Journal Extras for September 2023

The following pages contain supplementary information for these articles in the September 2023 issue of ASHRAE Journal:

Reducing Energy Use and Setting a New Standard

By Drew Roberts, P.E., Member ASHRAE; Ben Hobbs, P.E., Member ASHRAE; Johnathan Stewart; Kevin Mussler

Operation and Maintenance

To ensure the MEP systems continue to run efficiently for years to come, maintainability and serviceability were crucial factors in early design decisions, and the team paid close attention to where and how the equipment was installed. Most equipment was kept off the roof(s) and is easily accessible and serviceable from the ground in mechanical rooms with multiple units or single closet. The kitchen exhaust fans are the only two pieces of roof-mounted equipment. Maintaining clear roof space simplified the layout and design of the photovoltaic systems on the roof.

As an additional measure to streamline serviceability, the HVAC equipment was designed with external filter housings, and filters were standardized to 24 in. × 24 in. (0.6 m × 0.6 m) highly efficient MERV 13 filtration. This allows BCPS maintenance staff to keep one filter size for all equipment across both schools. The demand-control ventilation system was designed with maintainability and serviceability in mind. This sampling-based system uses two high quality single CO_2 sensors that sample the air of occupied spaces every 15 seconds and adjusts the ventilation accordingly. This approach requires the calibration of just two sensors for the whole school in lieu of sensors in each room.

The BAS selection was also important to facility managers as previous installations created challenges with remote monitoring and proprietary controls. Both schools were provided with nonproprietary controls and remote monitoring capabilities, allowing the BAS to be accessed during unoccupied schedules to identify issues with the control systems causing energy penalties.

Cost Effectiveness

It was necessary to create a design and building approach that was cost-effective so BCPS could replicate in the future without the need of a financial grant. The design team worked together to identify cost reduction opportunities throughout the design process. By taking an integrated approach with a focus on educating the students first and energy reduction second, there were multiple opportunities of cost shifting that allowed the design and construction team to work collaboratively and provide a high-performance design that met the traditional budgets set by BCPS.

Creating a tight envelope was essential in improving energy performance and reducing the HVAC system size. To ensure the building met the tight design requirements, it needed to exceed traditional ASTME779 standards of infiltration. The design parameters required the building to achieve a 0.15 cfm/ft^2 (0.8 L/s·m^2) air leakage rate. After a building pressure test, Graceland achieved 0.050 cfm/ft^2 (0.254 L/s·m^2) and Holabird achieved 0.059 cfm/ft^2 (0.3 L/s·m^2) air leakage rate. This high-performance envelope resulted in additional first cost savings of $100,000 for the heating and cooling systems. Additionally, we worked closely to optimize the fenestration, limiting it to less than 250 ft^2 (23 m^2) per classroom, eliminating the need for automatic daylight harvesting control required by code, saving an additional $45,000. Multiple analyses were run on lighting designs, specifically in classrooms, resulting in the selection of 2 × 4 troffers instead of direct/indirect pendants. This decision resulted in lower energy use and saved over $300,000 on the construction budget.

The MEP systems were optimized through a single DOAS with demand-control ventilation, further reducing the cost of the HVAC system by an additional $150,000. These energy efficient alternatives drastically reduced the size of the geothermal wellfield, saving an additional $600,000 in construction cost. The above cost-shifting strategies aided the project bidding at $34 million, including costs of the PV system owned by BCPS. The PV system was approximately $800,000 or 2.3% of the overall project budget. In summary, the total building cost including PV was $360/ft^2$ ($3875/m^2$), which was lower than the previous elementary schools built by BCPS that were not designed to achieve zero energy/zero operational carbon.

Environmental Impact

From the beginning, Graceland and Holabird were designed with a significant decarbonization goal. The original schools operated at 106 kBtu/ft^2·yr (1204 MJ/m^2·yr) and 70 kBtu/ft^2·yr (795 MJ/m^2·yr), contributing a combined 1,938 tons of CO_2 emissions. Through the replacement of these schools and the inclusion of a 523 kW roof- mounted photovoltaic array on each building, the emissions were greatly reduced. Natural gas use was limited to backup water heaters and a single gas-fired kitchen appliance. Both schools are performing better than the targeted energy model and producing more energy than they are consuming at each site. These buildings are now avoiding an additional 150.5 tons of carbon from the surrounding neighborhoods, aiding in a better environment for the community of Baltimore City Public Schools.

Heat Recovery Key to Technology Company Headquarters Renovation

By Dave Budd, P.E., Member ASHRAE; Caroline Traube, P.E., BEMP, Member ASHRAE; Michael Hedrick; Skander Spies, P.E., Associate Member ASHRAE

Operation and Maintenance

Examples of strategies deployed during design to ease long-term operations and maintenance include:

1. Removal of the existing maintenance-intensive and oversized industrial campus steam system and replacement with a lower temperature heating water system, allowing for heat recovery to be introduced at the plant level.

2. Use of a single size 24 in. × 24 in. (610 mm × 610 mm) MERV 13 filter to standardize filter maintenance across all AHUs on the campus.

3. Evaluation of the impact of Elliot Bay salt water and nearby train tracks to determine AHU material specifications and preempt early deterioration.

4. Sizing and configuration of the chilled water plant focused on simplicity and ease of operation. The two existing 800 ton (2813 kW) centrifugal chillers were supplemented with a third 800 ton (2813 kW) centrifugal to complete the high efficiency chilled water system. This resulted in simple scalable pumping and reuse of the existing primary-secondary configuration. It also supported full reuse of the existing cooling tower plant.

This facility began occupancy just before the start of the pandemic and has therefore had a slow rise in occupant count that continues to this day. From an operation and maintenance standpoint, the facilities staff reports a normal number of hot and cold calls during the first year as systems were adjusted, and then those calls have reduced since then. Conversations with the facilities staff indicate that the systems are all operating as intended with no major problems.

Here are some of the specific comments from the actual operation of the facility over the last few years from interviews with staff:

1. As a major heat recovery feature for this campus remodel, the chiller plant has a heat recovery chiller as its first stage of cooling, due to the highest operating efficiency mode (~8 COP). Reports indicate that the heat recovery chiller is running adequately loaded during shoulder seasons and is producing all heating for the building. The second stage of heating comes from air source heat pumps (~3.5 COP), and the final stage of heating is gas boilers (~0.9 COP). Through normal operation of the heating system, operators are able to leave the boilers off when outdoor temperatures get above 40°F (4.4°C) and during weekends and rely entirely on the heat recovery chiller and the air source heat pump.

2. The design of the campus air-handling systems included standardizing on a single filter size for all equipment. Facilities confirms that this has greatly reduced storage requirements and has been appreciated for simplicity in maintaining a filter replacement program.

3. Office building layout includes three large conference rooms at the west side of the buildings with a large amount of glass. Field technicians have been keeping an eye on these areas as similar installations usually result in complaint calls. But, for this facility, after interviewing attendees of these spaces during various times of the day, they mention no problems, and have commented that they didn't even pay attention to the mechanical system, an indication that the systems are working properly. As a final operational category, this facility was commissioned with ventilation capability up to 50% above ASHRAE Standard 62.1-2010 ventilation requirements. Due to the lower-than-normal occupancy, these higher rates have yet to be used, as the systems maintain stable CO_2 levels in all areas. But as the occupancy of the buildings continues to rise, these enhanced ventilation systems will provide higher outdoor air rates and continue to maintain low CO_2 levels in the building.

Cost Effectiveness

During concept design, extensive cost studies helped guide major system selection decision points to reduce first cost while leaving pathways open for high performance system refinements later in design. In schematic design, targeted whole building energy and cost analysis further optimized systems to ensure achievement of campus energy and operational goals. Key concept design decisions that drove major first cost savings as well as the majority of HVAC energy efficiency savings include:

The reuse and refurbishment of large portions of the chilled water plant, including two chillers, all cooling towers, and more than 3,000 ft (914 m) of chilled water and condenser water piping. This decision saved ~$1.1 million in first cost compared to demolition and installation of all new equipment.

Full demolition of the existing steam plant rather than a retrofit to accommodate the changed building load profile saved more than ~$510,000. The steam plant was replaced with a higher efficiency low temperature hot water plant inclusive of heat recovery.

Primary HVAC system decision to use high performance VAV: compared to a new higher efficiency dedicated outdoor air system paired with new radiant terminals, this approach saved more than $11 million; in this case and application, the incremental energy savings of the higher efficiency airside and terminal system did not adequately substantiate the additional cost.

4. Replacement of the existing laboratory air handlers with new high performance VAV air handlers. Compared to extensive renovation of the existing airside systems, the decision to purchase new air handlers saved ~$470,000. With major system direction defined in concept design, more detailed whole building energy analysis in schematic design helped determine the current design performance for energy use intensity (EUI) (~43 kBtu/ft^2·yr [488 MJ/m^2·yr]) and the gap remaining to achieve energy code compliance (~1.5 kBtu/ft^2·yr [17 MJ/m^2·yr]).

To determine the most cost-effective path to achieve the last remaining EUI points, the team completed life-cycle cost analysis of more than 30 energy efficiency measures ranging from rooftop photovoltaics (PV) to external shading to envelope upgrades to heat pump water heaters. Quantitative decision metrics included first cost, energy cost savings, social cost of carbon savings, energy use intensity savings, net present value and the first cost per EUI point saved. Qualitative input addressed factors such as operations and maintenance, occupant comfort, architecture and acoustics. Out of the study, air handler heat recovery was the notable energy efficiency measure added to the design. Measure payback was not an applicable metric in this case as the project team instead focused on the lowest cost approach to meet project energy performance goals.

Environmental Impact

The campus earned LEED v4 BD+C Gold Certification in 2021. The project exceeds the 90.1-2010 LEED v4 baseline energy model in terms of emissions savings by 45%. City of Seattle 2020 Benchmarking data (the first reporting year for this facility) indicates an energy use intensity of 40.5 kBtu/ft^2·yr (460 MJ/m^2·yr) and an emissions intensity of 0.4 kg CO_2e/ft^2, 37% lower than similar facilities. The project drove down embodied carbon emissions by the reuse of major central plant components. Existing chillers were retained and refurbished. The chilled water and condenser water mains as well as most of the existing chilled water distribution to campus buildings remain intact and are in use today. This sustainable reuse approach significantly reduced project embodied carbon emissions by avoiding the following product stages: materials extraction, transportation to factory, manufacturing, transportation to site and construction, for all reused equipment.

Reuse of the two existing chillers, eight existing cooling towers, approximately 3,050 linear ft (330 linear m) of chilled water supply and return and of 661 linear ft (202 linear m) of condenser water pipe saves about 1,046 MT CO_2e of embodied carbon. This carbon savings is roughly equivalent to 2.5 years of emissions associated with building operation (at 437 MT CO_2e/year).

A Carbon Leadership Forum (CLF) study on embodied carbon of MEP systems estimates that a typical large, high performance office building will have a mechanical embodied carbon intensity of 60 kg CO_2e/m^2. The reused-recycled mechanical equipment for this project came out to around 13 kg CO_2e/m^2, implying the project used 22% less embodied carbon of mechanical systems through recycled equipment compared to a typical building.

Maximizing Efficiency Using Traditional Systems

By Tracy Steward, Member ASHRAE; Jess Farber, P.E., Member ASHRAE; Neil Winegar, P.E., Member ASHRAE

Other Innovation

Using dynamic glazing for high volume, high glazing spaces proved to be a cost-neutral decision for the project. The design intended to create a transparent and inviting space that connects with nature and campus life while ensuring thermal and visual comfort. The traditional approach of using window shades may have been adequate but would have eliminated the picturesque campus views. In addition, the large windows would have been a significant investment loss if the shades remained closed. Instead, the cost was compared between a dynamic glazing system and a traditional double pane low E glazing unit with automatic shades. The construction manager determined that dynamic glazing was a cost-neutral solution to control glare and maintain daylight and campus views.

The use of automatic sash closers and occupancy sensors on the fume hoods provided substantial energy savings and increased occupant safety. This system is an excellent application for labs focused on coursework instead of research, allowing 100% sash closure when no one is present at the hood and reducing hood airflow to the minimum possible, per ANSI Z9.5-2012, Laboratory Ventilation Standard. Lab spaces without the presence of auto sash fume hood closures use significantly more energy and present a higher risk for injury. As a result, these factors should be considered for future lab renovation or construction projects.

Operation and Maintenance

The University of Louisville facilities team was closely involved in the HVAC system selection. As with many campuses across the country, variable air volume (VAV) systems gained popularity during the 1970s energy crisis and have become the preferred system type for servicing.

The best performing buildings over time require the ability for facilities teams to maintain and operate the building as designed. Innovation at the Belknap Academic Building provided consistency of systems and equipment, leveraged differently to achieve sustainability goals that are maintainable over the life of the building. All equipment, except for VAV terminals, is located within two interconnecting penthouses that open directly to a courtyard housing the lab exhaust system. All primary equipment is accessible via elevator for ease of service.

Cost Effectiveness

The cost shifting and design decisions implemented on this project made it possible to achieve a high-performance building within the existing construction budget. The most significant contribution was from the enhanced envelope, coupled with energy recovery strategies and an understanding of the building's diversity. The result was a 48% heating block load reduction (22 Btu/h·ft^2 [69 W/m^2] design) and a 42% cooling block load reduction (533 ft^2/ton [14 m^2/kW] design). Energy costs are incurred for the life of a building. From a code compliant 127.9 kBtu/ft^2·yr (1452.5 MJ/m^2·yr) to a realized 59 kBtu/ft^2·yr (670 MJ/m^2·yr), this project saves ~$115,000 annually, or ~$5,750,000 over the building's 50-year anticipated lifespan.

Environmental Impact

The Belknap Academic Building was holistically designed to have a minimal environmental impact, with accomplishments in water conservation, site integration, and a reduced carbon footprint. Energy reduction strategies contributed to ~2,500 tons of CO_2 avoidance, and the block cooling load was reduced by ~230 tons (809 kW), the equivalent of a centrifugal chiller with 550 lb (250 kg) of refrigerant in the central plant. Additionally, indoor water use was reduced by 36%. Condensate drainage from penthouse AHU/DOAS cooling coils, estimated at 650 gallons (2461 L) per day peak, was reclaimed to a storm water retention system. A large, roof-mounted photovoltaic array offsets more than 8% of electrical grid energy use. Strategic site selection minimized green space disturbance and enhanced connectivity.