HIGH PERFORMANCE MECHANICAL SYSTEMS FOR INSTITUTIONAL BUILDINGS

by Alan Butler AIA, LEED® AP

Napa Valley College, Life Science Building

INTRODUCTION

In the last decade we have seen a remarkable transformation in thought about how to deliver heating, ventilation and air conditioning to institutional buildings. These changes have been driven both by advances in technology and very much by the green revolution that promotes sustainable design for buildings. While the most obvious attribute of these building mechanical systems is greater energy efficiency, there are a host of other benefits in their utilization. Improved room acoustics, greater occupant control and comfort and healthier user environments are important reasons to consider these alternatives to conventional HVAC installations.

Many of these "new" systems are extensions of historic methods of cooling that have been used for millennia. Natural ventilation and night cooling are just more sophisticated ways of opening your window to cool down, adapted to the needs of complex modern buildings. On an even more basic level many of the methods described allow the occupant to simply open a window when it would benefit them. These approaches are not as sensitive as the conventional systems of prior generations that generated the thought that an office or classroom building had to be a hermetically sealed box.

Considered "experimental" or untested a few years ago, many of these methods now have a solid record of proven performance. The operational cost-benefits of all of these systems are something every institutional facilities manager needs to consider when embarking on new building or renovation projects. The added benefits of happier healthier users makes the case even more compelling. For those seeking more further information, a series of referenced articles can be found at www.tlcd.com.

I would like to thank Tony Costa of Costa Engineers, Napa, CA and Mike Lucas of AlfaTech, San Francisco for their valuable contributions and review of this white paper.

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April 2010

Santa Rosa Junior College, Plover Student Services Building

Indirect/direct evaporative cooling (IDEC) is most beneficial in hot dry climates with low humidity.

INDIRECT / DIRECT EVAPORATIVE COOLING

BASIC PRINCIPLES

This system has two major elements. Traditional direct evaporative cooling at the intake draws air though a water curtain, cooling and humidifying the incoming air stream. The closed loop indirect portion is a heat pipe / heat exchanger at the exhaust to extract waste heat and drive cooling cycles. The system typically uses 100% outside air.

BEST APPLICATIONS

Indirect/direct evaporative cooling (IDEC) is most beneficial in hot dry climates with low humidity. These systems are particularly well adapted to California Valley and Coastal climates. The use of 100% outside air is particularly beneficial where air quality is an issue. The evaporative cooling element also reduces the introduction of allergens and particulates into the air stream. The sweet spot for unit size using IDEC systems in the Western U.S. is around 40 tons, or about 16,000 c.f.m., which is suitable for a 12,000-15,000 sf office building.

ENERGY PROFILE

In institutional buildings, these systems have been able to function at ambient temperatures up to 103ºF without additional chilled water.[1] For example at the Sonoma State University Salazar Hall Renovation, a building with heavy concrete mass, the operators have been able to shut off its central plant chilled water and is currently operating 42% under Title 24 performance requirements. Typical institutional energy savings are 10-20% under Title 24.

OCCUPANT COMFORT/INTERFACE

Indirect/direct evaporative cooling adds some humidity to air which may be desirable in hot dry climates. By using 100% outside air, the system does not recycle indoor pollutants and helps remove outdoor pollutants in the incoming air stream.

COST & INSTALLATION PROFILE

Munters-DeChamps is a major supplier of IDEC units. These "boxcar" units can be roof, attic or ground mounted. The cost premium is 100% and payback can be expected in 5–15 years. Water usage concerns are an issue for some water utilities and governments, though this may not be much more than conventional cooling towers.

HIGHLIGHTED TLCD PROJECTS

Petaluma Campus Phase I: 70,000 gsf, penthouse mounted fan units. Installed 1994.

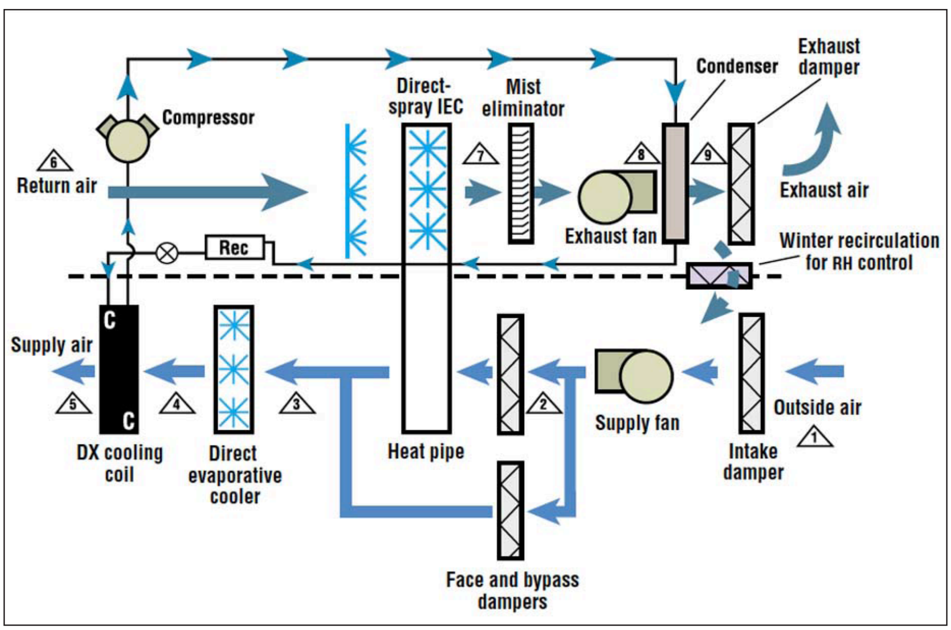
Petaluma Campus Phase II: 130,000 gsf, penthouse units on classroom buildings. Ground mounted central plant building feeding library through underground fiberglass duct systems. Both types feed displacement ventilation systems with a combination of ducted and underfloor distribution. Installed 2007.

Plover Student Service Center SRJC: 35,000 gsf conversion of old library to student services. Underfloor air distribution serves HVAC and electrical/data needs in retrofit. Some perimeter radiant ceiling panels at perimeter zones.

Salazar Hall Renovations SSU: 116,000 gsf conversion of library to classrooms, offices and labs.

Architects: TLCD Architecture, Santa Rosa, CA

Mechanical Engineer: Costa Engineers, Napa, CA

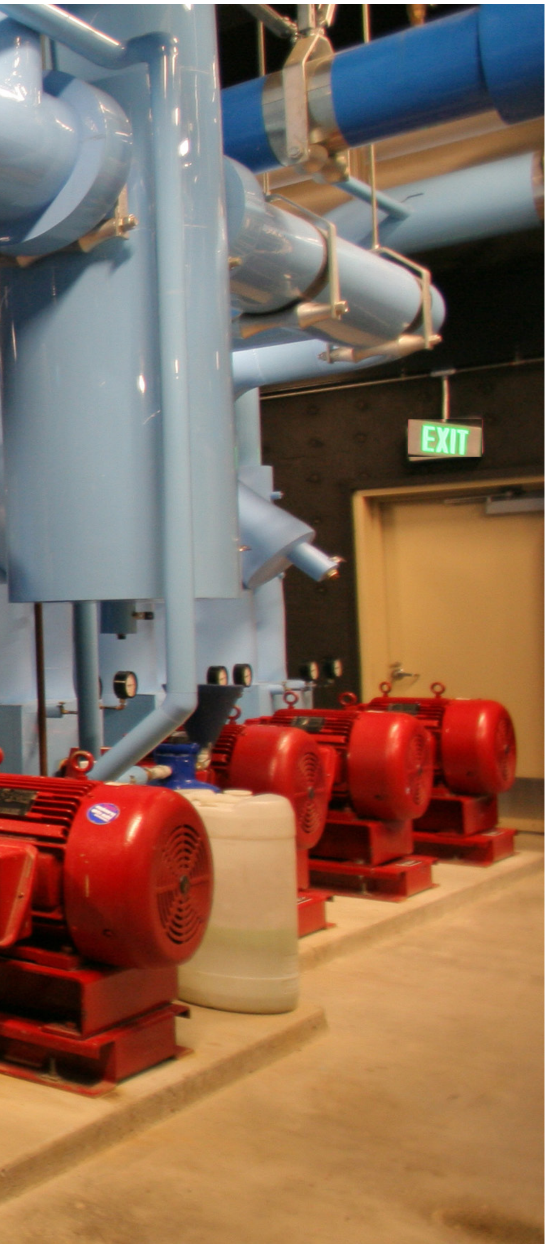


Two-stage evaporative cooling with third-stage integral DX cooling design schematic.

Napa Valley College, Central Thermal Energy Storage Plant

Effective use of TES systems depend on the specific electrical rate structures of an institution and is effective in reducing peak load demands.

THERMAL ENERGY STORAGE SYSTEMS



BASIC PRINCIPLES

Thermal Energy Storage (TES) systems use off peak power to generate ice or chilled water at off-peak demand periods. Chillers typically run at night which is a major benefit for institutions using demand/ time-of-day metering. This can substantially reduce electrical costs. Ice-bank units create and store cooling energy at night by freezing water in an insulated storage tank. It provides cooling during the day by circulating chilled water through the tank to the conventional air conditioning system, eliminating the need to run energy-intensive compressors during peak daytime hours. Air conditioning energy demand – typically 40-50% of a building's electricity use during expensive peak hours – can be reduced by as much as 80-90%.

BEST APPLICATIONS

Effective use of TES systems depend on the specific electrical rate structures of an institution and is effective in reducing peak load demands. Applications can range from large central plants to small or medium-size applications, such as Ice Bear roof top units. These can be retrofitted to smaller DX units. Used in conjunction with on-site renewable energy generation, such as photovoltaic or wind, renewable energy credit generated during peak use hours can offset off-peak usage for the TES systems.

ENERGY PROFILE

TES systems can reduce overall system energy costs by 10% and eliminate electrical demand charges from 12p.m. to 6 p.m. [2]

OCCUPANT COMFORT/ INTERFACE

Occupant comfort is comparable to traditional chilled water systems.

COST & INSTALLATION PROFILE

Cost reductions vary with rate structures, but electrical costs for chillers can be as low as one-third of peak demand costs. Cost premium is 100% of the chiller component cost and payback is estimated at 10-15 years.

HIGHLIGHTED TLCD PROJECTS

Frank P. Doyle Library: 145,000 gsf, 108 tons of ice generated by 5 ground-mounted units in separate utility yard. Feeds low temperature air distribution systems. Installed 2006.

Napa Valley College Central Plant: The campus central plant generates 450 tons of ice in twelve 76,000-pound units. The system distributes chilled water to a new campus distribution network. TES was installed here in 2006. Electrical usage is offset by a one-megawatt photovoltaic system on campus.

Architects: TLCD Architecture, Santa Rosa, CA

Mechanical Engineer: Costa Engineers, Napa, CA

Napa Valley College Life Science Building

Large, open high-ceiling spaces... are well suited for displacement ventilation because of the savings achieved by not cooling the upper regions of the volume.

BASIC PRINCIPLES

With displacement ventilation, air is introduced at the occupant level through underfloor or low perimeter duct systems. Air is 65ºF, ten degrees warmer than typical HVAC systems. Air moves along the floor and convectively up to exhaust vents or natural outlets. Cooling occurs at the occupant zone rather than at the ceiling level.[3]

BEST APPLICATIONS

Large, open high-ceiling spaces, such as libraries, are well suited for displacement ventilation because of the savings achieved by not cooling the upper regions of the volume. Classrooms and open office areas also benefit from displacement ventilation through comfort and acoustical advantages. These systems are not as well adapted to small office and highly subdivided spaces.

ENERGY PROFILE

The ten-degree difference in air temperature delivery offers a major advantage to building owners. Stratified heating and cooling results in less volume per occupied square foot. Increased economizer hours and downsizing of equipment are additional benefits because of higher (65ºF) delivery temperatures. The overall cooling load savings is estimated at 40%.

OCCUPANT COMFORT/ INTERFACE

Overall Comfort: Warmer air is more comfortable to occupants at floor level. There is a greater degree of occupant control with raised floor displacement systems. "Salad spinner" floor registers can be occupant adjusted without unbalancing the system. Lower air velocity is less noticeable and more comfortable.

Acoustics: Because of lower velocity and plenum distribution in raised floor systems, ambient noise is greatly reduced. These acoustical benefits are particularly meaningful in classroom and lecture environments.

Health Benefits: For the user, the greatest benefit is improved indoor air quality. Air rises in a columnar fashion around occupants and warm objects and is exhausted convectively - without the homogenization of room air as in typical HVAC systems. Therefore, pollutants and microbes are not distributed throughout room. Displacement ventilation often uses 100% outside air.

COST & INSTALLATION PROFILE

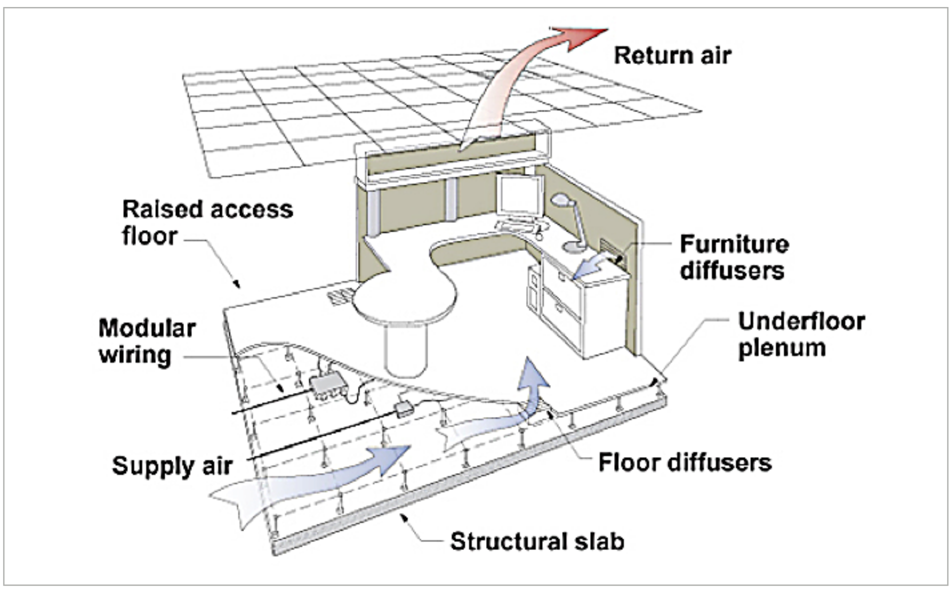
Raised plenum floor costs can be partially offset by reduced duct costs. With renovations in particular, raised floor provides data and power pathways rather than more difficult ceiling or wall spaces. Raised floor systems can significantly reduce future data or electrical remodel costs. This allows a high degree of future flexibility for power and data needs.[3]

HIGHLIGHTED TLCD PROJECTS

*Petaluma Campus Phase II***:** 130,000 gsf, 35,000 sf library and 55,000 sf classroom and dry lab building, 8,900 gsf life science and art labs. This project uses a Hybrid IDEC and Displacement system. Raised floor distribution is used in the library and first floor classrooms and ducted in upper floor rooms and wet/art labs.

Napa Valley College, Life Science Building: 20,000 gsf. Includes four life science labs, faculty offices and lobby. Ducted displacement system coupled with night flush system and TES chilled water supply. Central tower element provides for convective exhaust. Stratified cooling particularly efficient in tall day lit lobby.

Architects: TLCD Architecture, Santa Rosa, CA
Mechanical Engineer: Costa Engineers, Napa, CA



Santa Rosa Junior College, Frank P. Doyle Library, Low Temperature Diffuser in Ceiling

Low temperature systems have great utility in buildings with impacted or restricted spaces. The performance and occupant comfort feedback has been remarkable in the Frank P. Doyle Library.

LOW TEMPERATURE SYSTEMS

BASIC PRINCIPLES

Low temperature systems are basically traditional ceiling delivery systems with cooled air at 5-8ºF cooler (47ºF) than typical systems.

BEST APPLICATIONS

Low temperature systems are most effective in renovations and new construction where floor-to-floor plenum and chase spaces are limited. Cool delivery air requires non-condensing grilles (often plastic). High velocity delivery from these specialized grilles prevents cold air drafts.

ENERGY PROFILE

A reduced volume of air offsets delivery of low temperature air. Overall, these systems result in a 58% reduction in fan horsepower when compared to conventional systems. Duct requirements can also be reduced as much as 35% when utilized correctly.

OCCUPANT COMFORT/INTERFACE

The overall experience is that cooler delivery air is not an issue if properly distributed. This system was used in a major TLCD Architecture library project completed in 2006 and we have had no complaints about cold air drafts. The specialized diffusers "throw" the air out into the space very effectively.

COST & INSTALLATION PROFILE

Low temperature systems have reduced duct costs and reduce fan sizes. This can offset additional cooling load for lower temperature delivery air.

HIGHLIGHTED TLCD PROJECT

Frank P. Doyle Library, SRJC: 145,000 gsf, hybrid system with TES chilled water supply is performing at 10% below Title 24. Comfort level and evenness of occupied spaces is excellent.

Architects: TLCD Architecture, Santa Rosa, CA
Mechanical Engineer: Costa Engineers, Napa, CA

The Living Learning Center of University at the Oregon

This space uses an incredibly simple concept: only run the system when the users need it.

DEMAND CONTROLLED VENTILATION

BASIC PRINCIPLES

CO_2 sensors or occupant-controlled timing devices are used to control room ventilation. The CO_2 level of the room is used to determine the need for and amount of ventilation required. This avoids having fans run constantly in rooms that may not be in use. Occupant overrides can boost the ventilation for limited periods of time.[4]

BEST APPLICATIONS

Intermittently occupied rooms and rooms with large changes in occupant load are well suited to this strategy. Naturally ventilated buildings may only require occasional mechanical assistance to maintain air quality, making a sensor-based system more effective.

ENERGY PROFILE

Fans operate by demand, not constant operation or long hours on time clocks which are usually set for the worst case needs.

OCCUPANT COMFORT/ INTERFACE

One classroom example at the University of Oregon had a one-hour time switch that allowed the teacher to activate the ventilation fans when the instructor felt additional air circulation was necessary. Overrides from the CO_2 sensor were used to maintain minimum ventilation. As these classrooms had ample natural ventilation, the demand system encouraged the users to use the available operable windows.

COST & INSTALLATION PROFILE

Additional costs of sensors and time switches are offset by reduced fan loads coupled with operable windows or louvers. This type of system with user overrides allows users a good perceived level of control.[4]

HIGHLIGHTED PROJECT

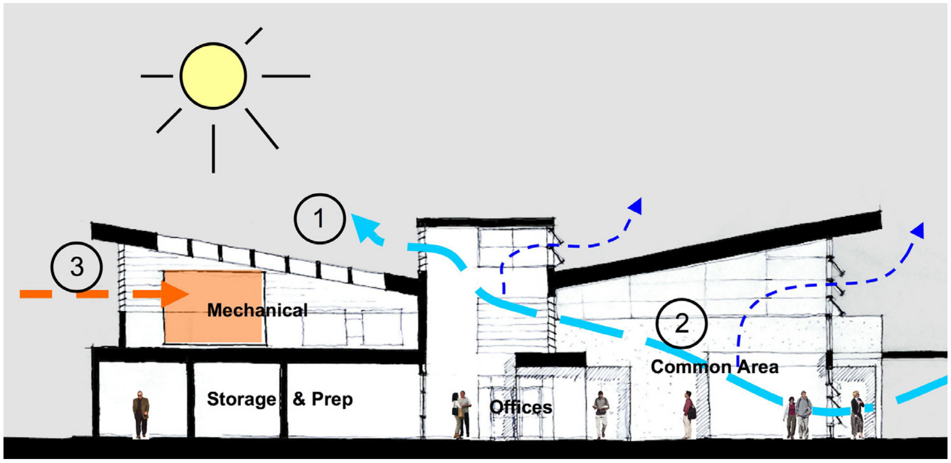
Living Learning Center, University of Oregon
Classrooms have a one-hour time switch coupled with a unique sliding glass door louver system for natural ventilation. When rooms are not occupied or natural ventilation is working, the fans are not on.

Architects: ZGF, Portland, OR
Mechanical Engineer: Interface Engineering Inc. Portland, OR

Napa Valley College, Life Science Building

Night cooling strategies are ideally adapted to California coastal climates which may have a 30-50 degree diurnal temperature swing. This system works best in high mass systems.

NIGHT / MASS COOLING SYSTEMS



Above: Building Section Diagram
1. Night Cooling & Natural Ventilation
2. Day Lit Common Space
3. Deep Building Overhangs for Shading

BASIC PRINCIPLES

Night/Mass cooling introduces cooler night-time air into the building cooling any thermal mass within the occupied space. Typically high volumes of cool night air are introduced during non-occupied hours to flush the building. The chilled thermal mass has a flywheel effect of absorbing building heat gain during early hours of occupancy reducing overall cooling load. Large operable outside louver systems are placed at low points in the building and fans and convective flow exhaust air from the building.[5]

BEST APPLICATIONS

Locations with large diurnal temperature swings (i.e. near coastal California) are ideal for this type of system. Cool night air on a thermal mass can offset hot days.

ENERGY PROFILE

With this system, a substantial reduction in cooling load can be realized. The reduction in cooling load is ultimately dependent on large amounts of thermal mass. Renovations of concrete and masonry buildings are ideal candidates for night / mass cooling.[5]

OCCUPANT COMFORT/INTERFACE

By cooling the mass of the building, user comfort is achievable with minimal use of mechanical systems, even during occupied periods.

COST & INSTALLATION PROFILE

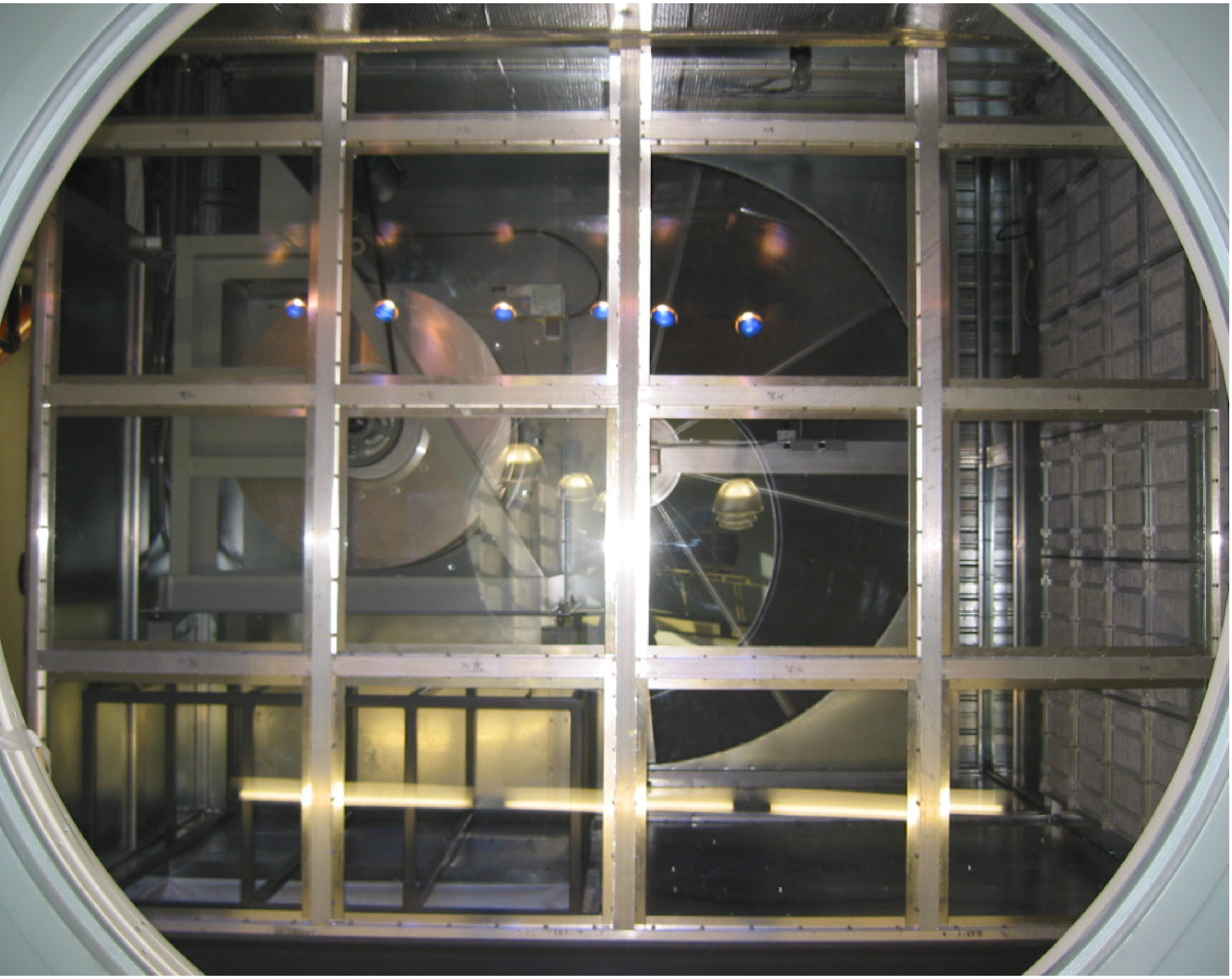
Installation requires additional louvers and exhaust systems which may be part of the regular HVAC system.

HIGHLIGHTED TLCD PROJECTS

Napa Valley College, Life Science Building: 20,000 gsf. Includes four life science labs, faculty offices and lobby. Ducted displacement system coupled with night flush system and TES chilled water supply. Central tower element provides for convective exhaust. Stratified cooling particularly efficient in tall day lit lobby. Concrete floors and steel structure enhance thermal mass.

Napa Valley College, McCarthy Library: 64,000 gsf of library space.

Architects: TLCD Architecture, Santa Rosa, CA
Mechanical Engineer: Costa Engineers, Napa, CA



Enthalpy Wheel View Port in Corridor at Ohlone College

Enthalpy wheels are best suited for buildings that have large outside air requirements such as classrooms, lecture theaters, laboratories or any use where large amounts of fresh air are needed.

ENTHALPY WHEEL ENERGY RECOVERY SYSTEMS

BASIC PRINCIPLES

Enthalpy wheels are rotating wheel heat exchangers that consist of a rotating cylinder filled with a large surface area of air-permeable material. Using material that removes water from an air stream (known as desiccant media), these systems recover the energy usually lost when air is exhausted from buildings to make way for code required fresh air. They are extremely efficient and can recover up to 95% of the annual energy lost through exhaust systems.[6]

BEST APPLICATIONS

Enthalpy wheels are best suited for buildings that have large outside air requirements such as classrooms, lecture theaters, laboratories or any use where large amounts of fresh air are needed.

ENERGY PROFILE

Substantial energy savings can be achieved when used in conjunction with other high efficiency systems such as geothermal water source heat pumps and chilled water systems. Ohlone College and Santa Rosa Junior College projects showed increased performances over Title 24 requirements by 52% and 38%, respectively.

OCCUPANT COMFORT/ INTERFACE

With a high level of energy recovery using enthalpy wheels, fresh air volumes can actually be increased. For example Ohlone College's fresh air volume was increased by 300%, while achieving a LEED Platinum certification. When faculty and students were surveyed, they said the most significant impact to them was the air quality "seems like all the windows are open" when in fact there are no operable windows. All outside air passing through the Enthalpy Wheel is filtered, removing dirt, grit, dust and allergenic pollen.

COST & INSTALLATION PROFILE

System payback depends on the size of the systems. Estimated payback for Ohlone College and SRJC projects is 18 months and 24 months respectively.[6] The units should be installed as close to the center of the building to minimize ductwork distribution.

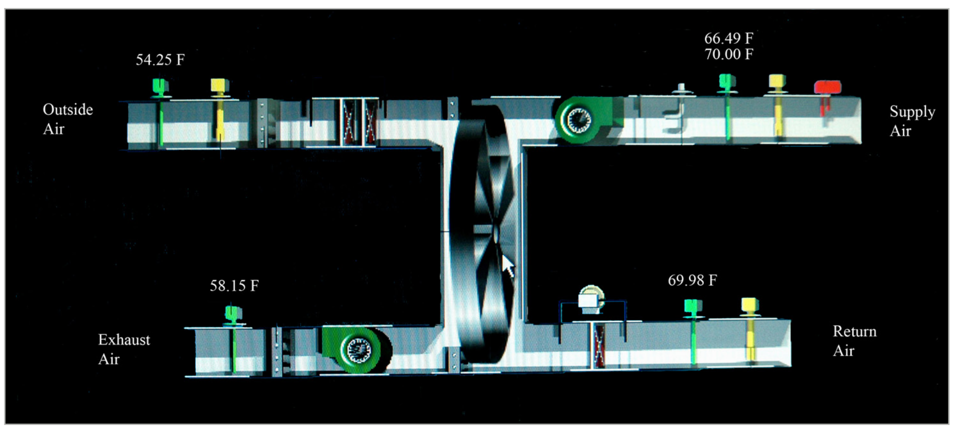
HIGHLIGHTED PROJECTS

Ohlone College - 133,000 gsf community college building, primarily medical science labs and classrooms.

Architects: Perkins + Will, San Francisco, CA
Mechanical Engineer: Alfa Tech, San Francisco, CA

Santa Rosa Junior College Student Services Building - 120,000 gsf multiuse community college building including office space, kitchen, cafeteria, and computer labs.

Architects: BSA, San Francisco, CA
Mechanical Engineer: Alfa Tech, San Francisco, CA



Enthalpy Wheel Diagram

Active Chilled Beam HVAC in Conference Room , Y2E2 Building, Stanford University

The best applications for chilled beams are new and existing buildings where ceiling plenum space is very limited and where a chilled water plant cost can be justified or is already available.

CHILLED BEAM HVAC SYSTEMS

BASIC PRINCIPLES

There are two basic types of chilled beams: passive and active. Both types take advantage of the fact that water is a more efficient medium than air to add/remove heat from a space. Less horsepower is required to move water than to move air resulting in considerable energy savings. Passive and active chilled beams are located in the ceiling areas. Passive chilled beams use natural convection induced by the chilled water to cool the air in the ceiling area. Passive beams provide limited cooling and are usually not considered for commercial applications. Active chilled beams use a small amount of primary air to induce additional flow across the chilled beam coils.[7]

BEST APPLICATIONS

The best applications for chilled beams are new and existing buildings where ceiling plenum space is very limited and where a chilled water plant cost can be justified or is already available. Projects with a high sensible load are better suited for the use of chilled beams. Examples of such spaces are laboratories and other equipment intensive spaces. Data centers do not lend themselves to this type of system because the sensible loads are too high for chilled beam systems. Sites with high humidity require special attention to prevent condensation.

ENERGY PROFILE

Chilled beams can provide substantial energy savings when compared to other HVAC systems because of the smaller fan loads and the increased efficiency of using water to provide the bulk of the space cooling. HVAC units for chilled beams can be as much as 30% to 15% smaller than typical systems' HVAC units. This considerable reduction in fan power allows for significant savings year-round because these fans run constantly whenever the building is occupied. The chilled water temperatures required for the chilled beams are typically higher (59º-61ºF) than those of typical chilled water plants (45º-50ºF) and this allows the chillers to operate more efficiently. Newer HVAC units that use desiccant wheels to treat the outside air also allow the use of the higher chilled water temperatures at the HVAC unit chilled water coil--therefore avoiding the need for cooler chilled water for dehumidification.

OCCUPANT COMFORT/ INTERFACE

Active chilled beam systems can provide the high level of comfort expected from a variable air volume (VAV) reheat system because all primary air is outside air and the amount of ventilation air used in these systems usually exceeds the minimum required by code in order to address the indoor air dew point (humidity control). The availability of 4-pipe chilled beams allows for zoning that provides high occupant thermal comfort.

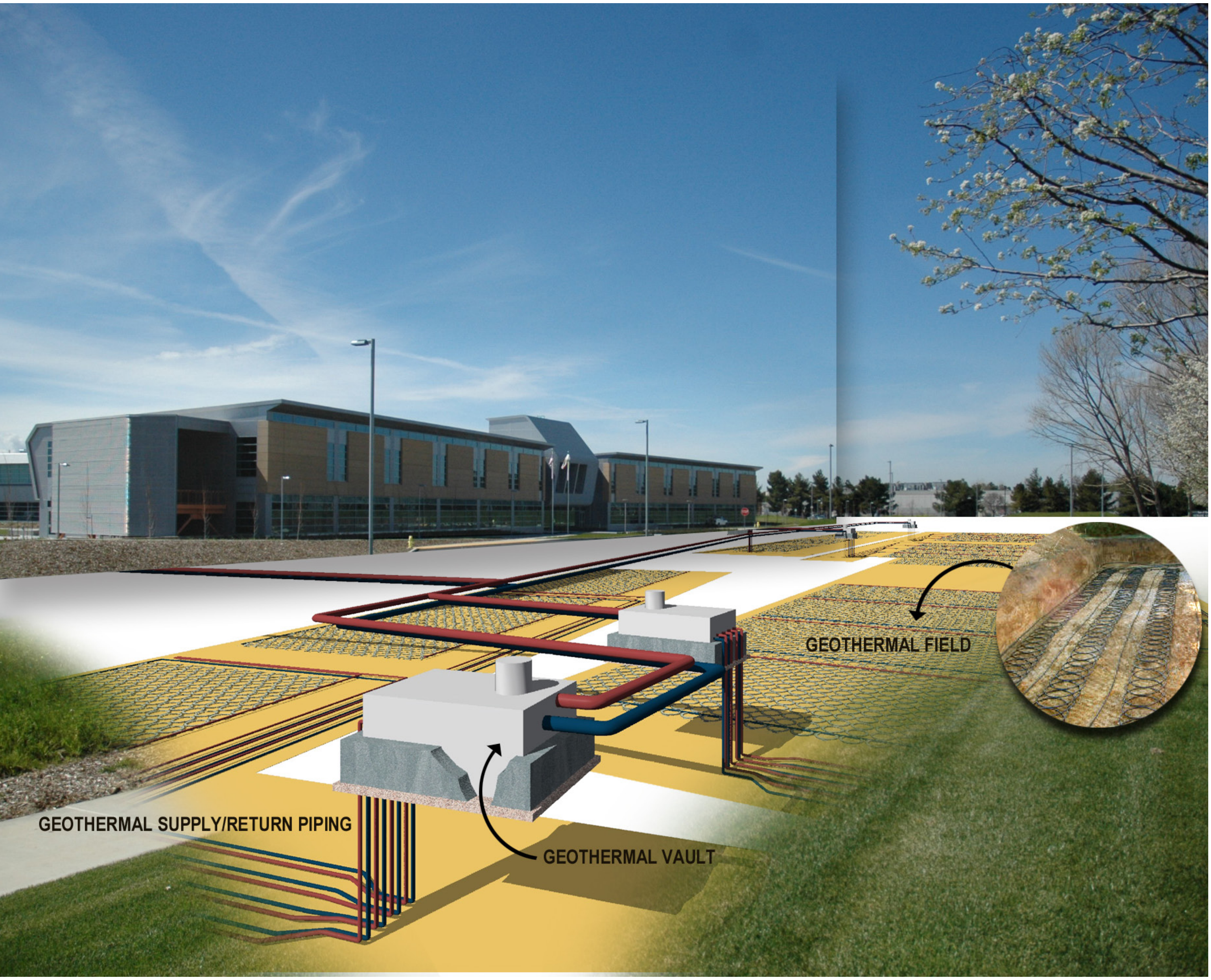
COST & INSTALLATION PROFILE

Typical cost of chilled beam systems are 5-15% higher compared to a VAV re-heat system, though much of this premium is due to the unfamiliarity of contractors with these systems. As these systems become more common it is expected that chilled beam systems have comparable price to VAV re-heat systems.

HIGHLIGHTED PROJECT

Y2E2 Environment & Energy Building, Stanford University - This laboratory, classroom and office building showcases a wealth of energy saving and sustainable design practices.

Architects: BOORA Architecture, Portland, OR
Mechanical Engineer: Arup, San Francisco, CA



Ohlone College, Horizontal Geothermal Field

The U.S. Environmental Protection Agency (EPA) has called ground source geothermal (heat pumps) the most energy-efficient, environmentally clean, and cost-effective space conditioning systems available today.

- Environmental Protection Agency (1993). Space Conditioning: The Next Frontier - Report 430-R-93-004. EPA.

BASIC PRINCIPLES

Geothermal ground source systems use the earth's constant temperature (61ºF in Northern California) to provide heating and cooling. These systems are significantly more energy efficient than traditional systems that absorb or reject heat to seasonally changing outside air.[8]

BEST APPLICATIONS

The best applications are new and existing buildings that have open space suitable for an underground geothermal ground source field. Non-enclosed parking areas, open sports fields, and landscaped areas are all suitable locations. The space required depends greatly on the sites geology, specifically the ground thermal conductivity. Unlike traditional systems, geothermal ground source systems do not evaporate water through cooling towers, so these systems can be used where water consumption is a concern.

Geothermal ground source systems do not require chillers, cooling towers or boilers. This significantly reduces mechanical space requirements and chemical water treatment required for cooling towers, chillers and boiler feed water systems.

ENERGY PROFILE

Energy is saved by using the constant temperature of the earth instead of heating and cooling using the outside air. Geothermal ground source systems can be used with unitary above-ceiling water source heat pumps, large floor by floor central air handling unit systems, or in place of open cooling towers for chiller heat rejection. Geothermal ground source heat pump systems used at Ohlone College and Santa Rosa Junior College in conjunction with Enthalpy Wheels showed increased performances over Title 24 of 52% and 38% respectively. Geothermal ground source water was used at The Buck Institute Stem Cell Research Lab and will save 7,500,000 gallons of water a year.

OCCUPANT COMFORT/ INTERFACE

Above ceiling water source heat pumps often used with geothermal ground source systems, provide heating and cooling at "point of use". This provides the optimum in environmental comfort since a unit and thermostat can be provided in as many zones or rooms as needed. Modern water source heat pumps can be equipped with high efficiency filters, two stage compressors and multi speed fans providing a very quiet and comfortable environment while saving significant energy.

COST & INSTALLATION PROFILE

The cost of multiple geoexchange wells can be significant. The cost of geothermal installations has been reduced in recent years in California due to the popularity of these systems, payback times are likely to reduce accordingly.

There is some increased maintenance cost and potential inconvenience for servicing multiple water source heat pumps in certain installations.

HIGHLIGHTED PROJECTS

Ohlone College, Newark CA –Platinum LEED certification, Horizontal Geothermal Ground Source System 300 tons.

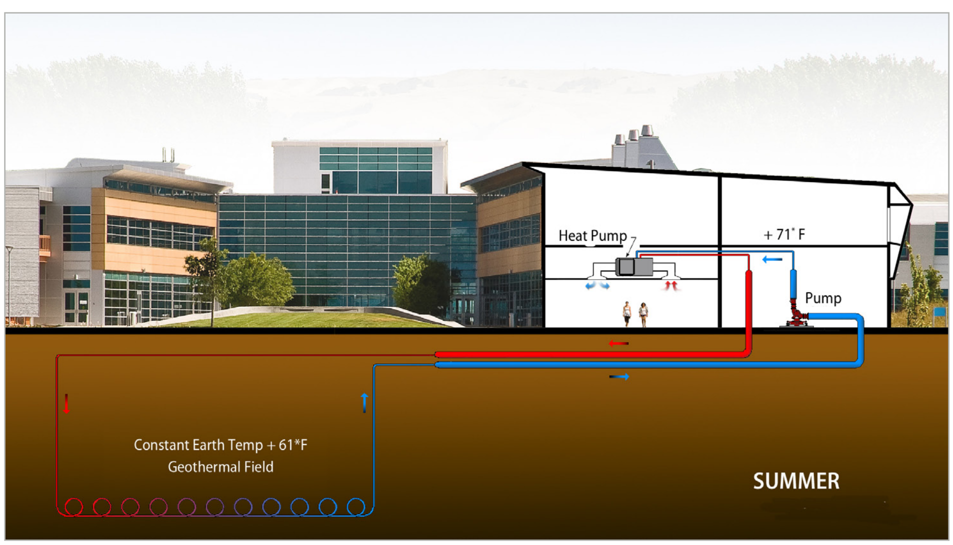
Architects: Perkins + Will, San Francisco, CA
Mechanical Engineer: Alfa Tech, San Francisco, CA

Santa Rosa Junior College - Student Services Building was designed for LEED Gold, Vertical Geothermal Ground Source System, 300 tons, (geothermal field located under campus road ways)

Architects: BSA, San Francisco, CA
Mechanical Engineer: Alfa Tech, San Francisco, CA

The Buck Institute Stem Cell Research Facility Expansion Novato, CA - Designed to LEED Gold, Vertical Geothermal Ground Source System, 1100 tons.

Architects: Perkins + Will, San Francisco, CA
Mechanical Engineer: Alfa Tech, San Francisco, CA



TLCD ARCHITECTURE PROJECTS OF INTEREST:

Frank P. Doyle Library, Santa Rosa Junior College
1501 Mendocino Avenue
Santa Rosa, CA 95401

High Performance Design Features
Thermal Energy Storage System (Ice Banks)
Low Temperature Air Distribution System
Photovoltaic Electrical Generation

Petaluma Campus Phase II, Santa Rosa Junior College
680 Sonoma Mountain Parkway
Petaluma, CA 94954

High Performance Design Features
Indirect/Direct Evaporative Cooling
Raised Floor Displacement Ventilation
Daylighting Monitors

Life Science Building, Napa Valley College
2277 Napa Vallejo Highway
Napa, CA 94558

High Performance Design Features
Thermal Energy Storage Systems (Ice Banks) Central Plant
Displacement Ventilation Air Distribution System
Night Ventilation of Thermal Mass
One-Megawatt Photovoltaic Electrical Generation System

McCarthy Library, Napa Valley College
2277 Napa Vallejo Highway
Napa, CA 94558

High Performance Design Features
Thermal Energy Storage System (Ice Banks)
Raised Floor Displacement Ventilation
Night Ventilation of Thermal Mass
One-Megawatt Photovoltaic Electrical Generation System
Daylighting/Lighting Control Systems
Fixed Exterior Sun-shading and Automatic Interior Roller Shades

REFERENCES

1 Detailed Article on this project was published in HPAC Engineering, July 2005, "Indirect / Direct Evaporative Cooling, How Sonoma State University Used an IEC/DEC system with an Energy-efficient Design to Cool a Building Without the Use of Chilled Water." For HPAC Engineering feature articles dating back to January 1992, visit www.hpac.com. Also see "Efficient Cooling for California Campuses" by Tony Costa, RE., ASHRE Journal, May 2005. A series of technical articles can be found at http://www.conservationmechsys.com/?page_id=17

2 Good overall information on TES systems can be found at PG&E Energy Efficiency Information©: "Thermal Energy Storage" http://www.pge.com/includes/docs/pdfs about/edusafety/training/pec/inforesource/thrmstor.pdf

3 See a general overview of Displacement Ventilation in "Applications Guide for Off-the-Shelf Equipment for Displacement Ventilation Use" by the California Energy Commission. May 2006 CEC-500-03-003Subtask 4.2j1 Deliverable

4 See http://www.archenergy.com/cec-eeb/P3-LoadControls/index.htm#TWO for a discussion of "Demand Control Ventilation" by the Arch Energy Corporation through the PIER (Public Interest Energy Research) Group program.

5 See http://www.archenergy.com/cec-eeb/P3-LoadControls/index.htm#TWO for a discussion of and "Night Ventilation with Building Thermal Mass" by the Arch Energy Corporation through the PIER (Public Interest Energy Research) Group program.

6 "Dispelling the Cost Myth, Case Study Ohlone College Newark Center" in High Performance Buildings magazine, Winter 2010. http://www.hpbmagazine.org/

7 Good general explanation of Chilled Beams systems in: "Chilled Beams in Labs, Eliminating Reheat & Saving Energy on a Budget" by Peter Rumsey P.E. et al from the ASHRAE Journal, January 2007. http://www.rumseyengineers.com/pdf/ASHRAE_chilled_beams.pdf

8 "Dispelling the Cost Myth, Case Study Ohlone College Newark Center" in High Performance Buildings magazine, Winter 2010. http://www.hpbmagazine.org/

* Note: Articles are hyperlinked for your convenience.

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