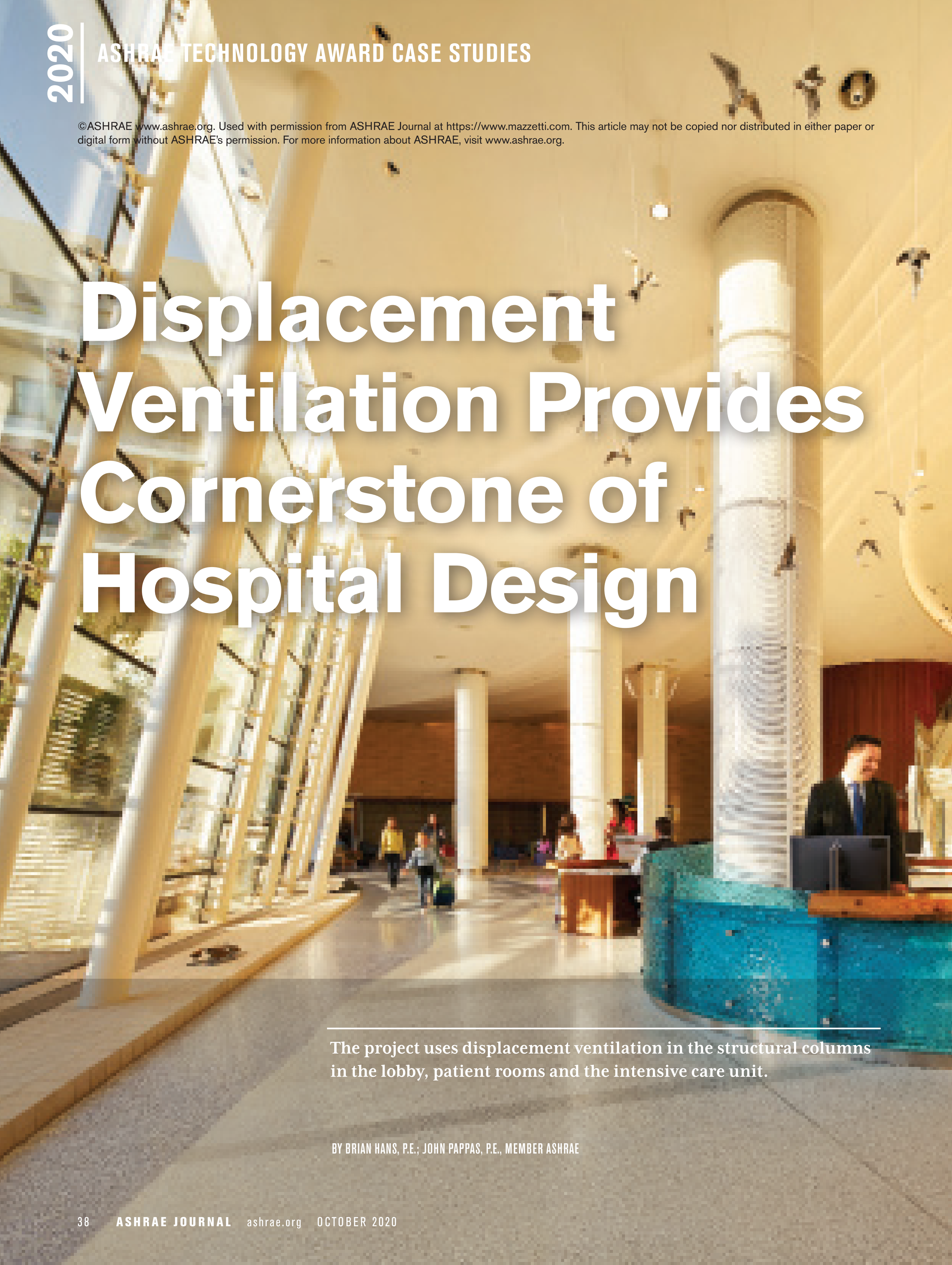

Displacement Ventilation Provides Cornerstone of Hospital Design

The project uses displacement ventilation in the structural columns in the lobby, patient rooms and the intensive care unit.

BY BRIAN HANS, P.E.; JOHN PAPPAS, P.E., MEMBER ASHRAE

Displacement ventilation was incorporated into the lobby's structural columns to seamlessly integrate the mechanical systems and provide efficient air distribution, reducing energy consumption and improving occupant comfort.

The overarching goal for the Lucile Packard Children's Hospital (Packard Children's) was to create an environment that aids healing by providing children and expectant mothers and their visitors warm, comfortable, light-filled and uplifting spaces, creating a "home away from home." The project embodies innovation and a true commitment to environmental sustainability. Displacement ventilation was a cornerstone system decision to achieving the project's energy-efficiency goals.

The new 521,000 net square feet (48 402 square meter) building sits atop a 192,000 square foot (17 837 square meter) garage, more than doubling the size of the existing pediatric and obstetrics hospital campus. The new building adds 149 patient beds for a total of 364 patient beds on the Palo Alto campus. It includes four floors consisting of two wings of ICU and acute care unit patient care beds, 12 operating/interventional radiology rooms, a full imaging area that includes MRI, CT and PET/CT, a grand light-filled lobby, public areas, and 3.5 acres (1.4 ha) of green space with gardens and artwork for patients, family and staff.

Energy Efficiency

CBECS 2018 benchmarking indicates a site EUI of 234 kBtu/ft^2·yr (2657 MJ/m^2·yr) and a source EUI of 427 kBtu/ft^2·yr (4849 MJ/m^2·yr) for general medical and surgical building types. Packard Children's is the second children's hospital ever, the fourth hospital in the country, and the fifth in the world to earn LEED Platinum certification. The site has an EUI of 179 kBtu/ft^2·yr (2033 MJ/m^2·yr) and a source EUI of 389 kBtu/ft^2·yr (4418 MJ/m^2·yr) (*Figure 1*). Modeled energy use and EUI reported are after the energy model had been calibrated with 12 months of collected data.

Energy-Efficiency Strategies

Displacement Ventilation. In 2007, just prior to starting work on Packard Children's, the project's

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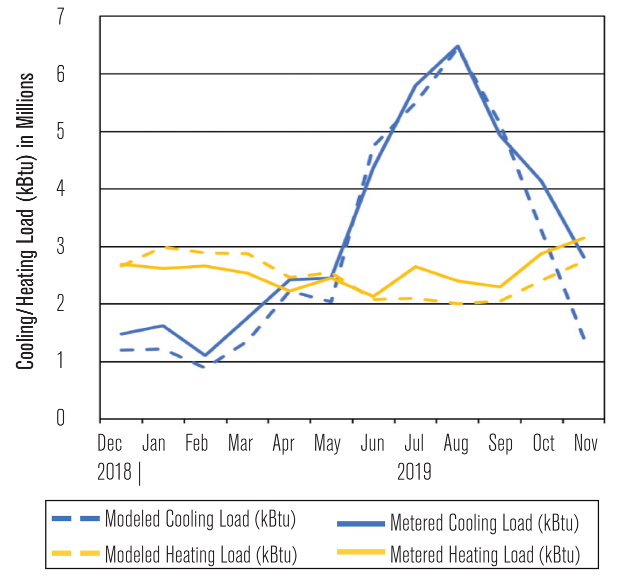
FIGURE 1 Modeled vs. metered cooling and heating loads.

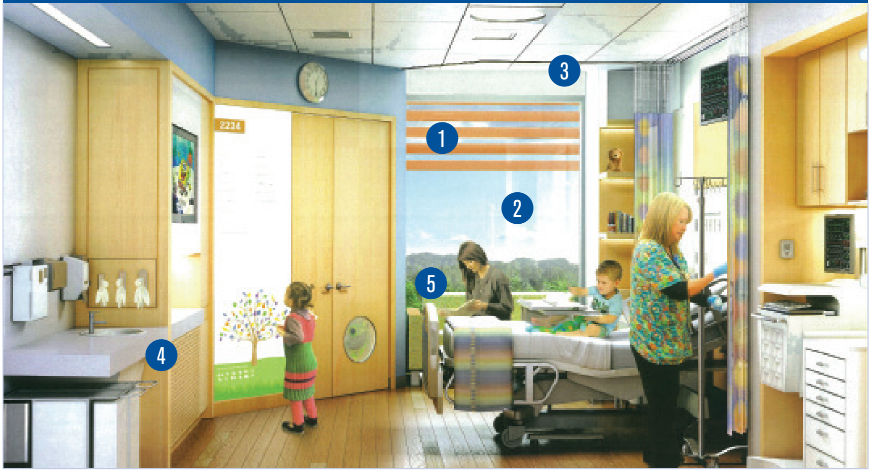


engineering firm formed a collaborative to evaluate alternative ventilation strategies for health-care facilities. This research went through rigorous testing procedures using computational fluid dynamics modeling and physical lab testing. It was subsequently validated by the National Institute of Health, amended to ASHRAE/ASHE Standard 170, *Ventilation of Health Care Facilities*, and adopted into code. The benefits were clear—displacement ventilation (DV) greatly reduced energy consumption, improved the removal of airborne particulate matter and increased the overall ventilation effectiveness. The project adopted DV in the following areas:

- Patient rooms (*Photo 1*): Low sidewall DV with radiant heating, reduced fan energy, decreased cooling energy, mitigated reheat energy, improved thermal comfort and lessened ambient noise from ventilation, which has been proven to reduce environmental fatigue.
- ICUs: Overhead DV system meets code requirements while enabling energy savings and promoting occupant comfort. ICUs use a combination diffuser, which switches from DV delivery in cooling to linear delivery in heating modes, allowing for a standard reheat system, given that ceiling area is at a premium and a separate radiant panel could not be accommodated.
- Entrance lobby: DV was incorporated into the lobby's structural columns to seamlessly integrate the mechanical systems and provide efficient air distribution, reducing energy consumption and improving occupant comfort.
- Integration of distribution with architecture: The team implemented creative ways to use spaces that would usually be considered "waste areas." For example, in ACU patient rooms, space under television sets was used to deliver low velocity air into the room. Dead areas within the cabinetry behind mounted televisions were used to bring air down to the floor level, thus not impacting the usable area of the patient room. In the main lobby the structural columns were wrapped with air distribution DV diffusers, which were specifically developed for this project and integrated into the column cover wraps, minimizing the impact on floor usable square footage. The result—a wave-like ceiling, without any visible diffusers, which achieved the "clean look" desired by the client.

Optimized Exterior Façade. A fixed external shading strategy was developed alongside the mechanical

PHOTO 1 Patient room. 1) BMS-activated automatic shading; 2) natural lighting; 3) radiant panels; 4) integrated DV; 5) window planters fed from a recycled water drip irrigation system.



Building at a Glance

Lucile Packard Children's Hospital

Location: Palo Alto, Calif.

Owner: Stanford Children's Hospital

Principal Use: Pediatric and obstetrics hospital

Gross Square Feet: 713,000

Conditioned Square Feet: 521,000

Substantial Completion/Occupancy: December 2017

PHOTO 2 Data center. 1) Rear return to economizers hidden behind metal closure access doors; 2) hot ceiling plenum return non-ducted–all openings to ceiling are sealed from "cold aisle"; 3) hot air containment chimney; 4) entire room is a "cold aisle," maintained at 67°F from air discharged off the top of the AHUs; 5) computer room air handling units–*N* + 2 with full economizer (160 tons net capacity).

systems to significantly reduce direct solar gain and facilitate implementation of the DV system for patient rooms. Direct sunlit areas of the floor where DV is used were limited to a maximum of 5% of the total floor area.

Daylighting. The use of daylighting has been optimized to maximize natural light, access to views, and mitigate energy consumption in many areas of the hospital. Patient rooms and corridors are designed to mitigate direct solar gain, while leveraging daylighting and access to views. Other areas, such as the post-anesthetic care unit, use skylights to access natural light, minimizing lighting energy use and facilitating a connection to the outdoors.

Other Energy-Efficiency Strategies

Data Center. In a departure from traditional facilities, the hospital's data center (*Photo 2*) is positioned on the roof (rather than in the basement). The relocation of the data center resulted in a dramatic reduction of building chilled water energy and allows the system to use cold nighttime outdoor air, as opposed to air-conditioned air, for much of the year.

Economizers are incorporated into the computer room AHUs directly from exterior walls. A combined return plenum is above the ceiling; each data cabinet's hot air discharge is captured through a hot "chimney," which is sent up into the plenum. When the outside air temperature is less than the return air temperature of the plenum, the plenum air is relieved using three large plenum relief fans. This technique, combined with the high temperature discharge of the IT cabinets (87°F [31°C]), allows use of the economizer cycle for up to 6,400 hours per year.

Energy Recovery. Heat and cooling recovery was used for 100% outdoor air systems in the ACU patient bed tower, minimizing air distribution into that tower.

Renewable Energy. All electrical energy provided to the building is from renewable sources. This includes a small amount of power produced on site (wind power and photovoltaic), with the remainder of the power from the City of Palo Alto. The latter is from 100% renewable sources.

Heating and Hot Water Energy. Eighty-eight percent of the building's heating and domestic hot water energy is provided from the campus central energy facilities' waste heat reclamation.

Indoor Air Quality/Indoor Environmental Quality

Displacement ventilation has been shown to be as effective as or more effective than standard dilution distribution systems for control of particulates in the patient environment. In 2007 the project's engineering firm led a collaborative study on alternate distribution systems ("Healthcare Ventilation Research Collaborative: Displacement Ventilation Research, Phase II Summary Report," tinyurl.com/y3mqou9m). This study was the basis for the design of Packard Children's; the team incorporated the report findings and recommendations to maximize the ventilation effectiveness and particulate control for patient rooms (*Figure 2*).

The design complies with and exceeds Facility Guidelines Institute (FGI)-prescribed Standard 170 for outdoor air and filtration levels and complies with all requirements of Table 4A of the California Mechanical Code (CMC). This compliance is more restrictive and stringent than ASHRAE Standard 62.1-2010. The study showed DV at 4 ach is 30% to 50% more effective than standard overhead distribution at 6 ach. *Figure 2* shows visually overhead ventilation tracer gas particulate modeling, which shows dispersion of particulate throughout the room vs. *Figure 3*, which shows particulate modeling for DV, and particulate is captured at the top of the room and removed. The use of DV was tailored so the design could provide the benefits of DV while still complying with the 2007 CMC requirements under which the building was permitted. DV is now a much more recognized

FIGURE 2 Result of tracer gas particulate modeling. Three ppm isosurface for overhead ventilation at 6 ach.

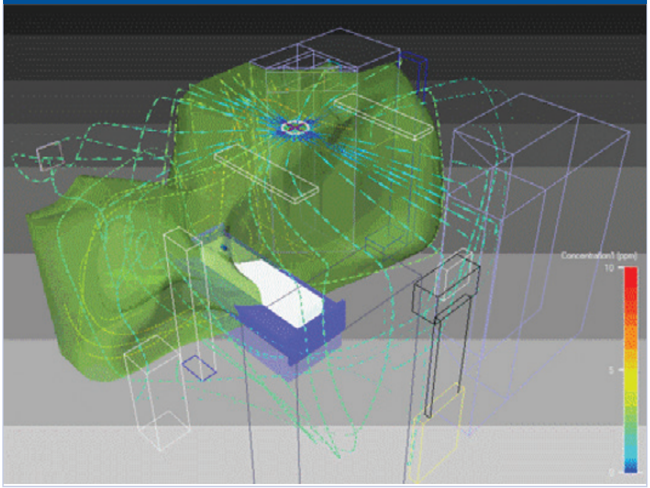
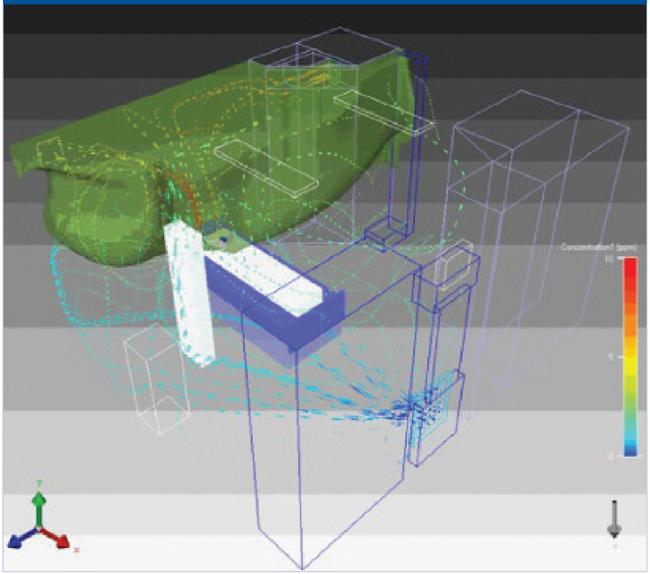


FIGURE 3 Result of tracer gas particulate modeling. Three ppm isosurface for displacement ventilation airflow pattern at 4 ach.



ventilation technique; however, at the time of submission, these techniques had to be shown and proven effective to be acceptable by the authority having jurisdiction.

Thermal comfort is maintained for each patient by following the FGI guidelines for single-patient room design and providing individual temperature control in patient rooms. DV is shown to increase the thermal comfort of the patent at the bedside when compared to an overhead ventilation (OV) distribution system, keeping the bedside condition at a desired 72°F (22°C). ASHRAE Standard 55-2010 analysis using the Center for the Built Environment's Thermal Comfort Tool shows that this design has a patient satisfaction rating of 94% and visitor satisfaction rating of 90%. A standard OV system provides patient satisfaction of 93% and visitor satisfaction of 79%. DV exceeds the ASHRAE Standard 55-2010 recommended satisfaction rate of 80%.

DV in patient rooms has significantly reduced noise to NC 25 levels. This aids in healing and improves environmental quality. Access to light and nature at every patient room leverages the advantages of biophilia.

Given that Packard Children's patients often come to them with very serious illnesses and with highly compromised immunosupressed immune systems, they chose to use HEPA filtration throughout the patient treatment process. The main lobby, check in, imaging, operating rooms (OR) and patient towers all use HEPA filtration. AHU velocities were reduced to 350 fpm to 400 fpm (1.8 m/s to 2 m/s) to offset the higher static pressure requirements for HEPA filtering. Normal static pressure losses for HEPA start at 1.5 in. w.c. to 2.0 in. w.c. (374 Pa to 498 Pa) when clean. With the reduced velocities, the starting static pressure of the HEPA filters was reduced to 1 in. w.c. (249 Pa). This allowed higher filtering levels with overall system static pressures equivalent to code minimum AHU designs.

Innovation

Innovation was a cornerstone element of the design philosophy throughout the building and design process. The extensive, unconventional use of displacement ventilation; low velocity air systems; extensive use of HEPA filtration; and maintenance-friendly MEP systems are all "out-of-the-box" innovations, changing the way traditional systems are used, increasing energy efficiency (and the hospital's overall sustainability) and improving the overall experience for patients. Other innovative strategies include:

- Halogenated drug recovery (HDR): This system collects and prevents anaesthetic drugs used during surgical procedures from being vented directly to the atmosphere, significantly reducing the carbon footprint of Packard Children's. The HDR system captures fluorinated ethers and gases classified as greenhouse gases (GHG) under the United Nations Framework Convention on Climate Change and others as defined by the final EPA Mandatory Reporting of GHGs Rule (74 FR 56260; October 30, 2009). The system installed at Packard Children's was the first central collection system installed in the United States.

- Rapidly adjusting OR temperatures (*Photo 3*): Specialty open-heart operating rooms were designed and tested to change the environment of the room from 80°F (27°C) maximum to 55°F (13°C) minimum, while maintaining humidity conditions between 30% and 60%. This design is feasible through use of a low temperature cooling system that rejects heat to the chilled water return system. Clinical requirements are to change the room temperature in five to 10 minutes from minimum to maximum and back. During commissioning, this cold OR system was demonstrated to clinical staff and passed with flying colors, meeting or exceeding the promised environmental temperature changes within the promised time frames.

Maintenance and Operation

Most of the critical air-handling units were designed using a “twin tunnel” air distribution system with $N+1$ multifan arrays. This enables each AHU to operate at 60% to 70% of total capacity while normal maintenance is being performed and half the unit is turned off. This allows for filter replacement, coil cleaning or replacement and maintenance, all without shutting down air to ORs or patient rooms.

The data center has been independently evaluated to be a Tier 3 configuration (as defined by the Uptime Institute), with a full $N+2$ air distribution system.

Electrical power was backed up with $N+1$ generators and “fly wheel” UPS systems and arranged for in-service maintenance of electrical equipment.

Critical plumbing systems like medical air, oxygen and medical vacuum were provided with $N+1$ or $N+2$ systems configurations and supplied with power from alternate sources, so both electrical and plumbing systems were concurrently maintainable.

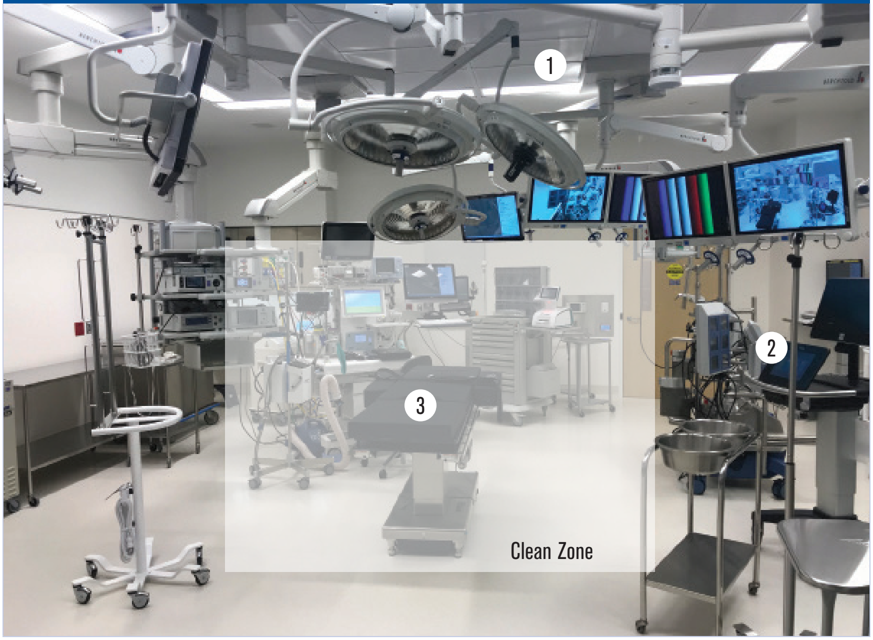
Spare capacity of 25% was built into airside and waterside systems to “future proof” the expansion and modification of the building for a 50-year life.

Cost-Effectiveness

The design team and owner

considered a variety of energy conservation measures (ECMs) for the HVAC system at the beginning of schematic design. Energy cost models were run for each system type, which included optimized envelope, variable air volume HVAC systems, 100% outdoor air systems with heat recovery, oversized air-handling units, displacement ventilation versus standard overhead distribution, plus various combinations of these options. This data was tabulated and compared with a baseline model based on ASHRAE/IESNA Standard 90.1-2007. We found the most effective results were a combination of multiple ECMs, including optimized exterior, DV with some 100% outdoor air and heat recovery, VAV, and oversized AHUs. This net result showed a simple payback of about four years and an internal rate of return of 23.8%.

PHOTO 3 Cardiac operating room. 1) Ceiling laminar flow diffuser grid above clean zone; 2) low return; 3) specialty open heart operating rooms are designed to fluctuate from 80°F (max) to 55°F (min).



Environmental Impact

Irrigation. Drought-tolerant and water-efficient landscaping is irrigated with nonpotable water only, which is collected in two 55,000 gallon (208 198 L) underground cisterns. The cistern system filters, stores and reuses water collected from rainfall, mechanical equipment condensate and even reverse osmosis deionized water regeneration rejection water.

According to research provided by the project's head planning architect, Packard Children's is the first hospital in California to use this cistern technology, which is expected to save as much as 800,000 gallons (3 million L) of irrigation water per year.

Low-Flow Fixtures. 3.38 million gallons (12.8 million L) worth of water is saved annually from the use of low-flow fixtures (as submitted for LEED credit WEp1) and 359.45 kgal (1.4 million L) per year for sterilization equipment that has heat exchangers rejecting heat to chilled water.

Reclaimed Materials. More than 28% of Packard Children's building materials contain recycled content (including carpet, tile, steel and concrete), and more than 26% of those materials were extracted or manufactured within 500 miles (805 km) of Palo Alto. Reclaimed wood either from the site or nearby demolition projects at Moffett Field was incorporated throughout the project.

Carbon (GHG Emissions) Reduction. The LEED-baseline energy model was used for energy results, and the Packard Children's LEED Proposed model (adjusted to match metered data) for the actual Packard Children's energy use. Energy Star Portfolio Manager was used to calculate the GHG emission. Packard Children's has a 40% reduction in CO_2 emissions compared to an equivalent ASHRAE Standard 90.1-2007 compliant facility.

Green Spaces. The building incorporates natural elements seamlessly—3.5 acres (1.4 ha) of gardens and green space for patients, families, visitors and staff to enjoy.

Acknowledgment

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