CODES AND STANDARDS ENHANCEMENT INITIATIVE (CASE)

Evaporative Cooling System Compliance Credit

2013 California Building Energy Efficiency Standards

California Utilities Statewide Codes and Standards Team September 2011

This report was prepared by the California Statewide Utility Codes and Standards Program and funded by the California utility customers under the auspices of the California Public Utilities Commission.

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1. Purpose

Evaporative cooling technologies have the potential to achieve significant energy and peak demand savings when compared to direct expansion (DX) systems – specifically those meeting the federally mandated minimum efficiency levels used as baseline systems for Title 24.

Evaporative cooling systems take advantage of the fact that water needs energy to evaporate (i.e., heat is needed for the phase transformation from liquid to gas). Water can absorb this heat from an air stream, thereby cooling the air. Thus, evaporative coolers cool air through the absorption of heat during the evaporation process.

Older evaporative cooling technologies pass outside air through a wet medium and then supply the cooled air to the space. These systems also add latent loads to the space, because the air picks up moisture from the wet medium. These 'direct' evaporative systems (often called "swamp coolers") have been around from before the advent of DX cooling. They are however not popular for space cooling applications in building types with static occupancies such as offices and have seen reduced use. This is because of the added latent loads and moisture issues they can create within the space.

Recent advances in technology has enabled evaporative cooling technologies to provide cool air without adding significant moisture into the space through the use of 'indirect' evaporative cooling technologies. These indirect systems separate the supply air stream (the air that will be sent into the conditioned space) from the working air stream (the air that is passed over the wet medium). There are also combinations of these two types of evaporative cooling systems, called "indirect-direct" systems, and "direct-indirect systems". For the purposes of this CASE report, all of these systems are included within the Indirect Evaporative Cooling systems category.

Further, there are combinations of indirect evaporative cooling systems with traditional DX coils. These hybrid systems can achieve significant improvements in performance over stand-alone evaporative cooling as well as stand-alone DX cooling technologies.

This CASE topic proposes a compliance credit for qualifying evaporative cooling technologies that use either stand-alone indirect evaporative cooling or a combination of indirect evaporative cooling with DX coils. By promoting these types of evaporative systems, the State of California will save energy, and encourage the more widespread adoption of an efficient technology.

2. Overview

a. Measure Title	Compliance Credits for Hybrid Evaporative Cooling Systems in Nonresidential Buildings
b. Description	Provide compliance credits for high-efficiency hybrid evaporative cooling system types in the performance method for compliance with code.
c. Type of Change	**Compliance Option -**The change would add or modify a new measure to the list of existing compliance options for meeting the Standards using the performance approach. This compliance option will specify modeling protocols for qualifying evaporative cooling systems. **Modeling -** The change would modify the nonresidential ACM Section 3.3 – HVAC Systems and Plants, by adding an optional simulation capability for qualifying evaporative cooling systems. This change will add the capability to model the improved performance of evaporative cooling systems in the proposed building, relative to the performance of the baseline equipment in the reference building.

d. Energy Benefits

The proposed CASE measures encourage cooling technologies that are more efficient than the current baseline systems assumed for the nonresidential standards. These proposed cooling technologies save both total energy and peak demand for buildings. Thus, the proposed technologies benefit from the Time Dependent Valuation (TDV), which encourages saving energy during peak periods.

The energy and peak demand benefits of the measure proposed for 2013 Standards are relative to prescriptive requirements in the 2008 Standards. Figure 1 identifies the following energy savings for the CASE proposed measures:

1. Site energy: Electrical energy savings in kWh/yr, for a prototype building and per square foot.
2. Electrical demand savings in kW for a prototype building and per square foot.
3. TDV energy savings for electricity and natural gas, as applicable.

Assumptions and calculations used to derive the energy and demand savings for the prototype building, including (but not limited to) hours of operations, energy and demand savings per unit of equipment, and square footage of the prototype building are described under *Section 3 Methodology* and *Section 4 Analysis and Results*.

CZ 3	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
Per Unit Measure	N/A	N/A	N/A	N/A	N/A
Per Prototype Building	22,246	7.30	-	168,312	-
Savings per square foot	3.86	0.0013	-	29.22	-

CZ 9	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
Per Unit Measure	N/A	N/A	N/A	N/A	N/A
Per Prototype Building	23,470	7.55	-	173,511	-
Savings per square foot	4.07	0.0013	-	30.12	-

CZ 12	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
Per Unit Measure	N/A	N/A	N/A	N/A	N/A
Per Prototype Building	21,908	7.07	-	163,445	-
Savings per square foot	3.80	0.0012	-	28.38	-

CZ 13	Electricity Savings (kwh/yr)	Demand Savings (kw)	Natural Gas Savings (Therms/yr)	TDV Electricity Savings	TDV Gas Savings
Per Unit Measure	N/A	N/A	N/A	N/A	N/A
Per Prototype Building	24,302	7.67	-	182,007	-
Savings per square foot	4.22	0.0013	-	31.60	-

Figure 1: Energy Savings for Representative Climate Zones

e. Non-Energy Benefits	There are no non-energy benefits to this measure.

f. Environmental Impact

Material Increase (I), Decrease (D), or No Change (NC): (All units are lbs/year)

	Mercury	Lead	Copper	Steel	Plastic	Others (Identify)
Per Unit Measure[1]	NC	NC	NC	NC	NC	NC
Per Prototype Building[2]	NC	NC	NC	NC	NC	NC

Water Consumption:

	On-Site (Not at the Powerplant) Water Savings (or Increase) (Gallons/Year)
Per Unit Measure[1]	(4 Gallons/Ton-hr)

1. Measure unit = Gallons of water used for 1 Ton of nominal cooling capacity for one hour of equipment run-time. This is the maximum water usage for evaporative systems that meet the qualification criteria for compliance credit. All systems will have water consumption at or below this threshold.
2. Note that there are substantial water savings at the power plant due to reduced generation based on energy saved by EC systems onsite. Refer to Section 4.3.4 for details.
3. For description of prototype buildings refer to Methodology section below.

Water Quality Impacts:

Potential increase (I), decrease (D), or no change (NC) in contamination compared to the base case.

	Mineralization (calcium, boron, and salts	Algae or Bacterial Buildup	Corrosives as a Result of PH Change	Others
Impact (I, D, or NC)	NC	NC	NC	NC
Comment on reasons for your impact assessment	Regular replacement of the evaporative medium and periodic flush of the sump water should prevent increased mineral content in the water from being expelled from the unit.	Regular replacement of the evaporative medium and periodic flush of the sump water should prevent algae or bacteria buildup.	Regular replacement of the evaporative medium and periodic flush of the sump water should prevent increased mineral content in the water being expelled from the unit.	

g. Technology Measures	**Measure Availability:** Indirect evaporative cooling technologies are currently manufactured by several manufacturers, as listed in Section 4.1.3 of this report. Advanced hybrid evaporative + DX cooling systems are currently manufactured by at least two manufacturers and others report that they will follow suit soon. These advanced hybrid systems are new to the marketplace and are expected to increase market share over the next decade. The code change proposed in this CASE report will encourage more manufacturers to manufacture high-efficiency indirect and hybrid systems. In addition, the Western Cooling Challenge is generating a healthy competition among manufacturers to develop new, market-ready products. **Useful Life, Persistence, and Maintenance:** The measures encouraged by this CASE topic have similar useful life and persistence characteristics as traditional DX based rooftop units. Evaporative cooling systems do require periodic replacement of the evaporative medium in order to prevent build-up of mineral deposits and scaling on the medium and thus can have potentially higher maintenance costs.
h. Performance Verification of the Proposed Measure	Current acceptance testing in Title 24 for nonresidential HVAC systems will be applicable to the systems promoted through this CASE topic.
i. Cost Effectiveness Since the proposed measure is not a prescriptive or a mandatory measure, cost-effectiveness analysis is not needed for this CASE topic. See the "*Methodology*" and "*Analysis and Results*" sections below for data on system costs and energy savings.	
j. Analysis Tools	Energy analysis and peak demand analysis for this measure can be conducted using existing compliance software.
k. Relationship to Other Measures	This measure does not directly affect any other measures. However, using the proposed measure will impact the trade-off of energy efficiency measures in the performance approach to compliance.

3. Methodology

This section describes the methodology that we followed to assess the measure availability, energy savings and feasibility of the proposed code change. The key elements of the methodology are as follows:

- Data Collection
- Review of Simulation Tool Capabilities
- Savings Analysis

This work was publicly vetted through our stakeholder outreach process, through which we requested and received feedback on the direction of the proposed changes via in-person meetings, webinars, email correspondence and phone calls. The stakeholder outreach process is described in detail at the end of the Methodology section.

3.1 Data Collection on Status of Evaporative Cooling Technologies

HMG evaluated the availability, market readiness and savings potential for evaporative cooling technologies by collecting data from a combination of sources. We conducted a literature review of scientific papers, journal articles, and industry publications; conducted interviews with manufacturers and mechanical engineers; and held ongoing communications with leading research groups.

3.1.1 Literature Review on Evaporative Cooling Technologies

Evaporative cooling (EC) technologies have evolved into a diverse range of technologies and applications – each specifically suited for a given occupancy and cooling/humidification need. HMG conducted a literature review of the technical potential and applicability of these various technologies. We reviewed manufacturers' literature, research papers, and laboratory studies conducted on behalf of the California Investor Owned Utilities (IOU), California Energy Commission Public Interest Energy Research (PIER) program and other organizations.

A short list of selected literature most relevant to the CASE topics is presented in Section 6 Bibliography and Other Research. A summary of the literature review is presented in Section 4 Analysis and Results.

3.1.2 Interviews with Manufacturers, Distributors and Mechanical Engineers

HMG developed a comprehensive questionnaire to collect information about evaporative cooling systems from manufacturers of evaporative cooling systems (specifically those that manufacture high-efficiency and hybrid units), distributors, and practicing engineers who have experience with evaporative cooling technologies.

Using the questionnaire, HMG collected information on the following topics:

- Types of EC systems
- Availability and sales channels of these types

- Relative market share of various types of EC systems
- Costs (purchase and installation) of EC systems
- Performance rating of various types of EC systems
- Water usage and controls of EC systems
- Field validation of EC system performance
- Occupant feedback on EC system operation
- Interest in stakeholder process participation

The interviews were structured in sections, and questions were tailored differently for each trade (manufacturer/ distributor/ engineer). Consequently, the questions were relevant to each interviewee, and information was gathered for each stage in the process (manufacturing, distribution, design and installation). Respondents were encouraged to give free-form answers, rather than choose from a prescribed set of answers, to elicit feedback beyond the content of the specific question. HMG chose this structure so that all relevant information could be gathered from the survey, even if a particular issue was not explicitly asked on the survey. A copy of the survey is presented in Section **Error! eference source not found.** and Section **Error! Reference source not found.** of this report.

3.1.3 Coordination with Western Cooling Challenge

The Western Cooling Challenge (WCC), established by the Western Cooling Efficiency Center (WCEC), is a voluntary competition to promote the development and use of high-efficiency and reliable evaporative cooling strategies.

The WCC is a collaborative process with industry. WCEC sets the goals and performance targets for qualifying systems. Manufacturers develop new products either based on existing products or new technologies that meet or exceed the WCC performance requirements. The WCC requires evaluation of the performance of this equipment in a third-party laboratory. Equipment that meets the WCC requirements based on the independent laboratory testing receives a ‘WCC compliant’ label and a report showing its energy efficiency.

The WCC performance requirements include energy efficiency of the unit at “annual average” and “peak” conditions, as well as volume of air delivered in various modes of operation, and water usage of the system as described in Section 4.1.6.

The challenge is open to any manufacturer that seeks to manufacture a stand-alone EC system or a hybrid EC/DX system.

HMG worked in close coordination with the WCEC to understand the performance criteria of the WCC program and the applicability of the WCC criteria to Title 24 compliance. The coordination was done through a series of conference calls and exchange of data between HMG and WCEC. The recommendations from this CASE topic, including the qualifying criteria for evaporative cooling systems and performance calculations, are based on the WCC requirements and criteria.

3.1.4 Association of Water Technologies Water Management Guidelines

A significant issue with EC systems is water usage of the equipment and the impact of water quality on system performance.

To investigate the potential impact of EC systems on water usage and water quality, HMG reviewed water management guidelines from the Association of Water Technologies (AWT). The AWT is a non-profit trade organization representing nearly 400 regional water treatment companies throughout the United States and internationally. These full-service companies specialize in the application of water treatments for industrial and commercial cooling and heating systems.

HMG then compared the water management guidelines from AWT to the WCC performance metrics for water consumption. HMG also compared the AWT guidelines to typical practices for water management in the EC products currently sold on the market and the WCC requirements for water consumption.

3.2 Simulation Tools Review

HMG reviewed the capabilities of energy simulation tools to evaluate the energy use of various evaporative cooling technologies – direct, indirect and hybrid systems. This included a review of existing algorithms in the nonresidential Alternate Calculation Method (ACM) for the 2008 Title 24 standards, the engineering manual for the DOE2.1 E simulation tool, and the reference manuals for EnergyPlus.

3.3 Energy Savings Analysis

HMG conducted energy simulation analysis using the DOE2.1E simulation engine and the 2008 ACM rules for an advanced hybrid EC/DX system. HMG chose this system since it is the only system that has met the Western Cooling Challenge criteria through independent testing as described in Section 4.1.6 of this report. The intent of HMG's simulation analysis was to understand the difference in energy use and savings (relative to a baseline system) predicted by the current modeling rules, compared with the energy use and savings claimed by manufacturers of this hybrid system.

The system was modeled first using the evaporative cooling algorithms in the 2008 Title 24 ACM, and then using a modified procedure for modeling these hybrid systems as DX systems with efficiency modeled per WCC program rules. The energy use and savings were then compared to evaluate additional savings captured using the modified procedure versus the 2008 ACM procedures.

Final energy analysis and recommendations are described in Section 4 of this report.

3.4 Stakeholder Meeting Process

All of the main approaches, assumptions, and methods of analysis used in this proposal have been presented for review at one of two public Nonresidential HVAC Stakeholder Meetings funded by the California investor-owned utilities (Pacific Gas and Electric, Southern California Edison, and Southern California Gas Company).

At each meeting, the utilities' CASE team asked for feedback on the proposed language and analysis thus far. The CASE team then sent out a summary of the meeting discussion and a summary of outstanding questions and issues.

A record of the Stakeholder Meeting presentations, summaries, and other supporting documents can be found at www.calcodes.com.

Stakeholder meetings were held on the following dates and locations:

- First HVAC Stakeholder Meeting: April 27th 2010, California Lighting Technology Center, Davis, CA
- Second HVAC Stakeholder Meeting: December 9th 2010, Webinar

4. Analysis and Results

This section describes our analysis and assumptions in detail.

4.1 Status of Evaporative Cooling Technologies

4.1.1 Types of Evaporative Cooling Technologies

This section provides an overview of the three EC technologies used for space cooling applications:

- Direct Evaporative Cooling (DEC) Systems
- Indirect Evaporative Cooling (IEC) Systems
- Hybrid Evaporative/DX Systems

DEC Systems

DEC systems cool the air by passing outdoor air over a wet medium. Water is evaporated into the incoming airstream, thereby cooling and humidifying the air. The high moisture content of the air delivered by a DEC system can cause indoor comfort issues (high humidity) and may also cause moisture damage to the building envelope. Further, there is potential for growth of mold due to high humidity. For these reasons, DEC systems have limited applications for space cooling in occupancies such as offices, retail, or warehouses where paper and fabric products may be affected by humidity. These systems are more commonly employed in industrial 'spot-cooling' applications where the humidity of the air does not impact (and in some cases may actually improve) occupants' comfort or reduce static for machinery.

DEC systems are a 'once-through' system where the supply air is 100% outdoor air treated through the evaporative process. The return air is exhausted to the outdoors and does not directly re-enter the supply stream (as is often the case in DX systems). Consequently, DEC systems move a lot of outdoor air through the space – both in terms of air volume and air speed. The high flow rate of fresh, outdoor air improves air quality. However, this high flow rate can make them incompatible with ducted designs suited for smaller airflows common to DX systems, and create uncomfortable drafts for occupants.

DEC systems are well suited for very dry climates; the dry, hot outdoor air has a large potential for cooling when it enters the evaporative medium. DEC systems do not perform as well when outdoor conditions are hot and humid since the higher humidity content of the outdoor air limits the heat transfer through evaporation of water on the evaporative medium. The cooling capacity and the cooling effectiveness of DEC systems thus decrease with higher humidity and higher outdoor wet bulb temperatures.

IEC Systems

IEC systems utilize the same sensible heat absorption principles of a DEC system, but without adding humidity to the supply air. IECs use two distinct air streams: "Working air" is directly cooled by passing through the evaporative media. The working air then extracts sensible heat from the supply air via heat exchangers (either one exchanger or an integrated series). Transferring sensible heat to this working air reduces the supply air's dry bulb temperature. The warm, humidified working air then exhausts to the outdoors without entering the conditioned space. In contrast to DEC systems, which transfer heat from sensible to latent conditions, IEC supply air actually contains less total (sensible and latent) heat than the incoming outdoor air. Humidity has not been removed, as with air conditioning, but heat has been extracted from the outdoor air. Although IEC systems typically use outdoor air for both the working and the supply air streams, they may use indoor return air for the supply air stream.

An indirect-direct system is a combination of the two types of systems above. Air first passes through an indirect system, which uses a heat exchanger to cool the air without adding humidity. The air then passes through a direct system, which further cools the air by adding humidity. Because the air was pre-cooled in the indirect stage, less humidity must be added in the direct state to attain the desired temperature. There are also systems that reverse the order of the indirect and direct stages – called direct-indirect systems.

Hybrid Systems

Hybrid cooling systems utilize an evaporative cooler as the primary system and conventional DX AC as the backup and/or for supplemental cooling. These hybrid systems are an emerging technology and manufacturer claims of energy efficiency of these systems exceeds those of other types of evaporative cooling systems.

The evaporative cooling component is usually an IEC system which cools the air without adding humidity to the supply air. When the IEC component cannot cool the air to the needed supply temperatures, the air passes through the DX coil, which cools the air to the desired temperature and addresses any latent cooling needs of the space. Since the air reaching the DX coil is significantly cooler than outdoor air at peak cooling conditions, the DX coil sees a lower cooling load, and can thus be smaller than if the DX coil were cooling outdoor air. Thus, a hybrid system can save significant energy even when the DX component is engaged. In addition, the hybrid systems allow for a range of control strategies and reuse of return and mixed air streams. Each system available in the market uses a different combination of outdoor, return, supply and mixed air streams, depending on the application of the hybrid system thus making them tailored for specific applications.

4.1.2 Efficiency of Evaporative Cooling Systems

This section describes the different efficiency metrics used for evaporative cooling systems and the differences between the definitions of efficiency in the Title 20 appliance standards and the industry.

Effectiveness for DEC and IEC Systems

The efficiency of an evaporative cooling system is defined differently than a DX system. The efficiency of a DEC and IEC system is based on the theoretical lowest temperature achievable for the supply air for a given outdoor air temperature (dry-bulb and wet-bulb). This metric, called *saturation effectiveness,*(also referred to as *effectiveness* or *saturation efficiency*), is the fraction of the difference between the outdoor dry bulb and wet bulb temperatures to which a EC can sensibly cool incoming ambient air expressed as a percentage:

$$\text{Effectiveness}\ (\varepsilon) = \left(\frac{T_{db,in} - T_{db,out}}{T_{db,in} - T_{wb,in}} \right) \times 100\%$$

Figure 2: Evaporative Cooling Saturation Effectiveness

$T_{db,in}$ refers to the dry bulb temperature of the air coming in to the evaporative cooler (typically outdoor air). $T_{db,out}$ refers to the dry bulb temperature of the air as it goes out of the evaporative cooler (the air supplied to the space). $T_{wb,in}$ refers to the wet bulb temperature of the air coming into the evaporative cooler. The denominator in the equation is called the *wet bulb depression* – it quantifies the magnitude of potential temperature change.

The dry bulb reduction capability of basic IEC systems depends on the wet-bulb depression. Most IEC systems can achieve higher effectiveness than DEC systems though the theoretical limit of evaporative temperature reduction still applies to the working air if a single evaporative medium is used.

Some IEC systems that use multiple cycles of indirect cooling can theoretically achieve supply air dry bulb temperatures lower than the outside air wet bulb temperature. In other words, systems can achieve effectiveness greater than 100%, through a system in which multiple distinct working air streams use cooled supply air from the previous working air heat exchange as incoming air. The resulting "cascading" heat exchange effect is called the Maisotsenko cycle (or "M-Cycle"), after its initial developer, Dr. Valeriy Maisotsenko. IEC systems on the market integrate this M-Cycle series of indirect cooling modules into a single "packaged" heat exchanger.

Because of the increased efficiency of IEC systems compared to DEC systems, the supply air-flow can be lower. Thus, in contrast to typical DEC systems, IEC systems have supply air flow-rates similar to those of DX units, which make ducted IEC compatible with standard AC distribution systems.

Due to the increased resistance of its multiple indirect stages, 'M-Cycle' IEC system can use more fan energy than DEC units or even comparably sized DX systems. However they still save energy compared to DX systems, due to higher system effectiveness and removal of the most energy intensive component, namely the compressor.

Hybrid System Efficiency

Defining the efficiency of hybrid systems is a tougher challenge, because of the combination of EC systems and DX systems and the various options for mixing air streams. Typically, hybrid systems are rated in terms of their effective Energy Efficiency Ratio (EER) to provide comparison with traditional DX systems and include the performance of both the EC and DX components.

Hybrid systems do not perform to the same part-load capacity and efficiency as traditional DX systems at various outdoor conditions. Indeed, manufacturers claim that hybrid systems do not suffer the same loss in efficiency at higher outdoor air temperatures as traditional DX systems. These claims however have been questioned by HVAC researchers and competitors. For the analysis of this CASE topic, HMG does not account for any performance boost for hybrid systems at peak conditions when compared with a DX-only system.

Title 20 Definition of EC System Efficiency

Evaporative coolers are regulated under Title 20 – the California Appliance Efficiency Standards. 2007 Title 20 Table D lists test methods for determining the efficiency of evaporative coolers. This table in turn refers to two ANSI/ASHRAE standards:

- ANSI/ASHRAE 133-2001 for packaged direct evaporative coolers and packaged indirect/direct evaporative coolers.
- ANSI/ASHRAE 143-2000 for packaged indirect evaporative coolers

Title 20 makes the following modifications for both test methods to make the testing more suitable to California conditions:

(A) Saturation effectiveness and total power of direct evaporative coolers, and cooling effectiveness and total power of indirect evaporative coolers, shall be measured at an airflow rate that corresponds to 0.3" external static pressure;

(B) Indoor dry bulb temperature shall be 80° F;

(C) Outdoor dry bulb temperature shall be 91° F;

(D) Outdoor wet bulb temperature shall be 69° F; and

(E) Evaporative Cooler Efficiency Ratio (ECER) shall be calculated using the following formula:
ECER = 1.08* (tin – (tdb – ε * (tdb – twb))) * Q / W

Where:

- tin = indoor dry bulb temperature from (B)
- tdb = outdoor dry bulb temperature from I
- twb = outdoor wet bulb temperature from (D)
- ε = measured saturation effectiveness divided by 100 or measured cooling effectiveness from (A)
- Q = measured air flow rate (cfm) from (A)
- W = measured total power (watts) from (A)

The ECER is a metric that is unique to California and to Title 20. It is not in use at the national level (e.g., through industry associations or through ANSI/ASHRAE).

4.1.3 Market Status of Evaporative Cooling Technologies

HMG conducted interviews with manufacturers, distributors and mechanical engineers to gauge the status of evaporative cooling technologies. In addition, HMG conducted a literature review of manufacturer literature and test reports from utility test laboratories. A short summary is provided here of the findings from this research.

Manufacturers that sell evaporative cooling systems or components in California include Aaon, Adobe Air, Champion Cooler, Coolerado Corporation, Master Chiller Inc, Munters, Phoenix Manufacturing Inc., Seeley International, Speakman CRS, Spec-air and United Metal Products.

Direct evaporative cooling systems dominate the market both in terms of sales and number of make and model numbers available. The effectiveness for these direct evaporative systems varies between 50%-85% depending on the type of evaporative medium used and the design of a given unit.

The number of manufacturers for IEC systems or hybrid EC systems is much smaller – Munters (who now owns Deschamps), Speakman CRS, and Coolerado are the major manufacturers. Of these, Speakman CRS makes systems designed for the residential and small commercial market. The other two manufacturers concentrate on commercial applications. Both Munters and Coolerado manufacture stand-alone evaporative cooling systems, as well as hybrid systems. Effectiveness of indirect systems can exceed the 100% theoretical limit of wet-bulb depression due to the multiple heat exchangers built into the newer IEC units. Manufacturers claim effectiveness up to 120% of wet-bulb depression.

Of the EC products available in the market, few systems are available 'off the shelf' or 'packaged' for sale in specified cooling capacity. The majority of products are custom designed systems that are built to the specifications provided by mechanical engineers.

For IEC and hybrid EC systems, one manufacturer – Coolerado – sells packaged IEC systems. These range from 3-6 tons of cooling capacity, and one hybrid EC/DX system at 8 ton capacity. The manufacturer claims efficiencies of EER 40+ for the range of products, based on a patented design that uses multiple heat exchangers.

Other manufacturers provide custom-built products that combine indirect or direct evaporative units with a DX coil. The cooling capacity can range from small (5 ton) to very large (excess of 100 tons) depending on the application. Efficiencies for these units are not easily available or replicable due to the custom nature of the product.

EC systems can serve a remarkably versatile range of buildings. In terms of building types where EC systems are typically installed, they range from low occupancy spaces (e.g., warehouses) and big-box retail to high occupancy or high internal gain spaces (e.g., industrial buildings and data centers). The newer hybrid EC/DX systems are being targeted as an alternative to DX rooftop units (RTU). Targeted building types include office buildings, small retail, restaurants, and other medium/large commercial buildings, in addition to the building types listed above.

The cost to a building owner for operating EC systems varies based on evaporative medium, type of EC system, and controls on system operation. Costs are usually reported as $/CFM of air delivered by the EC system, and average $3/CFM for DEC systems and $6-$9 or higher for IEC and hybrid units.

In addition EC system owners have increased water usage costs due to the use of water for evaporation as described below.

4.1.4 Water Usage of Evaporative Cooling Technologies

Water usage of EC systems is a cause of significant concern in California where water conservation measures are needed to ensure adequate supply of water to the state year-round. Since water in many hot and dry places that are suitable for use of EC systems tend to have higher mineral content, the evaporation of such water on the evaporative medium over time leaves mineral scales and deposits if the same water is recirculated over the evaporative medium. HMG asked manufacturers about the strategies employed in the EC systems to reduce water usage and deal with water quality impacts at the same time.

Impact of Water Quality on Evaporative Medium

Preliminary testing done by the Western Cooling Efficiency Center[1] on an indirect evaporative cooling unit in Davis, CA showed that without any means to control the mineral built-up and with a constant flow of water over the evaporative medium, the medium will be saturated with mineral built-up in a period equivalent to two seasons of operation in a climate such as Davis. While this is much better performance than anticipated, it nevertheless points to a need to address water quality impacts and potential costs for replacement of evaporative medium. One way to reduce accumulation of such minerals is to periodically flush the water flowing over the evaporative medium and replace with fresh water.

Water Management Strategies Commonly Employed

Most manufacturers offer water management features on their products to reduce water usage. Timed flush of the sump water is most common and perhaps the least technologically challenging method of reducing waste of water.

Some manufacturers control the sump flush using conductivity sensors that track the concentration of minerals in the water and actively manage the flush cycle to reduce frequency and quantity of water flushed from the unit and to keep the evaporative medium from scaling. A few manufacturers also actively monitor the amount of water sprayed on the evaporative medium by controlling the flow based on the need for cooling thus resulting in less water in the sump in the first place.

Another approach that some manufacturers and designers proposed was to treat the water being supplied to the EC system so that the mineral content in the water is reduced before it is used. This would result in less need for purge based on mineral build-up. It however, does add costs for treating the water.

HMG asked manufacturers for water consumption data for their products, but this data is not readily available for all systems available in the market. Average water consumption for products where such data was available ranges from 1.5-2.5 gallons/ton of cooling per hour when conductivity sensors are used. Systems that use timed sump flush may use more or less water depending on the mineral content of the water and frequency of the timed flush.

[1] http://www.etcc-ca.com/images/stories/et_summit_tues_tracks_2010/Mark_Modera_Ramin_Faramarzi.pdf

Water Savings Guidelines

HMG reviewed guidelines for water management from the Association of Water Technologies (AWT) as a point of reference for good water management practices. The AWT Green Task Force Best Practices Guidelines[2] outline the following strategies for managing water usage for technologies that use water for cooling:

- Minimizing water usage, including using non-potable makeup water where available
- Maximizing energy efficiency through maintaining clean heat-transfer surfaces
- Extending the life cycle of equipment by controlling corrosion and mechanical deterioration of materials
- Reducing carbon footprint of facilities personnel by integrating cooling water data mining into building management systems
- Favoring materials and processes friendly to the environment and operator safety

The AWT Green Task Force Best Practices Guidelines then provides three suggested options to minimize water consumption:

- Option 1 – Water System Management Program
  - Water treatment, conductivity controllers, automatic controls to adjust bleed-off
- Option 2 – Use of non-potable water
  - Harvested rainwater, storm water, pass-through cooling water etc.
  - Pre-treatment needed for water to be suitable for use with systems
- Option 3 – achieve both options

Water Usage on Site versus Water Saved at Power Plants

Regardless of the controls installed on EC systems and the reduction in water usage, these technologies nevertheless use more water onsite when compared with traditional DX systems. However, water usage on site is only one part of the overall tradeoff between water and energy in California as in the rest of the country.

A study conducted at the National Renewable Energy Laboratories[3] (NREL) evaluated water consumption at the power plants where large quantities of water are used to drive turbines or cool equipment that generates electricity. This report provides a baseline of water consumption at power plants (gallons/kWh produced) that can be compared against water usage on site from an evaporative cooling system (gallons/kWh savings). While the exact composition of power generation varies by

[2] http://www.awt.org/IndustryResources/cooling_water_management.pdf

[3] National Renewable Energy Laboratory, *Consumptive Water Use for U.S. Power Production*, Technical Report NREL/TP-550-33905, December 2003

location and source of power (gas, thermoelectric, hydroelectric, coal) the following table from the NREL report provides a high-level summary of water use for California.

State	Thermoelectric Site Power Million kWh/Yr	Hydroelectric Site Power Million kWh/Yr	Thermoelectric Site Water Gallons/kWh	Hydroelectric Site Water Gallons/kWh	Weighted Total Site Water Gallons/kWh
California	72,800	9,130	0.05	20.87	4.64

Figure 3: Excerpt from NREL Report on Water Usage in Electricity Generation

According to this NREL report, each kWh produced at the power plant on average consumes 4.64 gallons of water. This value of water consumption is much higher than the value of water consumed at site by using EC systems. The equivalent water usage savings by saving kWh on-site are presented in Section 4.3.4 of this report.

4.1.5 Limitations and Challenges in Evaluating Evaporative Cooling Technologies

HMG's research into EC systems brings into focus two related challenges that together hinder greater adoption of EC systems in the market as well as greater adoption by code bodies as prescriptive requirements.

Lack of field-verified performance of EC systems is the most significant obstacle to evaluating the performance of EC systems. Even for the newer higher-efficiency units tested under laboratory conditions, not enough information is available publicly about field performance of the same units. Manufacturers and designers often gather performance data on units installed in the field but these are one-time measurements of power consumption versus quantity, temperature and humidity of air delivered at the given site conditions. This data does provide information about the effectiveness of the unit and its capability to meet loads, but it does not provide enough data to evaluate annual energy usage across various indoor and outdoor conditions.

EC systems are rated according to their cooling capacity (CFM delivered) and their effectiveness. However, the definition of which outdoor conditions these two are to be measured at, or reported, vary depending on the standards one references. ASHRAE has two test standards – Standard 133-2008 for DEC systems and Standard 143-2000 for IEC systems. Both standards specify the test setup, measurement procedures and the wet-bulb depression at which the effectiveness of the unit is to be tested. It does not however specify the outdoor temperature and humidity conditions at which to test the units. The California Title 20 standards define Evaporative Cooler Efficiency Ratio (ECER) which uses criteria that are based on the ASHRAE standards but with some differences. While the ECER is based on the difference between indoor space temperature, outdoor dry bulb, and the outdoor wet-bulb depression, the efficiency calculation for ASHRAE is based on the intake air temperature of the unit, the outdoor dry bulb, and the wet-bulb depression. Thus, the same unit can result in two vastly different efficiency ratings, based on which standard is used to evaluate the efficiency.

Further, direct comparisons to EER of traditional AC systems are hampered by the differences in how EER is measured for AC systems vs. EC systems. While the efficiency rating for an AC system is not dependent on the space a unit serves, that is not necessarily true for EC systems. For EC systems, the presence of indoor air temperature as part of the efficiency equation brings the EC system sizing and space characteristics into play.

Due to the differences in efficiency ratings and lack of field performance data, it is difficult to conduct a direct comparison between EC systems and DX systems. Further, there are no test standards for hybrid systems that combine EC/DX systems and are the most efficient systems on the market according to manufacturer claims.

Taken together, these challenges pose a significant barrier for greater adoption of EC systems in the market and through codes and standards. One current collaboration – Western Cooling Challenge - between researchers and industry offers a potential solution to evaluating efficiency of EC systems as well as promote greater efficiency of EC systems.

4.1.6 Western Cooling Challenge

The Western Cooling Challenge (WCC) is a multiple-winner competition developed by the Western Cooling Efficiency Center (WCEC) to encourage HVAC manufacturers to develop and commercialize rooftop packaged air conditioning equipment (RTU) for dry climates that will reduce electrical demand and energy use by at least 40% compared to the Department of Energy (DOE) 2010 standards for RTUs.

The challenge encourages hybrid systems that combine indirect evaporative cooling with high efficiency DX systems. The evaporative and DX components can operate independently or together based upon outdoor temperature and humidity conditions and the cooling needs of the space.

The WCC has stringent criteria for energy efficiency and water use of these systems and each unit that participates in the challenge needs to prove its eligibility through laboratory tests conducted in third-party laboratories approved by the WCEC. For both energy and water use, the units are to be tested at two sets of outdoor environmental conditions – one a surrogate for peak design day conditions and the other a surrogate for average conditions during cooling season for the hot-dry climates in the western United States. Units that meet or exceed performance thresholds at these conditions through independent laboratory testing get the WCC certification.

The criteria and test conditions are described below and were developed so that incremental improvements to existing DX systems will not meet the performance thresholds, but the addition of commercially available add-on evaporative technologies will be able to meet the performance threshold. This was done so as to encourage major HVAC manufacturers to either develop their own solutions or partner with vendors that provide add-on evaporative units to meet the performance thresholds.

In order to qualify for the WCC, the manufacturer must demonstrate capacity to produce a minimum of 500 units per year as a way to encourage development of commercialized products rather than just a one-off prototype. Manufacturers must consider design factors such as cost-effectiveness, robustness, longevity, availability of replacement parts, accessibility for maintenance, and non-energy code compliance as a result of this requirement.

The Challenge also specifies that equipment must self-detect and communicate performance degradation, and must respond to line-voltage drop without increasing current draw on the electrical grid.

The following section describes the test conditions that are used to validate systems for the WCC and the performance thresholds they must meet.

Western Cooling Challenge Test conditions

The WCC selected three outdoor weather conditions to evaluate performance of systems that participate in the WCC. The first condition chosen was the ARI 340/360 test conditions which are to be used for establishing the nominal system cooling capacity of the hybrid cooling units. The ARI 340/360 test conditions assume that the unit operates with zero percent outside air. For many hybrid systems, this is not feasible since they are designed to provide a minimum amount of outside air at all times for both efficiency as well as operational reasons. For such systems, rated capacity is determined at ARI indoor and outdoor temperature conditions in the operating configuration used for the WCC nominal peak performance test. Rated sensible capacity is then calculated based on the temperature difference between indoor air and supply air.

The WCC peak condition represents the peak cooling conditions more appropriate for the warm regions of the western US – hot and dry – than the conditions assumed for the ARI 340/360 test. The WCC peak condition also assumes that hybrid units will be providing a minimum of 120 cfm/nominal-ton of outside air ventilation. The unit is tested at full capacity at the WCC peak conditions.

The WCC annual condition represents the average cooling season weather conditions typical in the warm regions of the western US. These annual conditions are cooler than the ARI 340/360 test conditions but are also much drier than the ARI 340/360 conditions. As with the peak condition, the unit is tested with 120 cfm/nominal-ton of outside air. Depending on the configuration of the hybrid unit being tested, the unit may operate in full capacity or at part load capacity at the WCC annual conditions.

Below are details of the three test conditions specified for the WCC:

Test Conditions/ Criteria	**ARI 340/360**	**WCC Peak**	**WCC Annual**
Outside Air Condition (Tdb°F/Twb°F)	95/75	105/73	90/64
Return Air Condition (Tdb°F/Twb°F)	78/67	78/64	78/64
Min. Outdoor Ventilation (cfm/nominal-ton)	0	120	120
External Static (in WC)	0.2-0.75	0.7	0.7
Min Filtration	NA	MERV 7	MERV 7
Operating Mode	Full Capacity	Full Capacity	Full or Part Capacity

Figure 4: WCC Test Conditions

Performance Thresholds to Qualify for WCC

The units participating in the WCC tested at the three conditions above need to meet certain performance thresholds at the WCC Peak and WCC Annual conditions in order to win the challenge.

Due to the differences in test conditions and the variations in equipment specifications, the WCC created three performance metrics:

Minimum Sensible Credited Cooling Capacity – The test protocol for the Challenge was designed to evaluate system performance while operating with 120 cfm/nominal ton outside air. For systems that have a minimum outside air fraction that exceeds 120 cfm/nominal ton, the WCC calculates a credited cooling capacity that does not count the cooling and dehumidification of additional outside air to return air conditions. This is important because it allows capacity and energy efficiency to be compared fairly between units even if they operate at different ventilation rates. If the correction were not made, the sensible capacity and energy efficiency of a system operating with 100% outside air would be misrepresented since it would include cooling of excess ventilation air.

Minimum Sensible Credited EER = Minimum Sensible Credited Cooling Capacity/ total kW. The kW includes all parasitic loads such as blowers, fans, pumps, and controls.

Total Credited EER – While this is not a qualifying criteria for the WCC, each unit that is tested for the WCC also has to report the total system EER which includes both the sensible and latent as well as ventilation cooling. The Total System EER is a metric that enables direct comparison of the hybrid units with DX units.

To address water usage of the units participating in the WCC, the performance threshold includes maximum water usage as well as maximum moisture content added to the supply air stream by the tested units at both peak and annual test conditions.

Details of the performance thresholds for the WCC peak and WCC annual conditions are below:

	WCC Peak Conditions	**WCC Annual Conditions**
Min Sensible Credited Capacity *(% sensible credited cooling at peak conditions)*	NA	80%
Min Sensible Credited EER *(kbtu/kWh)*	14	17
Max Supply Air Humidity	0.0092	0.0092
Max Water Use *(gal/ton-h)*	NA	4

Figure 5: WCC Performance Criteria

Details on the performance criteria and the equations used to calculate the performance metrics are explained in appendix **Error! Reference source not found.** of this report.

First Winner of the Western Cooling Challenge

The first system to meet and exceed the WCC criteria was announced in January 2010. Designed for small commercial applications with a nominal cooling capacity of 5-tons, the unit was tested at and by the National Renewable Energy Laboratories (NREL). The unit manufactured by the Coolerado Corporation and designed as Hybrid-1 in the WCC is now commercially available for sale as the Coolerado H-80.

Results from the NREL testing for this unit as shown in Figure 6 shows a total credited EER of 21.7 at WCC peak conditions and 29.1 at WCC Annual conditions. Initial savings estimates from the manufacturer based on these test results claim energy savings up to 60-80% compared to baseline system with SEER 13.

		Specification	Performance	Units
Peak Conditions (105°F/73°F)	Total Credited Cooling	36–360	61.7	kBtu/h
	Sensible Credited Cooling	–	56.9	kBtu/h
	Power	–	2.84	kW
	Credited EER	–	21.7	Btu/Wh
	Sensible Credited EER	≥14.0	20.1	Btu/Wh
	Outlet Humidity	≤0.0092	0.00917	–
	* Water Use	–	1.83	gal/ton·h (sensible credited)
	Water Evaporation	–	1.50	gal/ton·h (sensible credited)
Surrogate Annual Conditions (90°F/64°F)	Total Credited Cooling	–	47.7	kBtu/h
	Sensible Credited Cooling	–	45.6	kBtu/h
	Mean Power	–	1.64	kW
	Credited EER	–	29.1	Btu/Wh
	Sensible Credited EER	≥17.0	27.8	Btu/Wh
	* Water Use	≤4.0	1.84	gal/ton·h (sensible credited)
	Water Evaporation	–	1.50	gal/ton·h (sensible credited)

* NREL cannot verify through laboratory testing the unit's ability to withstand scaling caused by water evaporation. The measurements are made available in terms of water use and evaporation in the laboratory. Water use will vary in practice because of system adjustments for water quality.

Figure 6: Coolerado H-80 WCC Test Results

Source: Technical Report, NREL/TP-5500-46524, November 2010

4.2 Energy Simulation Tool Capabilities and Limitations

HMG reviewed capabilities of current simulation tools used for compliance with Title 24 as well as the new capabilities in EnergyPlus for modeling EC systems and hybrid EC/DX systems.

4.2.1 DOE 2.1-E

The DOE 2.1E simulation engine is currently the reference simulation engine for compliance with the nonresidential energy efficiency standards. DOE2.1E has built-in capabilities to model both DEC and IEC systems as stand-alone systems. DOE2.1E can also model hybrid systems where EC systems are used either as pre-cooling or in-line with DX systems.

The nonresidential ACM based on the DOE2.1E engine provides a path for modeling evaporative cooling through optional 'System 9' (§3.3.5). System 9 can either be run as a stand-alone evaporative cooling system, or evaporative cooling as pre-cooling for other systems.

Inputs needed for modeling include evaporative cooler fan capacity and brake horsepower (bhp), water pump capacity and brake horsepower (bhp), cooling capacity, and designation of system type. The ACM provides default inputs for saturation effectiveness for both direct as well as indirect evaporative processes and these can be changed by the user.

A limitation of DOE2.1E and the ACM by inference is that the saturation effectiveness of IEC systems is limited to 100%. Some of the IEC systems in the market today such as the ones using the 'M-cycle' process have effectiveness greater than 100%. These types of units are claimed to be the most efficient EC systems and the Coolerado H-80 referenced in the previous section uses the 'M-cycle' process.

Another limitation of DOE2.1E and ACM is that EC/DX hybrid system modeling assumes the indirect and DX components to be in the same airstream. This is not the case in some newer hybrid EC/DX units which have more options of mixing primary and secondary air streams as well as outdoor and return air. These systems cannot be modeled using DOE2.1E.

DOE2.1E also has no account of water usage of the EC systems and thus one cannot compare EC systems in terms of their water usage when using DOE2.1E.

4.2.2 EnergyPlus

EnergyPlus is a new simulation engine being developed with funding from the Department of Energy (DOE) and has a number of modules that deal with evaporative systems – direct, indirect and EC/DX hybrid systems.

Similar to DOE2.1E, EnergyPlus can model the saturation effectiveness of the evaporative medium, but has the ability to model effectiveness of IEC systems beyond 100%. The software can also calculate saturation effectiveness based on the thickness and area of the evaporative pad and the mass flow rate of air over the evaporative medium.

Another key advantage of EnergyPlus over DOE2.1E is its ability to model water usage of EC systems based on the evaporative medium characteristics and airflow over the medium.

EnergyPlus does have limitations in modeling some of the newer hybrid EC/DX units that have multiple options of mixing primary and secondary air streams as well as outdoor and return air streams. For example, EnergyPlus version 5 cannot place the condenser coil in the exhaust of an indirect evaporative cooler. Some EC/DX systems such as the Coolerado H-80 use variable frequency drives for the IEC fans and these cannot be directly modeled in EnergyPlus.

Another challenge with EnergyPlus is the complexity of the data input that is required for simulations. In addition to the inputs described for the EC system itself, the user must also specify all the system connections through what are known as nodes and branches in EnergyPlus. Specifying these connections can be challenging for new users and even for some experienced users.

Another issue with EnergyPlus as with the EC systems themselves is the need for validation of the algorithms against real-world data. As mentioned earlier in this report, very limited to no data is publicly available on the real-world performance of EC systems. Thus, it is not clear if there are any accuracy gains by using EnergyPlus when it comes to EC systems as compared to DOE2.1E and its known limitations.

4.2.3 Engineering Analysis

Manufacturers use custom software developed internally which are based on finite element or other first-principles modeling. These tools however are not available to designers/buyers of EC systems. These tools were also not available to the CASE team for analysis.

In absence of the availability of such tools, engineering firms often develop system sizing and efficiency guidelines based on manufacturer published data or results of calculations done by manufacturer to meet the specifications provided by the design engineer.

4.3 Energy Savings Analysis

HMG conducted energy simulation analysis of a typical hybrid EC/DX system (specifications similar to the one that is the first system to exceed the WCC criteria) using EnergyPro version 5 – the authorized compliance software for 2008 Title 24 requirements for nonresidential buildings.

4.3.1 Simulation Parameters

A prototype building model was chosen to represent a small commercial building with gross conditioned floor area of 5760 sf and 10’ ceiling height. The building has 40% window/wall area ratio and is oriented with the front of the building facing north. The simple building was chosen so that results from this small building can be scaled to larger building as needed. The building is modeled with three zones, each modeled with a packaged single zone (PSZ) cooling system with approximately 5-ton cooling capacity.

The goal of the simulation analysis was to study the impact of modeling a hybrid EC/DX system using the various options available in the DOE2.1E program and the performance metrics developed by the WCC. The following five system configurations were developed for comparison purposes.

Run#	**System Type Modeled**
1	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (85% eff) w/out Integrated Operation
2	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (85% eff) w/ Integrated Operation

3	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (100% eff) w/ Integrated Operation
4	PSZ w/ 17 EER (WCC Qualifying Criteria)
5	PSZ w/ 30 EER (Max EER allowed in EnergyPro)

Figure 7: CASE Energy Analysis System Modeling Options

The first three options are the built-in capabilities in DOE2.1E and thus EnergyPro to explicitly model evaporative cooling systems. These represent the current capabilities in the 2008 Title 24 ACM for modeling IEC/hybrid systems and show the above code performance of these systems currently modeled.

In Run#1, the system was modeled as a packaged single zone system with indirect evaporative pre-cooling using the default saturation effectiveness for the indirect evaporative medium. The system in Run#1 was modeled without integrated operation of the evaporative and DX components.

Run#2 used the same specs as Run#1 except the evaporative and DX components operated in an integral manner (both or either as needed).

Run#3 was similar to Run#2 except the saturation effectiveness was a max 100% as allowed by DOE2.1E. Thus, Run#3 defines the maximum efficiency that can be modeled for the evaporative component of the EC/DX hybrid system within DOE2.1E and the maximum efficiency and savings that can be modeled in the 2008 Title 24 compliance software.

Run#4 and Run#5 use an alternative approach to model the hybrid system based on the performance specification of the Western Cooling Challenge. In Run#4, the packages single zone system was modeled as a traditional DX system but with an EER of 17 which is analogous to the minimum performance threshold for the WCC. Run#5 models the packaged single zone system using an EER of 30 which is the highest EER allowed to be modeled by EnergyPro and which coincidently is close to the credited EER of the first winter of the WCC.

Each of the five system types were modeled in four climate zones that represent the range of cooling conditions in the state – CZ 3 (San Francisco Bay Area coastal climate), CZ12 (Sacramento – inland with some coastal breeze at night), CZ13 (inland central valley) and CZ9 (inland southern California).

Simulations were conducted using the recent weather files developed by the California Energy Commission and hourly simulation results were analyzed using 2013 TDVversion 3. Since the EnergyPro software uses the 2008 TDV values by default, the CASE team extracted hourly simulation results in CSV files and then applied the 15-yr nonresidential 2013 TDV hourly values from TDV version 3 developed by E3 for the CEC.

4.3.2 Base Simulation Results – Climate Zone 12

The five system types were initially run in CZ 12 to verify the simulation algorithms used by EnergyPro and compare simulation results. For each of the five cases, the standard design system is a PSZ with SEER 13/EER 10 as defined by Title 24 2008 and the minimum federal efficiency standards.

In each case, the proposed and standard designs were compared to develop compliance margin beyond code using both the source energy as well as TDV based on the 15-year 2013 TDV version 3.

Results as seen in Figure 8 show that Runs 1 through 3 show improved energy performance as effectiveness of the evaporative medium increases and the hybrid system operates in an integrated manner. Run#2 shows improved performance of ~3% compared to Run#1 when using the TDV metric for comparison. Similarly Run#3 shows improved performance of an additional ~1.5% over Run#2 using TDV.

Run#4 which represents the ‘floor’ of the performance expected from a system that meets the WCC requirements shows performance similar to Run#2. Run#5 which is the highest efficiency that can be modeled in EnergyPro shows a performance improvement of ~6% over Run#4 or ~10% over Run#1.

	Run#	Modeling Approach	S=Standard; P=Propo	Heating Energy	Cooling Energy	Lighting Energy	Receptacle	Fan Energy	process	total	Compliance Margin	% Improvement Total
TDV Energy	R1	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL w/OUT integrated Operation	S	0.23	19.16	8.84	13.68	8.56	9.12	59.60		
			P	0.57	9.02	8.84	13.68	10.21	9.12	51.44	8.16	13.69%
	R2	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (0.85) w/integrated Operation	S	0.23	19.16	8.84	13.68	8.56	9.12	59.60		
			P	0.57	7.10	8.84	13.68	10.21	9.12	49.52	10.08	16.91%
	R3	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (1.0) w/integrated Operation	S	0.25	19.28	8.84	13.68	8.56	9.12	59.73		
			P	0.57	6.36	8.84	13.68	10.21	9.12	48.77	10.96	18.34%
	R4	PSZ w/17 EER (WCC Annual EER target)	S	0.19	18.78	8.84	13.68	8.56	9.12	59.17		
			P	0.28	6.72	8.84	13.68	10.21	9.12	48.84	10.33	17.46%
	R5	PSZ w/30 EER (max allowable EER in EnergyPro)	S	0.19	18.78	8.84	13.68	8.56	9.12	59.17		
			P	0.28	3.05	8.84	13.68	10.21	9.12	45.17	14.00	23.66%
Source Energy	R1	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL w/OUT integrated Operation	S	0.04	2.53	1.36	2.17	1.33	1.45	8.89		
			P	0.10	0.99	1.36	2.17	1.58	1.45	7.65	1.23	13.88%
	R2	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (0.85) w/integrated Operation	S	0.04	2.53	1.36	2.17	1.33	1.45	8.89		
			P	0.10	0.77	1.36	2.17	1.58	1.45	7.44	1.45	16.30%
	R3	PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (1.0) w/integrated Operation	S	0.05	2.55	1.36	2.17	1.33	1.45	8.91		
			P	0.10	0.68	1.36	2.17	1.58	1.45	7.35	1.56	17.45%
	R4	PSZ w/17 EER and NO EVAP COOLER	S	0.04	2.48	1.36	2.17	1.33	1.45	8.82		
			P	0.05	0.72	1.36	2.17	1.58	1.45	7.34	1.48	16.79%
	R5	PSZ w/30 EER and NO EVAP COOLER	S	0.04	2.48	1.36	2.17	1.33	1.45	8.82		
			P	0.05	0.33	1.36	2.17	1.58	1.45	6.95	1.88	21.27%

Figure 8: CASE Simulation Results CZ12

Another way to look at the results from Figure 8 is that the modeling approach in Run#5 produces increased compliance margin to the order of 5% over Run#3. This represents the additional performance credit that is possible for the higher efficiency EC/DX hybrid systems that pass the WCC criteria beyond what is currently possible through the Title 24 compliance rules.

The savings for all runs 1-5 are less than the savings claimed by systems in the market that have specs modeled in each of these runs. Thus the modeling produces results that are conservative when compared to the manufacturer claims. Since there is lack of field monitored data for the systems being modeled, it is not clear if the manufacturers' claims can be validated. Thus, the conservative savings estimate is a hedge against systems not performing as advertised, but at the same time provides a performance credit to encourage more high efficiency IEC/hybrid systems to be developed and installed.

4.3.3 Simulation Results Comparison

After the initial simulation done in CZ12, the simulations for Run#3, 4 and 5 were conducted in CZ 3, 9, and 13 to gauge differences by climate zone due to the three methods of modeling hybrid EC/DX systems. Below we present results for Run#3 and Run#5 – the first represents the maximum savings currently calculated in 2008 Title 24 code for evaporative cooling systems and the second represents the added savings that can be captured by using the credited EER of the hybrid system rather than using the built-in evaporative cooling model in DOE2.1E.

Comparing the two runs provides data on the additional savings that can be captured and the added compliance credit that is to be given to qualifying IEC and hybrid EC/DX systems in the 2013 code by using the credited EER approach.

	TDV Energy Savings	
	Compliance Margin	% Improvement Total
R3	**PSZ w/EVAP PRE COOLER and INDIRECT EVAP COOL (100% Eff.) w/ Integrated Operation**	
CZ03	11.30	18.71%
CZ09	12.32	20.76%
CZ12	10.96	18.34%
CZ13	13.40	22.19%
R5	**PSZ w/30 EER (max allowable EER in EnergyPro)**	
CZ03	14.42	24.11%
CZ09	14.86	25.38%
CZ12	14.00	23.66%
CZ13	15.59	26.20%

Figure 9: Simulation Results – Comparing Run#3 and Run#5

Figure 9 shows that using the current procedures in Title 24, the maximum energy savings that can be calculated range from ~18% to ~22% depending on the climate zone. Compared to that the energy savings from the alternative approach of using credited EER results in savings between ~24% and ~26%. The difference between these two runs is shown in Figure 10 below.

TDV Energy Savings - R5 over R3		
CZ	Compliance Margin	% Improvement
CZ03	3.12	5.40%
CZ09	2.55	4.62%
CZ12	3.05	5.32%
CZ13	2.19	4.02%

Figure 10: Simulation Results – Added Compliance Margin Run#5 over Run #3

Simulation results for the four climate zones show an average increase of 4%-5% in compliance margin when modeling the system using the credited EER approach over the explicit modeling for an indirect evaporative cooling system. This increased compliance margin is in effect the compliance credit that can be given to high-efficiency hybrid EC/DX systems above and beyond what is currently already provided in Title 24 which is represented by Run#3.

4.3.4 Water Savings

Power plants in California use an average of 4.64 gallons of water per kWh generated as described in Section 4.1.4. Evaporative cooling systems on average consume 1.5-2.5 gallons/ton-hr of delivered cooling capacity. The criteria for the WCC specifies water consumption to be a maximum of 4 gallons/ton-hr at rated annual conditions.

To compare these three sets of numbers, HMG conducted the following analysis based on the simulation results for Run5.

The hourly data output for Run5 was analyzed to identify the number of hours of the year the system would operate to provide cooling to the building. It was then conservatively estimated that the system would operate at its maximum cooling capacity (15 tons total). While this is not true in reality, this was done to get the highest possible estimate of cooling capacity on an annual basis. The total annual cooling tonnage was calculated based on adding up the hourly cooling capacity.

This total annual cooling tonnage was then multiplied by the 4 gallons/ton-hr and 2.5 gallons/ton-hr respectively to get the maximum annual and average annual water consumption on site.

These numbers were then compared to the amount of water that would be saved at the power plant based on the amount of energy (kWh) saved on site. The site kWh savings were converted to source kWh savings first and then multiplied by the 4.64 gallons/kWh to derive amount of water saved at the power plant.

Figure 11 provides a summary of the three sets of values for Run 5 across the four representative climate zones. The water savings at the power plant is orders of magnitude larger than the onsite water consumption proving that EC systems will save the state both energy and water on a system-wide basis.

R5 CZ 3	**Max Annual EC System Water Usage** (Gallons)	**Average Annual EC System Water Usage** (Gallons)	**Reduced Water Consumption at Power Plant** (Gallons)
Per Prototype Building	94,500	59,063	309,666
Per square foot	16	10	54

R5 CZ 9	**Max Annual EC System Water Usage** (Gallons)	**Average Annual EC System Water Usage** (Gallons)	**Reduced Water Consumption at Power Plant** (Gallons)
Per Prototype Building	94,680	59,175	326,708
Per square foot	16	10	57

R5 CZ 12	**Max Annual EC System Water Usage** (Gallons)	**Average Annual EC System Water Usage** (Gallons)	**Reduced Water Consumption at Power Plant** (Gallons)
Per Prototype Building	97,920	61,200	304,971
Per square foot	17	11	53

R5 CZ 13	**Max Annual EC System Water Usage** (Gallons)	**Average Annual EC System Water Usage** (Gallons)	**Reduced Water Consumption at Power Plant** (Gallons)
Per Prototype Building	96,180	60,113	338,292
Per square foot	17	10	59

Figure 11: Comparison of Onsite Water Consumption versus Water Savings at Power Plant Due to Site Energy Savings

4.3.5 Proposed Code Revisions

Indirect evaporative cooling systems and hybrid HVAC systems that combine evaporative cooling technologies with DX cooling technologies and those that meet or exceed the performance criteria for the Western Cooling Challenge be given a compliance credit in the performance approach of the 2013 Title 24 code. Details on the Western Cooling Challenge criteria and calculation methods are in Appendix **Error! Reference source not found.** of this document.

The performance credit is to be given by modeling the proposed system using the following criteria:

- System Type – Packaged Single Zone (PSZ)
- System Efficiency – Total System EER per WCC test results
- System capacity – Sensible and Latent capacity per WCC test results

In addition, the CASE recommends that the compliance software allow EER values above 30 to be modeled in the software. This limitation is not inherent to the DOE2.1E engine and removing this limitation would enable appropriate modeling of systems that have total EER above 30 per WCC testing.

5. Recommended Language for the Nonresidential ACM Manual

The proposed nonresidential ACM language will be developed in coordination with the California Energy Commission (CEC) contractors who are developing the 2013 ACM. These efforts include making the ACM software neutral through the use of standard data dictionary definitions being developed by the CEC contractors instead of DOE2.1E specific keywords and calculation algorithms.

6. Bibliography and Other Research

This section lists research studies, reports, and personal communications that provide background for this research.

6.1 Experts Consulted

HMG consulted with experts at various organizations per below:

- UC Davis/WCEC – Jonathan Woolley provided critical information about the Western Cooling Challenge and assisted in understanding the calculation procedures used for the Western Cooling Challenge.
- Lawrence Berkeley National Laboratory (LBNL) – Spencer Dutton at the LBNL provided overview of the EnergyPlus modules for EC systems as well as limitations of the algorithms.
- Steven Gates – Steven Gates of James Hirsch and Associates provided inputs on the modeling of PSZ and EC systems and specifically the limitations and assumptions built into DOE2.1E on modeling performance of systems at various outdoor conditions.
- Mike Scofield – Mike Scofield of Conservation Mechanical Systems provided data on performance of EC systems in the field including spot measurements.
- James Dirkes – James Dirkes of the Building Performance Tem provided energy simulation model results for a hybrid EC/DX system using EnergyPlus for comparison with the DOE2.1E results. Mr. Dirkes also provided a ASHRAE presentation and paper on modeling procedures used to model the hybrid system in EnergyPlus and assumptions made due to limitations of the software.

6.2 Reports Reviewed

HMG reviewed the following reports and documents in support of this CASE topic:

- Woolley Jonathan, Modera Mark. Advancing Development of Hybrid Rooftop Packaged Air Conditioners: Test Protocol and Performance Criteria for the Western Cooling Challenge. ASHRAE 2011-86098.
- Woolley Jonathan. UC Davis Western Cooling Challenge Program Requirements. Western Cooling Efficiency Center, November 2010.
- Kozubal Eric, Slayzak Steven. Coolerado 5 Ton RTU Performance: Western Cooling Challenge Results. NREL Technical Report NREL/TP-5550-46524, Revised November 2010.
- Kozubal Eric, Slayzak Steven. Coolerado 5 Ton RTU Performance: Western Cooling Challenge Results. NREL Technical Report NREL/TP-550-46524, September 2009.
- Dirkes James V II, Hoffman Ryan J. Energy Simulation Results for Indirect Evaporative-Assisted DX Cooling Systems. 2011 ASHRAE Winter Conference, Las Vegas, January 2011.

- Deschamps Nick. Myths and Realities of Indirect Evaporative Cooling Systems. 2011 ASHRAE Winter Conference, Las Vegas, January 2011.
- Association of Water Technologies Water Management Guidelines http://www.awt.org/IndustryResources/cooling_water_management.pdf
- DOE 2.1E Engineering Reference Manual
- EnergyPlus Reference Manuals
- Bourassa Norman, Haves Philip, and Huang Joe. A Computer Simulation Appraisal of Nonresidential Low Energy Cooling Systems in California. LBNL, May 2002. http://buildings.lbl.gov/CEC/pubs/E4P21T1a2_LBNL-50677.pdf.
- Hunn, B.D., and J.L. Peterson. Cost-Effectiveness of Indirect Evaporative Cooling for Commercial Buildings in Texas. ASHRAE, 1996.
- Pacific Gas & Electric Company. Demonstrating and Evaluating Direct / Indirect Cooling of Large Roof Top Units: Does evaporative cooling work for big customers? Pacific Gas & Electric Company, Emerging Technologies Program. http://www.etccca.com/images/stories/results/DualCool_072805.pdf
- Davis, Robert A. Laboratory Evaluation of the Seeley Climate Wizard Indirect Evaporative Cooler. Pacific Gas & Electric Company, Emerging Technologies Program, September 30, 2009. http://www.etcc-ca.com/images/etaar0911-climatewizardeval.pdf.
- Bauman, F., E. Arens, T. Xu, H. Zhang, T. Akimoto, and K. Muira. "LBNL: The Impact of Humidity Standards on Energy Efficient Cooling in California," August 1996. http://escholarship.org/uc/item/00f102t1?query=commercial%20evaporative
- Modera Mark, Faramazi Ramin. Emerging Cooling Technologies for Residences. 2010 Emerging Technologies Summit, November 2010, Sacramento CA. http://www.etcca.com/images/stories/et_summit_tues_tracks_2010/Mark_Modera_Ramin_Faramarzi.pdf