2014 ASHRAE TECHNOLOGY AWARD CASE STUDIES

The Oakland Unified School District, La Escuelita Education Center maintains comfort using a multi-pronged conditioning strategy that relies on local climate, thermal mass and sophisticated controls.

HONORABLE MENTION

EDUCATIONAL FACILITIES, NEW

Climate-Adapted Design *For California School*

BY BRENT EUBANKS, P.E., MEMBER ASHRAE; AND GLENN FRIEDMAN, P.E., MEMBER ASHRAE

BUILDING AT A GLANCE

OUSD

La Escuelita Educational Center

Location: Oakland, Calif.

Owner: Oakland Unified School District

Principal Use: K–8 school, district administrative functions

Includes: classrooms, two-story great room, offices, data center, kitchen, health clinic, TV studio

Employees/Occupants: 1,850

Gross Square Footage: 71,500

Conditioned Space Square Footage: 54,900

Substantial Completion/Occupancy: August 2012

Occupancy: 100%

National Distinctions/Awards: 2014 C.A.S.H./AIACC Leroy F. Greene Design + Planning Awards Program; Award of Excellence, New Built Category; 2011 C.A.S.H./AIACC Leroy F. Greene Design + Planning Awards Program; Award of Merit, Project-in-Design

Design Architect and Architect of Record: MVE Institutional

The Oakland Unified School District (OUSD) is one of the largest in California with more than 80 schools and 36,000 students, primarily from low income communities. Funded by a bond, the La Escuelita Education Center (LEEC) project replaces an outdated campus—consisting primarily of decrepit portable classrooms—with a modern facility. OUSD-LEEC Phase 1 includes a kindergarten and elementary school, as well as district support facilities.

The new LEEC campus meets the requirements of the California Collaborative for High Performance Schools (CA-CHPS), including compliance with ASHRAE Standards 55 and 62.1 (2010 versions), while maintaining the long-standing district policy of avoiding compressor-based cooling for classrooms and administrative offices.

Brent Eubanks, P.E., is a mechanical engineer and certified permaculture designer and Glenn Friedman, P.E., is a principal at Taylor Engineering in Alameda, Calif. Both are members of the Golden Gate ASHRAE Chapter.

PHOTOS COURTESY OF NW ARCHITECTURAL PHOTOGRAPHY

ABOVE AND LEFT Large ceiling fans in each classroom provide comfort cooling on the hottest days.

COURTESY OF NW ARCHITECTURAL PHOTOGRAPHY

These goals were achieved by a combination of building orientation, careful lighting and daylighting design, and an HVAC strategy that capitalizes on Oakland's Mediterranean climate with its reliable breezes and significant diurnal temperature swings.

Systems Description

While the data center, clinic, and TV studio use a high-efficiency, single-duct VAV HVAC system, the classrooms do not use compressor-based cooling. Maintaining comfort required a multi-pronged conditioning strategy that relies on local climate, thermal mass and sophisticated controls.

The classrooms and offices have operable windows (with switches that disable HVAC), allowing for occupant control and passive natural ventilation. When windows are closed these spaces are cooled by unconditioned 100% outdoor air from central AHUs. Displacement diffusers deliver air to the classrooms, which improves ventilation effectiveness and IAQ, and also rejects occupant heat from the space rather than mixing it into the rooms' air mass. Air supply is controlled by demand and outdoor air temperature, delivering large volumes when the weather is cool but reducing to ventilation minimum when weather is warm.

Additional cooling is provided by thermal mass: a 4 in. (25 mm) concrete floor slab and a 2 in. (25 mm) thick cement plaster layer on interior walls. Thermal mass is charged (cooled) at night by a high volume purge cycle, leveraging a cooling season diurnal temperature swing of 20°F (11°C) or more. This cycle is controlled based on outdoor air temperature, room temperature, and thermal mass temperature from sensors embedded in the floor and walls to minimize fan energy and avoid overcooling. This provides a thermal flywheel effect to maintain comfort even on warm days.

A final element of the classroom cooling strategy is automatically controlled high volume, low speed (HVLS) ceiling fans. The fans are off during the first stage of cooling, when the supply air is cool, so that displacement ventilation provides beneficial stratification in the occupied zone. As the outdoor temperature (and, thus SAT) rises, the ceiling fans activate to provide up to 4°F (2°C) additional effective cooling.

The ceiling fans also assist in heating, which is by parallel fan-powered VAV (FP-VAV) boxes with hot water coils in each room. Heated air is delivered via the same displacement diffusers used for cooling, while the ceiling fan operates at low speed to destratify the space and ensure uniform heating.

These cooling and heating strategies are also applied in the great room, which has a dedicated single-zone AHU with economizer to provide heating, ventilation and 100% outdoor air cooling. However, the great room is periodically subject to high occupant densities, up to 10 ft^2 (0.9 m^2) per person. This exceeds what outdoor air cooling and thermal mass alone can support, so a pair of passive evaporative downdraft towers ("cool towers") is employed to address these loads.

The towers are 40 ft (12 m) tall and 12 ft (3.7 m) square with high-pressure fogging nozzles at the top that inject a modulated volume of very finely atomized water. The water evaporates and cools the air, which drops under buoyancy pressure, cooling the space and then relieving through automatic louver/dampers installed near the ceiling. Each tower also has a wind scoop that faces west into the prevailing wind to provide cooling and ventilation without evaporation when the weather is suitable. Tower and AHU controls are integrated so that the towers provide natural ventilation and respond first to a high CO_2 signal, energizing the AHU for mixed mode ventilation only when the towers cannot provide sufficient fresh air.

FIGURE 1 Cooling by displacement ventilation (cool weather).

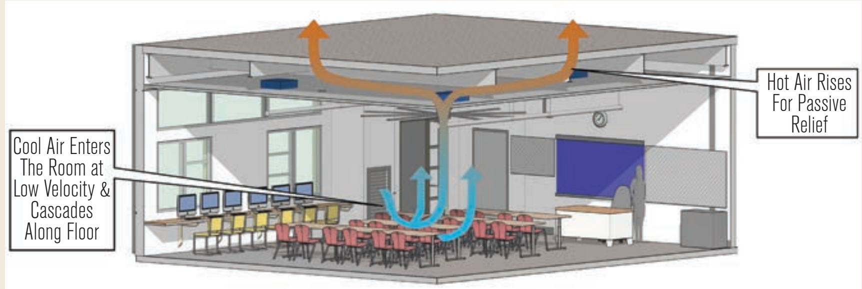


FIGURE 2 Cooling by automatic ceiling fan (warm weather).

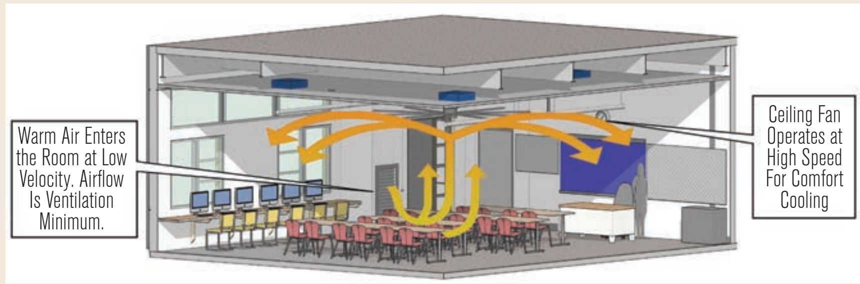
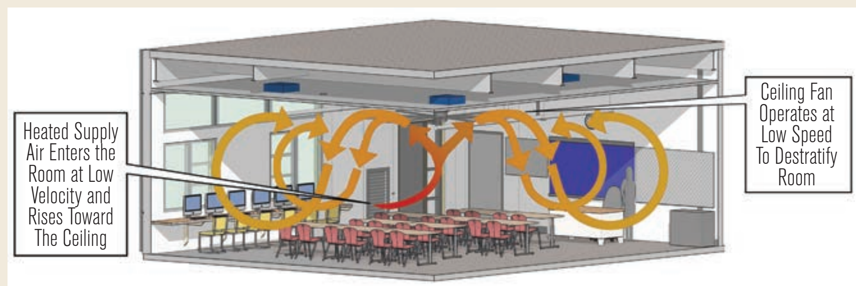


FIGURE 3 Heating with automatic ceiling fan assistance (cold weather).



Energy-Efficient Design Features

OUSD-LEEC is intended to be a showcase green project, so minimizing energy use is a key priority. Strategies employed include:

• Classroom cooling strategy is based on thermal mass, natural and mixed mode ventilation, and ceiling fans rather than compressors.

• Cool towers provide as much as 50,000 cfm (24 L/s) and 90 tons (317 kW) of cooling without fans or coils on hot days, and natural ventilation on mild days.

• Ceiling fans use efficient direct drive electronically commutated (EC) motors, drawing 80 W to provide 4°F (2°C) of perceived cooling.

• AHUs use high-efficiency variable-speed fan arrays, with demand-based static pressure setpoint reset to minimize fan energy.

• FP-VAV boxes use efficient variable-speed EC motors.

• VAV-reheat boxes use dual-maximum control sequences and supply air temperature control, with demand-based supply air and static pressure resets to minimize reheat and fan energy.

• Data center AHUs have digital scroll compressors and custom control programming to maximize airflow when economizer is available, and minimize fan energy, favoring DX cooling, when economizer is locked out. The system is 100% redundant with both units running to minimize fan power.

• Kitchen exhaust hood uses a variable-speed fan controlled by heat and smoke sensors to minimize exhaust when not actively cooking.

• Heating hot water is by condensing boilers with variable-speed pumping, with supply water temperature reset to maximize condensing operation.

• A 203 kW photovoltaic array provides an estimated 280,000 kWh per year.

• Solar hot water panels provide hot water for the kitchen and bathrooms.

• Classrooms and offices are designed for daylighting: oriented for southern exposures with overhangs and daylighting windows, orientation specific glazing, and automatic dimming controls.

• The design easily beats Title 24, with EnergyPro models showing savings of 29.9% in TDV energy use. When modeled according to CA-CHPS rules, which permit the inclusion of on site renewable energy, savings were 48.5% TDV energy and 55.6% energy cost relative to a baseline building.

• The data center was modeled separately, for a utility rebate program. Third-party analysis showed 72% energy savings relative to baseline.

Measured Energy Use

The project includes extensive energy metering, independently measuring HVAC, lighting and plug energy. However, challenges during the controls installation and commissioning meant that no useful data was recorded in the first year of operation. While these issues have been corrected, going forward, detailed historical energy use data is not available.

Campus-wide energy use intensity, calculated from utility bills, was found to be 41.7 kBtu/ft^2 (131.5 kWh/m^2) per year. For comparison, a baseline EUI was developed from CBECS data, weighted based on building areas used for different purposes (e.g., classroom, kitchen, datacenter, etc). With a weighted baseline of 57.8 kBtu/ft^2 (182.3 kWh/m^2), the project demonstrates a savings of 28% over baseline. In addition, a number of energy-wasting installation and controls issues were corrected during the commissioning process, so future savings are expected to be higher.

FIGURE 4 Evaporative downdraft cool tower.

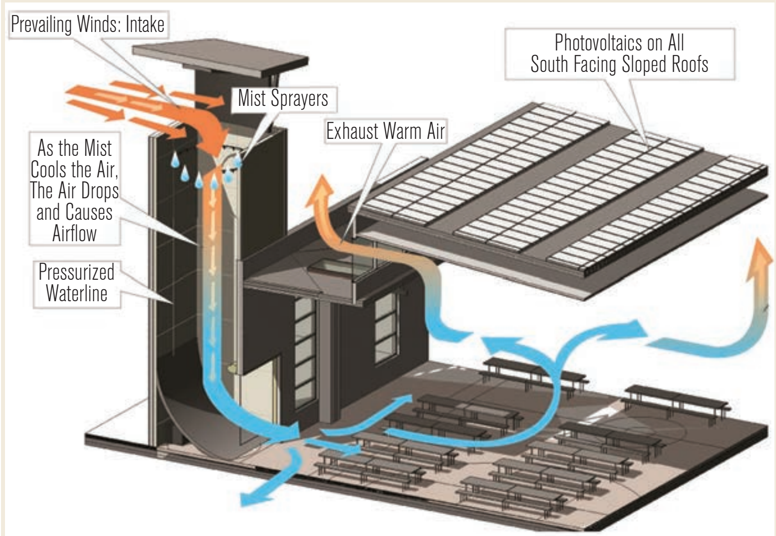
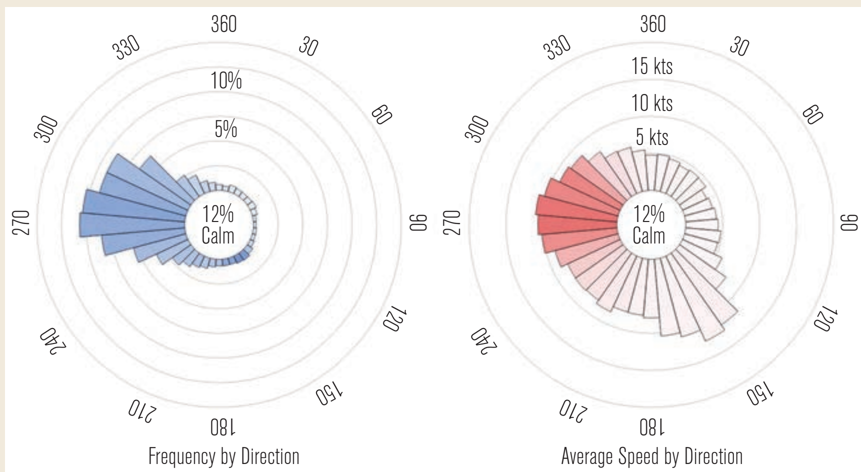


FIGURE 5 Cooling season prevailing winds.



Indoor Air Quality

Per CHPS, low-emitting materials were used throughout the project to minimize pollutants. Classroom and office indoor air quality (and ASHRAE Standard 62.1 compliance) is ensured by 100% outdoor air ventilation and cooling with MERV 11 filters. Displacement diffusers enhance ventilation effectiveness, but ventilation minimums were not reduced. CO_2 demand-controlled ventilation is used in all classrooms, common areas, and conference rooms.

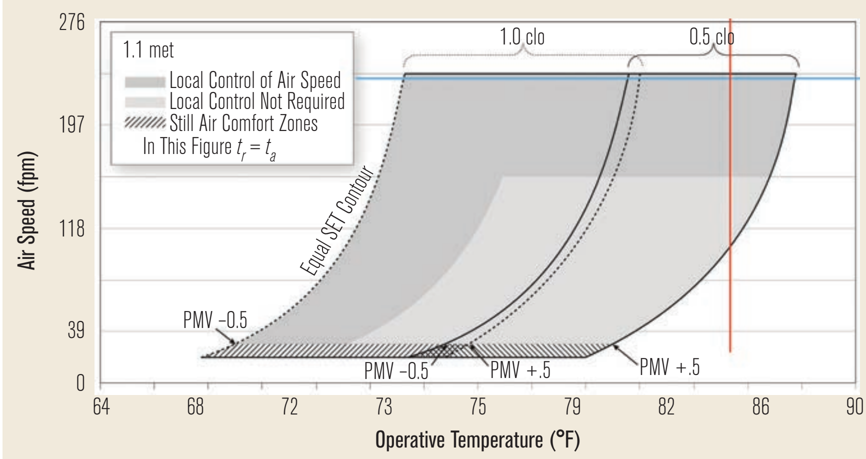
Thermal Comfort

ASHRAE Standard 55 compliance is a CHPS requirement, and cooling densely occupied (30 ft^2 to 45 ft^2/person [3 m^2 to 4 m^2]) classrooms on an 89°F/66°F (32°C/19°C) design day without the use of compressors was one of the principal design challenges. Simulation demonstrated that high mass floors (145 lb/ft^3 [2323 kg/m^3]) and walls (95 lb/ft^3 [1522 kg/m^3]), coupled with night cooling ventilation, maintains the worst-case room at or below 74°F (23°C) for 88% of a TMY-3 weather year. (Simulations assumed a conventional mixed-air system. Due to budget constraints, displacement was not modeled, but is understood to improve both ventilation and cooling performance, providing an additional margin of safety to the design.)

For 12% of the year indoor temperatures are expected to range up to 85°F (29°C). During these periods the ceilings fans will operate automatically to provide up to 220 fpm (1 m/s) of cooling via air movement, maintaining comfort for lightly clothed individuals as shown in *Figure 6*. Adjustable thermostats and manual override fan controls in every classroom give occupants local control of their space.

There have been no too-hot comfort complaints. There were some too-cold complaints. These were traced to an incorrect boiler installation resulting in low hot water supply temperatures, which has now been corrected.

FIGURE 6 Design condition for ceiling fan cooling, from the Standard Effective Temperature chart (ASHRAE Standard 55).



Maintenance and Operations

Construction was financed by a municipal bond, but operating expenses are paid out of general school district funds, so controlling operating costs was a design priority. Design features that minimize ongoing maintenance include:

- The fundamental cooling system—thermal mass walls and floor—does not require mechanical service and never breaks down.
- Classroom AHUs are very simple: just fans in a box, with no heating coil, cooling coil, compressors, pumps or economizer to maintain.
- Most fans use direct-drive motors, eliminating belt replacement.
- Ceiling fans are a robust industrial design with a 10-year warranty.
- The cool tower fogger system avoids water recirculation and evaporative media, eliminating periodic cleaning and most routine maintenance.
- Extensive power metering via the energy management and control system allows operators to observe energy use trends and identify loads that would otherwise be hidden.

Cost Effectiveness

Per our office standard, details such as duct and pipe sizes were determined by life-cycle cost analysis. However, due to client requirements and project funding structure, cost effectiveness calculations were not performed for the project as a whole. Client requirements dictated a high performance building without compressors, so a traditional HVAC system was not an alternative. The project itself is funded by a bond, while operating costs will be paid from the district budget—two separate pools of money. As such, minimizing operating and maintenance costs was prioritized over construction costs. That said, the mechanical system ultimately cost \$43/ft^2 (\$463/m^2)—within 10% of the schematic design cost estimate for a conventional HVAC system.

Environmental Impact

As a CHPS project, a number of non-mechanical design features reduce the project's environmental impact, including daylighting, water efficient fixtures, storm water control via bioswales populated with native plants, and rapidly renewable, recycled, and low emissions materials.

A grant-financed 203 kW photovoltaic system will provide an estimated 280,000 kWh per year, offsetting 66.5 metric tons of CO_2 every year. Solar thermal panels provide for all domestic hot water use.

The mechanical design serves to reduce environmental impact chiefly through the energy efficiency measures described above. In addition, the elimination of compressors and coils from the primary AHUs reduces the embodied energy of the mechanical system, while the use of foggers rather than evaporative media in the cool towers eliminates the water waste associated with sump blowdown.

Innovation

Some of the most innovative elements of the HVAC system reflect a very old idea: the principal of designing around local climatic conditions. During early SD, a study of local weather patterns identified the significant cooling season diurnal temperature swing, which enables the thermal mass/night purge cooling strategy.

It also identified a prevailing west wind in the cooling season, which allows the cool towers to provide natural ventilation and eliminate great room AHU operation for much of the year.

Finally, this study highlighted the coincidence of low humidity with high dry-bulb temperatures, which makes evaporative cooling a practical option during the peak of the cooling season.

The project embodies high technology innovations as well. The cool towers are an ancient concept from vernacular architecture, but their implementation relies on a modern DDC system and complex programming to harness natural forces while avoiding overcooling and drafts. The use of the high-pressure (2,000 psi [14 MPa]) atomizing foggers in this context is also unprecedented to the best of our knowledge. Similar towers on other projects have relied on evaporative media, which require maintenance and create air-side pressure drop (limiting its usefulness on windless days), or low-pressure sprayers that can create dripping and blow through due to incomplete evaporation.

In the great room, louver/dampers provide a relief path for the cool tower, while ceiling fans provide additional cooling.

The ceiling fans also represent innovation on several fronts. They were developed in collaboration with a well-known manufacturer as a new product specifically for schools. At our request, the manufacturer constructed a mock-up classroom to test a variety of blade sizes and configurations, and was able to provide air velocity profile data using a three-axis anemometer.

This enabled us to optimize the design for uniform air velocities (avoiding under-cooling and drafts) and to have confidence in ASHRAE Standard 55 compliance, which was later validated by field tests in the completed building, in collaboration with the manufacturer and an independent research university.

Automatic control of ceiling fans is also unusual, and enables several innovative features. Although a manual override allows the teacher to control the fan directly, no occupant interaction is required. The multi-mode cooling strategy automatically activates the ceiling fans when supply air temperatures rise enough that the displacement diffusers no longer provide beneficial stratification.

In heating the ceiling, fans automatically mix and destratify, which allows the displacement diffusers to deliver heating air, avoiding the need for a separate heating system as is typical with displacement cooling systems. The ceiling fans also operate automatically during the night purge cycle to improve heat transfer to the thermal mass. ■