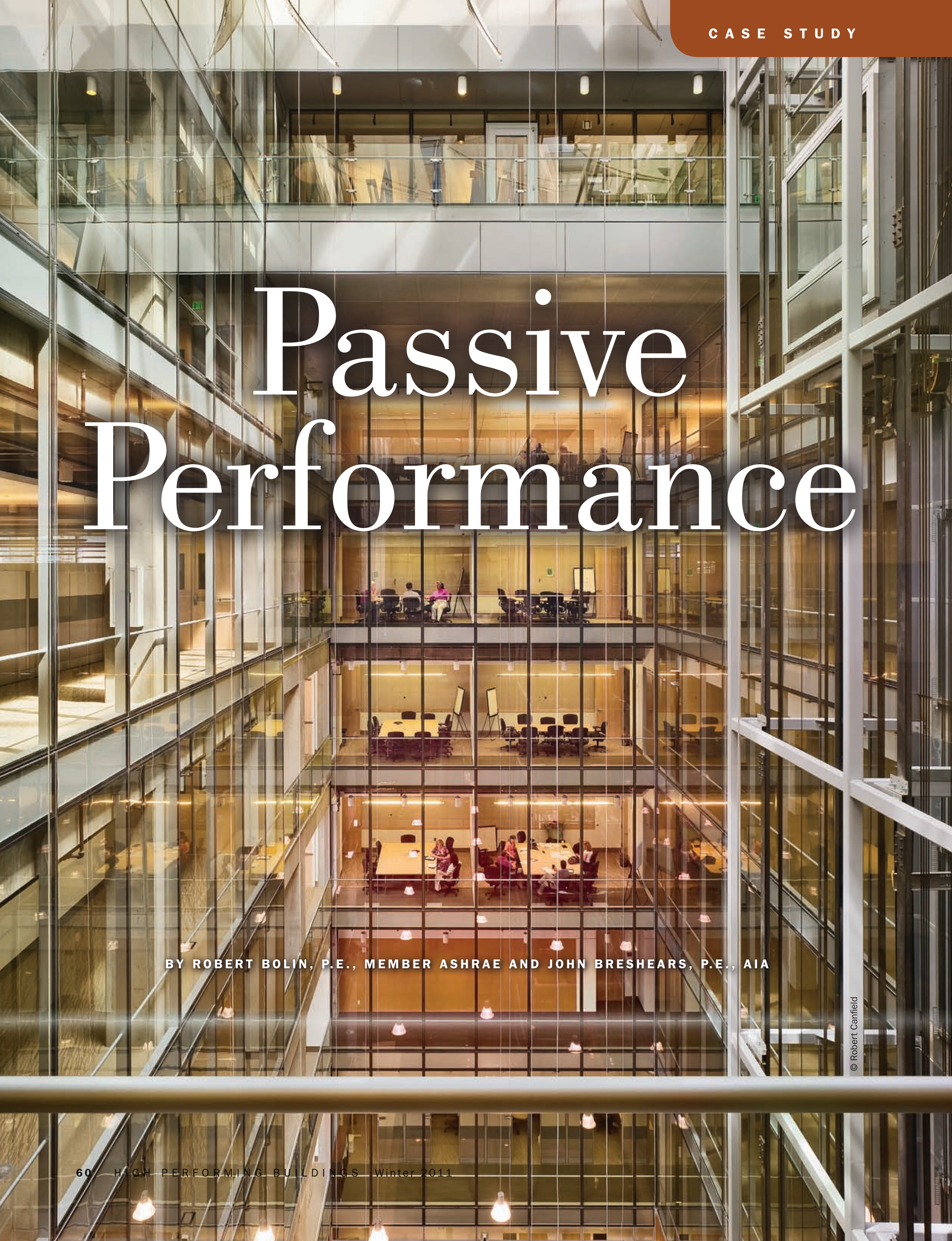

Passive Performance

BY ROBERT BOLIN, P.E., MEMBER ASHRAE AND JOHN BRESHEARS, P.E., AIA

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Situated on the high plains at the base of the Rocky Mountains, Denver has a semi-arid climate with sunny days and low humidity—ideal conditions for passive building strategies. The Region 8 EPA Headquarters harnesses nature's resources, capturing the benefits of free cooling, daylighting and solar energy.

The EPA Region 8 Headquarters serves the mountain states of Colorado, Montana, North Dakota, South Dakota, Utah and Wyoming. The facility, which opened in 2007, consolidated EPA offices that were previously spread out over 23 floors in two towers. Its setting in the revitalized urban district known as LoDo near alternative forms of transportation serves to remind the public of the EPA's mission of sustainability.

The General Services Administration (GSA) leases the building on behalf of the EPA. Both organizations require LEED Silver for their buildings as a minimum standard. The Region 8 Headquarters achieved LEED-NC Gold using holistic and integrated design, smart site orientation, an efficient underfloor air-distribution system, and a vegetated roof that manages storm water and minimizes the heat island effect.

Minimizing Loads

The building team designed the massing and orientation to capture the maximum climatic benefits (such as daylight and renewable energy) while minimizing thermal loads on the building. The team selected a "double L" design concept (see diagram, Page 62), which satisfied the desire to create a central atrium and worked well with the building's position on a street grid that is oriented 45° to the cardinal compass points.

A "sunward L" with legs facing southeast and southwest receives most of the solar radiation while the "windward L" bears the brunt of most of the wind. A series of preliminary studies comparing the merits of different building massing options with resulting thermal loads and daylight availability confirmed the performance benefits of this "double L" atrium approach.

The eastern break between these two wings forms the primary entrance to the building and is adjacent to an urban park, while the western gap orients occupants toward views of the Rocky Mountains.

Curtainwall systems for each "L" are designed as siblings, with the south-facing leg tailored to harvest direct sunlight while minimizing solar gain via a series of horizontal sunshades and lightshelves. The other leg is designed to maximize daylight harvesting from the diffuse north sky while blocking low-angle summer sun with vertical blinds. The nine-story northern leg shelters a roof terrace on the eight-story southern leg from the wind while leaving it exposed to the sun.

The building team evaluated the performance of alternative glazing, external shading devices and reflective versus vegetated roof. The team performed these analyses in an effort to achieve the requisite

Opposite A central atrium provides daylight to the interior of the EPA Region 8 Headquarters in Denver. Energy modeling showed that the atrium design offered the best combination of energy efficiency and daylighting.

BUILDING AT A GLANCE

Name EPA Region 8 Headquarters

Location Denver

Owner Opus Northwest

Principal Uses Office, Conference Center, Retail

Employees/Occupants 775 EPA personnel/900 occupants

Occupancy 100%

Rentable Square Footage 300,000 total; 248,849 (EPA)
Conditioned Space 257,400

Total Cost $90,000,000
Cost Per Square Foot $300

Substantial Completion/Occupancy January 2007

Distinctions/Awards Evergreen Award for Ecommercial category, Eco-Structure Magazine (2009); American Architecture Award (2008); Federal Energy Saver Showcase Award (2007); LEED-NC Gold balance of useful versus harmful energy flows that would also meet the challenging aesthetic and development goals of the LoDo District.

The district maintains design criteria intended to preserve architectural characteristics of the area. The LoDo requirement for street-front presence, for example, conflicted with government security-related mandates for building setback. Other district requirements influenced material use, cornice heights and architectural expression of center block alleys.

KEY SUSTAINABLE FEATURES

Water Conservation
Low-flow plumbing fixtures (aerators and automatic faucets, showers, sinks)
Waterless urinals, dual-flush toilets
Water-conserving mechanical system design
Drought tolerant and low maintenance landscape design using sustainable and native species
Drip irrigation system

Storm Water Management
20,000 ft^2 modular vegetated roof system planted with sedum that reduces storm water pollution, minimizes heat island effects and absorbs carbon dioxide

Recycled Materials
Construction Waste: More than 75% was recycled and diverted from landfills
Countertops: Local stone, recycled glass, aluminum scraps
Acoustic Ceiling Tiles: Recycled glass
Wall covering: Recycled fabric, bamboo
Floors: Recycled tires, natural cork
Carpet: Recycled content 8%–35%

Daylighting
Lightshelves
Exterior vertical fins for shading, atrium sails to control daylight, solar heat gain and glare
Lighting controls with occupancy sensors

Individual Controls
Task lighting
Floor diffusers

HVAC
Underfloor air-distribution system
Variable speed chillers, pumps and cooling tower fans
Air-side economizers
Demand-control ventilation
Air-side energy recovery
Parking ventilation and exhaust based on carbon monoxide sensing

Construction Site
All equipment operated with biodiesel fuel


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The 20,000 ft^2 vegetated roof (covering three terraced levels) controls storm water, absorbs carbon dioxide and decreases the urban heat island effect. It is the first vegetated roof in Denver used to manage storm water.

Passive Strategies

Passive strategies take advantage of Colorado's Front Range climate. While security concerns and hardened perimeter requirements prevented an exclusive natural ventilation strategy, the low humidity and large daily diurnal temperature variation provide an ideal opportunity to flush cool night air through the building. The concrete structure is designed to maximize its exposure to the building interior, reducing cooling requirements through radiant and convective cooling.

Iterative energy and daylight simulation helped balance internal daylighting with undesirable glare and winter passive solar heating with summer solar protection. Design performance decisions were ultimately based on components that worked best over the entire year, not just seasonally.

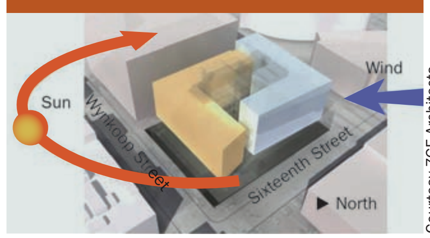
The EPA Region 8 Headquarters building serves as a pilot project for the first green roof used as a storm water management system in Colorado. The design team sought to use a 4 in. extensive vegetated roof in place of the typically required storm water control tanks and filters.

However, Colorado water rights law, based on the principal of prior appropriation common to many western states, precludes the capture and reuse of storm water because rights to that use are assumed to be owned by others. The design team worked closely with regulatory agencies to design a vegetated roof system with minimal water retention capability—just enough to irrigate the area.

A joint effort by the design team, the EPA and national experts to present documented performance data, together with a commitment by the EPA to monitor and test the effectiveness of the system for a five-year trial period, convinced local authorities to approve the vegetated roof. The team presented studies comparing vegetated roof runoff rate reductions with standard methods for quantifying hydrologic runoff. It also provided studies showing vegetated roofs' removal rates of phosphates, organic matter and other pollutants.

Through a coalition of the EPA, Colorado State University and the Denver Botanical Garden, the vegetated roof continues to serve as a test bed for storm water management, new plant breeds for the Front Range area and urban heat island reduction.

DOUBLE "L" SCHEME



Courtesy ZGF Architects

Two "L"-shaped wings enclose a central atrium. The eight-story "L" (left) faces southeast and southwest, receiving most of the solar radiation. The nine-story "L" wing (right) takes the brunt of the prevailing winds and shelters the roof terrace on top of the eight-story wing.

ENERGY AT A GLANCE

Energy Use Intensity (Site) 74.3 kBtu/ft^2
Electricity 44.3 kBtu/ft^2
District Steam 30 kBtu/ft^2
Renewable Energy Data unavailable

Annual Source Energy 192 kBtu/ft^2

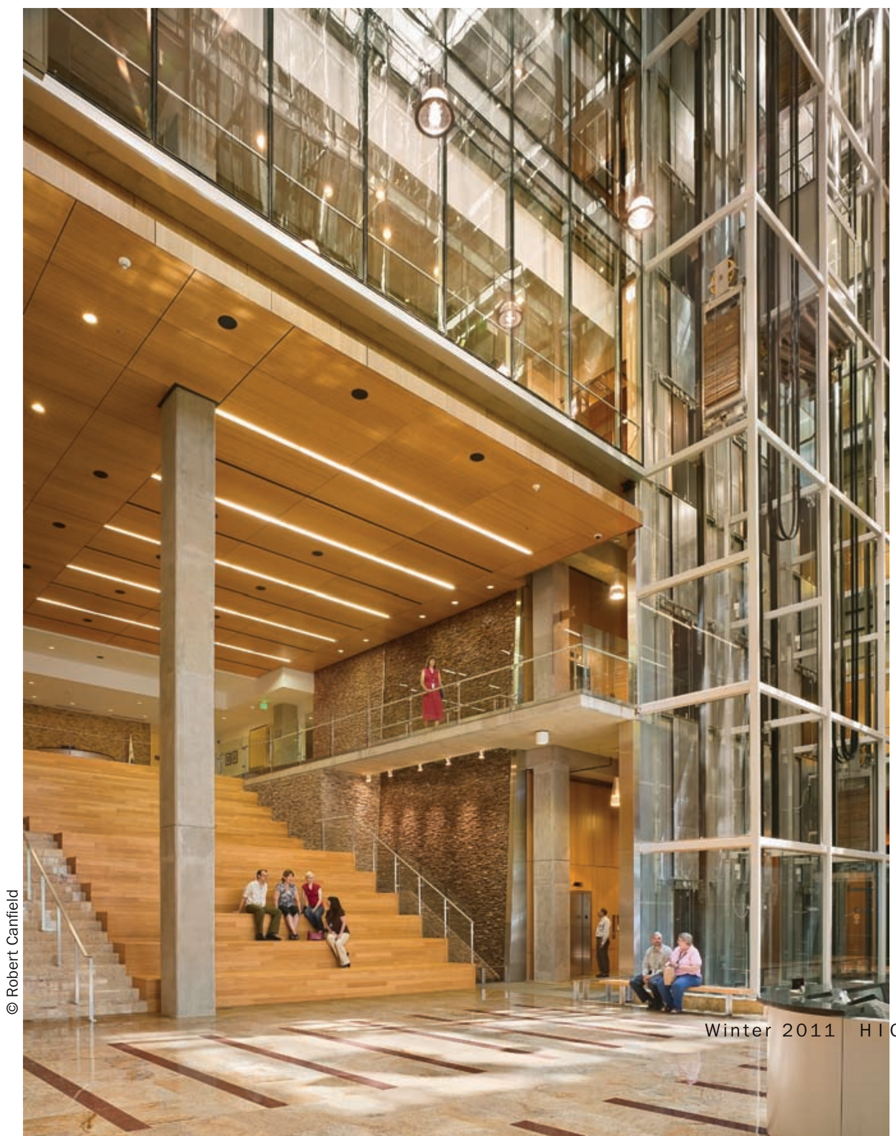
Annual Energy Cost Index (ECI) $1.72/ft^2

Savings vs. Standard 90.1-1999 Design Building 25.4%

ENERGY STAR Rating 96 (2008)

Optimizing Active Systems

An integrated suite of mechanical, electrical and plumbing (MEP) systems are designed to work in conjunction with the building's architecture and structure, supplying only the required supplementary conditioning at any given time and allowing the building to take advantage of its passive features.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Above Water trickles down a sloped stone wall (upper left), under a raised walkway and next to a lobby bench. The water feature, reminiscent of a Colorado stream, contributes to the ambiance of the lobby and adds a small amount of humidity to the building.

Left The two-story lobby and nine-story atrium serve as the "hearth" of the building, providing a light-filled informal gathering area. The building team selected rapidly renewable or high recycled content materials including flooring made from bamboo, recycled tires and natural cork.

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Horizontal external shading on the southeast and southwest sides of the building minimizes solar penetration (heat gain and glare) while maximizing distribution of daylight. The external shading works in coordination with interior automated shades and atrium sails to provide daylight throughout each floor.

BUILDING ENVELOPE

Roof
Type Vegetated roof
Overall R-value R-31 (0.032 U-value)

Walls
Type Brick/Curtainwall spandrel
Overall R-value R-20 (U-value: 0.05)/R-17.5 (U-value: 0.057)
Glazing percentage: 45%

Foundation
Under slab insulation R-value: R-20 (U-Value: 0.050)

Windows (Tower/Brick Base)
U-value (center of glass/assembly) 0.29/0.34; 0.47/0.50
Solar Heat Gain Coefficient (SHGC) 0.38/0.70
Visual transmittance 70%/79%

DAYTIME CLEANING SAVINGS

The EPA has taken steps to increase the building's operational efficiency as well. A daytime cleaning program allows the building to be "put to sleep" for 10 hours every night, instead of continuing to consume resources for a nighttime cleaning crew.

This program saves energy and money, while avoiding emissions and reducing light pollution. The daytime cleaning program reduced the building's energy costs in 2007 by 28%, saving nearly $250,000, or $0.80/ft^2.

UFAD SYSTEM SURVEY

The Center for the Built Environment (CBE) at the University of California, Berkeley, with the help of project architect ZGF, conducted a post-occupancy evaluation in March 2008 based on performance data and occupant survey results. One primary area of assessment focused on effectiveness of the underfloor air-distribution (UFAD) system, designed to provide ventilation, comfort, and heating and cooling to the occupants in the office space above the second floor.

Extensive testing and commissioning by CBE revealed at the time that the building's HVAC system with UFAD ranked as one of the best performing systems of its type in the nation, satisfying occupants and operators. In fact, 75% of the occupants who responded preferred the UFAD over traditional systems.

The occupant and operator survey evaluated comfort, air quality, floor diffusers, acoustics, cleanliness and maintenance of the UFAD system. The results showed that the systems were performing well.

The survey results ranked high relative to the CBE database benchmarks, including 73% approval for thermal comfort and 87% approval for air quality. The acoustical performance at 71% was notably higher than the CBE database and was considered better than most buildings in its class. About 25% of respondents reported complaints about the diffusers, including noise, drafts and problems with adjustments. Some potential problems cited by respondents are inherent to UFAD systems, so operators did not regard them as major issues.

Thermal comfort data were collected from four of the six floors served by the UFAD system during a period of three days and indicated the occupied areas were performing within comfort standards. Average room temperatures were within ASHRAE standards; stratification performance was acceptable although lower than optimal; and supply plenum performance was satisfactory with low leakage.

Survey results ranked high in nearly all categories, averaging above 70% in percentile rankings.

An underfloor air-distribution (UFAD) system on all office floors (third floor and above) provides added flexibility for office reconfiguration and a healthy, quiet and ultra-low energy ventilation system. The UFAD system also helps expand the free cooling outdoor air economizer zone operation available for the Denver climate, allowing the use of 100% outside air more frequently to cool the space instead of mechanical refrigeration.

The first and second floors accommodate public functions, including a conference center, and are served by a conventional overhead VAV system.

A demand-controlled ventilation (DCV) system controls the UFAD system using carbon dioxide sensors throughout the building and monitoring stations in the air handlers. The installation was the subject of subsequent post-occupancy evaluation by the Center for the Built Environment at the University of California, Berkeley (see *UFAD System Survey*).

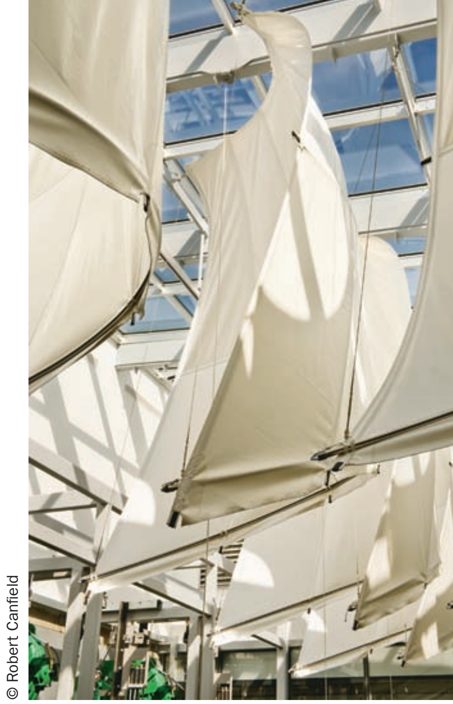
An air-side energy recovery system using runaround loops transfers energy from the building relief air to the outdoor air in the air-handling units, further reducing energy demands for mechanical heating and cooling. The air-handling systems include air-side economizers, taking maximum advantage of the Colorado climate for free cooling.

The roof-mounted central cooling plant is comprised of high-efficiency, variable speed electrical centrifugal chillers, variable speed pumps and cooling tower fans with variable speed motors. The adjacency of this plant equipment minimizes piping pressure and thermal losses, further improving energy efficiency.

Plate and frame heat exchangers are provided for waterside free cooling and a separate circuit is provided for after-hour and 24-hour loads. For space and domestic hot water heating, the building connects to a district steam heating system. A cascade approach converts the steam to space heating hot water and then recaptures the waste heat from steam condensate, which is used as the source for the domestic hot water.

An extensive analysis of the predicted passive daylight performance informed the development of the lighting layout and controls. In the daylight zones of the southeast and southwest exposures, a series of interior automated venetian blinds are installed above the lightshelves and exterior sunshades. The blinds follow the solar position using a timing control sequence to maximize useful daylight and minimize glare throughout the varied conditions of the solar calendar.

Zoning and dimming solutions are designed to work closely with the daylight control systems, optimizing the use of electric lighting power against the added cooling load of entering solar radiation. The system redirects daylight down through the atrium to light the common space at the floor level and office floor plates above, while protecting occupants near the atrium walls on the upper floors from the sun's glare.



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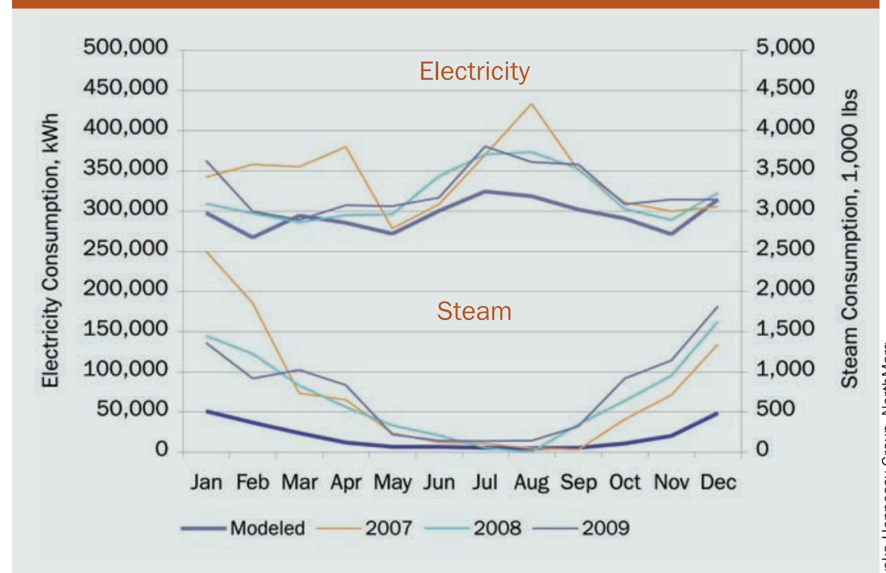
Above left The building interior is 85% naturally lit, using interior shades, exterior fins and parabolic sails in the atrium to manage daylight, solar heat gain and glare. These strategies, along with an integrated lighting control system, help reduce building energy use.

Above right South-facing canvas sails suspended from the top of the atrium redirect sunlight downward and prevent glare. A Portland sail making company fabricated the sails, and a Denver theatrical rigging company employed rock climbers to hang them.

MODELED VERSUS ACTUAL ENERGY USE 2007–2009



Syska Hennessy Group, NorthMarq

This chart compare the DOE-2 energy modeling data with the actual energy consumption data for the building's first three years of operation. The energy modeling data reflects the final figures that were included for the LEED certification submittal and has not been calibrated to actual building operation. Therefore, discrepancies appear between the model data and actual utility bill data, which can occur when actual data is compared with the design model data.

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A combination of high-efficacy T8 and compact fluorescent lamps provide automatically controlled and dimmed ambient lighting. User-controlled task lighting coupled with occupancy sensors provide well-lit, well-integrated, and energy-efficient lighting throughout the building.

A single daylight model was shared between the architect and engineer. Using this common model, ZGF and Syska Hennessy worked together to efficiently refine the design and assess its performance.

A design session with a physical model on a heliodon (artificial sun) at a local university provided unexpected insights that sent the design in a direction different from the original concept. The elliptical profile of the reflector grid on a standard fluorescent light fixture provided the inspiration for an array of south-facing sail shapes suspended below the atrium glazing.

The building team selected a small sail making company in Portland that fabricated the sails using materials and technology from

Above **The EPA Region 8 Headquarters is a mixed-use building that meets the EPA's security requirements and its mission of sustainability. Energy and daylighting simulation helped the building team design the building's massing and orientation to take maximum advantage of the sunny, dry climate.**

Above left **A 10 kW array of 48 photovoltaic panels is mounted on the south corner of the building's vegetated roof. The array supplements the power needed to run the building's emergency response center and reduces emergency generator load and fuel consumption when solar energy is available.**

LESSONS LEARNED

Even though the project didn't have the funding to promote onsite energy generation from initial design, the building team created functionality and flexibility within the building's infrastructure that included the necessary support for future onsite generation. Subsequently, during construction, supplemental funding was secured for a 10 kW rooftop photovoltaic array mounted above the planted area on the vegetated roof.

To design a high performing building, decisions on alternative strategies must be made by evaluating them with total building performance modeling. Although building teams may focus only on energy modeling, this project shows the importance of daylight modeling for balancing daylight and glare with the amount of energy used.

Designers need post-occupancy feedback on how the building is actually performing so this data can be used to continually tune building performance. For example, higher cooling season energy consumption shown in early electric bills led the design team to discover that the night-flushing regime designed was not being executed properly, and the issue was corrected.

Widely divergent steam charges in the first year of operation led to the discovery of a malfunctioning ultrasonic steam meter. Externally induced vibrations were causing the meter to register a flow even when the steam was fully shut off. The building likely used less steam than building data indicates, but steam consumption is still higher than modeled.

The local utility has adjusted the meter repeatedly, although ongoing readings still suggest some discrepancy between actual and metered consumption. The design team, the building engineer, the commissioning agent and the local utility continue to communicate and investigate. This challenge serves as a reminder that operating a building as designed is not always a straightforward achievement.

The building's vegetated roof is the first for the city of Denver, demonstrating that policy can be shifted in the face of compelling evidence. Calculations show that the 4 in. vegetated roof meets storm water control rights regulations while providing sufficient water to support sedum and drought tolerant plant species. This roof is the subject of ongoing monitoring and research.

the yachting industry. A theatrical rigging company in Denver hired a group of rock climbers to install the sails at the top of the atrium.

Due to their elliptical sectional profile, the sail shapes gather daylight from any incident angle and focus it in the desired downward direction. Ultimately, the turnkey solution was completed for a lower cost than the budget allowance. Looking up from the atrium floor, the sails evoke the sun, wind and light.

The building's HVAC, lighting and water systems were tuned through a rigorous commissioning process, including a measurement and verification plan. Additional testing and verification began during design development, continued through construction and turnover, and remain part of the culture of the building operation today.

Renewable Energy Generation

Building-integrated PV panels were designed for inclusion in the spandrel panels of the "sunward L," while the cornice of the "northern L" was designed to accommodate a series of vertical axis wind turbines under a concentrating airfoil. Both systems were beyond the project budget and ultimately were not included in the construction.

However, the EPA secured funding from its security division for a 10 kW, 48-panel rooftop photovoltaic system that is mounted above the planted area on the vegetated roof. The installation contributes to the electrical security backup of the building, while also offsetting the base building load. The building's electrical infrastructure is designed to accommodate the wind turbines in the future, should the organization choose to install them.

During the process of design and construction, the national EPA headquarters in Washington made an agency-wide commitment to purchase 100% renewable energy. Wind-generated power purchased from Excel Energy offsets the energy use of the Region 8 headquarters.

Conclusion

The building was designed, built and is being operated in a way that supports the EPA's mission of environmental stewardship. Its LEED-NC Gold certification, ENERGY STAR rating of 96 and positive occupant survey results are testament to the integrated building process from design and construction through operation. ●

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The building's exterior blends the brick façades found throughout Denver's Lower Downtown Historic District with the more modern steel and glass façades of the newer areas of development. Vertical sunshades on the building's northeast and northwest sides block low sun angles during the early morning and late afternoon hours.

BUILDING TEAM

Building Owner, General Contractor
Opus Northwest

Client/Tenant General Services Administration on behalf of the U.S. Environmental Protection Agency

Architect of Record
Opus Architecture & Engineering

Design, Landscape Architect; Environmental Consultant
Zimmer Gunsul Frasca Architects

Consulting Architect
Shears Adkins Architects

MEP Design Engineer, MP Engineer of Record, Energy Modeler
Syska Hennessy Group

Associate Mechanical Engineer
Doyle Engineering

Electrical Engineer of Record
BCER Engineering

Structural Engineer
KPFF Consulting Engineers

Blast Engineer
Hinman Consulting Engineers

Civil Engineer Martin/Martin Consulting

Lighting Design Keylight + Shadow

LEED Consultant
Architectural Energy Corporation

EPA LEED Review Consultants
ENSAR/RMI

Security Consultant Kroll

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