Meeting sustainability goals in a lab with 142 fume hoods is a huge challenge for design engineers. It’s an even taller order when those labs require the flexibility to change rapidly, such as from a wet lab to a dry one. Both were the case for the new Undergraduate Teaching Laboratories at Johns Hopkins University (JHU).

Designers met those goals, creating a building that used 50% less energy in 2016 compared to ASHRAE Standard 90.1-2007’s baseline. This helped the building earn LEED Platinum certification.

The teaching and research lab brings together undergraduate labs and faculty research in the biology, chemistry, neuroscience, and biophysics departments and provides a student commons area.

It was the first major construction following an initiative to reduce carbon emissions by 51% by 2025.

Energy Efficiency

Energy consumption in a laboratory is driven by outdoor air (OA) requirements, the heating and cooling to condition this air, and high internal heat gains from laboratory equipment. The 105,000 gross ft$^2$ (9755 gross m$^2$) Undergraduate Teaching Laboratories (UTL) building uses a number of technologies, strategies, and systems specifically designed to mitigate the energy impact of these drivers including:

- Enthalpy and sensible energy recovery wheels to deliver neutral temperature ventilation air;
- Chilled beams, radiant floor heating, and perimeter radiators;
- Waterside economizer using air-handling unit (AHU) cooling coils (free winter cooling);
- District energy from campus trigeneration plants;
• High-efficiency lighting and daylighting with occupancy sensor controls;
• High performance fume hoods;
• Occupancy based airflow reset;
• “Decommissioning switches” to turn off airflow to vacant labs; and
• High performing envelope and minimal east/west glazing.

Energy use is shown in Table 1. In 2016, energy consumption of 144 kBTU per gross ft$^2$ (1635 MJ per gross m$^2$) was lower than the modeled design, 192 kBTU per gross ft$^2$ (2180 MJ per gross m$^2$), which confirms a 50% cost savings over ASHRAE Standard 90.1-2007’s baseline of 408 kBTU per gross ft$^2$ (4633 MJ per gross m$^2$).

The installed air-handling system (Figure 1) uses two energy recovery wheels: a 3A molecular sieve-coated media enthalpy wheel and a sensible wheel. The two wheels act to recover exhaust energy and reheat air toward a neutral temperature. This design decouples ventilation requirements from heating/cooling demands. Active chilled beams provide sensible cooling throughout the building, while perimeter radiation offsets envelope heating losses.

Because ventilation air is kept at 68°F (20°C), reheat coils are not required at supply terminals. In addition to reducing/eliminating reheat, neutral supply air allows displacement makeup air delivery system that significantly reduces ductwork. Ducted air was sized only as required to drive chilled beam cooling.

Exhaust venturi valves maintain the required exhaust flow (fume hood flow and minimum air change rate) in each laboratory. Exhausts on each floor are summed, and large floor-based supply valves introduce the balance of the floor’s makeup air (minus ducted chilled beam air) into a pressurized plenum above the corridor ceiling.

The makeup air is passively pulled through large displacement grilles, with fabric backdraft dampers that balance pressures between the plenum and labs. This air delivery concept inherently creates a low-pressure, high-volumetric offset that ensures each laboratory is negatively pressurized with respect to the corridor. It also significantly simplifies controls, improves the quality of the building design via minimizing ductwork, and eliminates dumping of cold (or reheated) air.\(^1\)

Dual energy recovery wheels have a large impact on system sizing. At the installed design airflow, the dual wheel system saves 300 tons (1055 kW) of cooling compared with a glycol run-around recovery system. Together with airflow-saving technologies, the peak heating and cooling was reduced by 4,000 MBH (1.2 MW) and 500 tons (1758 kW). Figure 2 shows how reheat is eliminated if air is supplied at a neutral temperature. In traditional systems, reheat is required when airflow requirements exceed the cooling requirement; this occurs frequently in labs with high air
change rates (ventilation driven) or densities of fume hoods (hood driven).

Table 2 compares terminal loads and flows for two common lab modules, a biology lab and an organic chemistry teaching lab. The analysis demonstrates how reheat is nearly eliminated in the building. It also highlights the difference in ducted supply air that results from the combination of chilled beams, high performance fume hoods, and displacement systems. Overall, the total AHU capacity is 30% smaller than a baseline system, and approximately 40,000 cfm (18,878 L/s) of this air is delivered via the plenum. Fully ducted supply air for the building is less than 0.6 cfm per gross ft² (3 L/s per gross m²).

To maximize performance, a manifolded exhaust system combines general and fume hood exhaust prior to the recovery system. While the use of wheels was critical to this building’s impressive energy savings, risks of cross-contamination, vis-à-vis fume hood exhaust, had to be evaluated. Fortunately, the owner, with 25 years’ experience and 3 million cfm (1.4 million L/s) of installed wheel capacity in laboratory applications, had expertise on this topic.

Together with Johns Hopkins University safety officers (JHU Health Safety and Environment), the design team was able to evaluate and approve the use of wheels early in design. This process included review of the building’s HVAC systems, the lab’s safety protocols, equipment specifications and commissioning requirements, and an analysis of expected research and chemical use (including spill scenarios). The wheel manufacturer was sole-sourced based on testing of desiccants cross-contamination approved by the safety officer that limited the maximum carryover to 0.045% per wheel (0.09% for two wheels in series). Prior to occupancy, the system was commissioned and verified via a tracer SF6 gas test, in accordance with ASHRAE Standard 84–2008, *Method of Testing Air-to-Air Heat/Energy Exchangers*. See “Code and Safety Concerns Using Desiccant Wheels” for more on wheel safety.

### Indoor Air Quality (IAQ) and Thermal Comfort

While energy efficiency was an important driver in design, laboratory safety and indoor environmental quality were paramount. The design team met regularly with officers from JHU Health Safety and Environment to review design, set standards, and investigate new technologies. This process ensured that the laboratories exceeded all safety requirements and provided new direction for future lab designs at the campus.

High performance fume hoods were used to reduce airflow. Hood velocities were designed to maintain...
Laboratories were designed so air cascades across the space, with displacement grilles located near the entry to sweep air toward the general exhaust in the back. A representative portion of a typical laboratory was constructed at the chilled beam manufacturer’s laboratory. The engineer developed a test to prove performance and air quality, specifically near fume hoods, which was witness-tested by the owner and engineer. In addition, a post-occupancy smoke visualization was performed to demonstrate air movement, ventilation effectiveness, and pressurization relationships.

The exposed concrete structure creates a high thermal inertia building with a stable mass that helps mitigate fluctuations in temperature and radiant asymmetry. Perimeter radiation was used at all window exposures to offset winter conduction losses, and a radiant floor heating system was installed in the commons to enhance comfort in the 20 ft (6.2 m) high space. To prevent condensation on chilled beams and piping, humidity...
is tightly controlled under 56°F (13°C) dew point (<55% RH). Space air temperatures are maintained between 72°F and 74°F (22°C and 23°C).

Innovation

The building’s real innovation was not the technologies and systems themselves, but rather how these systems complement each other and integrate with the architecture to simplify design, maintain space quality, and offset construction costs via standardization. The Undergraduate Teaching Laboratories was as an addition to an existing building, and matching floor-to-floor heights (13 ft, 4 in. [4.1 m]) was a significant challenge. The neutral air displacement system, combined with chilled beams and high performance fume hoods, greatly reduced ductwork size, allowing for repeatable distribution and ceiling clouds located 9 ft, 4 in. (2.8 m) above finished floor in all laboratories, including those with high fume hood densities.

The systems were designed for flexibility and adaptability to accommodate rapidly changing convergent science teaching and research where space types change between wet and dry, classroom and laboratory, and interdisciplinary and multidisciplinary work. The chilled beam design, for example, was standardized in all labs. This allows a wet laboratory to be converted to dry (and vice versa) by altering the general exhaust and displacement airflow rates, but no physical changes to the distribution system (ducts, chilled beams, air valves, etc.) are required. This standardization and flexibility ensures energy performance is not compromised in future modifications.

Operation and Maintenance

HVAC equipment was centralized to reduce maintenance. Three large AHUs located in a penthouse provide supply air throughout the building. Valve galleries are located next to shafts to house venturi exhaust air valves, rather than locating them overhead (Photo 2). Supply air terminals (VAV boxes and venturi valves) were designed for easy access and located in the corridor outside the laboratory (Figure 3). Within the labs, ceilings were left exposed to structure, allowing for easy access to utilities. The labs were designed using a modular approach, where utility pathways, sizes, and shutoff locations were all standardized. This provides familiarity that simplifies maintenance. The maintenance needs of the new technologies used were thoroughly reviewed with the owner during the design process.

Cost Effectiveness

The design process allowed the proposed systems to be optimally integrated with the building’s architecture,

Code and Safety Concerns Using Desiccant Wheels

When considering desiccant wheels in laboratories, design teams must consider a number of codes and standards including requirements outlined for International Mechanical Code (IMC) hazardous exhaust, National Fire Protection Association, ANSI/AIHA/ASSE Z9.5, American National Standard for Laboratory Ventilation, and ASHRAE Standard 62.1 air classifications. If fume hood exhausts are considered hazardous per IMC, manifolding exhaust from separate control zones is restricted and exhaust recovery is often not allowed or is cost prohibitive. ASHRAE Standard 62.1-2007 classifies fume hood exhaust as Class 4 air and restricts (any) recirculation of this air. This effectively would prohibit the use of energy wheels due to cross-contamination.

An addendum was included with Standard 62.1-2013 that allows a responsible environmental health and safety (EH&S) professional to reclassify fume hood exhaust as Class 3 based on an evaluation of chemicals used, total exhaust volume, systems used, and the resultant concentrations at the energy recovery device. With Class 3 air, up to 5% recirculation is allowed; however, when the fume hood exhaust class is lowered, this author recommends specifying wheels that have been independently tested to limit cross contamination to less than 0.1%.
which minimized the cost penalty for using energy-efficient technologies (Refer to Table 2 for ducted airflows). For example, the high performance fume hood and the makeup air displacement distribution system saved ductwork, air handling, and central cooling/heating plant capacity (off-site). Other technologies, such as the energy wheels, had a high first cost, but the payback was quick. Overall, the combined premium for all the energy-efficiency measures (wheels, chilled beams, lights, roof insulation, lighting, etc.) was estimated to be less than 2% of the building cost, and the payback was approximately four years.

**Environmental Impact**

The building and its HVAC systems clearly demonstrate the university’s commitment to sustainability. With an energy savings of over 50% (cost and EUI), and an annual avoidance of almost 2,000 metric tons of CO₂, which is far from common even by green building standards, this building raises the bar on laboratory energy performance and challenges preconceptions of laboratory energy intensity. The buildings’ success and proven reliability will facilitate future environmental efforts and help the university achieve its carbon reduction goals.

**Conclusion**

The visibly and functionally “green” building is a model for energy efficiency, sustainable site development, and interior environmental quality. The iconic building has become a compelling draw for students, faculty, and the wider campus community.

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**References**