INDIRECT EVAPORATIVE COOLING

TECHNOLOGY SNAPSHOT

- With an Indirect Evaporative Cooling system the supply air is passively cooled before it enters the space by passing over a medium that has been directly evaporatively cooled on an adjacent but isolated side. Thus no moisture is added to the supply air stream.
- IEC systems often utilize greater outdoor air supply than standard equipment thus providing improved indoor air quality (IAQ).
- Uses 20% less energy than new California Title 24 energy code and up to a 20% reduction during peak demand periods.* Compared to existing systems energy reduction can be as much as 50% and 80% respectively.
- Energy savings and IAQ improvements contribute to green and energy efficiency program targets.

* Western Cooling Competition through WCEC

Pictured above, the San Luis National Wildlife Refuge Headquarters in Los Banos, CA, uses Indirect Evaporative Cooling to meet its cooling needs. (Source: Catalyst Architecture)

With Zero Net Energy[1] (ZNE) a growing building design and energy policy trend, design firms and owners are striving to meet heating, ventilation and air conditioning (HVAC) loads with optimum comfort and minimal energy. Indirect Evaporative Cooling (IEC) offers a highly efficient way to cool an indoor space without raising the humidity.

Today's indirect evaporative coolers use only a fraction of the energy of typical HVAC systems such as Variable Air Volume (VAV) or Direct Expansion (DX) rooftop package units.

Cooling accounts for 15% of the electricity in California office buildings and up to 30% of peak electric demand.[2] IEC is gaining favor by leading design firms for reducing this end load.

This ZNE Technology Application (TA) Guide provides an overview of Indirect Evaporative Cooling - an approach that can be combined with, or in some cases replace, traditional or advanced cooling systems to significantly reduce cooling energy use.

This TA Guide describes the IEC technology, its features and benefits, and illustrates energy performance from both modeled and measured results. There are application examples and overviews on costs and trends, along with a list of related resources. Indirect Evaporative Cooling is applicable to a wide range of building types including office, schools, retail, industrial and warehouse, and it is a growing trend for cooling in datacenters.

1 Zero net energy buildings have greatly reduced energy loads that, averaged over a year, can be 100% met with onsite renewable energy. There are now almost 50 documented commercial buildings in California that have been verified or are targeting ZNE. (NBI 2014)

2 California Commercial End-Use Survey (CEUS) and the Western Cooling Efficiency Alliance (WCEC)

Technology Overview

EVAPORATIVE COOLING DEFINITIONS AND APPROACHES

Packaged indirect evaporative cooler: An indirect evaporative cooler with integrated or nonintegrated primary and secondary air passages and provided with both primary and secondary air-moving devices. This device also includes the entire water distribution, collection and recirculation system with pump and piping.

Evaporatively cooled air conditioner: An air conditioner whose refrigerating system uses an evaporatively cooled condenser. This includes products that are retrofitted to an RTU and come in two forms:

A) Evaporative Condensers having water sprayed directly on the condenser coil.

B) Condenser Precooling using air that has been evaporatively cooled and then passed over the condenser.

In both cases efficiently reducing the operating temperature of the condenser reduces its energy use.

Widespread deployment of this technology in average to dry climates in the United States could have significant positive impact on electric demand and ease the burden on the utility grid.

FEMP Report, 2007

Evaporative cooling methods were around long before the advent of mechanically based cooling and can be found in traditional architecture in hot and dry climates around the globe. Evaporative coolers work by adding water vapor to hot air which, through the process of evaporation, removes sensible heat from the air and effectively lowers its temperature.

Fortunately, manufacturers and designers have been expanding on the inherent cooling efficiency of the evaporative process and have developed technologies to use evaporative methods 'indirectly' to avoid the introduction of added humidity and to combine these systems with traditional, compressor-based cooling methods.

Indirect evaporative cooling can also be effectively used in buildings with cooling towers. The cooling tower may be used to evaporatively precool ventilation air for one or more air handling units (AHU), reducing the load on the mechanical cooling system. This can work in new or retrofit applications.

A major trend in low or zero net energy buildings is toward passive systems and away from mechanical (compressor-based) cooling.[3]

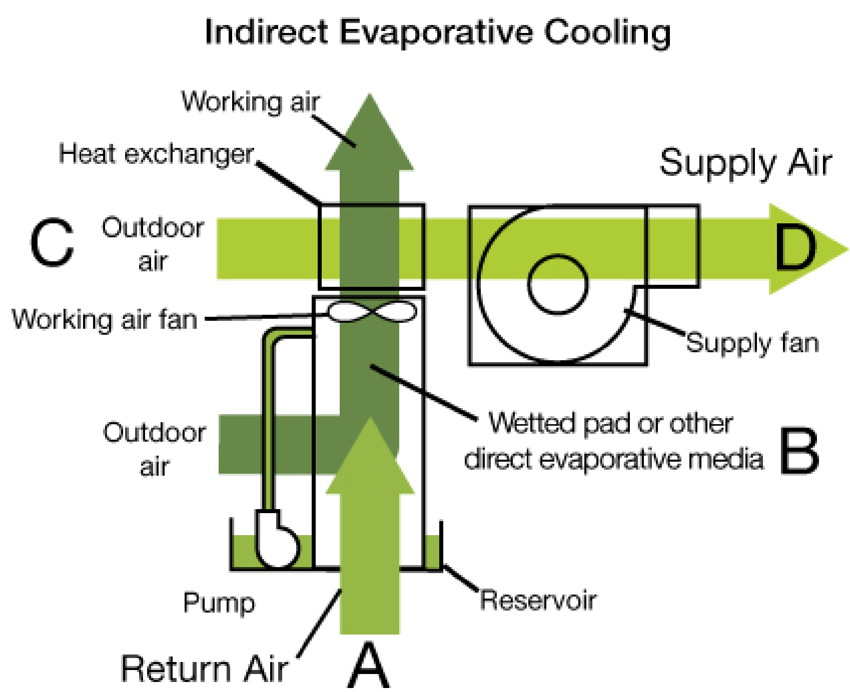
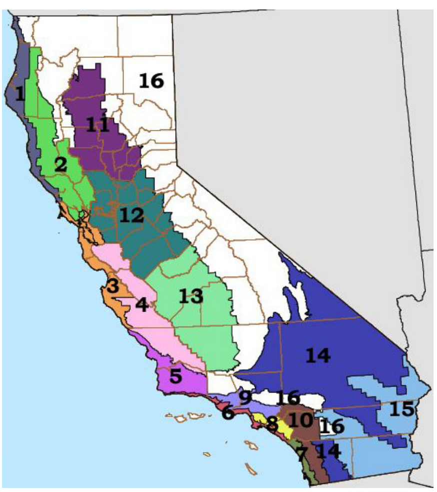


Figure 1: IEC Fundamentals: the A, B, Cs = D cool dry air. Typical arrangement of indirect evaporative cooling system.

3 NBI Getting to Zero Status Update, 2014

California's 16 Building Climate Zones. Design teams, when analyzing full weather data and HVAC system options, may be surprised at the wide range of locations suitable for Indirect Evaporative Cooling. (Source: California Energy Commission)



EVAPORATIVE EFFECTIVENESS CALCULATION

Evaporative effectiveness (EF) is a measure of how closely the supply air temperature (SAT) leaving the evaporative cooler approaches the outdoor wet-bulb temperature (T_{wb}).

$$EF = \frac{T_{db} - SAT}{T_{db} - T_{wb}}$$

The typical EF of **indirect evaporative coolers is 75%**.

In Figure 1 return air (A) passes from the space directly over a wetted medium (B) to passively remove sensible heat before discharging it to the outside. Outdoor air (C) enters as a secondary air stream, crosses the medium in an adjacent but isolated side and is 'indirectly' evaporatively cooled before being delivered to the space (D). Compressor-based equipment becomes stage-2 cooling.

Cooling Towers

Conventional evaporative cooling towers and condensers are used to cool water or refrigerant. The cooled liquid is then piped to a chiller or an AHU coil to cool the supply air stream. Evaporative cooling towers can also be harnessed to reduce energy consumption in other ways. A cooling tower may be used to precool the condenser of an air conditioner unit. Another method is to use the cooling tower as a ventilation air precooling application in cases where additional downstream cooling may still be required by the design. In both cases the cooling tower is used to increase the capacity of the system and reduce the electrical demand of the Direct Expansion air conditioner or chiller. Under particular cooling load and outside air conditions the evaporative cooling provided by the cooling tower may be able to meet cooling needs without the necessity of mechanical (DX refrigeration cycle) cooling.

Climate-Specific Cooling

Evaporative cooling, whether direct or indirect, is a climate-specific approach. When used effectively, IECs allow design teams to push the supply air temperature closer to the outdoor dew-point temperature to satisfy the cooling load. This serves to **extend the applicability of evaporative cooling to the majority of regions in California**. Because climate conditions are so important for evaporative cooling it is important that design teams analyze a complete year's worth of hourly weather data for a particular site when considering cooling strategies and technologies for a project. Evaporative cooling is most effective in hot and dry climates. Psychrometric analysis including a year's worth of hourly data can assist design teams in understanding the relationship between cooling strategies and various climate variables and can indicate the impacts of short-term changes in humidity on a given strategy.

Evaporative Cooling Effectiveness

To calculate the temperature delivered by evaporative cooling equipment it is helpful to use the Evaporative Effectiveness Calculation (see sidebar) approach based on the design dry bulb (T_{db}) and wet bulb temperatures (T_{wb}) for the specific location. Table 1 shows the possible supply air temperature achievable in select California cities with indirect evaporative coolers based on this calculation. Evaporative cooling is more effective when the design wet bulb depression (the difference between T_{db} and T_{wb}) is greater, as in a hot dry climate such as Palm Springs. But IECs alone can often completely meet the design Supply Air Temp in more modest climates such as San Francisco, Los Angeles and San Jose (Table 1 SAT of 68°F, 69°F and 72°F respectively for these cities).

Table 1: Indirect Evaporative Cooling Effectiveness at Select California Locations

City	Design T_{db} / T_{wb}, °F	IEC's SAT, °F	ΔT: Design T_{db} minus IEC SAT, °F
Sacramento	100/71	78	22
Palm Springs	111/73	82	29
Los Angeles	84/64	69	15
San Diego	84/66	72	12
San Jose	92/67	73	19
San Francisco	83/63	68	15

Water

Because water is fundamental to the evaporative process, and a highly valuable resource, it is important to cover the ways in which water is used by this equipment. The 'water balance' of evaporative systems refers to all the water inflows and outflows associated with the equipment. Water outflows include evaporation, water purged or dumped during operation and miscellaneous losses such as overflow. These outflows are replaced by make-up water on the supply side.

As a function of the evaporative process, water outflow increases with lower humidity levels and higher temperature. It is also typical to see higher water usage if there is a high concentration of dissolved minerals in the water because of the need for additional purge cycles. Most available packaged indirect evaporative coolers include intelligent purge-cycle functionality that is tied to either a timer or mineral concentration levels. Equipment that continuously purges water should be avoided in locations that are water constrained.

Water Use Efficiency

Evaluating estimated water use is important when comparing different evaporative approaches and equipment. The Western Cooling Efficiency Center research team reviewed the water usage of direct and indirect evaporative and traditional compressor-based cooling systems in relation to the California Energy Commission (CEC) water-use-level recommendations for evaporative units of **0.15 gallons per minute per ton** (gpm/ton). All high efficiency evaporative coolers included in the study met the CEC's minimum efficiency levels. It was also determined that the water-use penalty associated with the additional off-site energy generation needed for compressor-based cooling almost always exceeded the on-site water used by the evaporative cooling equipment.

A study found that increases in water use by indirect evaporative cooling in Denver were offset by the reduction in energy provided by a local, thermally driven power plant, which consumes water to produce electricity. For this reason, the indirect evaporative cooling did not increase overall regional water consumption.[4]

WAYS TO OPTIMIZE WATER EFFICIENCY IN INDIRECT EVAPORATIVE COOLERS

- Minimize the cooling load
- Compare system specifications for water use metrics - water use efficiency features may vary between equipment
- Ensure installed and ongoing commissioning of the entire system
- Train building operation staff on operations, continued commissioning and maintenance requirements

4 Deane,J., Metzger, I. National Renewable Energy Laboratory (NREL) Multistaged Indirect Evaporative Cooler Evaluation for the U.S. General Services Administration (GSA), February 2014

UC Merced Science & Engineering 1 Building, 180,339 gsf, built in 2006 (Source: CIEE)

It is important to consider the peak cooling demand reductions often attributed to indirect evaporative precooling. The Science & Engineering Building (S&E 1) at UC Merced demonstrated a 51% reduction in peak chilled water usage by using a variety of measures and design features, including evaporatively precooling the ventilation air needed in the lab.[5] As noted in Table 2, the cooling load was reduced from 3.74 to 1.85 tons per thousand gross square feet (gsf). This example highlights the need to closely evaluate not only the amount of water used directly by the evaporative cooling equipment but the impact this choice might have on reducing loads and energy use of the project as both of the factors can account for reduced water use.

Table 2: UC Merced S&E 1 reduced peak chilled water by more than 50% through evaporative precooling of ventilation air.

	Benchmark*	S&E 1 As-operated	Reduction
Peak Chilled Water	3.74 tons/1k gsf	1.85 tons/1k gsf	51%

* Energy-use benchmarks are based on data, adjusted for building type and climate, from eight other UC and California State University campuses.

Maintaining water efficiency of the selected equipment is critical. This means getting more value or work out of the water that is consumed by the system and making sure water is not being wasted or lost during system operation.

Energy Use and Savings

As outdoor temperatures increase, the efficiency of conventional air-cooled air conditioning systems decreases while evaporative-based systems typically become more efficient.[6]

Savings over Code

For the new California 2013 Title 24 Nonresidential Buildings Energy Standards (Title 24), the energy use of indirect evaporative systems was modeled in comparison with compliance requirements. Table 3 shows two system IEC configurations (R3 and R5) compared to compliance systems in four California climate zones. **The analysis concluded that the savings potential for new construction was on the order of 18-26% and that these savings were 'conservative'.** The analysis uses the California required Time Dependent Value (TDV) of energy, which considers the peak impacts. Since cooling is directly aligned with, and the primary reason for, peak energy use in California the TDV savings are very significant.

5 NBI, Science & Engineering Building I, UC Merced Measured Performance Case Study, December 2009

6 Faramarzi, R., Southern California Edison, Performance Comparison of Evaporatively-Cooled Condenser versus Air-Cooled Condenser Air Conditioners, ACEEE Summer Study Proceedings 2010

Table 3: Time Dependent Value of Energy Savings from Evaporative and Indirect Evaporative Systems in offices over Code Compliance Systems. (Source: HMG C.A.S.E. Study).

	TDV Energy Savings	
	Compliance Margin	% Improvement Total
R3	PSZ w/EVAP PRE COOLER and INDRECT EVAP COOL (100% Eff.) w/ Integrated Operation	
Oakland (CZ 3)	11.3	18.7%
Burbank-Gledale (CZ 9)	12.3	20.8%
Sacramento (CZ 12)	11.0	18.3%
Fresno (CZ 13)	13.4	22.2%
R5	PSZ w/30 EER (max allowable EER in Energy Pro)	
Oakland (CZ 3)	14.4	24.1%
Burbank-Gledale (CZ 9)	14.9	25.4%
Sacramento (CZ 12)	14.0	23.7%
Fresno (CZ 13)	15.6	26.2%

Modeled Savings over Existing Systems

Table 4 shows the results of a recent modeling analysis of multistage indirect evaporative cooling savings and costs across the West. IECs cut the cooling energy use by more than 57% in all of the studied applications, and small classrooms saved around 60%.[7] Data Centers showed a 77-92% energy reduction, a key reason owners and facility directors of these energy-intensive buildings are taking notice and applying IEC systems to meet their large cooling needs.

Table 4: A recent study modeled the energy savings potential and locations for indirect evaporative cooling. Small classroom applications across the West were estimated to save around 60% of cooling energy.[8]

Location	Metric	Small Classroom	Data Center	Quick-Serve Restaurant
Phoenix, AZ	Percent Energy Use Reduction	65%	77%	70%
	Simple Payback (yrs)	11	14.3	9.9
	Net Present Value	$6,552	$1,241,631	$1,999
Las Vegas, NV	Percent Energy Use Reduction	68%	76%	
	Simple Payback (yrs)	12.7	13.1	
	Net Present Value	$5,599	$1,666,419	
Los Angeles, CA	Percent Energy Use Reduction	63%	81%	
	Simple Payback (yrs)	52.1	16.5	
	Net Present Value	-$3,016	$969,384	
Albuquerque, NM	Percent Energy Use Reduction	66%	86%	
	Simple Payback (yrs)	173.5	17.7	
	Net Present Value	-$12,345	$638,040	
Colorado Springs, CO	Percent Energy Use Reduction	64%	88%	57%
	Simple Payback (yrs)	275.2	13	61.8
	Net Present Value	-$8,827	$1,091,370	$-6,835
Helena, MT	Percent Energy Use Reduction	65%	92%	
	Simple Payback (yrs)	345.4	14.4	
	Net Present Value	-$9,002	$1,060,271	

8 Deane, J. NREL, 2014 Ibid

7 Deane, J. NREL, Ibid

Measured Savings over Existing Systems

In summer 2013 an IEC combined with a baseline (minimum code compliant efficiency) 5-ton rooftop unit (RTU) was field tested in the moderate climate of Vancouver, Washington.[9] The indirect evaporative cooler precooled the outside air before it entered the RTU, thus reducing the load on the RTU. Figure 2 illustrates analysis of the daily energy use and average outdoor temperature of the different operating modes of the IEC. The green circles represent the baseline mode, and the blue squares represent the integrated mode. The lower daily energy use of the integrated mode reduced the amount of energy needed by the RTU to meet the cooling energy use by about 35%.

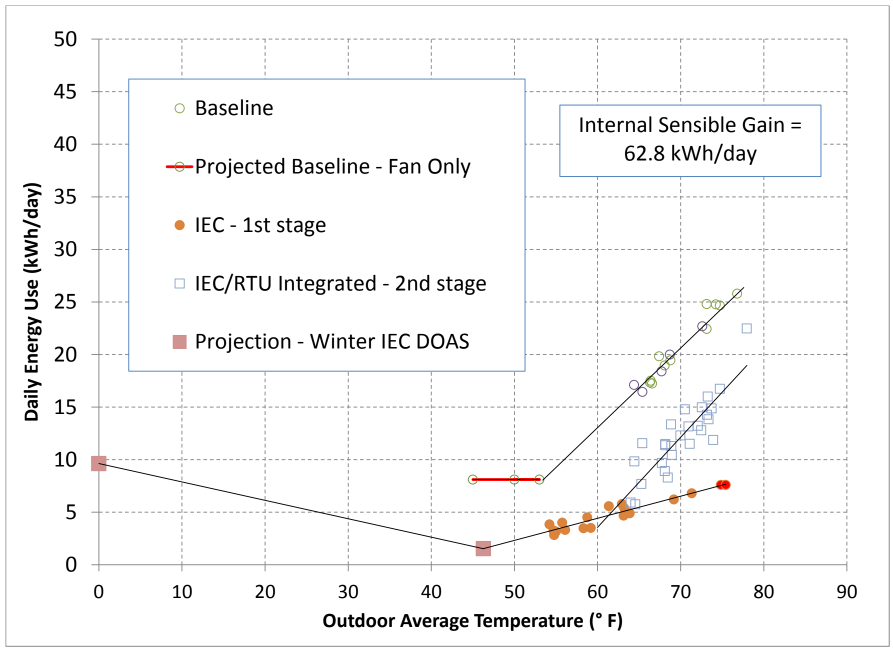


Figure 2: Measured results of a code RTU running without evaporative assistance (baseline in graph) and with indirect evaporative assistance reduced the cooling energy use by about 35%. (Source: NBI)

Winter Ventilation with IEC. The IEC being tested featured a highly efficient variable-speed fan and can function as a dedicated outside air system (DOAS) to efficiently ventilate the space during the winter months after the cooling section had been winterized (supply water off and water line drained). With this added benefit the annualized energy savings provided by **intergrating the IEC unit with the RTU and using the IEC for winter ventilation air increased energy savings to an average of 53%** compared to the RTU alone.[10]

9 NBI, Advanced Evaporative Cooling Equipment Field Performance Monitoring, report to NEEA February 2014

10 NBI, Report to NEEA 2014, Ibid

Significant measured savings were also found in the hot dry climate of Denver in the 2014 NREL study on IEC, with the multistaged IEC achieving an 80% reduction in energy use compared to a traditional RTU.[11]

In the Western Cooling Challenge (Challenge) the WCEC tested a number of 'hybrid' indirect evaporative systems that combine IEC with a refrigeration-cycle system. The Challenge tested performance at standard and peak conditions with a minimum requirement of having a peak Energy Efficiency Ratio (EER) of 14 and an annual average of a 17 EER.[12] The IEC systems tested performed, in general, at or above 20 EER **– 52% more efficient than code - and with an average peak reduction of 20%.**

Table 5: Summary of Measured Savings of Hybrid Indirect Evaporative Cooling Systems over Code RTUs

Study-Location	Reference	Average Savings
WCED - CA	Annual HVAC Energy Savings	52%
NBI Northwest	Cooling Season HVAC Savings	35%
	Annual HVAC Energy Savings (IE used for winter ventilation)	53%
NREL Denver	Annual HVAC Energy Savings	80%

California Code – Metrics and Requirements

Energy Efficiency Ratio (EER)

Compressor-based HVAC systems are subject to the California Appliance Efficiency Regulations (Title 20) established by the California Energy Commission based on the systems EER. For example, a 10-ton unit must have a minimum EER of 11.5. Evaporative cooling systems must also meet a set of minimum EER requirements ranging from an EER of 11.7 – 12.2, but the system's code performance is determined through a specified test procedure in Title 20. Today's Direct and Indirect Evaporative Cooling systems easily meet or exceed this code requirement.

Evaporative Cooler Efficiency Ratio (ECER)

To establish a more relevant metric for evaporative cooler comparisons, the CEC also developed an evaporative cooler rating parameter called the ECER using a slightly modified version of standard ASHRAE test methods.[13] The ECER is specified by Title 20 to standardize reporting for vendors and simplify comparisons between units. California Title 20 requires testing and disclosure of this metric, but there is currently no minimum ECER performance requirement for evaporative systems. When a project specifies the use of evaporative cooling equipment in California, the following information is required to be part of the code submission: a) Cooling Effectiveness, b) Total power (watts), c) Airflow Rate (cfm) and d) ECER.

11 National Renewable Energy Lab (NREL) Multistaged Indirect Evaporative Cooler Evaluation for GSA, February 2014

12 The units in the Western Cooling Challenge were 5, 8 and 20 tons

13 The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) established the national test standards for HVAC equipment.

Credits

The Title 24 whole-building energy code does have performance credits for high-efficiency stand-alone and packaged hybrid indirect evaporative systems when modeling the HVAC system. Information on the performance credits and modeling criteria can be found at the CEC Title 24 website.

Beyond Code

Energy efficiency programs such as Savings by Design or green building program such as LEED set energy requirements 'beyond code' for projects to achieve points and possible incentives. In many climates IECs can reduce energy use and peak demand by 40% or more over standard code-level equipment in many commercial buildings. Design firms may be able to utilize energy models and the new Commercial Buildings Energy Modeling Guidelines and Procedures available through COMNET[14] to provide documentation of the savings potential when applying for these programs.

A conventionally designed office building with a similar usage profile to Golden Hill would typically use a centrifugal chiller-based cooling. However, the chiller was energy modeled and rejected as it would expend 10 times the energy of the evaporative cooling system on an annual basis.

Golden Hill case study

An Indirect/Direct Evaporative Cooling unit installed at Golden Hill Office Center, Lakewood, CO (Source: *High Performance Buildings* magazine)

14 The Commercial Energy Service Network (COMNET) provides free Energy Modeling Protocol Guidelines and is recognized by USGBC for application within the LEED program.

Application Examples

Orinda City Hall (Source: David Wakely ©2009)

Orinda City Hall

- Built in 2009
- Public Order and Safety
- 13,907 gsf
- Modeled EUI: 60 kBtu/gsf/yr
- 60+% Savings over Title 24-2004

Orinda City Hall, Orinda, CA

The Orinda City Hall was able to combine natural ventilation with an air-to-air indirect/direct evaporative cooler to meet 100% of its cooling load. This resulted in a building that was projected to **reduce its energy use by more than 60% compared to Title 24-2008**.

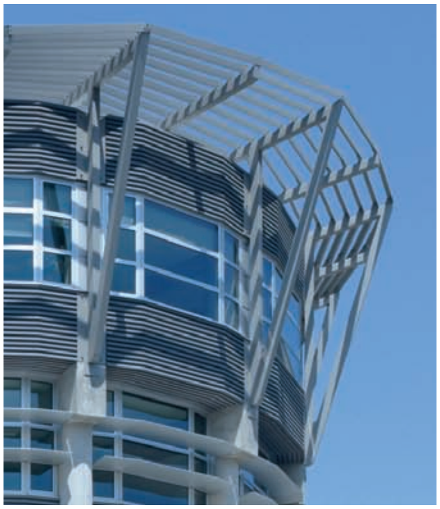
The initial modeling of a code-level building with indirect/direct evaporative cooling resulted in equipment that would be both large and expensive; it would have taken up an entire side of the building. So the mechanical engineering team worked closely with the architects from early in the design phase to get the building's energy load significantly reduced. The team minimized solar gain by properly sizing and shading windows while still allowing for passive cross ventilation. The use of high efficiency light fixtures with advanced daylight controls saved both power and heat in the space. ***"It took a good 30 to 40 percent reduction in loads to get to the goal of eliminating compressors,"*** says Gwelen Paliaga, senior mechanical designer at Taylor Engineering.

Ceiling fans assist the ventilation strategy and keep spaces comfortable by providing air movement. For periods of the day when natural ventilation does not provide sufficient cooling, the indirect evaporative cooler turns on to meet the remainder of the load.

One of the biggest challenges of IEC as an additional cooling strategy is ensuring the ability to control all approaches in a way that optimizes efficiencies. In this building, when outside conditions are favorable for natural ventilation the occupants are alerted by lighted signs positioned throughout the building. If any zone gets too hot, even when in natural ventilation mode, the evaporative cooler will turn on and provide air to that zone. The selection of IEC has been one part of the design puzzle that helps meet the energy and thermal comfort targets for Orinda City Hall.

"The fallback position was, if we can't eliminate air conditioning altogether, can we do non-compressor cooling and only naturally ventilate this building?"

Harry Siegel
Siegel and Strain Architects



David Brower Center Exterior (Source: Center for the Built Environment, University of California Berkeley)

David Brower Center

- Built in 2009
- Mixed Use
- 45,000 gsf
- Measured EUI: 49 kBtus/gsf/yr (offices & restaurant)
- 42% savings over Title 24 - 2001

Figure 3: Displacement ventilation is provided through the raised floor. Two rooftop dedicated outside air systems (DOAS) supply 100% of the indirectly evaporatively pre-cooled outdoor air to the entire building. (Source: *High Performance Buildings* magazine)

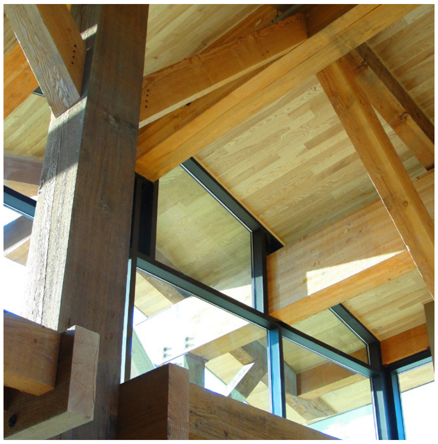
David Brower Center, Berkeley, CA

This mixed-use building in downtown Berkeley seeks to honor its namesake, David Brower, an early and longtime advocate for the environmental movement. The envelope was carefully designed to minimize skin loads, and all cooling is done using indirect evaporative cooling from a cooling tower with an efficient hydronic radiant distribution system and dedicated outside air ventilation. This leading-edge design was targeted at, and achieved, 42% less energy than code and 60% less energy than the average U.S. building of similar use. The measured energy use intensity is 49 kBtus/gsf/yr (includes offices and a ground-floor restaurant).

This design highlights the inherent efficiencies associated with decoupling space conditioning from space ventilation. The combination enhances the performance of the cooling tower (used for conditioning the water used in the radiant system) by using IEC to also precool the building ventilation air. The design reflects the weather conditions for the East Bay where dehumidification is not typically required during cooling periods.

The radiant cooling strategy allows the building to utilize an expanded comfort zone with the summer set point being 78°F. The indirect evaporative cooler is able to deliver 75°F air to rooftop air handlers during the warmer periods, which is then delivered to the office spaces via a raised floor displacement ventilation system (Figure 3). The building uses compressor cooling only in a small number of meeting rooms. This strategy, combined with the radiant cooling system and effective night flushing, has been successful at fully maintaining interior comfort. Commissioning and continuous monitoring have been key to ongoing successful operations and occupant comfort for this integrated system.

The office space has no compressor-based cooling, and comfort has been maintained without difficulty.



Above: The ceiling detail of the San Luis Wildlife Refuge Visitors Center. Right: Exterior of the Visitors Center. (Source: Catalyst Architects)

San Luis National Wildlife Refuge

- Built in 2011
- Interpretative Center
- 16,500 gsf
- Modeled Net EUI = Zero
- Catalyst Architects

San Luis National Wildlife Refuge Headquarters and Visitors Center, Los Banos, CA

The U.S. Fish and Wildlife Service (Service) wanted to create a high performance, zero net energy model for future visitor centers and showcase it to the 150,000 annual visitors to the San Luis National Wildlife Refuge Complex. The design team first drew from classic desert architecture incorporating passive solar to reduce heating and cooling loads and costs, the use of sunshades, a 'cool roof', high-mass walls and colored paint on exterior stucco surfaces to reflecting or absorb heat. The walkways for servicing the solar panels are bright white urethane to minimize the heat island effect. Windows are operable, low-e, high R-value and vary in size by orientation.

The first stage of cooling is also passive: hot air is vented through clerestory windows to create a "whole-house fan" that moves air through the facility (thermal displacement ventilation). Stage-two cooling is from a highly energy efficient precooling/multi-stage indirect evaporative cooling system. The system is optimized by occupancy sensors and remote electronic access which enables off-peak precooling. Ventilation and thermal comfort exceed standards, and healthy indoor air quality is further enhanced by the selection of adhesives, sealants, finishes and carpets that prevent harmful off-gassing of pollutants.

A commissioning agent was actively engaged from the beginning of design, and enhanced commissioning, measurement, and verification were done to ensure correct installation and operation of systems. These post-occupancy efforts identified needs to reprogram the systems and modify some hardware during the facility's first year of operation.

The environmental leadership at San Luis will have a lasting impact on the way visitor centers are realized in the future. Design principles developed here have now been used at four other Service Visitor Centers in California. In addition, a surprising number of design professionals and contractors have been visiting to learn about this LEED Platinum building.

Case Study content from the [U.S. Fish and Wildlife Project Summary] and [Catalyst Architects].

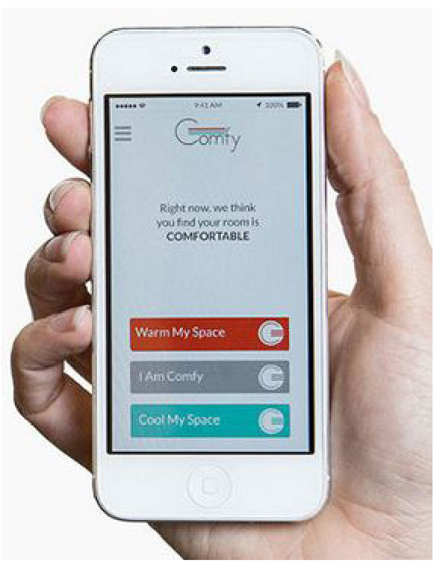
The Indirect Evaporative Cooling system at San Luis Wildlife Refuge Visitors Center (Source: U.S. Fish and Wildlife Service)

Cost Characterization

Costs for evaporative-based equipment are typically calculated on a cubic-foot-per-minute (cfm) of airflow basis or per ton (12,000 Btus) of cooling; the costs per cfm or ton can vary widely. A recent report included a market scan of smaller evaporative units, approximately 1,000 to 2,000 CFM, and found the cost ranges were extreme - from $1 to $15 per cfm.[15] In general, the lower-cost units are direct evaporative coolers (not targeted here), and the higher cost are indirect/direct evaporative coolers. Indirect-only evaporative coolers tend to occupy the mid-range. These costs do not include installation. A West Coast HVAC distributor and installer (WESCOR) with extensive knowledge of and experience with indirect evaporative cooling systems indicates a lower-cost range on its website and lists indirect-only evaporative modules in the $1.95 to $2.30 per cfm range.

Trends

Occupant-Based Thermal Comfort Strategies



Trends are toward personal control of thermal comfort (Source: *FastCompany Magazine*)

Common approaches to HVAC focus almost exclusively on control of ambient air temperature across a large area to provide thermal comfort. More recent trends are for more direct thermal comfort by providing heating and cooling with low-energy personal comfort systems or by controlling HVAC based on occupant polling. The provision of air movement for cooling - through low-energy ceiling or desk fans, or through natural ventilation - is a traditional occupant-based approach making a comeback in zero net and other ultra-low energy buildings.

Low-energy personal comfort system options will also soon include ergonomic chairs equipped with highly efficient heating and cooling capabilities. This approach can reduce overall energy use by allowing the ambient temperature deadband to be widened while maintaining occupant satisfaction. Low-energy personal comfort systems may also be useful in mitigating thermal problems from architectural or HVAC design issues without significantly increasing energy use and in some cases may entirely eliminate the need for ambient heating or cooling.

Control of HVAC based on occupant polling can reduce energy use caused by over-cooling or over-heating while addressing varying occupant needs based on differences in clothing and/or metabolism. In addition, cold or hot “calls” can often be addressed with less ongoing impact on overall system control and the associated increases in energy use.

There may be potential synergies between the occupant-based strategies, resulting in various combinations of the strategies being implemented together. At this writing, occupant-polling-based HVAC control and innovative low-energy personal comfort systems are too new to allow predictions regarding market adoption alone or in combination with each other or radiant + DOAS systems.

15 NBI, Report to NEEA 2014, IBID

Dedicated Outdoor Air Systems with Radiant Cooling/ Heating or Other Hydronic-Based Systems

Another trend in HVAC design is toward the decoupling of ventilation from cooling and heating — with dedicated outdoor air systems combined with radiant or other hydronic-distribution-based systems. As noted, indirect evaporative cooling can be synergistic with these systems, contributing to tempering of outdoor air as well as the provision of chilled water.

The DOAS system often includes increased amounts of outside air (OA) beyond ASHRAE standard ventilation requirements and may include dehumidification and/or heat recovery. In Seattle's Bullitt Center for example, the DOAS brings in 30% more OA than required and is an integrated part of a system that combines operable, automated windows as first-stage cooling and heat recovery when applicable.

Hydronic radiant systems – with in-floor/ceiling slabs or via radiant panel – are being used more widely in projects targeting ZNE than in the standard commercial designs which are still dominated by VAV and packaged rooftop units. Like Indirect Evaporative systems, the energy savings of these systems are getting the attention of leading designers and owners wanting to achieve deeper energy reductions while maintaining high standards for occupant comfort and indoor air quality.

Radiant piping system at David Brower Building (Courtesy: *High Performance Buildings* magazine)

Resources

Western Cooling Efficiency Center (WCEC)

California Public Utilities Commission (CPUC) Energy Efficiency Strategic Plan

CPUC ZNE Buildings Site http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/Zero+Net+Energy+Buildings.htm

New Buildings Institute (NBI) ZNE Resource Site http://newbuildings.org/zero-energy

Center for the Built Environment (CBE), University of California, Berkeley, CA

ASHRAE *Advanced Energy Design Guide* for Small to Medium Office Buildings

Net Zero Energy Design; Hootman, T. 2013

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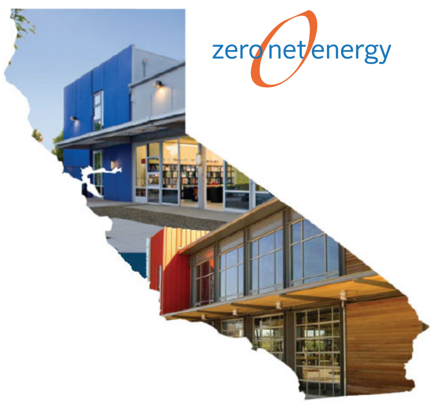
The ZNE Technology Application Guides bring information on readily available leading-edge technologies found in today's ZNE buildings to California design firms and owners. Low and zero net energy buildings may be eligible for federal tax credits. In addition, California utility companies offer energy efficiency programs such as Savings by Design for new construction commercial buildings.



Energy Upgrade California® is a state initiative to educate residents and small business consumers about energy management. The initiative helps Californians take action to save energy and conserve natural resources, reduce demand on the electricity grid, and make informed energy management choices at home and at work. It is supported by an alliance of the California Public Utilities Commission, the California Energy Commission, utilities, regional energy networks, local governments, businesses, and nonprofits to help communities meet state and local energy and climate action goals. Funding comes from investor-owned utility customers under the auspices of the California Public Utilities Commission.

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