Design & Engineering Services

Assessment of Market-Ready Evaporative Technologies for HVAC Applications

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Disclaimer

ABBREVIATIONS AND ACRONYMS

ACH	Air changes per hour
ASHRAE	American Society of Heating, Refrigeration, and Air Conditioning Engineers
ECER	Evaporative Cooling Efficiency Ratio
EER	Energy Efficiency Ratio

FIGURES

TABLES

TABLE OF CONTENTS

EXECUTIVE SUMMARY

This report compiles and summarizes current information on market-ready evaporative cooling technologies based on reviews of published literature, public agency studies and manufacturers' websites. In many cases, the published information was supplemented with interviews of manufacturers' representatives, contractors, researchers and consultants. It is intended to be a resource on the characteristics of the majority of evaporative technologies available in the market and to guide utility and public benefit demonstration opportunities for saving energy and reducing demand-side peak loads. The report focus is on high-efficiency systems that could eliminate or significantly reduce compressor-based cooling equipment in the 20-ton and under size range, primarily residential and small commercial.[1]

Basic techniques that cool the air through the evaporation of water have been used for centuries, and direct evaporative coolers have been sold in the U.S. since the 1930s. Various studies and sources cited in this report reflect the ability of modern evaporative coolers to reduce peak cooling power demand in hot dry climates by as much as 80 percent and cooling energy usage by as much as 70 percent. This impressive savings potential is coupled with a highly market-attractive non-energy benefit in many cases: a significant improvement of indoor air quality through the introduction of 100 percent outside air during cooling. However, for a variety of reasons the market penetration of evaporative coolers has remained low.

Evaporative cooling technologies accomplish all or part of comfort cooling by transferring sensible heat (hot, dry air) to latent heat (cooler, moist air) through the process of evaporating water at ambient temperatures. Evaporative cooling is particularly effective in reducing peak demand because its power demand remains constant as outside temperatures rise. The efficiency and capacity of systems also tend to increase at higher outside temperatures while standard compressor-based systems become less effective at high outside temperature. The hot, dry climates of Southern California Edison are especially well-suited to this technology group.

[1] Throughout the remainder of the report, we use "DX" to refer to compressor-based air conditioning.

TECHNOLOGY TYPES

This report considers all forms of evaporative cooling, from the simplest direct cooling to complex multi-stage systems, which may also be coupled with vapor compression air conditioning. The diagram below displays the general relationships of the primary technologies considered followed by brief descriptions of the categories.

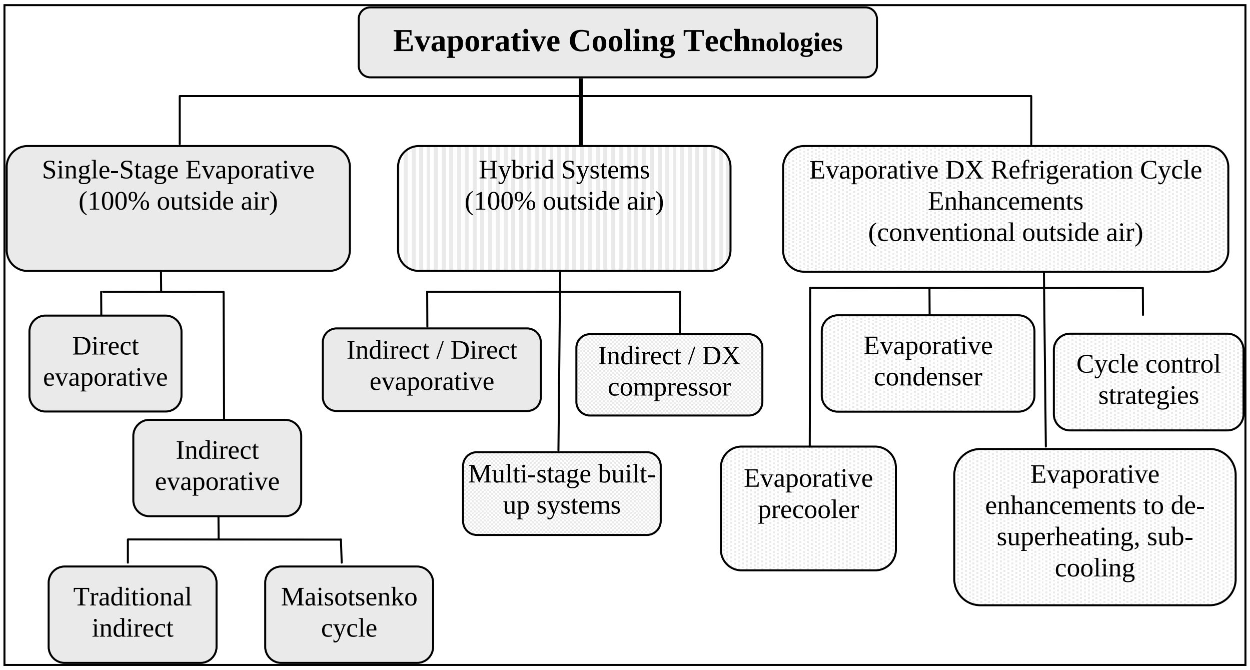

FIGURE 1: EVAPORATIVE COOLING TECHNOLOGIES - FAMILY TREE

DIRECT EVAPORATIVE COOLING

Direct evaporative cooling is the most cost effective of the evaporative modes. It is a very reasonable choice as an energy-saving add-on to a conventionally cooled house. In many climates, direct evaporative cannot achieve the ASHRAE comfort range on the hottest, most humid days of the year, so it is often used along with a DX system back-up. Thus, direct evaporative has not been seen as a means to reduce peak demand. However, time-based lock-outs might address that issue in some settings with little added discomfort.

INDIRECT EVAPORATIVE COOLING

Indirect evaporative cooling cools the supply air without adding moisture. Until recently, these units were not efficient enough to fully meet cooling needs in the residential and small commercial market. However, newer technology can achieve indoor comfort conditions that make this a viable option for completely replacing DX.

INDIRECT / DIRECT EVAPORATIVE COOLING

Staging indirect and direct cooling steps can achieve lower supply temperatures than direct only. Residential and small commercial systems of this type also have the potential for completely replacing DX. An indirect/direct combination for a larger commercial establishment is typically part of a multi-stage built-up system that incorporates a form of conventional cooling such as an evaporative condenser or chilled water system.

INDIRECT/DX-COMPRESSOR COMBINATIONS

Indirect/DX-compressor combinations are often used in larger commercial-scale applications, sometimes also coupled with a direct cooling phase. They achieve significant energy and demand savings. Until recently, these packages have not been accessible to smaller commercial buildings with packaged rooftop units. Well-designed indirect/DX applications can often achieve full cooling with no use of the high demand DX component but the latter, however, adds security through its availability to supplement or as a backup.

REFRIGERATION CYCLE ENHANCEMENTS

Refrigeration cycle enhancements such as evaporative condensers have only recently been used to displace air-cooled residential sized units of less than 5 tons. Although they do not achieve savings as high as the pure evaporative systems, they do provide clear and reliable energy and demand savings. They also have the advantage of working directly with DX system ducting and covering all peak weather conditions.

ADVANTAGES AND BARRIERS

In addition to clear energy usage and demand savings, evaporative coolers can also provide better indoor air quality. The technologies other than the refrigeration cycle enhancements of Figure 1 continually bring 100 percent outside air into the room, with several times more air changes per hour than found with DX systems. This can improve air quality both because of the continual flushing of indoor pollutants and, for direct evaporative components, because of the cleaning and filtering of outside air as it passes through the wetted media.

Given the advantages of evaporative cooling, it is reasonable to ask why the technology is not more widely used. Our interviews and review of the literature highlight the following key barriers to broader adoption of the technology.

- Perceived poor image of the products, often stemming from associations with low-cost, less effective and less aesthetically attractive “swamp coolers” of prior years. More advanced systems effectively address these issues.
- Scale accumulation from continual evaporation has been a major problem in some systems’ performance and reliability. Modern products use a variety of purge and cleaning techniques to address this issue, but the site water quality and system design must be considered during engineering.
- Water usage concerns are a primary issue for some water utilities and governments. However, the added water used by an evaporative cooler is a very small portion of

typical residential use and normally greatly offset by reduced water use due to the avoided power generation. Increased data on the water trade-offs is needed.

- Initial cost sensitivity has been a major barrier to adopting more efficient units, particularly in the smaller size ranges. However, the payback periods from energy savings may be just 1–2 years.
- Changes to ventilation design may be needed to the increased air flow rates of direct and indirect systems.
- HVAC efficiency ratings and codes do not properly address or correspond to the technology attributes.
- The technology's potential and limitations are poorly understood resulting in poor design and/or lack of proper maintenance. The field needs more unambiguously favorable demonstrations. Builders and designers need a better understanding of evaporative design. Contractors, owners, facility managers and homeowners need a better understanding of required maintenance.

TARGETED OPPORTUNITIES

Refinement of specific energy efficiency investment opportunities is beyond the scope of this report but can be assisted based on the product status, characteristics, market priorities, and savings potential described herein. The review done for this report identifies several possible opportunities and are listed below in a broad view, summarized by objective and market sector

Most evaporative cooling demonstration projects have taken place in Northern California, but the technology can perform to even greater advantage in Southern California. Some Southern California applications show the promise of completely supplanting conventional DX cooling, giving rise to a need for good southern California demonstrations, rather than the model based conjectures of regional performance. Refinement of the appropriate research, demonstration approach or incentive design is necessary as follow up work.

OPTION #1

REPLACE DX IN RESIDENTIAL NEW CONSTRUCTION

Three products on the market show the capability of being the sole cooling in new residential construction. A principal challenge with this option is to adapt the new construction market to the successful application of the technology. A good initial approach to this option may be in the form of a design competition for designers and builders leading to a field demonstration.

OPTION #2

PROMOTE ADOPTION OF ADVANCED DIRECT EVAPORATIVE IN EXISTING RESIDENTIAL

High-efficiency direct evaporative cooling is readily available in the current marketplace. At least three manufacturers are offering sleek modern designs with thermostatic controls. As an option for saving money on summer cooling, this technology could be widely and cost-effectively applied. This option would be to subsidize and/or promote the installation of qualifying equipment. To incorporate greater potential for demand reduction, lock-out controls could be placed on DX systems in demonstration houses to prevent running DX during peak demand times and to determine the demand and comfort impacts.

OPTION #3

PROMOTE ADOPTION OF EVAPORATIVE CONDENSERS IN EXISTING AND NEW RESIDENTIAL AND SMALL COMMERCIAL

The evaporative condenser is distinguished by two prominent advantages:

1) It can be applied in all cases where a conventional compressor system is used without modifying any interior air flows, and

2) If the sizing is correct, there will be little chance of failing to meet comfort conditions, and the energy and demand savings will be reasonably certain.

Currently there is one product of this type marketed at the residential scale and a larger rooftop configuration for small commercial. This option has the potential for significant advances if promoted with subsidies for qualifying equipment.

OPTION #4

INCREASE RESEARCH AND DEMONSTRATIONS FOR COMMERCIAL ROOF TOP UNITS

Evaporative cooling applications for small and mid-sized office and retail occupancies have not been widely demonstrated. Two currently marketed products are well suited for this market, and two prototypes are under development. This type of application is characterized by the need to maintain reasonably strict interior comfort conditions. In addition to providing energy and demand savings, these systems also deal effectively with the high ventilation needs of these structures during much of the year. For light commercial, proven field performance, solutions to installation and maintenance barriers, product design, production and retail costs, and market awareness and education are all areas that need additional research and demonstrations.

Any of the above opportunities could help achieve the critical mass of evidence necessary for significant advances in the use of evaporative technology.

INTRODUCTION

This report compiles and summarizes information on market-ready evaporative cooling technologies. It is intended to guide design of demonstration opportunities for saving energy and reducing demand-side peak loads in Southern California Edison territory. The report focus is on high-efficiency systems that could eliminate or significantly reduce compressor-based cooling equipment in the 20-ton and under size range, primarily residential and small commercial. We also include some discussion of larger commercial systems, to the extent that they may have potential for future scaling to smaller applications.

A broad definition of evaporative cooling technologies includes any technique that accomplishes part of comfort cooling by transferring sensible heat (hot, dry air) to latent heat (cooler, moist air) by evaporating water at ambient temperatures. Previous reports have stated that this technology could reduce cooling demand and energy in typical Central Valley cooling conditions by 70 percent (Davis Energy Group, 2002). Evaporative cooling is particularly important in its potential to reduce peak demand. Briefly, the evaporative process requires only a constant fan power as the outside temperature increases, while a conventional DX[2] system demands significantly increased power with increased outside temperatures. During peak demand intervals the difference between evaporative and DX is at its maximum.

Despite its high potential for energy and demand savings the market penetration of evaporative cooling remains low. For example, in California only 5.7 percent of the commercial sector floorspace is cooled by evaporative systems (PIER 2003).

Several authors have written thorough descriptions of general evaporative cooling technology, including Bom (1998), Kinney (2004), and Davis Energy Group (2004); those descriptions are not repeated here. (See Appendix F, Bibliography, for a more complete list of background reading.)

This report is divided into the following major sections:

- The unique airflow characteristics of evaporative cooling, as it applies to various categories of buildings.
- The major evaporative cooling technologies, including examples of currently available products.
- The benefits of evaporative cooling and the barriers (actual and perceived) to its adoption, including air quality improvement, energy and demand savings, water usage, and installation/maintenance issues.

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[2] Throughout this report, we use "DX" to refer to compressor-based air conditioning.

- A psychrometric chart perspective of the technology categories, in the context of Southern California Edison climate zones.
- Some target opportunities that could be appropriate to expanding the effective use of evaporative technologies in Southern California Edison territory.
- Appendices contain additional information and summaries, including an overall summary chart of the advantages and disadvantages of each technology category and more tables with detailed characteristics of the products discussed.

STUDY METHODOLOGY

The project began with gathering information from a review of published literature, public agency studies and manufacturers' websites. In many cases, the published information was supplemented with interviews of manufacturers' representatives, contractors, researchers and consultants[3]. These individuals are listed under Contacts in Appendix E.

Despite the report's broad definition of evaporative cooling, several technologies were removed from the scope of the investigation.

- Large-scale evaporative cooling tower technology is well known and standard engineering that does not scale easily to the under 20-ton focus of this report.
- Evaporative cooling of gas turbine generator inlet air or internal stages is not directly applicable to the report context.
- Desiccant evaporative cooling systems have the potential to extend evaporative cooling to much more humid climates. This technology is currently implemented in some east coast regions, often by companies such as Munters in large built-up systems. Although desiccant cooling could potentially apply in this report's target size range, the technology was excluded because its climate focus is typically much more humid than SCE territory.

We believe that the information here reasonably summarizes the range of advanced products and technologies available, particularly in the residential and small commercial end of the marketplace; however, the manufacturer list cannot be considered complete. In keeping with our objective, we include only a few reviews of larger engineering firms and concentrate on manufacturers selling products in the U.S.. Additional relevant information might be derived from surveys of HVAC component manufacturers, contractors and distributors, as well as study of foreign manufacturers, particularly Australian and Indian, where evaporative technology is a major and well-developed cooling mode.

[3] The products and manufacturers selected were based on the parameters of this report scope and methodology as described in this section. This work should not be misconstrued as inclusive of all equipment manufacturers, but is simply based on the selection criteria described in the document. The scope and basis were approved and authorized by SCE.

All the cited evaporative technology costs here are approximate. Most products do not have published prices, except for the most basic models distributed through retail chains. Manufacturers' prices do not include installation or distributor/contract margins, which are both significant factors of the total cost to the end consumer. Further, several of the more advanced technologies are still being developed, with no firm prices yet set.

Section 0 provides some simple ratio-based analysis to compare energy requirements of different technologies on a roughly even footing. Original analysis was not intended to be part of this effort, but manufacturers' claims and independent measurement reports were presented with a wide variety of efficiency perspectives. New measures such as a Title 20 Evaporative Cooling Efficiency Ratio (ECER) and "room capacity" have recently been introduced by others in an attempt to facilitate comparison of technologies. However, in our experience these measures did not resolve the comparability issue.

In the course of the review, we compiled a fairly lengthy bibliography of articles published on evaporative cooling in general, as well as on specific topics such as air quality impacts. (See Appendix F)

AIRFLOW CHARACTERISTICS

Evaporative cooling has distinctive characteristics for air handling and equipment types, with varying implications depending on the type of building in which it is used. This section gives a brief overview of the air distribution considerations and the applicability of different technologies for various categories of structures. The technology types are further described in Section 0. Section 0 discusses installation and maintenance considerations in more detail.

AIR DISTRIBUTION

Most evaporative cooling technologies provide 100 percent ventilation air to the conditioned spaces, introducing up to five air changes per hour (ACH). This fresh air, used as the heat transfer medium, confers a significant air quality benefit as a byproduct of the cooling process. Distribution airflows for evaporative coolers are at least double those for conventional design DX systems, and the building exhaust airflows must accommodate this greater volume. In the residential context, these higher ventilation rates often involve use of novel “house-as-duct” schemes that vent through the attic. In larger commercial systems, the channeling of the ventilation air supports energy recovery from building exhaust for an additional increase in efficiency.

Systems that are capable of fully replacing DX are particularly attractive for new construction that uses hydronic or other ductless heating. The ability to use the whole house as a duct for evaporative cooling means that no ducts at all are needed. Resulting cost reductions may offset the incremental cost of the evaporative coolers.

An efficient overall scheme for cooling should also involve bringing in cool nighttime air when possible. Evaporative units can be run at night for this purpose, although the evaporative media, and the heat exchangers in an indirect unit, do increase airflow resistance compared to an unobstructed intake fan. In an NREL field monitoring report of a residential indirect/direct system (2005), fan activity significantly added to the total cooling energy when the system was used extensively at night for pre-cooling and a separate fan was used for internal whole-house circulation. Some manufacturers are working on improved fan efficiency or media bypass options to improve this area.

BUILDING TYPES

The under-20 ton air conditioner size range that is the focus of this report is found primarily in residential and light commercial application. From the perspective of cooling systems, the residential and small commercial facilities (under 10,000 square feet) may often have similar needs. At the other end of the commercial size range, large buildings often use complex built-up HVAC systems that incorporate some type of evaporative technology at one or more stages. In between these two extremes, however, evaporative technologies are not yet in widespread use.

This report assumes the following basic characteristics of each facility category:

SINGLE FAMILY RESIDENTIAL

- No regulatory ventilation requirements
- May be subject to community covenants restricting appearance of rooftop equipment
- Probably does not have the structure in place to capture exhaust air for energy recovery.

COMMERCIAL

- Ventilation requirements for code-compliance and occupant comfort
- Packaged (smaller buildings) or built-up (larger buildings) roof-top units are typical.
- In larger buildings, ductwork often has the capacity to channel exhaust air for energy recovery

INDUSTRIAL

High ventilation requirements as a result of some or all of:

- frequent open doors
- high dust levels,
- toxic materials

The following table summarizes the type of evaporative technologies most applicable and most often used, based on these building type characteristics. Technology types are further described in Section 0.

TABLE 1: TECHNOLOGY TYPE BY BUILDING CATEGORY

<table>
<tr><th rowspan="2">Size</th><th colspan="3">Building Category</th></tr>
<tr><th>Single-Family Residential</th><th>Commercial</th><th>Industrial</th></tr>
<tr><td>Small (<10,000 sq ft)</td><td colspan="2"><u>Best evaporative technology:</u>
- Indirect and Indirect/Direct for greatest savings
- Direct for lowest first cost
- Evaporative condenser for retrofit compatible with existing DX ductwork.
<u>Current Usage:</u>
- Direct evaporative in common residential use in the southwest
- Very little current use in small office buildings with packaged RTUs</td><td rowspan="3">Best evaporative <u>technology:</u>
- Direct evaporative, for low cost and ability to deal with high outside air levels

<u>Current Usage:</u>
- Direct evaporative widely used</td></tr>
<tr><td>Medium (10,000 – 50,000 sq ft)</td><td>N/A</td><td><u>Best evaporative technology:</u>
- Packaged hybrid systems including indirect evaporative, exhaust energy recovery and economizers
- Evaporative condensers
<u>Current Usage:</u>
- Very little current use in most commercial facilities
- Some direct evaporative use in large box retail in hot, dry areas</td></tr>
<tr><td>Large (>50,000 sq ft)</td><td>N/A</td><td><u>Best evaporative technology:</u>
- Large-scale engineered built-up hybrid systems combining direct and indirect evaporative plus exhaust energy recovery and economizers
<u>Current Usage:</u>
- Built-up systems with evaporative enhancements common and well-demonstrated</td></tr>
</table>

TECHNOLOGIES

This report considers the range of evaporative cooling, from the simplest direct cooling to complex multi-stage systems, which may also be coupled with vapor compression air conditioning. The terminology introduced in Figure 2 is used for categorizing these technologies throughout the report. These technologies are described briefly below the chart and discussed further in section numbers indicated.

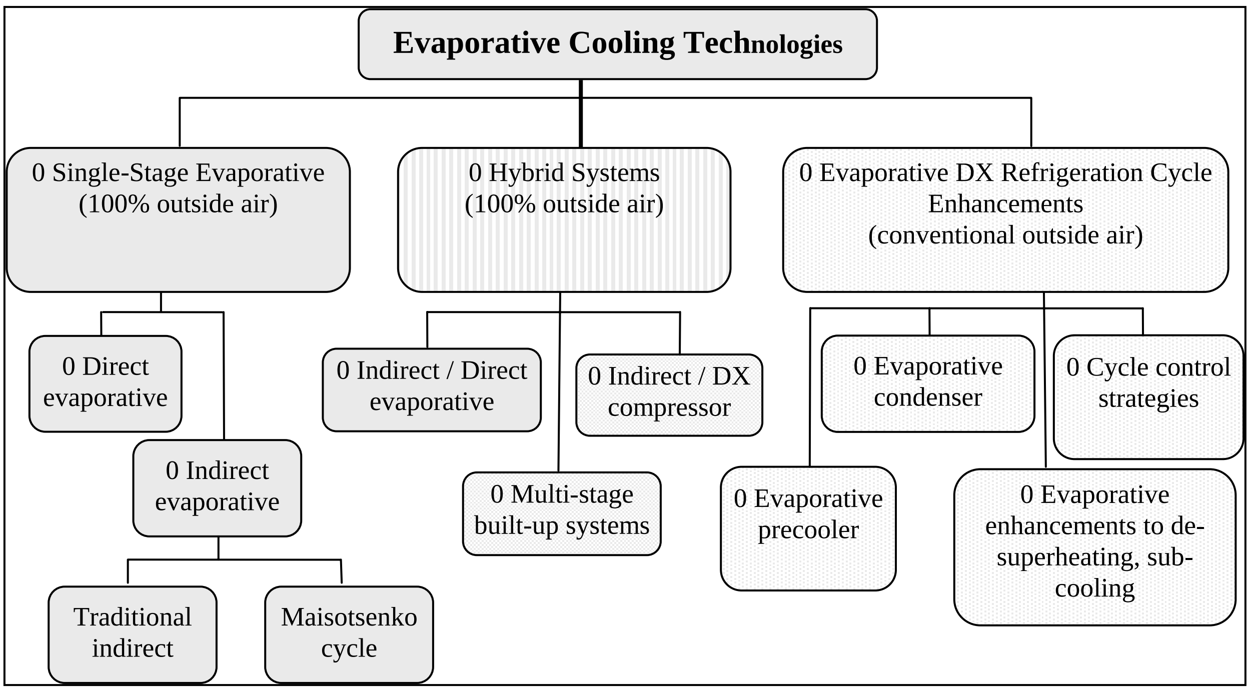

FIGURE 2: EVAPORATIVE COOLING TECHNOLOGIES.

Numbers refer to paragraphs with more detailed explanation. The darkest shading indicates systems that generate cooling only from evaporative technologies. The lightest shading represents technologies that always distribute air through the DX system.

SINGLE-STAGE EVAPORATIVE COOLING

Single-Stage Evaporative cooling works by evaporating water in the air stream, transferring sensible heat (dry bulb temperature) to latent heat (higher humidity). This process may be either of the following:

DIRECT

Direct, sending the higher humidity air directly to the conditioned space, or

INDIRECT

Indirect, using a heat exchanger to cool the supply air without adding moisture and then exhaust the humidified air.

HYBRID SYSTEMS

Hybrid Systems consist of at least one evaporative cooling stage coupled with another cooling system, which may be evaporative or DX.

INDIRECT/DIRECT SYSTEMS

Indirect/direct systems begin with an indirect stage, followed by a direct stage, resulting in more cooling than either component would accomplish alone.

MULTI-STAGE BUILT-UP SYSTEMS

Multi-stage built-up systems, typically used in large commercial applications, may incorporate both indirect and direct evaporative stages plus a DX module for extreme conditions.

INDIRECT/DX

Indirect/DX, a new packaged design currently being tested for small to medium commercial use, consists of an indirect cooler, followed when conditions require by a DX compressor stage.

DX REFRIGERATION CYCLE ENHANCEMENTS

DX refrigeration cycle enhancements rely on a DX system to deliver the conditioned air, but use evaporation to reduce the condenser load and enhance efficiency.

EVAPORATIVE PRE-COOLERS

Evaporative coolers place a direct evaporative unit in front of the condenser air intake, increasing the ability of the condenser to dissipate heat.

EVAPORATIVE CONDENSERS

Evaporative condensers cool the heated refrigerant by running it through wetted evaporator coils, which are evaporatively cooled in a strong air stream.

EVAPORATIVE ENHANCEMENTS TO DESUPERHEATING AND SUBCOOLING

Evaporative enhancements to desuperheating and subcooling use evaporation to subcool liquid refrigerant and desuperheat evaporated refrigerant.

CYCLE CONTROL STRATEGIES

Cycle control strategies increase the evaporation of condensate on the evaporator coil through more frequent on/off cycling.

Almost everything commonly considered “evaporative cooling” falls in the Single-Stage Evaporative or Hybrid categories.

Each of these basic technologies is discussed in more detail below, including some examples of currently available products. Section 5.2 discusses the savings potential of these technologies, and Section 6 gives a psychrometric view in the context of the SCE territory.

SINGLE-STAGE EVAPORATIVE

The technologies of these two basic types of evaporative systems can be used on their own (typically in residential applications) or incorporated into the more complex systems discussed later.

DIRECT EVAPORATIVE SYSTEMS

Direct evaporative cooling is the simplest and lowest cost of the evaporative modes. It is a very reasonable choice as an energy-saving add-on to a conventionally cooled house and in many industrial settings. This cooling method is far less effective at wet bulb temperatures greater than 70° F, which are usually associated with utility peak demand. Thus, if a back-up DX system is also used, direct evaporative will give minimal peak demand savings at design cooling conditions.

Standard direct evaporative cooling in residential sizes uses evaporative media made of shredded aspen fibers, about 1-2 inches thick. This traditional medium typically leads to an effectiveness[4] of about 55-70 percent, is inexpensive, and functions reasonably well. (At least one manufacturer is producing a newer aspen pad, currently being tested, that is claimed to be at least 80 percent efficient.) Standard direct evaporative coolers at the residential scale cost less than $500 and can supply up to 65 percent of the typical annual residential cooling load. While the standard models can save significant energy, advanced direct evaporative models can deliver a slightly lower dry bulb temperature.

Advanced direct evaporative coolers use a rigid evaporative medium about 8-12 inches thick, with effectiveness in the 80-90 percent range, resulting in a lower delivered temperature. Although more expensive, this medium leads to a lower profile and sleeker looking design, as well as the enhanced effectiveness. Thus, advanced units typically have the advantages of increased comfort and a more attractive appearance. Because this project focused on high-efficiency models, standard models are not discussed further.

The advanced units typically cost less than $1,000. However, they can still give unsatisfactory cooling in extreme muggy periods when the wet bulb temperature is higher than 70° F, and DX cooling will be used as backup. Most manufacturers offer their advanced units to be used in this way, as a complement to a conventional system.

[4] "Effectiveness" expresses how well the cooling medium succeeds in reducing the dry bulb temperature of the air toward the initial wet bulb temperature. For example, if the initial difference between dry and wet bulb temperature is 30° and the cooler reduces the dry bulb temperature by 20°, its effectiveness is 67 percent. Variations of this term used in the literature include "saturation efficiency," "wet bulb effectiveness," and others.

The larger manufacturers see the need to offer an advanced, thermostat-controlled, unobtrusive unit as a feature in new construction and in high-end retrofits. This offers the homeowner a valued option for cooling energy savings.

Direct evaporative cooling has been available for decades, and most residential evaporative cooler sales are of this type. A partial listing of the advanced products of this type is given in Table 2.

TABLE 2: DIRECT EVAPORATIVE PRODUCTS

Manufacturer/Brand	Standard Residential Scale	Advanced/ Built-in Residential	Commercial Scale
Adobe	Several models 1500-4000 cfm	MasterCool 2976-4000 cfm @ 0.3” MasterComfort new for 2006	
Champion / Essick / Tradewinds	Several models	Champion UltraCool and Essick ComfortCool 2000–5000 cfm	
Seeley Int’l / Breezeair	Several models	Elite Series 3010 4980 cfm @ 0.3”	RPB Series 19,000-38,000 cfm
Phoenix Manufacturing Inc. (PMI)	Several models	AeroCool Pro 2623–3850 cfm @ 0.3”	
Champion / Spec-Air			GL ACER to 22,000 cfm

INDIRECT EVAPORATIVE SYSTEMS

Indirect coolers use a heat exchanger to transfer heat from the warm incoming air to segregated, evaporatively-cooled air. The latter is exhausted without entering the indoor space. As temperatures rise, indirect evaporative cooling shows its unique ability to cool significant volumes of fresh ventilation air without increasing demand and while also keeping the water content of the indoor air constant. This de-couples the required cooling ventilation energy from the outdoor temperature, saving both demand and energy. The energy savings can exceed 70 percent where high ventilation rates are required, as in Title 24[5] or from general air quality concerns.

Indirect evaporative products currently on the market are of two basic types. The *traditional type* uses a standard plate-type heat exchanger and can reduce the dry bulb temperature with a wet bulb effectiveness of about 75 percent. In most cases, this traditional indirect evaporative cooling is the first part of a two-stage indirect/direct evaporative process, which is discussed further in Section 0. Pure indirect evaporative cooling may also be used for specialty applications such as large kitchen and industrial use. Commercial scale applications are characterized by the need for much higher air flow and

[5] For example, Title 24 requires minimum ventilation of 150 cfm/1000 sq ft for an office with typical occupancy.

often by ductwork that can capture exhaust air for additional heat exchange before it is released. While commercial scale indirect units can be used on their own, they are often found in larger specially engineered package systems, such as those from Spec-Aire.

The *second type* of indirect cooler uses a more complex heat exchanger, involving multiple indirect heat exchange steps. Currently available products using this technology fall in the residential to light commercial range. They are based on the Maisotsenko cycle, which uses a staged, cross-flow channeling system to cool air incrementally. The process can theoretically reduce the dry bulb temperature with an effectiveness of 100 percent or more. In a complex heat exchange, the limiting "best achievable" outlet temperature becomes the dewpoint temperature, typically about 10° to 15°F lower than the wet bulb temperature.[6] (Wicker, 2003) According to the manufacturer, a Maisotsenko unit was tested by an independent lab at low air flow rates, showing a wet bulb effectiveness of 120 percent. At more typical flow rates, a 2006 PG&E evaluation showed 85-95 percent effectiveness. This level potentially makes the indirect unit sufficient without further supplementation.

This unit has the best heat exchange performance seen for indirect evaporative coolers, but the increased performance comes at the price of a high pressure drop through the exchanger, more than twice the pressure drop through a "standard" heat exchanger. Higher fan power has been needed as a result. A residential scale unit currently has a fan of 1200-1800 watts. The manufacturer states that recent refinements to this unit have reduced the fan power to a more typical 750 watts, but performance testing for this latest configuration is not yet available.

The Coolerado is the one product in the current market that uses a Maisotsenko cycle-based heat exchanger alone. This manufacturer estimates that a very well-executed indirect evaporative cooler will be able to handle the full residential cooling load in all but the coastal regions of California. The product offering is straightforward cooling only, intended as an add-on or as original equipment in new construction. When the cooler can handle the full load without the need for a backup compressor system, the purchase and installation cost in new construction can be comparable to a conventional cooling installation.

Some currently available indirect evaporative cooling products are shown in Table 3. Several of the commercial manufacturers who make hybrid systems shown later in Table 4 also make optional indirect-only units. They have not been repeated here.

TABLE 3: INDIRECT EVAPORATIVE PRODUCTS

Manufacturer / Brand	Residential Scale	Commercial Scale
Coolerado	R400 and R600 1,000 – 1,500 cfm @ .4"	
Spec Air		Stage II 2,000 – 77,000 cfm

[6] See Section 0 for a psychrometric view of this process.

HYBRID SYSTEMS

The hybrid category includes all systems that combine cooling from at least two different categories, ranging from the pure-evaporative indirect/direct system to complex systems with many stages.

INDIRECT / DIRECT EVAPORATIVE

This two-stage evaporative cooling uses an indirect cooler to pre-cool the incoming air, which then passes to a direct evaporative cooling stage. The direct stage adds water to the air, but the system can still fully achieve the comfort conditions in areas of low humidity.

RESIDENTIAL

Most recent product development has been directed at the residential sector, which may also be applicable to some small office buildings.

Adobe Air has sold an indirect add-on module for their direct evaporative coolers for the last 17 years, although it is not a major part of their market. The design is modular, allowing up to four modules to be stacked together. Indirect-stage efficiencies for single-inlet units range from 40-55 percent, depending on static pressure and the sizing of the direct evaporative model to which it is attached. This indirect module permits additional reduction of the direct unit's supply temperature by up to 5°F, depending on weather conditions. The unit costs nearly as much as the direct evaporative cooler to which it would be attached. In the residential size range, this approach has not generally been seen as cost effective. This indirect module is not compatible with the company's newest MasterComfort series of direct evaporative coolers.

Speakman/OASys, offers a packaged indirect/direct unit, which has been monitored on a whole-house ducted system, as well as some other residential, office, and classroom settings beginning in 2004. (e.g. NREL, 2005; Bisbee, 2005; Davis Energy Group, 2005) A refined OASys, designed for better fan efficiency and easier maintenance access, is scheduled to be monitored in 2006 in the PG&E test facility.

Another manufacturer, Essick, is beta testing an indirect module to add to one of their residential-sized direct evaporative unit. This module was developed by Spec Air, an affiliated company in the Champion Cooler group. Using their 20 years of experience with high-end commercial built-up systems, Spec Air has scaled this technology to residential size. To balance performance and price/marketability considerations in the residential market, the indirect efficiency will not be quite as high as that of Spec Air's large commercial line. The new product is expected on the market soon and is included here because it is likely to provide a good example of new residential/light commercial possibilities using the indirect/direct approach.

COMMERCIAL

The indirect/direct combination for larger commercial establishments is typically part of multi-stage built-up systems described in the following section.

Some currently available Indirect/Direct products are shown in Table 4, at the end of the discussion of all the hybrid technology varieties.

MULTI-STAGE BUILT-UP SYSTEMS

Many large-scale and engineered systems use a hybrid approach involving multiple components, often including both indirect and direct evaporative cooling as well as a conventional cooling module. The “conventional model” is often an evaporative condenser (see Section 0) or chilled water system. Some built-up systems in educational or medical facilities that serve cooling loads of several hundred tons have met 100 percent of the cooling load without the need for any DX cooling (Costa, 2005; DEG, 2002). In the larger engineered systems, the package units are usually designed to recover cooling from the exhaust air, which significantly lowers the ventilation cooling load. These larger systems often use heat pipe or heat wheel heat exchangers. It is interesting to note that the use of the three techniques together–exhaust air heat recovery, indirect evaporative cooling and direct evaporative cooling–may meet the full cooling load and provide 100 percent outside air, even without any of those individual components being exceptionally efficient.

Spec Air offers a 7.5-ton rooftop unit including integrated gas heat that would be particularly applicable in small- to medium-scale commercial construction. This is the smallest of the units to include benefits of heat recovery from the building exhaust air.

INDIRECT / DX

A totally different hybrid approach is used by the Desert Aire CoolAire unit. The core of this unit is an indirect evaporative cooler using a Maisotsenko heat exchanger. It is packaged with an efficient economizer plus a DX cycle that can be used when necessary to get the last 10° or so of cooling in the supply air. The purge air stream, which is cooler than outside air, is channeled across the compressor/condenser, to further enhance efficiency.

In many climates the unit should perform well as an indirect evaporative cooler, without recourse to the compressor stage. The compressor stage adds the capability to work with higher internal gains and in more humid regions. The intended application for this unit is as a rooftop package unit serving small- to medium-scale commercial loads. The current beta test units include a gas pack for heating. This unit is not currently on the market, but it is a promising approach and illustrates the diversity of hybrid evaporative approaches.

Table 4 gives a partial listing of manufacturers for the various categories of hybrid equipment. As large engineered systems were not the primary focus of this study, it is likely that there are several more suppliers in this category than the examples shown here.

TABLE 4: HYBRID SYSTEMS

Manufacturer / Brand (technology type)	Residential Scale	Commercial Scale Packaged	Commercial Scale Engineered
OASys (IDEC)	1350-1650 cfm		
Champion / Essick (IDEC[7])	Beta-test model To about 4,000 cfm		
AdobeAir ICM (IDEC)	1,500 – 4,000 cfm		
Spec Air (multi-stage)		ACER 2,400 – 25,000 cfm	Spec and Spectrum series To 250,000 cfm
Des Champs (multi-stage)		EPX 2,000 – 10,000 cfm Oasis 5,000 – 60,000 cfm	
McQuay / RoofPak (multi-stage)		30-100 ton	
Desert Aire / CoolAire (indirect / DX)		Prototype 1800 cfm	

[7] Indirect Evaporative Cooler (IDEC)

EVAPORATIVE DX REFRIGERATION CYCLE ENHANCEMENTS

This section lists a number of technologies that use evaporation to enhance various stages of a traditional DX cycle. These technologies only enhance, never replace, the underlying DX system, which is a key distinction with the previous sections. By providing all cooling through the DX system, these systems require no change in DX ductwork or air flow patterns. As another consequence, these systems do not bring in the additional fresh air associated with direct and indirect evaporative cooling. Thus, they may be the best efficiency choice in situations of heavily polluted or extremely humid outdoor air.

In large-scale systems, evaporative refrigeration enhancements are the established industry standard, where they often take the form of wet cooling towers to lower the refrigerant condensation temperature. Methods of wet cooling the condenser have only recently been designed for smaller and residential systems.

Figure 3 gives an overview of the points in the condenser/compressor cycle where the various refrigeration cycle enhancement technologies have their effect.

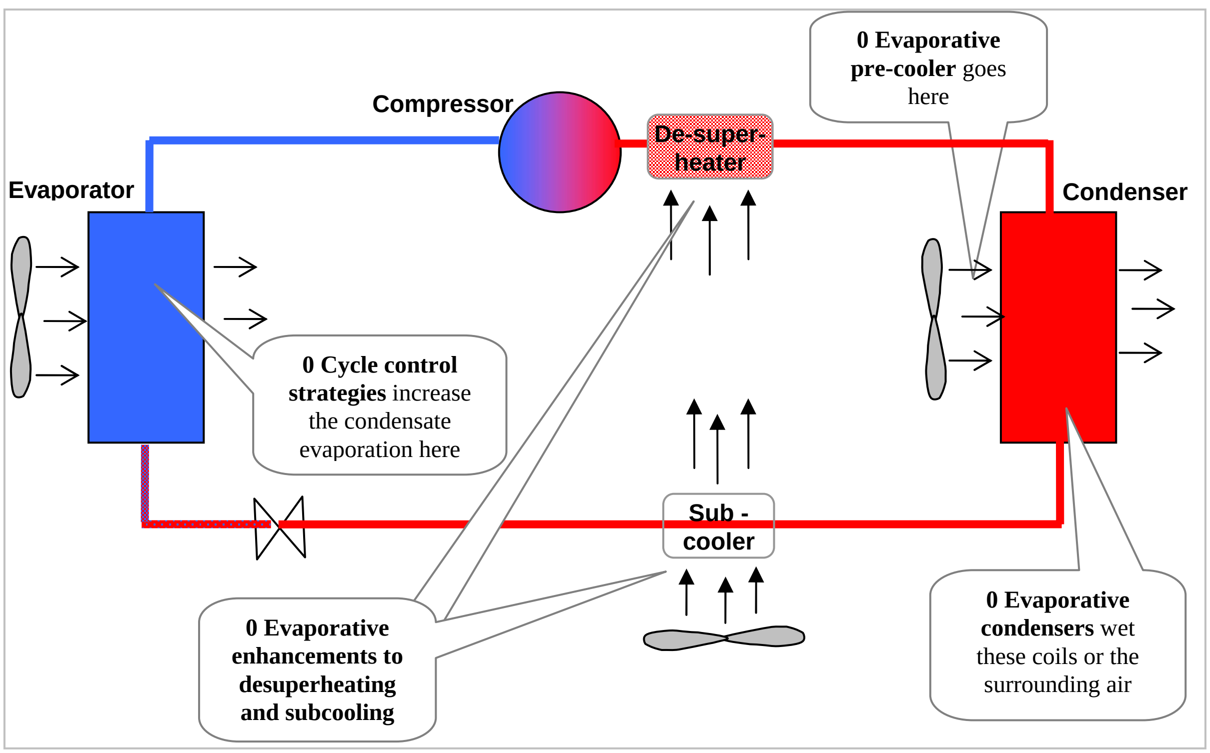

FIGURE 3: DX REFRIGERATION CYCLE ENHANCEMENTS USE EVAPORATIVE COOLING TO REDUCE CONDENSER LOAD AT VARIOUS STAGES OF THE TYPICAL DX CYCLE.

EVAPORATIVE PRE-COOLERS

Evaporative pre-coolers are sold as a relatively simple add-on module to commercial DX units. Typically made to order to fit the DX condenser air intake, they can be used at any size, although manufacturer discussions indicate they are primarily sold for units of 40 tons or more. Their flat rectangular style makes their use problematic for residential air conditioners, which may have rounded corners and air intake on multiple sides. Evaporative pre-cooling is a particular advantage as ambient air temperatures rise, offsetting the DX efficiency decrease that would otherwise occur under those conditions. A PG&E PIER study (1999) showed a 24 percent increase in EER at maximum test conditions (115° T_d/ 75° T_w) and a 7 percent EER increase at 82° T_d/ 65° T_w.

Some currently available evaporative pre-coolers are shown in Table 5, at the end of the discussion of all the varieties of DX refrigeration cycle enhancements.

EVAPORATIVE CONDENSERS

Evaporative condensers have only recently been used to displace air-cooled residential sized units of less than 5 tons, with the Freus unit being the primary current example. Because residential units are typically air cooled, the evaporative cooling improvement adds significant compressor efficiency gains, particularly at peak outdoor temperatures above 100°F. The Freus is a third-generation product that increases the efficiency of a compressor-based system on the order of 50 percent at higher temperatures. In essence this technology decouples the system demand from the outdoor temperature creating a clear and reliable demand savings.

EVAPORATIVE ENHANCEMENTS TO DE-SUPERHEATING AND SUB-COOLING

De-superheating and sub-cooling provide another approach to evaporative refrigeration enhancements, with an add-on module currently available through Global Energy Group's EER+. This technology is most cost effective for commercial units with outputs exceeding 10 tons. The EER+ enhances the cooling output of the evaporator by sub-cooling the refrigerant as it exits the condenser. The system also de-superheats the refrigerant as it exits the compressor, leading to a reduction in operating pressure and a slight (less than 5 percent) reduction in demand. Most of the energy saving comes from the increased system output. Monitoring of this technology has shown energy savings on the order of 15-20 percent (Armstrong, et al. [PNNL], 2006).

EER+ technology involves quite small direct evaporative coolers applied just to cooling key portions of the refrigerant loop. The evaporative cooling load is so small that the condensation from the treated unit can constitute the entire water source. *Unlike all other evaporative technologies reviewed, this application is self-contained with respect to water; it needs no external water supply.* Notably, the EER+ provides the greatest savings when applied to older DX technology. The older, lower EER units had generally undersized evaporators. These respond favorably to sub-cooling because it allows the evaporator to fill completely with refrigerant in the liquid state. Without the sub-cooling, a spotty mixture of liquid and gas may come from a condenser that had not fully condensed the refrigerant. Newer, higher efficiency DX units achieve the higher efficiency by increasing the size of the evaporator and eliminating this problem. Nevertheless, many older units in the 10-plus ton size would respond favorably to this type of treatment. Most of these older units use the refrigerant R22, which is still available but is being phased out. According to the manufacturer, replacement refrigerants R407C and R410A can be used as non-ozone-depleting substitutions.

CYCLE CONTROL STRATEGIES

Cycle control strategies comprise the fourth approach to refrigeration cycle evaporative enhancements. This control method involves turning the refrigerant cycle on and off, with on/off cycles of 2-6 minutes, while leaving the fan on the entire time. Some water condenses on the evaporator during the on cycle; during the off-cycle this small amount of water is evaporated, cooling the air. This strategy is in essence reclaiming the condensation (latent) cooling and converting it to air (sensible) cooling.

The tests of this control approach on the Freus showed that during the off cycles the evaporation did pre-cool the condenser, leading to increases in EER of 7-27 percent. (NREL, 2006) There may be a concern that short-cycling a compressor could shorten its life through intermittent lubrication or through insulation degradation from repeated in-rush currents during the frequent starts. This is a unique compressor design issue that may be tolerable in some compressors. The PG&E test facility plans to test a Freus unit in this control mode in 2006.

A partial list of manufacturers with these various types of evaporative DX refrigeration cycle enhancements is given in Table 5.

TABLE 5: EVAPORATIVE DX REFRIGERATION CYCLE ENHANCEMENT PRODUCTS

Manufacturer/Brand (technology type)	**Residential Scale**	**Commercial Scale**
Metal Form Manufacturing / Energy Saver (evaporative pre-cooler)		All sizes
Premier Industries (evaporative pre-cooler)		All sizes
Freus (evaporative condenser)	3.5 – 10 tons (1 – 3 units)	Rooftop gas/electric package to 6 tons;
Global Energy Group / EER+ (de-superheater & sub-cooler)		To 100 tons
Engineered systems (various technologies)		Any size

BENEFITS AND BARRIERS

AIR QUALITY BENEFITS

Evaporative cooling continually brings in 100 percent outside air, typically with five or more air changes per hour (ACH). This process can improve indoor air quality, both because of the continual flushing of indoor pollutants and because of the cleaning and filtering of outside air as it passes through the wetted media.[8] A high level of outside air is demanded by hospitals, schools, laboratories and other venues that need constant ventilation or see the increased health benefits of improved air quality. With evaporative cooling, the fresh air is a natural byproduct of the cooling process, not something that requires even more cooling energy.

In contrast to the five ACH of evaporative systems, a conventional DX system might admit only about one ACH. Conventional systems can meet added ventilation-induced load only with a major expenditure of energy input. At higher outside temperatures (above 90°F) the DX cooling load due to ventilation alone can be more than half the total cooling load. In short, compressor-based systems seek to avoid high ventilation rates and encourage closed spaces, while the evaporative systems lead to much better ventilated spaces.

Several studies have sought to quantify the cleansing effect of evaporative coolers. For example,

- A Davis Energy Group study (2005) of re-locatable classrooms in California compared evaporative coolers to compressor air conditioners. They found that the evaporative coolers saved energy while also producing lower CO_2 concentrations, lower average particulate matter (although some peaks were higher) and lower formaldehyde and other VOC levels (although these were also sensitive to indoor activities and building materials).
- Articles by Paschold and Li (2003) found that El Paso residences with direct evaporative coolers had on average 35-40 percent lower indoor particulate matter concentrations.
- Seeley International has certified its Breezair direct evaporative cooler under German indoor air quality standards (VDI hygienic standard for ventilation systems). When

[8] The washing effects of passing through a wetted medium arise only from coolers that have a direct evaporative component. Indirect-only evaporative cooling will still, however, have air quality benefits from the greater volume of fresh air, combined with whatever intake filters are used.

the unit was run with its automatic drying cycle of 60 minutes/day, they found removal of 53 percent of all airborne bacteria and 25 percent of all endotoxins.

Title 24 and ASHRAE Standard 62R for indoor air quality require ventilation rates that, with no other changes, could be higher than normally used with DX systems. A 1997 article by Scofield & Bergman gives examples of how two-stage evaporative cooling can meet or exceed the ventilation standards in hot, dry regions while also *reducing* total energy costs.

There have been occasional questions about whether evaporative coolers might increase the risk of *Legionella*, because spread of that disease was noted in a few cases of building air distribution or water heating. However, we found no published evidence of *Legionella* being clearly linked to an evaporative cooler. Direct evaporative coolers do not typically spray large aerosol droplets, the vehicle for transferring the bacteria, into the room air. In addition, the water on the evaporative pads is generally fairly cool, not at a temperature that would foster bacteria growth. With other evaporative technologies (indirect and evaporative condensers), none of the evaporatively cooled air enters the room, further preventing the transfer of bacteria from the evaporative media.

In most direct evaporative applications, the increased intake of filtered outside air is an advantage. However, in extreme cases of central urban or industrial locations, evaporative cooling may not be appropriate from an indoor air quality perspective if the outside air cannot be adequately cleansed.

SAVINGS POTENTIAL

The hot dry climate of the SCE region is particularly well-suited to achieving both energy and demand savings from evaporative cooling.[9] The best current systems appear capable of reducing peak demand up to 80 percent and energy usage by 70 percent or more, in comparison to traditional DX cooling. With respect to the energy savings, although it is difficult to calculate a truly comparable EER across these widely varied technologies,[10] estimated EERs for evaporative coolers can be in the range of 20 – 40, as opposed to typical DX systems in the 11 – 13 range.

Although the summary in this report is from limited available studies and generalized assumptions, the savings opportunities, even if deeply discounted, are compelling. In addition, the secondary comfort benefits from these systems can often be a prime driver for decision makers.

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[9] See Section 0 for a psychrometric view.

[10] Efficiency measures are discussed further in the section on Comparison Methods, beginning on page 27.

PEAK DEMAND REDUCTION

A profoundly useful aspect of evaporative cooling is that the cooling load can be satisfied by a *constant* electric demand, even as outdoor temperatures rise. By comparison, the electrical demand of an air-cooled DX system increases dramatically at higher temperatures. Compressor-based cooling becomes less efficient as temperatures rise because the condenser is rejecting heat to warmer surroundings and because the ventilation air needs to be further cooled. This leads to higher demand from DX systems because they are typically somewhat over-sizing to provide good cooling performance at the higher temperatures.

Figure 4 shows a demand comparison under peak conditions for a typical DX unit (assumed EER 10), an indirect/direct evaporative cooler, and an evaporative condenser. The evaporative condenser, which uses evaporation to increase the efficiency of the DX condenser, reduces the power demand by about 40 percent, and the indirect/direct cooler reduces the demand by 80 percent, resulting in a constant load during an otherwise "peak" period.

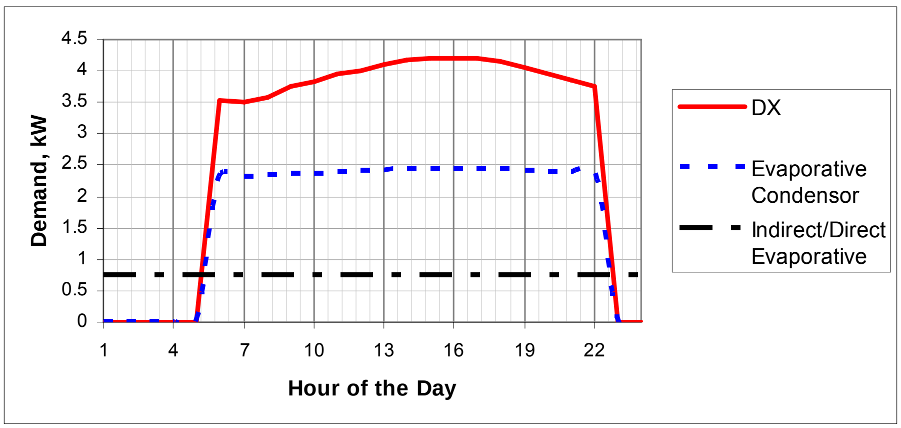

FIGURE 4: DX AND EVAPORATIVE DEMAND FOR COMPARABLE LOAD DURING PEAK DAY. ***SOURCE: BASED ON MONITORING DATA FROM DAVIS ENERGY GROUP (1998B), ASSUMING A PEAK TEMPERATURE OF 108°F***

ENERGY SAVINGS

Expected energy savings from the reviewed technologies can range from 20 percent for sub-cooling and de-superheating enhancements to 70 percent for indirect and IDEC technologies. For these approximations, we developed a simple "common sense" comparison, using the limited number of good whole-building monitoring or modeling studies available. These studies were primarily done in the residential context, and additional studies are needed for more rigorous conclusions: to reflect a wider variety of occupancy categories and climates, to confirm initial study results, and to monitor experience as new equipment ages. However, the general magnitude of these preliminary conclusions should still be reliable.

COMBINED DEMAND AND ENERGY COMPARISONS

Figure 5 summarizes the estimates for both energy savings and peak demand reduction.

- The greatest reduction in both energy and demand is associated with indirect, and indirect/direct evaporative cooling. That is because the most efficient systems appear capable of totally replacing DX in hot dry climates. The greatest energy savings also favor this group.
- Direct evaporative cooling also shows energy savings of about 65 percent, but no demand savings. Because direct evaporative cannot achieve the standard comfort conditions at the worst times of the summer, back up DX is still assumed to be used at peak times. Time-based lock-outs might address this issue with little added discomfort in some settings.
- The evaporative condenser has peak demand and energy savings of about 40 percent. As a modification to a DX unit, this technology has the ability to be implemented without altering the interior airflow.
- The indirect/DX combination can eliminate need for the DX unit during much of the year, so it shows more energy reduction than the evaporative condenser. However, it shows less peak demand reduction than the evaporative condenser because both the indirect and DX components run during the hottest times.
- The evaporative enhancements to de-superheating and sub-cooling offer significant energy savings, primarily when applied to older, less efficient equipment. However, there is little peak demand saving, because the DX unit is still working at its maximum in extreme conditions.

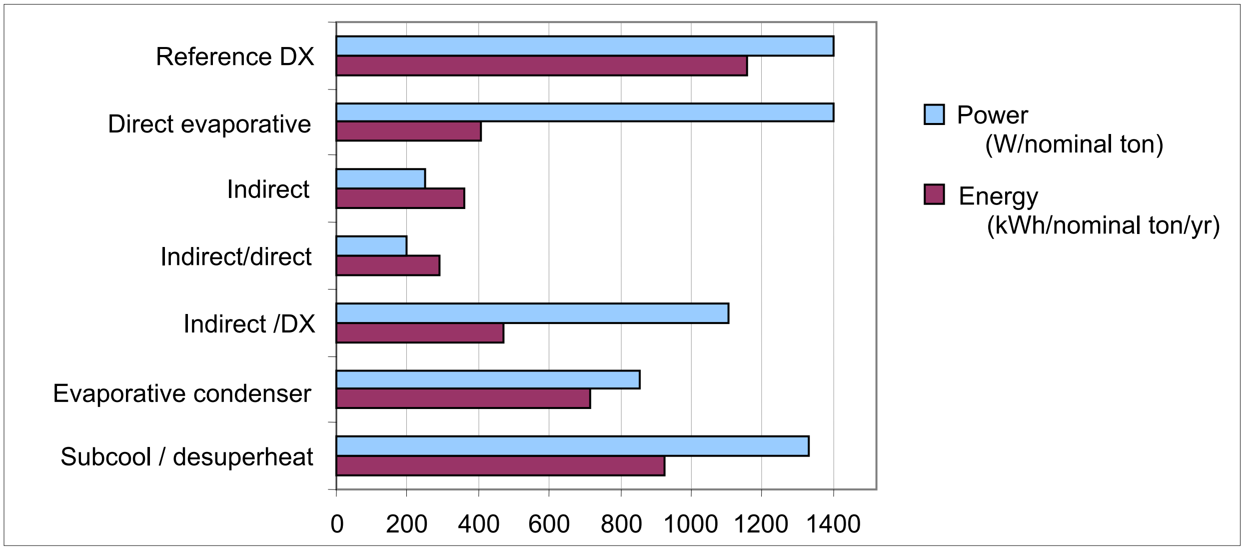

FIGURE 5: APPROXIMATE PEAK DEMAND AND ENERGY USE BY TECHNOLOGY

Table 6 shows the numbers on which the above graph is based. The comparisons proceed from limited and very generalized assumptions, which are described further in Appendix C. Despite the limited precision, the results should be reasonable approximations to the very significant performance levels for the different cooling technologies. Note that this summary still does not reflect the secondary comfort differences between the systems related to increased ventilation, nor does it contain any of the standard air conditioner metrics such as EER. The following section discusses the limitations of available metrics.

TABLE 6: COMPARISON OF DEMAND AND ENERGY IMPACTS

	Whole House (3 ton DX or equivalent)			**Savings Per Nominal Ton DX Displaced**			
Technology	**Power @ 80°F, kW**	**Power @ 110 °F, kW**	**Annual Cooling Energy, kWh/yr**	**Peak Demand Offset kW/ nominal ton**		**Annual Energy Savings kWh/ nominal ton yr**	
1. Reference (3 nominal tons)	3.64	4.25	3,506	n/a		n/a	
2. Direct Evaporative	0.5	4.25	1,238	0.00	0%	756	**65%**
3. Indirect Evaporative	0.75	0.75	1,097	1.17	**83%**	803	**69%**
4. Indirect/ Direct	0.6	0.6	878	1.22	**86%**	876	**75%**
5. Indirect / DX	0.75	3.35	1,420	0.30	**21%**	695	**59%**
6. Evaporative Condenser	2.25	2.6	2,167	0.55	**39%**	446	**38%**
7. Subcool/ De-superheat	3.45	4.03	2,805	0.07	**5%**	234	**20%**

COMPARISON METHODS

An ideal performance metric allows comparison across a variety of air cooling and conditioning options, showing the degree of comfort each achieves for a given amount of power and energy used. Because of differences in the ways cooling technologies handle air and create comfort, it is difficult to find a single metric that works consistently for the full range. The evaporative and DX cooling elude simple direct comparison because of three fundamental differences.

The following enumeration draws largely on summaries in PG&E reports (2004 and 2006).

CAPACITY DEFINITION

The standard EER efficiency rating for DX systems is based on cooling capacity, defined as enthalpy reduction for a system that is both cooling and dehumidifying re-circulated indoor air. Because evaporative coolers typically use 100% outside air and do not remove any moisture, this DX-based cooling capacity calculation is not directly applicable.

LOAD REDUCTION CHARACTERISTICS

The standard DX capacity definition omits the load reduction factors that arise from the 100 percent outside air use of evaporative coolers. For example:

- By continually bringing in outside air, evaporative coolers pressurize the internal space, reducing or eliminating infiltration of warm outside air.

- By continually exhausting inside air, evaporative coolers automatically eliminate latent gains from humidity generated internally.
- Evaporative coolers must move larger v+olumes of air, because they supply air at a higher temperature than DX. The increased air movement can result in equivalent comfort at a slightly higher temperature.

SENSITIVITY TO TEMPERATURE LEVEL

In addition, the temperature conditions that have the greatest impact on evaporative system efficiency are very different from those that have the greatest impact on DX system efficiency. Thus, the relative performance of the two types of systems varies significantly with assumed outdoor temperatures and indoor setpoints.

- Evaporative-only cooling ability drops off drastically as the indoor setpoint approaches the outdoor wet bulb temperature, the typical minimum that the cooling (leaving or supply) air can achieve. Compressor-based cooling, on the other hand is relatively stable for lower setpoints.
- As previously noted, the demand of a DX system increases dramatically as outdoor temperatures rise, while evaporative system demand remains stable in these conditions.

Several attempts have been made to expand the traditional EER to apply to evaporative systems. However, although each can result in a reasonable metric for evaluating specific equipment *within* a single technology, none is totally suitable for comparisons *between* technologies.

ECER

The California Energy Commission (CEC) specifies a Title 20 Evaporative Cooling Efficiency Ratio (ECER) for comparing evaporative coolers. Ideally, this ECER could be used for comparisons between evaporative and DX technology. However, as with the compressor based EER, this measure assumes the intake air is at return air temperature; It does not take any credit for conditioning the ventilation air, and thus it leads to an underestimate of evaporative performance. ECER is useful for relative comparisons of products of the same evaporative technology type, but it should be used very cautiously when comparing different types of cooling technology.

ASHRAE 133 AND 143

In another approach, ASHRAE 133 and 143 specify EER calculations for direct and indirect evaporative coolers respectively. These calculations take credit for conditioning 100 percent of the outside air and thereby may overrate the evaporative performance in relation to typical compressor cooling EERs. The ASHRAE-based EER for an evaporative cooler can be as much as three time its ECER. The differences between these rating approaches can result in reported EERs differing by as much as a factor of three. Evaporative cooler EERs of greater than 60 may result when tests are based just on peak hot, dry conditions, where a more rigorous comparison over the whole cooling season may find a less astounding EER of about 20. As a specific example of the difference between these two measures, the PG&E tests (2006) of a Maisotsenko cycle evaporative cooler resulted in an ECER-type measure of about 10, and an ASHRAE-type EER using outside air of about 30.

Ultimately, the comparison rests on whole-building estimates of annual cooling energy and peak demand for reasonably comparable applications, as in Table 6. Appendix C describes the studies from which that table was derived. These cases derived performance parameters from site or laboratory monitoring, then used the derived parameters in an annual building model to produce an annual cooling energy estimate. The essence of a good comparison lies in the proper sizing of the comparable systems, as the manufacturers have tuned their product models to the most common comparison situations. Together, these references provide a good description of the pertinent measurement and analysis methods.

WATER USAGE

Water use in evaporative cooling comes from two primary uses: water for evaporation and purge water for keeping dissolved minerals from accumulating as the water evaporates.

- For evaporative water, the usage rate will increase with lower humidity and higher temperature. The amount of evaporative water use correlates closely with wet bulb depression (the difference between the dry bulb temperature and the wet bulb temperature).
- The need for purge water is very dependent on the concentration of dissolved salt in the water. Instead of purging continuously, the better evaporative coolers will purge just at set intervals or, even more intelligently, only when a certain sump mineral concentration is reached.

Typically, the purge water usage is of the same magnitude as the evaporated water, although a wide range of relationships has been reported. New systems that purge only as needed have been reported to use as little as 5 percent of total water for purging (Kinney, 2004a). Older coolers, whose filters were continually being flushed, have been reported to use twice as much water for purging as was evaporated. (Kariscak, 1998).

Usually, monitored water use is given in the aggregated form of an average hourly usage for all operating hours. A PG&E study (2004) explored water use more thoroughly and developed water use estimates as a function of wet bulb depression. This methodical approach to water use analysis could lead to more standardized methods of water use comparison.

Monitored water use in residential-sized evaporative cooling installations has shown average water flow of 5-10 gallons per hour of operation. (Davis Energy Group, 2004) These monitored systems had sensible outputs of about 2 -3 tons. One of the largest evaporative systems, 368 tons, had a maximum makeup water use of 35 gallons/minute (2,100 gal/hr). When these observed water use rates are normalized for system size, they all fall in the range of 0.05 – 0.1 gpm/ton.

In a review of evaporative cooler performance issues, Larry Kinney noted that reduced electricity also lowers water use at the electric power plant, where it is typically used for cooling. For average southwest U.S. cities, he estimated this reduction in water use at the power plant level offset about 1/3 of the increased water use of the evaporative cooler.

When reviewing an evaporative cooler's compliance with Title 24 standards, CEC staff considered concerns of the California Urban Water Conservation Council regarding the impact of evaporative cooling. (CEC, 2006) In this case, they have recommended a maximum water use rate of 0.15 gpm/ton. This level exceeds all the observed water use rates in recent studies of high efficiency units.[11]

CEC staff estimated that total statewide water use would increase by less than .004 percent if the unit being reviewed were installed for cooling in all new homes. In that calculation, the total water use denominator included agricultural and industrial as well as residential usage. Others have estimated the water use of a residential evaporative cooler in relation to average residential water use. For example, the 2003 Kinney paper concluded that a modern evaporative cooler in the southwest U.S. uses about 5,800 gal/yr, only 3.3 percent of average single-family household water use. To put this in perspective, changing a home's 2.5 gpm showerheads to 1.5 gpm fixtures could save 8 percent of average single-family water use, based on typical water usage distribution from the American Water Works Association. It should be noted that these water use comparisons are annual. In practice, the evaporative water use does usually occur in the three summer months when water is in most critical supply.

INSTALLATION AND MAINTENANCE

Reported problems with evaporative coolers can often be traced to the fact that they are distinctly different from vapor compression air conditioners in their installation, operation and maintenance. Typical practices for DX systems, such as minimizing intake of fresh air, will actually prevent direct and IDEC evaporative coolers from working. Also, evaporative coolers in the residential setting are not simply push-button automatic. Some manual control is needed, and a good system will at best have controls that set an alarm when attention is required.

INSTALLATION

The most obvious installation difference between evaporative and DX cooling may be that evaporative coolers require water lines. Though not a complicated plumbing job, it is one that many HVAC contractors are unfamiliar with. In addition the systems can be heavier than their traditional counterparts due to the saturated weight of the heat exchanger, particularly in the Desert CoolAire hybrid prototype that combines a DX with the indirect evaporative core and also has a gas pack. The issues of plumbing, correct setting of water flow rate, filtering and the weight impacts are all issues outside the typical small residential or light commercial HVAC system installation.

Because units other than those in the category of evaporative DX-assistance move much more air than traditional DX, they require an air distribution system capable of handling the higher air flow rates. That may be either larger ductwork, or, in an unducted setting

[11] To calculate this consumption rate per ton, there is a complication of determining the equivalent capacity of the evaporative cooler. For water use calculations, the evaporative tons output should be based on conventional tons displaced or based on the total sensible cooling of the evaporative unit.

(typically residential or small office), using the entire building as the exhaust duct. The latter is accomplished through the appropriate use of open windows or properly located and sized “up-ducts.” An up-duct is a ceiling vent with a damper that opens automatically from the increased inside pressure when the cooler is on, which permits the attic to function as the relief duct. With this configuration, depending on the degree of insulation on the attic floor, there may be some additional energy benefit from cooling the attic. Manufacturers typically recommend 2 square feet of ventilation opening per 1,000 cfm of supply airflow.

DX cooling is forgiving of distribution inefficiency, although it compensates by using more energy to maintain stable comfort levels. By contrast, evaporative cooling is very sensitive to distribution inefficiencies (such as inadequate ducting or ducting the supply air through the attic) that can increase supply temperatures and cause the system to fall short of the comfort zone.

Operation and Maintenance

Any air conditioning system needs regular maintenance to operate most efficiently. Evaporative coolers are even more sensitive to proper maintenance and operation. In some cases, poor setup or maintenance may cause them to shut down entirely, rather than just run at slightly lower efficiency. The regular maintenance requirements are straightforward and require no more time than recommended DX maintenance. Steps typically include periodic filter cleaning or replacement,[12] oiling and an annual drain and dry-out. Units vary significantly in the frequency required for filter cleaning or replacement and the degree to which drain cycles are automated. For ongoing operation, the occupant must also assure that windows and doors are open in the proper locations, unless sufficient automatic up-ducts have been installed.

[12] In standard direct evaporative coolers, the evaporator pads may need annual replacement. In advanced units, the evaporative medial lasts for five-plus years.

BARRIERS TO ADOPTION

Given the large potential reduction in peak demand and energy use from evaporative cooling, it is reasonable to ask why the technology is not more widely used. Our interviews and review of the literature highlight the several past barriers to broader adoption of the technology. While the list may appear lengthy, none are insurmountable and several are primarily residual perceptions based on older technologies.

- **Image.** The general "swamp cooler" label stems from an era in which direct evaporative coolers were chosen solely for low cost. Many associate these early style units with poor performance and low effectiveness. In reality, today's refined technologies and updated packaging have addressed many of those early limitations. The early perceptions have been reflected in covenants and restrictions prohibiting evaporative coolers in certain communities. During the California energy crisis of 2000, restrictions were relaxed in some areas to allow window-mounted units that are not so conspicuous and much easier to maintain.
- **Impact of poor water quality**. Continuous evaporation can leave scale deposits in the evaporative and sump section of the cooler, or on the coils in the case of evaporative enhancements of DX refrigeration cycles. Some previous systems installed as demos in SCE territory were removed due to serious core blockage and damage due to poor water quality. Locations with extremely high amounts of suspended solids may have to assess individual system approaches to filtering and scaling to find the solution for their area. As noted in Section 0, newer evaporative units attempt to avoid scale problems while also reducing water usage by running purge cycles only at controlled intervals. A recent study by ADM Associates for SMUD showed that scale on the coils of an evaporative condenser tended to flake off naturally, and suggested annual cleaning procedures of the sump to remove the accumulation. Additional short and long term testing of a variety of controls and equipment would be useful.
- **Lack of Strong Demonstrations**. We have only a limited number of field tests and demonstration projects of the newer evaporative technologies. Some recent demonstrations have contained design, distribution and/or maintenance flaws that compromised performance results. While identifying such flaws is a primary function of field tests, the field needs more unambiguously favorable demonstrations of corrected equipment and maintenance procedures.
- **Perceived inability to handle extreme hot/moist conditions**. This perception derives largely from early direct evaporative coolers. While these direct coolers cannot handle the worst cooling conditions, newer IDEC and indirect technologies appear capable of completely replacing DX in most California climate zones. The original perception may have been further exacerbated by residential experience with improperly sized, installed, or maintained units.
- **Water usage.** Some water utilities have raise concerns about water usage, although, as discussed earlier, these fears may be based on incomplete information. Additional testing could help further define the amount of water used under combinations of weather, water quality, and purge controls.

- **Cost.** Price sensitivity has been seen as a major barrier to adopting more efficient units, particularly in the residential market, although the payback periods from energy savings may be just 1-2 years.
- **Design.** The necessity to properly size and channel air distribution**,** plus the need for water to and from the unit, require thoughtful design. When addressed early in the planning process of a new building, it may be no more difficult to incorporate evaporative than compressor-based technology.
- **Retrofit constraints.** The different airflow requirements, plus the plumbing requirements, mean that most evaporative cooling systems are not simply drop-in replacements for existing DX equipment. In these situations, using evaporative technologies to enhance the DX cycle may be a simpler approach that will still achieve energy savings.
- **Builder and contractor training.** Given the low market penetration of evaporative cooling equipment, most builders and contractors are unfamiliar with the sources of equipment and contractors, as well as with the equipment's requirements for air flow, plumbing, and maintenance.
- **Maintenance.** Maintenance steps for evaporative coolers are different from those for DX systems, but require no more time or money. Keys to good maintenance include accessible equipment and parts, as well as proper initial installation and set-up.
- **Ratings and code compliance.** Because of the challenges in easily comparing the efficiency of DX and evaporative systems (described in the section on energy savings), energy codes do not always give proper credit for the savings associated with evaporative equipment.

SCE CLIMATE AND THE PSYCHROMETRIC CHART VIEW

For building code purposes, California is divided into 16 climate zones, nine of which are found in Southern California Edison territory. Evaporative cooling works best in hot climates with a relatively low humidity. These climate conditions have a large wet bulb depression (difference between dry bulb and wet bulb temperatures), and leading to the greatest evaporative cooling capacity. Hot, dry weather is common in large parts of the SCE territory. Figure 6 maps the SCE service territory with the applicable California climate zones noted. [See Appendix D, Climate Zones, for a chart of design temperature conditions by zone.]

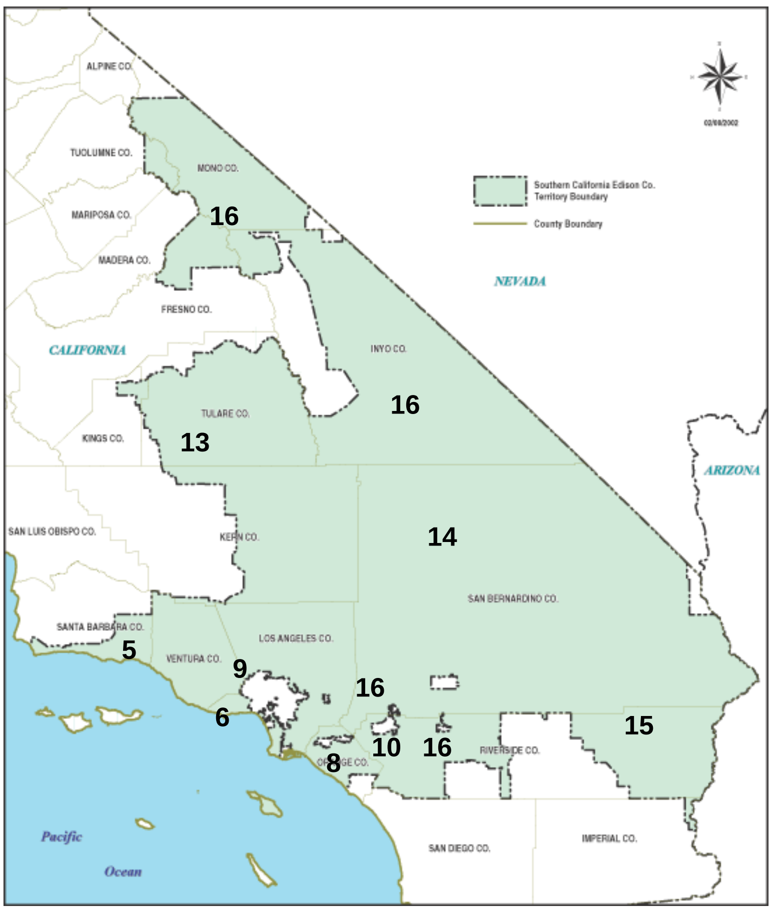

FIGURE 6: BASE MAP FROM SOUTHERN CALIFORNIA EDISON (WWW.SCE.COM)

A psychrometric chart can more clearly display the potential of each general technology in southern California. Figure 7 combines multiple data sources to build this picture. The ultimate cooling objective is always to transform the initial air state into the comfort zone conditions. The region labeled “common cooling conditions” delineates common initial air states where cooling is necessary. The region labeled “extreme conditions” shows the prudent evaporative design conditions that may occur for the most extreme 40 hours per year. Although a minor portion of the total annual cooling load, these conditions are definitely associated with peak demand conditions. (This chart is more completely described in the “About Figure 7” on page 37.)

This figure clearly shows that the low absolute humidity conditions in almost all of SCE territory are very favorable to evaporative cooling. In essence, evaporative cooling can be used throughout SCE territory in buildings with typical levels of internal gain.

Well-designed evaporative cooling can have significant demand and energy benefits, as shown in section 0. It is readily possible to move from the pool labeled “common conditions” to the comfort conditions using any of the evaporative technologies and to save more than 60 percent of cooling energy. An evaporative system that is capable *only* of proceeding from the common conditions to the comfort zone, however, cannot be counted on as the sole cooling mode. A backup DX unit may still be used on those worst days, doing nothing to curb the demand peak. Therefore, limited evaporative cooling capacity cannot be counted on for demand savings even though it can have strong energy savings.

Peak demand savings can be expected only if the evaporative systems can proceed from the extreme conditions to the comfort zone, serving as the sole cooling mode in those situations. Figure 7 shows that performance of direct evaporative systems, no matter how efficient the evaporative process, will be constrained to upward sloping paths such as “A.” Thus they will not be able to reach the comfort zone from the extreme conditions. The other evaporative cycles, “B”,”C” and “D,” potentially can get from the extreme conditions to the comfort zone. When they are properly sized and designed, these cycles can reasonably be the sole cooling mode and will therefore have a directly obtainable demand offset for every ton of conventional (air-cooled) compressor cooling displaced.

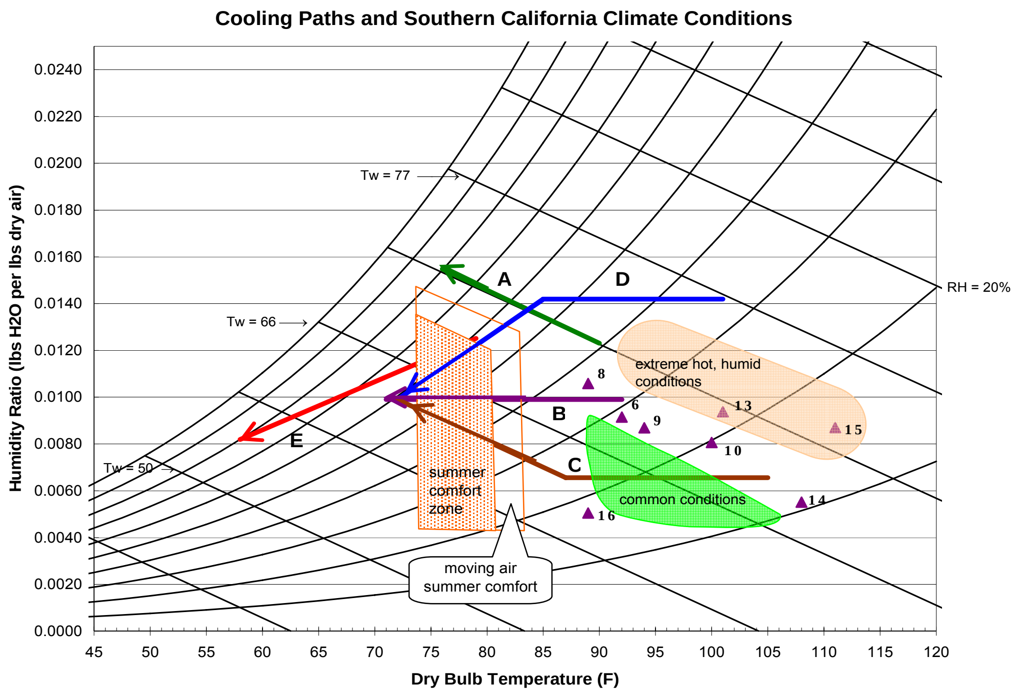

FIGURE 7 PSYCHROMETRIC VIEW OF EVAPORATIVE COOLING. (SEE "ABOUT FIGURE 7" FOR FURTHER DESCRIPTIONS)
A: DIRECT EVAPORATIVE B: INDIRECT EVAPORATIVE C: INDIRECT / DIRECT
D: INDIRECT / DX E: DX

ABOUT FIGURE 7

▲	Climate Zone Design Conditions: The numbered triangles show 0.5 percent cooling design conditions for representative cities in each SCE climate zone, the most commonly published reference data.
	Outside Air Characteristics: The pink-shaded region shows the extreme hot, humid conditions that create the greatest cooling challenge and result in the greatest cooling power demand. This region is representative of the evaporative cooling wet bulb design conditions, rather than the cooling design conditions shown by the triangles. The green shaded region shows common conditions more frequently found.
	Target Indoor Air Conditions: The trapezoidal orange shaded region shows ASHRAE summer comfort conditions. The larger orange outline shows the moving air comfort zone, reflecting the fact that comfortable temperatures can be a few degrees higher if the room has noticeable air movement, such as is created by most evaporative-only cooling systems.
	The chart also shows the psychrometric cooling paths followed by each of the technologies described.
	A Direct evaporative – Line A shows the air state moving upward along the wet bulb line, neither gaining nor losing energy, as the air absorbs water. In chess, this would be a move allowed to the bishop of enthalpy, often referred to as “constant wet bulb.”
	B Indirect evaporative – Line B shows the air state moving laterally (horizontally) toward lower temperatures. The lateral movement represents a constant amount of water in the air as the air cools. The inlet air is isolated from the evaporative air so that it neither gains nor loses water as it cools. It is cooled as the result of an indirect evaporative heat exchange. In chess, this would be a move allowed to the rook of absolute humidity.
	C Indirect/Direct – Line C shows a lateral indirect stage, followed by an upward diagonal direct stage. This would be the knight’s move.
	D Indirect/Compressor – Line D begins with a lateral indirect stage, followed by a compressor stage that draws both heat and water from the air. Here the starting point can be much wetter or hotter than the California sites, or there can be a high internal gain in the building.
	E Compressor only – Line E shows typical compression cooling, both reducing the temperature and removing water from the air as it passes through an evaporator coil. This is the only path that does not alter the supply and return airflow. (A to D all use a high outdoor air flow.) Because DX cooling recirculates indoor air, the line starts at a typical indoor temperature. The associated outdoor air can be much hotter/wetter than the California sites. The evaporative benefits for this path all proceed from enhancements to the refrigeration cycle or its control.

TARGETED OPPORTUNITIES

This section briefly outlines some technology opportunities matched to market sectors that could lead to increased market penetration of evaporative technologies. It is outside the scope of this report to develop research or public benefit mechanisms but further identification and refinement of opportunities can be made based on the product status, characteristics, market priorities, and savings potential described herein.

Clearly, more good demonstration projects are needed for evaporative cooling. The few very good examples of monitored demonstrations have been primarily in the residential sector. This work so far has been sufficient to support a reasonable conviction that evaporative cooling can be a major component of the residential and light commercial cooling markets. However, the breadth of operational experience is limited since there have been only a few of these examples. The critical mass of evidence necessary to build a convincing case has not yet been reached in the residential sector; it is even sparser in the commercial sector.

Most of the demonstration projects have taken place in Northern California, not in Southern California where evaporative technology can perform to even greater advantage. Most Southern California regions show the promise of completely supplanting conventional DX cooling, giving rise to an even greater need for southern demonstrations, rather than the model based conjectures of regional performance.

Some requirements for a good demonstration project:

- Commitment to a vision and a plan that has identified the most fruitful or cost-effective avenues of action.
- Identified learning objectives for the project.
- An information and M&V component that keys into a larger plan, which may include information, training, marketing, institutional activity (codes, standards) and incentives.
- Consideration of the market barriers that would impede roll-out of demonstration project results.
- Production partnerships to accelerate design modifications and manufacturing options.

The review done for this report identifies several possible opportunities. Several opportunities assume some incentive to increase market adoption where technologies are well developed – an approach previously in place at SCE for residential direct and IDEC ducted evaporative systems in 2005. As noted above, utility or public benefit investment decisions have a complexity of considerations to which the content of this report can contribute. The list below is a broad view summarized by objective and market sector.

OPTION #1

REPLACE DX IN RESIDENTIAL NEW CONSTRUCTION

There are three products on the market, which demonstrate the capability to serve as the sole cooling in new residential construction: OASYS, Coolerado, and Essick beta indirect/direct unit. The installed costs of this technology in new construction are about the same (or less) than conventional cooling. This new construction niche is favored by a low incremental cost and high energy (2,000 kWh/yr) and peak demand savings (3 kW) in a population of at least ten thousand new residences per year. This is a potentially large and growing part of the evaporative cooling resource.

A principal challenge with this option is to adapt the new construction to the successful application of the technology. This will require special design consideration for high ventilation and air flow rates, high thermal distribution efficiency, and provision for high exhaust rates. The test buildings should be designed with evaporative cooling in mind from the outset. Because of this sensitivity to design, a good demonstration of this technology may be inherently small at first.

A good initial approach to this option may be in the form of a design competition for designers and builders, leading to a field demonstration of 5-10 indirect/direct units, then to the development of a plan book or design seminar.

In matters of creativity and design, it is best to avoid a directed top-down approach. The bottom-up approach will probably produce some creative and sound approaches while establishing local design resources. This is an important start. Ultimately the technology will need to become fashionable among local designers and builders if it is to be effective. As a newsworthy event, there will be some free exposure here for the technology and its benefits to consumers.

This could start as a modest program that places two of each type (six in all) throughout the service territory. With appropriate M&V and the sample plans, this effort would constitute a coherent evaporative design resource for new residential construction.

OPTION #2

PROMOTE ADOPTION OF ADVANCED DIRECT EVAPORATIVE IN EXISTING RESIDENTIAL

High-efficiency direct evaporative cooling is readily available in the current market. At least three manufacturers are offering sleek, modern designs with thermostatic controls. As an option for saving money on summer cooling, this technology could be widely and cost-effectively applied. It is reasonable for even high-end residential customers to turn to direct evaporative cooling for comfort and as a hedge against high summer electric bills. It could even become trendy. Anecdotally, the newer, more efficient technology is noticeably more effective than the standard technology. Also anecdotally, in some years direct evaporative technology provides all cooling in cities such as Hemet and Palm Springs. Users of this technology could also constitute a reservoir of potential candidates for a voluntary demand program with peak lock-out of compressor cooling and to determine the demand and comfort impacts.

The operation of this technology is well known; it does not need to be demonstrated for technical reasons. However, as an approach to addressing a significant market barrier, the newer, sleeker versions need to establish a measure of market recognition and acceptability.

This option could be approached in a big way (unlike the small scale demo suggested in option #1) with the subsidized installation of qualifying equipment. If financed by a utility, the market penetration could proceed quickly to a very large pool of candidates within the existing residential sector.

Direct evaporative technology has distinct maintenance needs (annual or semi-annual) in order to insure proper operation. The maintenance is usually a simple 1-hour proposition. An incentive program incorporating some maintenance could easily be organized on a large scale. The maintenance aspect could also facilitate gathering data on scaling experience in areas with hard water.

Demand savings could also be targeted where direct evaporative is in place, through a pilot program for the Dx lock-out controls. The key first step is to increase market acceptability and penetration.

OPTION #3

PROMOTE ADOPTION OF EVAPORATIVE CONDENSERS IN EXISTING AND NEW RESIDENTIAL AND SMALL COMMERCIAL

The evaporative condenser is distinguished by two prominent advantages: 1) it can be applied in all cases where a conventional compressor system is used, without modifying any interior air flows, and 2) if the sizing is correct, there will be little chance of failing to meet comfort conditions, and the energy and demand savings will be reasonably certain.

Currently there is one product of this type marketed at the residential scale (the Freus) and a larger rooftop configuration for small commercial. However, the general technology is not new and others are poised to follow suit. This product did not fit readily into established Title 24 categories for new construction, either as evaporative cooling or efficient DX. Therefore, it is currently in process for energy savings certification under Title 24. The initial CEC staff report acknowledges both energy and demand savings.

As with other evaporative technologies, this approach requires at least simple annual maintenance. The unit currently marketed includes a thorough explanation of maintenance issues.

This option has the potential for significant advances if promoted with subsidies for qualifying equipment.

OPTION #4

INCREASE RESEARCH AND DEMONSTRATIONS FOR COMMERCIAL ROOF TOP UNITS

Evaporative cooling applications for retail and office occupancies have not been widely demonstrated. Two currently marketed products are well suited for this market: Spec-Air “ACER,” Coolerado, and two prototypes (the Desert CoolAire and the Freus evaporative condenser rooftop package) are at the demonstration stage. This type of application is characterized by the need to maintain reasonably strict interior comfort conditions. A significant advantage of evaporative cooling in this context is the very cost-effective way in which it deals with the high ventilation needs of these occupancies.

The eligible market here is reasonably homogenous in the sense that most units are installed on rooftops in about the same way, and this technology is not markedly different from the current business model. As with the other evaporative technologies, there are simple but necessary maintenance requirements.

There are significant differences in the current market offerings. The Spec-Air “ACER” includes key features such as an economizer and heat recovery from the exhaust air stream. It also includes an evaporatively-cooled condenser. The smallest version of this unit is 7.5 tons. This is a small version of a comprehensive large-building evaporative HVAC system. The prototype Desert CoolAire is intended as 5-ton equivalent and holds good promise in the design addressing small commercial needs for heat, economizer, indirect and Dx.

The Coolerado and the Freus have neither the economizer nor the exhaust-air heat recovery, but they come in smaller sizes suitable for displacing the more common five-ton rooftop unit. These can provide significant energy and demand savings by evaporatively cooling the ventilation air.

For light commercial, proven field performance, solutions to installation and maintenance barriers, product design, production and retail costs, and market awareness and education are all areas that need additional research and demonstrations. This is necessary to help evaporative technologies significantly impact the substantial rooftop unit market and reduce energy and demand for this cooling sector. There are several past and current research and demo experiences to build on for the initial proof-of-concept and market effort.

In summary, evaporative cooling holds the potential for a level of energy and demand savings than cannot be ignored. There are abundant opportunities for the additional demonstration designs and incentive projects needed to extend the use of this technology.

APPENDICES

A. SUMMARY OF ADVANTAGES AND DISADVANTAGES BY TECHNOLOGY CATEGORY

TECHNOLOGY TYPE ADVANTAGES AND DISADVANTAGES

Method	Advantages	Disadvantages
Direct	• Simple • Significant reductions in energy usage • Added humidity may be beneficial in hot, very dry situations • Filtering capacity of wetted media and large volume of outside air can improve IAQ	• Requires water hookup and uses some water • Added humidity not desirable in most climates. Can't get to ASHRAE comfort zone when the outside wet bulb temperature is above 68°. • Practical cooling limit is several degrees above the outside wet bulb temperature • Back-up DX may still be desired, which can prevent peak demand savings. However, lock-out controls could address this problem with little decrease in comfort conditions.
Indirect	• Significant reduction in energy use • Power demand remains constant as cooling requirements increase • No added humidity • Large volume of outside air can improve IAQ • Newer Maisotsenko cycle technology can cool to near the wet bulb temperature	• Requires water hookup and uses some water • Some technologies less effective than direct • Until recently, too large and costly for residential applications
2-stage Indirect / Direct	• Significant reduction in energy use • Can achieve comfort zone in wider range of conditions than direct evaporative • Power demand remains constant as cooling requirements increase • Filtering capacity of wetted media and large volume of outside air can improve IAQ	• Requires water hookup and uses some water • More complex and costly than Direct
Indirect / Compressor	• Reduction in energy use • Indirect cooling module alone is sufficient in many weather conditions • Increases compressor capacity and DX efficiency • DX system available for the extreme (high wet bulb temperature) days • Large volume of outside air can improve IAQ	• Requires water hookup and uses some water • Newly packaged technology currently at the prototype stage
Refrigeration cycle enhance-ments	• Increases compressor capacity and DX efficiency • DX system can handle the extreme (high wet bulb temperature) days • Can operate on DX condensate, no additional water supply required	• May require water hookup • Can't achieve the level of demand reduction found with the best evaporative-only technologies

B. Product Information Templates

See the Product Information Supplement (separate document) to this report for more detailed information regarding current products. The forms in the supplement provide only a snapshot overview of information available from product brochures and manufacturers. Because of the wide number of product models and frequent changes, the information there should not be considered definitive for any given current model, nor a complete listing of all brands and models available.

C. ENERGY AND DEMAND SAVINGS ESTIMATES

The savings estimates in section 0 were based on the few available publications field or lab studies with results quantified in a fashion to permit comparison. These cases derived performance parameters from site or laboratory monitoring, then used the derived parameters in an annual building model to produce an annual cooling energy estimate.

TABLE 7: STUDIES ON WHICH SAVINGS POTENTIAL ESTIMATES WERE BASED

Date	Study	Technology Covered	Type of Testing
Evaporative Only			
2006	PG&E TES	Coolerado (Maisotsenko cycle) indirect evaporative	Lab testing of prototype, using ASHRAE test standards
2004	PG&E TES	Standard direct evaporative, Advanced direct evaporative, Indirect / Direct	Lab testing of off-the-shelf units, using ASHRAE test standards
Evaporative DX Refrigeration Cycle Enhancements			
2006	ADM for SMUD	Freus evaporative condenser, compared to EER 7, Title-24 SEER 13, and premium efficiency SEER 16 DX	-Modeling for energy use -Survey for residential customer satisfaction -Visual field inspection for scaling and maintenance
2006	Armstrong et al, for PNNL	GEG evaporative assist to de-superheating and sub-cooling, compared to AAON conventional RTU (ARI EER 11)	Field monitoring
2006	CEC	Freus evaporative condenser, compared to Title 24 standard DX	Modeling for Title 24, using MICROPASS
1998	Davis Energy Group for PG&E	AC2 evaporative condenser, compared to typical 3 ton SEER 10 DX	Field monitoring in small office building, comparison to earlier lab testing

The specific numbers in the Table 6 comparison of power and energy usage, in section 0, were derived as follows.

Reference air-cooled compressor: We posited a reference air-cooled compressor system drawn from simulations for a nominal 3-ton, 10 EER residential application at two key operating temperatures, 80°F and 110°F. This reference system is assumed to operate in climate zones 13 or 14 instead of zone 12 as originally modeled.[13] The cooling load was ratioed from the zone 12 calculation to other zones using the standard cooling energy by climate zone for Title 24 compliance. (Source data from DEG 1998b and CEC 2006)

[13] The climate zones in SCE territory are shown in Section 0 and Appendix D.

Comparably sized evaporative units: Available specifications and monitoring reports as shown below provided the basis for the energy use characteristics and power requirements of evaporative units sized comparably to the reference compressor.

- Direct evaporative power reduction was based on 2004 work by PG&E. To reflect weather periods in which direct evaporative cannot reach comfort conditions, 25 percent of the cooling is still assumed to be compressor based, giving no demand reduction at the worst peak times. The remaining 75 percent of DX energy is assumed replaced by the evaporative cooler, with energy reduction proportionate to the 80° power reduction.
- For the **evaporative condenser** (row 6 in the table, but described next because several other calculations follow from this one), the power reduction was based on a study by the Davis Energy Group (1998b), adjusted for zone 13. Annual energy savings were derived from the ratio of these 80° F power levels. This general ratio approach was found to be a reasonable approximation for the original study's annual simulation for the condenser use in zone 12.
- The **indirect evaporative** and **indirect/direct evaporative** technology power ratios were based on the 2006 and 2004 work by PG&E. Energy savings here were again based on the ratio of 80° F power levels, with one modification. We added 500 hours/yr of non-cooling fan use. In monitoring, this fan use was the major constituent of indirect cooling energy. This addition assumes some effort, based on recent designs, to improve this area, but there is room for further improvement.
- For the **indirect/DX technology** the power at 80° F equals that for indirect evaporative and the power for 110°F equals the sum of the indirect evaporative and evaporative condenser power. The energy usage assumes indirect evaporative is sufficient for 3/4 of the cooling season and the DX unit is added for the remaining 1/4. Recent testing (not yet published) has also been done for the Maisotsenko-cycle indirect core of this equipment by NREL and by New Buildings Institute.
- The **sub-cooling/de-superheating** savings were assumed to be 5 percent for demand and 20 percent for energy. From the manufacturer's case studies, this is a reasonable interpretation of the observed results in southeast U.S. demonstrations.

D. CLIMATE ZONES

Climate Zone Design Condition Characteristics

		Design Standard	0.1% cooling		0.5% cooling		1.0% cooling		2.0% cooling		Evaporative Cooling Wetbulb	
Zone	Representative City	Elev (ft)	DB	MC WB	DB	MC WB	DB	MC WB	DB	MC WB	Design 0.1%	Design 0.5%
CZ16	Mount Shasta	3535	93	62	89	61	88	61	84	59	61	59
CZ15	El Centro	-30	115	74	111	73	110	73	107	73	74	72
CZ14	China Lake	2220	112	70	108	68	107	68	104	68	72	70
CZ14	Barstow	2162	107	69	104	69	103	69	100	67	73	71
CZ13	Bakersfield	475	106	71	102	70	101	70	98	68	77	75
CZ12	Sacramento	17	104	72	100	70	98	70	94	68	75	73
CZ11	Red Bluff	342	107	70	104	69	102	68	98	66	70	68
CZ10	Riverside	840	104	70	100	69	99	68	95	65	75	72
CZ 9	Pasadena	864	99	69	94	68	92	68	88	67	75	73
CZ 8	El Toro	380	96	69	89	69	87	69	82	68	69	67
CZ 7	San Diego	13	88	70	83	69	82	69	78	68	66	64
CZ6	Los Angeles CO	270	99	69	92	68	90	68	86	67	71	69
CZ6	Los Angeles AP	97	91	67	84	67	83	67	79	66	68	66
CZ 5	Santa Maria	236	90	66	83	64	82	63	78	61	74	72
CZ 4	Sunnyvale	97	96	68	88	66	86	66	80	64	74	72
CZ 3	Oakland	6	91	66	84	64	82	64	77	62	73	71
CZ 2	Santa Rosa	167	99	69	96	68	95	68	92	66	73	71
CZ 1	Arcata	218	75	61	69	59	68	59	65	58	73	71

Zones found In SCE territory (even though the single "representative city" may not be in SCE territory)
Representative city climate characteristics from CEC / ACM Joint Appendix II

E. CONTACTS

The following individuals were interviewed in the course of gathering information for this report:

Consultants and Researchers	
Lance Elberling	PG&E
Robert Foster	Evaporative Cooling Institute, NM State University
Marc Hoeschele	Davis Energy Group
Larry Kinney	Formerly of SW Energy Efficiency Program
Leo Rainer	Davis Energy Group
Company Representatives	
Rocky Bacchus	Freus
Bob Bullock	Metal Form Manufacturing / Energy Saver Division
Rick Gillan	Coolerado
Thomas H. Hebert	Global Energy Group / EER+
Jim Hess	Phoenix Manufacturing Inc. (PMI)
Si Hyland	Speakman CRS / OASys
Mark Muller	Seeley International / Breezair or Convair
Roger Palmer	AdobeAir / MasterCool
Jim Pettry	Champion Cooler Corp / Essick Air
Mike Worth	Champion Cooler Corp / Spec-Air

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