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OTHER INSTITUTIONAL, EXISTING BUILDING COMMISSIONING

Vivarium *Retrocommissioning*

BY ADAM WHEELER, P.E., MEMBER ASHRAE

BUILDING AT A GLANCE

UCSF Vivarium Building

Location: San Francisco

Owner: University of California

Principal Use: Basic research

Includes: Animal housing, procedure and support rooms, staff rooms, cage wash and processing, MEP equipment

Employees/Occupants: 30 people, up to 250,000 mice

Occupancy: 100%

Gross Square Footage: 191,000

Conditioned Space Square Footage: 189,000

Substantial Completion/Occupancy: 2005

Some people picture a poorly maintained or "neglected" building when they think of candidates for retrocommissioning. But, the particular requirements of well-maintained critical facilities such as vivariums may mean they're good candidates, too. Sometimes, these buildings need retrocommissioning because the rigors of day-to-day work overshadow efficiency concerns. Or, owners defer conservation measures—vivarium owners aren't inclined to make changes that may endanger the animals if systems are working adequately.

When a San Francisco university's vivarium needed energy and operation improvements, however, the solution was carefully implemented monitoring-based retrocommissioning. The result is a building that meets the unique needs of its animal and human occupants and saves the university more than $200,000 per year.

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ABOVE Users were trained to cap unused cage rack connections and configure controls for the actual number and type of racks installed to ensure consistent ventilation rates.

LEFT Cage racks are fully ventilated with house supply and exhaust air. Users are trained to keep flexible connections short and consistent.

Vivarium Design Considerations/Challenges

Like all research laboratories, vivariums tend to be big energy consumers, largely due to ventilation requirements. The six-floor University of California, San Francisco's (UCSF) specialized vivarium is no exception. Temperature, humidity and ventilation must be maintained within strict limits to care responsibly for the animals, to ensure comfort and safety of the humans working with them, and to safeguard the investments of knowledge, time and money made in the animals. A small subpopulation of animals can represent an investment of years of work and six or seven figures that can be put at risk by a small oversight.

Consequently, redundancy of mechanical and electrical systems is critical, and great care must be taken in any work done affecting occupied areas. When these systems are working adequately, great concern exists on the part of users, operators and maintenance staff over any proposed modifications. A good deal of trust, careful planning and thorough explanation are required if energy-efficiency measures (EEMs) are to be implemented.

Special design considerations for vivariums include:

- Consistent pressurization regimes both to protect vulnerable animals and to isolate pathogens within subpopulations;
- Ventilation requirements that are not always informed by current technology and practices but are prescribed by regulatory and accrediting organizations;
- The interfacing of the HVAC system with "process equipment" that can vary widely in detail between or even within vivariums, such as racks of cages that must provide consistent temperature and ventilation conditions at very low flows to tens of thousands of housing units, or automated washing and sterilizing equipment;
- Designing and building systems that can be operated reliably by personnel of varying ability and experience.

Vivariums demand creative solutions from HVAC professionals at all levels since standard practices are often not adequate for starting, balancing and operating these systems.

Project Summary

UCSF's vivarium building was built in 2003–2005 as a state-of-the-art facility with 88,813 gross ft^2 (8251 gross m^2) of conditioned space. Its monitoring-based commissioning project was undertaken in 2013 to improve building energy efficiency and operation.

Four of the building's six floors are devoted primarily to laboratory animal housing with space for support and procedures, including a surgical suite on the third floor that may also be used for humans during a local disaster. The second floor provides common support services of cage, equipment, bedding and food handling, washing and sterilizing. The bottom floor and roof house mechanical and electrical equipment for the building including redundancy to a theoretical "N+1" level.

The facility has a continuous 100% outdoor air ventilation requirement dictated by the animal occupants. This is provided by four rooftop air handlers designed and originally balanced to operate at about 39,000 cfm (18 406 L/s) each at 7 in. w.c. (1744 Pa) static pressure, fitted with 75 hp motors (56 kW), and four rooftop exhaust fans balanced to operate at about 39,000 cfm (18 406 L/s) each and 6.5 in. w.g. (1620 Pa) total static pressure, fitted with 60 hp (45 kW) motors.

Temperature and humidification requirements are met by chilled water and hot water coils and steam humidifiers incorporated within the air handlers, along with hot water terminal reheat coils. Additionally, HEPA filtration is provided within the air handlers, and both

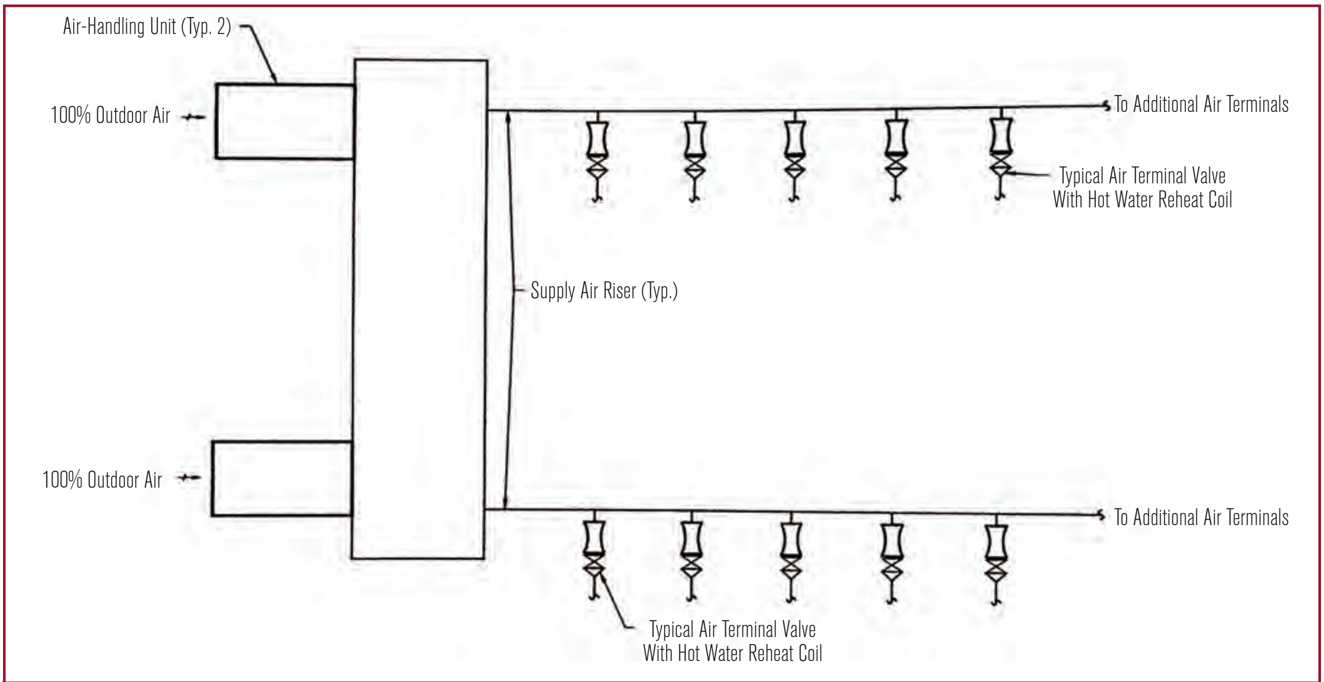

FIGURE 1 Supply air system.

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supply and exhaust air are provided with carbon filtration for odor and VOC mitigation (*Figures 1* and *2*).

Zone airflow is tightly controlled by pressure-independent variable airflow control valves on every supply and exhaust connection, with flow measurement added to increase precision of airflow and space pressurization control. Reversible room pressurization is provided via the BMS, and each room's air change rate is calculated, displayed and logged. Room pressurization is controlled by tracking and adjusting supply and exhaust airflows (*Figures 2* and *3*), which requires a high level of measurement accuracy, particularly in the housing rooms served by four airflow control valves.

The facility is provided with chilled water and steam by the adjacent campus utility plant. Chilled water is used for cooling and minor process loads, and steam is used to produce heating hot water and to boil water for the steam humidifiers, as well as domestic hot water and substantial service to cage and equipment washing and sterilizing equipment.

The building is controlled by a sophisticated BMS that is interfaced with the HVAC equipment and the low voltage lighting control system. The BMS provides access to all controller parameters on a single bus, has extensive data logging capabilities and is part of a greater campus network. The BMS also monitors and logs data from the chilled water and steam meters. Electrical metering is monitored and logged by the separate campus supervisory control and data acquisition (SCADA) system.

Energy Efficiency

Compliance with ASHRAE/IESNA Standard 100-2006, *Energy Conservation in Existing Buildings*, was evaluated as part of the project and the building was established to be substantially in compliance at the time of completion, with only minor exceptions. All exceptions noted were discussed with remedial actions planned and documented in the final commissioning report.

The project team carefully eliminated system elements such as bypass flow, fixed high static pressure setpoint, and fixed supply air (SA) temperature setpoint (no reset range), which, due to the nature of the building use, occupancy and systems, were excessive or unnecessary. All changes were tested carefully to verify acceptable operation could continue afterward and changes were implemented one at a time so the cause of any unexpected consequences could be more easily traced and to control synergistic effects.

Revising the original "one size fits all" elements of the HVAC (airflow, temperature and occupancy schedule) and lighting design (illumination level and occupancy schedule) to more closely match the actual use and requirements of each zone yielded significant energy savings. Elimination of excess airflow by

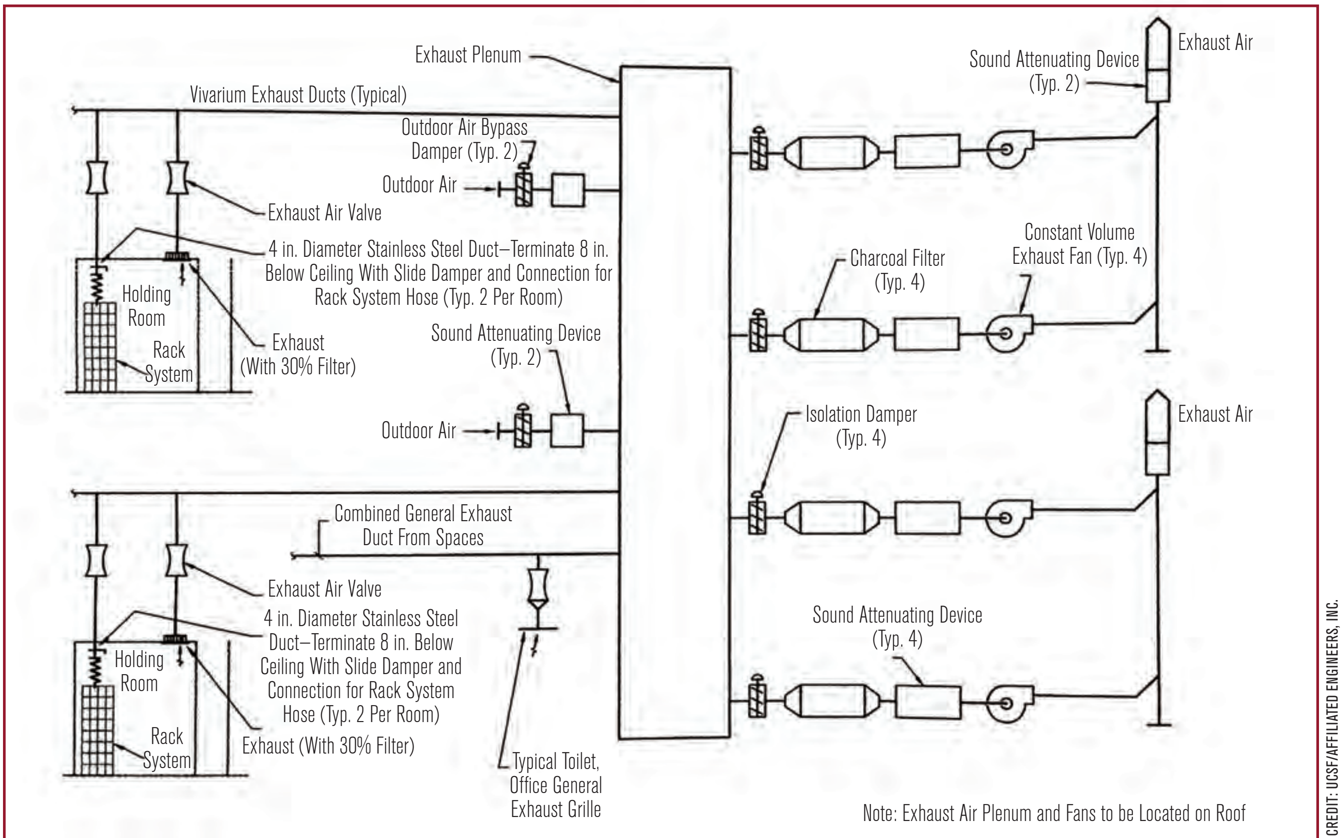

FIGURE 2 Exhaust air system. The building is continuously ventilated with 100% outdoor air, and cage racks are ventilated independently from the human occupied spaces.

meticulous zone-by-zone analysis further reduced loads and duct and piping pressure losses, increasing the efficiency of delivering the remaining necessary utilities. Isolation vs. operation of redundant standby equipment was considered to determine the more efficient approach.

Energy use intensity (EUI) as a relative measure of building operating efficiency went from 328 kBtu/ft^2·yr (3725 MJ/m^2·yr) to 242 kBtu/ft^2·yr (2748 MJ/m^2·yr) (modeled to correct for weather data per the utility incentive program under which the project occurred). The building has high steam process load.

The electrical EUI, more reflective of HVAC energy use, went from 118 kBtu/ft^2·yr (1340 MJ/m^2·yr) to 62.4 kBtu/ft^2·yr (708.6 MJ/m^2·yr). Actual measured energy use for the 12 months following implementation of the measures yielded an EUI of 234 kBtu/ft^2·yr (2657 MJ/m^2·yr) total, with 62 kBtu/ft^2·yr (704.1 MJ/m^2·yr) for electrical use.

IAQ and Thermal Comfort

IAQ is a constant and primary consideration for the operation of this building, both for the health of the animals and of the people that work with them daily. Air exchange rates were required to be maintained at or above 10 air changes per hour (ach) (1.4 cfm/ft^2 [7.1 L/s·m^2]) to comply with legacy animal care guidelines due to accreditation concerns, though lower rates may be acceptable in the future for human-occupied areas.

Regulations and guidelines of groups including the Association for Assessment and Accreditation of Laboratory Animal Care, Environment Health and Safety, Occupational Health and Safety Administration and Uniform Building Code generally exceeding those of ASHRAE Standard 62.1-2013 were verified and observed in applicable spaces. For spaces such as break rooms, hallways, storage and utility rooms Standard 62.1-2013 values were applied where allowable.

Air quality testing for particulates and ammonia levels was performed during the project in the soiled cage wash area and typical animal rooms to verify adequacy of IAQ where ventilation rates were modified. Ammonia levels were verified to be below 10 ppm via spot checks throughout the facility. (The NIOSH recommended exposure limit is 25 ppm averaged over an 8-hour day, with a 35 ppm short term—15 minute—maximum limit.) Test locations

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were chosen to verify ventilation effectiveness. Ventilation effectiveness appears well served by air inlet and outlet locations. Heating air temperatures kept within 15 F (8.3°C) of room temperature further support this.

Feedback and complaints were solicited continuously from staff during testing and implementation. Three complaints were received and addressed.

Proactive detailed monitoring for odors and measurement of animal housing airflow and temperature performed immediately before and after measure implementation caught five other issues. These issues were addressed through analysis of zone equipment components both on site and via BMS.

A total of eight issues with animal housing airflow were recorded that were hardware related. Of these, six were traced to faulty elements within the cage racks and their connections. One issue was traced to a faulty airflow control valve and one to an airflow measurement calibration issue and addressed by O&M personnel.

Seven zone issues were found and addressed with software setpoint adjustments and programming upgrades.

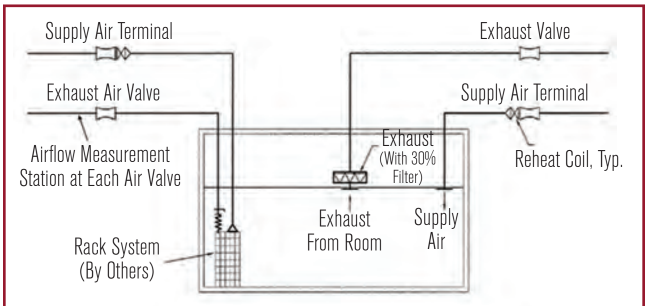

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FIGURE 3 Typical small animal room. Airflow measurement stations for cage racks were added immediately prior to initial occupancy at each airflow control valve to improve measurement accuracy for pressurization control.

Additional data collected included BMS airflow rates supported by air balancer spot checks, and contemporaneous partial-exhaust biosafety cabinet certification.

Room pressurization is maintained building-wide via exhaust airflow (EA) setpoints calculated by adding an offset to measured supply airflow (SA). Manual testing was used to establish a “curve” correlating valve position to airflow below BMS measurement range in some cases and proper room pressurization verified manually.

Pressure sensors were added to the BMS to improve

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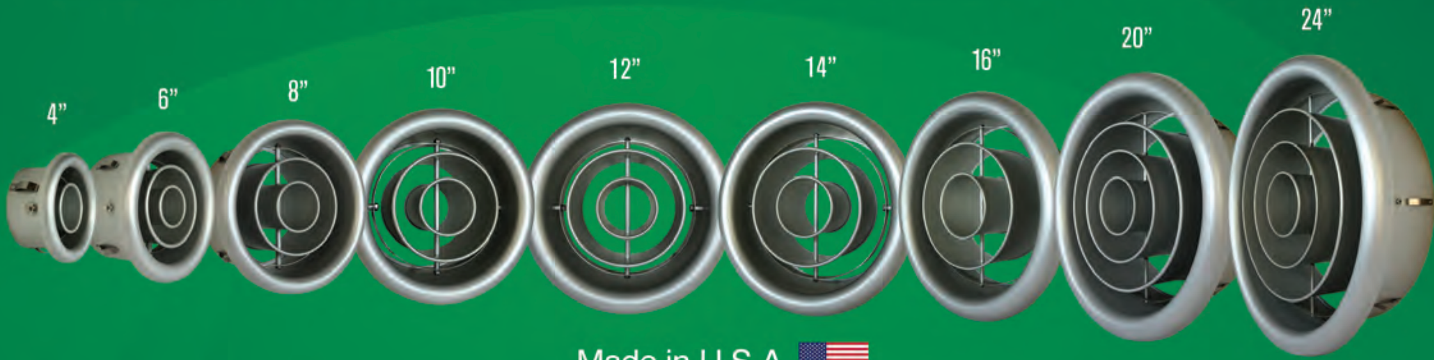

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ensurance of IAQ in cage wash areas. Post-occupancy purge was added in occupancy-controlled rooms such as biosafety cabinet (BSC) rooms, surgery suites and procedure rooms to further ensure IAQ. Preoccupancy ventilation was programmed and verified when a room standby mode was added. Pollutant source control/isolation via a pressure "cascade" to the exhaust air outlet was the typical approach; a portion of the air supplied to clean or sterile zones flows toward corridors, BSCs, ventilated cage racks, isolation zones or the soiled cage wash area where it is exhausted.

Thermal comfort for people and animals, including humidity control improvement, was addressed and verified by measurement and by polling human occupants. Relative humidity is maintained between 40% and 60% at 72 F (22°C) (except in the immediate vicinity of washing activities). The original design's "one size fits all" temperature setpoint of 68 F, ±0.5 F (20°C, ±0.3°C) was updated to suit the varied environments of clothing and activity ranging from surgery with assumed clothing insulation and metabolic factors of 1.1 clo and 2.0 met, respectively, plus radiant heating from lighting and equipment (68 F, ±0.5 F [20°C, ±0.3°C]), to ungowned break rooms with assumed clothing insulation and metabolic factors of 0.57 clo and 1.0 met (73 F, ±3 F [23°C, ±1.7°C]). Unoccupied areas were allowed to get as warm as their purpose could tolerate, with reheat eliminated.

Innovations and Other Keys to Success

While this project's success was more due to teamwork, persistence, attention to detail, common sense and prioritizing project goals over profits than to any recent innovations, it might be said those elements are "innovations that never go out of style."

Combatting Mechanical Hysteresis

UCSF's control manager discovered that the pressure-independent venturi-type (mechanical) airflow control valves installed at each terminal in the building have a tendency to "wind up." That is, as their springs compress to limit airflow, a finite percentage will overshoot and cause airflow to measure slightly low due to mechanical

hysteresis. The phenomenon is more apparent at the desirable lower system static pressures and decreases with rising pressure. This incrementally signals the control system that more static pressure is needed, and as the system responds the cycle repeats. This issue was addressed by intentionally lowering the duct static pressure setpoint approximately 20% every four hours to allow the springs to relax and let the system approach the required static pressure from below.

Hybrid Multimode Zone Control

Prior to this project, minimum airflow had been limited to the minimum measurable cfm at each terminal. In non-critical areas where lower flows were desired, such as areas that could be scheduled unoccupied, storage rooms, out-of-service housing rooms, etc., a standby mode was introduced and manually verified to ensure desired pressurization was maintained at very low flow rates. Maintaining smooth control and required pressure relationships while transitioning between modes is a non-trivial control challenge that was met by a team effort in developing and refining the strategy and verifying operation in the field.

Second-Decile Average Control

To control fan speed to provide the duct pressure needed to serve all zone airflow control valves, a reset strategy was implemented based on demand at the zone level. All zones were polled and ranked in order of pressure demand (valve position), then divided into 10 equal groups (deciles) (*Figure 4*). The average valve position of the second decile was calculated and a setpoint established for this average that would provide adequate flow to all critical zones that did not have an equipment deficiency. The first decile is less useful because it will contain valves that are 100% open. They may be providing satisfactory flow, less than satisfactory flow, or may be faulty, but to distinguish the reason in real time is not practically attainable. Unsatisfactory flow rates are alarmed for attention by O&M personnel.

Leveraging Professional Memory

By retaining a commissioning firm and personnel with extensive familiarity with the specialized type of building (the processes unique to vivarium occupancy as well as the conventional HVAC equipment), and this building specifically (including some of the users and operating staff), the project set itself up for success. Not only were

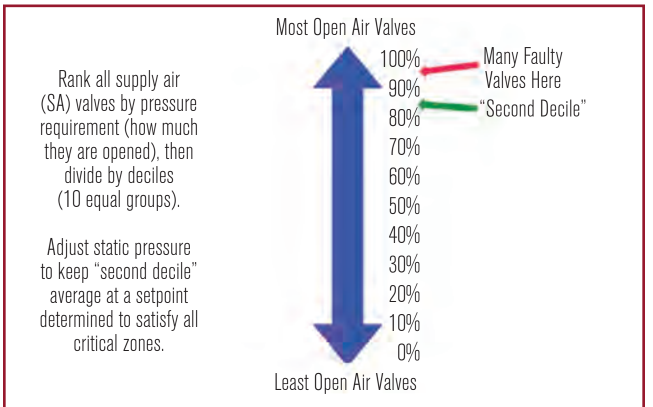

FIGURE 4 Second decile SA/EA static pressure reset. Carefully selected setpoints for the average of the second decile of zone demand was used for supply and exhaust system static pressure control to provide a more consistent metric of actual conditions.

we able to use data and recommendations generated by the new building commissioning, but the familiarity with the underlying conditions, the equipment, systems and especially the relationships with management and staff provided a huge advantage throughout the project.

Enhanced Loop Tuning

By dedicating greater effort to control loop tuning, we were able to eliminate the conservative (–1% to +5%) dead band originally programmed building-wide for airflow control, saving an estimated 3% of excess building airflow with one measure alone. Such a dead band is a common approach to getting a control system working with less time and effort. To tune loops, especially such a large volume, takes significant expertise, time and patience that is not typically available with competitive bids and aggressive construction schedules.

Operation & Maintenance

The project team worked closely with building engineers to improve their familiarity with the building's specialized systems and their understanding of how to address issues locally to avoid global "fixes" that tend to mask the underlying issue and increase energy use. We added programming to allow operators to easily place rooms taken out of service in a "standby" mode maintaining required pressurization with minimal airflow.

We also added programming to automatically calculate the required airflow for animal housing rooms based on the number and type of housing devices (cage racks) being used in the room at any time. This allows operators to easily provide the correct airflow for changing room conditions.

Training was highly emphasized in a variety of modes:

- Involvement of users and O&M personnel in commissioning meetings, surveys and tests;
- Involvement of commissioning personnel with O&M staff in equipment troubleshooting and repair for deficiencies identified during commissioning;
- Providing multiple training sessions, both during and after implementing measures;
- Providing training/reference manuals; and
- Providing separate training sessions and manuals for users and O&M personnel.

Improving building function as a corollary to improving energy efficiency was an important part of the project. The zone-by-zone audit exposed multiple deficiencies due to process equipment issues and use/design mismatches that were able to be resolved, such as adjusting airflow to match the actual equipment installed in a given room, and building that ability into the control software. By tuning loops and improving alarming criteria in the BMS, deficient zone equipment was exposed and repaired.


Cage cleaning, sterilization and preparation area ventilation rates were reduced during unoccupied times while pressure relationships were maintained.

Prior to the effort, some zone requirements had either not been met or had been met by operating the central systems at a higher rate to satisfy the deficient zones. The net effect of reducing the demand on the central systems brought building operation into true compliance with its "N+1" redundancy intent, which had not been the case in the first decade of occupancy due to conditions not anticipated in the design. Additionally, the room air change rate calculation method was improved to more accurately reflect the ventilation of the human occupied portion of each space resulting in increased ventilation rates in some cases.

Cost Effectiveness

Simple payback was less than one year from project completion after incentive. The project took 20 months from contract initiation to measure implementation. Due to utility incentive structure, a comprehensive effort was made to quantify all costs and time incurred by all parties in the project, including items typically considered "overhead." The total was $525,367. The calculated annual energy savings of 1,440,384 kWh and 23,106 therms provide a savings to UCSF of over $200,000 per year at their approximate current average costs of $0.13/kWh and $1.10/therm under the direct access power purchase agreement. Electrical demand reduction calculated to 302 kW, but is not considered in the savings estimate or incentive program. This resulted in an incentive payment of $393,895 to the university, or a simple payback of 10.6 months.

Environmental Impact

Approximately 500 tons of CO_2 emissions are avoided annually, at the low CO_2 intensity of regional electrical power. This estimate is based on 0.524 lb CO_2/kWh and 13.446 lb CO_2/therm published rates and the modeled (weather data corrected) electrical and natural gas savings.

Conclusion

Ultimately, this project's success was largely due to the building being designed and started up as if it were 100% laboratory animal housing, when about half the space is human occupied. The human occupancy occurs during predictable, scheduled times, making such spaces suitable for unoccupied-time setbacks of temperature and ventilation rates. The project could not have been successful without a highly detailed, persistent approach to address the unique needs of each part of the building, the patience to work through the necessary administrative requirements, and the presence, expertise, support and participation of dedicated operation and maintenance personnel and willing users.

Acknowledgments

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