HONORABLE MENTION: INSTITUTIONAL BUILDINGS, EXISTING

Stauffer I Laboratory Building retrofit saved more than $228,000 in FY2009. The retrofit is expected to match or exceed that level annually.

FUME HOOD RETROFIT

By **Molly McGuire, P.E.,** Member ASHRAE; **Mark Hydeman, P.E.,** Fellow ASHRAE; and **Scott Gould**

The in-house energy group at Stanford University, in Stanford, Calif., conducted a campus-wide study in 2002 to identify high energy density buildings with significant potential for retrofit savings. Each of the campus buildings was evaluated by site energy consumption and cost as a function of the building size.

In the process of this analysis, Stanford identified 12 buildings representing roughly one-third of the total campus electrical consumption, which accounted for a combined operating cost of $15.3 million annually. Stanford selected Stauffer I Laboratory Building as an early project due to its small size, high energy intensity, and similarity to nearby buildings that also would be candidates, pending success with the lab retrofit.

The Stauffer I Building (*Photo 1*) is a chemical research laboratory with wet and dry laboratories. The building also contains support space for researchers and administrators with office, conference room and other non-laboratory space. Stauffer I has three stories—two above grade and one below—and was constructed in 1959–60.

The main building HVAC system consists of three central 100% outdoor air constant volume air-handling units (AHUs) located in the basement with intake air louvers that connect to ventilation wells adjacent to the build-

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ing. These AHUs use chilled water for cooling and serve zones with hot water reheat. Three exhaust fans located in an enclosed attic area serve the fume and general exhaust for the laboratories and general exhaust for the offices and other support areas. Each of these fans has a dedicated exhaust stack on the roof. The air-handling units and exhaust fans were designed to be constant volume systems, but prior to the retrofit, the AHUs and exhaust fans were retrofitted with variable speed drives used for balancing only.

The zones had pneumatic controls and the central fans (air handlers and exhaust fans) were controlled by an industrial energy management and controls system (EMCS) maintained by Stanford's EMCS group. Supplemental cooling for certain high-load spaces (primarily dry laboratories in the basement) was provided by dedicated chilled water fan coils.

As with most buildings on Stanford's campus, Stauffer I is served by central chilled water and steam from the Stanford cogeneration plant. Hot water for heating and reheat coils is provided by a steam to hot water heat exchanger.

Since construction in 1960, the building has had many retrofits resulting in a complicated duct system and a lack of spare capacity on all supply and exhaust fans. Additionally, intensive users—current research included the use of nuclear magnetic resonance and molecular tweezers—required tight temperature control and low vibration.

At the beginning of the design process, the building operator identified a number of additional existing operational issues. Both the supply and exhaust fans were operating at nearly full capacity. Additionally, any change in an individual laboratory layout required a full building test and rebalance. Maintaining the correct relative room pressurizations was problematic. The building operator often received thermal and acoustical complaints from occupants.

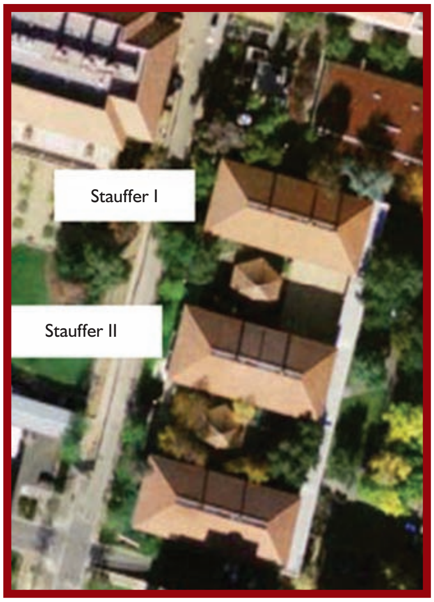

Photo 1: Stauffer I lab at Stanford University.

Building at a Glance

Name: Stanford University Stauffer Building I Laboratory VAV conversion

Location: Stanford, Calif.

Owner: Stanford University

Principal Use: Chemical Research

Gross Square Footage: 28,000

Conditioned Space: 22,000

Substantial Completion/Occupancy: Retrofit completed 2007

Occupancy: 100%

The Design

The project was implemented in three phases: Phase 1, an assessment of the potential energy cost savings from multiple energy conserving retrofit measures; Phase 2, a detailed life-cycle cost analysis and the selection of the final package of energy efficiency measures; and Phase 3, the construction project implementing the selected measures. The Phase 1 and Phase 2 projects were conducted in 2002–2003. Construction began in June 2006 and was completed in July 2007.

The final design for the retrofit is shown in *Figure 1.* Based on life-cycle cost analysis and evaluation of safety and comfort impacts, the following measures were implemented in the retrofit:

- Replacement of pneumatic zone controls with a direct digital control (DDC) system, which enabled supply air temperature reset in response to zone demand;
- Conversion of all constant volume zones to variable air volume (VAV) zones by adding calibrated control valves to supply and exhaust ducts;
- Conversion of the constant volume bypass air hoods to VAV hoods by installing blank-off plates over the existing bypass pathways;
- Addition of occupancy sensors at the fume hoods to provide variable face velocity during hood "occupied" and "unoccupied" conditions;
- Reduction of total exhaust air quantity while maintaining the University Environmental Health and Safety Department's recommended stack velocity requirements by reducing the diameter of the three main exhaust stacks (based on an estimated 30% reduction in fume exhaust through diversity observed at other laboratories on campus with VAV fume exhaust);
- Addition of differential pressure sensors across the supply valves, enabling dynamic reset of the supply fan duct pressure setpoint while ensuring adequate pressure for control of the supply valves;
- Addition of intake bypass dampers at the three exhaust fans and corresponding barometric makeup air dampers at the roof;

- Installation of barometric makeup air dampers to the laboratories for pressure relief during smoke exhaust mode; and
- Addition of acoustical treatment to the supply and exhaust ductwork at the non-laboratory spaces.

The laboratory airflow and room pressurization management system that was installed in this building is a preengineered system. The project was innovative in the way that it implemented enhancements to the system to improve energy performance. Construction time and cost were reduced through use of a design-assist procurement process. The contractor was engaged at the end of the design development stage to participate in detailing valve installation and control components in the existing ductwork. The construction document set, developed by the contractor, served as the shop drawings, further reducing construction costs and schedule.

The contractor, engineers, owners and occupants met early to collaboratively develop a process for construction that would cause minimal disruption for researchers. Individual hoods were down for no more than two days at a time and work in each laboratory was limited to three consecutive days. The contractor maintained a two-week rolling schedule that was made available to all laboratory occupants. The team used trend data from other installations of similar nature and occupancy to determine a system diversity to be used for sizing the exhaust stack reductions and exhaust fan bypasses.

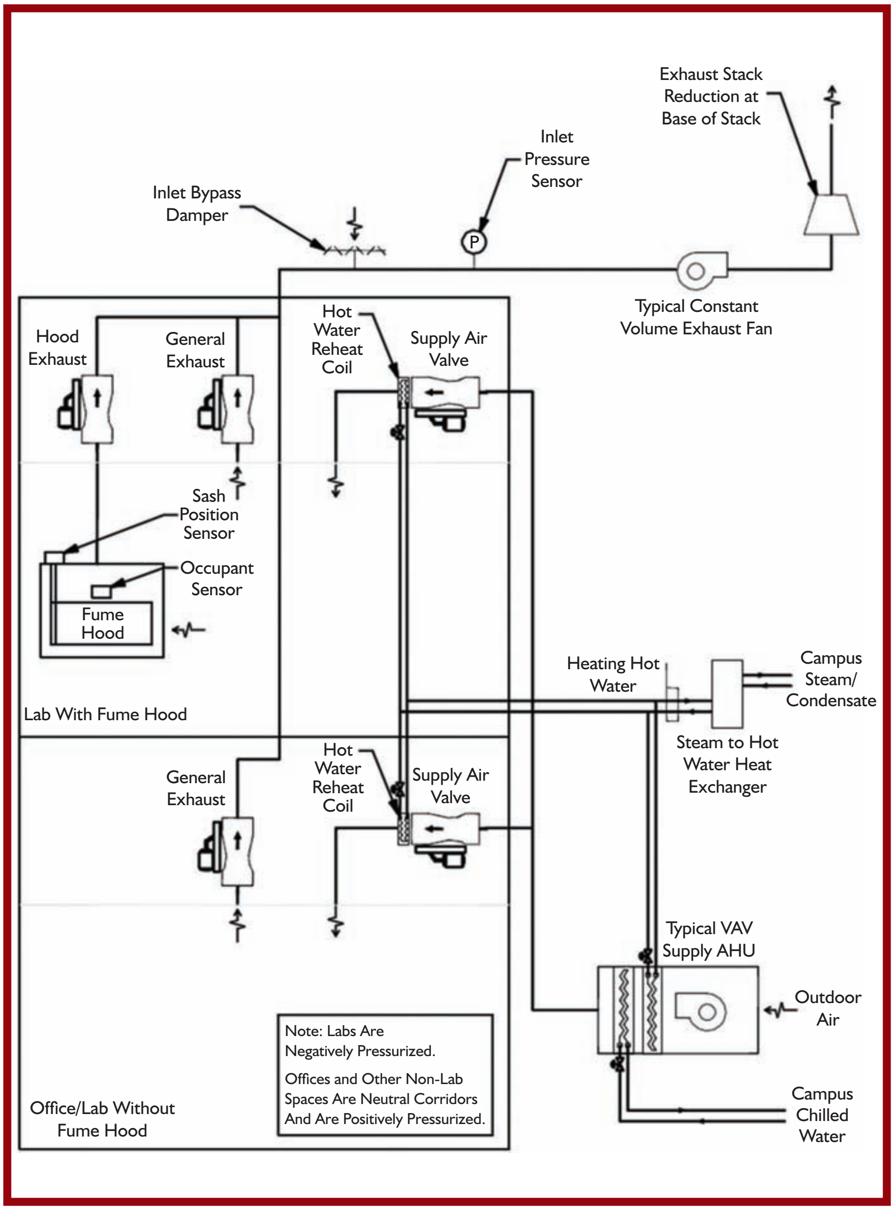

Figure 1: Stauffer I chemistry laboratory VAV retrofit system.

Because valve position for these pressure independent valves was not available for supply pressure feedback as a standard option, the team developed an innovative scheme to provide differential pressure measurements across the calibrated zone valves for reset of the supply duct pressures. Differential pressure sensors ensure that each valve has sufficient pressure to retain its desired accuracy for airflow control, while allowing reset of the system static pressure.

Results: Energy

Construction began in June 2006 and completed in July 2007. Post-retrofit collection of metered electrical, chilled water and steam data has shown more than a 60% reduction in building energy consumption relative to preretrofit data. In 2009, both chilled water and steam use were down 70% compared with an average preretrofit year. Correlation to outdoor air dry-bulb temperature is often used when comparing energy performance before and after a retrofit. In laboratory buildings that use 100% outside air, the relationship between outdoor air temperature and heating and cooling energy is even more pronounced. *Figure 2* shows chilled water and steam energy use as a function of outdoor air temperature before and after the retrofit. Data collected during the retrofit (June 2006 to July 2007) were discarded.

Campus steam, used primarily for heating and reheat, showed a dramatic reduction in the warmer summer months. Prior to the retrofit, the building had a significant steam demand, even in the warmer summer months, due to the high level of reheat required to maintain comfort at the design airflow rate. Once the zones were converted to VAV controls, the airflows were allowed to reduce to the minimum required ventilation rates and reheat was nearly eliminated for the warmest months.

Electricity, on the other hand, shows little correlation to outdoor air temperature due to high non-HVAC process loads and high minimum ventilation rates. Calendar years 2008 and 2009 showed a 40% decrease in electricity use compared with prior years, as seen in *Figure 3*. This decrease is primarily due to a reduction in supply and exhaust fan energy. The supply fans now operate at part load for most of the year. The exhaust fans, although still operating at constant volume to maintain safe exhaust stack velocities, operate at a reduced speed because of the exhaust stack modifications.

Results: Indoor Environmental Quality

The retrofitted systems provide significantly improved air quality, thermal comfort, and acoustical control compared with the original constant volume design. The VAV system dynamically controls space airflows, allowing the system to more precisely address two critical laboratory air quality health and safety concerns: room pressurization and hood face airflow. In each space, supply valves track exhaust airflow to maintain constant room pressurization as airflows rise and fall in response to demand. Pressure-independent air valves maintain airflow setpoints regardless of duct system pressure, so changes to one part of the system no longer impact the air balance in others. Additionally, building pressurization conditions, such as stack effect, no longer impact room pressurization, as the valves compensate to maintain airflows. Finally, the door pressurizations under emergency conditions are significantly reduced, as shown by measuring door pull force with all smoke dampers closed.

Hood face airflow conditions, another critical element to safe laboratory design, are now actively controlled through monitoring of hood sash position and the corresponding control of hood airflow. Face velocity is maintained at 60 fpm (0.30 m/s) for an unoccupied hood. Hood zone presence sensors indicate when a hood is occupied, and trigger an increase in hood face velocity to 100 fpm (0.51 m/s). Additionally, the hood exhaust valves are controlled to an absolute minimum, regardless of sash position or occupied state, to maintain sufficient dilution airflow for chemicals in the exhaust ductwork. The new control system provides alarms to alert the maintenance staff when hood airflow or room air balance is out of range. The system also alarms on equipment malfunction or failure.

VAV control of the spaces also provides greatly improved thermal comfort. The DDC system provides tighter temperature control, and spaces operate at less-than-design airflows for most of the year, reducing the risk of draft due to high airflows. The supply air temperature is reset higher than design cooling temperature for much of the year, further reducing the risk of local discomfort.

The acoustical environment has been improved, largely due to reduced operating fan speeds and airflows. Fume hoods operate at a fraction of the design airflow rate much of the time. The acoustical noise in each space was measured under both pre- and

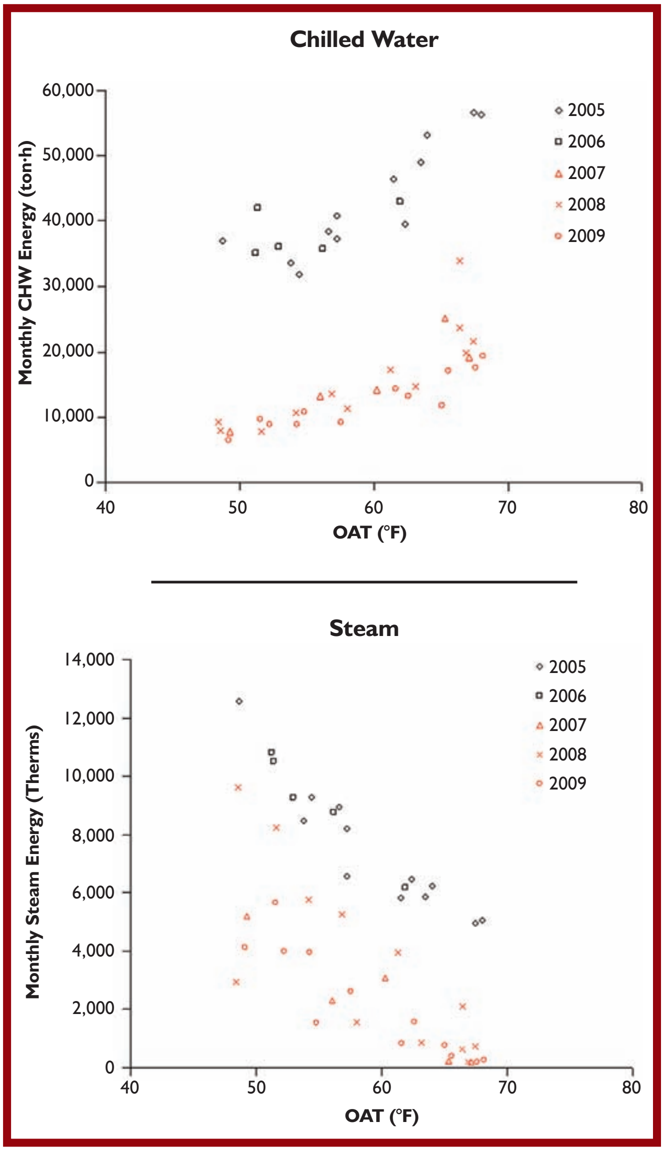

Figure 2: Pre- and post-retrofit chilled water and steam consumption.

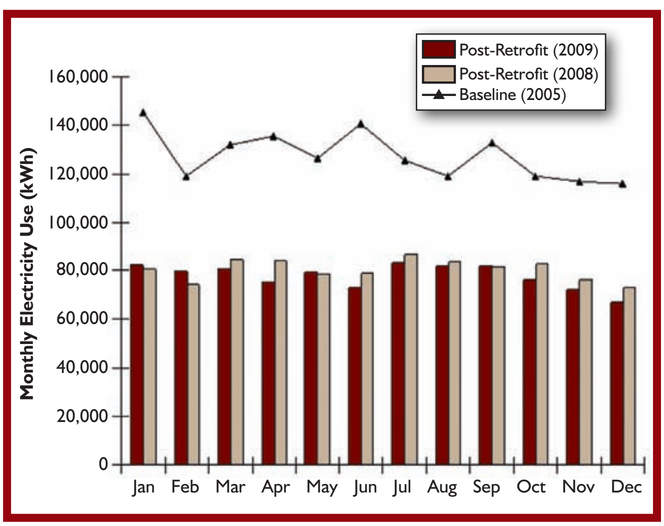

Figure 3: Monthly pre- and post-retrofit electricity consumption.

post-retrofit conditions by an acoustician. In most cases, noise levels in all octave bands were measurably reduced; acoustical noise dropped by as much as 6 NC in some cases.

Results: Operation and Maintenance

The retrofit system has significantly improved operation and maintenance as follows:

- The DDC system provides alarming, remote access and trending to assist diagnostics;
- The diversity in the exhaust and supply systems makes it easier to modify laboratories as all three supply and exhaust systems now have spare capacity; previously, the three exhaust fans operated at 60 Hz; following the retrofit, they operate below 45 Hz;
- There is less strain on the equipment, which increases the life of the filters, belts, and bearings; and
- The system provides feedback and control at the zone level, which improves testing and diagnostics.

Results: Financial Payback

Buildings on campus pay a flat (not time-of-day) rate for chilled water, steam, and electricity from the central plant. Based on the current rates, Stanford saved $49,000 in fiscal year 2007 (fiscal year 2007), $176,000 in fiscal year 2008 (the first full year of operation under the new retrofit), and $228,000 in fiscal year 2009. Savings is expected to match or exceed fiscal year 2009 levels in the future. Based on a project cost of $850,000, a utility rebate of $181,000, a conservative annual average cost savings estimate of $200,000, and Stanford's internal real discount rate of 4.4%, payback will occur by fiscal year 2011. Cumulative net present value, based on avoided energy cost, exceeds $800,000 over 10 years. This analysis assumes that the energy prices do not escalate faster than inflation; in reality, savings may exceed these projections.

Based on Stauffer I performance, Stanford has implemented, or is in the process of implementing, this design approach on a number of additional campus buildings. A similar retrofit of the adjacent laboratory, Stauffer II, was completed in 2008 and has shown comparable savings. Construction is currently under way on the Beckman CMGM project—a 185,000 ft^2 (17 187 m^2) laboratory at the Stanford Medical Center—using (10 219 m^2) a design that builds on the successes of Stauffer I and II. Stanford is designing the retrofit for a fourth laboratory—110,000 ft^2 (10 219 m^2) Gilbert Hall. The more than 60% energy savings achieved on Stauffer I continue to serve as a catalyst for many similar energy-efficiency retrofits of laboratories at Stanford.

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