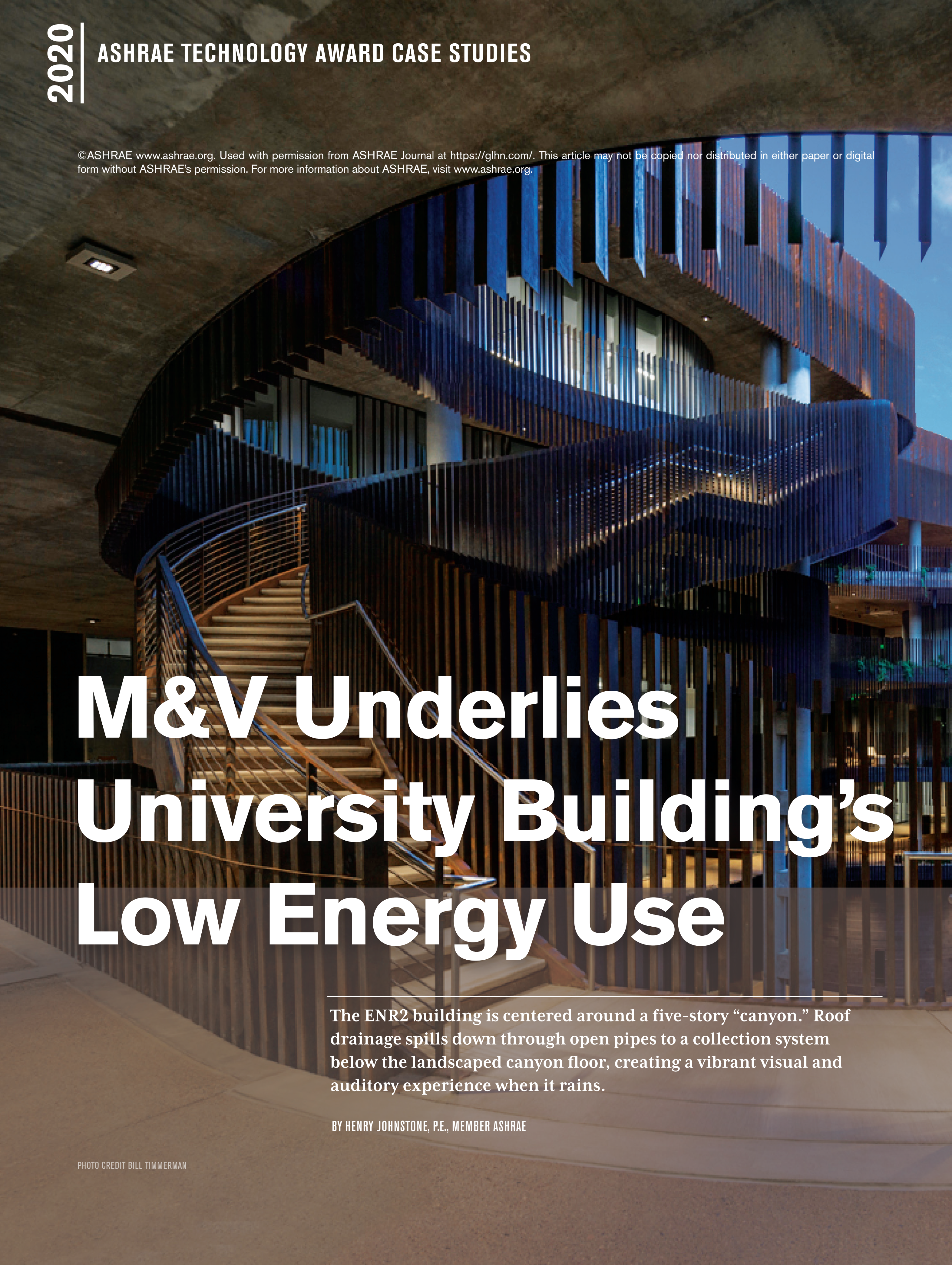

2020 ASHRAE TECHNOLOGY AWARD CASE STUDIES

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M&V Underlies University Building's Low Energy Use

The ENR2 building is centered around a five-story "canyon." Roof drainage spills down through open pipes to a collection system below the landscaped canyon floor, creating a vibrant visual and auditory experience when it rains.

BY HENRY JOHNSTONE, P.E., MEMBER ASHRAE

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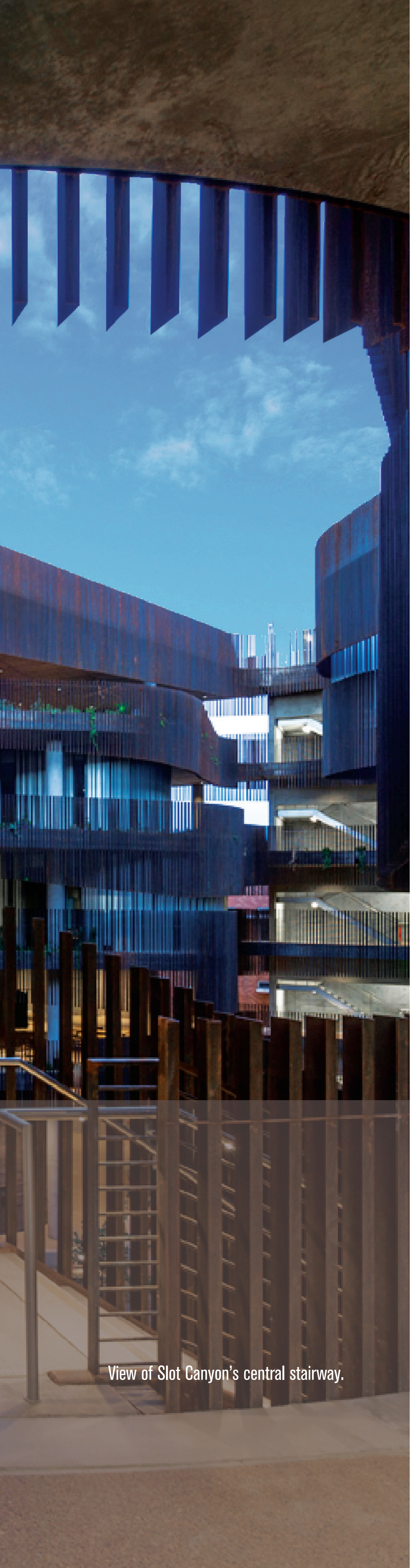

View of Slot Canyon's central stairway.

The second Environmental and Natural Resources Building (ENR2) at the University of Arizona houses academic departments and interdisciplinary programs related to the study of earth sciences, natural resources, and the environment. A design brief, published in 2012, laid out a set of aspirational goals for a building that would promote interaction and collaboration among its occupants, students, and the community at large, and would reflect the university's stewardship of its energy and water resources. It was completed in Summer 2015, and achieved USGBC LEED NC v3 Platinum certification.

The building is centered around a stunning, five-story "canyon," formed of sinuous inward-facing, planted balconies connected by a winding staircase. Roof drainage spills down through open pipes to a collection system below the landscaped canyon floor, creating a vibrant visual and auditory experience when it rains. Since initial occupancy in the fall of 2015, the building has proved to be extremely popular among the university community, and is routinely scheduled not only for class, dry lab, and lecture, but also for campus-wide conferences and special events that include awards ceremonies, Sunday worship, and even an open-air opera.

The 207,632 gross square foot (19 290 gross square meter) building (*Figure 1*) is formed of two blocks oriented along the east-west axis of the central canyon. The first floor includes two large lecture halls, café, and the public interaction space on the canyon floor. Floors 2 through 5 contain primarily closed perimeter offices, open center office bays, and conference/dry-lab spaces in "pods" constructed along open-air collaboration space within the balconies and at the rooftop level. Green-roof landscaping technologies were applied at the balconies and sections of the upper-deck to enable a thriving population of desert plants suited for the arid climate of the Sonoran Desert. These are sustained through an irrigation system fed from the underground rainwater cistern or, during the dry periods, municipal reclaimed water. After three years, plant materials throughout the space are

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Building at a Glance

Environmental and Natural Resources Building (ENR2)

Location: Tucson, Ariz.

Owner: The University of Arizona

Principal Use: Office, classrooms, lecture rooms, auditorium

Employees/Occupants (from Energy Model): Peak occupants: 616; Peak transients: 1,267; FTE occupants: 452

Gross Square Feet: 207,632

Substantial Completion/Occupancy: 2015

Occupancy: Daily avg. transients (students/visitors): 1,047 quite robust, with tiers of hanging vines draping down through multiple canyon levels.

Energy Efficiency

Energy Systems

Early in design, the University's Planning Design and Construction Department (PD&C) made it explicitly clear that simple operation, proven technology, low annual maintenance, and long-term durability were to be equally prioritized with high energy efficiency. The design process involved integration of feedback from a broad section of the University's planning, engineering, and operations groups' knowledge base. Designing and detailing the building envelope and shade fins, landscaped balconies, and unusual building systems involved a high level of collaboration among the architect, engineer, and contractor team. Certainty that the aggressive energy-use targets required to reach LEED Platinum would actually be achieved was established through implementation of whole-building commissioning and an energy measurement and verification (M&V) program, originally intended to run through the first two full years of operation, but which is still in operation, thanks to the efforts of PD&C (*Figure 3*).

A simplified list of energy-efficient technologies includes the following.

Building Design and Envelope

- Passive conditioning of primary building circulation;
- Solar shade fins; and
- Deep, high thermal mass, overhanging balconies store nighttime coolness.

HVAC

- Dedicated outside air units serving chilled-beam and underfloor displacement floors 2–5; single duct VAV with reheat floor 1;
- Occupancy control of outside air ventilation and room temperature set point; and
- Ventilation relief under balcony overhangs and large ceiling fans.

Electrical

- Lighting control, including vacancy sensing, daylighting, task lighting;
- High-efficiency lighting fixtures;
- Separated metering of house, HVAC, lighting panels;
- Submetering of HVAC, lighting, plug loads; and
- Preparation for rooftop solar PV above green roof ("agrivoltaics") (*Figure 2*).

FIGURE 1 Aerial perspective of building model, including roof-mounted DOAS.

Energy modeling began early in the project. Design was targeted to exceed ANSI/ASHRAE/IESNA Standard 90.1-2007 by 30%. Use of a hydronic loop with overhead chilled beams on the perimeter, along with low static underfloor displacement ventilation in the central open offices and conference rooms, and stand-alone four-pipe fan-coil systems for the larger pod areas, yielded significant fan-power savings over an all-air baseline alternative, since water has a higher heat-transfer capacity over air. These savings are seen in fan horsepower savings. While the proposed building consumed slightly higher overall cooling energy than the baseline, the total cooling system yielded energy savings.

Some difficulties in modeling HVAC systems, as configured for this building, were experienced. These were discussed with the software vendor to construct workarounds, and were then vetted, extensively, with the LEED reviewer. A comparison showing annual energy consumption for the ANSI/ASHRAE/IESNA Standard 90.1 baseline compared to the design model and year 2017 M&V results is shown in *Table 2*.

Results show a significant variance between the modeled versus actual projection for heating (*Figure 4*). Some of this can be attributed to overestimated lighting and internal loads in the model, which drove the power and, thus, the cooling loads lower. More heat than modeled was certainly needed in

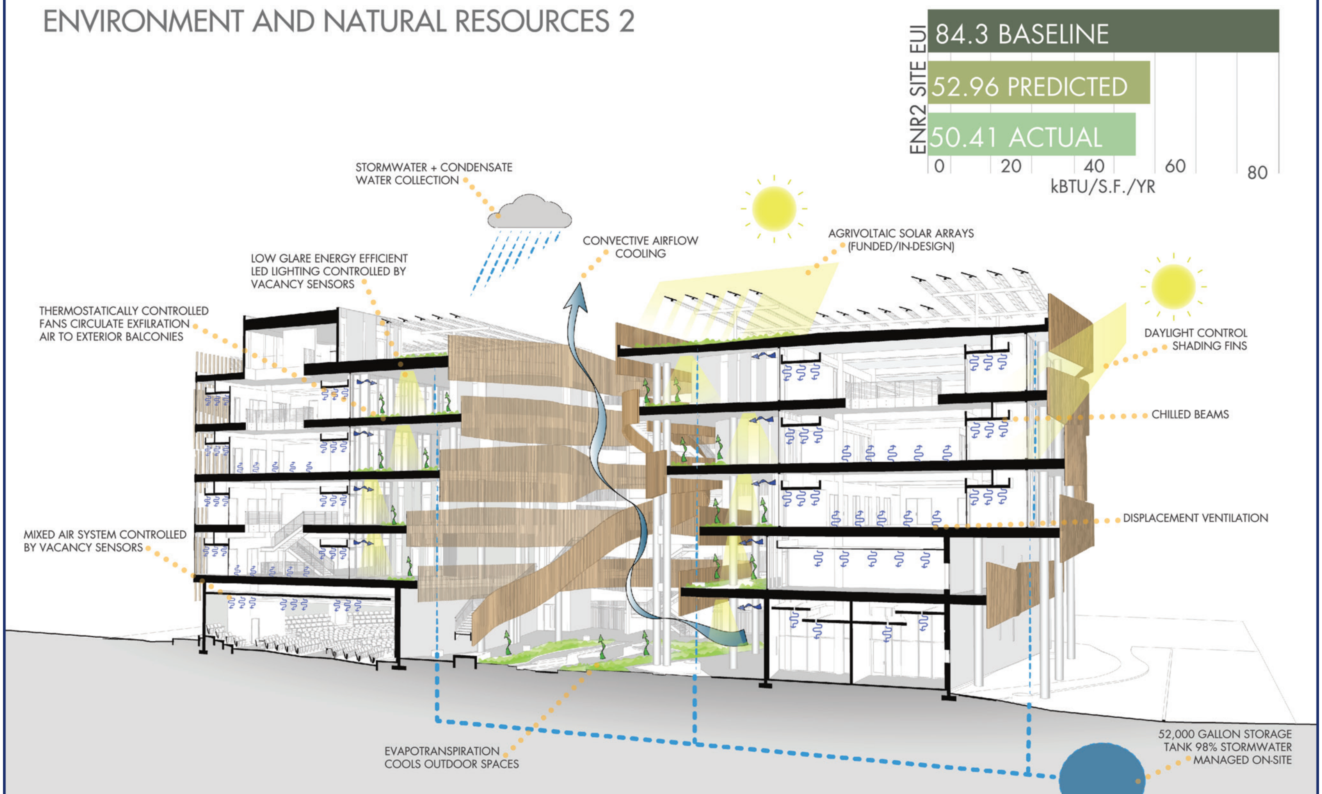

FIGURE 2 Diagrammatic sectional perspective with EUI.

winter and reheat during summer dehumidification. Overall, however, energy efficiency of the building is tracking expectations, and remains substantially below other campus buildings with similar occupancy.

Indoor Air Quality and Thermal Comfort

Indoor air quality (IAQ) was of great concern to building users in early design, as well as a factor in decisions to allocate large areas of the canyon floor and balconies to passively tempered circulation, collaboration, and study. During the academic year, these spaces are highly utilized by students and staff. Indoor spaces on the upper levels are ventilated through the dedicated outdoor air units, which include airflow stations and modulating dampers. These floors are generally overventilated to maintain a consistent positive pressurization during occupancy.

Space and return air monitoring is used in the pods and large lecture halls on the first floor to modulate outside air in proportion to actual CO_2 levels. Daily trends of outside air damper position, taken over multiple class periods, demonstrate the value of this approach in matching HVAC energy load to occupancy. Ventilation effectiveness varies by the various system types. The underfloor systems used in conference rooms and open offices operate with a 1.2 multiplier in cooling mode, which is predominant. Chilled-beam spaces are generally designed to provide a primary plus induced 50 fpm at the occupant level, using only ventilation air as the primary driver.

TABLE 1 Regional temperature range.

ASHRAE Tucson Design Conditions			
Winter	32°F DB	**Summer**	104°F DB / 73°F WB

Thermal comfort has been satisfactory through the first three years. Although chilled-beam offices are ganged together for cooling and heating control, the overall number of thermostats/occupant (12–15 people/stat) is higher than most comparable buildings. Discharge air temperature in the open office underfloor air distribution (UFAD) spaces was adjusted upward, from 65 to 68 in the first cooling season in response to occupant perception. The population of the Environmental and Natural Resources Building 2 is amenable to adapting

TABLE 2 ENR2 code and modeled vs. actual performance.

	Baseline	ENR2 Model	ENR2 2017
Heating (kBtu/yr)	1,028,400	228,831	1,981,440
Cooling (kBtu/yr)	6,281,196	6,651,936	5,051,100
Electric Power (kBtu/yr)	5,206,600	4,115,786	3,434,037
Total (kBtu/yr)	12,516,200	10,996,554	10,466,577
EUI (kBtu/ft^2·yr)	60	53	50

their clothing decisions to the office environment. Occupant surveys were distributed the first winter after occupancy and again in the fall of 2018, with a high level of participation. Seventy-two percent were satisfied with thermal comfort, and over 91% were satisfied with IAQ.

Innovation

Although hydronic chilled-beams and UFAD systems may no longer be considered innovative in the HVAC space at large, the systems in the ENR2 building are among the first of their type at the University of Arizona and across southern Arizona. Some aspects of this installation differ from typical systems installed elsewhere.

One dual-tunnel air handler was provided for each of the north and south building blocks. Shown in *Figure 5*, these units temper outside ventilation air through a 1-row preheat coil and a 10-row cooling coil. A bypass damper reduces fan static pressure during heating or when downstream sensible cooling is possible. This damper closes to allow the coil to dehumidify during Tucson's summer monsoon season (*Table 1*). Tempered air is then available to be drawn through either the chilled-beam or the displacement airstreams, which are nominally operated at differing temperatures (55°F [12.8°C] chilled beam [CB], 68°F [20°C] displacement ventilation [DV]). Return air dampers enable mixing, used primarily in the DV stream. Under occupied conditions, primary air to activate induction in the chilled beams is, in almost all cases, limited to the minimum ventilation requirements. While this approach requires large chilled beams, it substantially lowers fan horsepower, air-handler size, and duct sizes serving the perimeter.

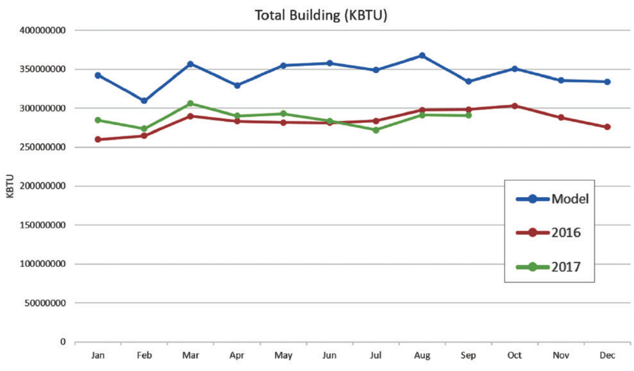

FIGURE 3 Modeled vs. monitored performance for 2016 and 2017.

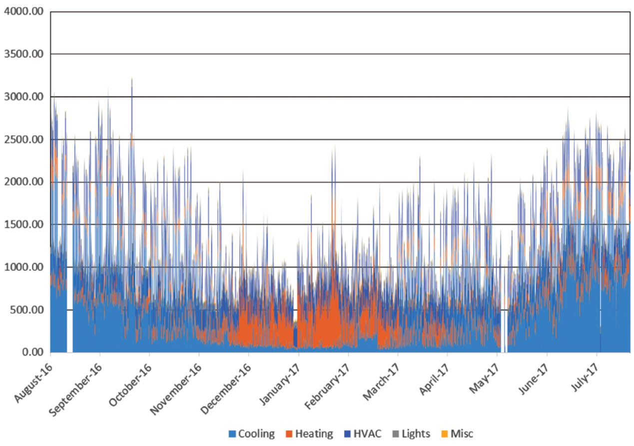

FIGURE 4 Energy consumption of cooling, heating, HVAC, lights, misc. loads.

TABLE 3 ENR2 mechanical system cost and payback vs. baseline system.

ENR2	$41.43/ft^2	Premium at 123,985 ft^2	$177,299	
Baseline	$40/ft^2	Annual Energy Savings	$73,500	
ENR2 Premium	$1.43/ft^2			2.4 Year Payback

Another unusual approach taken in the design of the chilled-beam system is that it is two-pipe, 55°F chilled water, with three to four offices ganged to each thermostat. Heating is accomplished through a hot-water coil in a terminal unit, serving each exposure per floor. The entire bank of offices along the south exposure, for example, are provided with a single heated air temperature, based on the average of individual room stats. Although this approach was a cause of concern during design, it has proven to be satisfactory in operation. Uniform and low-velocity air distribution induced by the hydronic units provided with this air appears to address cold (or hot) draft complaints.

Operations and Maintenance (O&M)

Year three of operation has not revealed any latent operation and maintenance issues, occupant complaints, or unusual numbers of HVAC shop calls. The most significant issues have related to faulty metering early on and a failure of the automatic control of the outside air dampers due to a stuck damper actuator. Interestingly, that failure was first picked up in review of monthly M&V data, when a large variance in monthly building chilled-water consumption over the previous year was observed.

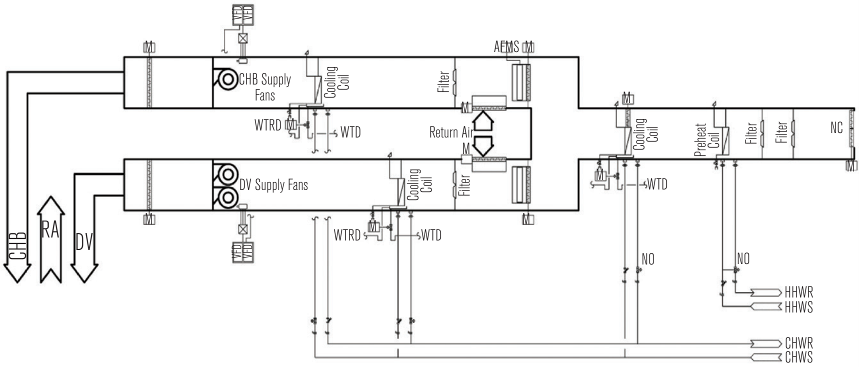

FIGURE 5 Dual-tunnel air handler.

ENR2's courtyard attracts a thriving, passively cooled ecosystem.

Cost Effectiveness

Demonstration of the cost-effectiveness of systems designed for ENR2 was a continual challenge. As one of the first systems of its kind in Southern Arizona, contractors found it difficult to estimate labor costs. This may have driven a premium of the upper-floor system over the more conventional single-duct reheat systems installed on the first floor (*Table 3*). Although use of chilled beams and UFAD did enable a 1 ft reduction in the floor- to-floor heights, it was difficult, in the end, to discern any tangible reduction in general construction cost. The effort to contain the mechanical budget at under \$45/ft^2 (\$484/m^2) drove much of the simplification to dual-tunnel outside air units and the two-pipe, chilled-beam arrangement. Collaboration with the general contractor and subcontractors to derive a perimeter chilled-beam installation detail that worked within the overall construction sequence involved extensive three-dimensional modeling, independent clash detection software and construction of a mock-up. Yet the final cost per square foot based on the general contractor's schedule of values for mechanical systems yields a 2.4-year payback over a conventional VAV with reheat system.

Environmental Impact

A side-by-side comparison of ENR2 building energy use to other buildings on the University of Arizona campus with similar occupancy is dramatically low. A more significant impact of this building design is the potential long-term benefit that would be derived if the project's primary objectives of ensuring interdisciplinary collaboration between environmental, earth sciences, natural resources and an engaged student and faculty yields practical results addressing the causes and effects of climate change. The success of this building is also due to the Integrated Design Process (IDP). Lead by the University's Planning, Design and Construction staff, Design Architects, Richard + Bauer, the A/E of record, GLHN, user groups and the local community worked closely together to balance the cost, energy, space and aesthetic demands. ■

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