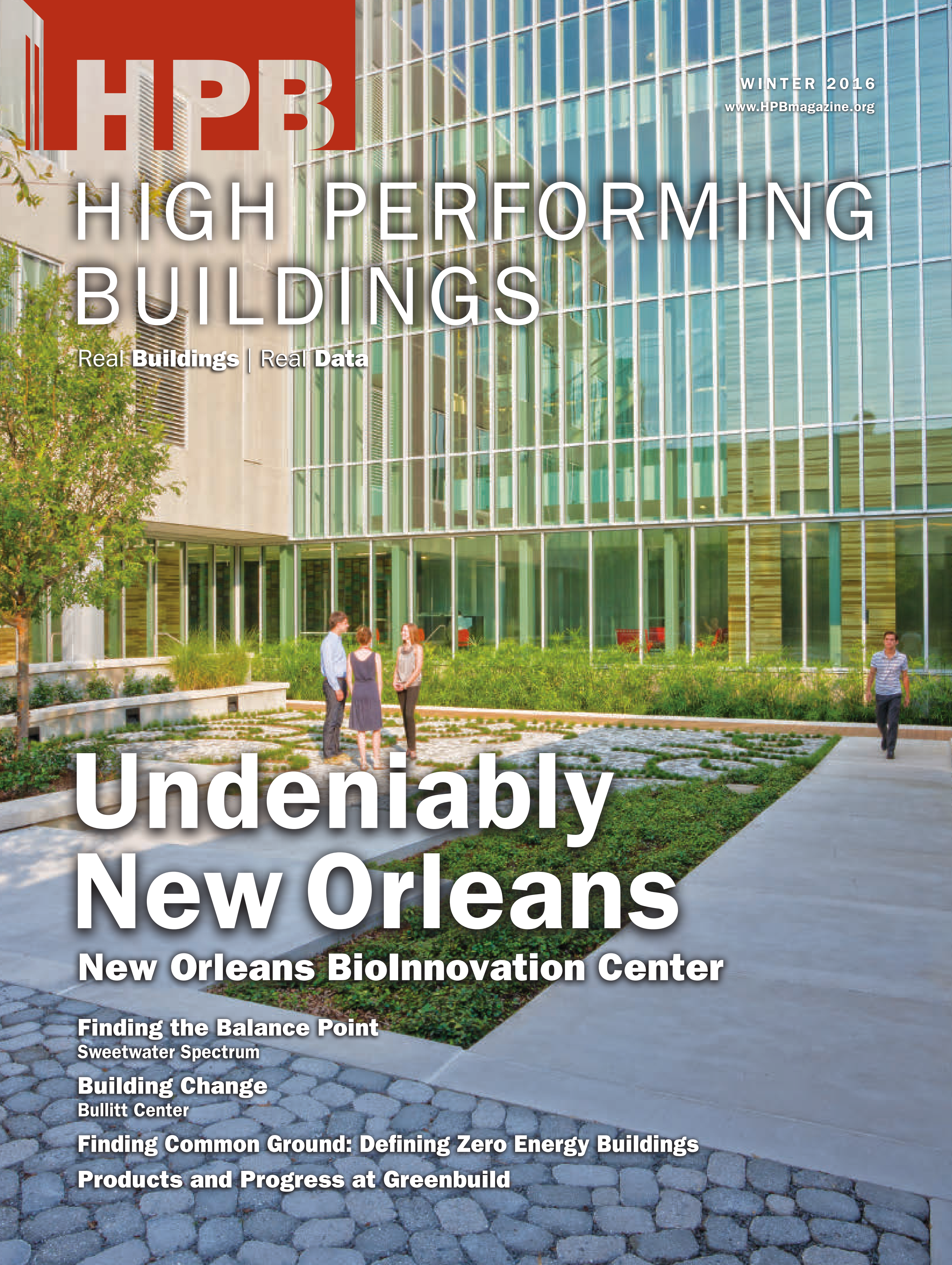


HPB

WINTER 2016

www.HPBmagazine.org

HIGH PERFORMING BUILDINGS

Real **Buildings** | Real **Data**

Undeniably New Orleans

New Orleans BioInnovation Center

Finding the Balance Point
Sweetwater Spectrum

Building Change
Bullitt Center

Finding Common Ground: Defining Zero Energy Buildings

Products and Progress at Greenbuild

Building Change

View of the Bullitt Center from the South. The building extends to the property line at ground level, but steps back at the upper levels to provide a thinner floor plate for better daylight performance and to fit within floor area ratio limits set by the zoning code. Mature trees in McGilvra Park to the west shade the lower floors.

© Nic Lehoux

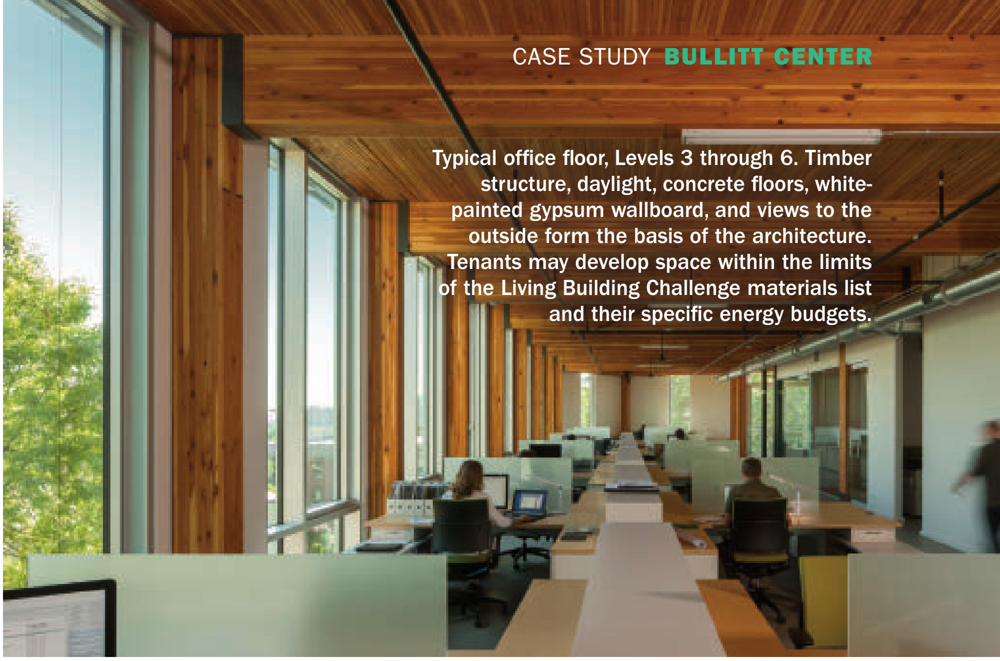
BY JIM HANFORD, AIA; MARC BRUNE, P.E.; CHRISTOPHER MEEK, AIA; AND MICHAEL GILBRIDE

IN 2009, THE BULLITT FOUNDATION set out to change the world with a building. Led by president Denis Hayes, organizer of the first Earth Day, the Foundation's plans called for the Bullitt Center to be the first speculative development to achieve Living Building Challenge certification, meaning it would have to meet the toughest environmental sustainability requirements while also attracting tenants to make it financially sustainable. More than two years into operation, those lofty goals are becoming reality. It is achieving net positive energy use, challenging regulatory hurdles in pursuit of using harvested rainwater as its water source, and raising the sustainability bar as it seeks to live up to its moniker as "The Greenest Office Building in the World."

Net Zero Energy

In design, predicted energy use for the Bullitt Center was driven down to an annual energy use intensity (EUI) of 15–16 kBtu/ft^2. This matched estimates of what could be reasonably generated on site, following detailed parametric studies of potential solar photovoltaic configurations. The resulting 242 kW canopy PV array is a distinguishing design feature, extending beyond the building's footprint and encompassing 14,303 ft^2.

In the past year, the six-story building has been operating at an EUI near 11 kBtu/ft^2—an astonishing feat given that its performance is 79% below the stringent 2009 Seattle Energy Code baseline (*Figure 1*). The successful net positive energy operation is achieved through attention to every driver of energy use in the building, from the architecture, to HVAC systems and delivery of thermal comfort, to lighting



Typical office floor, Levels 3 through 6. Timber structure, daylight, concrete floors, white-painted gypsum wallboard, and views to the outside form the basis of the architecture. Tenants may develop space within the limits of the Living Building Challenge materials list and their specific energy budgets.

© Nic Lehoux

and plug loads, and ultimately to the occupants and their decision-making around energy consumption (*Figure 2*).

From a design perspective, the building massing is driven by the goal of using daylighting as the primary means of illumination, with glazed façades oriented for solar control. The thermally efficient skin achieves a heat loss rate 30% better than Seattle's code; the largest enhancement comes from the triple-glazed aluminum curtainwall systems. Automated exterior blinds enhance solar control for much of the glazing.

The building's mechanical system includes 26 closed-loop geothermal bores that are 400 ft deep and connect to water-to-water heat pumps. Three heat pumps serve the changeover radiant floor system for space heating and cooling, one heat pump serves the 5,200 cfm heat recovery unit (HRU), and one heat pump provides domestic hot water. The HRU includes a 70% effective sensible heat recovery wheel.

Automated windows are operated via direct digital control to provide the first stage of space cooling.

Modeling during design was performed with two different building analysis software programs for energy and comfort modeling. Both models used a Seattle TMY2 weather file and identical geometries.

The building was assumed to be fully occupied with 150 ft^2/person peak occupancy in the open office spaces. Occupant density significantly affected the energy loads since each person was assumed to work at a computer. The model assumed a mix of equipment use: desktop computer stations with two monitors each (65%), laptops plus a monitor (20%) and thin-clients plus a monitor (15%).

Other typical office equipment was also included in the model. Schedules were applied to simulate the building operating at about 80% of peak occupancy from 8 a.m. to 5 p.m. weekdays.

The Bullitt Center's energy use is measured and monitored at the

View west along rooftop photovoltaic array. PV panels are elevated above the membrane roof on a steel structure. A single array tilted to follow the building's zoning envelope was found to provide maximum power potential on the tight urban site.

© Benjamin Benschneider

"The **culture of conservation extends beyond choosing to use the stairs over the elevator** to operation of windows and shades, to behavior that affects the water systems, and of course to energy performance."

BUILDING AT A GLANCE

Name Bullitt Center

Location Seattle

Owner The Bullitt Foundation

Principal Use Office

Employees/Occupants 125

Expected (Design) Occupancy 170
Percent Occupied 74%

Gross Square Footage 52,000
Conditioned Space 50,142

Distinctions/Awards
AIA COTE Top Ten, 2015; Sustainable Buildings Industry Council Beyond Green Honor Award, 2014; American Council of Engineering Companies National Engineering Excellence Honor Award, 2014

Total Cost $18.2 million (construction cost)
Cost per Square Foot $349

Substantial Completion/Occupancy April 2013

ENERGY AT A GLANCE (U.S)

Annual Energy Use Intensity (EUI) (Site) 10.8 kBtu/ft^2
Electricity (Grid Purchase) 2.3 kBtu/ft^2
Electricity (on-Site Solar or Wind Installation) 8.5 kBtu/ft^2

Annual On-Site Renewable Energy Exported 9.2 kBtu/ft^2

Annual Net Energy Use Intensity –6.9 kBtu/ft^2

Annual Source (Primary) Energy 15.7 kBtu/ft^2

Annual Energy Cost Index (ECI) $0/ft^2

Annual Load Factor 45%

Savings vs. 2009 Seattle Energy Code Design Building* 79%

ENERGY STAR Rating 100

Carbon Footprint 0 lb $CO_2e/ft^2 \cdot yr$

Heating Degree Days (Base 65˚F) 4,615

Cooling Degree Days (Base 65˚F) 192

Annual Hours Occupied 2,500

*2009 Seattle Energy Code baseline approximately 10–20% better than ASHRAE Standard 90.1-2007. Baseline model not calibrated.

WATER AT A GLANCE

Annual Water Use 50,442 gallons

KEY SUSTAINABLE FEATURES

Water Conservation Rainwater captured in 56,000 gallon cistern for all building and site uses (potable use pending regulatory approval). Composting toilets.

Recycled Materials Salvaged wood formwork. Materials selected for compliance with Living Building Challenge Red List (chemicals to avoid) and Appropriate Sourcing (distance radius limits).

Daylighting Daylight penetration (2% daylight factor, overcast sky) approximately 20 ft into the space. Exterior automated blinds for glare control.

Individual Controls Windows (sliding doors) in conference room areas manually operated. Local control of ceiling fans.

Carbon Reduction Strategies Forest Stewardship Council-certified heavy timber wood structure, locally harvested. Operational net zero energy and net zero water.

Transportation Mitigation Strategies No on-site automobile parking. Parking for 29 bicycles. Showers in each restroom. Located in neighborhood with Walk Score of 98.

Other Major Sustainable Features 242 kW PV array. "Irresistible stair." Regenerative elevator. Small green roof areas including constructed wetland for graywater treatment.

BUILDING ENVELOPE

Roof
Type Styrene-butadiene-styrene (SBS) modified on wood decking, rubberized asphalt on concrete
Overall R-value R-40

Walls
Type Steel stud, continuous exterior insulation
Overall R-value R-25
Glazing Percentage 40%

Basement/Foundation
Slab Edge Insulation R-value R-10
Basement Wall Insulation R-value R-10
Basement Floor R-value R-10
Under-Slab Insulation R-value R-10

Windows
Effective U-factor for Assembly 0.25
Solar Heat Gain Coefficient (SHGC) 0.32
Visual Transmittance 0.56

Location
Latitude 47.5
Orientation NW/SE

BUILDING TEAM

Building Owner/Representative The Bullitt Foundation/Point 32

Architect The Miller Hull Partnership

General Contractor Schuchart

Mechanical, Electrical Engineer; Energy Modeler PAE Consulting Engineers

Structural Engineer DCI Engineers

Civil Engineer Springline Design

Landscape Architect Berger Partnership

Lighting Design Luma Lighting Design

Commissioning Agent Keithly Barber Associates

Daylighting Design Support University of Washington Integrated Design Lab

Solar PV Design Solar Design Associates

Water Systems Design 2020 Engineering

Building Envelope Consultant RDH

individual circuit level. Each circuit is designated as a building load or a tenant load and categorized by type of use, such as HVAC or lighting.

These data are displayed in an interactive public dashboard at the Bullitt Center and on the Web. Unfortunately, the submetering system wasn't fully commissioned and has only recently been providing useful end use data, so the data presented in this article are from the utility net metering system.

Without end use breakdowns, it is not easy to explain where the better-than-expected energy use is coming from, but the design and ownership team believe it is primarily tenant-related (*Figure 3*). Less dense office occupancies and more efficient computing equipment have been identified as likely sources of the discrepancy.

Net Zero Water

The building's once-through water system is designed to operate independently of any utility, using collected rainwater as its water source and treating wastewater on site. Rainwater is collected from the roof and stored in a 56,000 gallon cistern.

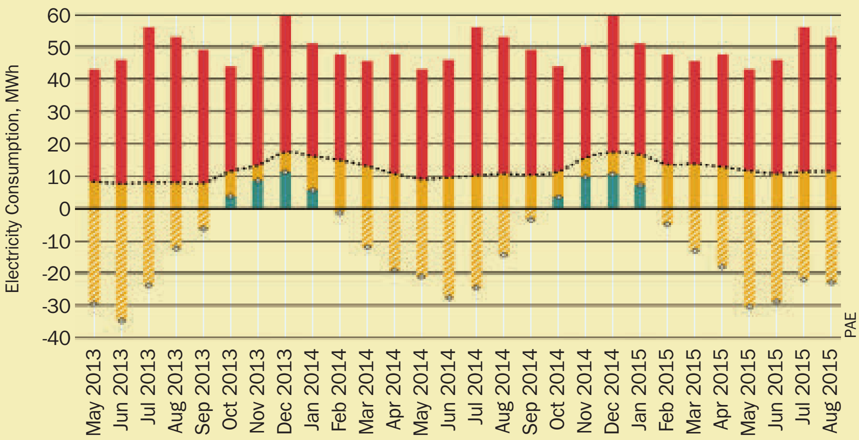
The Living Building Challenge

The Living Building Challenge (living-future.org/lbc) is an advanced green building certification administered by the International Living Future Institute. It is based on adherence to 20 performance requirements called imperatives organized into seven "Petals."

Significant imperatives discussed in this article include net zero energy, net zero water, chemical Red List and sourcing, and civilized environment and healthy air. All imperatives must be met and documented following one year of operation to achieve full Living Building status.

Net zero energy is defined as site energy and measured on an annual basis. Net zero water requires all water be captured, used, and disposed of on site, although storm water flows are to mimic pre-development hydrology.

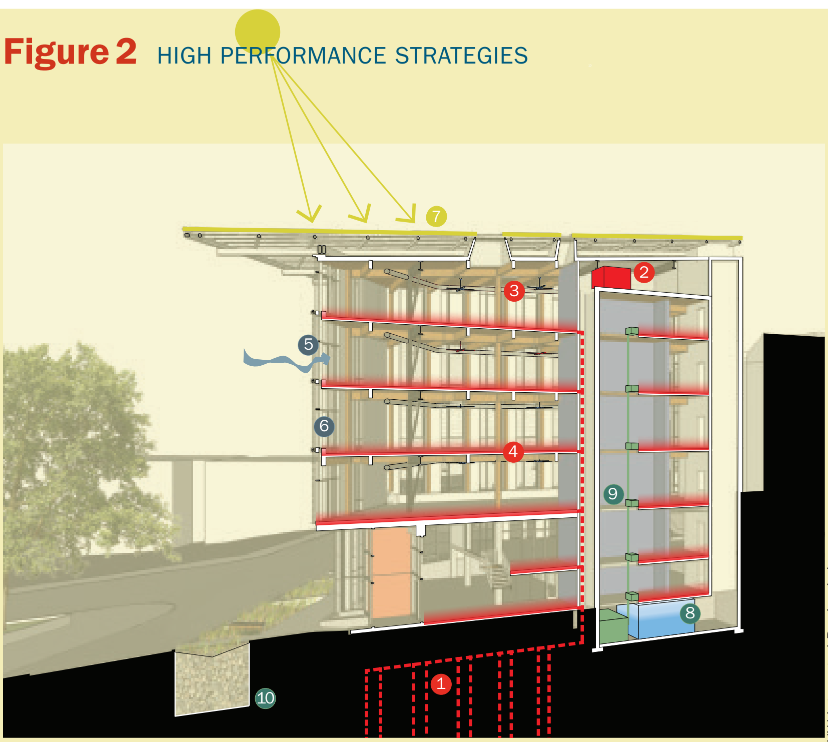
Figure 1 ENERGY USE, PRODUCTION



Utility Power Used
PV Exported to Utility
PV Used by Bullitt
Savings Over Baseline*
Bullitt Building Use
Utility Net Meter

*Baseline is 2012 Seattle Energy Code.

Figure 2 HIGH PERFORMANCE STRATEGIES



UW Integrated Design Lab

Heating/Cooling Fresh Air

1. Closed-Loop Geothermal Wells
2. Dedicated Ventilation System With Heat Recovery Wheel and Demand-Controlled Ventilation
3. Low-Velocity Ceiling Fans
4. Radiant In-Floor Heating and Cooling

Envelope

5. Automatically Actuated Windows Provide Fresh Air and Night Flush Ventilation
6. Triple-Glazed Curtainwall

Energy Production

7. 242 kW PV Solar Panel Array

Water Conservation

8. 56,000 Gallon Cistern Stores Rainwater for Building/Site Use*
9. Composting Toilets
10. Infiltration Trench for Treated Graywater

*When approved by the King County Health Department, the building's water purification system will provide drinking water to the building.

The rainwater is designed to be filtered, disinfected with UV and chlorine, and stored as potable water in a 500-gallon day tank. While the filtration and disinfection is sufficient to bring the water to potable quality, current regulations have thus far prevented the project from providing rainwater to potable water fixtures, and municipal water is provided instead.

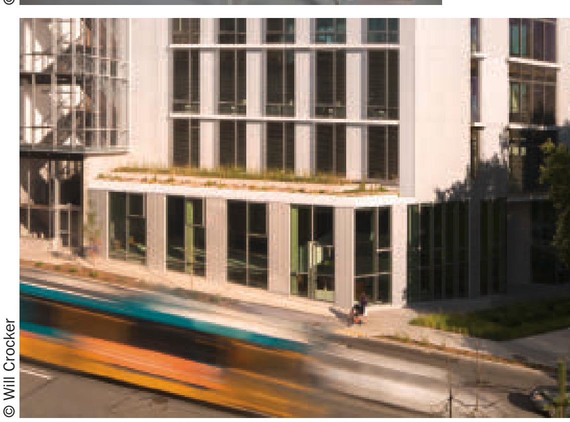
The building owner is working to establish an independent water district for eventual approval to the rainwater-to-potable system. Rainwater is provided to the building's foam flush toilets.

Graywater is collected from the building's showers, sinks, floor drains, and lavatories, but not reused.

Below Ten composters in the basement collect waste from toilets on the six occupied floors. Toilets are exhausted through the composting units. The first compost was offloaded in January 2015, 18 months after initial occupancy, for treatment and eventual use as fertilizer.

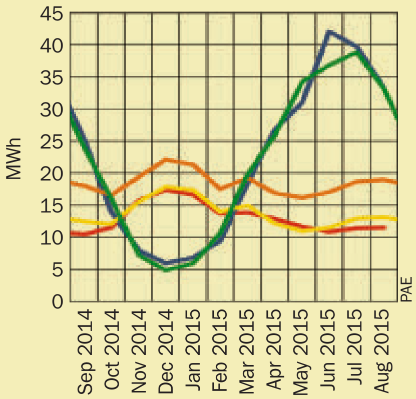
Bottom The constructed wetland for graywater treatment is located on the third-level green roof area on the building's north terrace. The wetland treatment system allows water from the building's showers, sinks and floor drains to be returned to the local aquifer rather than a wastewater treatment plant.

© Benjamin Benschneider



© Will Crocker

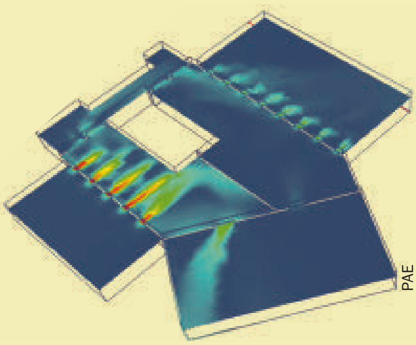
Figure 3
ACTUAL VS. PREDICTED ENERGY DATA



- Actual Energy Consumption
- Predicted Energy Consumption 75% Occupied
- Predicted Energy Consumption 25% Occupied
- Actual Energy Production
- Predicted Energy Production

Actual and predicted energy consumption and production, and occupancy-calibrated energy model. To explore lower-than-expected energy use and whether or not occupancy explained the differences, PAE reran the energy model using partial occupancy scenarios. The graphic shows that actual energy use in the building is trending at about the 25% occupancy level even though occupancy levels are actually 75% of what was expected.

Figure 4
NATURAL VENTILATION MODEL



Velocity Magnitude (ft/s)

5.04623
4.5
4
3.5
3
2.5
2
1.5
1
0

Model image from computational fluid dynamics (CFD) analysis on subdivided office floor. CFD was used to analyze the impacts of subdivided office floors on the ventilation/passive cooling performance and to recommend design improvements.


© Nic Lehoux

Instead, it is stored in a 500-gallon tank, then pumped through a constructed wetland on the building's north terrace. The water recirculates through the wetland and finally flows into swales at grade to replenish the local groundwater aquifer.

All toilets in the building feed into the composting waste system. The foam flush toilets use approximately 0.04 gallons of rainwater per flush. The toilets prewash the bowl with foam when they are approached; the foam lubricates the bowl and feeds continuously during use to allow solids to pass through the fixture.

Ten composting bins in the basement collect nutrients from the toilets. The composters are continuously exhausted, manually turned daily, and have excess leachate pumped to a storage tank. The leachate is hauled away approximately every 12 to 18 months for treatment and reuse as fertilizer.

Daylighting

Daylight is intended to be the primary source of illumination in all tenant spaces. Building massing, window specifications, floor plate organization, and space planning are designed so no workstations are more than 20 ft from a window.


© Nic Lehoux

Top View towards downtown Seattle from west-facing office/conference area. This area on the sixth floor looks over the McGilvra Park tree canopy to the downtown core and beyond. At lower levels this façade is shaded by the mature trees in the park. Large lift/slide doors can open wide to create an outdoor "deck" experience

Above Primary daylighting façades face southeast (seen here) and northwest, and are approximately 60% glazed. The overall window-to-wall ratio is 40%. Exterior automatic operable blinds provide solar and glare control.

To manage dynamic sunlight, a weather-responsive automated exterior horizontal blind system is included. This system enables sunlight diffusion, glare control, and dynamic solar shading based on current solar exposure. And, importantly, it reverts to maximum unobstructed aperture area under Seattle's overcast skies or during clear sky conditions on façades that are not receiving direct sunlight.

The Bullitt Center design reflects a modeled 67% reduction in electric lighting power consumption over a code building. This includes a connected lighting power density target of 0.4 W/ft² with additional reductions in lighting power via photocell-controlled continuous dimming, vacancy sensing, time clock-based sweep controls, and manual wall switches.

The persistent delivery of sufficient, visually comfortable daylight illuminance and luminance for significant periods of the occupied times is critical to meeting net zero annual energy. Accordingly, proper operation of the automated exterior blinds must be maintained for comfort and energy performance.

Blind slat tilt-control and deployment schedules are pre-programmed based on latitude, longitude, and façade orientations. A solar radiation sensor on the roof deploys or retracts the shading system based on sky conditions.

Technically, tenants may choose to install any lighting and lighting controls system that meets the Seattle Energy Code (SEC), so long as they do not exceed a maximum annual total power allowance codified in the tenant "green" lease.

Current lighting energy use is less than anticipated, primarily due to tenants manually turning off ambient overhead lighting more than expected. This is likely due to the conservation-oriented nature of many of the building tenant organizations and because lighting is a particularly "visible" source of energy use building occupants can directly impact.

Natural Ventilation and Passive Cooling

The building is provided with actuated windows for indoor comfort. During occupied hours, the windows operate during suitable conditions to maintain 70°F.

A night flush mode maintains 60°F zone air temperature. Occupant override allows user control of the windows and reverts to automatic control after a set time limit.

The building's natural ventilation performance was modeled to understand cooling comfort and window size requirements (*Figure 4*). Tenants are encouraged to maintain a minimum amount of openings in partition walls to maintain the designed cross-ventilation rate.

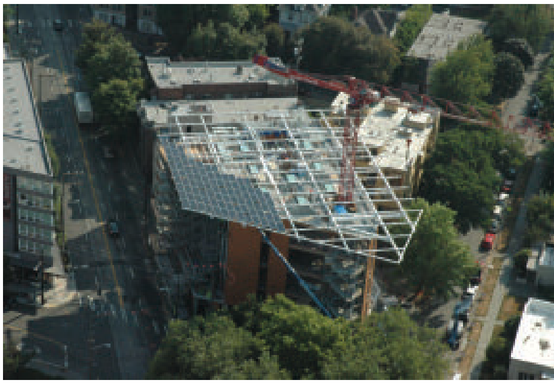
Materials

The Living Building Challenge presents challenging requirements for materials procurement. The Red List imperative enumerates 14 chemicals to avoid in building components, with the intent of removing chemicals harmful to humans and the environment from the entire building life cycle.

The Appropriate Sourcing imperative promotes development of ecological and regional building solutions by limiting the distance materials may travel to the building site. The result is a built work that derives its aesthetic from its structure and a minimal materials palette, in this case showcasing regionally sourced wood and concrete. The design and construction team worked with subcontractors and material suppliers in screening materials.

Below Installation of the photovoltaic array on its support structure was coincident with construction of the building.

Bottom The lower two floors are concrete and upper four floors are heavy timber. The project was the first newly constructed heavy timber building in Seattle in 80 years. Steel was used for wood connections and for lateral load-resisting braced frames on the upper floors.



© Miller Hull

© Miller Hull

© Miller Hull

Window system installation in progress. Air tightness at the interface between the curtainwall and fluid-applied air/weather barrier is achieved with ethylene propylene diene terpolymer (EPDM) flap integrated into aluminum framing. The curtainwall incorporates 4 ft by 10 ft parallel arm vents with motorized actuators and operable windows, which extend 7 in.

Lessons Learned

☐ **Net Zero Energy Indoor Environment.** Achieving net zero energy performance can be architecturally liberating. Spaces within the building are extremely well daylit and comfortable. Simple HVAC and lighting systems reduce ceiling clutter. Reducing the number of finishes to simplify materials vetting under the Living Building Challenge promotes expression of the building structure and allows the aesthetics to derive from environmental performance.

☐ **Metering and Verification Systems Need Commissioning, Too.** Operational challenges have been experienced with end use submetering and in maintaining the data interface/dashboard through ongoing tenant improvements and changes in the building. After more than a year of troubleshooting and validation efforts, the system is only recently reporting reliable data. With any complex system, many possible sources of error exist, and a process of verification needs to continue beyond the initial commissioning for the submetering.

☐ **High Performance and High User Engagement Can Be Achieved Without "Big Data."** In the design phases, detailed feedback was viewed as essential to the performance and to supporting appropriate behaviors. However, tenants are working toward project success, and the building is exceeding energy performance expectations even without detailed energy use data.

☐ **Need for Building Operator "Buy-In."** The building requires a full-time on-site skilled building engineer, although this person's role should diminish over time. The operator has delivered ongoing building commissioning of the energy, water, and metering systems over the first year and a half of operation, as is typical of high performance buildings. The design team believes it would have helped in the transition from construction to occupancy if the eventual operator had been involved in the design process.

☐ **Manual vs. Automatic.** The exterior shading system and the operable windows are automated, zoned by façade. Automation allows the windows to be used in night flush mode so they can be controlled after hours. However, this introduces challenges when windows open during the day without full input from occupants. An occupant override option is provided to allow ultimate user control.

☐ **Open Office Tension.** Two major design approaches to achieve net zero energy and related performance—the daylighting design and the natural ventilation approach—rely on an open office concept for the leased office space. As a result, the vast majority of the spaces have no partitions.

The open office decision was made early on, but a constant tension existed between this design and some tenants' desires for visual and acoustical privacy. Most tenants have created smaller private zones and enclosed conference areas for use when privacy is required. These decisions need to be made early in the design process and then revisited as the design moves forward.

The User Experience

Thermal comfort is anecdotally reported to be very good, even during summer 2015, which had a record-setting number of days with elevated temperatures. The thermally massive floors (3 in. of concrete over 6 in. of solid wood) provide an excellent heat sink in the summer and warmth in the winter, but in swing seasons may feel too cool when the radiant heating isn't energized. Heating setpoints were adjusted upward to solve this comfort issue.

Visually, the operable blinds provide excellent glare control. The design team expected some tenants might install interior blinds for more localized control of daylight. However, as of this writing, blinds have only been installed on the sixth floor where exterior blinds were not included due to the shading effect of the 20 ft overhang of the rooftop PV array.

Users say the Bullitt Center restrooms have no odors, even though they contain composting toilets. They are exhausted at the point of use through the toilet bowl. The restrooms are under continuous negative pressure to ensure composter vapors never reach the occupants.

Adherence to the materials Red List helps to achieve a high level of indoor air quality. However, other than testing for respirable suspended particulates and volatile organic compounds, no data is available to support this contention.

Project Successes/ Resulting Changes

With its own water supply and treatment system and its own energy plant, the construction of the Bullitt Center came at a cost premium. Because of the integrated design, however, it is not possible to calculate exactly what portion of its $350/ft^2 cost might be attributed to its environmental features or its high performance. The

Occupant Role in Project Success

The Bullitt Center design team knew that the project could only reach its goals with the cooperation of the people who would use it. Tenants have not only bought into sustainability goals, but their conservation-minded behavior is contributing to the building's lower than predicted energy use.

The "irresistible stair" is an example of how the building was designed to promote a more interactive, low-energy, interior environment. The unconditioned exit stair meets the fire code with rated construction between the stair and occupied space and sprinklers. But, it is pulled to the exterior of the building and made attractive.

Tenants prefer to use the stair over the elevator. The culture of conservation extends beyond the stair to operation of windows and shades, to behavior that affects the water systems, and to energy performance.

Bullitt Center leases differ from those for more conventional buildings. Besides outlining Living Building Challenge requirements for tenant improvements, use of shared resources (such as the server room), and other green practices, the leases also have set energy budgets for each space.

The intent is the tenants pay typical electricity costs, and if they do not exceed their budgets in a given year, they are fully reimbursed. In reality, however, the budgets haven't been fully implemented due to difficulties with the submetering system and because the building is vastly outperforming energy projections.

The "irresistible stair." What would otherwise be a windowless exit stair is pulled to the perimeter and made into a desirable part of the building. The stair is unconditioned and separated from the office areas with fire-rated construction, which was a significant design challenge.

© Miller Hull

Bullitt Center website (www.bullitcenter.org) has a more in-depth discussion of project costs.

More importantly, the cost of the project met the owner's requirements for economic feasibility. With a fully leased building, the project is making positive returns at typical class A rents in Seattle.

From a structural perspective, an example of change is the project spurred the City of Seattle to create the Living Building Pilot Program, which grants certain departures, such as additional floor area ratio (the square footage of a building divided by the lot's square footage) and building height, for projects targeting Living Building certification. The building height departure was the only departure used in this project, and the extra 10 ft of height was divided among each of the floors to increase structure height for better daylight penetration.

When approval is finally in place for operating as a water district, the project will be the first commercial building in the region to run on rainwater. It has also proven that using composting toilets in a multistory urban building is viable.

The project is the first in the region in which the public utility has contracted with a speculative building developer supplying high levels of energy efficiency as a grid resource. Using the term "negawatt-hours," the Bullitt Center receives monthly payments for the difference between its consumption and what a code building would have used, while passing on to tenants the full energy cost (which has been zero).

In the future, this type of arrangement would allow other building owners and developers a more direct and predictable return on additional investment in efficiency.

© Nic Lehoux

The "irresistible stair" and the cantilevered photovoltaic array, which extends into the right-of-way, are two distinctive design elements. The building is 10 ft higher than allowed by Seattle's building code, but city officials granted a departure. The additional height helps optimize daylighting on each floor.

Conclusion

The Bullitt Center has exceeded its original goals. It has operated on a net positive energy basis, was the seventh and largest Living Building when it was certified in Spring 2015, and is the first urban commercial project to be so recognized. And, since opening in 2013, the building has hosted more than 6,000 visitors interested in learning how they can achieve similar results in their own communities. ●

ABOUT THE AUTHORS

Jim Hanford, AIA, LEED AP BD+C, is an associate at The Miller Hull Partnership in Seattle.

Marc Brune, P.E., is a senior associate at PAE Consulting Engineers in Portland, Ore.

Christopher Meek, AIA, is associate professor at the University of Washington Department of Architecture and director of the Center for Integrated Design in Seattle.

Michael Gilbride is a research associate at the University of Washington Department of Architecture Integrated Design Lab in Seattle.