RESEARCH. INNOVATION. PARTNERSHIP.

ANNUAL REPORT
2010-2011

WCEC
WESTERN COOLING EFFICIENCY CENTER

INTRODUCTION

EXPLORING MANY OPTIONS FOR ENERGY EFFICIENCY

Our focus on technical excellence and rewarding partnerships has positioned us for continued growth and leadership in the field of energy efficiency. This document, the second Annual Report on Cooling in the West, demonstrates our diverse scope of research and expertise by highlighting many of our latest accomplishments. Furthermore, this document describes how our pioneering research continues to lay the foundation for crucial future projects pertaining to energy efficient cooling in the Western United States.

To better communicate the impact of our research, this report presents our work by sector, organizing each project by their respective research focus, and conveys many of our findings in the "By the Numbers" section. Specifically, the sectors are as follows: Single-Family Residential; Multi-Family Residential; Hotels, Dorms, Hospitality; Light Commercial and Retail; and Cross-Cutting Technologies. With over 20 concurrent research projects the WCEC is a pioneer in the field of energy efficiency.

In collaboration with our affiliates and stakeholders, the WCEC is providing results on a multitude of energy efficiency projects including Swimming Pools as Heat Sinks, Evaporative Pre-Cooling Retrofits, Hotel Control Study, Aerosol-based sealing of enclosures and many more. The WCEC continues to expand its influence by applying its vast research knowledge to new sectors that may benefit greatly from increased energy efficiency. The Multi-tenant Light Commercial Project, for example, combines our research and expertise with the Energy Efficiency Center and the California Lighting Technology Center to create holistic energy efficiency solutions for this critical, challenging, and chronically under-served market sector.

Looking forward, we believe the evolution in energy efficiency will be less about any single technological solution and more about combining strategies and solutions for achieving energy efficiency goals. These strategies will address the multitude of ways in which we use, and interact with, HVAC systems. We intend to approach buildings holistically, understanding the ways in which different technologies interact with each other and how we, in turn, interact with the building and its systems. From building envelop sealing to behavior and RTU retrofits to heat sink swimming pools, the WCEC's continued research will continue to reduce energy usage in the Western United States.

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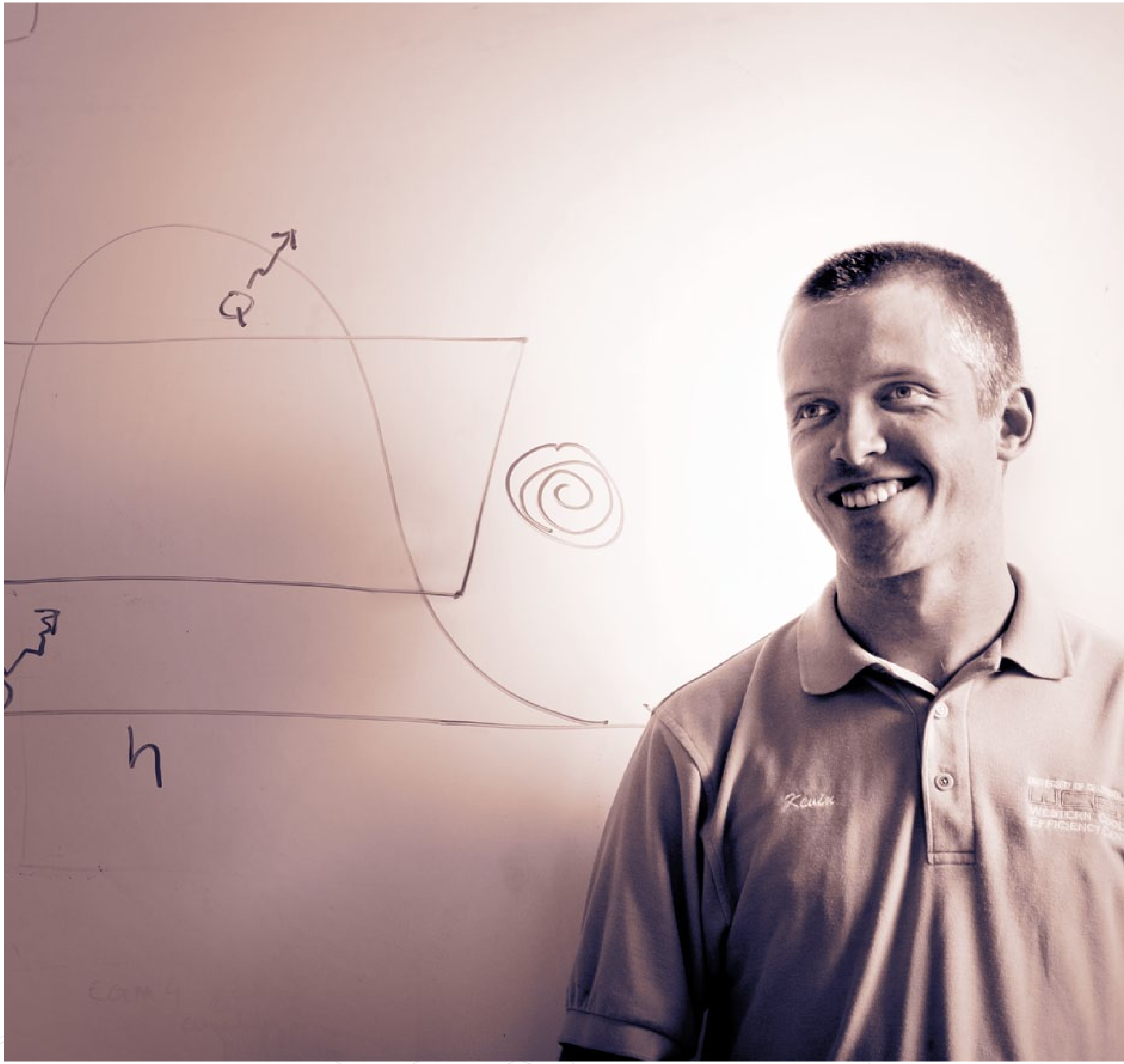


WESTERN COOLING EFFICIENCY CENTER

BY THE NUMBERS

30%

Reduction in air conditioning energy use when rejecting waste heat to a swim-ming pool
pg. 10

4.8

Annual energy cost savings directly achieved by installed demonstrations from 2004-2010, in millions
pg. 58

16%

Commercial buildings have some exposed ductwork on the roof
pg. 74

40,000

Number of technicians installing and maintaining equipment in California
pg. 70

15.4

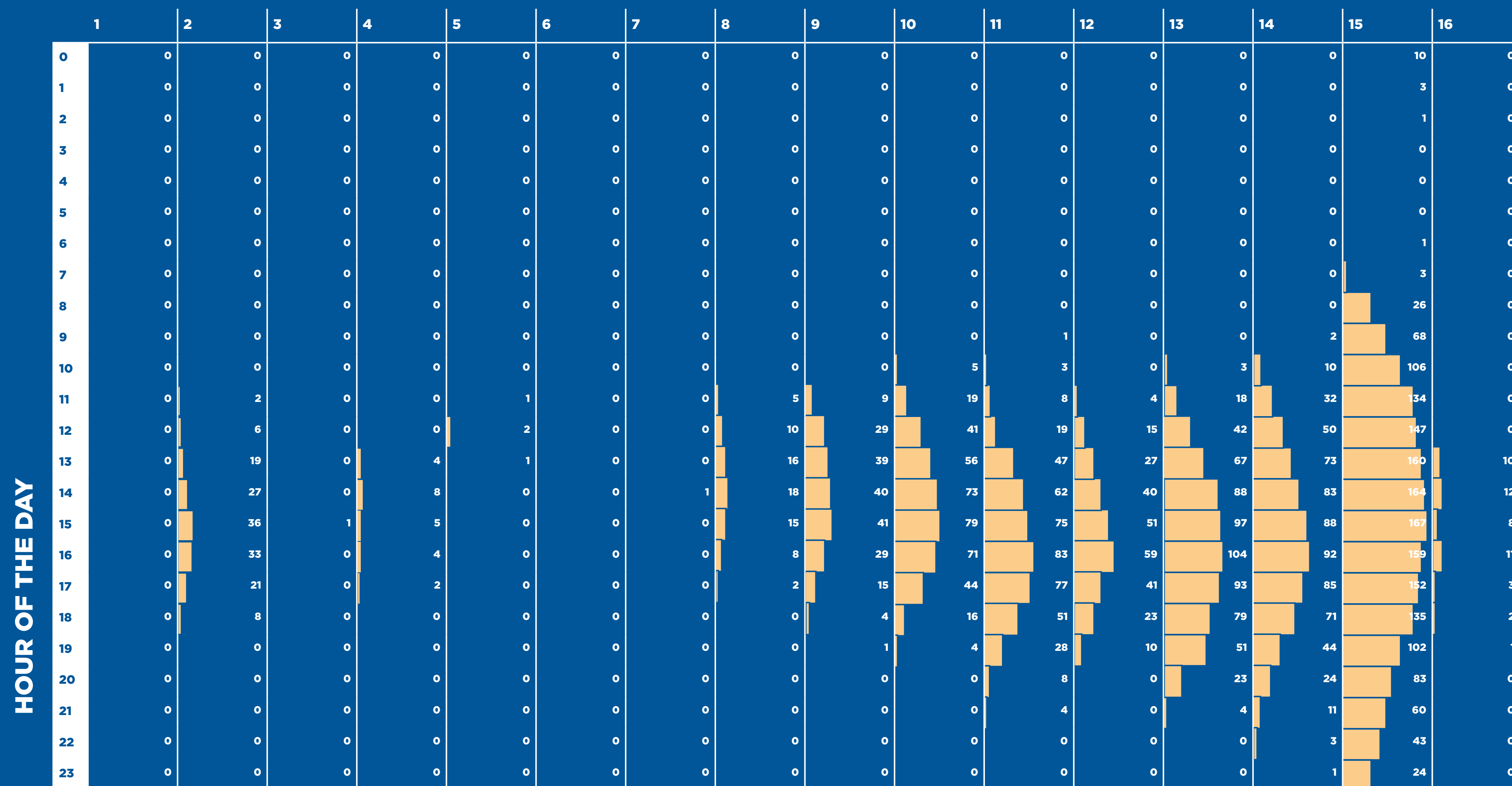
Estimated kW peak demand savings per year when using DualCool
pg. 42

65%

Demand reduction achieved by the Coolerado H80, compared to similarly sized conventional equipment
pg. 50

FUN FACTS

HOW MANY HOURS OF OVER 90°F IN CALIFORNIA PER YEAR?



Hour of the day	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	26	0
9	0	0	0	0	0	0	0	0	0	0	1	0	0	2	68	0
10	0	0	0	0	0	0	0	0	0	5	3	0	3	10	106	0
11	0	2	0	0	1	0	0	5	9	19	8	4	18	32	134	0
12	0	6	0	0	2	0	0	10	29	41	19	15	42	50	147	0
13	0	19	0	4	1	0	0	16	39	56	47	27	67	73	160	10
14	0	27	0	8	0	0	1	18	40	73	62	40	88	83	164	12
15	0	36	1	5	0	0	0	15	41	79	75	51	97	88	167	8
16	0	33	0	4	0	0	0	8	29	71	83	59	104	92	159	11
17	0	21	0	2	0	0	0	2	15	44	77	41	93	85	152	3
18	0	8	0	0	0	0	0	0	4	16	51	23	79	71	135	2
19	0	0	0	0	0	0	0	0	1	4	28	10	51	44	102	1
20	0	0	0	0	0	0	0	0	0	0	8	0	23	24	83	0
21	0	0	0	0	0	0	0	0	0	0	4	0	4	11	60	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	3	43	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	1	24	0

CLIMATE ZONE MAP

40%

The minimum energy savings required by the Western Cooling Challenge for climate appropriate rooftop air conditioners

25%

Annual energy use in commercial buildings consumed by cooling and ventilation

50%

Percentage of summertime peak electricity demand for commercial buildings that is attributable to cooling and ventilation

15%

The goal for market penetration of climate appropriate cooling equipment in 2015, as set forth by the California Energy Efficiency Strategic Plan

12%

The percentage savings possible from Fault Detection and Diagnostics on an RTU

SINGLE FAMILY RESIDENTIAL

Swimming Pools as Heat Sinks for Unitary Air Conditioners

Graywater Reuse for Evaporative Cooling

In-Home Energy Display Usability

Radiant Cooling

Thermal Storage

Evaporative Condenser Water Management

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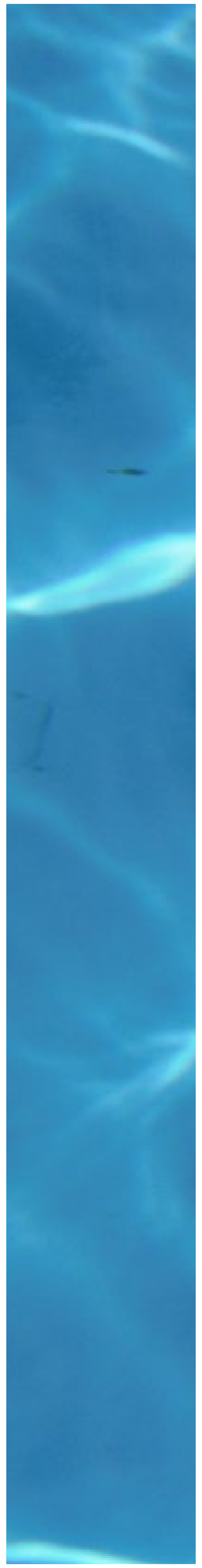


SWIMMING POOLS AS HEAT SINKS FOR UNITARY AIR CONDITIONERS

Two seemingly unrelated events, air conditioners rejecting heat from a condenser to the atmosphere and pools burning natural gas for pool heating, can share resources thereby reducing air conditioner energy consumption and peak demand, while simultaneously reducing the amount of energy needed to maintain a pools temperature. By pumping pool water through a tube-in-tube designed condenser coil system (Figure S1) the water will effectively cool the coil/refrigerant without the need for a loud, inefficient fan. The resulting warm water can then be pumped back to the pool, thereby heating the pool, without using any additional energy. This reduction in condenser temperature reduces the load on the compressor, which is the largest consumer of electrical energy in an air conditioner. The most significant savings are realized during peak conditions when ambient air temperatures often exceed 100°F, while pool temperatures remain at a relatively constant temperature of 80-85°F.

Another advantage of using pool water to cool a condenser arises out of the improved heat transfer properties of water relative to air. Using water allows refrigerant temperatures to be only 20°F higher than the sink temperatures instead of the 35°F difference experienced by a comparable air

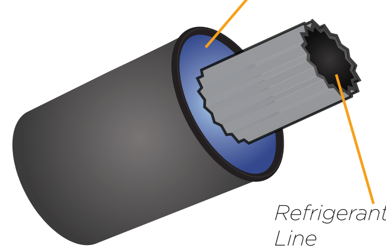


FIGURE S1: TUBE-IN-TUBE DESIGN

cooled condenser system. Therefore, the combined effect of lower temperatures seen by the condenser and the improved heat transfer properties of water result in a 30-35°F reduction in condensing refrigerant temperatures during peak conditions for air conditioning systems rejecting heat to a swimming pool.

YEAR 2 ACCOMPLISHMENTS

The second and final experiment to validate the swimming pool heat transfer model for calculating pool temperatures, given local weather data and pool characteristics, was completed. The second experiment differed from the first in that there was heat delivered to, and extracted from, the pool for house heating and cooling, whereas the first simply looked at the temperature response of a passive pool to varying weather conditions. The final result was very promising, showing that the predicted pool temperatures matched well with the observed pool temperatures.

With the pool model validated for pools that include the influence of external heat loads, the model was then used to analyze the feasibility of air conditioning systems that reject waste heat to a swimming pool in multiple California Climate Zones. In addition, the pools modeled had a range of shading conditions and air conditioning system sizes connected to them. Feasibility was ultimately determined by studying the pool size necessary to achieve a maximum hourly pool temperature of 90 °F over the entire summer. Using the results of the simulations, a tool is being developed to assist contractors with sizing pools that exchange heat with an air conditioner. The tool will allow the contractor to take into account the amount of shading a particular pool has and the impact that air conditioning system sizes have on the maximum pool temperatures experienced.

Systems that reject waste heat to a swimming pool have been shown to reduce overall air conditioning energy use by 30% and peak demand by 30-35%

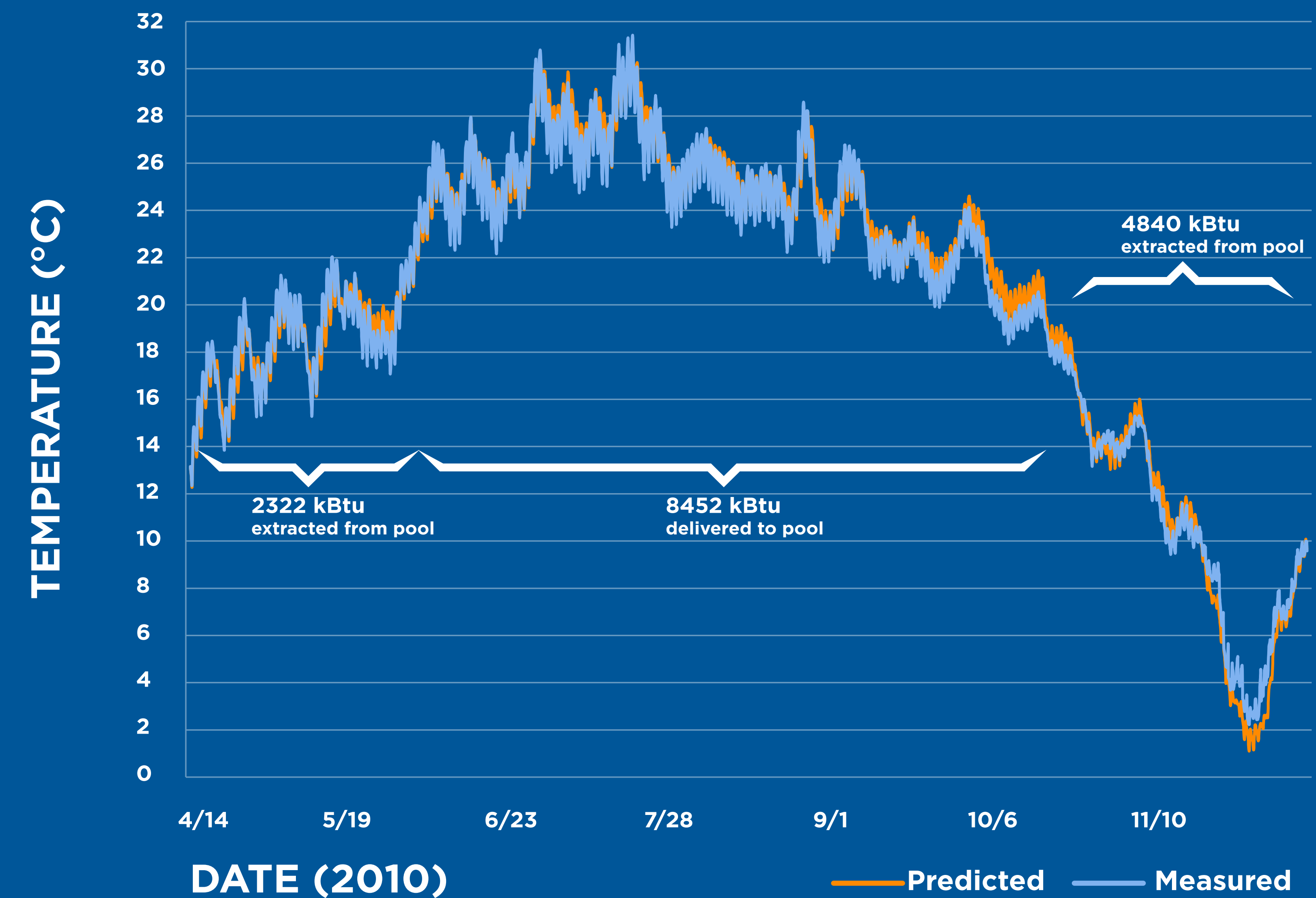


Figure S2: Predicted and measured pool temperatures for a pool exchanging heat with a heat pump in Sacramento, California, observed 4/15/10 - 12/12/10

GRAYWATER REUSE FOR EVAPORATIVE COOLING

The topic of water conservation is currently receiving significant worldwide attention, specifically in regions where population density and water supply is in a fragile balance. California is one such place where demand often surpasses supply, resulting in large legal, environmental and economic consequences during periods of drought. The situation will continue to worsen as the population continues to grow, increasingly straining water supplies, making water conservation ever more important over time.

Consequently, water conservation and the intelligent reuse of water are becoming more commonplace. Graywater is wastewater generated from bathing and washing and is considered lightly loaded. Graywater excludes wastewater from toilets, urinals, bidets, kitchen waste or from diaper laundering. Graywater commonly accounts for approximately 65% of residential wastewater.

One of the potential uses for graywater is in evaporative cooling technologies, which tend to be well suited for climates that have correspondingly delicate water supplies. Using gray water for evaporative, or hybrid evaporative cooling contains significant potential to reduce energy use in hot and dry climates. However, since water is continuously evaporated when used in cooling applications the water quantity, and quality, pose major challenges.

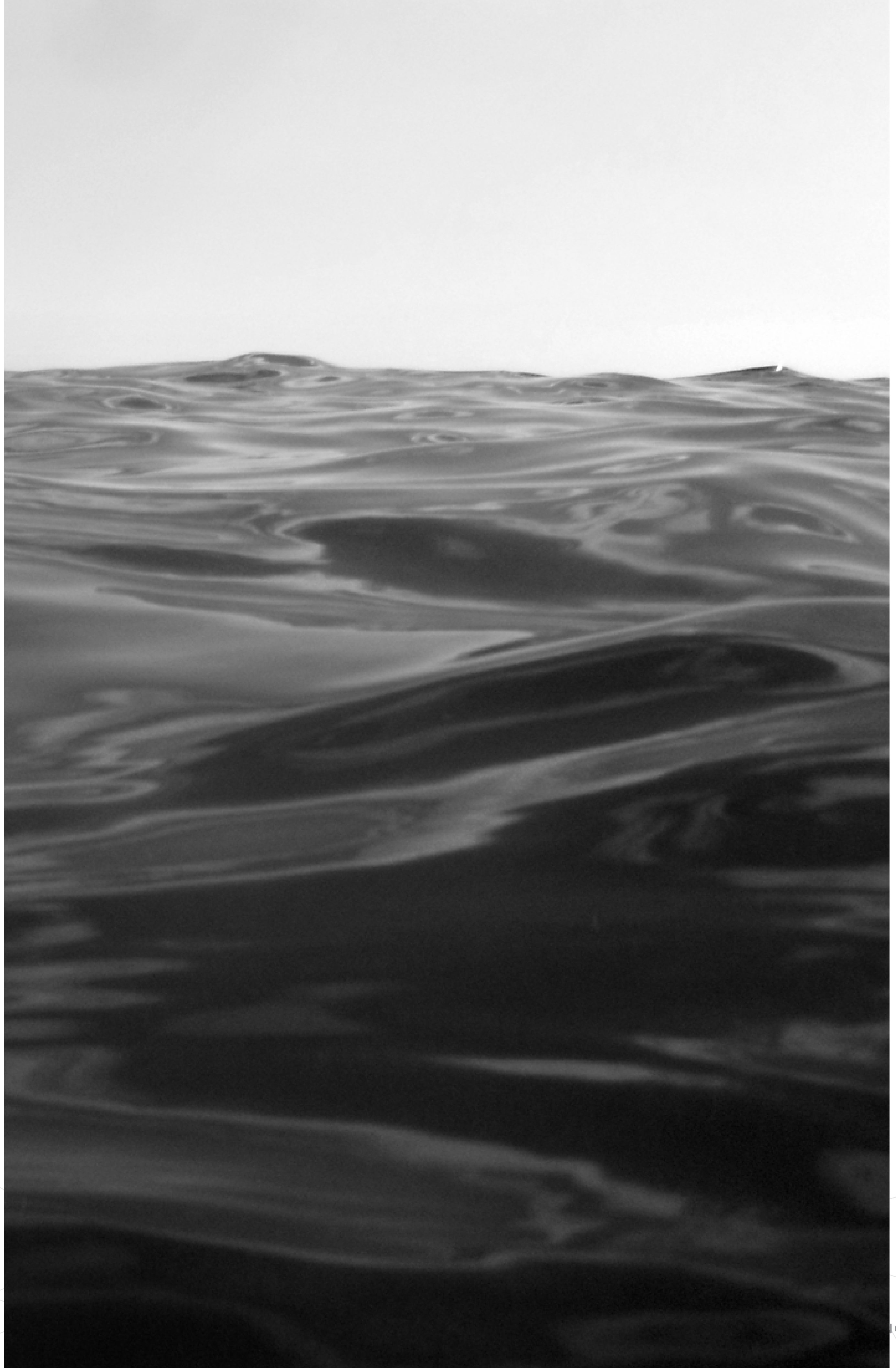
This project focuses on how to approach graywater reuse in California while adhering to applicable public health and safety regulations, including California's Title 22 requirements for tertiary disinfected recycled water, while meeting efficiency design standards addressed in California's Title 24, Chapter 16: Graywater Standards.

YEAR 2 ACCOMPLISHMENTS

An initial review was performed to gain a better understanding of existing technologies and available products. Current water use trends in aquaculture and manufacturing were also investigated, along with current trends in treatment methods for wastewater and graywater. In addition, California's laws governing public health, water use, and energy efficiency, pertaining to reclaimed water and graywater, were studied in order to satisfy regulatory requirements.

In order to use graywater in evaporative cooling several requirements must be met and numerous challenges arise. The primary goals of this project are to minimize the project's footprint, meet regulation standards by demonstrating reliability and effluent quality, minimize energy, minimize maintenance, minimize adding hardness, and a avoid negative ecological impact, all while maintaining safety standards and an economically feasible design.

Clothes washing machine discharge was found to be the least regulated graywater source, allowing collection without requiring a building permit. In addition, a washing machine can supply large quantities of graywater at any time, which allows immediate treatment and analysis along with evaluating various storage strategies. Therefore, the WCEC has acquired a high efficiency washing machine and intends to gather graywater from said washing machine onsite to replicate a typical variance in heavy graywater effluent with high chemical oxygen demand.



PATH FORWARD

The graywater will be treated using a variety of physical, chemical and biological treatment configurations. These treatment options will be evaluated based on effectiveness, reliability and economy. The first configuration to be evaluated will be an aerobic attached-growth, single pass, intermittent trickling, bio-filter design. A variety of design variables will be investigated, such as filter depth, media type, detergent type, inlet water quality, and filter configuration, to determine an acceptable contaminant removal curve and, ultimately, a final design. Each configuration will be extensively tested before and after treatment using a variety of metrics, including: chemical oxygen demand (COD), biological oxygen demand (BOD), turbidity, pH, solids, conductivity, alkalinity, and hardness.

WESTERN COOLING EFFICIENCY CENT

IN-HOME ENERGY DISPLAY USABILITY

The success of In-Home Energy Displays (IHEDs) as energy-saving devices relies heavily on the willingness of users to take the extra effort to view the displayed information and then respond to it. For these reasons the ease of using—accessing, modifying, viewing, interpreting, etc.—depends on the design of the interface. Furthermore, as shown by several studies, effectiveness of these devices is influenced by other environmental and social variables, such as presence or absence of energy saving goals on the part of users, social comparison with neighbors and peers, and presence or absence of incentives to monitor energy usage.

This study will explore interface design and social environmental influences on the effectiveness of IHEDs. First, usability of IHEDs will be examined by recording the obstacles users find in a sample of devices with different interface designs (using in-lab observation of user interaction with the devices). Then, actual use of IHEDs in a natural setting will show what obstacles emerge when a device is being used in the context of users' everyday life (an observation of usage in a natural living environment).

The first part of the project will employ a task-based methodology adapted from Energy Star usability tests for programmable thermostats. The approach involves identifying the key tasks that occupants would perform on IHEDs. A group of users will then be asked, in the lab, to perform a representative subset of the possible tasks in one of several IHEDs to be examined. An overall usability score for each tested type of IHED will be calculated based on the subjects' ability to perform the combination of tasks assigned. The Energy Star methodology selected a metric based on the time and ability to complete the task. The metric employed a logistic function to normalize measurements between zero and one. A similar approach will be employed here. This part of the project aims to demonstrate proof of concept rather than conclusively measure the usability of different IHEDs. Students, staff and faculty will be recruited for the usability tests rather than a representative cross-section of California's population.

To capture other behavioral elements influencing the effectiveness of IHEDs, such as users' goals or comparison and competition with peers, the second part of the project involves a field study in a natural setting. Residents of West Village (the biggest ZeroNetEnergy community in the US, built inside UC Davis campus, equipped with IHEDs) will be surveyed on the general reasons behind their choice to move to this specific housing community, any previous experience with IHEDs, and their attitudes towards residential energy use. In addition, residential energy use data for the participating households will be collected from a pre-existing centralized energy monitoring system. The combination of data on residents' reported motivation and experience and data on their actual energy use will provide information useful to establish the relationship between residents' goals/motivations/social environment and their actual energy use behavior. The attitudinal portion of the survey will be repeated at the end of a six month period, to gauge whether life in a ZNE community and presence of IHEDs has changed resident's views on energy use. Further, a subset of the population will be interviewed to further understand which elements have more influence on residents' behavior.

West Village gives us the opportunity of studying a large group of almost identical dwellings (in terms of equipment, appliances and envelope) built and occupied at the same time in the same area. These characteristics will allow to factor out several external variables and better weigh the role of behavioral and social components on the way residents make decisions about energy use. Furthermore, the current tenant agreement includes utility bills in the rent, so residents have no economical incentive to save energy. This particular setting will give us the opportunity to test how other behavioral factors that can influence energy conservation choices. Knowledge of how energy conservation choices are made in the absence of direct economic incentives will be relevant to determine how to encourage energy saving behavior in groups that are not directly responsible for paying energy bills.

Conclusions will be drawn from the two complementary parts of the study and recommendations for both manufacturers and utility program designers will be given.

RADIANT COOLING

The residential air conditioning market is almost entirely dominated by vapor compression systems, also known as direct expansion (DX) systems, whether split systems or roof top units. Typically these work by blowing chilled air through ducts into the rooms to be cooled. There are two main sources of inefficiency in this design – heat introduced into the airstream by the blower motor and losses in the ducts.

The blower that forces the air through the ducts is located in the airstream, so all of the heat generated by the motor gets added to the cold air. The DX system has to work harder to compensate for this, which adds to the power use and thus reduces efficiency.

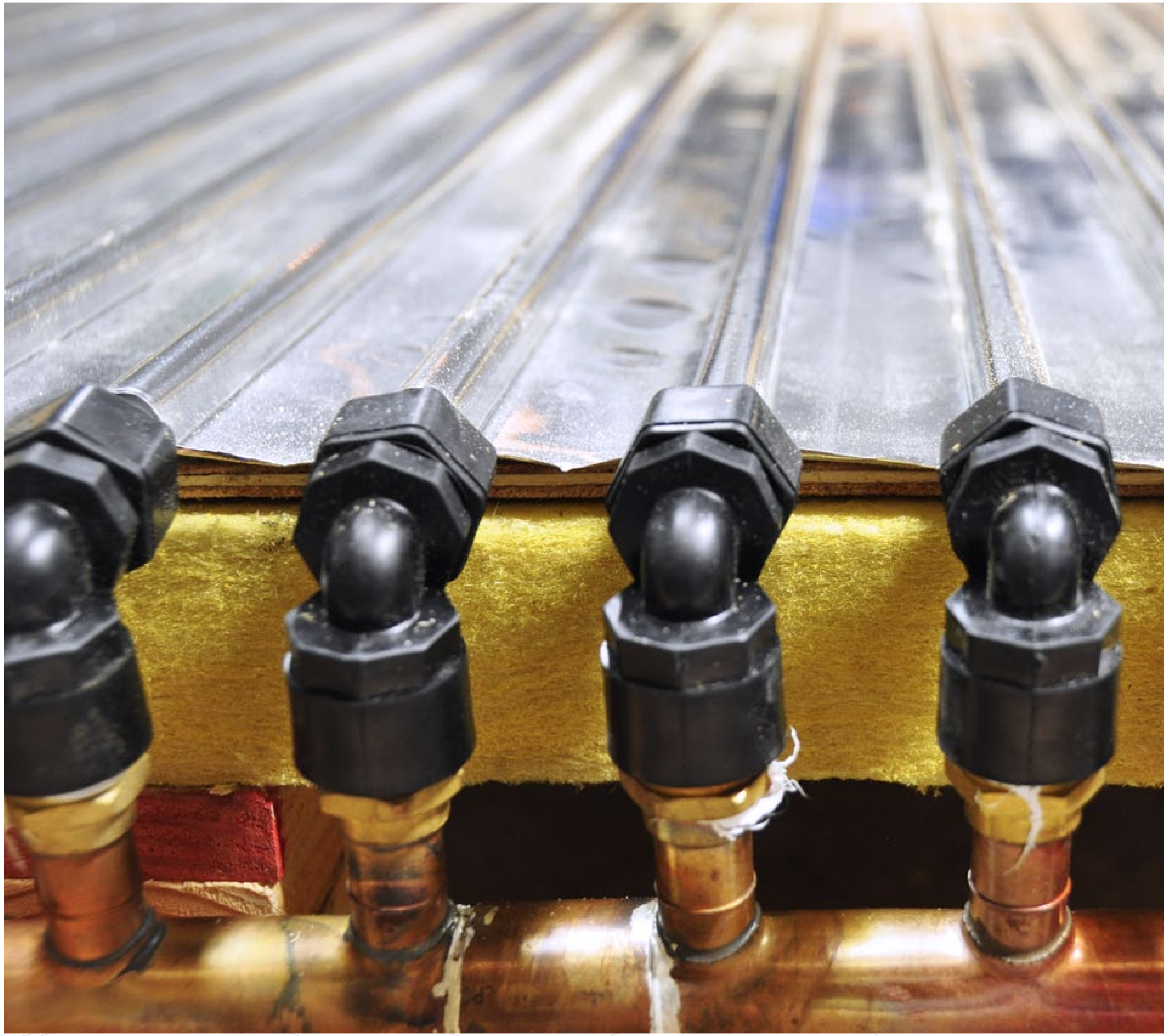
Losses in the ducts can come about in two ways – heat leaks and air leaks. Many ducts are in unconditioned spaces, such as attics or crawl spaces. Cold air flowing through a duct in a hot attic will absorb heat before reaching the room it is intended to cool, so the DX system will have to cool more air than would be needed in the absence of these heat leaks. And some of the air will leak from the ducts into the hot attic which will reduce the airflow to the room.

These effects can result in losses of up to 40%. One way to reduce them is to use water as the heat transfer medium. Pound for pound, water has over four times the cooling capacity of air, and in terms of volume, this goes up to 4000. The energy need to move one cubic foot of water can be considerably less than that needed to move 4000 cubic feet of air. The pipes needed for water are considerably smaller than for air, and it is therefore easier to insulate them to reduce heat gain. So embedding pipes in the floor, walls or ceiling or a building and running cold water through them can be a very efficient way of cooling a building. Such a system has the added benefit that using the same pipes to carry hot water turns the cooling system into a heating system.

The question of comfort is also relevant to the advantages of radiant systems over forced air systems. The level of comfort we feel in a given environment is a function of the air temperature, the humidity level, motion of the air (annoying drafts vs cooling breezes), and thermal radiation. Every object emits thermal radiation, with hotter things emitting more than colder ones. Hold your hand next to a hot surface, such as a grill, and it will heat up as it absorbs more radiation than it emits. Hold it next to a cold surface, such as a block of ice, and it will feel cold as it is emitting more than it absorbs. The hottest body around is the sun - standing in direct sunlight on a hot day is less comfortable than standing in the shade, even though the air temperature is the same. Cooling a house using a radiant system gives a similar effect. By lowering the temperature of the surfaces of the room, it allows the occupants to feel cool in slightly warmer air than they would with a DX system. This allows the thermostat to be set a couple of degrees higher, leading to further energy savings. The same applies to radiant heating - radiant heating in floors has become increasingly popular in recent years, and it would be nice to think that the same piping network can be used for both heating and cooling.

Radiant systems are also well suited to peak load shifting (PLS). PLS allows the power requirements of a cooling system to be spread over the whole day rather than the hours when the cooling is needed. This involves cooling down a large thermal mass overnight, when electricity is cheaper and chillers are more efficient, and using the stored cooling power to keep the building cool during the day. PLS can most easily be integrated into buildings that are designed with a large thermal mass that can be used for storage, such as a concrete slab floor in a big box store. The effect of PLS is to even out the demand for power which reduces the need for spare generating capacity. Even in a single family home with a concrete slab foundation, the slab can have enough mass to allow useful thermal storage and peak load shifting.

So it would seem that radiantly heating and cooling buildings is clearly better than using a forced air system. There are, however, potential pitfalls to radiant systems. The most significant of these is condensation. The cooling capacity of a radiant system is proportional to the difference in temperature between the radiant surface and the other surfaces



of the room being cooled, and to the area of the radiant surface. If the radiant surface is colder than the dew point of the air in the room then water will condense on it. In a typical house the cooling requirements will mean that the floor temperature needs to be somewhere in the region of 55-65°F, which will feel uncomfortably cold underfoot. Any floor coverings will reduce the effectiveness of the cooling system, and be likely to absorb moisture leading to potential mold problems. To prevent this, either a higher temperature and a larger active surface area is required, or the cooling load needs to be kept low by properly insulating the house and reducing air leaks and solar gain from windows etc. This is easy to do in a new building but more difficult and costly in an older one. Radiant ceiling panels for commercial buildings exist but remain a relatively niche market due in large part to the cost of the panels.

All of the above considerations lead to the residential radiant cooling project that we are working on at WCEC. This project has the aim of building a radiant cooling and heating system for single family homes that combines thermal storage for peak load shifting with a low cost radiant surface.

RADIANT PANELS

To allow the system to be installed in older houses at minimal cost, the radiant surface was designed as a ceiling mounted panel. The panel has an aluminum face for good thermal performance, a wood frame to provide structural rigidity, and is painted with a flat white primer - this helps with cooling effectiveness and allows the panels to be painted to match the interior color of the house if desired (typical white/off white paints will not significantly affect the performance). The chilled water is pumped through a plastic tube embedded in the panel. Figure S3 shows four panels installed in a house for field tests. The ribs visible on the underside of the panel contain the water piping.

Figure S3: The panels attach directly to the ceiling keeping the installation costs to a minimum (these panels are shown during installation and are still unfinished)

To determine the optimal design for the panels, the thermal performance was modeled for a variety of different scenarios – the aluminum thickness was varied, as were the pipe spacing and diameter. Figure S4 shows the expected cooling power of the panels for a room temperature of 76°F and a water temperature of 58°F. As the aluminum gets thicker the performance improves, as does the cost due to the greater expense of the thicker metal. The best compromise between performance and cost come from using a 20 gauge (0.032") sheet. This is a standard thickness, which keeps the cost down, and is sufficiently thick to provide structural rigidity to the panel.

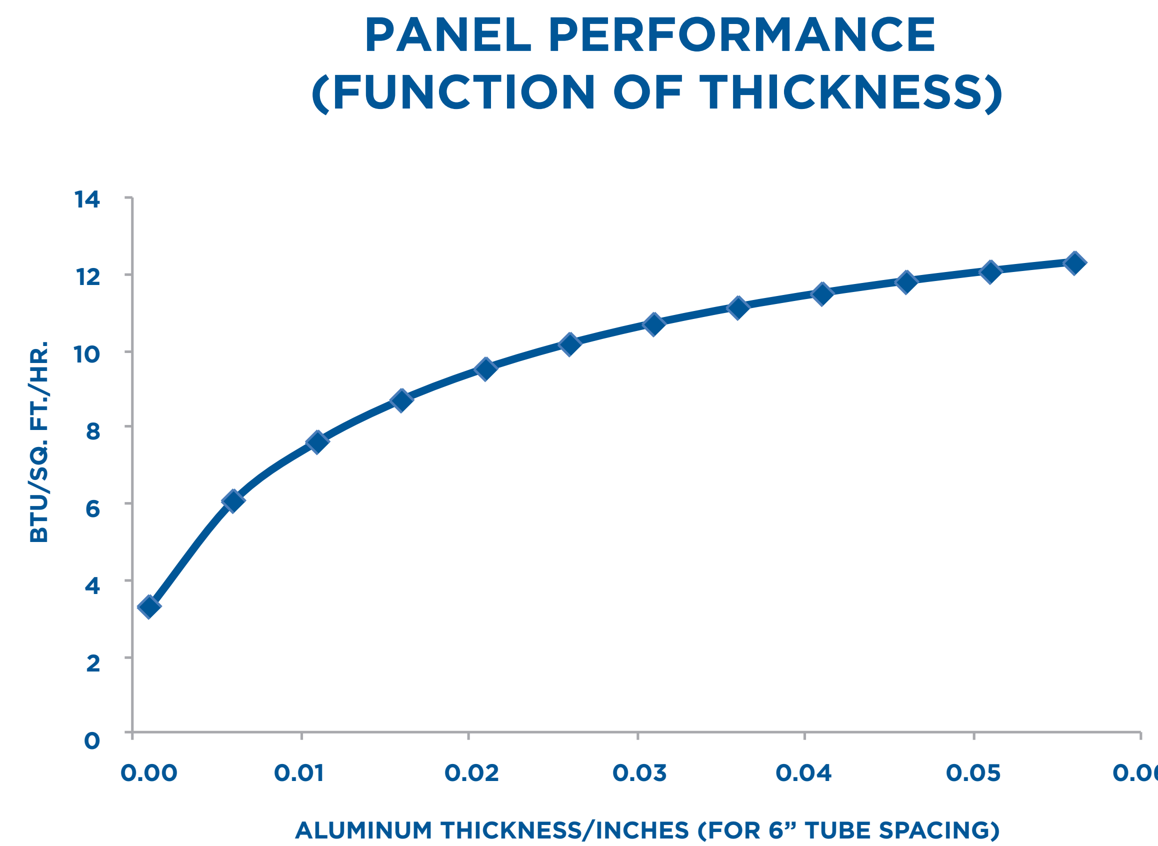


Figure S4: Modeled thermal performance of the panels as a function of aluminum thickness for a 6" tube spacing

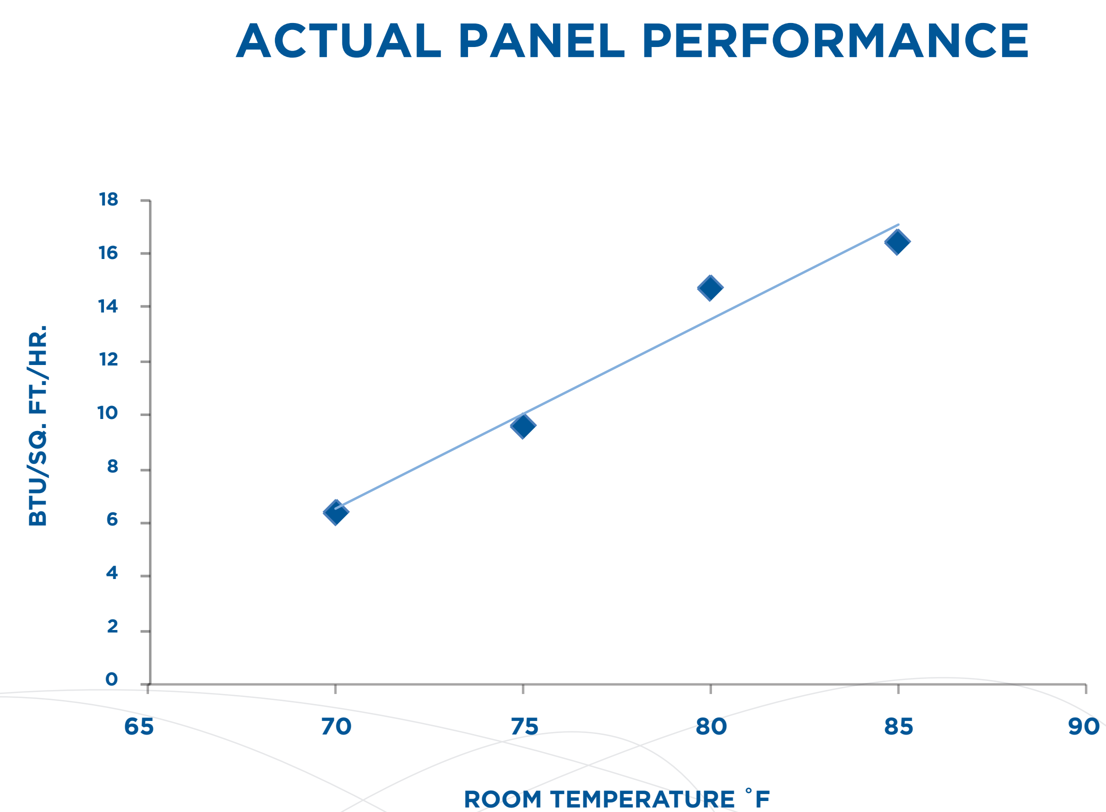


Figure S5 shows the actual thermal performance of a panel with 6" tube spacing as found in a lab test. The real panel performs fractionally better than the model, most likely because the heat transfer between the tubing and the aluminum is better in reality than in the model

Figure S6: Prototype tank showing copper heat exchanger at top

Figure S8: Tank in situ at field test site. The water in the tank is used to cool water pumped through the panels which are mounted on the ceiling, as the radiant cooling section.

THERMAL STORAGE

In order to completely remove peak loads, the system needs to be able to store enough cooling capacity to keep the house cool through the hottest part of the day. The cheapest storage material we could find was water. To determine how much water is needed typical single story and two story houses in several climate zones were modeled.

Climate Zone #	Highest daily peak cooling load (BTU)		Storage capacity required (gal)	
	1 story	2 story	1 story	2 story
2	94494	128296	379	515
8	81544	108805	327	437
9	96170	138016	386	554
10	104520	135458	420	544
12	100495	129114	404	519
13	129103	162757	518	654
15	125969	155066	506	623

The tank is designed to hold enough water to store sufficient cooling power to allow the system to not use any electricity, except the water pump, during peak hours. The water is chilled using a DX system – the copper heat exchanger is seen at the top of the tank in Figure S6. The tank walls and lid are made from structural insulated roofing panels, a low cost way of combining strength and thermal insulation. As seen in Figure S7, when the temperature outside is nearly 90°F, the temperature in the tank rises at a rate of less than 1/20th of a degree per hour.

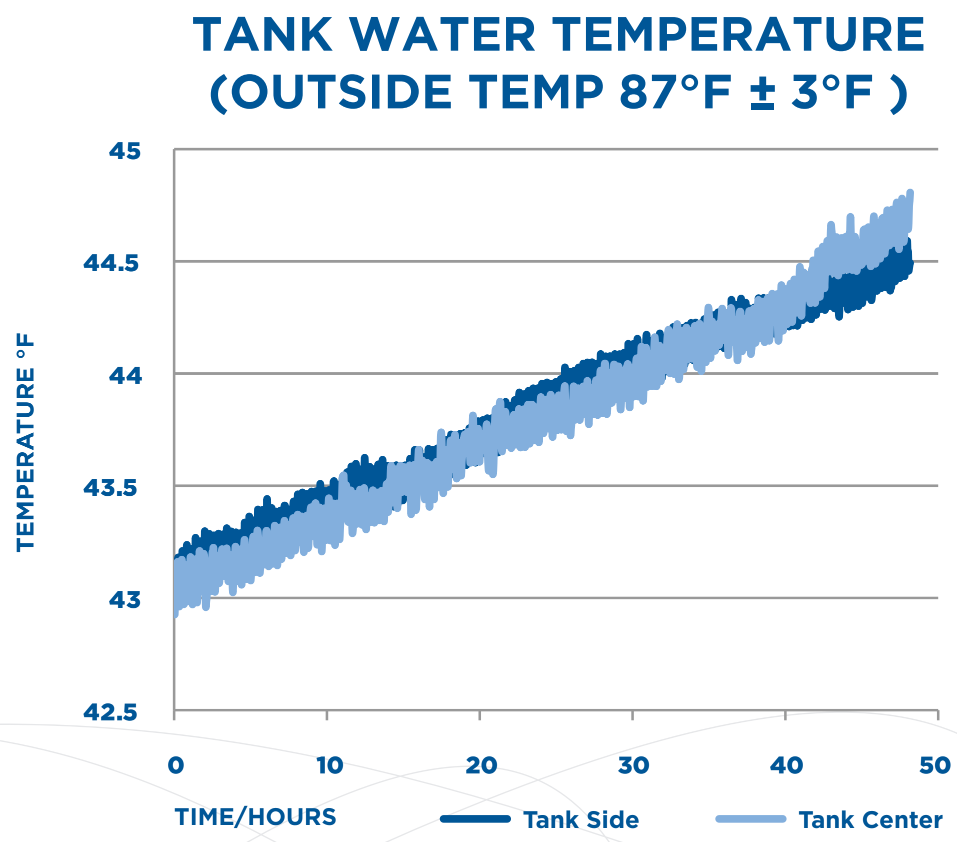


Figure S7: Rise in tank water temperature due to external heating

EVAPORATIVE CONDENSER WATER MANAGEMENT

The efficiency of the condenser in a DX system is proportional to the temperature difference between the evaporator and the condenser. As the outside air heats up the efficiency drops. This is why evaporative pre-cooling is being studied (see page 38 in this report) so intensively.

A different approach to the issue of keeping the condenser cool is to directly spray water onto the condenser. The water then evaporates off the coil, the energy required for this being provided by the refrigerant. This allows the coil to stay relatively cool even on hot days.

Utilities, industrial manufacturers, and consumers have all expressed concern regarding the use of evaporative cooling technologies due to their susceptibility of mineral deposits onto critical surfaces. The most common minerals of concern that are dissolved in the water supply are calcium and magnesium, which, in the presence of carbonate, form crystals of calcium carbonate ($CaCO_3$) and magnesium carbonate ($MgCO_3$). The total concentration of magnesium and calcium in water is generally referred to as the relative "hardness" of water.

Calcium and magnesium carbonate are inversely-soluble minerals, meaning that their solubility decreases with increasing temperature. This phenomenon, combined with the evaporation of water, causes the solution to become saturated and the minerals to precipitate on hot surfaces, causing crystal formation, commonly referred to as scale. The accumulation of scale on heat exchanging surfaces, such as heat exchangers, condenser coils, or cellulose based evaporative media, blocks air flow and reduces the capacity and efficiency of the system over time.

In order to reduce the concentration of scale-forming minerals in evaporative systems that circulate water, the water in the sump is either regularly bled off, or the sump is completely purged on a schedule, and replaced with fresh water. Treating water for hardness may reduce the water consumption for evaporative cooling systems by reducing or eliminating the need for bleeding or purging.

The WCEC is undertaking research on several fronts to address this issue. On the practical side, we have set up a water cooled condenser (an Aquachill model) in our lab and are putting it through an accelerated aging process, running it 24/7 with no purging or bleeding. The experimental set up used is shown in Figure S9.

The condenser is supplied with hot air from the heat exchanger, and the hot water tank and evaporator coil provide a heat load similar to a typical house so that the condenser will run as normal. To keep the conditions constant throughout the experiment the condenser is enclosed in a large box so the final set up looks like Figure S10

This will allow us to determine the failure modes of this type of equipment and provide a performance baseline for further tests. In parallel with this we are testing a number of water treatment technologies that might be suitable for residential use – electromagnetic, magnetic, and innovative chemical methods. These are designed to prevent scale formation and/or to prevent scale attaching to surfaces.

Based on the results of these tests we will decide which of the treatments tested will be most likely to succeed. We will, once the Aquachill has stopped working, refurbish it, fit the favored water treatment system to it to and repeat our initial tests. We will then be able to judge the effect of the treatment of the long term efficiency of the system.
In addition to the experimental tests we are conducting a program of research to develop a better theoretical understanding of the chemistry of hard water and the way in which scale formation can be controlled.

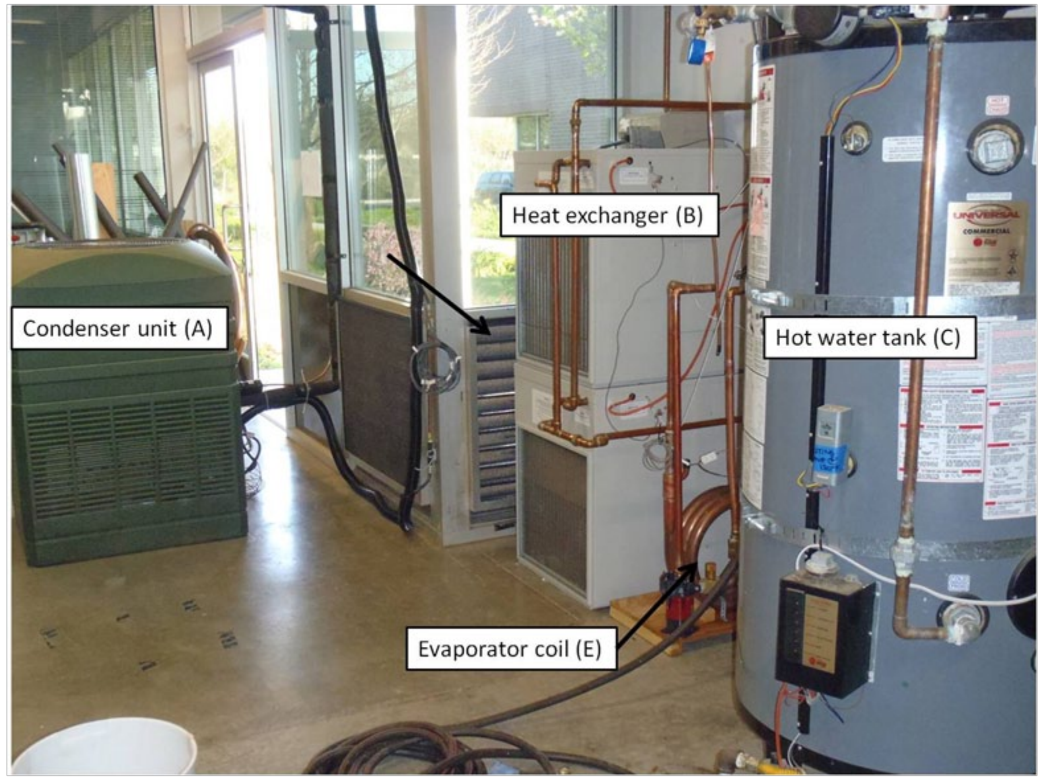


Figure S9: Experimental layout for water cooled condenser testing

Figure S10: Aquachill in its temperature controlled box, with insulated ducts supplying temperature controlled air

MULTI-FAMILY RESIDENTIAL, HOTELS, DORMS, HOSPITALITY

Hotel Controls Study

Multi-family Ventilation Diagnosis, Modeling and Improvement

WESTERN COOLING EFFICIENCY CENTER

HOTEL CONTROLS STUDY

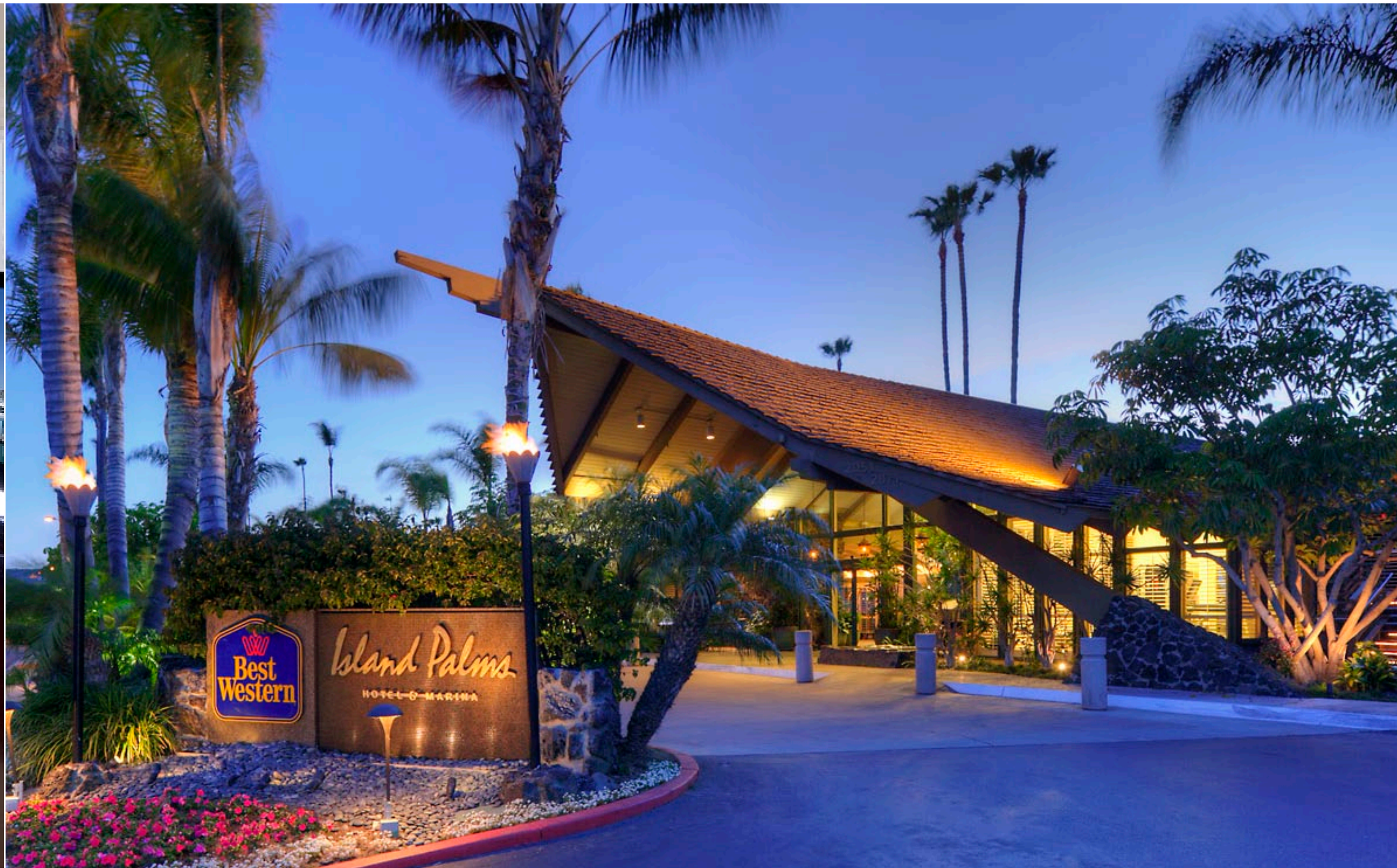
Occupancy controls, which reduce energy use when spaces are unoccupied, have been gaining interest in the field of energy efficiency. These controls are common in lighting systems, but have not gained much ground in the HVAC industry. A potential challenge in implementing occupancy controls in the HVAC industry is the time delay in returning an unoccupied space to the desired temperature when occupancy resumes.

Recent strides by HVAC manufacturers have introduced more sophisticated controls that calculate setback and setup temperatures based on the amount of time the heating and cooling equipment needs to bring the space back to the user defined setpoint temperature. This method allows the building manager to adjust the allowable recovery time to bring the room back to the setpoint. Theoretically, a longer recovery time would result in greater energy savings but may be more noticeable to the occupant.

A similar method for reducing energy consumption, specifically in buildings with a central management system, is to provide the central management system with a tool that can further increase setback and setup temperatures based on their knowledge of occupancy. In hotels this means increasing recovery times for vacant rooms.

During the summer of 2010, occupancy controls and an energy management system (EMS) were installed at the Best Western Island Palms hotel in San Diego, CA. The study included 12 rooms that were instrumented with temperature and current loggers collecting data every 15 minutes. Four rooms were used as a base case with the occupancy and EMS controls turned off while the other eight rooms utilized the controls. The data was analyzed between three groups: Baseline, occupancy controls, and occupancy with EMS controls. The daily energy use was calculated for all groups and plotted against the daily average outdoor air temperature. The results suggest that cooling energy consumption was reduced for average daily outdoor air temperatures higher than 68°F by utilizing the occupancy controls and EMS system, while at average daily outdoor air temperatures lower than 68°F no energy savings from the technology was observed.

Extrapolating the results to typical meteorological data for climate zone seven (which includes San Diego) yields a savings estimate of 100kWh/Year per hotel guest room for the occupancy controls plus EMS technology compared to the baseline. The demand response event produced mixed results in which some of the thermostats did not receive the wireless load shed command. Because the sample size was small, it is unclear what percentage of the guest rooms in the hotel did not receive the signal. No complaints were received from guests. This study took place in a very temperate climate in San Diego, CA, while the energy savings potential of these technologies could be better realized in hotter climates. Future research should focus on a hotter climate to better correlate energy savings to outdoor air temperature.



WESTERN COOLING EFFICIENCY CENTER

MULTI-FAMILY VENTILATION DIAGNOSIS, MODELING AND IMPROVEMENT

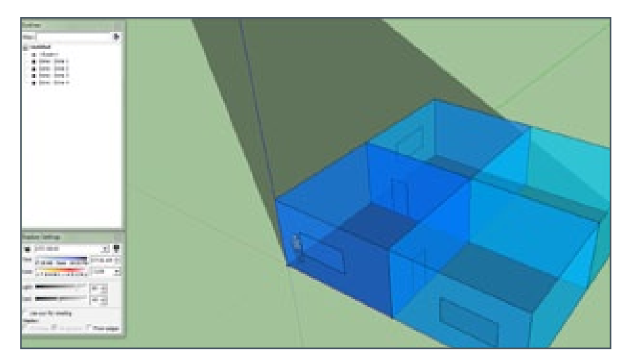
There are various performance and efficiency issues associated with HVAC in multi-family buildings that have yet to be addressed, specifically over-ventilation. The cause of these inefficiencies stems from a lack of tools and procedures to adequately analyze HVAC in multi-family buildings. In addition to inadequate tools and procedures, the type of ventilation schemes employed in multi-family buildings often changes between multi-unit exhaust to single-family methodologies at an undefined design point.

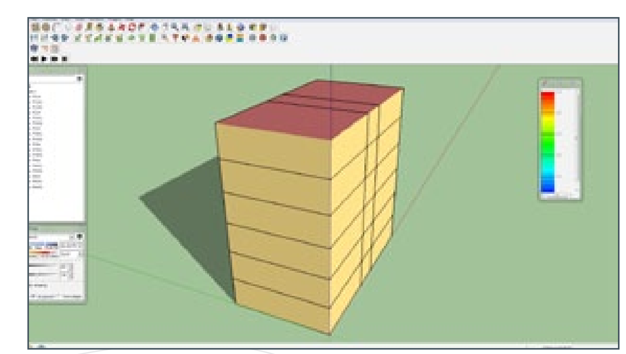
The implications of moving more air than necessary through over-ventilation are threefold; the primary inefficiency is a result of excess fan energy, the secondary inefficiency is that, as a result of excess air entering the conditioned space, these buildings heat and cool far more air than is necessary, and the final deficiency is the oversized A/C equipment required to satisfy these inflated heating and cooling loads. Unfortunately, very little is known about what is being installed, and how well these systems are working.

Therefore, WCEC's Multi-Family Ventilation project will address the challenges encountered in the HVAC of Multi-Family buildings by investigating the following target areas:

1. **Building Envelope:** by investigating cost-effective remediation and retrofit systems for envelopes of existing multi-family buildings to improve R-values between duct locations and outdoors, and reducing excess air infiltration due to leaky, un-balanceable exhaust shafts.
2. **Whole Building Systems Integration:** by addressing the tenant-space interactions and problems associated with common exhaust shafts serving multiple tenants, as well as inter-apartment leakage that creates air flows between apartments.
3. **Codes and Standards Support, Information Resources, and Market Connections:** by collecting the data required to produce a realistic treatment of multi-family HVAC, especially ventilation, in California Title-24 Residential Standards, and ASHRAE IAQ (i.e. 62.1 and 62.2) standards.

Thus far, WCEC has focused on review and summary of the current codes and standards with respect to residential ventilation, in both low and high rise applications, in order to propose potential improvements. The MFV team has also identified several potential technologies that may contribute to the goals of the MFV project; for example, reducing infiltration/exfiltration by sealing ventilation shafts and building envelopes using an aerosolized sealant. Furthermore, the MFV team has built an Energy Plus model to evaluate the effectiveness of these various retrofit options and will use the results of these simulations to refine the MFV demonstration program.





LIGHT COMMERCIAL & RETAIL

- Multi-tenant Light Commercial Retrofit Project
- RTU Retrofit Initiative
- Night Cooling of Building Thermal Mass
- Evaporative Pre-Cooling Retrofits
- Condenser-Air Pre-Cooling
- The Fault Detection and Diagnostics Initiative
- The Western Cooling Challenge

MULTI-TENANT LIGHT COMMERCIAL RETROFIT PROJECT

California's goals for increasing energy efficiency and reducing peak demand will require efforts to address existing buildings. A significant portion of California's existing building stock is classified as Multi-Tenant Light Commercial (MTLC), which includes office parks, strip malls, and mixed-use buildings that typically range between 100 and 500 kilowatts. Multi-Tenant Light Commercial (MTLC) buildings pose a particular challenge for a variety of reasons including:

- Split incentives due to ownership and lease arrangements
- High transaction costs with poor investment return
- Risk averse customers
- Lack of customer/end user energy education and expertise
- Significant variance in building type, vintage, use, and management practices

Therefore, WCEC is partnering with the California Lighting Technology Center (CLTC) and the Energy Efficiency Center (EEC) to identify and overcome the barriers encountered when addressing energy-efficiency retrofits in the MTLC market. Furthermore, this MTLC project aims to develop technological and market-based approaches that will increase deployment of energy-efficient technologies and reduce peak demand for existing MTLC buildings in California. Some of the key objectives of the project are:

- Develop audit and analysis tools that facilitate the selection and implementation of integrated technology solutions for different segments of the MTLC market in California
- Develop integrated technology packages that address lighting, envelope, HVAC and controls that are suitable for cost-effective retrofit solutions for the MTLC market
- Provide recommendations for market-ready packages of energy efficiency retrofit products that can be inserted into energy efficiency utility programs upon completion of the proposed program
- Reduce peak electricity demand in existing MTLC facilities by 30-50%
- Increase the cooling capacity of existing RTUs in multi-RTU facilities by 20%
- Reduce the connected load of HVAC equipment in existing MTLC buildings to match the reductions in cooling loads from the envelope, lighting and controls retrofits and capacity improvements provided by RTU retrofits
- Develop utility programs that will bring the integrated technology packages to the market
- Demonstrate the integrated retrofit packages
- Validate performance of turn-key retrofit packages in operation
- Validate the expected energy savings from turn-key retrofit packages in MTLC facilities
- Improve penetration of emerging energy efficiency technologies
- Demonstrate that energy consumption in MTLC can be cost effectively reduced by at least 30% through deployment of energy-efficient retrofit packages

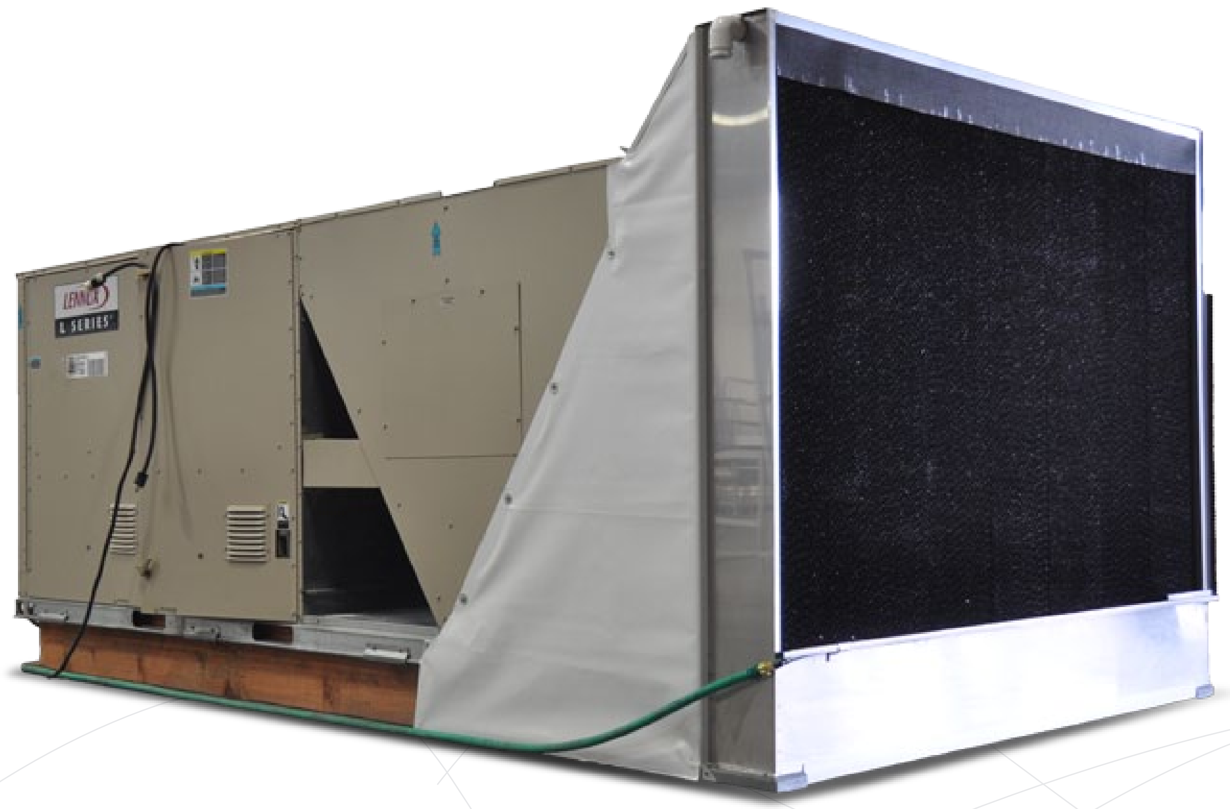
Thus far, WCEC has begun gathering potential technologies that may contribute to the goals of the MTLC project and we hope to leverage our knowledge of these individual components and technologies into integrated solutions for the MTLC market. WCEC has also been in close collaboration with the CLTC and the EEC to begin tailoring the goals and schedules of each project phase in order to provide a preliminary demonstration plan that allows for a more unified approach to addressing the MTLC challenges. Similarly, WCEC has been cooperating with the CLTC to provide technical insight to the EEC for the initial stage market research.

WESTERN COOLING EFFICIENCY CENTER

RTU RETROFIT INITIATIVE

WCEC plans to test a variety of technologies that have the potential to increase Roof Top air conditioning Unit (RTU) efficiency and reduce peak energy demand. The costs associated with replacing an RTU are typically very high so there is significant interest in technologies that can be added to existing RTUs, or retrofitted, that raise their efficiency. In California, RTUs represent approximately 70% of the commercial cooling market, so even a modest improvement in efficiency could have a big impact. This initiative will focus on evaporative condenser air pre-cooling retrofit options, but several technologies, including demand control ventilation, will be included in this research. These technologies will be tested in the WCEC laboratory as well as in the field in order to determine the effectiveness of each technology with the ultimate goal of developing a tool that will predict the energy savings that may be attributed to each technology.

In order to design this evaluation tool for RTU retrofit technologies, there are two main areas of necessary research. Measurement and verification of the upcoming technologies will be required in order to determine the possible contribution of each technology. In addition, it will be necessary to understand how RTU's are currently operating in the field in order to make an informed decision on which technologies might have the greatest impact. For example, demand control ventilation saves energy costs by reducing the fan speed when the air conditioner is working under a partial load. This may be a beneficial technology if most air conditioning fans are constantly running at full speed, but will be less beneficial if most units fail to use the fan at all. In addition, evaporative condenser air pre-coolers may require a high quality water source, and it will be necessary to determine whether this is easily provided to commercial RTUs. To gather information that will assist in developing an understanding of typical air conditioner operation and resource availability, a field survey will be conducted in several climate zones in California. In addition, an attempt will be made to comb existing databases for information related to fan operation modes. Some known data bases that may be accessible include fan operating data from Portland Energy Conservation Inc's (PECI) AirCare Plus program and the California end-use commercial survey. This information will help to determine which technologies may be most beneficial to widely promote, and will assist with designing a tool for predicting possible energy savings. Ultimately, it is hoped that utilities management can use this tool to effectively design rebates and incentives programs to spur more customers towards effective technologies that can reduce energy demand.



NIGHT COOLING OF BUILDING THERMAL MASS

Thermal Energy Storage has the potential to significantly reduce peak energy demand by allowing space conditioning processes to be performed at night. In addition to reducing peak energy consumption, it may also be possible to increase the overall efficiency by leveraging the advantages of cooler environmental conditions experienced at night. One such advantage, for example, is increased effectiveness of evaporative cooling technologies due to typically lower wet bulb temperatures.

Over the course of the previous year WCEC has developed an Energy Plus model of Wal-Mart's HE6 radiantly cooled store in Sacramento, CA, with the goal of evaluating the potential for storing thermal energy in the concrete slab. Initially, this model was intended to focus solely on simulating the stores' radiant system, but, in order to validate the model through comparison to real-world data, other components were eventually added. The model has been continuously refined and improved as our understanding of the store has increased and our knowledge of Energy Plus has improved.

EVAPORATIVE PRE-COOLING RETROFITS

Evaporative pre-cooling is a promising up and coming technology that is able to improve cooling efficiency and reduce peak demand. It is achieved by forcing outside air through an evaporative media before entering the condenser. Lowering the outside air temperature improves the air's ability to remove heat from the condenser- translating to a lower energy consumption of the Air Conditioning Unit.

WICKOOL®

WicKool® is a completely passive implementation of Condenser Air Pre-Cooling. It is designed to use a special media that can "wick" condensate water into the path of the air flowing through the condenser.

The first WicKool® prototype was installed on the roof of the Target Retail Store in August 2009. In the fall of this year, the WCEC was able to install ten addition WicKool® units on roof top units (RTU) ranging from 4-24 tons of cooling capacity. During the installation it was observed the media, used to wick the water in front of the condenser, was degrading more rapidly than expected. The lab tests of the collected samples showed over a 50% loss in performance. To help solve this media longevity issue, the WCEC sponsored a senior design project, for mechanical engineering students in their final year of study, to focus on finding candidates for replacement media. At the end of their project, the senior design team provided the WCEC with two viable media replacement candidates. The first is a cellulose material that is currently manufactured in the USA for use in residential humidifiers (See figure L1). It is composed of soft and hard wood fibers that have been chemically treated to inhibit microbial growth and increase durability. The cellulose displayed great wicking ability in the lab and was projected to last up to 4 months in the field. It is inexpensive and could be replaced every season, much like the indoor air filter. The second is a polypropylene (PP) material for use in residential humidifiers (See figure L2); however currently, it is only manufactured in China - making it considerably harder to obtain then cellulose. In the lab, the PP had a decent wicking ability; however, the most noticeable characteristic was its rigidity and the projected lifetime of a year of use in the field.

The WCEC was able to move forward with purchasing the cellulose material in time for field testing during summer 2011. Even though the cellulose performed great in lab tests, in the six weeks it has been in the field it is not producing the expected results. Most noticeably, the cellulose material lacks rigidity when it is saturated with water, drastically shortening the materials expected life on larger RTUs. With these results, the WCEC began looking into a PP purchase from the manufacturer in China; however, at this time, no purchase has been finalized. In the upcoming year, the WCEC will field test the PP material on the rooftop of Target.

Figure L1: Sample of cellulose humidifier pad composed of hard and soft wood fibers.

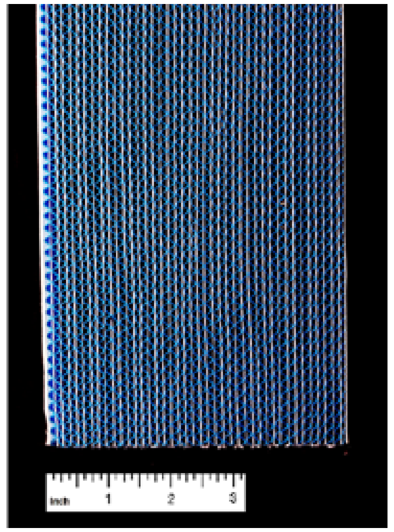


Figure L2: Sample of polypropylene humidifier pad.

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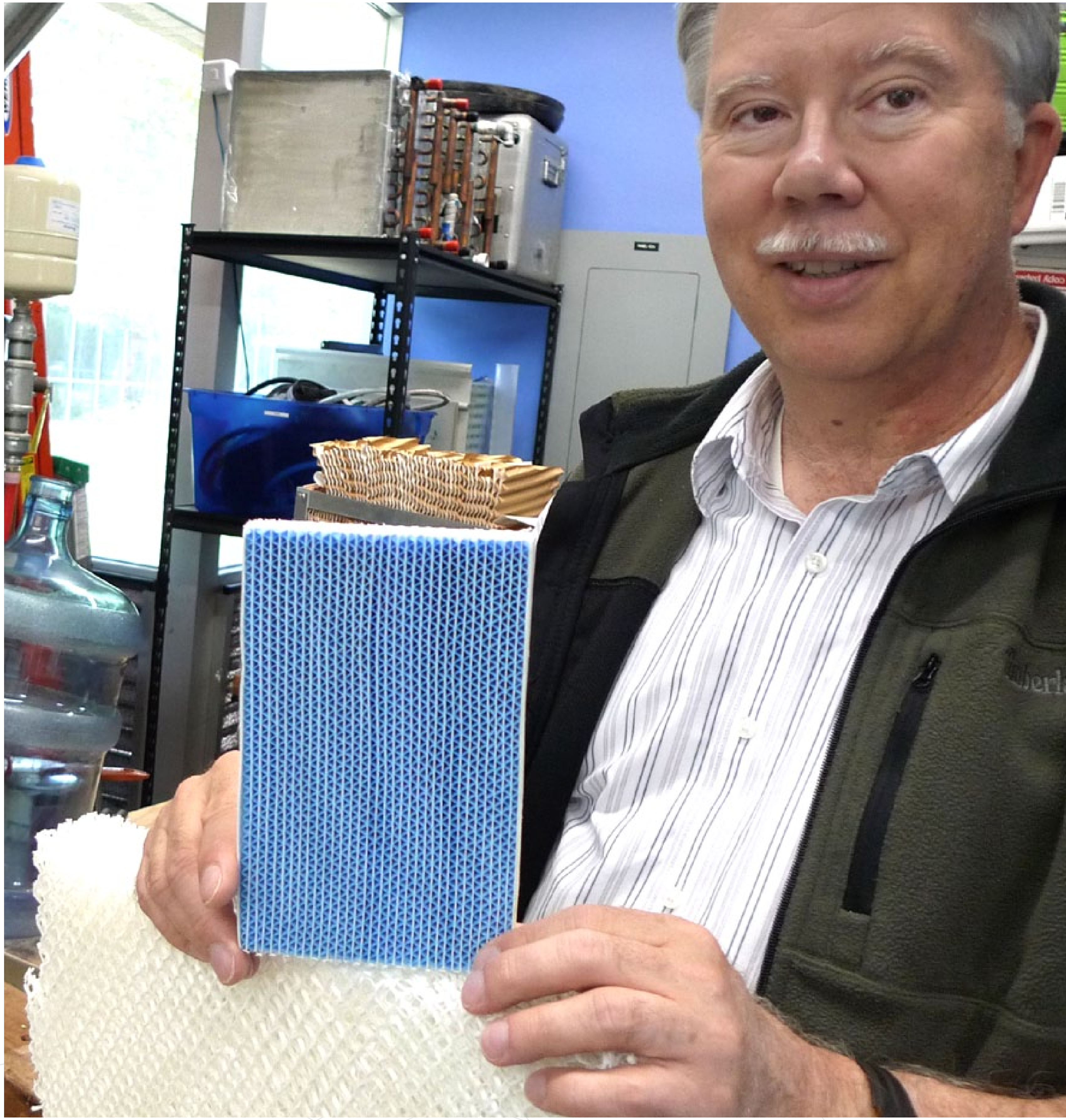


FLASHCOOL

FlashCool is a direct evaporative condenser air pre-cooler on a 50-ton refrigeration condenser on Target in Davis. It works by having air pass through a water-sprayed pad before it reaches the condenser. FlashCool contains two improvements over an earlier iteration: The condenser fans were replaced with variable speed fans, and the misters that clogged previously have been replaced with a more robust large nozzle system. FlashCool was replaced with the current version in late summer 2010.

Flashcool has large nozzles spraying water on pads (Figure L6). Not shown in this picture is the dust cover that covers the frame and the drift eliminator behind the blue pad.

WCEC is collecting weather data (barometric pressure, temperature, and relative humidity), compressor current and Target's electrical sub metering data. The electrical sub-metering is down to 15 minutes. Efficiency and capacity measurements are not possible because of the complexity of the system.

Flashcool delivered savings both in total energy use per day and maximum power demand per day (Figures L3 and L4). The baseline data was recorded over the summer of 2010 and the Flashcool data was recorded over the summer of 2011. The daily energy savings are dependent on temperature, with approximately a 20% savings at low temperature and a 10% savings at high temperature. The power demand savings is approximately 15% and is not strongly temperature dependent. The savings is due to a combination of the condenser air pre-cooling and the variable speed condenser fans. WCEC will generate one more data set to attempt to separate out the effect of the fan controls versus the effect of the pre-cooler.

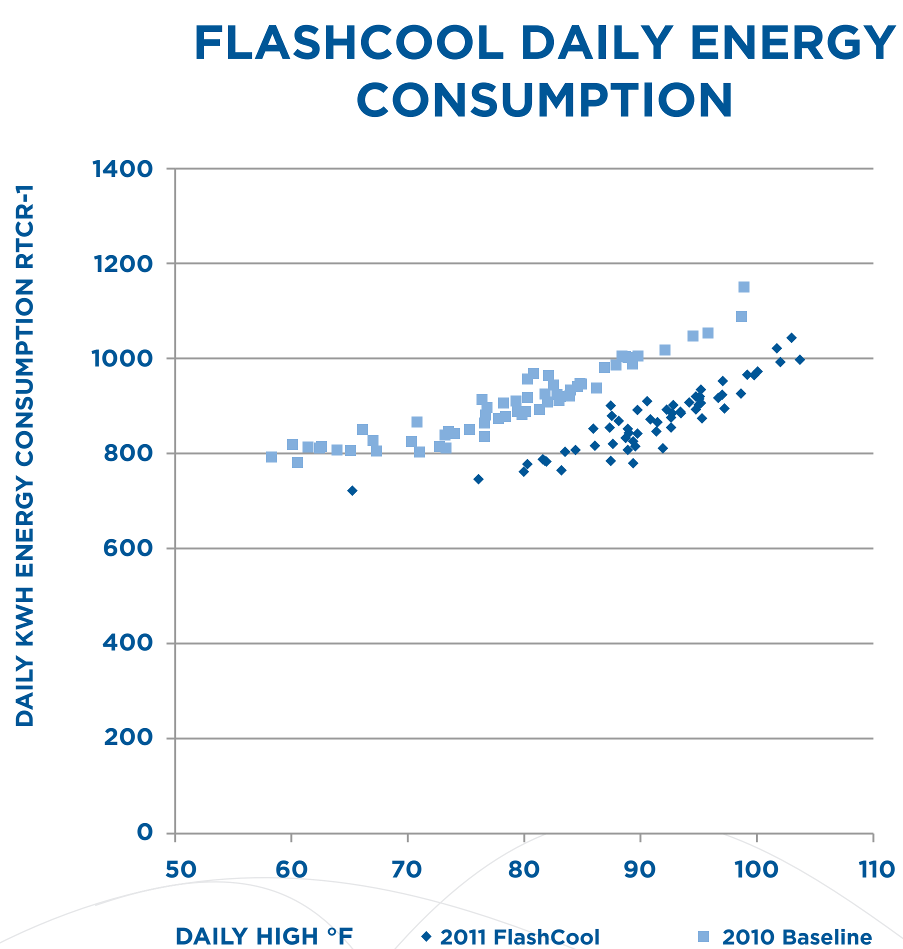


Figure L3: Daily Energy Consumption
The Daily energy consumption is a little narrower of a band because any anomalous activity, such as stocking, tends to average out over the course of the day.

PATH FORWARD

The next thing we will do is to try to tell what saving come just from the variable speed fans. We will turn off the water pump and remove the pads to separate out the savings from the two major changes. There is some statistically insignificant data from when FlashCool's pump was offline that still shows saving over baseline, but worse performance than with the water pump spraying.

Figure L5: Original Flashcool design

Figure L6: Inside of a current, new FlashCool Nacelle

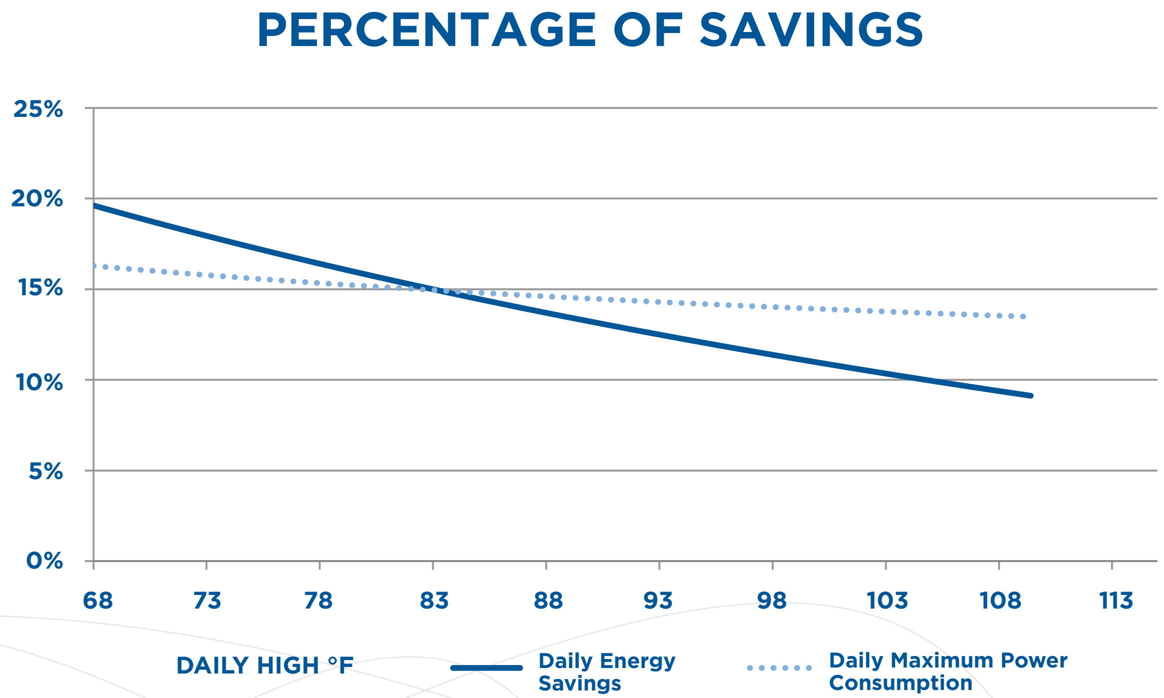


Figure L4 Percent Savings, based up arithmetic to linear fit lines

DUALCOOL

DualCool is a both a condenser air pre-cooler and a ventilation air pre-cooler. The ventilation air is pre-cooled without adding moisture by passing the evaporatively cooled sump water through a water to air heat exchanger. Dual Cool is installed on two roof top units on the Target in Davis. Dual Cool is only installed on the first stage of the two-stage condenser. When the second stage turns on for additional capacity, the air is not pre-cooled to the second stage condenser. An air side analysis of the coefficient of performance (COP) of both RTUs before and after Dual Cool was completed to determine the "before" and "after" results of installing Dual Cool (Figure L7 and Figure L8). The results show that the efficiency improvement resulting from Dual Cool is 10-50% (depending on outdoor air temperature) when operating in the first stage and approximately half of that when operating in the second stage (Figure L9).

ANALYSIS OF COP IMPROVEMENT (FOR RTU 6 & RTU 9)

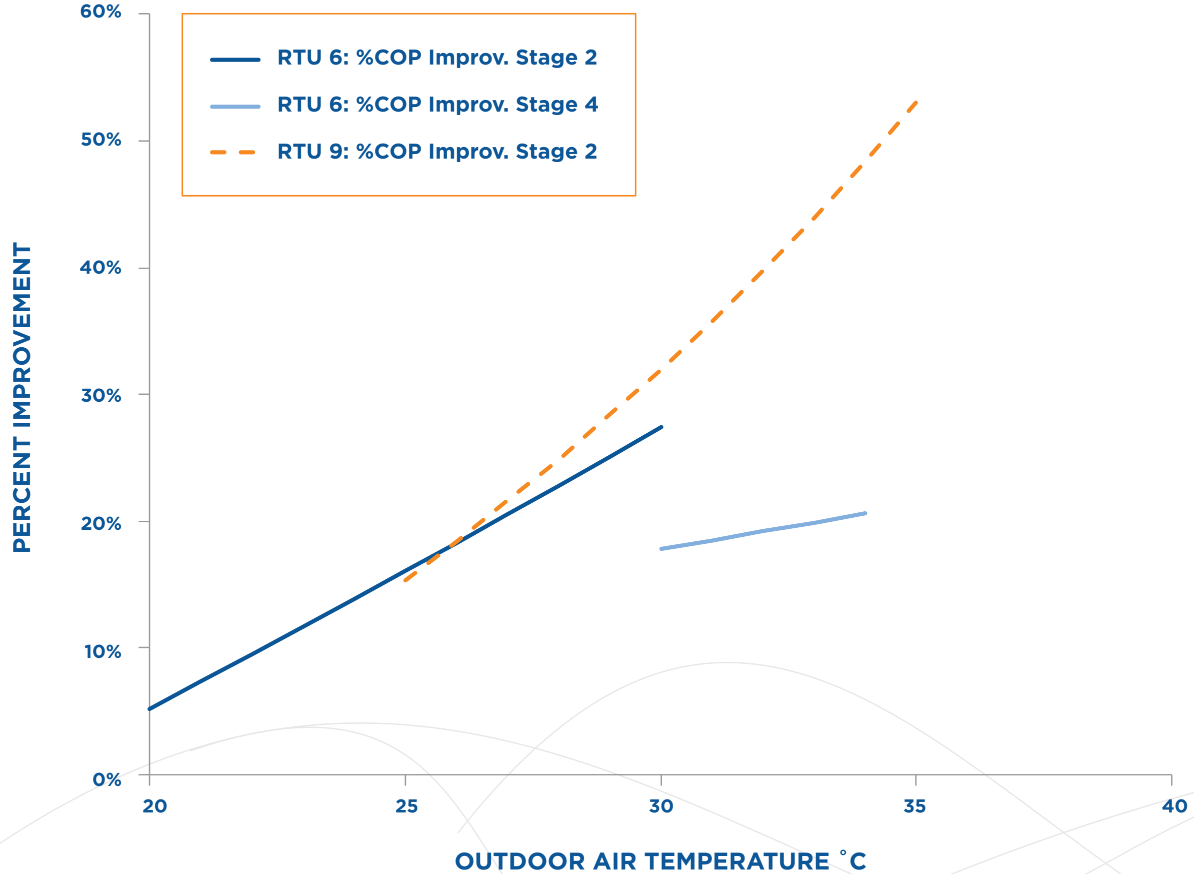


Figure L9

WESTERN COOLING EFFICIENCY CENTER

ANALYSIS OF COP (FOR RTU-6) DUALCOOL RETROFIT

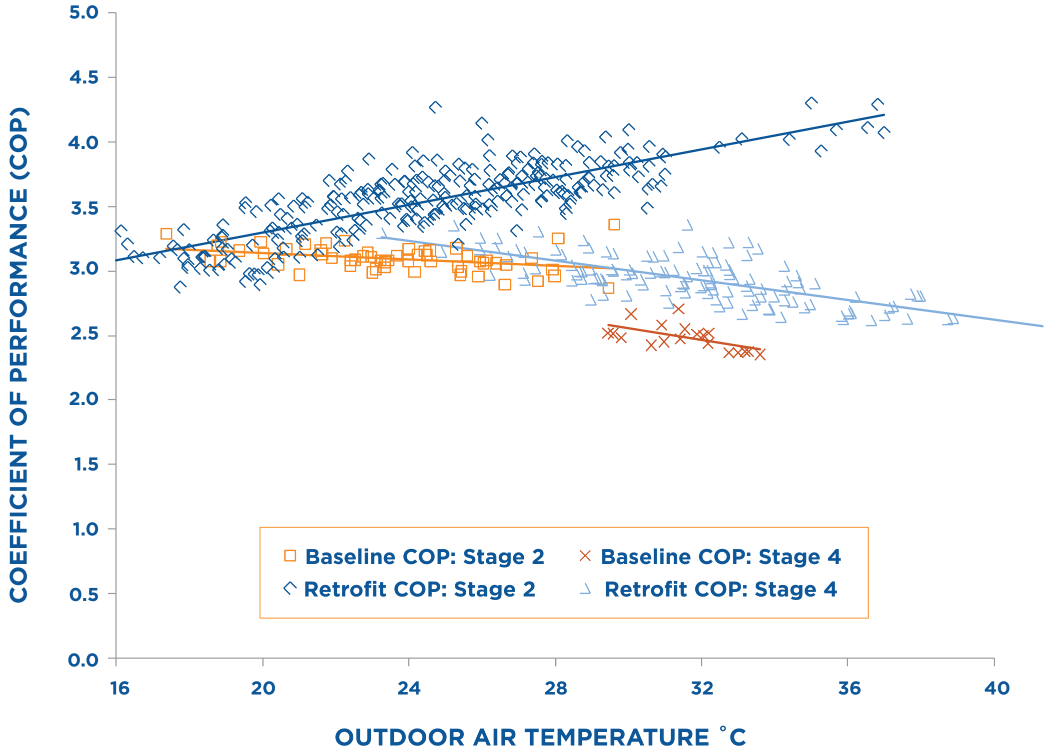


Figure L7

ANALYSIS OF COP (FOR RTU-9) DUALCOOL RETROFIT

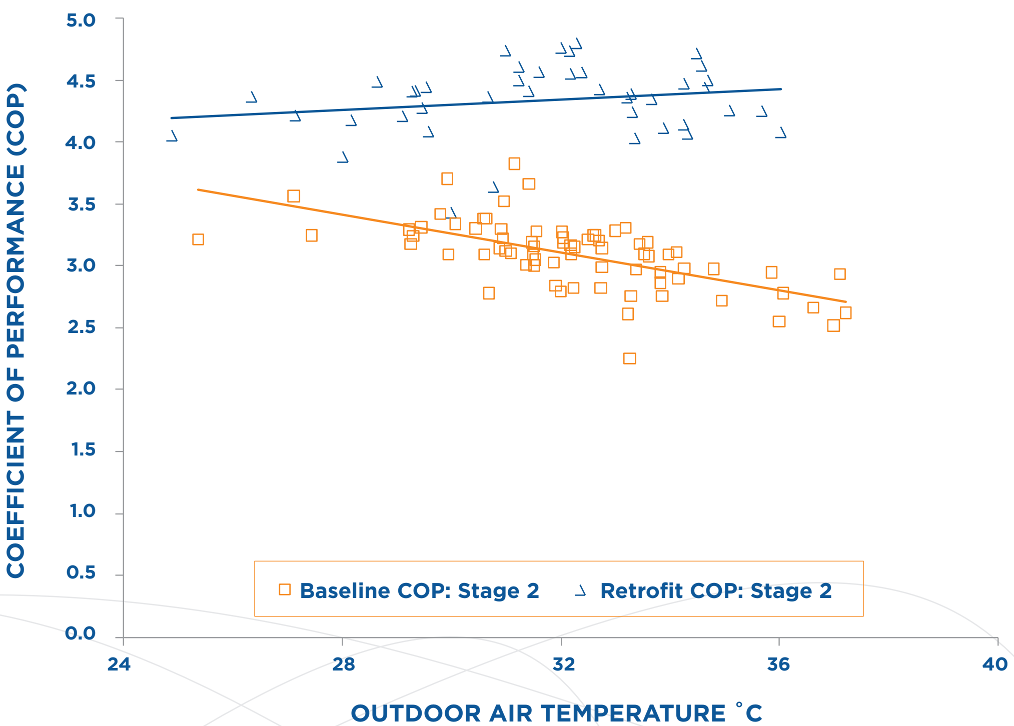


Figure L8

CONDENSER AIR PRE-COOLING

CONDENSER AIR PRE-COOLING TEST PROTOCOL PROJECT

As part of our collaboration with SCE and SDG&E, WCEC is developing a standard test protocol to evaluate condenser air pre-coolers as retrofits for packaged rooftop air conditioners and split systems. Market-available pre-cooler technologies employ many different designs and operating schemes which may significantly impact their performance and reliability. Consequently, two products in this category could offer significantly different efficiency improvements, use different amounts of water, and require widely different maintenance practices. WCEC's efforts here are addressing the need for a standard basis of comparison for various systems. The test protocol in development will identify the metrics that are most appropriate for making fair comparisons of alternative products, and will define all of the specific measurements and calculations necessary to determine those values.

As an example, water use efficiency will be an important value for comparison of various evaporative pre-coolers since two devices might offer similar energy savings, while demanding considerably different amounts of water. The protocol will define exactly how to measure and calculate this metric accurately in order to develop a comparable characterization of each device. The definition of such a standard protocol is important since the choice of measurement technique and calculation for each metric may significantly bias the results. Further, the protocol will offer a method for calculating the energy savings impact from a device in various applications, and will be used to develop example estimates of the energy and peak demand savings potential for a few technologies tested as part of the protocol development.

Some of the metrics that the test protocol will highlight include:

- Evaporative effectiveness of the pre-cooler
- Water use efficiency for the pre-cooler
- Sensitivity of performance to wind
- Sensitivity of performance to application (airflow, geometry, etc)
- Maintenance requirements
- Reliability concerns (carry-over of water onto condenser coils, etc)

PROJECT STATUS, RESULTS, AND PATH FORWARD

The path toward developing a standard test protocol that is appropriate for comparison of various devices includes testing multiple devices, and evaluating various field test methods, instrumentation strategies, and calculation procedures. Comparison of the various approaches will lead eventually to a straightforward, accurate, and robust methodology. In the first phase of this project, WCEC instrumented and monitored a three-ton conventional split condenser unit, retrofit with the MistEcology AC-Spritzer. The technology was installed on a split system serving conditioning for a conference room, and operated under regular conditions during monitoring periods. The primary aims of the effort were to instrument the equipment in several ways, to compare various monitoring and calculation strategies, and to quantify the sensitivity of results to all potentially impactful variables. System capacity and efficiency were determined by way of a refrigerant-side monitoring approach that relies only on compressor suction pressure and temperature, compressor discharge pressure and temperature, liquid line temperature, and compressor power draw. Water flow rate was measured with an inline paddlewheel flow meter to evaluate water use efficiency, and a full suite of meteorological conditions were measured in order to test sensitivity to climatic variables.

The most important realization through this effort was that quantifying evaporative effectiveness for a pre-cooler through field tests can be problematic. The measurements needed to calculate the metric can be easily skewed if not properly installed, and the value is highly sensitive to multiple variables that are not straightforwardly measured. A proper approach for determining this value deserves serious focus within a standard test protocol. WCEC identified three separate options for calculating the evaporative effectiveness, they each require measurement of outside air conditions, but rely separately on:

- Direct measurement of coil inlet temperature
- Measurement of exhaust air humidity ratio
- Numerical calculation based on performance data

The third method can build from various performance metrics to calculate evaporative effectiveness. For the MistEcology AC-Spritzer, this method results in an average effectiveness of 41%, 44%, and 48%, depending on whether power draw, COP, or capacity was used as the basis for calculation. The first and second methods are simpler, and don't require a numerical solution, but can yield noisy and bias results based due to the physical location of the instrumentation required, and air flow distribution characteristics that cannot be easily accounted for. As the project continues, these lessons will be incorporated into a standard protocol that highlights a method that minimizes monitored points and defines specific approaches to reduce the uncertainty from key measurements.

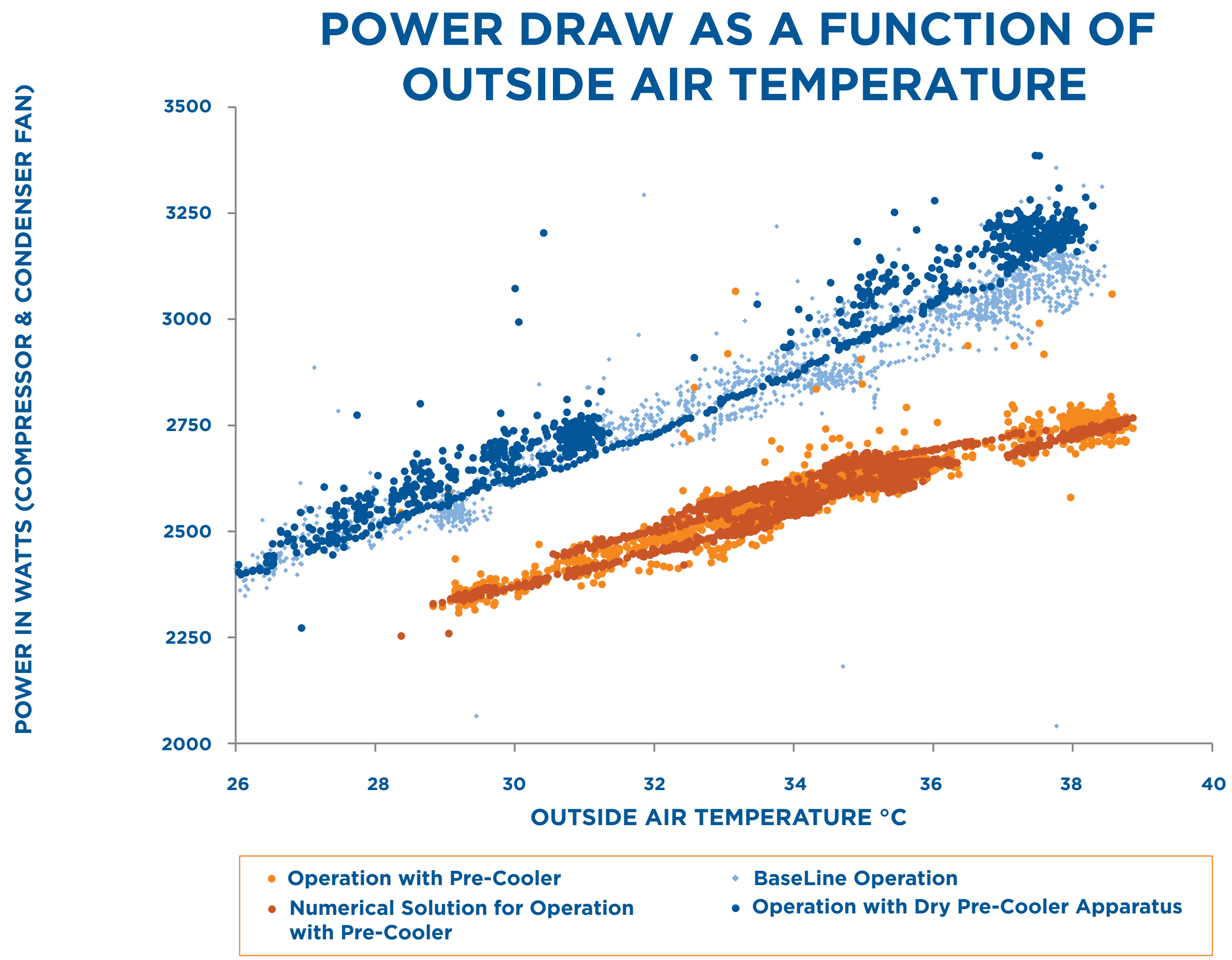


Figure L10 Electric power draw for the compressor and condenser fan as a function of outside air temperature for four different data sets generated though the study

Although the final intent is the development of a standard protocol to evaluate the numerous evaporative pre-cooler devices, WCEC's recent tests also provide some performance numbers for the MistEcology AC-Spritzer. Figure L10 presents the power draw for the condenser unit as a function of outside air temperature for four different data sets generated through the study. These data sets trend baseline operation, operation with the pre-cooler apparatus installed but operating dry, operation with the pre-cooler functioning, as well as the correlated values for calculated power draw generated through the numerical method for determining evaporative effectiveness. Most importantly, these results indicate power reduction of roughly 10% for the condenser unit across the observed conditions.

THE FAULT DETECTION AND DIAGNOSTICS INITIATIVE

One of WCEC's major initiatives over the last year has been related to Fault Detection and Diagnostics ("FDD"). This is a technology that uses hardware, sensors, and software to detect and diagnose problems with Rooftop Units. This technology has been pursued by developers for decades, although recent advances suggest that it may be reaching a "tipping-point," where the technology will soon begin to advance rapidly. California's Long-Term Energy Efficiency Strategic Plan is adding motivation for moving this technology to the market place, with its goals of achieving Zero-Net Energy commercial buildings by 2030, and its more specific goal of advancing climate-optimized HVAC equipment. They have identified a set of actions that must take place to reach these goals, including the development of national standards for FDD tools.

WCEC is working on advancing this technology in a code change proposal project funded by the California Energy Commission's Public Interest Energy Research program, in collaboration with New Buildings Institute (NBI). And in a project for Southern California Edison WCEC is helping the utilities to reach out to the industry and advance the technology.

CALIFORNIA CODE CHANGE PROPOSAL

As a part of the CEC-funded project, WCEC and NBI are developing a proposal to incorporate a prescriptive requirement for FDD into California's Title 24 Building Code. If adopted, this would require that the following conditions be detectable by any rooftop unit installed in California:

- Low refrigerant charge
- Air temperature sensor malfunction
- Economizer not economizing
- Economizer not economizing at the correct temperatures
- Excess outdoor air

In addition, tools would have to calculate a system efficiency metric that can be compared with no-fault or historical performance, and faults detected by the tool would have to be annunciated to some form of fault management tool, or to the zone thermostat. There would be exceptions for RTUs that are below a given size, and for buildings that incorporate extra energy efficiency measures elsewhere in the building.

WCEC analyzed the market and identified a number of tools that are currently available or under development that could meet these requirements (see Figures L11 and L12). Analysis conducted by the overall project team indicates that an FDD tool would save approximately 12% of annual energy for an RTU. This analysis used time-dependent valuation for time-of-use energy savings, and considered the probability that a fault will exist, the probability that the FDD system will detect the fault, and the probability that a fault would have been detected without use of an FDD tool. It is expected that once this code proposal is adopted, original equipment manufacturers would begin to incorporate these faults into their suite of RTU alarms.

With the support of Southern California Edison Company, WCEC is also facilitating the "FDD Subcommittee" — a subcommittee of the Western HVAC Performance Alliance. This group of industry leaders is organized to develop and implement a roadmap to meeting the goals of the Strategic Plan with regards to FDD. This 17-member committee consists of researchers, contractors, original equipment manufacturers, third-party FDD tool developers, end users, and equipment manufacturer associations. WCEC is in the process of drafting the roadmap that will identify the actions needed to move FDD into the marketplace. These actions include engineering and behavioral research, technology development, emerging technology support, codes and standards, demonstration projects, case studies, and energy savings estimation.

WCEC is also working to standardize FDD technology by spearheading an effort to develop an ASHRAE Standard Method of Test for FDD. ASHRAE Standard 207P will provide metrics for the performance of an FDD method, and describe test conditions and test methods for demonstrating that the tool can detect and diagnose faults. This Standard is a necessary precursor to including FDD in building performance standards. A WCEC Staff Engineer has been nominated to Chair the committee that is forming to draft this standard.

PATH FORWARD

In the upcoming year, we plan to continue working with various stakeholders to further the commercialization of FDD:

- Working with the California Energy Commission to support the proposed changes to Title 24.
- Working with manufacturers to ensure that they understand the new requirements and are ready with new tools to hit the marketplace when the new code goes into effect.
- Working with owners and contractors to ensure that there is an understanding of the new requirements, how to use the new tools, and what benefits they can bring.
- Working with the FDD Subcommittee to finalize the industry roadmap and chart the course for FDD in the future.
- Leading the ASHRAE committee that is tasked with developing a standard for testing FDD tools (SPC-207P).

Tool Name	Status	Developer
FDSI Insight V.1	Available	Field Diagnostics, Inc
Sensus MI	Available	University of Nebraska
ClimaCheck	Available	ClimaCheck Inc.
Sentinel/Insight	Beta	Field Diagnostics, Inc
SMDS	Pilot	PNNL
NILM	Pilot	MIT
Low Cost NILM	Pilot	MIT
Virtjoule	Developing	Virtjoule Inc.
Low Cost SMDS	Developing	PNNL

Figure L11: Description of some of the Third-Party tools available for accomplishing Automated Fault Detection and Diagnostics in Rooftop Units Industry Outreach

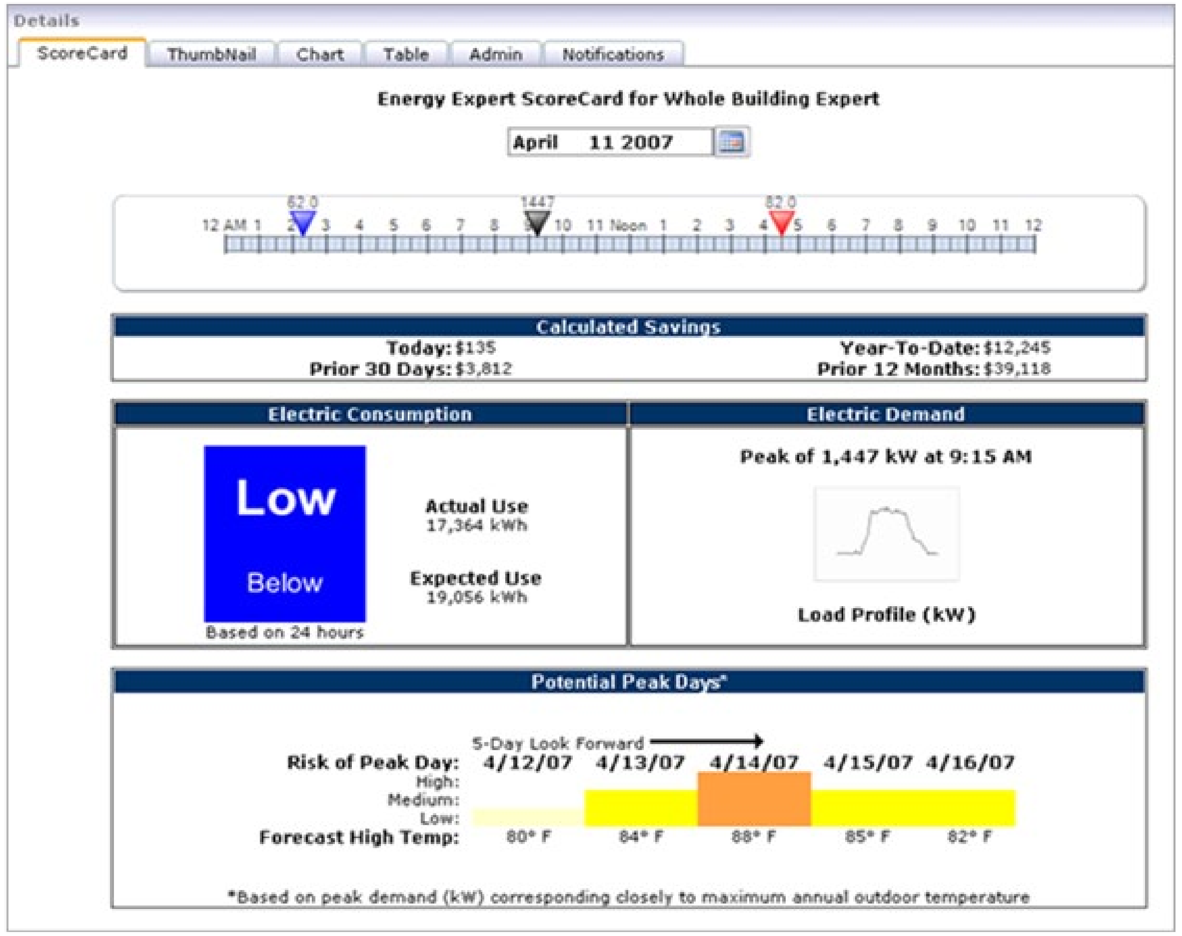


Figure L12: Interface used by one Third-Party FDD Tool (NorthWrite.com)

WESTERN COOLING EFFICIENCY CENTER

THE WESTERN COOLING CHALLENGE

The Western Cooling Challenge is a multiple winner competition that encourages HVAC manufacturers to develop climate-appropriate rooftop packaged air conditioning equipment that will reduce electrical demand and energy use in Western climates by at least 40% compared to current federal standards. The intent of the Challenge is to advance the market introduction of commercialized products, and thus encourages participants to consider many non-performance-based design factors such as cost-effectiveness, system reliability, and non-energy code compliance. WCEC conducts laboratory testing and monitors field demonstration of equipment to prove real-world performance and equipment reliability while providing transparency to the industry by serving as a neutral evaluator of these advanced technologies.

The Challenge does not say how to achieve the ambitious performance requirements; so technologies appropriate for the Challenge draw on various strategies including: indirect evaporative cooling, variable speed fans, multiple stage compressors, evaporatively cooled condensers, and use of part-load operating modes that can provide reduced capacity cooling with very high efficiency. All of the systems in design, testing, and demonstration are some variation of a hybrid unit that combine many of these strategies to achieve the aggressive Challenge performance targets.

In summary, the Challenge invites manufacturers to design and commercialize rooftop packaged units that meet the following key criteria:

- Minimum sensible credited EER of 14.0 at full capacity operation, with 120cfm/AHRI nominal ton ventilation rate, external resistance equivalent to 0.7" WC ESP at 350 cfm/nominal ton, and under WCC Peak Conditions
- Minimum sensible credited EER of 17 at full capacity operation, with 120cfm/nominal ton ventilation rate, external resistance equivalent to 0.7" WC ESP at 350 cfm/nominal ton, and under WCC Annual Conditions
- Provide some dehumidification, $\Delta\omega$=0.000363 lb/lb from WCC Peak Conditions
- Maximum water use of 4gal/ton-hr
- Demonstrated minimum production capacity of 500 units/year
- Ability to detect and communicate performance degradation

UC DAVIS WESTERN COOLING CHALLENGE CERTIFIED

HISTORY & STATUS OF THE CHALLENGE

The Western Cooling Challenge was announced in 2008, and quickly drew the first formal entry from Coolerado who was confident their hybrid system could meet the Challenge criteria. Their equipment, the Coolerado H80, a five ton nominal rooftop packaged air conditioner was laboratory tested in Colorado at the National Renewable Energy Lab, and as summarized in Figure L13, surpassed the Challenge requirements with flying colors. Coolerado's hybrid system couples indirect evaporative cooling with two stage vapor-compression cooling. The indirect evaporative cooler can operate alone or it can act as a pre-cooler for the vapor-compression system. When the compressor operates, exhaust from the indirect evaporative cooler is used for condenser cooling. The indirect evaporative cooler used for the system is an integral device with multiple air pathways that exchange heat and mass to cool supply air without the addition of moisture. Motorized dampers control the balance of outside air and return air, and the system operates with a minimum outside air fraction of approximately 45%. Variable speed supply fans for both supply and exhaust allow for part load operation when only a fraction of the full load capacity is needed.

Although there were initially almost a dozen manufacturers signed on as participants in the Challenge - in part due to economic decline and a general lack of R&D resources within the industry – most of these manufacturers backed away from the program, and Coolerado's hybrid stood as the singular formal entry for more than 18 months. However, 2010 and 2011 brought revitalization for the program; much in part due to championed leadership and support for the Challenge by Southern California Edison. WCEC has been working closely with several manufacturers to foster the development of equipment that might meet the rigorous performance criteria, and has been arranging and conducting field evaluations of the Coolerado H80 and various potential Challenge competitors. As a direct result of these efforts, WCEC is pleased to announce several manufacturers in the pipeline, and currently two new formal Challenge competitors – Speakman Cooling Solutions, and TRANE. WCEC is arranging and working through laboratory testing and field demonstrations for both of these systems, and anticipates having results for each of the systems by the end of winter.

TRANE's hybrid rooftop unit couples evaporative condenser air cooling, and indirect evaporative ventilation air cooling, with a 3 stage vapor-compression system. The indirect evaporative cooler is a water coil located in the ventilation air stream, which draws cold water from the sump of the direct evaporative condenser air cooler. The equipment operates as a conventional rooftop unit typically would, except that whenever the unit is drawing ventilation air, the indirect evaporative cooler operates, and whenever the compressors cycle, the evaporative condenser air pre cooler operates. In this way, the vapor compression efficiency is greatly improved, the load on the vapor compression system is greatly reduced, and 100% outside air cooling can be extended well beyond typical economizer hours without the compressor.

Speakman Cooling Solutions' entry, the Air20 Quattro|Hybrid CRS-2500 is a hybrid version of their new indirect-direct evaporative cooler. The system uses indirect-evaporative cooling, vapor-compression cooling, and direct evaporative cooling. Each cooling component operates independently or in concert depending on the measured outside air conditions and commissioned settings for the system. The indirect evaporative cooler is a water coil, which draws cold water from the sump of a direct-evaporative cooler that pre-cools air for the vapor-compression condenser. Motorized dampers control the balance of outside air and return air. The system can be programmed to provide a minimum fraction of continuous ventilation in all modes, or can be allowed to operate as a recirculation only machine when meteorological conditions demand operation in vapor compression mode.

COMPARISON RESULTS FOR COOLERADO'S COP

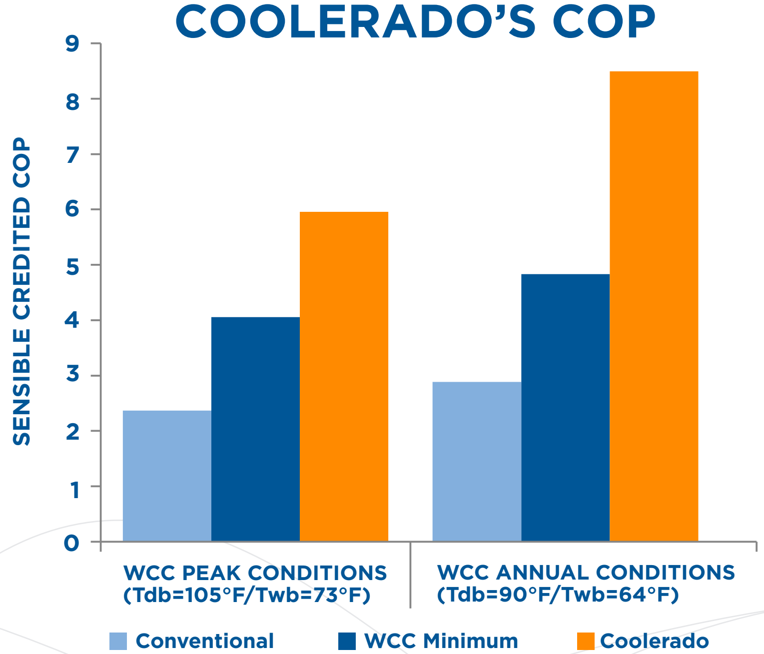
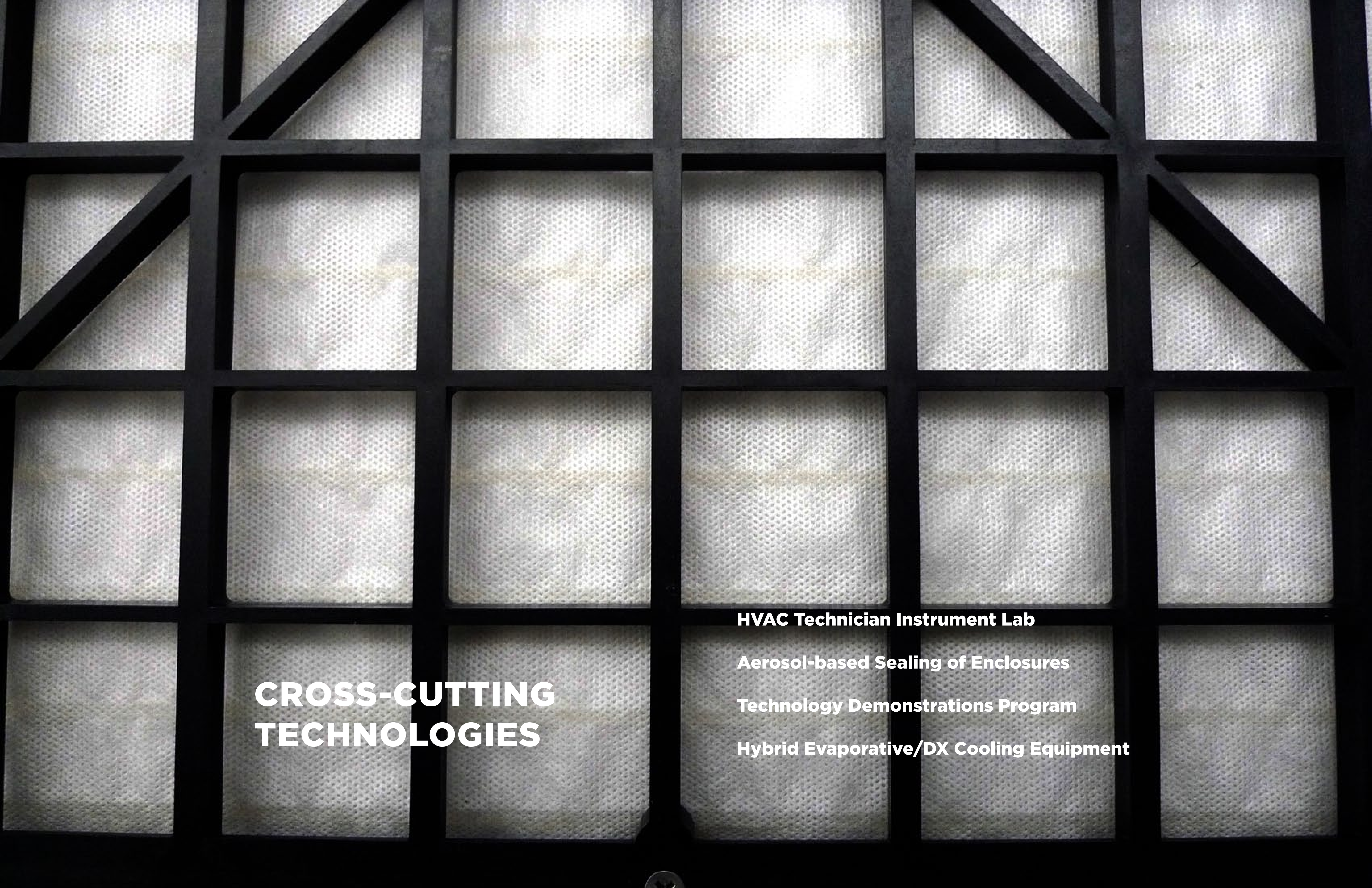


Figure L13 – Laboratory tests indicate that the Coolerado H80 can use 65% less electricity than a similarly-sized contemporary rooftop packed unit in hot-dry climate conditions

PATH FORWARD

In the coming year, with championed support from Southern California Edison, WCEC anticipates the Challenge to grow in leaps and bounds. We will be executing numerous field studies, spur additional manufacturer participation, and increase outreach through general publicity, academic publications, and by participation with vital HVAC trade organizations such as the Western HVAC Performance Alliance, ASHRAE, and ACCA. The underlying goal of these activities is to stimulate interest, support, and activity within the HVAC industry related to hybrid rooftop air conditioners, and to advance the market introduction of the promising technologies that are being developed for the Challenge.

- Develop website and other outreach tools for the Western Cooling Challenge
- Complete testing of the Speakman Hybrid CRS-2500 Air2O Quattro with the National Renewable Energy Laboratory in Colorado
- Conduct laboratory Testing of the TRANE Voyager DC in collaboration with Oak Ridge National Laboratory in Tennessee
- Outreach to energy efficiency programs, contractor trade organizations, and ASHRAE chapters, to engage in industry wide learning about WCC equipment
- Develop collaborations with utilities throughout California to support scaled field placement of Cooling Challenge technologies with the aim of installing up to 20 certified units in various California Climate Zones by the end of 2012
- Collaborate with LBNL to move forward on developing an EnergyPlus module that is appropriate for modeling WCC equipment
- Continue coordination with promising manufacturers to encourage commercialization of WCC equipment
- Continue collaboration with Cooling Challenge manufacturers to provide feedback on field operation of equipment that we might help to improve reliability and performance of the equipment



CROSS-CUTTING TECHNOLOGIES

- HVAC Technician Instrument Lab
- Aerosol-based Sealing of Enclosures
- Technology Demonstrations Program
- Hybrid Evaporative/DX Cooling Equipment

HVAC TECHNICIAN INSTRUMENT LAB

One of WCEC's upcoming projects is the development of an HVAC Technician Instrument Lab (HTIL) to test the accuracy, reliability, and usability of the instruments typically used by contractors and used in utility maintenance programs.

The instrumentation typically used by technicians in utility refrigerant charge and airflow and duct sealing programs and in private-practice is not adequate to produce the measured savings that are expected. The "HVAC Energy Efficiency Maintenance Study," co-authored by WCEC (see a separate section of this report) shows that a typical technician's measurement of subcooling and superheat (required for accurate refrigerant charge of the AC system) can be off by up to 9°F from the optimal temperature, leading to an inaccurate charge. Similar problems exist with other technician instrumentation used for other utility programs that aim to reduce electricity and gas use, such as duct test and seal and quality installation.

The ultimate goal of this project is to facilitate the adoption of more suitable instrumentation for HVAC installation and maintenance and suitable methods of using these instruments, and thereby to increase energy savings from utility programs. This will be accomplished through testing (including development of standardized test procedures for instruments and equipment), demonstration, development of best practices, education on best practices, and dissemination of product information (including make and model identification, if appropriate, or generically if necessary). The HTIL will be similar in objective and methods to the National Building Controls Information Project, implemented by the Iowa Energy Center (see figure C1).

HTIL will have a significant impact on the energy performance of residential and small commercial building HVAC by providing information to contractors, technicians, utility program managers and policymakers about appropriate tools and techniques. This information will affect the choice of instruments and measurement methods, enabling technicians to better install and maintain HVAC systems to achieve significant energy savings.

The objective of this project is to develop and launch a laboratory that will lead a standard-setting process for field instruments, conduct research on measurement methods, educate technicians on appropriate tools and techniques, disseminate information on tools and techniques through a website and publications, and provide instrument testing.

Another objective is to reach out to the industry to ensure that the research is meeting commercialization needs, and to solicit funding from industry entities for subsequent activities.

SCOPE OF WORK

The HVAC Technician Instrument Laboratory (HTIL) will be located at the Western Cooling Efficiency Center (WCEC) at UC Davis, although some testing may be done through partnerships with other laboratories. WCEC already has a lab for testing AC equipment and is making plans to expand laboratory space, some of which will be dedicated to the HTIL. Work to develop and launch the lab includes the following tasks:

Year One

- Establish an HTIL Advisory Committee and hold at least one Technical Forum
- Review lab and field studies that document the link between instrument accuracy and maintenance quality. Visit labs performing similar functions in other sectors
- Identify human factors that go into measurements
- Establish priority list for testing products
- Identify requirements for instrument accuracy and measurement methods. Initiate the process for development of a standard, guideline, or protocol for instrumentation and measurement
- Develop detailed requirements for laboratory
- Build and commission laboratory
- Develop online resource to compare manufacturers' reported data and discuss measurement methods
- Identify co-funders for Year 2

Year Two

- Test multiple makes and models of two types of instruments: pipe temperature, duct air temperature, duct air humidity, duct airflow, refrigerant pressure, or power. Report on suitability of instruments
- Test effects of human factors on measurements. Develop and report on best practices for making measurements
- Disseminate reports
- Hold trainings at HTIL
- Integrate findings with IOU training curriculum on measurement best practices
- Demonstrate usefulness of HTIL to industry, and seek continuing support

WESTERN COOLING EFFICIENCY CENTER

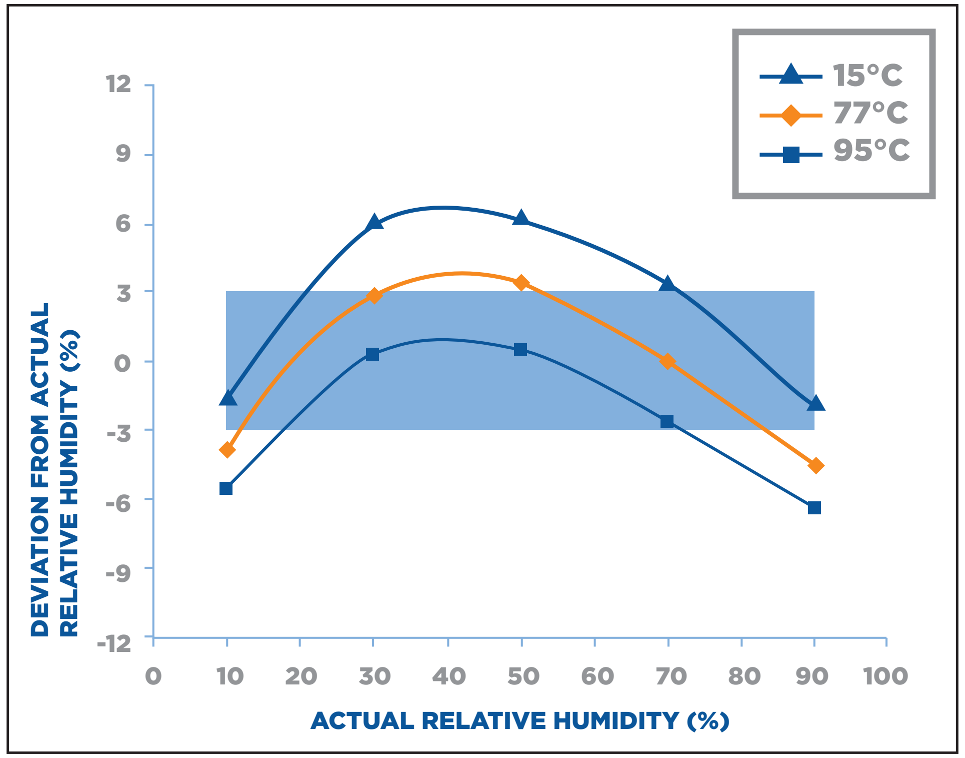


Figure C1: Example test apparatus and results from a similar Laboratory at Iowa Energy Center (Product Testing Report Supplement: Duct - Mounted Relative Humidity Transmitters. NBCIP, www.buildingcontrols.org).

AEROSOL-BASED SEALING OF ENCLOSURES

Building shells are notorious for leaking, causing unintended air flows between conditioned and unconditioned spaces, which results in additional heating and cooling loads that the HVAC equipment must remove. A significant effort has been made to reduce the leaks in building shells through current construction practices, but the problem remains one of high labor costs, constant vigilance and quality control. Through a partnership with ConSol, WCEC has received funding from Build America to investigate building shell sealing in both retrofit and new build applications. The objective of this research is to develop and demonstrate a remote sealing process that uses aerosolized sealant to simultaneously measure, find and seal leaks in a building. The process involves pressurizing a space with a fog of sealant particles that will travel to, and as they escape, seal the leaks. A similar process, developed by Lawrence Berkeley Laboratory and commercialized by a company called Aeroseal, has been used to seal leaks in ducts with great success.

The first round of funding for this project was restricted to small scale laboratory tests of the sealing process. WCEC constructed an 8' x 8' x 4' enclosure with leak panels distributed at various locations around the shell of the enclosure. Using slightly modified Aeroseal equipment, a commercially available product for sealing leaks in existing ductwork, WCEC has begun a series of tests in the enclosure to study sealant particle distribution inside the box, sealing rate, and sealant deposit locations.

The first test showed very promising results, sealing the entire box to near zero leakage in 5 minutes. Subsequent tests varied the sealant injection rate and controlled the pressure within the enclosure to study impacts of each on the time needed for adequate sealing and sealant deposit locations. Figure C2 illustrates the results from the initial sealing tests of the enclosure.

In all three tests the enclosure was sealed very tight. The results clearly show that reducing sealant injection rates greatly increased the sealing time, and controlling the pressure inside the enclosure at lower pressures with the same sealant flow yielded similar results. Repeatability tests are needed to confirm the results, but overall the technology seems promising. WCEC is currently in the process of proposing more research through Build America to test the application protocol of aerosol-sealing of enclosures on actual buildings.

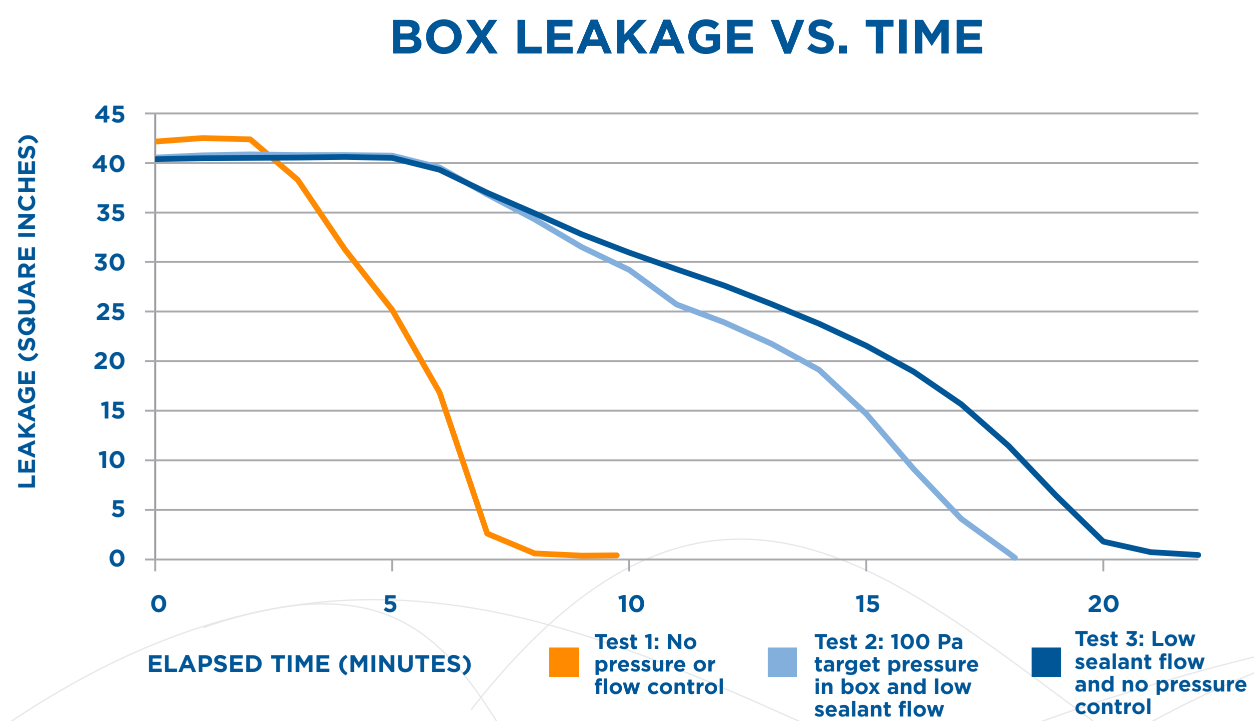


Figure C2: Sealing results from first series of tests

WESTERN COOLING EFFICIENCY CENTER

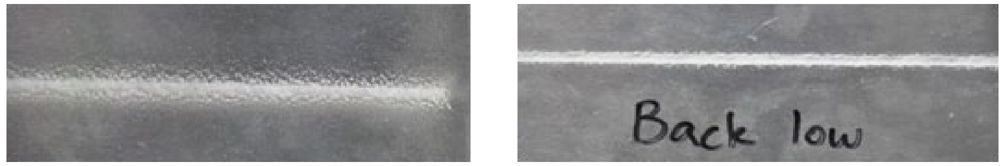


Figure C3: Same leak panel showing different sealant deposit patterns. The image on the left is from Test 1 with high sealant flow and no pressure control, and the image on the right is from Test 2 with a 100 Pascal pressure target in the enclosure and low sealant flow rate.

WESTERN COOLING EFFICIENCY CENTER

TECHNOLOGY DEMONSTRATIONS PROGRAM

As part of WCEC's mission to accelerate the successful application of energy efficient HVAC technologies, the Center engages in a variety of technology demonstrations and beta-testing activities. The sheer breadth of market available efficiency products creates a daunting task for institutional decision makers who have neither the time nor expert judgment to prioritize the value of the various technologies. Thus a significant focus for WCEC's demonstration efforts is to highlight some of the most appropriate HVAC technologies, and to provide a reliable perspective on the market readiness, cost effectiveness, and project-by-project appropriateness for various strategies.

This work to design and facilitate the market adoption of energy-efficient technologies in lighting and HVAC relies heavily on the continued support from our partners: SPEED (the State Partnership for Energy Efficient Demonstrations), CEC (California Energy Commission) and CIEE (California Institute for Energy and the Environment). Our demonstration activities are public-private collaborations that foster the deployment of advanced technologies, with special focus on implementing energy efficiency strategies in coordination with facilities managers and planners at large public institutions such as the University of California, the California State University, the Department of General Services, and local municipalities. These institutions regularly set the bar for best practices in building design and facility management, so the focus is partly to build familiarity with the next generation of efficiency technologies amongst decision makers and champions within these agencies. WCEC manages trial installations and beta tests in collaboration with these institutions; then develops case studies, fact sheets, web resources, education and training activities based on the mutual learning derived.

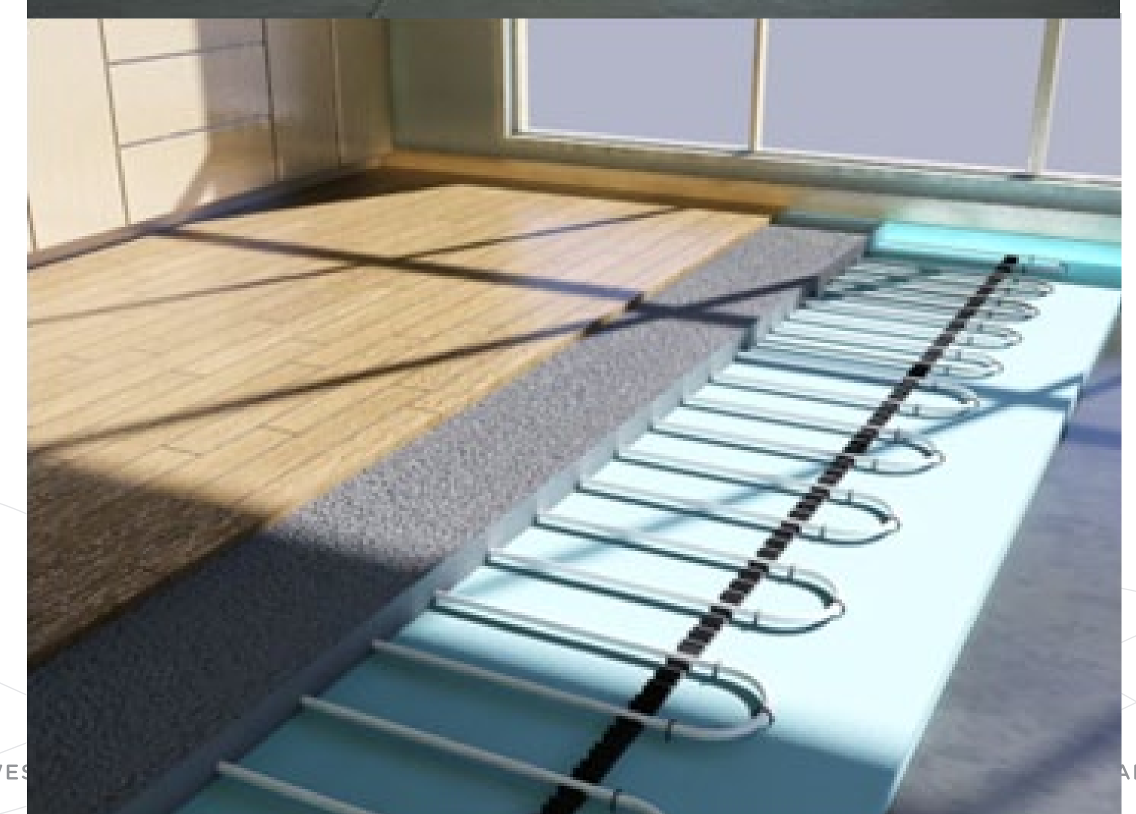
Technologies that are successful in trial demonstrations can end up on a fast track toward wide spread application throughout these institutions, and technologies that fall short of performance or cost effectiveness thresholds receive feedback about necessary improvements as learned through on field installation and monitored operation.

Advanced HVAC technologies face many barriers to market success. WCEC's technology demonstration activities help to bridge these impasses by managing a variety of technology transfer activities. These demonstrations work to overcome the general mistrust about new technologies, prove cost effectiveness and other values, build understanding about the characteristics and caveats for application of various efficiency technologies, inform revisions to building energy performance codes and standard specifications, generate group purchasing agreements, and feed into development utility incentive programs. The collective learning generated from these activities stimulates market demand beyond the institutions in which demonstrations occur. It leads to broader adoption by energy efficiency implementation programs throughout the region, and highlights the needs for specific research and development activities within the industry. Manufacturers benefit from expert feedback about the market readiness of their advanced products and by gaining an ushered market introduction; institutions benefit from learning about the appropriateness of market available efficiency strategies; and the public benefits greatly as the program fosters progress toward state goals for energy and peak demand reduction, climate change mitigation, environmental responsibility, and economic vitality.

RECENT ACTIVITIES FOR WCEC'S TECHNOLOGY DEMONSTRATIONS PROGRAM

WCEC's field demonstration activities are varied, and focus on many different technologies to reduce HVAC energy use. Some of the technologies in focus are well-vetted products that deserve better understanding and broader market application, while others are new to market with well established research foundations in need of beta-scale testing and in-field evaluation. Case studies, fact sheets, technology reviews and other demonstration results are available as literature on WCEC website; some of the demonstration projects in process or recently completed include:

1. Application and evaluation of Air Care Plus, an enhanced HVAC maintenance program, at University of California, Davis
2. Field demonstration and beta test of the Coolerado H80 Hybrid RTU at the University House, University of California, Davis
3. Field demonstration and beta test of the Coolerado H80 Hybrid RTU at Naval Air Weapons Station, China Lake
4. Field demonstration of aerosol duct sealing for central exhaust systems in the Tercero, Pierce residence halls at the University of California, Davis
5. Technology review of on-board fault detection and diagnostic tools for rooftop packaged air conditioners
6. Demand controlled kitchen ventilation at Beale Air Force Base
7. Aerosol duct sealing for supply and return systems at Beale Air Force Base
8. CAV to VFD conversion and demand controlled space ventilation at Beale Air Force Base
9. Field evaluation of the EvaporCoolTM condenser air pre cooler applied on an air-cooled Chiller at Beale Air Force Base
10. Retrofits for commercial refrigeration systems at Beale Air Force Base
11. Field demonstration of integrated retrofits for conventional rooftop packaged units at Navy Base San Diego
12. Evaluation of energy impacts for Telkonet's occupancy sensing thermostats at the Potter and Sereno residence halls at the University of California, Davis
13. Study of the experiences and lessons learned through design and construction of the radiantly heated and cooled, USGBC LEED Platinum Certified Gallagher Hall



PATH FORWARD

WCEC's field demonstration efforts and related technology transfer activities have proven invaluable to informing specific research and development needs within the industry; vetting technologies in collaboration with institutional end users; and for providing constructive feedback to manufacturers about needed technology iterations and derivatives. Our activities on this front will continue to grow in the coming year, some specific efforts will include:

1. Continuation of demonstration activities with public institutions and University campuses throughout California
2. Acceleration of demonstration activities with municipalities, and municipal utilities
3. Involving undergraduate and graduate students in the process of field evaluation of technologies, in part as an educational tool for training engineers for experience with energy efficiency for buildings
4. Highlight and comparison of the experiences and lessons learned through design and construction of various high efficiency green buildings throughout the region
5. Specific focus on broad application of well-vetted technologies that can achieve large near term energy savings

HYBRID EVAPORATIVE/DX COOLING EQUIPMENT

Direct evaporative cooling (DEC), as the name suggests, involves cooling air by evaporating water into it. The air gives up the energy needed to evaporate the water, and is cooler as a result. This method cooling can be much more energy efficient than a D/X system under the right conditions. The downside of direct evaporative cooling is that the moisture content of the air is raised during the process. Using DEC to cool houses can lead to uncomfortable levels of humidity - this is why they are often called "swamp coolers". This limitation can be overcome by using the cool wet air created by a DEC to cool a second air stream without evaporating additional water into it. Cooling generally takes place in a heat exchanger (HX) with a wet channel in which the water is evaporated, and a dry channel where the air is cooled without the addition of water. This two stage process is known as indirect evaporative cooling (IEC). While IECs can provide cool dry air sufficient for many cooling situations, they are limited by the humidity of the initial air supply – if the air is damp to start with it, this limits the amount of water that can be evaporated and hence the cooling that can be delivered. A solution to this problem can be found in the emergent designs of hybrid air conditioners that combine an IEC with D/X system – the IEC provides energy efficient cooling when the conditions are right, and is backed up by the D/X system at other times. The WCEC is developing a software tool to aid in the design of hybrid air conditioners and selection of components for them.

While the D/X technology is fairly well developed, the designs for existing indirect evaporative heat exchangers are generally based on convenient materials and geometries, with indications being that performance can be improved considerably. The WCEC is undertaking a program of research to investigate and attempt to improve the performance of IECs at both the macroscopic and microscopic levels. Activities will include: modeling of heat and mass transfer in indirect evaporative heat exchangers; investigation of surface materials, surface coatings, and alternative micro-scale geometries; understanding the impacts of materials and geometry on scale build-up, and the impact of scale on heat transfer and evaporative performance. In addition, we expect to uncover materials and geometries that will improve energy performance, while also minimizing water use.

ACCOMPLISHMENTS

Our current work is mainly focused on the mathematical formulation, coding and implementation of a two-dimensional (2-D) model to simulate the pressure drop and heat transfer rate of IECs. This 2-D model will serve as a basis for characterizing the performance of IEC HXs and is designed for inclusion in the hybrid system tool. The mathematical framework of the model has been set up, and code has been written to calculate the pressure drop in the dry channel. Preliminary testing of the model has been carried out by running calculations for the geometry used in an innovative IEC HX, developed and tested by Davis Energy Group (DEG). The chosen IEC HX has "C" shaped air pathways in the dry channel, as shown in figure C4, which cannot be simulated using a 1-D IEC model. The results of the simulation have been compared to laboratory test data: the results for the pressure drop are illustrated in figure C5.

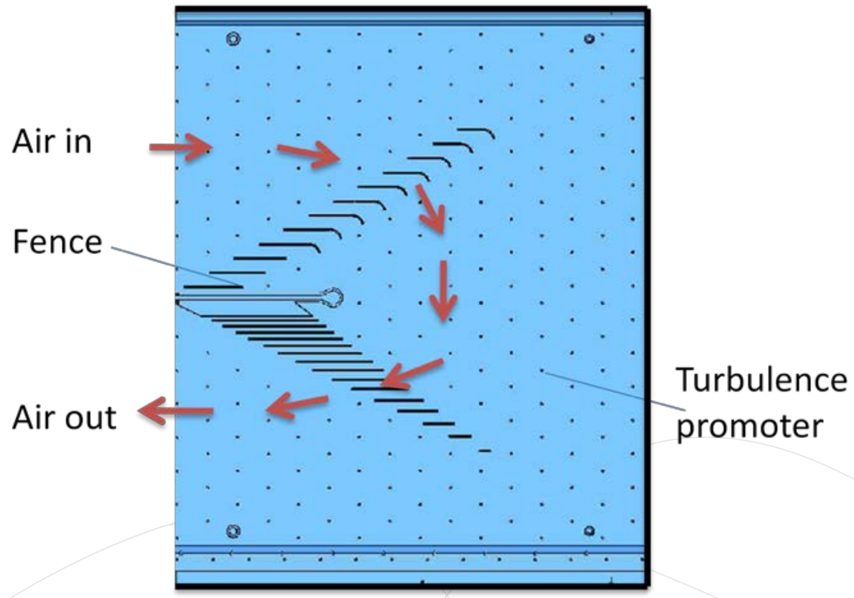


Figure C4: Schematic of the air pathways in the dry channel of the IEC HX developed by Davis Energy Group

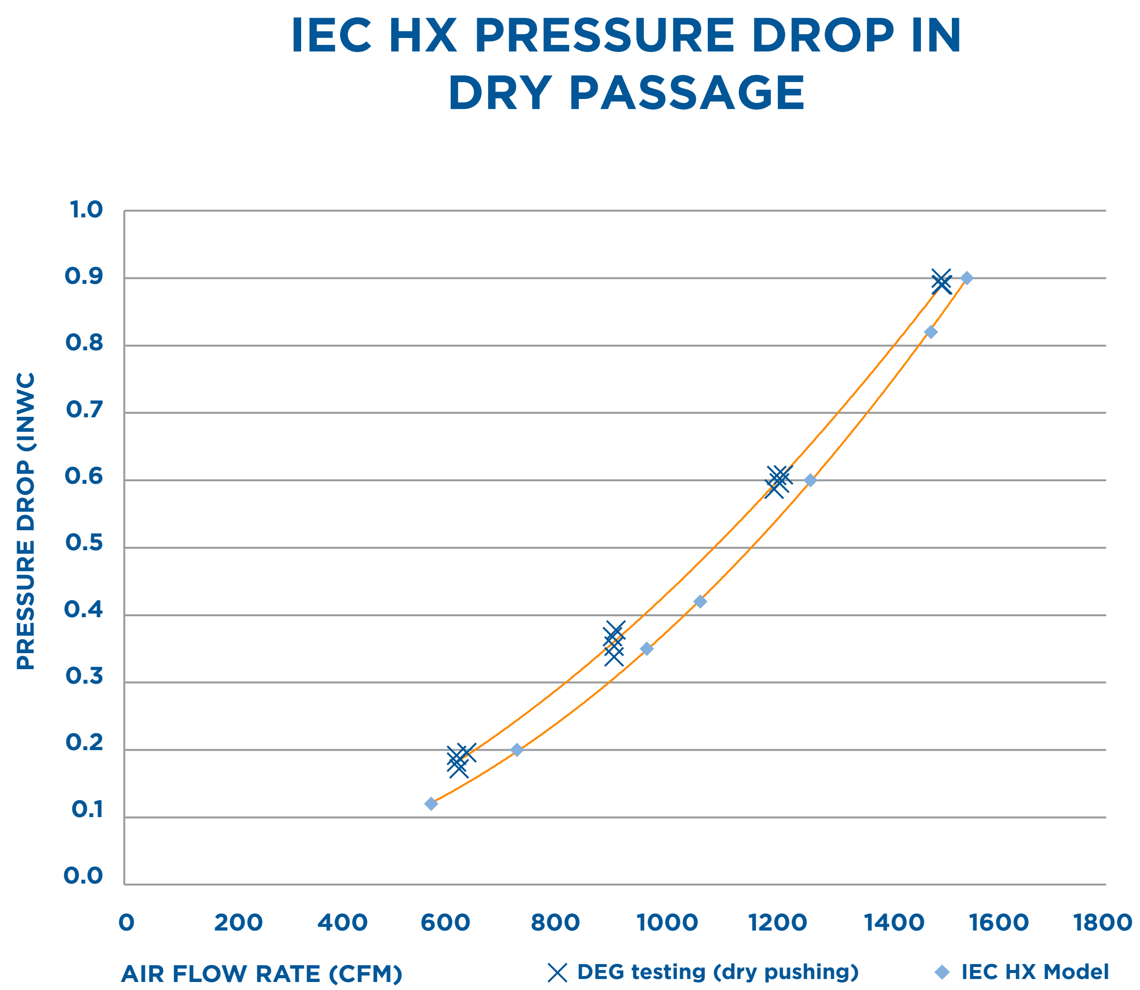


Figure C5: Comparison of the test data with the simulation results of the pressure drop in the dry passage of the IEC HX developed by Davis Energy Group (DEG)

PATH FORWARD

Though the proposed model has demonstrated that it can replicate the behavior of a real HX, the accuracy of the model depends heavily on an appropriate determination of the value of the surface roughness as an input parameter.

Work will continue on the 2-D IEC HX model, which will be expanded to cover the wet channel. A primary focus will be on the effect of surface roughness and coating on evaporation rates in the wet channel. In parallel with this, the overall hybrid system model will be further developed and expanded to allow analysis of a wide variety of configurations of hybrid systems.

INDUSTRY SUPPORT

Initiative on Human Behavior Affecting HVAC Performance

HVAC Performance Alliance

PG&E Case Studies: T-24 Code Change Proposals

HVAC Energy Maintenance Study

Education & Outreach

INITIATIVE ON HUMAN BEHAVIOR AFFECTING HVAC PERFORMANCE

WCEC has recently added to its roster a well-qualified social scientist to help in developing another major initiative that is just launching: Human Behavior Affecting HVAC Performance. Two programs are just launching, and several proposed projects should be launching in the upcoming months. The Maintenance Behavior project tries to understand what behavioral, social, and organizational factors influence a homeowner or small business owner in deciding whether or not to have their HVAC systems maintained. The In Home Energy Display project will test the usability and efficacy of the new wave of energy feedback/information mechanisms and determine how attitudes towards energy affect their use.

MAINTENANCE BEHAVIOR

All of the California Investor Owned Utilities are launching Quality Maintenance programs to encourage homeowners and business owners to receive maintenance on their HVAC systems. The California Long Term Strategic Plan recognizes the importance of understanding and influencing the behavior of the multiplicity of factors that influence HVAC efficiency. In particular, the Plan calls for behavioral research related to HVAC Quality Maintenance programs.

The barriers to effective maintenance of residential and small commercial air conditioning units are only in part technical. There are a host of behavioral issues on the part of users (whether homeowners or small business managers) that can influence when and how a unit is maintained. Behavioral barriers to effective AC maintenance stem from the way in which each stakeholder's specific knowledge and beliefs about AC affect their approach to maintenance.

This study is providing answers to questions about the specific knowledge and beliefs that underlie decisions about HVAC maintenance.

- **RQ 1** What do homeowners and small business managers know and believe about AC maintenance?
- **RQ 2** What are current behaviors regarding AC maintenance on the part of homeowners and small business managers?

Behavioral barriers may also stem from more general attitudes and values that users do not explicitly or consciously associate with HVAC, but that have consequences on AC maintenance motivation and behavior. For example, attitudes towards technology in general, attitudes towards maintenance in general, attitudes towards energy efficiency and environmental issues, attitudes towards financial priorities, etc. Likewise, general value orientations (different "lenses" that leads people to decide what things are right or wrong; responsibilities and rights) may affect the ways in which people think about AC units maintenance.

This study is exploring these general attitudes and value orientations of users to determine whether and how they drive decision making about maintenance of HVAC units. A better understanding of differences in general attitudes and value orientations can help tailor messages and incentives to the concerns of each user. The comparison with attitudes towards other kinds of technologies and maintenance behaviors is part of the study's contribution to understand the place that maintenance of energy saving technology has within the person's priority systems. Once this place is better defined and understood, it may be easier to create targeted messages (or implement various forms of maintenance service) that respond to the needs and priorities of users, as guided by a set of values "in context". Questions answered will be:

- **RQ 3** What are the attitudes involved/activated when considering maintenance for an AC? (energy? environment? Finance? Comfort?)
- **RQ 4** How are these attitudes related to AC maintenance behaviors in comparison to other "maintenance behaviors"? (Other technology, health issues, etc.) What place does maintenance of energy saving technology take within people's priority systems?
- **RQ 5** What are the core values and value orientations driving maintenance related decisions for users?

We are currently in Phase I of the study, in which we are using both surveys and in person interviews to gather information. Surveys are a practical and broad reaching way of gauging views of large and heterogeneous populations, such as homeowners and small commercial building owners and managers.

Phase II of the study will interview contractors and maintenance technicians to contrast the information gathered in the surveys against their experience and observation working with customers. This part of the study will use Focus Groups that allow for a more nuanced and in depth exploration of the views of a smaller and likely more homogeneous group of people, such as AC contractors and maintenance technicians. Phase II overlaps chronologically with Phase I.

Based on the answers to the research questions in Phases I and II, Phase III of the study will test possible messages or other interventions that utilities or contractors could implement to influence decision making on maintenance issues.

WESTERN COOLING EFFICIENCY CENTER

HVAC PERFORMANCE ALLIANCE

WCEC has continued to support the Western HVAC Performance Alliance ("the Alliance") over the last year. The Alliance is was established in 2009 with a mission to provide input from the HVAC community to the Investor-Owned Utilities (IOUs) in the State of California in support of the goals of the California Long Term Energy Efficiency Strategic Plan (CLTEESP).

- Maximize the many benefits of cooling, heating, indoor air quality, and energy efficiency services to consumers
- Minimize the use of gas and electricity via sustainable practice and programs
- Benefit the individuals and organizations that ably deliver the above to consumers and society

Through this collaboration, the Alliance hopes that the residential and small commercial HVAC industry will be transformed to ensure that technology, equipment, installation and maintenance are of the highest quality to promote energy efficiency and peak load reduction.

The Alliance involves California utilities, CEC, CPUC, Contractors State License Board (CSLB), manufacturer associations, contractor associations, distributor associations, code official associations, and individual manufacturers, contractors, distributors, and code officials (see Table on page 33 for a breakdown of the more than 100 members of the Alliance). The Alliance has become the primary conduit between the HVAC Industry and energy program planners and policy makers—organized to transform the way HVAC is built, installed, and maintained. WCEC has been asked by the California IOUs to serve as one of the administrators and facilitators of this breakthrough organization.

During the last year WCEC has facilitated meetings of the Alliance's Steering Committee, Compliance committee, and HVAC in Whole Building Performance Committee.

4 HVAC GOALS OF THE CALIFORNIA LONG TERM ENERGY EFFICIENCY STRATEGIC PLAN

GOAL 1: Consistent and effective compliance, enforcement, and verification of applicable building and appliance standards.

GOAL 2: Quality HVAC installation and maintenance becomes the norm. The marketplace understands and values the performance benefits of quality installation and maintenance.

GOAL 3: Building industry design and construction practices that fully integrate building performance to reduce cooling and heating loads.

GOAL 4: Develop new hot/dry climate HVAC technologies (equipment and controls, including system diagnostics) and greatly accelerate their marketplace penetration.

The Compliance Committee has been quite active with the leadership of WCEC staff.

- This committee has developed new Title24 compliance forms, dramatically reducing the paperwork required for complying with Title 24, which should help to improve compliance rates
- This committee has drafted a standard agreement between HERS raters, contractors, and homeowners that commits all parties to a second service call, when the weather was too cold upon initial installation
- The committee has overseen a pilot test of on-line permitting
- The committee has tracked enforcement activities by the CSLB, which have included development of an on-line form to report violating contractors and conducting "stings" in several distinct locations
- WCEC staff attended Title 24 stakeholder meetings representing the Alliance Compliance committee (as well as other stakeholders), and is tracking the requirements for the upcoming version of Title24
- WCEC staff has participated in the IOU-led Compliance Industry Advisory Group, a broad group of stakeholders providing guidance to the IOUs on issues related to compliance (moving beyond HVAC). For that committee, WCEC has contributed to drafting a white-paper on the need for software to facilitate the compliance process for simple HVAC replacement
- WCEC led discussions of California Senate Bill 454 which would give authority to the California Energy Commission to enforce Title 24 and Title 20, and direct utilities to require compliance with Title 24 in their incentive programs

With the support of Southern California Edison Company, WCEC is also facilitating an Automated Fault Detection and Diagnostics Subcommittee of the Advanced Technology Committee. This committee of industry leaders is organized to develop and implement a roadmap to meeting the goals of the Strategic Plan with regards to FDD. See the section on the "FDD Initiative" for a description of this 17-member committee consisting of researchers, contractors, original equipment manufacturers, third-party FDD tool developers, end users, and equipment manufacturer associations.

During this year the HVAC in Whole Building Performance subcommittee was launched, with active facilitation by WCEC staff. This committee has over 50 members and is responsible for overseeing the utility and other industry efforts to deliver whole-building based efficiency programs, which focus not just on HVAC, but other elements such as windows, insulation, solar gains, and roofs.

California IOU	Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), Southern California Gas (SoCalGas)
California Public Utilities Commission	California Public Utilities Commission (CPUC)
Certifying Body	Building Performance Institute, Inc. (BPI), CalCERTS, Inc., HVAC Excellence, NATE, Northern California / Hawaii NEBB, RESNET
Codes and Standards Official (Association or Jurisdiction)	CALBO, IAPMO, International Code Council (ICC)
Contractor – Nonresidential	ACCO Engineered Systems, Air-Tro, Aire Rite Air Conditioning & Refrigeration, Barr Engineering, Comfort Air, Inc., EMCOR/Mesa Energy, HVAC Consulting Heating & Air Conditioning, Indoor Environmental Services, Integrity Mechanical Systems Corporation, JBS Heating and Air, London's Air Conditioning & Heating Inc., Marina Mechanical, Mechanical Air Service, Inc., Teamwrkx Mechanical, Western Allied Corporation, Zodiac HVAC Inc.
Contractor – Residential	ASI Hastings Heating and A/C, Beutler Corporation, Henry Bush Plumbing, Heating, A/C and Home Energy Solutions, Kahn Air Conditioning, Inc., Sanborn's West Coast Mechanical, Sawyer's Heating & Air, Sears Holding Corporation
Contractor Association	ACCA, ACTA, CAL SMACNA, IHACI, SMACNA Los Angeles
Controls – Manufacturer, Distributor	Honeywell
Distributor	Indio Cooling & Heating Supply, Specialty A/C Products, TruTech Tools, US Air Conditioning Distributors
Distributor Association	HARDI
Educator, Trainer	American Trainco, Inc., Delmar, Cengage Learning, Ecology Action, El Camino College, Energy Analysis Technologies, HVACRedu.net, JATC Air Conditioning and Refrigeration, Mechanical Systems Design & Consulting (MSDC), Mt. San Antonio College, National Comfort Institute (NCI), Praxis Green, RSES, Sheet Metal Workers (SMWIA) Local 104 Training Fund, The Pipe Trades Training Center
Engineering Society	American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
Government (Other than CPUC)	California Energy Commission (CEC), U.S. EPA Region 9
HVAC Manufacturer	Carrier Corporation, Danfoss, Ingersoll Rand, Trane Residential Solutions, Johnson Controls , Lennox Industries, Rheem Manufacturing, Williams Comfort
HVAC Manufacturer Association	AHRI
Organized Labor	Joint Committee on Energy and Environmental Policy (JCEEP), PIPE Trust Fund, SMWIA Local 162 and Local 206, Southern CA Pipe Trades, District Council 16
Other Stakeholder	Air Conditioning, Heating & Refrigeration NEWS (ACHRNews), Better Buildings, Inc. (BBI), California Center for Sustainable Energy (CCSE), Conservation Services Group (CSG), Contracting Business.com Magazine, Efficiency Power, ICF International, New Buildings Institute (NBI), Portland Energy Conservation, Inc. (PECI), Resource Solutions Group (RSG), Roltay Inc. Energy Services, Synergy Companies, Western Cooling Efficiency Center, UCDavis (WCEC)
Owner, Facility Management, or Property Management Association	
Owner, Facility Management, or Property Management Company	American Realty Advisors, Irvine Company, Jack in the Box, PM Realty Group
Publicly Owned Utility	SMUD
Third Party Quality Assurance Provider	American Commissioning Group, LLC, Enalasys Corporation, Field Diagnostic Services, Inc. (FDS), Proctor Engineering, Verified, Inc.,

PG&E CASE STUDIES – T-24 CODE CHANGE PROPOSALS

During this year, WCEC wrapped up its participation in the development of codes and standards to forward energy efficiency for cooling. Over the past year, WCEC has participated in the CEC Title 24 2013 revision process, by helping the Heschong-Mahone-Group (HMG) to develop Codes And Standards Enhancement (CASE) studies for PG&E for Fault Detection and Diagnostics, Non-Residential Radiant Cooling, Non-Residential Cool Roofs, Residential Infiltration and Testing, and Residential Zone Air Conditioning.

FAULT DETECTION DIAGNOSTICS

FDD has not until this point been included as a requirement in T-24. As a part of this PG&E CASE study, WCEC and NBI are helping PECI and HMG to develop a proposal to incorporate a prescriptive requirement for FDD into California's Title 24 Building Code. See a more detailed description of this activity in the section on the FDD Initiative.

NON-RESIDENTIAL RADIANT COOLING

Radiant cooling saves energy, but up to this point it has not been allowed to get credit under T-24. This CASE study developed an alternative method for T-24 compliance for a radiant cooling system, which takes into account occupant thermal comfort, and evaluated the cost effectiveness and energy savings for these systems. This was done through modifications to the nonresidential ACM rules. Energy savings and thermal comfort were established through a combination of building energy simulation using state-of-the-art building energy simulation tools, a review of published data on radiant system performance, and industry stakeholder participation.

WCEC Staff assisted HMG in developing an Energy Plus model of a radiantly cooled big-box store to evaluate the accuracy of the radiant module within Energy Plus. WCEC provided summaries of measured data collected from a big-box store that corroborated the model inputs and results. The model was also used to provide reasonable guidelines and recommendations for energy plus inputs in order to use Energy Plus for T-24 compliance.

NON-RESIDENTIAL COOL DUCTS

WCEC participated in development of a CASE study to investigate the statewide savings from "Cool Ducts". Although this technology has promise, it was not selected to be included in the 2013 revision of T-24. Rather, it will be considered for the Reach Code or for future versions.

Outdoor ducts experience significant unwanted heat gains during the cooling season. Current Title 24 duct insulation requirements reduce conductive heat transfer through the duct wall, but do not address radiative heat transfer from the duct to ambient and solar gain by the ducts. Unwanted duct heat gains can be minimized through the use of high-reflectivity, high-emissivity "cool duct" coatings, which have the potential to reduce the solar heat gains by ~80%. Cool ducts will reduce beneficial wintertime solar heat gains, and high-emissivity surfaces increase radiative heat losses to cool surroundings and the night sky relative to low-emissivity surfaces. WCEC efforts in this area will include efforts to quantify the prevalence of exterior ductwork.

To evaluate the impacts of a T-24 requirement for cool ducts, models will be developed, but the prevalence of exposed ductwork throughout California first has to be known. To quantify the prevalence of exposed ductwork, a methodology was developed that randomly select buildings from County Assessors' parcel data to. 500 parcels were selected from each California Climate Zone to be surveyed. The surveys were conducted in Google Earth and Bing maps to get a high resolution picture of each rooftop. With this information we recorded the presence or absence of exposed ductwork, and where present we measured the length and width of ducts. We also recorded orientation of primary run, and color of duct. Our surveys tell us the area of exposed ductwork across an entire Climate Zone to within +/-5%.

Parcel data was obtained from ParcelQuest, a local company that collects and organizes data from County Assessors, and a student then surveyed a randomized set of that data for each California Climate Zone. Results vary widely between Climate Zones ranging from 2 % percent of buildings with exposed ductwork in CZ 16 (totaling 0.16M ft2) to 22% of buildings with exposed ductwork in CZ 9 (totaling 8.2M ft2). The results suggest that there are roughly 41M ft2 of exposed ductwork statewide in California and about 16% of commercial buildings have exposed ductwork on the roof. A summary of the findings are presented in **Table 555**. The Heschong Mahone Group will be using the survey results as inputs for a duct thermal model that will calculate the impact solar heat gains have on exposed ductwork on air conditioning efficiency and the potential benefit from a requirement for Cool Ducts.

	Total number of parcels	Prevalence of exposed ducts	Total exposed area surveyed (ft2)	Average exposed area per parcel (ft2)	Average exposed area per parcel with exposed ducts (ft2)	Total exposed area (million ft2)
CZ1*	14,793	6%	7,948	16	256	0.2
CZ2	20,254	12%	17,341	35	299	0.7
CZ3	70,242	22%	57,320	115	521	8.1
CZ4	22,701	25%	83,280	167	677	3.8
CZ5	7,055	10%	13,749	27	275	0.2
CZ6	43,335	20%	44,867	90	458	3.9
CZ7	22,459	24%	34,427	69	287	1.5
CZ8	61,978	21%	41,189	82	389	5.1
CZ9	87,416	22%	47,138	94	432	8.2
CZ10	42,553	15%	28,618	57	377	2.4
CZ11	27,130	6%	13,984	28	451	0.8
CZ12	62,982	10%	29,118	58	607	3.7
CZ13	35,472	8%	25,673	51	676	1.8
CZ14	12,213	7%	10,743	21	316	0.3
CZ15	12,932	12%	22,025	44	367	0.6
CZ16*	24,155	2%	3,373	7	281	0.2
Weighted Averages	**-**	**16%**	**36,487**	**73**	**454**	**-**
Totals	**567670**	**-**	**-**	**-**	**-**	**41.4**

RESIDENTIAL INFILTRATION AND TESTING

The goal of this project is to develop requirements that would reduce the air leakage of new homes and get those requirements adopted into the 2013 Residential Standards.

The current code includes prescriptive air sealing requirements, and provides a performance credit for an air barrier, and for certified leakage testing. The proposed code changes eliminate the credit for air barriers, and institutes a base-code prescriptive maximum air leakage rate of 3 ACH50 for single family homes in 13 CEC Climate Zones, measured using the new Resnet Draft Standard 802 test protocol. It appears that this change may not move forward due to some sentiment that further research to assure IAQ may be needed.

RESIDENTIAL ZONE AIR CONDITIONING

The goal of this project is to investigate the validity of the current treatment of zonal air conditioning systems and suggest any appropriate changes to the 2013 Residential Standards. Mark Modera participated in field testing over the past year for this project, the results of which indicated that bypass dampers, at least in two-zone systems, reduced the overall cooling system efficiency (i.e. energy delivered at the grilles divided by electricity consumption by the cooling equipment). The suggested changes currently include prohibiting the use of bypass dampers, requiring that zonal systems meet the same coil flow and fan power consumption requirements as for single zone systems, and eliminating the compliance credit for zoned systems.

HVAC ENERGY MAINTENANCE STUDY

California Ratepayers paid millions of dollars from 2006-2009 for Refrigerant Charge and Airflow and Duct Sealing Programs. While the result of these programs should have been phenomenal savings, the measured and attributed savings ranged wildly from 5 to 46% of the expected savings, according to one controversial EM&V Study. WCEC worked with the Davis Energy Group to analyze the uncertainties involved in Maintenance Measures. Highlights of our analysis include the following key observations.

KEY OBSERVATIONS

Uncertainties are inherent in programs such as these and are not well accounted for. There are many interrelated sources of uncertainty, including measurement errors, uncertainties in predicting human behavior, and the compounding effect of performing calculations on imperfect data (see Figure E1). Perhaps the most important observation here is that, with the program specifications, methods, and tools commonly used today, it is difficult for a simple refrigerant charge adjustment to be implemented, measured, and verified to the level of confidence that is required by the CPUC. It is impossible to eliminate all sources of uncertainty, but they should be mitigated where possible. A good understanding of uncertainties by program designers, contractors, and technicians is important.

Additional screening and more sophisticated diagnostic/servicing approaches would benefit future programs. Quality maintenance programs have the potential to be successful, but their design and structure could be improved. For example, if technicians perform basic screening of HVAC systems to determine whether (and which) services are likely to improve efficiency before implementing charge adjustments, average energy savings per building could be increased. Furthermore, implementing multiple measures can potentially save much more energy than the current strategy of implementing single, simple measures, particularly when multiple faults are present. The costs of providing such a comprehensive service may be higher. However, the additional savings might justify the cost at a large number of sites. The presence of multiple faults and the need for multiple measures complicates diagnostic/service protocols in ways that are not well understood. There is not a thorough, up to date, and independent assessment of the baseline fault conditions of the over 10 million unitary air conditioners in California. Further study would help to develop appropriate diagnostic and service strategies that can be guided by the principles of making sure that no harm is done to the system, that energy efficiency is improved, and that to the greatest extent possible every site visit results in an energy efficiency improvement.

Human factors are significant but are poorly understood. The behavior, motivations, preparation, and constraints on technicians, owners, tenants, contractors, and EM&V specialists can make or break a program. This is an area that has been overlooked in the field of behavioral research, and a better understanding of why people do what they do is critical. If broad CPUC energy efficiency policy goals are to be achieved, the measurement of "free-ridership" needs to be improved to recognize that HVAC quality maintenance measures and services do not currently exist without the support of energy efficiency programs.

Measurement and verification processes must be improved. EM&V processes and instrumentation need to be improved and integrated with program delivery, quality control and reporting. One-time field EER measurements appear to be of marginal value since uncertainties can approach ±20%. Even with high-quality, time-series EER measurements, there is uncertainty in simulating the annual kWh savings, in part due to behavioral factors affecting occupancy and thermostat patterns. Longer term, broadly implemented pre- and post-measurements of kWh consumption would reduce uncertainty, and could be implemented using utility smart meters and/or web based sub metering.

RESEARCH PLAN

In the report, we developed a Research Plan for Maintenance in California. This plan included the following elements:

- Definition of Combined Measures
- Screening Tools
- Diagnostic Protocol
- Instrumentation Needs
- Human Factors
- Verification and Program Reporting
- Measurement and Verification
- Training of technicians, contractors, owners, consumers, manufacturers, etc.
- Value of Savings

New programs are being launched currently, and it will be important to design and evaluate them with these factors in mind. WCEC will likely play an important role in follow-up work to this study. Some of this work will be through the Western HVAC Performance Alliance (see the WHPA section of this report), while other parts will be the subject of solicitations from the CPUC and/or the IOUs.

REASON	PROGRAM	PROCESS	MEASUREMENTS	SYSTEM	HUMAN
Measure Not Capable of Savings	Measure choice	Uncertainty in performance criteria or algorithms, Definition of metrics, Definition of process	Accuracy of contractors' measurements, Calibration procedures		High cooling setpoints=no savings
Measure Capable of Savings, but Savings not Achieved	Program Verification, Incentives (to whom, how much)	Adherence to process	Particular instrument used, Particular instrument calibration, Instrument placement, Instrument robustness and ease of use	Condition of system, Environmental conditions during test, Vintage/age	Training, Language, Motivation, Incentive Level, Integrity, Attention to detail, Awareness of verification, Seasonality of work, Time pressures
Savings Achieved, but not Persistent	Timing of M&V	Change in conditions between service and M& V	Long-term datalogging	Leaks, Degradation, Other changes over time, failure of some components (run capacitors?) affect operation/savings	Homeowner maintenance behavior, Homeowner takeback effect
Savings Persistent, but not Measured	Contractor participation in M&V	Definition of metrics, Definition and adherence to M&V process Sampling issues	Long-term datalogging, Accuracy of M&V measurements, Calibration of M&V instruments		M&V Training, M&V Motivation, Contractor motivation for participating

Figure E1: Sources of Uncertainty in HVAC Maintenance Programs

EDUCATION AND OUTREACH

WCEC is building closer connections to affiliates, sponsors and stakeholders from a diversity of outreach venues. We strive to increase the awareness, understanding and importance of energy efficiency technologies and strategies. Our multi-faceted approach includes, but is not limited to:

OUTREACH VISUAL COMMUNICATION

Visualizing our work that will better serve our sponsors, afilliates and the general public plays a vital part in our outreach goals. Created a new website **(wcec.ucdavis.edu)** that succeeds in being visually appealing and relevant while focused on portraying current content in a clear and creative way. We are rethinking the way we disseminate our research information by writing press articles, newsletters and brochures that tell a more general story that is relevant to people's lives. This makes our work more relatable and thus helps to create more buzz within the mainstream media.

UC DAVIS COOLING & HEATING EFFICIENCY WORKGROUP

In the past year, we were able to iron out some bugs with the on-campus facilities managers. These real world problems that are typical of new technology now have practical solutions that can be implemented by facilities managers. Using the campus as a real world demonstration tool gives our engineers a higher level of feedback between the resulting tests and facilities managers. This collaboration with facilities personnel educates them on the energy savings from new thermostat technology and sealing leaks in ductwork.

CITY OF DAVIS SUSTAINABILITY

WCEC continues to collaborate with the City of Davis Sustainability Program, working with facility managers and contracted energy consultants to advise and recommend climate appropriate technology for the city offices building renovation.

2011 CALIFORNIA HIGHER EDUCATION SUSTAINABILITY CONFERENCE

WCEC attended this year's Sustainability Conference at California State University Long Beach. WCEC's involvement in the conference included a combined booth presence with the CLTC that highlighted our center's research with a focus on the PIER demonstrations. In addition to the booth, Jonathan Wooley gave a presentation at the conference devoted to WCEC's PIER demonstration work.

OUTREACH TO US DEPARTMENT OF ENERGY

DOE has announced a high-efficiency RTU challenge this quarter, which as far as we can tell, was inspired by WCEC's Western Cooling Challenge. Along these lines, WCEC has continued to work with both NREL and ORNL on testing of Western Cooling Challenge equipment. The latest entry to the challenge (a "5-ton" unit from Speakman) is scheduled to be tested next quarter at NREL.

In addition, WCEC has continued working with LBNL this year to develop a partnership whereby WCEC would provide technical support on DOE Test Procedures for HVAC equipment.

Finally, WCEC completed contracts and began preparing work statements for our second year with two DOE Build America teams (ConSol and Davis Energy Group). A test apparatus for one of those efforts, testing the viability of using aerosol-based sealing for building shells, was constructed at the center.

OUTREACH AND ADVISING TO ARCHITECTS & ENGINEERS

WCEC has maintained contact and general advising of architects and engineers interested to include advanced cooling technologies in their building projects. This included a visit by Rob Hammon from Consol, along with Khaled Mahjoib (from Syria), who are working on a net-zero energy building planned for construction later this year in mid-town Sacramento. The building includes 4 stories of residential over ground-level retail and integrates solar, green roof, other efficiency measures and designs, water capture and re-use, and other innovative, sustainable design strategies.

Both Mark Modera and Kristin Heinemeier attended the ASHRAE Summer Meeting in Montreal in June. Mark attended the Handbook Committee and Existing Building Commissioning (GPC 1.2) meetings, as well as a number of Technical Committee meetings, including Duct Design (TC 5.2), Radiant Heating/Cooling (TC 6.5), Water Treatment (TC 3.6), and Ventilation and Infiltration (TC 4.3). In addition, at that meeting, the ASHRAE Honors and Awards committee voted to name Mark Modera as a Fellow of ASHRAE.

Curtis Harrington is working with ClimateMaster to help apply the swimming pool research to create market ready applications.