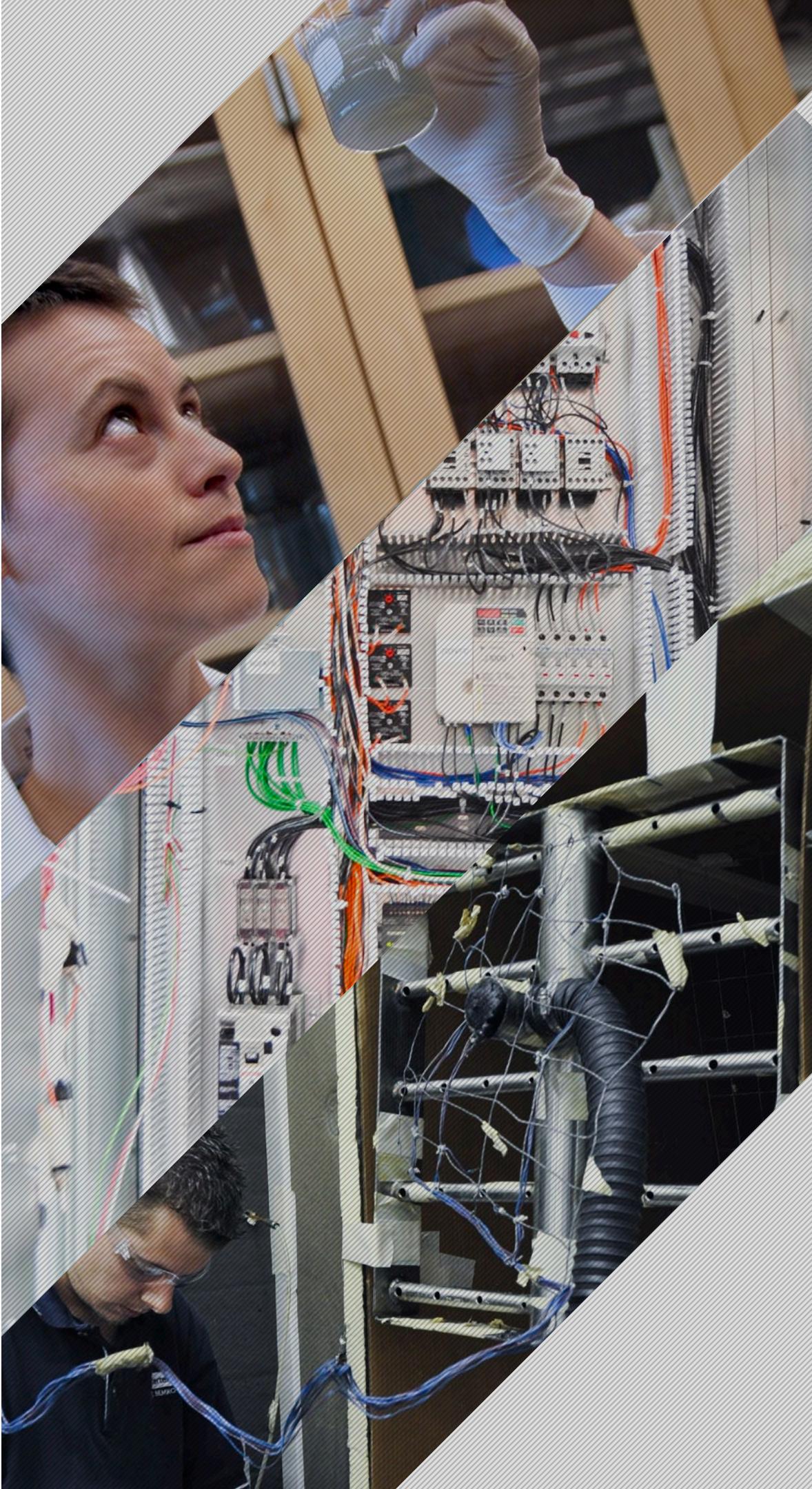


**ANNUAL REPORT  
ON COOLING  
IN THE WEST  
2011-2012**

*RESEARCH.  
INNOVATION.  
PARTNERSHIP.*

**UCDAVIS**  
UNIVERSITY OF CALIFORNIA  
**WCEC**  
WESTERN COOLING EFFICIENCY CENTER

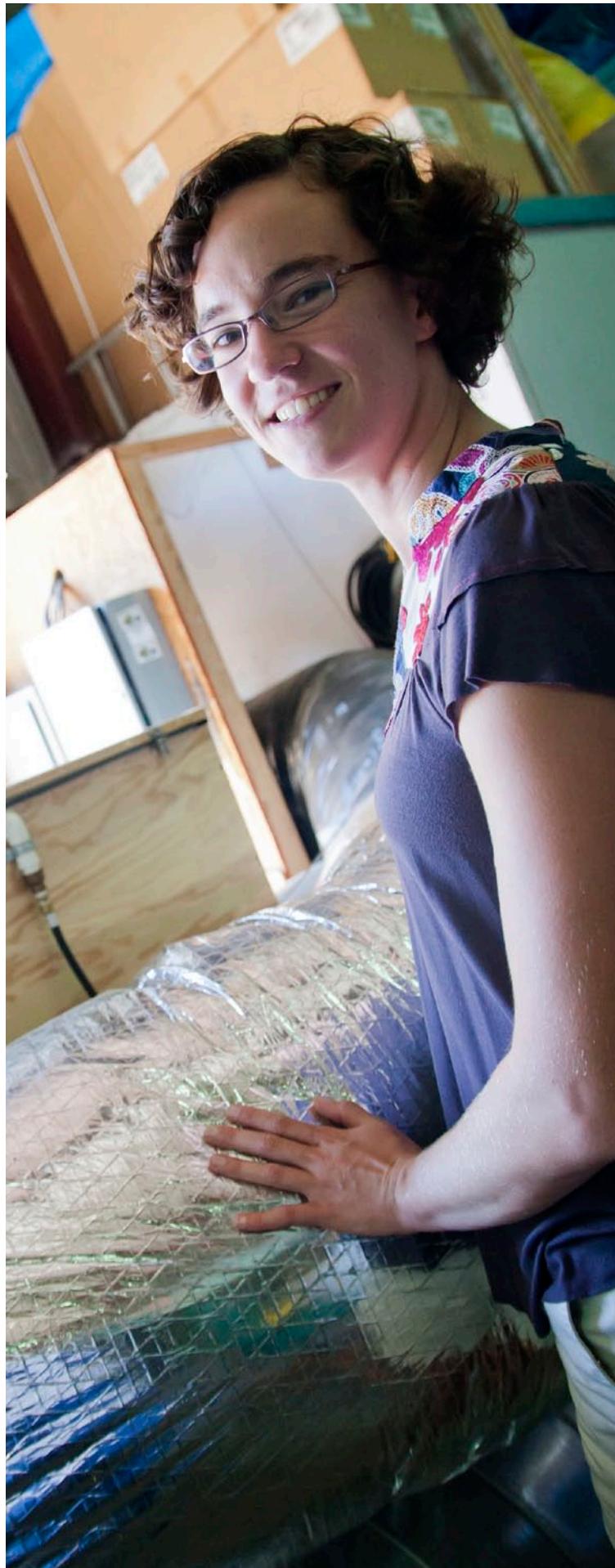


## INTRODUCTION

### BACKGROUND

Heating, Ventilating and Air Conditioning are taken for granted, “out-of-sight, out-of-mind” services to most residential and light commercial consumers. The products are typically long-lived, having 15-20+ year life spans. Combined, these two conditions result in little incentive for manufacturers to market innovative new technologies directly to consumers, who neither understand nor care about HVAC technologies anyway. This lack of consumer understanding of HVAC technologies, combined with the long, out-of-sight, out-of-mind life of HVAC equipment, means that there is little immediate consumer pressure on manufacturers to innovate, leading to a field where the basic technologies underlying the field do not change rapidly. Consumers are thus not terribly well informed when faced with making multi-thousand-dollar decisions—decisions which typically come only when building a new structure, or in a near-crisis when the existing system breaks...a decision that probably won't be revisited for well over a decade. In neither case is the consumer likely to be financially or practically positioned to consider anything but the most immediately economical and available option. Given these pressures, large manufacturers have learned how to efficiently build mass quantities of universally distributed small HVAC equipment for residences and small commercial buildings, and are not particularly encouraged to customize their product offerings to optimize performance in particular climates. It is, however, these small HVAC products that represent the majority of the peak electricity demand associated with cooling in California. These trends create some of the key challenges faced by the Western Cooling Efficiency Center, whose mission is to impact the energy efficiency and peak electricity demand of the installed base of cooling equipment in western climates.

The California Public Utility Commission's Energy Efficiency Strategic Plan calls for two key changes in this industry: a) widespread adoption of climate-appropriate HVAC technologies in California, and b) transformation of the HVAC industry in California. These are ambitious directives that require simultaneous actions on a variety of fronts. The push toward climate-appropriate technologies implies, by its very nature, different products for different markets, which reduces efficiencies of scale, both in manufacturing, and in product marketing. On the other hand, the major impediment to transforming the HVAC industry in California is less on the manufacturing side and more on the sales and service side. Due to the low barriers to entry into this side of the business, HVAC sales and service is delivered by thousands of small businesses that are difficult to influence effectively.



The concept of climate-appropriate technologies for California brings its own set of challenges. California's climate is characterized by low humidity and large day-night temperature swings, which together translate to a large peak electricity demand relative to the energy consumption for cooling. Thus, utilities are forced to acquire and maintain a large generation/transmission/distribution infrastructure to service extremely short peak-demand periods. Moreover, various pressures make capturing the marginal cost to utilities of serving this load a challenge. This climate does, however, create significant opportunities for efficiency, primarily through the use of water and thermal storage in cooling processes, although both of these strategies bring their own complications. In the case of water-consuming cooling technologies, there is a long somewhat-problematic history within the state, with issues ranging from the maintenance problems associated with water consuming technologies, to a debate over whether water should be used at all, to the market perception that evaporative cooling is for "people who cannot afford real air conditioning". In the case of thermal storage, the challenges are the issue of scale (i.e. the efficiency and practicality of small-scale thermal storage), and the business model and value proposition to the customer, which are influenced by trade-offs between rational electricity pricing and simplicity of execution with customers. In other words, the electricity rate structure significantly impacts the commercial viability of thermal storage, particularly in smaller installations, and it is hard to make long-term decisions based upon something that can change as quickly as rate structures.

## WCEC PROGRAM STRATEGY

The WCEC has been pursuing various strategies to address the reduction of cooling electricity consumption and peak demand in California with support from the California Energy Commission and the California electric and gas utility companies. The strategies have included:

- » Enticing major manufacturers to build climate-appropriate cooling technologies
- » Verifying the performance of climate-appropriate cooling technologies
- » Facilitating retrofits of existing cooling equipment (climate appropriate and otherwise)
- » Understanding and improving the longevity of energy performance
- » Understanding and improving consumer behavior/attitudes relative to climate appropriate technologies and HVAC maintenance
- » Developing and testing technologies for reducing cooling/heating loads
- » Developing and testing technologies for reducing energy use and electricity demand associated with distributing heating and cooling and ventilation in buildings

## OVERVIEW OF WCEC ACTIVITIES IN 2011-2012

This Annual Report on Cooling in the West provides an overview of the activities and accomplishments of the center over the past year. It is organized by market sector, although a number of our activities do or will cut across multiple sectors.



## **WCEC STAFFING**

WCEC continued to grow as demand for our RD&D expertise rose. We recruited new staff that complemented our existing expertise in support of our interdisciplinary mission. **David Grupp** was hired as an Associate Engineer to head the CIEE PIER State Partnership for Energy Efficiency Demonstration Program. David's doctoral work at UC Davis focused on the study and design of fuel-cell-powered transportation and refrigeration systems, and led to the construction of two working demonstrations and an SAE award-winning publication. David is also the lead engineer designing the HVAC thermal test laboratory for WCEC's new research facility at West Village. **Erica McKenzie** (Ph.D. in environmental engineering from UC Davis) was hired to lead our efforts to better characterize water efficiency opportunities for evaporative cooling equipment, focused on understanding the fundamental impacts of water evaporation on HVAC system components. **Laura Flynn** (graduate student in community development) was hired to support a range of research focused on human behavior impacts to HVAC performance. WCEC also hired **Peter Breyfogle** as an assistant engineer working on evaporative cooling projects and helping with lab design; and **Mayra Vega** as a graduate student researcher focused on WCEC's Phase-Change Material research. Last but not least, WCEC now has a Program Manager, **Jim Rix**, who is responsible for day-to-day management of the Center. He oversees budgets and helps to build and sustain relationships with the Center's Affiliates.

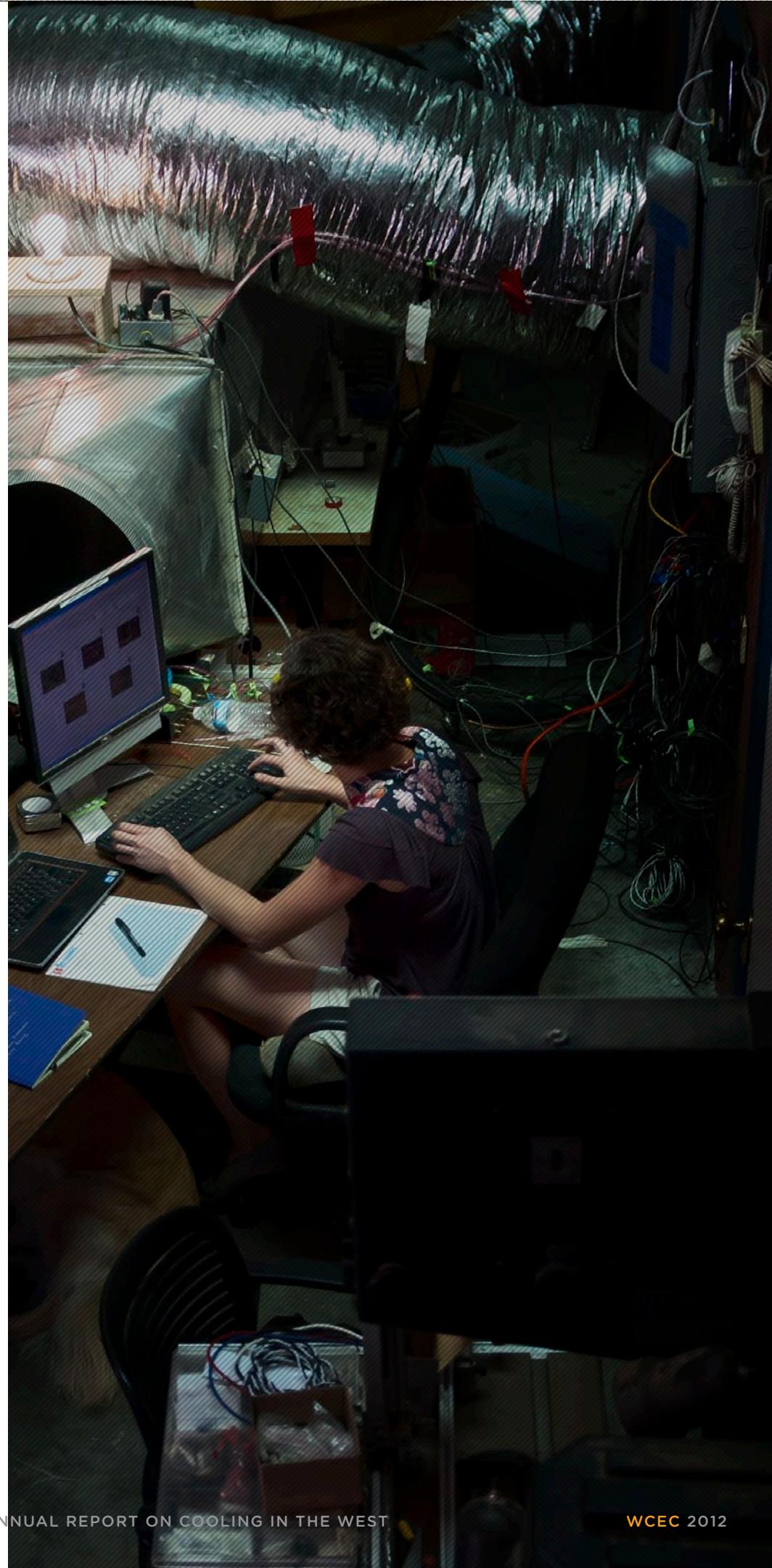
## **WCEC FACILITY**

The requirements for testing energy efficient HVAC equipment (especially evaporative technologies) are unique. Since our requirements are so specialized, and the need for testing both Western Cooling Challenge and RTU retrofit equipment has increased significantly, WCEC is designing an HVAC thermal test laboratory that can accommodate these needs and more. The new 2,000 sq. ft. lab, located at UC Davis' West Village, the largest ZNE community in the country, will be equipped with an environmental chamber for research on evaporative cooling systems. The lab will control temperature, humidity, and air flow for systems up to 5 tons. While the facility is not large enough for full scale tests of large RTUs, the lab will allow WCEC to test and reconfigure a wide range of experiments in house, rather than outsourcing and managing such tests remotely.



## TABLE OF CONTENTS

By the Numbers	6
<b>Single Family Residential</b>	<b>7</b>
A. Swimming Pools as Heat Sinks for Unitary Air Conditioners	8
B. Evaporative Condenser Water Management	11
C. Graywater Reuse for Evaporative Cooling	14
D. Radiant Cooling	17
<b>Multi-Family Residential, Hotels, Dorms, Hospitality</b>	<b>20</b>
E. Multi-Family Ventilation Diagnosis, Modeling and Improvement	21
F. Adaptive Thermostats for Dorms Field Study	25
<b>Light Commercial &amp; Retail</b>	<b>29</b>
G. Multi-Tenant Light Commercial Project	30
H. RTU Retrofit Initiative	34
I. The Fault Detection and Diagnostics Initiative	37
J. The Western Cooling Challenge	39
<b>Cross-Cutting Technologies</b>	<b>42</b>
K. Technology Demonstrations Program	43
L. Hybrid Evaporative/DX Cooling Equipment	46
M. Aerosol Sealing for Building Envelopes	50
N. Phase-Change Materials for Hydronic Systems	53
O. HVAC Technician Instrument Lab	56
<b>Industry Support</b>	<b>58</b>
P. HVAC Performance Alliance	59
Q. HVAC Behavioral Research Initiative	61
R. Education and Outreach	67



## BY THE NUMBERS

**70%** of all commercial cooling in California is handled by RTUs.

**35%** of all RTUs have the fan running 24/7.

**11,000** gallons of water used for a baseline longevity test of a water-cooled condenser.

**1-10%** Amount of total household water use increase when using an evaporative condenser.

**up to 30%** cooling energy saved when using a water cooled condenser in a residential home

**>50%** of envelope leakage in new and existing homes sealed by aerosol injection.

UC Davis' Gallagher Hall is roughly **60%** more efficient than similar buildings in its class.

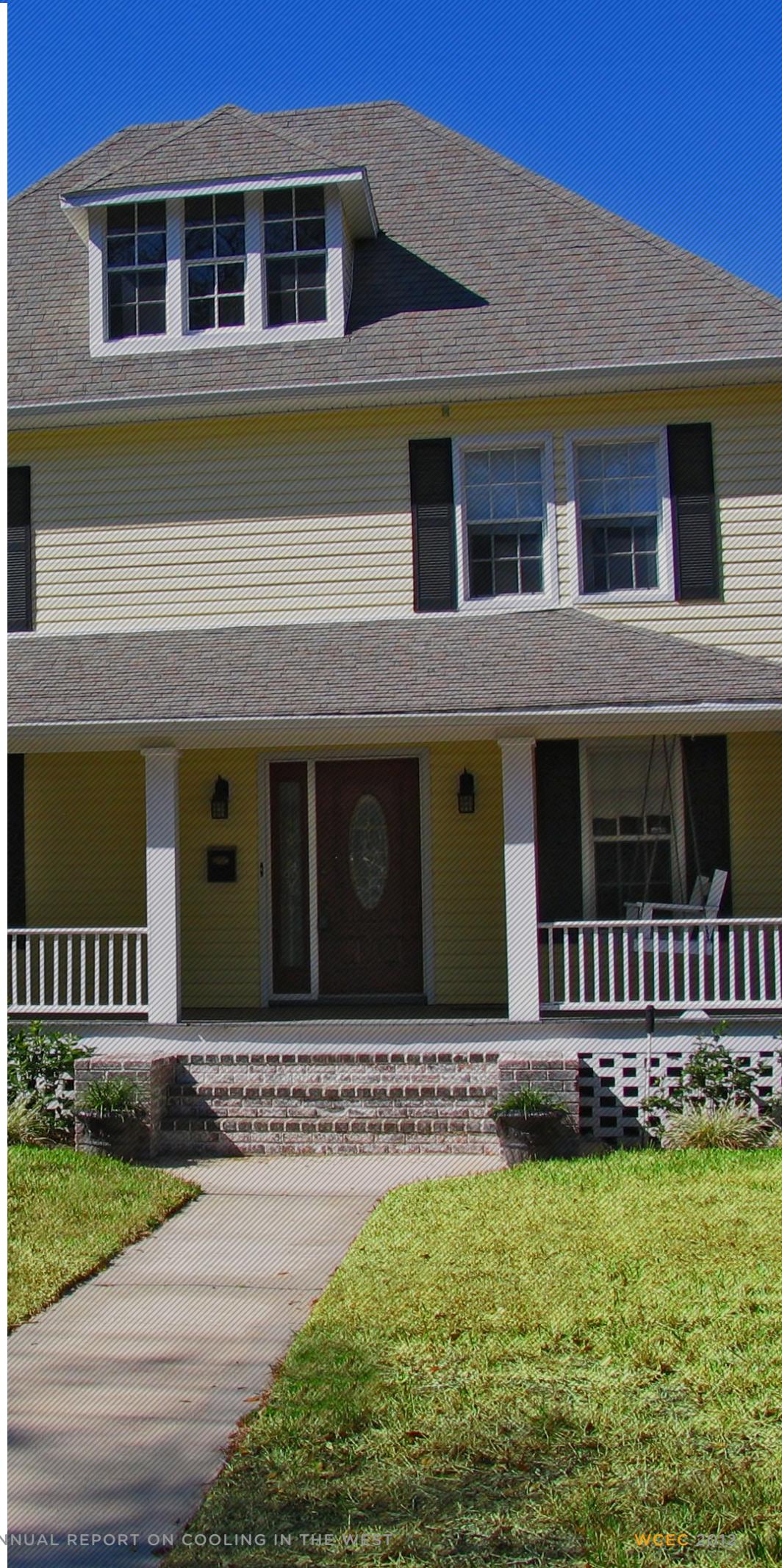
**70%** of all RTUs are 5-ton or less. According to a preliminary MTLC field study

**131** number of organizations that are members of the Western HVAC Performance Alliance

Magnesium has **1000X** the solubility of calcium.

## SINGLE FAMILY RESIDENTIAL

A. Swimming Pools as Heat Sinks for Unitary Air Conditioners	8
B. Evaporative Condenser Water Management	11
C. Graywater Reuse for Evaporative Cooling	14
D. Radiant Cooling	17





## A. SWIMMING POOLS AS HEAT SINKS FOR UNITARY AIR CONDITIONERS

The basic premise of this effort is that simultaneously rejecting heat from condensers to the atmosphere, while burning natural gas to heat swimming pools is imprudent. Therefore, by rejecting condenser heat to a swimming pool instead of ambient air, the energy is transferred instead of wasted. Furthermore, the reduction in sink temperatures seen by the condenser reduces compressor energy consumption during most hours of the day that require cooling. The savings realized during peak conditions will be most significant since ambient air temperatures often exceed 100°F while pool temperatures stay relatively constant between 80-85°F.

Another advantage arises out of the improved heat transfer properties of water relative to air, which allows refrigerant temperatures to be only 20°F higher than the sink temperatures. By comparison, an analogous air cooled condenser requires the refrigerant temperature to be 35°F higher than the sink temperature. Therefore, rejecting heat to a swimming pool can reduce condensing refrigerant temperatures by 30-35°F during peak conditions.

A thermal model developed to calculate pool temperatures based on local weather data, shading of the pool, and pool size has been developed and validated against two experiments. The first test looked at the natural temperature response of a pool, while the second test monitored a pool that exchanges heat with a heat pump. Both experimental validations showed that the thermal model could accurately predict hourly pool temperatures.

Last year's effort has been focused on using the model to simulate the performance of an air conditioning system that rejects heat to a pool in several climate zones. Multiple air conditioning system sizes were considered along with various shading conditions and pool sizes to map the performance of a pool-coupled air conditioner in different scenarios. The results of the simulations are presented in greater detail in a paper recently submitted to Energy and Buildings. Figure A1 and Figure A2 present

the energy savings and peak demand savings predicted for a 4-Ton water-source heat pump rejecting heat to a swimming pool in each of the climate zones considered. These results were developed for pools that achieve a maximum hourly pool temperature of 90°F (i.e. the pool temperature reached a maximum of 90°F during one hour in the summer).

## COOLING SEASON ENERGY SAVINGS

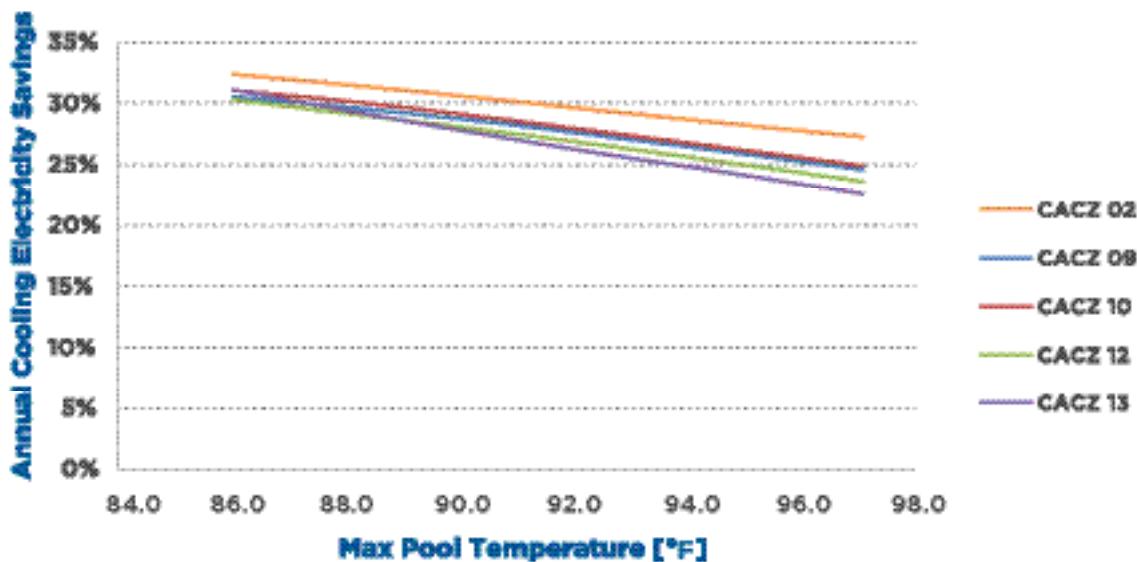


Figure A1

## COOLING SEASON PEAK SAVINGS

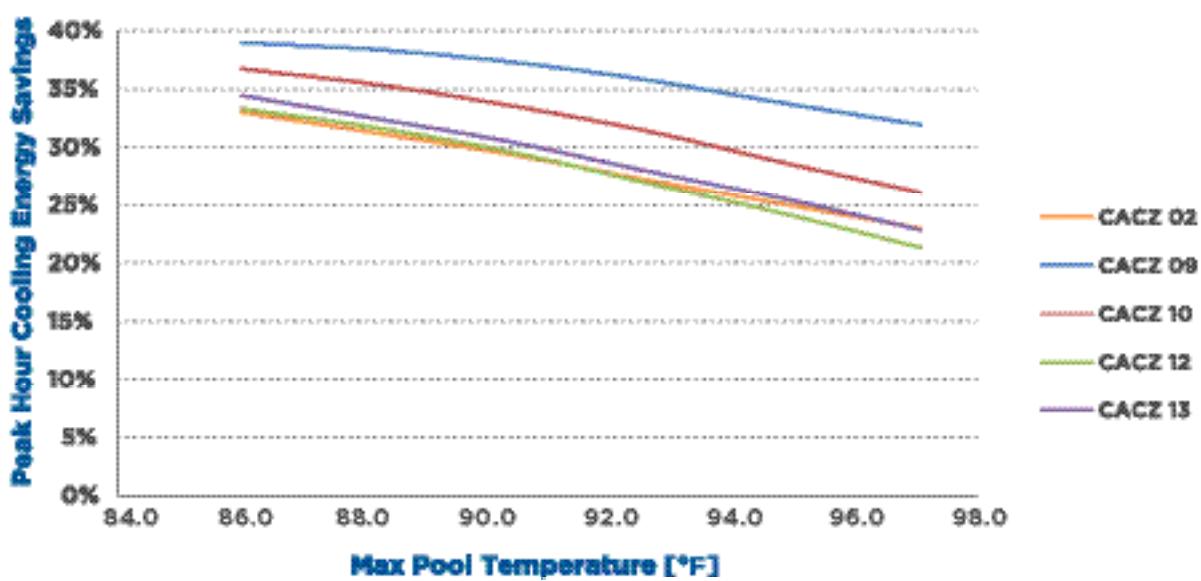


Figure A2

## PATH FORWARD

The analysis suggests that rejecting air conditioning heat to a swimming pool can save approximately 25-30% of single-family residential cooling energy use and reduce cooling electricity demand during peak conditions by 30-35%, as compared to using the same compressor to reject the heat to ambient air. The savings is expected to vary depending on the severity of the climate, as well as the pool temperature experienced during the summer.

The resulting heat added to a pool by the heat exchange with an air conditioner can also directly offset fossil fuels used to heat a swimming pool or simply extend the swimming season to more hours in the year.

In some climate zones rejecting heat to a swimming pool can result in overheating of the pool. Methods for reducing the heat load gained by the pool or assisting the pool in rejecting heat should be explored. One method for reducing the solar heat load absorbed by the pool is to increase the reflectivity of the pool using hydrosols. Hydrosols are micro-sized gas bubbles suspended in a liquid, as opposed to aerosols that are micro-sized liquid bubbles suspended in a gas. These can have a significant impact on the pool's reflective properties. Hydrosols have been shown to increase reflectivity of water bodies by as much as four times, by effectively "brightening" the water. Future research goals may include analyzing the impact that hydrosols can have on pools used as heat sinks. ☀



## B. WATER MANAGEMENT FOR WATER COOLED CONDENSERS

Residential air conditioning, with an annual load factor of 7%, is a challenging and costly peak load for utilities to meet (2004 California Residential Appliance Saturation Survey). In California, 94% of air conditioning is provided by compressor based cooling. Only 6% of homes employed evaporation of water for cooling, despite the fact that evaporative systems have a large potential to reduce both the peak electricity demand and the energy use associated with residential and light-commercial cooling.

One commercial evaporative condenser product marketed toward residential customers is the AquaChill, which is manufactured by Beutler Corporation in 3-5 ton systems. In 2009, SCE completed lab testing of a production AquaChill unit. Operational EERs, which include indoor fan energy use, were reported as 14.2 (a standard unit is roughly 11 EER) in mild conditions down to 13 in hot-dry conditions (115°F outdoor dry bulb, 74°F wet bulb). The laboratory study at SCE did not evaluate the long term performance of the system.

Management of evaporative cooling units is essential to their longevity and protecting return on investment; particular care must be taken to reduce the effects of hard water on the system. Evaporative processes lead to the concentration of minerals in the cooling water reservoir which eventually precipitate out of solution, fouling the condensing coil, pumps, piping, and any other surfaces in contact with the liquid. Fouling of heat transfer surfaces and mechanical elements like pumps leads to a degradation of system efficiency, requiring higher energetic input for the same magnitude of cooling. Concern for system longevity and the ability of the unit to deliver energy savings over a reasonable lifespan impedes adoption of the technology in energy efficiency programs.

Through research funded by Southern California Edison and the California Energy Commission, WCEC sought to assess the longevity of the AquaChill and to provide recommendations for operation and maintenance of the system to maintain performance and energy efficiency. A secondary objective was to evaluate water management strategies to minimize the use of bleed water to reduce water consumption of the system.

The first step toward completing the objective was to run a full scale AquaChill to “failure”, defined as a loss of efficiency of 25% or more. A worst-case, accelerated test was completed by operating the AquaChill condenser for 2000 hours with no water treatment or bleed, which is against the manufacturers’ recommendation. At the end of the test, the efficiency decreased



Small scale test apparatus

only 26% though large amounts of scale were found on the coil, inside the nozzles, in the sump, and on the drift eliminator. The total amount of scale was estimated at over 30lb. Efforts to restore the system performance by cleaning the sump, drift eliminator, and water delivery system were largely unsuccessful, increasing system efficiency only slightly (Figure B1, "Test 1").

Small scale testing of a similar system design was also conducted to analyze the performance of multiple water management and treatment strategies directly. The small scale test evaluated three treatment and/or management strategies at a time compared to a no-bleed control. The strategies applied were low bleed (8% more water than evaporated), high bleed (40% more water than evaporated), and static magnets. The capacity of each system was measured and compared to determine the total impact that each strategy had on performance. The results showed that although the higher bleed rate was more effective at maintaining initial capacity, the lower bleed rate had a decrease of only 10% at the end of the experiment. The water savings made this an interesting treatment to pursue in the second round of AquaChill testing. In addition, the low bleed rate significantly reduced the number of pump failures from six to one. The static magnets reduced the number of pump failures from six to two, but did not reduce scale on the coil.

## INITIAL, FINAL AND REFURBISHED AQUACHILL PERFORMANCE

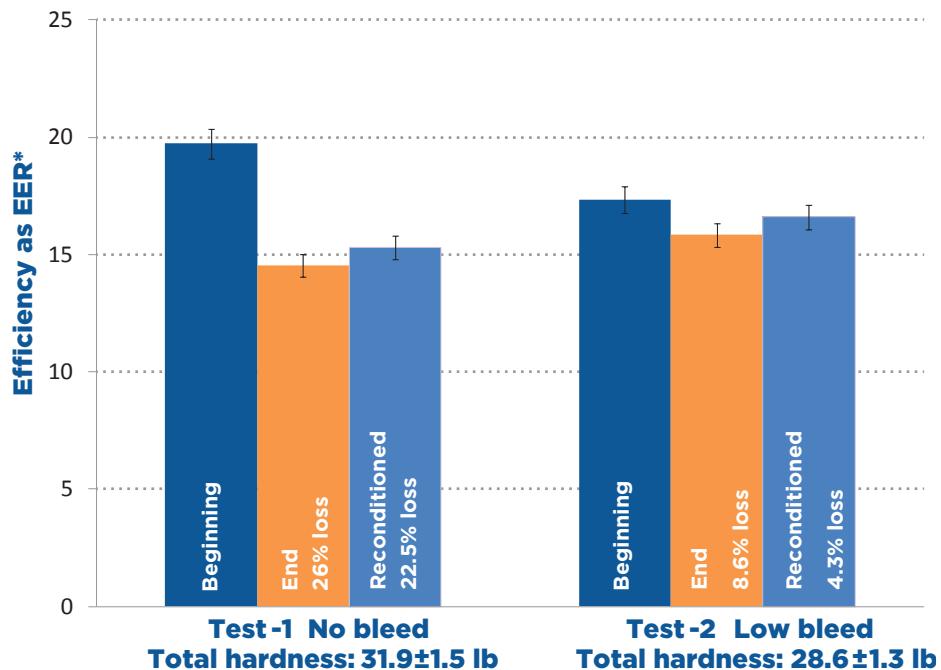


Figure B1: Initial, end, and refurbished performance of AquaChill in test 1 and test 2 (wet bulb temperature between 66-67.5°F).

\*EER is condensing unit efficiency only and does not include evaporator fan power.

Although the change in capacity over time was a useful result, a mass balance of the minerals precipitated from the sump water provided more detailed information on the chemistry of scale formation. Because of its low solubility, calcium was observed to be largely or entirely precipitated in all systems in all bleed rates tested. This indicates that in supply waters with elevated calcium concentrations, an increased bleed rate may increase the total mass of scale formed (i.e., the increased bleed may hurt rather than help). However, magnesium, which has a solubility 1000 greater than calcium, was more effectively removed by the bleed. Under no bleed conditions, a vast majority of the magnesium precipitated out, but when a bleed was introduced, the mass and percentage magnesium precipitated dropped off quickly. At the high bleed condition, magnesium was not found to contribute to mineral scale. Because Davis water has two times more magnesium than calcium, using a bleed rate in the range studied is expected to be a reasonable means for scale prevention.

As seen in Figure B1, even after 2,000 hours, implementing the low bleed in the full scale tests significantly

reduced the loss of efficiency. In addition, the low bleed eliminated pump failures, reduced cleaning requirements, and drastically reduced scale formation on the copper coil. The efficiency of the low bleed system was nearly restored by cleaning the cabinet and drift eliminator, a quick and easy process taking less than 15 minutes.

WCEC has proposed to undertake additional research to develop bleed recommendations based on water chemistry. This research aims to understand the effects of various water quality parameters to determine their influence on scale formation. Water quality parameters to be assessed will include: pH, non-carbonate alkalinity (e.g.,  $\text{SO}_4$ ,  $\text{PO}_4$ ), Ca, Mg, Si. The results of this proposed study will be used to develop a “personalized bleed evaluator” to optimize water use in an evaporative condenser while minimizing scale formation.

Although no major benefit was seen from the static magnets, WCEC is planning to re-test them in combination with a low bleed scenario. In addition, future testing will include an electro-magnetic pulsing device and a vortex device, both in combination with low bleed.

Although additional research is important and will optimize evaporative cooling water use in California, the need for this research should not impede the adoption of the AquaChill and other water cooled condenser technologies. The system is remarkably robust, operating with a reasonable efficiency even when run with no bleed for 2,000 hours of operation. ☐



*Condenser coil after 11,000 gallons of water with no bleed cycle. Even looking like this, the system had lost only 26% of its efficiency*



### C. GRAYWATER REUSE FOR EVAPORATIVE COOLING

Water conservation and appropriate water use are topics that are 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. Evaporative condenser technologies offer an energy saving method to achieve cooling in hot and arid climates, however there has been concern regarding the additional water burden associated with achieving these energy gains. WCEC has been engaging in a three component approach to optimizing the understanding and minimizing that water burden. The three WCEC research components are as follows:

1. Quantifying the water burden for an evaporative condenser operating as recommended by the manufacturer.
2. Understanding the implications of aqueous chemistry on evaporative condenser performance and using this understanding to minimize the water burden.
3. Explore alternative water sources to reduce or eliminate the water burden associated with the evaporative condenser.

As previously discussed, researchers at WCEC conducted an analysis of the evaporative condenser's water burden. The analysis revealed that, when operated at manufacturer recommended water use conditions, the use of an evaporative condenser resulted in between 1-10% increase in a typical household annual water volume (depending on climate zone). Additionally, research at WCEC has determined that the water quality (local aqueous chemistry) is expected to substantially impact the amount and type of mineral scale formed in the evaporative condenser which in turn impacts the evaporative condenser performance. This discovery has opened the door to the idea of "optimized personalized water management," an area that requires further research but also offers the promise of reducing the (already low) water burden associated with evaporative condensers.

The WCEC has also been evaluating alternative water sources, where alternative water supply is considered any non-potable water source. If an appropriate alternative water source could be identified and implemented, the water burden associated with evaporative condensers could be dramatically reduced or even entirely eliminated. There is also the potential that the alternative water supply could also replace potable water (i.e., drinking water) use for selected use cases; in such cases, a high quality yet non-potable water source could be substituted with no impact to human health (e.g., toilet flushing, landscape irrigation, and evaporative condensing). Treated graywater (i.e., laundry water and shower water) and collected rainwater are both being considered as potential alternative water supply sources. In order for graywater to be reused, it must be treated to comply with California Title 22 (tertiary disinfected water for reuse). WCEC researchers have identified that an appropriate graywater treatment system must not only comply with CA Title 22, but also must be safe, easily maintained, energy efficient, economical, and have a small footprint.

## YEAR 3 ACCOMPLISHMENTS

A numerical analysis was undertaken to better understand the energy and water burdens for an evaporative condenser air conditioning system coupled with greywater treatment and reuse. This analysis yielded some interesting results. The evaporative conditioner water burden seen in evaporative systems can be offset by the implementation of an in-home decentralized greywater treatment and reuse plan, where shower and laundry wash water is treated and then recycled in-home for the evaporative cooling as well as other beneficial re-uses such as irrigation and toilet flushing. Treated greywater would eliminate the additional tap water burden, thus making evaporative condensers have lower total energy use compared to conventional forced air units. Also, energy creation often uses water in the generation



process, the reduced energy use from a water cooled condenser, combined with a greywater treatment system, would effectively reduce water use at the power generation point. The use of greywater would also enable an evaporative condenser water management strategy that could potentially improve the evaporative condenser's long term efficiency. Greywater could also meet a household winter-time toilet flushing water demand ( $13.2 \text{ m}^3$ ) and 12% of a household summer landscape irrigation water demand ( $45 \text{ of } 375 \text{ m}^3$ ).

Additionally, the components and challenges associated with the construction and operation of a physical system were further explored. CA Title 22 was seemingly written with centralized graywater treatment in mind, and as such has built in a number of requirements that are

challenging for a small, decentralized residential treatment approach. These challenges are regulatory in nature (rather than technological), and include: daily coliform testing, expensive continuous turbidity monitoring, redundant system components, and component alarms. However, many authorities in both the academic and regulatory world have acknowledged the importance of a decentralized water treatment approach.

The WCEC is working to develop a graywater treatment train that will be demonstrated to meet the health-based treatment requirements of the CA Title 22. In this vein, two primary treatment methods have been explored:

1. Mixing and floc settling
2. Dissolved air flotation

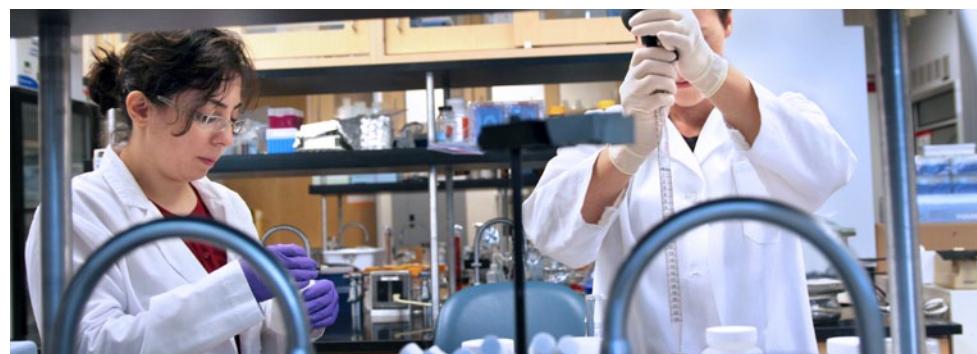
The primary treatment methods, both of which included a coagulation step, were evaluated for the removal of suspended solids and oxidizable material (primarily organic matter), and were tested across a suite of graywater compositions generated using Davis, CA municipal water. Among the four coagulants tested, aluminum sulfate was found to be the most effective. Dissolved air flotation was found to be effective at varying coagulate doses, whereas mixing and floc settling was less robust to varying water qualities. Coagulation combined with an air flotation step is being employed as a primary treatment step. In this ongoing research, the coagulated/floatation water is being fed into an unsaturated sand filter where mechanical straining, interception, and adsorption will promote the removal of suspended and dissolved solids, while biological activity will oxidize putrescible material. This filtration/oxidation step was recently setup, and has not yet been optimized, however extended batch treatment has yielded promising results, including >90% removal of both turbidity and oxidizable material.

## PATH FORWARD

The coming two months will be used to fully establish and optimize the graywater secondary treatment step (filtration/oxidation), which will be coupled with a chlorination disinfection step. The completed treatment train will then be evaluated and compared with the CA Title 22 health-based criteria. The results of this effort will be made available as a white paper, or an academic publication; the results will also be shared with the California Department of Public Health.

The WCEC has also begun evaluating rainwater as another alternative water source. Rainwater is a good alternative water resource for an evaporative cooling application, due to its purity (minimal pathogens) and softness (minimal calcium and magnesium). While rainwater is considered to be a promising potential alternative water source, it is a less studied water source. Future research regarding the potential use of rainwater in evaporative condensers includes the following components:

- » Impact of long-term rainwater storage on water pathogenicity
- » Potential treatment requirements to minimize human health impacts
- » Verification of long-term evaporative condenser performance using collected rainwater 



## D. RESIDENTIAL RADIANT COOLING SYSTEMS

Not all energy consumption is the same, especially in climates with large diurnal temperature swings that require heavy, concentrated energy supply to meet peak-time demand. Increasing efficiency is important to the reduction of energy consumption, but it does not sufficiently address the problems with severe, peak-time energy use. The radiant cooling project at WCEC seeks to reduce the use of peak-time energy in residential applications by shifting the cooling demand to off-peak hours through thermal storage.

The obvious candidate as a storage material is water—cheap, stable, chemically benign, and having a high heat capacity. The ubiquity of water also lowers the psychological barriers to acceptance, which will help with market penetration.

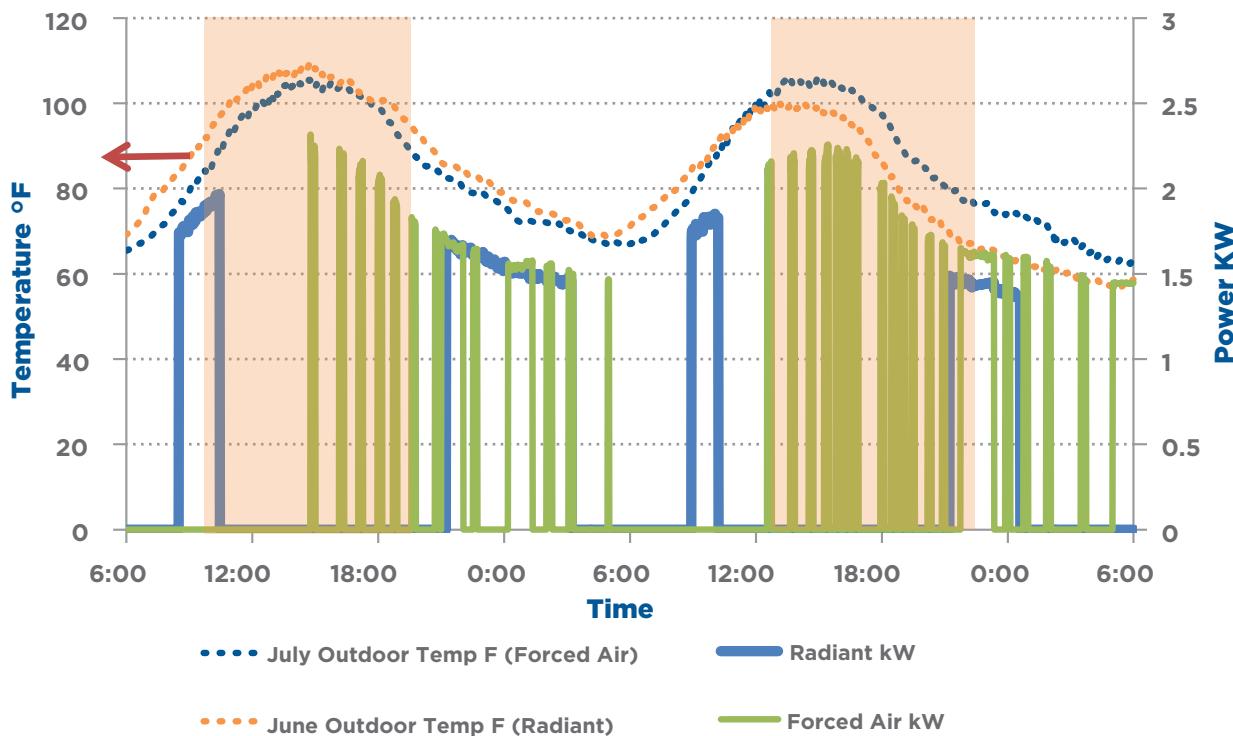
Once the chilled water has been stored it becomes necessary to deliver the cooling to the building, for which the obvious options are a radiant system or a fan coil system. The advantage of the radiant system is that the water in the panel can be at a considerably higher temperature than the heat exchanger of a fan coil system, meaning that water can be stored at higher temperatures if space is not an issue, and that condensation can more easily be avoided. The fan coil system has the added disadvantage that it is still relying on chilled air to cool the interior of the building, requiring blower power in addition to the power used to pump the chilled water.

### CURRENT STATUS

The initial phase of the project, as reported on last year, was to design and lab test radiant panels and storage tanks. The residential radiant cooling project reached the field testing stage last summer with the successful installation of two complete systems in Sacramento test homes. Building envelope renovations were made in both houses to ensure a maximum benefit from the radiant systems. Both systems in the test houses used the same custom built chilled water storage tank and evaporator unit, as well as the same condenser unit. However they used different approaches to the radiant ceiling. One test site (on 6th Ave in Sacramento) is set up with panels designed and built by WCEC which are primarily intended for use in retrofit applications, as they are designed to be installed by simply screwing them into the pre-existing ceiling without any further need for finishing. The other site (on Grandstaff Drive) has panels designed by Uponor which are drywall faced and designed either to work with a suspended ceiling or to be screwed directly into the joists in a new build or deep retrofit. These panels need to be taped and mudded the way a standard drywall ceiling would be finished.



## LOAD SHIFTING PERFORMANCE: RADIANT VS. FORCED AIR



*Figure D1: Comparison of hall temperature maintained by the forced air system vs. the radiant system*

### TESTING RESULTS

We are now analyzing close to a year's worth of data on these two houses. We took advantage of the recent hot spell and reverted the cooling of the Grandstaff drive house to its forced air system for a month to provide good baseline data. Analysis of the data collected so far is now underway and the initial results are very promising both in terms of efficiency and load shifting. Figure D1 shows data taken over two days (June 16th -17th 2012) using the radiant/chilled water system superimposed on data taken on July 21st -22nd using the forced air system. The dates were chosen on the basis of having similar outdoor temperature levels (the temperature on the second day in June is somewhat cooler than the second day in July - the average temperature difference over the two days is less than 0.6°F). Two things stand out:

- » Load shifting: the complete elimination of compressor load from peak hours by the radiant system (the hydronic circulator pump uses approximately 150W which is the total power draw during peak hours). This is the primary aim of the thermal storage component of the system
- » The relationship between outdoor temperature and compressor power – the loss of efficiency and concomitant increase in power draw by the compressor at high outdoor temperatures means that the radiant system, operating during cooler off-peak hours, is generating cooling at a more efficient time of day.

The improvement in efficiency due to operating the compressor at lower temperatures is to some extent offset by inevitable storage losses as the chilled water needs to be kept at a low temperature for 12 hrs or more. However unlike the decline in efficiency, these are not inherent in the system, and can be minimized by optimal design and sizing of the storage tank.

An additional benefit of the radiant system is seen in figure D2 which compares the hall temperature maintained by the two systems during the first afternoon of the comparison period. It is clear that the radiant system provides a more stable temperature due to the longer time constant provided by the thermal mass of the building. Combined with the better balance of conductive, convective, and radiative heat transfer this will improve occupant comfort when compared to a forced air system.

### PATH FORWARD

Over the next few months we will be analyzing the data we have collected to determine the actual performance of the system in terms of savings and amount of load shifted off the afternoon peak, writing up the project final report, and putting together proposals for potential follow ups to this project, designed to progress the system towards commercialization. ☀

## TEMPERATURE COMPARISON: RADIANT VS. FORCED AIR

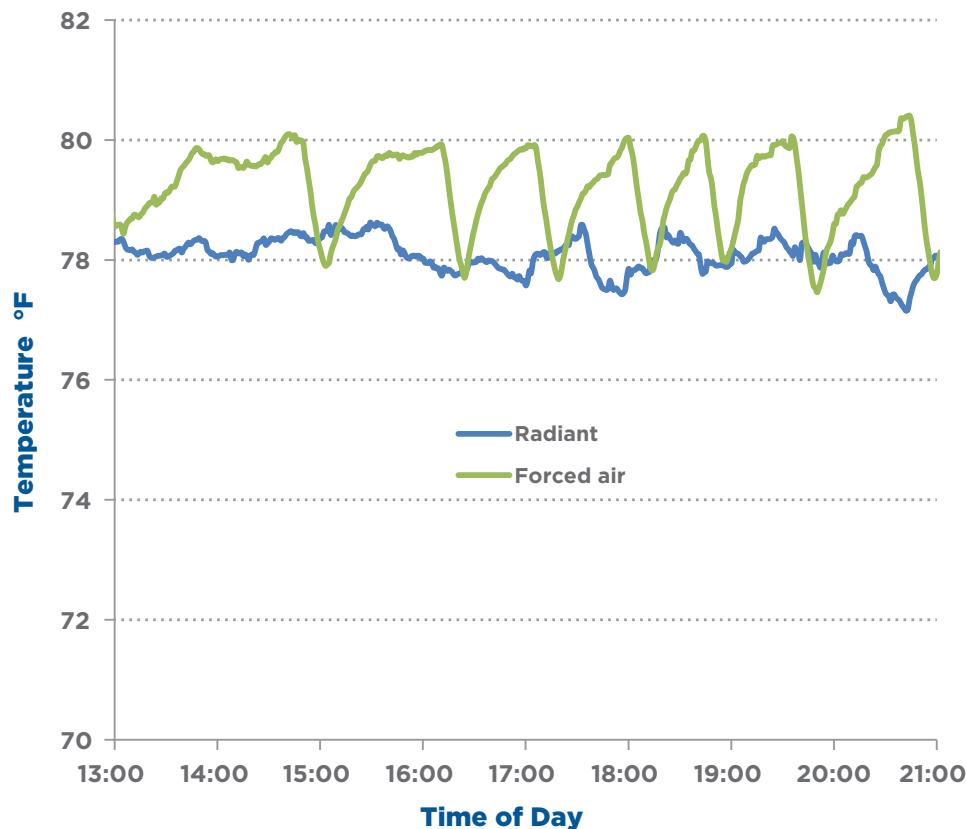


Figure D2: Comparison of hall temperature maintained by the forced air system vs. the radiant system



## MULTI-FAMILY RESIDENTIAL, HOTELS, DORMS, HOSPITALITY

---

**E.** Multi-Family Ventilation  
Diagnosis, Modeling and  
Improvement

21

**F.** Adaptive Thermostats for Dorms  
Field Study

25

---

## E. MULTI-FAMILY VENTILATION

Multi-Family buildings are a unique class of structure with specialized design demands and distinctive energy use profiles. The WCEC's Multi-family Ventilation project, which is part of a larger PIER funded project addressing several code relevant measures specific to multi-family buildings, intends to investigate and identify the unique HVAC challenges encountered in multi-family buildings. Ultimately, the Multi-family Ventilation Project will recommend changes to California building codes in order to improve performance and reduce energy use in multi-family buildings.

The process of ventilating inhabited spaces has been studied since 1836 and numerous guidelines for providing adequate ventilation are available from a variety of sources ranging from local building codes to national organizations. Unfortunately, due to the historical dominance of single-family construction in California, multi-family buildings have been largely overlooked by the building code improvement process. Thus far, multi-family buildings have fallen between commercial and residential jurisdictions and, as a result, have been addressed in a piecemeal fashion resulting in a hodgepodge of codes and standards. Therefore, many of the unique characteristics of multi-family buildings are either unaddressed or forced to adhere to guidelines that were developed for entirely different purposes.

In order to properly address the problems associated with ventilation in multi-family buildings, it was essential that current codes and standards be critically evaluated for areas of potential improvement. In addition to evaluating the codes, the WCEC created and executed several surveys to gather perspectives of practitioners familiar with California's Title 24 as well as national standards like ASHRAE 62.1 and ASHRAE 62.2.

The results of these investigations revealed that there are two distinct sets of code requirements outlined in Title 24: one for commercial and high-rise (4 stories or more) buildings, and one for low-rise (3 stories or less) residential buildings. The ventilation and exhaust rates specified in these two sections of the code are very different (see Figure E1), resulting in significant variation in ventilation system design. No discernible technical rationale was found for specifying two distinctly different ventilation code requirements for buildings with identical use types that may only differ by a single story. It is understandable that commercial buildings specify higher ventilation rates for a variety of reasons including higher occupant density and potential process contaminants; however, there is no clear technical reason behind lumping commercial buildings and residential buildings together as they currently are.



## HIGH VS. LOW-RISE VENTILATION REQUIREMENTS

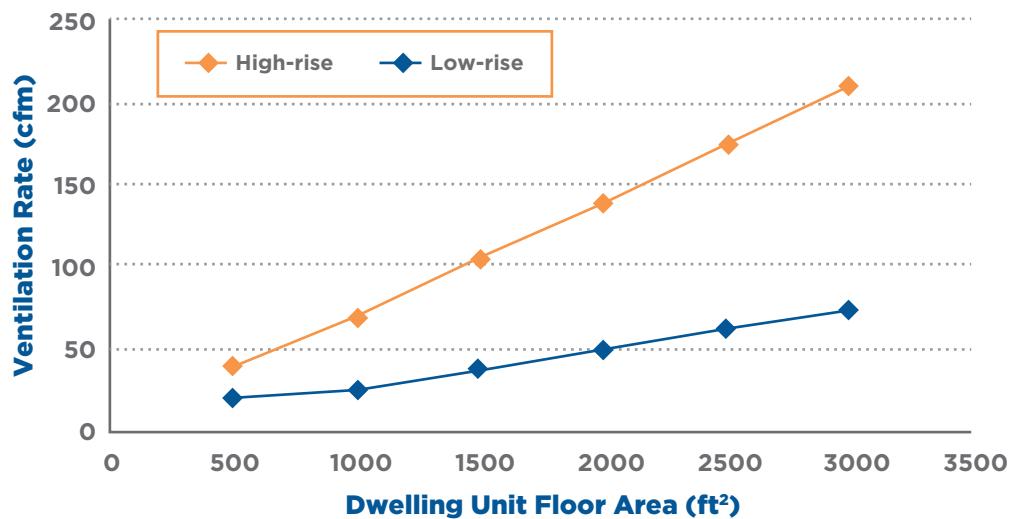


Figure E1: Comparison of ventilation rates required by Title 24

The second inconsistency between the various sections of Title 24 that specify ventilation rates arises from the idea that low-rise ventilation requirements allow infiltration to be incorporated into their calculations. One of the most notable problems with “infiltration credits” is that the source of the air cannot be guaranteed, which is particularly troublesome in multifamily buildings where this air may come from other units rather than from outside air.

In addition, infiltration is driven by the difference between indoor conditions and the outdoor environment, which is highly variable and unreliable. The pressure difference, or  $\Delta P$ , is a function of the temperature difference, or  $\Delta T$ , between the environment and inside the building, the wind direction, and the wind velocity. Figures 2d and Figure E3 illustrate two different pressure profiles that are likely to occur during the heating season (Figure E2) and the cooling season (Figure E3). As you can see the “Total Heating Pressure” in Figure E2 has a negative slope and the “Total Cooling Pressure” in Figure E3 has a positive slope indicating a complete reversal of flow for these two seasons. The effect of this flow reversal on ventilation systems can lead to profound performance related problems such as over ventilation (i.e. wasted energy) and under ventilation (unacceptable indoor air quality).

## HEATING SEASON PRESSURE PROFILE

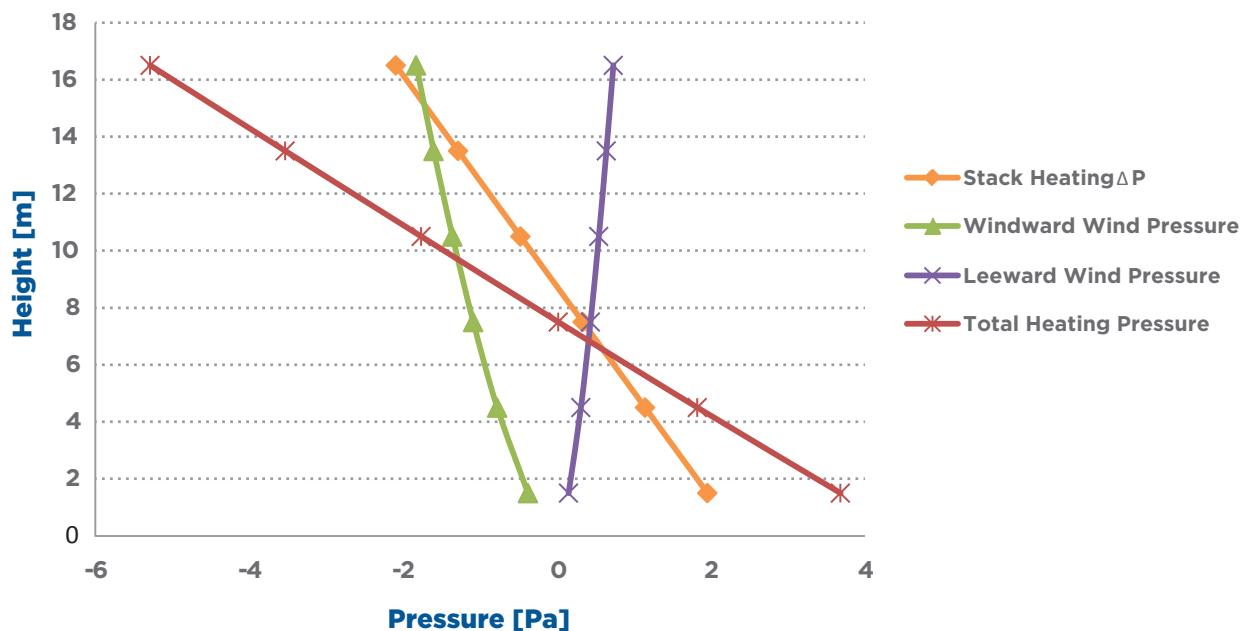


Figure E2: Example of a pressure profile experienced during the heating season

## HEATING SEASON PRESSURE PROFILE

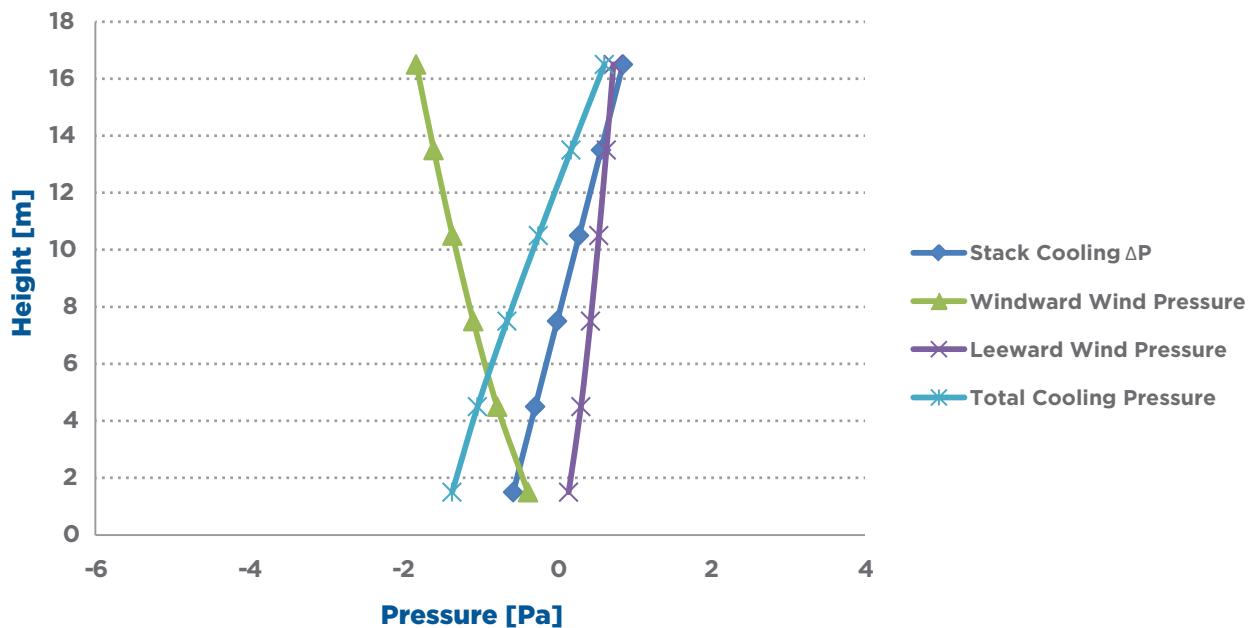


Figure E3: Example of a pressure profile experienced during the Cooling season.

\*Note: Positive pressures in Figures E2 and E3 indicate a pressure forcing air out of the building.

## PATH FORWARD

Through modeling, simulation, and field studies, the WCEC intends to pursue the effects and impacts of the following recommendations for Title 24 to improve ventilation performance in multifamily buildings:

*For all ventilation systems*

- » Code Consolidation: Combine all residential buildings, including multifamily high-rise buildings, under a set of requirements outlined in ASHRAE 62.2 (addendum J)
- » Compartmentalization: tighten the envelope of each apartment to reduce airflow among units and between the interior and exterior of the building

*For ventilation systems that use large central shafts*

- » Ventilation Duct Sealing: reduce ventilation duct leakage
- » Constant Airflow Regulators: use constant air flow regulators at each ventilation register to minimize over- and under-ventilation ☐



## F. ADAPTIVE THERMOSTATS

Buildings, such as hotel rooms and university residence halls, are often mechanically conditioned to a constant set-point, regardless of whether or not they are occupied. This is a waste of energy and money, but has historically been the only way to manage temperature and indoor air quality without zealous manual regulation by users or facilities managers. Programmable thermostats that vary temperature set-points and ventilation according to pre-defined schedules do offer added system control and offer the possibility of energy savings. However, if occupancy patterns are not predictable, it is difficult to define a programmed thermostat schedule, and the potential for energy savings is diminished. Various emerging thermostat technologies employ occupancy sensing and adaptive learning algorithms to better align system operation to occupancy trends. WCEC is currently investigating the breadth of applicability for these technologies and the extent to which they may reliably offer energy savings.

### MARKET ASSESSMENT

In theory, building types with highly predictable

schedules could be served well enough by a programmable thermostat, and buildings with high relative occupancy would have little room for benefit from an occupancy sensing control. Buildings with unpredictable occupancy schedules and relatively low occupancy rates have the most to gain from thermostats that respond to occupancy. Figure F1 orients the relative appropriateness of occupancy control for nine different building types by comparing their schedule predictability and relative number of occupied hours.

According to this assessment, hotels and conference or assembly halls should be the most appropriate markets. University residence halls have a comparatively high occupancy rate, but also one of the least predictable schedules, making them a likely candidate for cost effective energy savings. University residence halls are also burdened with a principal-agent problem where users do not have a financial incentive for energy-wise system management. In this case, occupancy sensing control could make an even more significant difference by negating wasteful behavior.

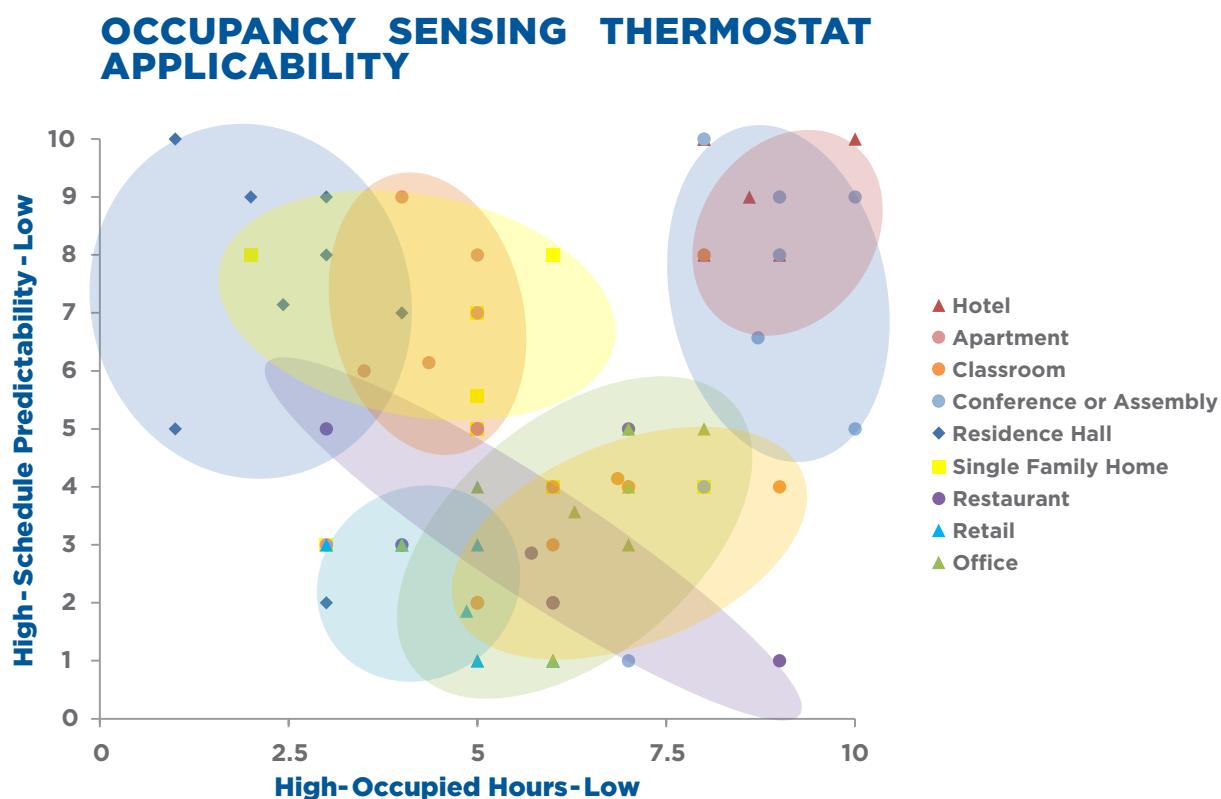


Figure F1: Applicability of occupancy sensing thermostats in various building types



Other characteristics that must be considered include mechanical system efficiency, typical thermal load characteristics, and design constraints for each facility type. For example, some offices have highly variable occupancy rates, yet unless the associated mechanical equipment has part-load operating capability, and zone-by-zone thermostat control, an occupancy sensing thermostat will not save energy on a low-occupancy day.

## FIELD RESEARCH

Over the past year WCEC has observed the installation of Telkonet's EcoInsight in several university residence halls. The technology is an occupancy sensing adaptive thermostat that allows space temperature to drift by several degrees during vacant periods. The thermostat learns the rate at which a heating and cooling system can respond and will operate to ensure that a room can recover from a set back within a reasonable time once it is re-occupied.

Each thermostat has an on-board infrared motion detector that senses when a room is occupied. Vacancy in a room triggers adjustment of the active set-point, which allows temperature to drift and results in a reduced duty cycle for the conditioning and ventilation systems. The system incorporates an on-board light sensor and logic to distinguish between vacancy and a nighttime condition where occupants are sleeping. Additionally, if the thermostat is not ideally located to clearly observe occupancy, Telkonet can incorporate a remote occupancy sensor that communicates wirelessly with the thermostat.

Telkonet applies a learning algorithm called Recovery Time™ which continually adapts the set-back temperature for unoc-

cupied periods such that a room can recover quickly upon the occupant's return. Facility managers are able to program an acceptable recovery time, and the thermostat learns how quickly the associated mechanical system is able to respond, allowing the room temperature to drift only so far that it can return to the occupied set-point within the allotted time. The algorithm is designed to adapt to changes in season, and in mechanical system characteristics such as a switch between heating and cooling mode. The set-back response can also be tiered such that after a long period of vacancy, temperature is allowed to drift even further; achieving added savings over unoccupied weekends or vacations. In addition to these adaptive control strategies, facility managers can select absolute limits for the set-back temperature to avoid damage to building materials and equipment. During occupied periods, users are allowed temperature control, although facility managers may limit the selectable set-point bandwidth to avoid excessive heating or cooling by residents.

WCEC's study focused especially on Bixby Hall. The building is a five-story high-rise dormitory constructed in 1965, with a two pipe fan coil system for heating and cooling. Ventilation for the building is provided by windows and a single constant speed air handling unit that serves all of the corridors and bathrooms. Prior to the study, each room had unrestricted manual thermostats that allowed students to drive the room temperature as they preferred. After the retrofit, each room had one Telkonet thermostat to control the individual room fan coil.

## RESULTS

Through review of a season of field observations, we find that these adaptive control schemes reliably shift temperature set points during vacant periods, and that there is a clear relationship between vacancy and reduced chilled water energy consumption. However we also find that the energy savings achieved is sensitive to the application in which the thermostats are installed. In one building, we observed no energy savings at all because the thermostats only held limited sway over operation for the building heating and cooling. In other buildings, even while runtime for individual room fan coils was reduced significantly, we believe that adjacent rooms may pick up some of load from rooms following a set-back schedule.

Various system operating data was collected from Bixby Hall in fifteen minute periods over the course of several months in 2012. Figure F2 plots the fan coil duty cycle for one room as a function of outside air temperature for both occupied and unoccupied periods. The duty cycle in this case is the number of seconds of operation within each record period. The chart records every period in the month of May 2012. The vertically oriented histogram shows the frequency that the duty cycle is within a certain range. Interestingly, there is not a clear trend between outside air temperature and duty cycle since there are too many other factors that influence the load within a particular room. Nicely, for vacant periods the driving duty cycle is reduced dramatically. In fact, for vacant periods, the fan coil remains off nearly 90 percent of the time.

## DUTY CYCLE COMPARISON

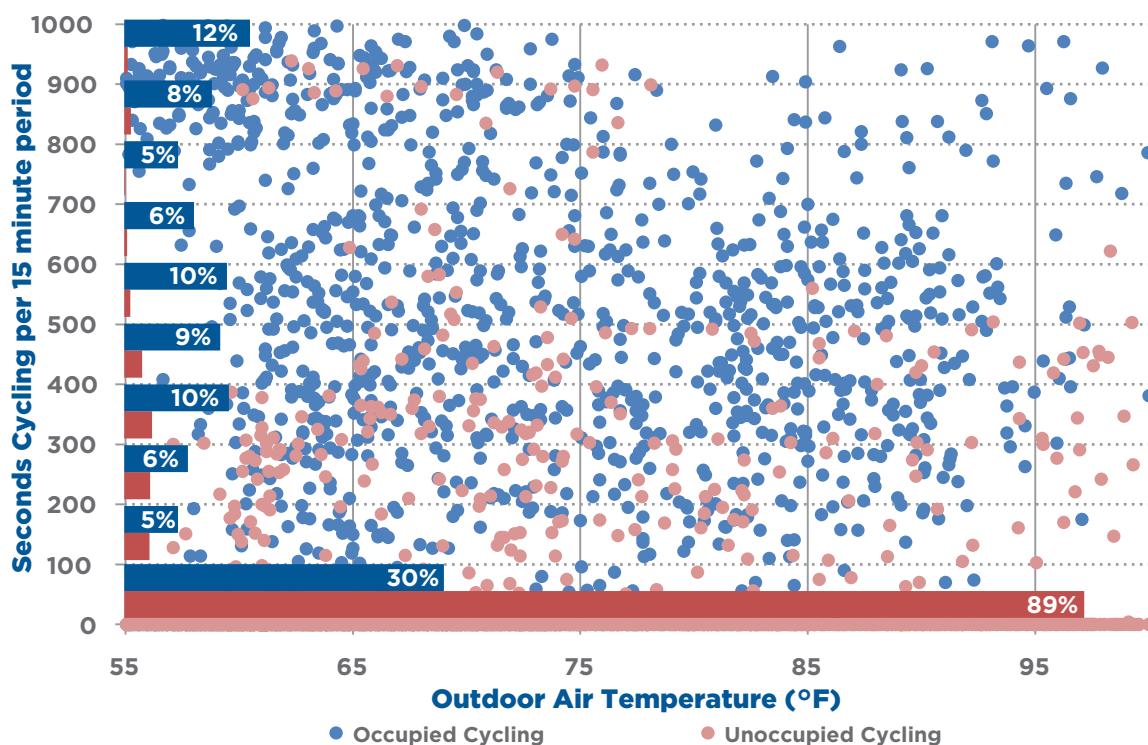


Figure F2: Comparison of Duty Cycle during Occupied and Unoccupied Record Periods, Bixby Room 314, May 2012

Figure F3 plots the hourly whole building chilled water energy consumption as a function of the hourly average outside air temperature for an eight week period between April and June 2012. Each record is binned by the magnitude of building occupancy for the hour, measured as the percentage of room thermostats in the building that record occupancy. There is a clear correlation between chilled water energy consumption and outside air temperature, though for any given outside air temperature there is wide variability in the chilled water energy de-

mand due to factors such as solar gains, plug loads, and occupant thermal gains. Interestingly the range of variation in hourly chilled water energy use for any given outside air temperature seems to be independent of the occupancy rate. However, a regression for chilled water energy use as a function of outside air temperature in each occupancy bin indicates that despite the wide variability hour-to-hour, on average there is significantly less chilled water consumption for lower occupancy periods.

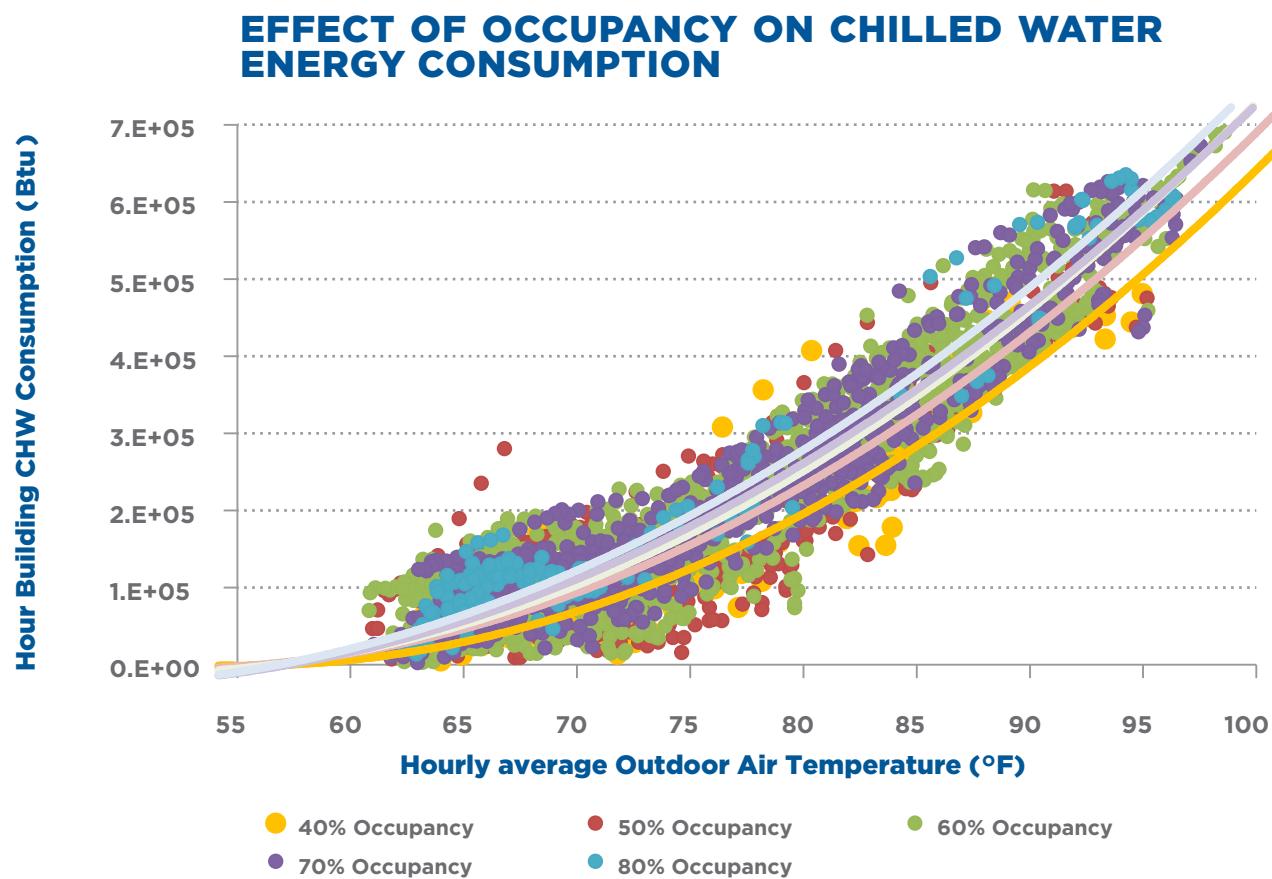


Figure F3: Whole Building Chilled Water Energy Consumption as a Function of Outside Air Temperature and Building Occupancy Rate

## PATH FORWARD

Monitoring for Bixby Hall will continue for the next several months, and measured energy consumption will be used to develop a more complete analysis of savings due the Telkonet system. Additionally, since this study, we have observed several other installations in similar residence halls.

In the near future we will compare each of these buildings side-by-side. We will control the thermostats for each building in various ways to better test for exactly how much energy savings is owed to the occupancy-sensing adaptive scheduling control strategies. ☒

## LIGHT COMMERCIAL & RETAIL

G. Multi-Tenant Light Commercial Project	30
H. RTU Retrofit Initiative	34
I. The Fault Detection and Diagnostics Initiative	37
J. The Western Cooling Challenge	39



## G. MULTI-TENANT LIGHT COMMERCIAL

One of California's most aggressive energy goals is to achieve net-zero energy for all new residential construction by 2020 and new commercial construction by 2030. Unfortunately, these goals do not address existing buildings which represent the vast majority of California's building stock. Some progress stands to be gained from California's goal of 30% to 70% energy savings by 2020 through retrofits of its existing buildings; however, this initiative is relatively ambiguous because of the wide range of savings targets and because it is directed at both commercial and residential buildings.

In an attempt to address some of this ambiguity, the WCEC, in cooperation with the CLTC and the EEC, are focusing on a specific, and traditionally underserved, market termed Multi-Tenant Light Commercial (MTLC). For the purposes of this project, the MTLC market consists of buildings that contain between 2 and 25 small and medium businesses, have a total footprint of less than 350,000ft<sup>2</sup>, and have a peak load less than 499kW. Using an integrated approach that will include improvements to envelope systems, lighting systems, and mechanical systems, the MTLC project aims to reduce energy consumption, and peak demand, by 30%-50%.

In general, retrofitting buildings for energy efficiency is an inherently more difficult process than addressing energy challenges at the point of design in new buildings. From a

technical perspective, retrofits often require a host of additional considerations due to the limitations of a buildings existing infrastructure. From a logistical perspective, energy related retrofits must overcome yet more challenges that range from high initial investment costs to end user education.

Multi-Tenant Light Commercial buildings present several unique challenges that result from the nature of the tenant-landlord relationship, the relatively small size of the businesses, broad variations in energy consumption of each business, and the multitude of possible building attributes. As such, the first of many tasks in the MTLC project is to characterize the market in an attempt to create methods by which MTLC buildings and businesses may be classified. Then, using the characteristics of each business type and the variety of building attributes, the hurdles to addressing energy efficiency will be identified.

Preliminary results of several initial surveys aimed at assessing the MTLC market have identified 6 archetypes outlined in Figure G1. Several databases, including CEUS and CBECS were used to corroborate metrics for these MTLC archetypes, such as Energy Intensity. The MTLC archetypes are being combined with the appropriate metrics to create a baseline for purposes of comparing and evaluating actual energy use (i.e. utility smart meter data).



## MTLC BUILDING ARCHETYPES AND ATTRIBUTES

	Attributes	Example
Community Shopping Center	150,000 ft <sup>2</sup> -300,000 ft <sup>2</sup>	
Neighborhood Shopping Center	30,000 ft <sup>2</sup> -150,000 ft <sup>2</sup>	
Strip Mall/Convenience Center	150,000 ft <sup>2</sup> 350,000 ft <sup>2</sup>	
Small Office Park	< 30,000 ft <sup>2</sup>	
Mixed Use Building	Residential & Commercial	
Main Street Building	Streetside/No Exclusive Parking	

*Figure G1*

The resolution of the MTLC database being compiled will increase over time as more individual smart meter data becomes available. More important than adding to the database, however, is the information gleaned from evaluating smart meter data. The WCEC team is developing a mathematical tool that combines smart meter data and weather data to identify trends and evaluate performance characteristics of specific businesses as well as entire MTLC facilities.

In figure G2, for example, the optimized trend lines produced by our analysis tool intersect at 57°F and 72°F, which are the respective heating and cooling balance points specific to this building. In addition, figure G2 illustrates the energy consumed by lighting and miscellaneous plug loads at nearly 4kw as shown by the horizontal region between heating and cooling balance points. All of this information can then be used to predict and possibly evaluate the impact of various potential energy efficiency retrofit strategies.

## POWER USE VS. OUTDOOR AIR TEMPERATURE

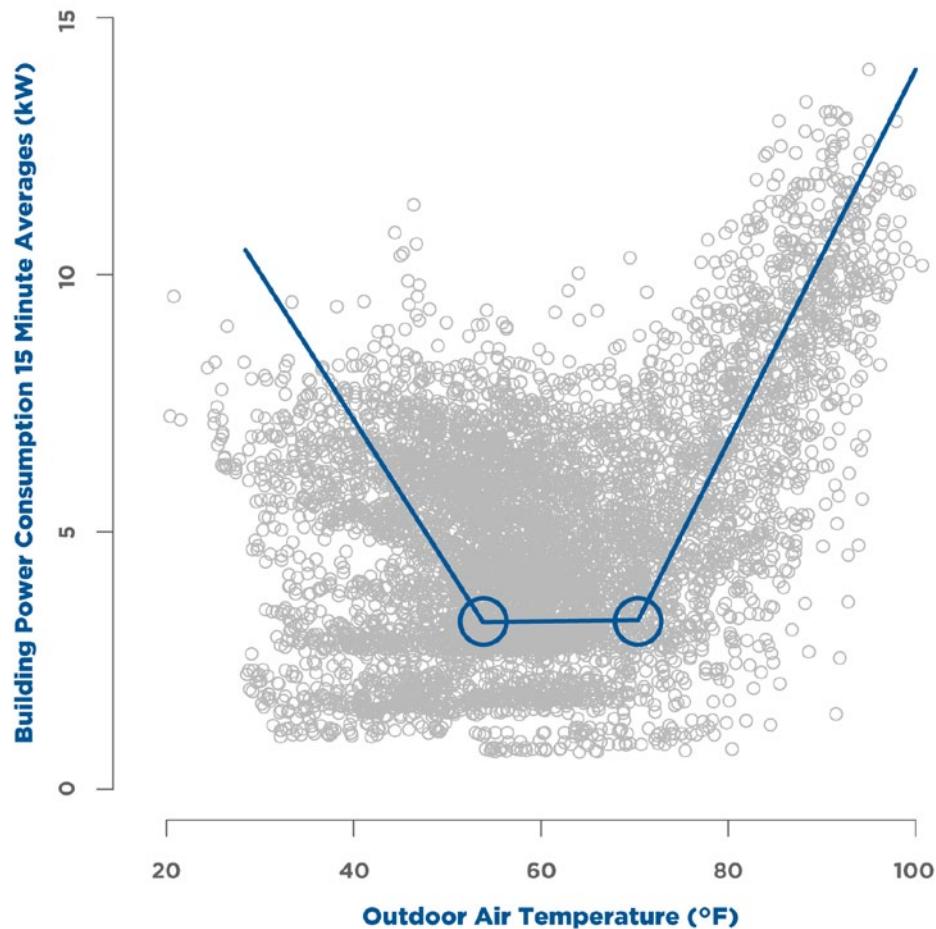


Figure G2

Many of the potential retrofit solutions specific to HVAC depend not only on the performance of the building but the attributes of system design. For example, two identical spaces within an MTLC building may have different thermal zones and, therefore, a different number and size of rooftop units, even if the same amount of overall heating and cooling capacity is re-

quired. A preliminary field study of MTLC buildings performed by the WCEC illustrates the distribution of the size and number of RTU's (Figure G3). This information aligns with several previous studies performed by PNNL, PECL, & NBI and highlights the need to address a large number of small units; nearly 80% of the RTUs surveyed were 6 tons or less.

## NUMBER OF RTUS VS. RTU CAPACITY

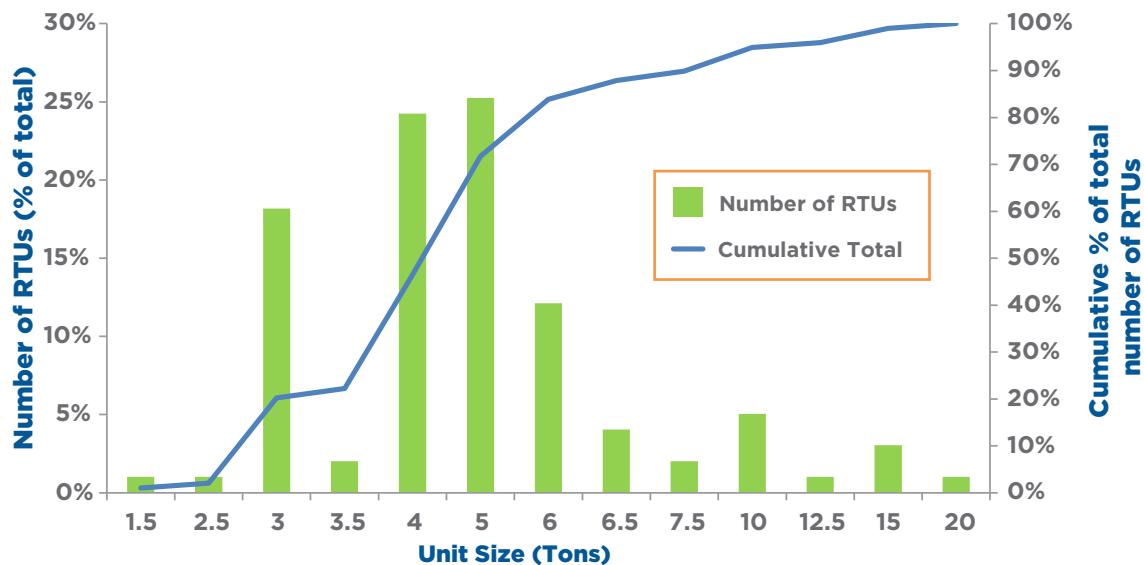


Figure G3

## PATH FORWARD

Looking forward the WCEC will compile a list of potentially appropriate HVAC retrofit solutions and evaluate their performance through various simulations. Using the information gathered thus far, these simulations will be tailored to address the unique attributes of MTLC related buildings and systems. In

addition to evaluating the performance of each solution individually, the WCEC will evaluate the performance of various packages of HVAC technologies and, eventually, overall performance of integrated envelope, lighting and HVAC retrofit solutions. ☐



Figure H1: WCEC engineer Perry Young installing an air to hot water heat exchanger for conditioning of the test chamber air

## H. RTU RETROFITS

It is estimated that roughly 70% of the non-residential space in California is conditioned by packaged roof-top units (RTUs). This prevalence makes these units a key component of any energy efficiency programs targeting non-residential buildings. However, addressing the energy performance of this equipment is complicated by their longevity. Stand-alone RTUs are estimated to last approximately 20 years on average. This long replacement cycle limits the market penetration rate of new energy-efficient HVAC packaged equipment in light commercial buildings.

Another issue associated with this type of equipment is that RTUs have an electrical load factor on the order of 20% in California. Load factor is defined as the ratio of average annual electricity consumption to coincident peak electricity demand. This low load factor stems from the fact that cooling compressors (which represent the largest power draw in this equipment) are off for much of the year, but are generally running simultaneously across the population during peak electricity demand times. This translates to a disproportionate peak electric demand associated with RTUs, which in turn translates to a poor use of capital for utilities in California.

One option for improving the energy efficiency and lowering peak electricity demand of RTUs within a shorter time frame is an initiative to improve energy efficiency through cost effective RTU retrofits. These strategies are focused on the facilitation of self-sustaining business models for profitably delivering comprehensive RTU retrofits that save electricity and natural gas, while significantly reducing peak electricity demand. Simplified calculations suggest significant energy savings potential for retrofits of RTUs. As an example, evaporative pre-cooling of condenser air has been shown to reduce compressor energy use by 10-40%, depending upon the climate.

The first two years of a WCEC initiative to retrofit RTUs consists of the following activities:

- » Develop a test protocol and analysis method for impacts of Condenser-Air Pre-Coolers
- » Survey and analyze RTU fan operating patterns and quantify potential impacts of efficient fans/motors as retrofit technologies

## TEST PROTOCOL DEVELOPMENT

Evaporative pre-coolers pass the inlet air through a wet evaporative media, decreasing the dry bulb air temperature toward the

wet bulb temperature. There are a large number of evaporative pre-coolers available on the market; however, no standard exists by which to measure their performance, so WCEC has authored a draft laboratory test protocol for condenser-air pre-coolers. The laboratory test protocol assesses the energy savings and water use of evaporative pre-coolers with respect to outdoor dry bulb and wet bulb temperatures. The protocol also has tests for assessing the impacts of wind and hard water on pre-cooler operation. WCEC is working to get the protocol established as an ASHRAE test standard. At the July 2012 meeting in San Antonio, Texas, ASHRAE technical committee 5.7 approved the Title Purpose and Scope for the proposed "Method of Test for Determining Energy Performance and Water-Use Efficiency of Add-On Evaporative Pre-Coolers for Unitary Air Conditioning Equipment" and will be sending it to the standards committee.

WCEC is currently using the draft protocol to test three evaporative pre-cooler products. The objective is to evaluate the protocol while gathering data on three commercially available products: Daikin's "Ene-cut", Mist Ecology's "AC Spritzer," and

Greenway Design Group's "Cool-N-Save". While waiting for construction of a new 2,000 ft<sup>2</sup> laboratory, WCEC has constructed a temporary test facility (Figure H1) capable of testing a 3-ton condensing unit with pre-cooler installed. Testing of the baseline condensing unit has been completed and testing of the pre-coolers is currently underway. Results for the pre-cooler testing are expected in Fall 2012.

Furthermore, WCEC is developing an analysis tool to quantify the impact of pre-coolers on energy savings of the RTU stock in California. While the protocol will quantify the pre-cooling delivered and the energy savings of the condensing unit under test, additional work is needed to estimate the energy savings for a typical RTU in California. RTUs are more efficient when the outside air temperature is cooler, but the efficiency increase with respect to temperature decrease varies among units. A preliminary analysis of 26 RTU models shows that RTUs with refrigerant R-410A are slightly more sensitive to temperature changes than RTUs with refrigerant R-22 (Figure H2). However, the difference is small, and both data sets are in good agreement

## TEMPERATURE IMPACT ON COP BY REFRIGERANT TYPE

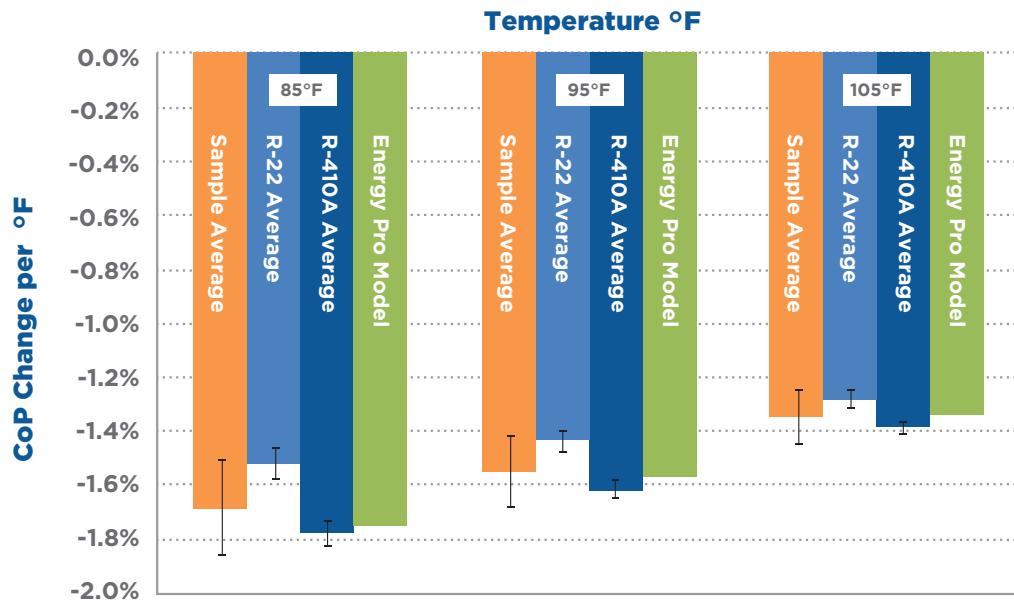


Figure H2: An analysis of 26 RTUs showed that those with 410-A refrigerant have a slightly larger efficiency decrease when temperature is increased when compared to units with R-22.

with assumptions used by a Title 24 compliant energy modeling program, Energy Pro. WCEC is continuing to analyze manufacturer RTU data to determine the expected mean and range of the slope of RTU performance. This data will be combined with laboratory test data to determine the expected energy savings impacts of pre-coolers on RTUs in the field.

### RTU FAN SURVEY

A cursory analysis of the DEER database (Database for Energy Efficient Resources) suggests that the electricity use of commercial RTUs is split roughly equally between the compressor and the fans. The analysis behind these numbers, based principally on computer simulations, seems to imply that RTU fans are

run continuously, rather than cycling with the compressor. This is not surprising, as Title 24 energy performance calculations require non-residential buildings to meet ASHRAE Standard 62.1 for ventilation. For code compliance purposes in buildings with RTUs this is generally achieved by having RTU fans run continuously (at least during occupied hours). The exception is for the subset of these buildings that have dedicated ventilation systems.

Anecdotal evidence, as well as field research from the mid-1990s, suggest that a significant fraction of RTUs operated with the fan cycling with the compressor (or furnace), similar to most residential systems. Whether or not the fan is cycling with the

compressor is a very important consideration with respect to the energy savings to be expected from a fan retrofit program for existing RTUs, impacting the savings by as much as a factor of three. Something that can be even more problematic would be a utility program that winds up actually increasing electricity consumption by turning a cycling fan into a continuous-operation fan in order to assure ventilation-code compliance.

An analysis of a survey of 149 RTUs in the Pacific Northwest completed by Bonneville Power Authority (BPA) determined that 35% of RTUs have the fan running 24hrs/day. A significant

portion (25%) run 8-12 hours/day, which is consistent with the expected number of occupied hours for a commercial building. WCEC and subcontractor Davis Energy Group are currently surveying 200 RTUs in California to determine the percentage of fans that are run continuously. Data is expected to be available in Fall 2012. The resulting data set will be combined with existing data to estimate the energy savings potential from fan retrofits (such as high efficiency motors and fan speed control). ☀

## SURVEY OF FAN OPERATION

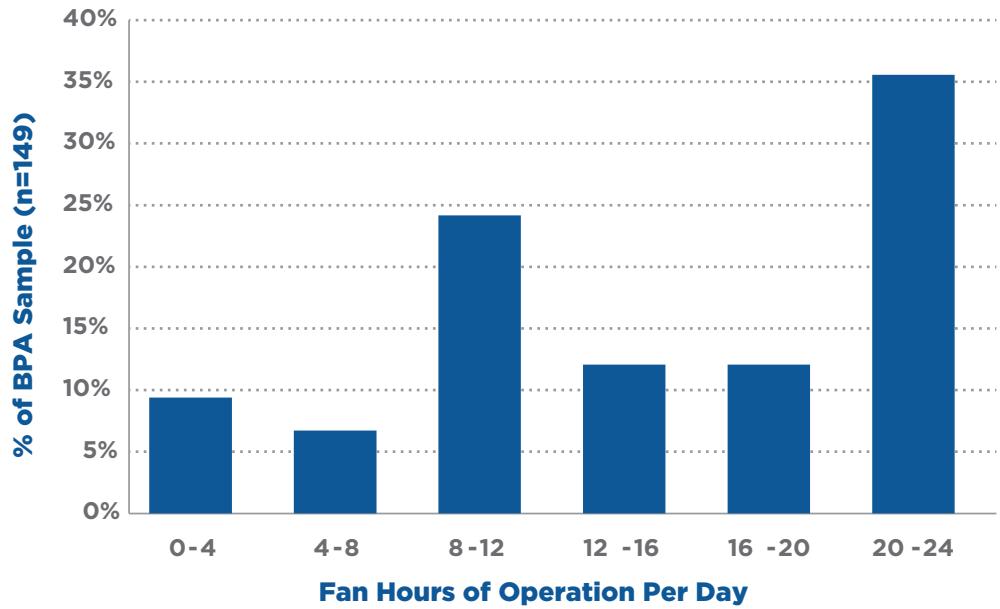
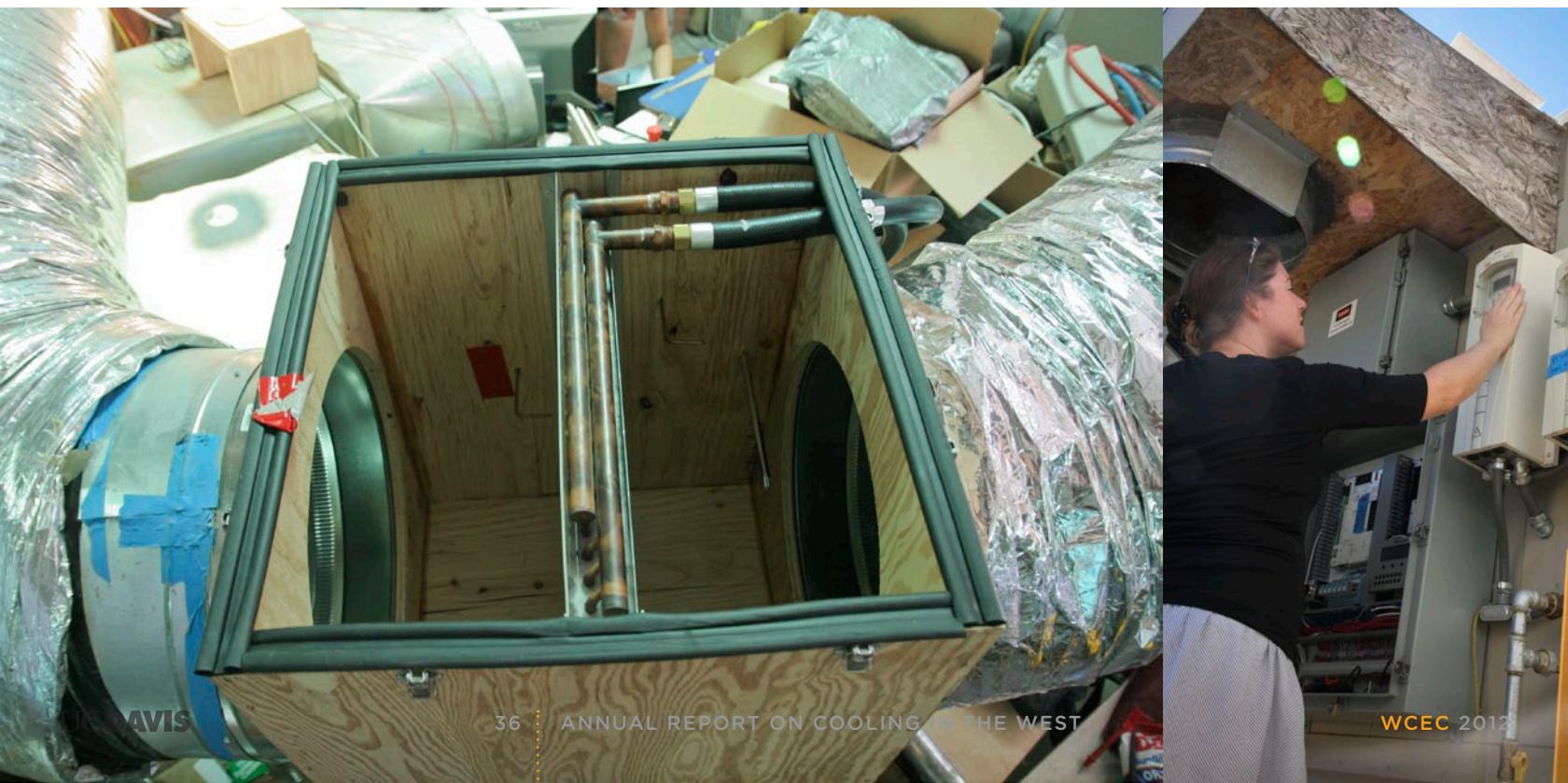


Figure H3: Survey of Fan Operation of 149 RTUs in Pacific Northwest



## I. 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 has helped advance 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)—in partnership with Portland Energy Conservation, Inc (PECI); and in a project for Southern California Edison, WCEC is helping the utilities reach out to the industry and advance the technology.

## CALIFORNIA CODE CHANGE PROPOSAL

WCEC is proud to announce that, as a part of the CEC-funded project, WCEC and its partners were successful in getting the CEC to incorporate a mandatory requirement for FDD into California's Title 24 Building Code. This will require that the following conditions be detectable by any rooftop unit installed in California:

- » Air temperature sensor failure/fault
- » Not economizing when it should
- » Economizing when it should not
- » Damper not modulating
- » Excess outdoor air

There are 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. Analysis conducted by the overall project team indicates that an FDD tool will save approximately 12% of annual energy for a typical RTU in an office building. 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.

Deg of Diff	Deg of Urg	# Days Paybl	Total Savings Per Year	Electricity Savings Per Year	Equip Savings One Time	Revenue Savings One Time	Cost Savings Description	Equipment Type	Equipment ID #	Resolution	Create Case
1	1	Low	11	\$1,068	\$1,068	\$0	\$0 Light schedule violates unoccupied policy	Lighting	01_FA_LZ1_01		
2	1	Low	13	\$936	\$936	\$0	\$0 Cooling schedule or setpoint violates unoccupied policy	HVAC	01_TL_PHP_01		
3	1	Low	18	\$684	\$684	\$0	\$0 Refrigeration setpoint violates policy	Refrigeration	0B_FA_SSCO_04		
4	2	Low	19	\$1,168	\$1,168	\$0	\$0 Cooling - Occupied Schedule or Setpoint	HVAC	01_VA_PHP_02		
5	3	Low	93	\$816	\$816	\$0	\$0 Economizer Damper setting causing excess conditioning	HVAC	0C_GPK_03		
6	4	Low	204	\$624	\$624	\$0	\$0 High Side fan operation causing inefficient energy usage	HVAC	0B_FA_SSCO_04		
7	5	High	29	\$5,592	\$792	\$4,000	\$800 Existing or near term system failure	Refrigeration	01_FA_OCCM_01		

Figure ii: Interface used by one Third-Party FDD Tool (FieldDiagnostics.com)

## INDUSTRY OUTREACH

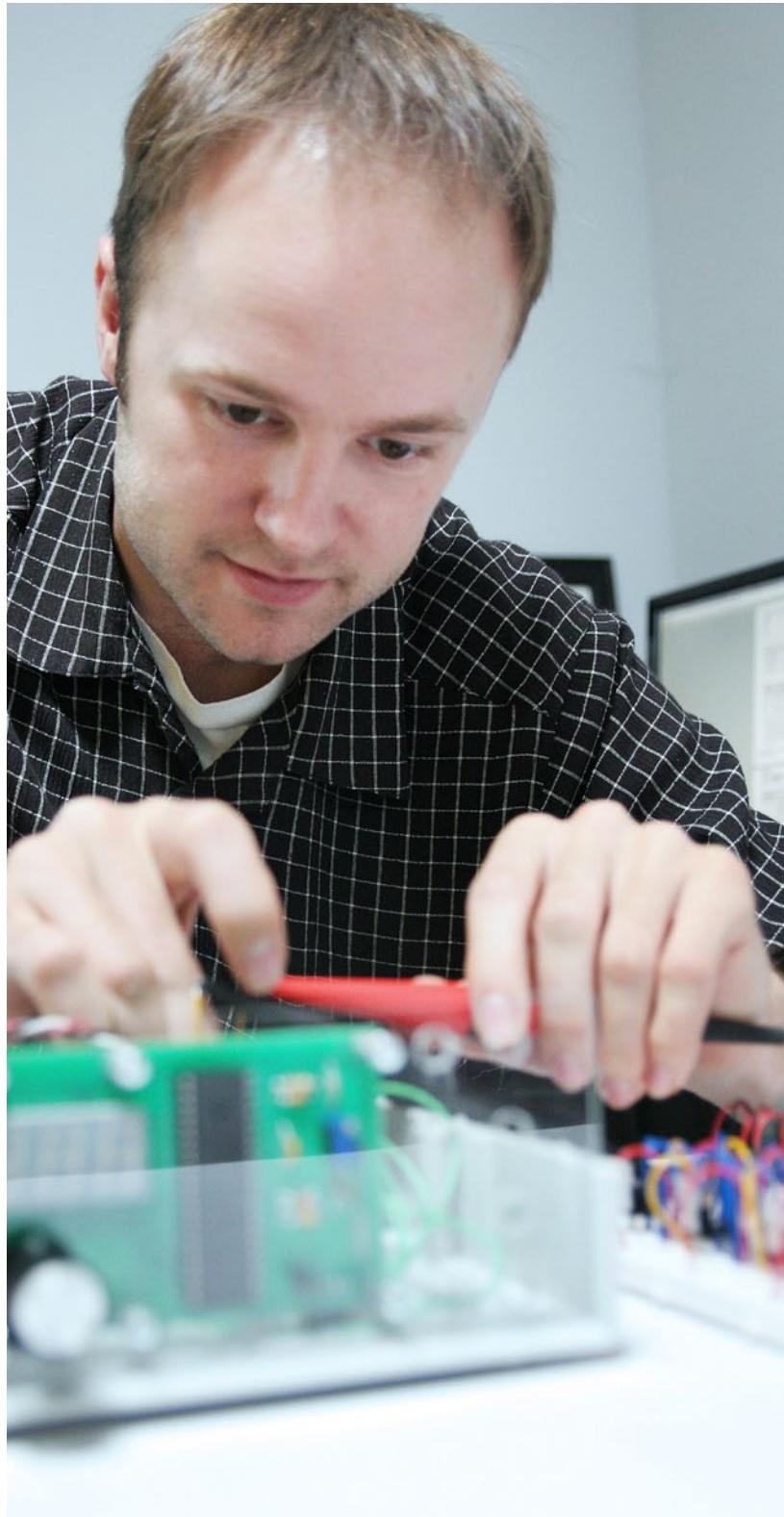
With the support of Southern California Edison Company, WCEC is also facilitating the “FDD Subcommittee” — a subcommittee of the Western HVAC Performance Alliance. This group of industry leaders is organized to develop and implement a roadmap to meeting the goals of the Strategic Plan with regards to FDD. This 17-member committee consists of researchers, contractors, original equipment manufacturers, third-party FDD tool developers, end users, and equipment manufacturer associations. WCEC has drafted a roadmap that identifies 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.

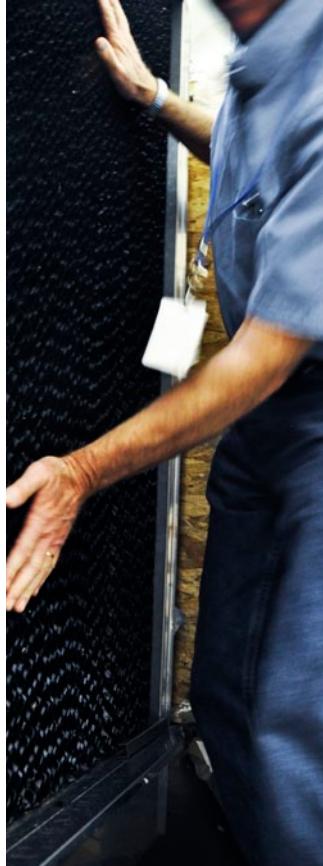
WCEC is also working to standardize FDD technology by spearheading an effort to develop an ASHRAE Standard Method of Test for FDD. ASHRAE Standard 207P will provide metrics for the performance of an FDD method, and describe test conditions and test methods for demonstrating that the tool can detect and diagnose faults. This Standard is a necessary precursor to including FDD in building performance standards. Kristin Heinemeier, a WCEC Staff Engineer, is chair of the committee that has formed 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 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 (January 1, 2014)
- » 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 carry out 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) ☈





## J. WESTERN COOLING CHALLENGE

The Western Cooling Challenge is a multiple winner competition that encourages HVAC manufacturers to develop climate-appropriate rooftop packaged air conditioners that use at least 40% less energy at peak compared to current federal standards. WCEC conducts laboratory testing to certify equipment performance in hot-dry conditions, and champions field demonstrations of these systems to prove real-world performance and equipment reliability. The extensive data collected through these efforts informs utilities, customers, and the industry about the energy savings that can reliably be expected from these emerging 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 hybrid systems that combine many of these strategies in various ways to achieve the aggressive Challenge performance targets.

### HISTORY & STATUS OF THE CHALLENGE

The Western Cooling Challenge was announced in 2008, and quickly drew the first formal entry from Coolerado. Their equipment, the Coolerado H80 surpassed the Challenge performance requirements by a large mar-

gin – laboratory testing indicated 65% energy savings at peak cooling conditions.

In 2011 and 2012, the Western Cooling Challenge has seen substantially large progress and growing participation from many manufacturers. Notably, Trane has entered the fray with the 15-25 ton Trane Voyager DC. The system was laboratory tested at Intertek in June 2012, and recorded a 40% energy savings operating at full load and at peak cooling conditions. Currently, WCEC is coordinating several field demonstrations of the equipment, which will be installed over the coming months and evaluated across the 2013 cooling season.

Not all of the hybrid equipment evaluated by our program have proven so successful. Speakman Cooling Solutions developed the Air20 Quattro|Hybrid CRS-2500, and while laboratory tests showed that certain operating modes for this system were significantly more efficient than a DOE 2010 standard RTU, the full load efficiency fell short of the Western Cooling Challenge criteria.

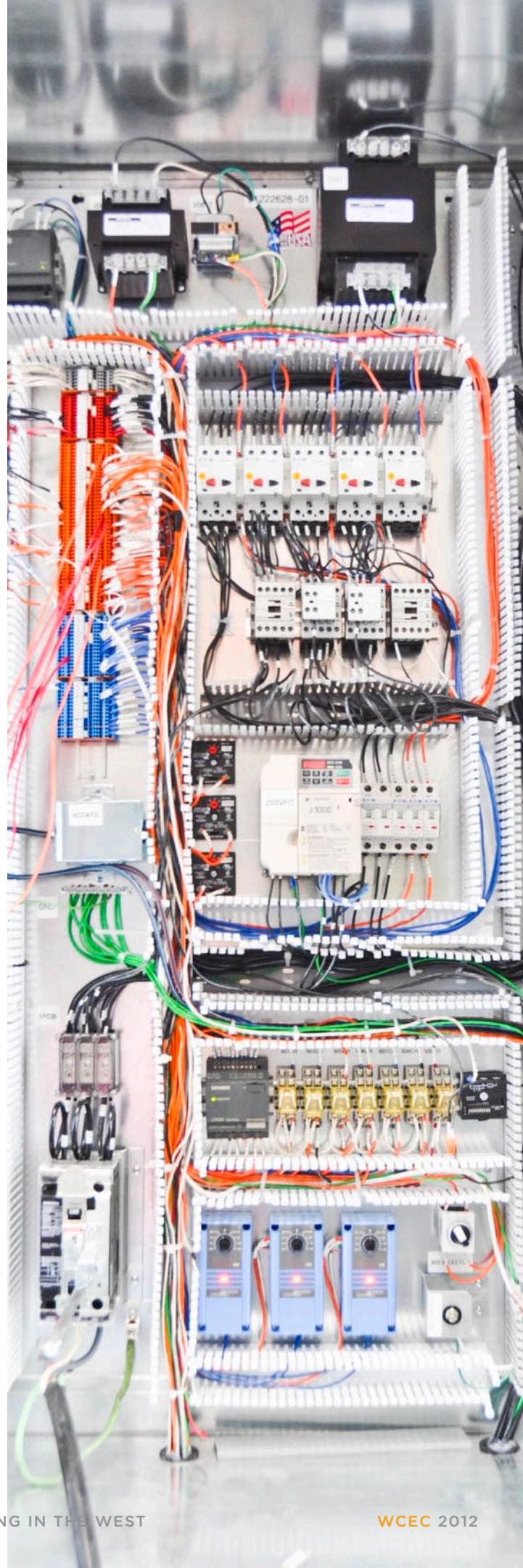
Munters has recently introduced the EPX 5000, a packaged hybrid Dedicated Outside Air System, which was formally submitted to the Challenge for certification testing. This equipment uses building return air as the secondary air stream of a uniquely designed indirect evaporative cooler, and incorporates a high efficiency vapor compression system to provide additional capacity or dehumidification when necessary.

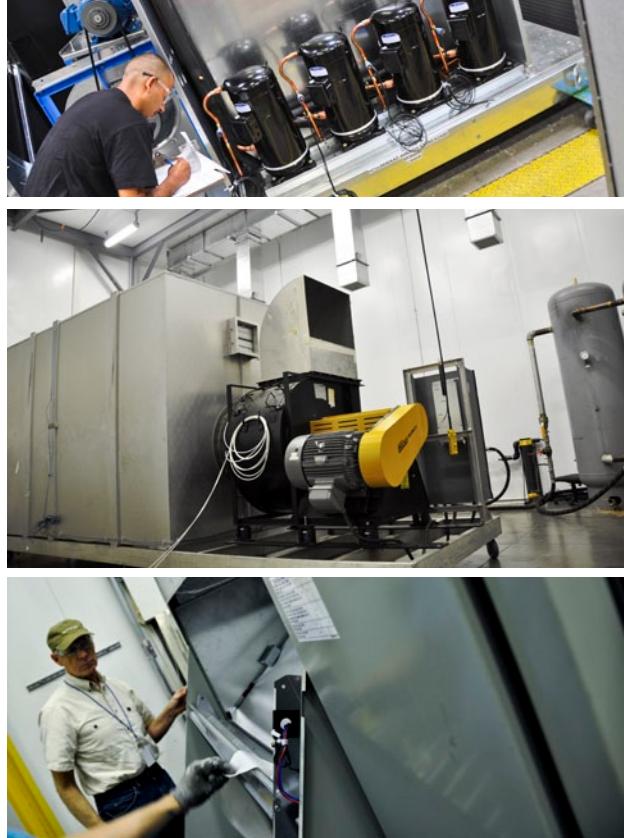
## HIGHLIGHTS FROM THE FIELD

WCEC has partnered with Southern California Edison, Pacific Gas & Electric and a range of equipment manufacturers to field test the performance of several different hybrid rooftop air conditioners. These demonstrations will serve to characterize system performance across a wide range of field applications, and will offer our manufacturing partners heuristic insight into any product improvements needed for broad scale field deployment. California utilities want to move Western Cooling Challenge products toward rebate programs, and will rely on WCEC's field performance reports to justify such incentives.

Manufacturers in the Western Cooling Challenge field evaluation spotlight include Coolerado, Trane, Seeley, Munters, Daikin-McQuay, and AirMax. Ultimately, the detailed field performance from monitoring each of these systems will inform a unified benchmarking report that compares these products' price and performance against conventional alternatives.

Field data from two Coolerado H80 systems shows compelling real world performance, and has also provided insight into a range of opportunities for further optimization. One of the systems was installed at UC Davis, and another is operating at the Naval Air Weapons Station, China Lake. Each of these systems have been operating reliably for many months, and using far less energy than the conventional rooftop units they replaced.





### PATH FORWARD

In the coming year, with support from CEC, Southern California Edison and PG&E, WCEC will be turning out a wide array of results to characterize the operation and performance of the hybrid rooftop air conditioners currently in evaluation. We will conclude numerous field studies, spur additional manufacturer participation, and increase outreach through general publicity, academic publications, and participation with various HVAC trade associations.

As WCEC digs deep into the wide array of climate-appropriate cooling strategies, it has become apparent that the performance metrics defined for the Western Cooling Challenge are somewhat narrowly defined. Just as ANSI/AHRI 340/360 test protocol for conventional rooftop air conditioners cannot appropriately test hybrid RTU's, the Challenge test protocol excludes some types of climate-appropriate technologies that might achieve equal savings. Thus, WCEC will redefine an evaluation protocol for the Western Cooling Challenge that can provide a fair comparison for a wider range of climate appropriate air conditioning systems.

Further, now that equipment performance for various Challenge systems has been well characterized, WCEC will work toward developing publicly available modeling tools that can simulate these systems as part of whole building systems for compliance calculations. An active project in collaboration with LBNL focuses on development of an EnergyPlus module designed specifically for simulating WCC equipment. ☈

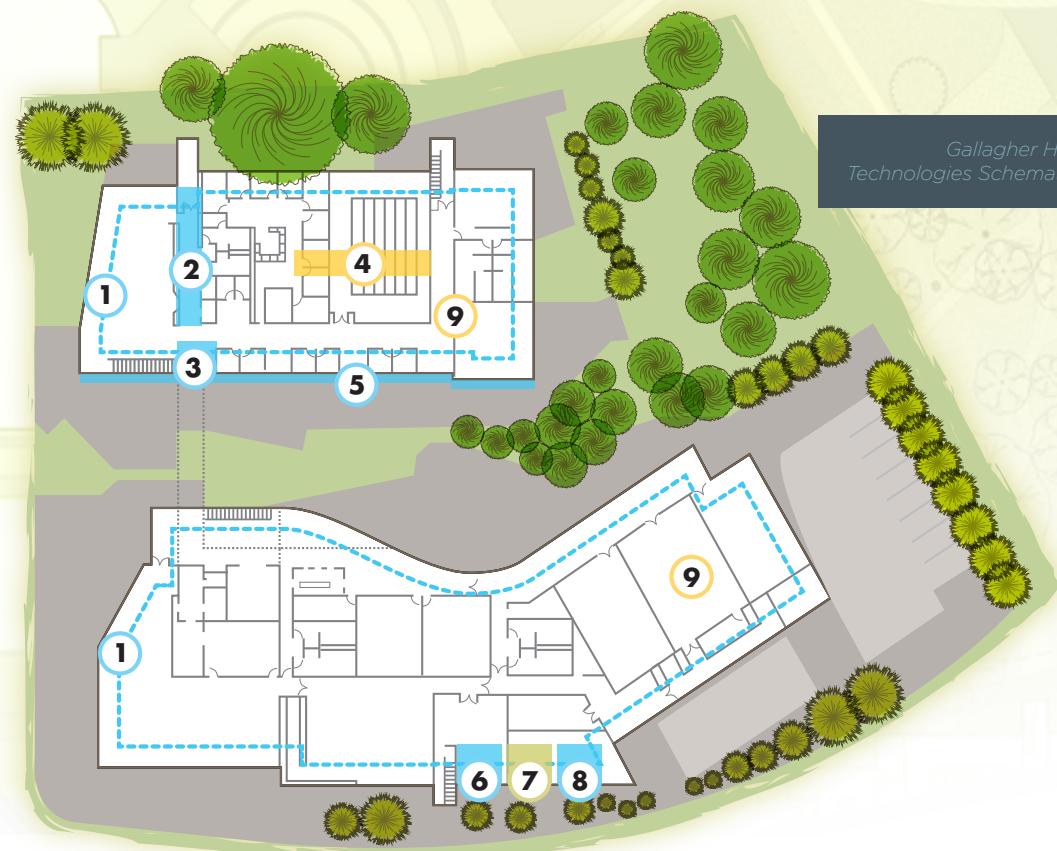
## CROSS-CUTTING TECHNOLOGIES

<b>K. Technologies Demonstrations Program</b>	43
<b>L. Hybrid Evaporative/DX Cooling Equipment</b>	46
<b>M. Aerosol Sealing of Building Envelopes</b>	50
<b>N. Phase-Change Materials for Hydronic Systems</b>	53
<b>O. HVAC Technician Instrument Lab</b>	56



**LEGEND**

1. Radiant floor & ceiling panels
2. Displacement Ventilation
3. Operable Windows
4. Light Well
5. Rain Screens
6. Chiller & Heat Pump
7. PV Inverters
8. Boiler/Hot Water Heater
9. Solar Panels



## K. 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, unbiased 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 and 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 use through these institutions, while technologies that fall short of performance or cost effectiveness thresholds receive feedback about necessary improvements learned in field installations and monitored operations. Advanced HVAC technologies face many barriers to market success. WCEC's technology demonstration activities help to bridge these barriers 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 information into 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. The benefits of this program are widespread. 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 as the program fosters progress toward state goals for energy and peak demand reduction, climate change mitigation, environmental responsibility, and economic vitality.

## RECENT WCEC DEMONSTRATION PROJECTS

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. Areas of focus this year include:

- » **Gallagher Hall Smart Building Design Study:** Davis' Gallagher Hall houses the Graduate School of Management. This 89,000 SF building has earned a LEED Platinum rating and stands out on campus as an example of smart building design. Innovative engineering including radiant heating and cooling, a dedicated outside air system, and solar management make this building roughly 60% more efficient than similar buildings in its class. WCEC is performing an in-depth analysis of the building's energy flow and evaluating the unique technologies this building utilizes.
- » **Laboratory Efficiency:** The SPEED program, in partnership with the Alliance to Save Energy (ASE) and Lawrence Berkeley National Laboratory (LBNL) has begun an in-depth study of energy consumption of fume hoods and the effectiveness of "Shut-the-Sash" campaigns on University campuses. The goals of the study are to determine the typical configuration of California University laboratories, to estimate the amount of energy that can be saved with ideal sash management, and to understand which factors make the Shut-the-Sash campaign effective.
- » **RTU Retrofit Optimizers:** Packaged air conditioners typically utilize inexpensive and antiquated control technology. New advances and falling costs in the field of controls and motor control have made retrofit control technology an attractive way to save energy on these types of units. A field demonstration of one of these control technologies underway at SDSU (San Diego State University) retrofits 4 roof top units ranging in size from 8.5 to 25 tons and will be monitored for energy savings.



Continuing work includes:

- » Field demonstration and beta test of the Coolerado H80 Hybrid RTU at Naval Air Weapons Station, China Lake
- » Field demonstration of aerosol duct sealing for central exhaust systems in the Art Building at Davis
- » Field evaluation of the EvaporCool™ condenser air pre cooler on an air-cooled chiller at Beale Air Force Base
- » Evaluation of energy impacts for Telkonet's occupancy sensing thermostats at the Bixby residence hall at Davis

## PATH FORWARD

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

- » Continuation of demonstration activities with public institutions and University campuses throughout California
- » Acceleration of demonstration activities with municipalities, and municipal utilities
- » Involving undergraduate and graduate students in field evaluation of technologies, in part as an educational tool by providing training for engineers in building energy efficiency
- » Highlighting and comparing the experiences and lessons learned through design and construction of various high efficiency green buildings throughout the region
- » Specific focus on broad application of well-vetted technologies that can achieve large, near term energy savings ☐





## L. HYBRID EVAPORATIVE/DX COOLING EQUIPMENT

Indirect evaporative cooling (IEC) is attractive for space cooling in dry and hot climates due to its lower energy consumption (when compared to standard vapor compression air conditioners) and lack of humidification (when compared to direct evaporative cooling). The core technology, the IEHX (heat exchanger), is the most critical component in advanced IEC or hybrid IEC/DX systems. As such, the IEHX is the main focus of research for this study.

IEHX's can be configured in many ways, and their performance is heavily dependent on the operating conditions and the climate in which they are used. To characterize the thermal behavior of these coolers and to support their implementation by HVAC designers, a practical, accurate IEHX model is needed, preferably incorporated into building simulation packages (e.g. EnergyPlus). However, characterizing the performance of an IEC or hybrid IEC/DX system for cooling buildings in building simulation programs for different climates and different operating conditions, would take hundreds and even thousands of simulations. In this case, reduced computation time is crucial. This project attempts to address the above concerns by building a simplified IEHX model.

Typically, two approaches have been used in the analysis of an IEHX: the numerical (finite difference/element) approach, and the analytical approach. The first approach numerically integrates the governing differential equations to find the outlet conditions of the fluid streams. In the second approach, the whole IEHX is considered as a single element, and after making any necessary simplifying assumptions, the controlling differential equations can be integrated analytically, resulting in a fairly simple-to-use model. For some IEHXs with complex extended surfaces, the fluid flow and heat transfer are too difficult to characterize. In this case, it is time consuming or even impossible to obtain such detailed heat transfer coefficients for modeling purposes.

## MODEL PREDICTIONS FOR DRY-SIDE OUTLET-AIR

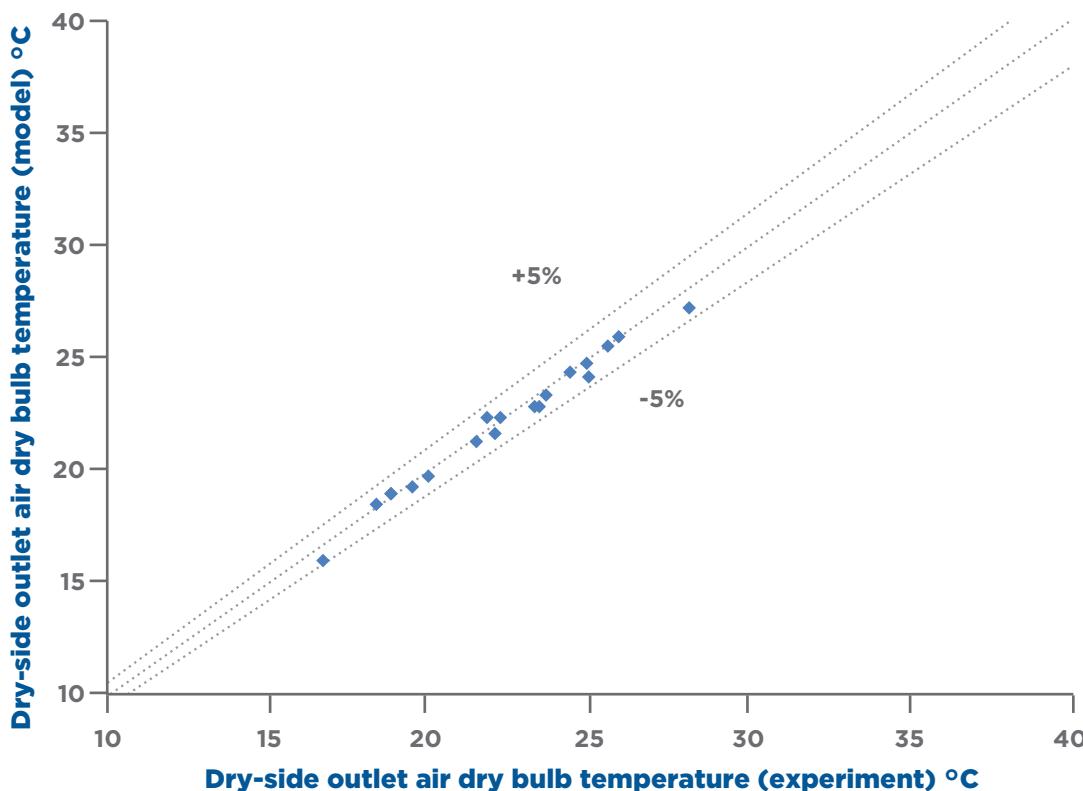


Figure L1: Comparison of model predictions for dry-side outlet-air dry bulb temperatures with experimental data

Alternatively, a model utilizing the IEHX catalog data as inputs would be very useful for engineering practice. But our survey of the literature was unable to uncover a practical IEHX model that can be adopted for system-level hybrid IEHX/DX performance simulation. Thus, one of the goals of this project is to propose and verify an IEHX model that meets the following criteria:

1. Uses manufacturers' catalog or performance testing data as inputs
2. Predicts the IEC thermal performance in different climates and operation conditions
3. Requires short calculation time and provide reasonable accuracy

We have developed a model which, through some approximations, modifies the governing differential equations that describe IEHX heat/mass transfer behavior to produce a methodology that is analogous to the effectiveness-NTU method for sensible-only heat exchangers. The simplified set of equations can then be solved within short computation times and with numerical stability. Figure i1 shows some initial results where we compare the predictions of this model to experimental data, in this case tests on the HyPak heat exchanger developed by Davis Energy Group. This modeling work has been summarized and submitted to ASHRAE HVAC&R Research journal for publication.

We are carrying out a number of experiments to both provide input data for our model and to verify the predictions of the model. The goal of this initial experiment is to obtain the pressure drop characteristics of an indirect evaporative heat exchanger (IEHX) with wicking and/or pin-fin surfaces operated in dry and wet conditions. This experiment focuses on gathering pressure loss data in a single channel.

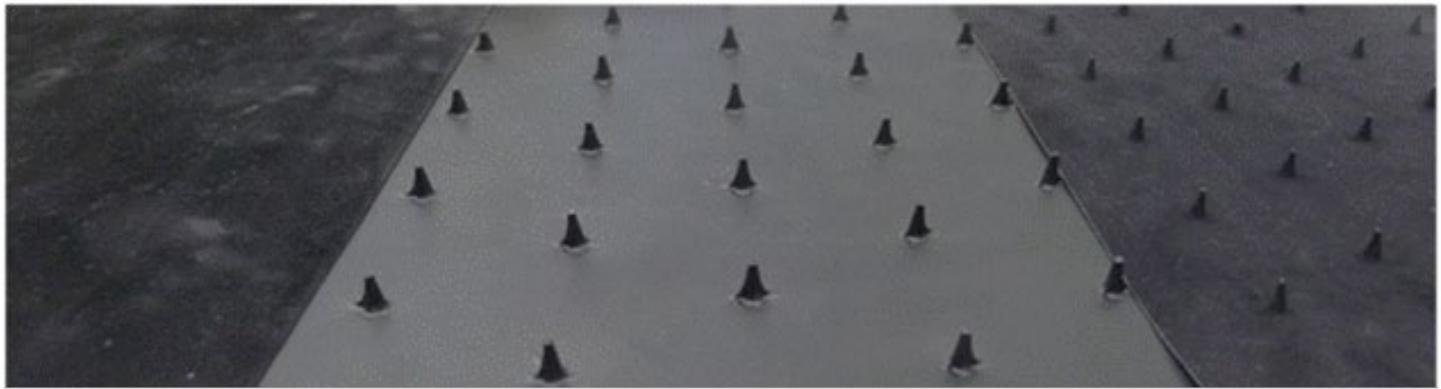


Figure L2: Samples of IEHX surfaces used for the experiment study. Left: flocked surface; center: smoothed pin-fin surface; right: flocked pin-fin surface

The test section models a parallel plate channel with a height of 3/8" and a width of 10.75". The IEHX surfaces used in this study were selected from an industrial design by Davis Energy Group. To accompany the design operation, the air flow velocity in the channel ranges from 2-5m/s, meaning the flow is transitionally turbulent, with the range of Reynolds numbers of roughly  $2300 < Re < 6000$ . However, to obtain a full range of pressure loss characteristics of the channel for benchmarking, the range of Reynolds numbers was extended beyond this range.

### FRICTION TEST OF FLOCKED CHANNEL IN DRY CONDITION

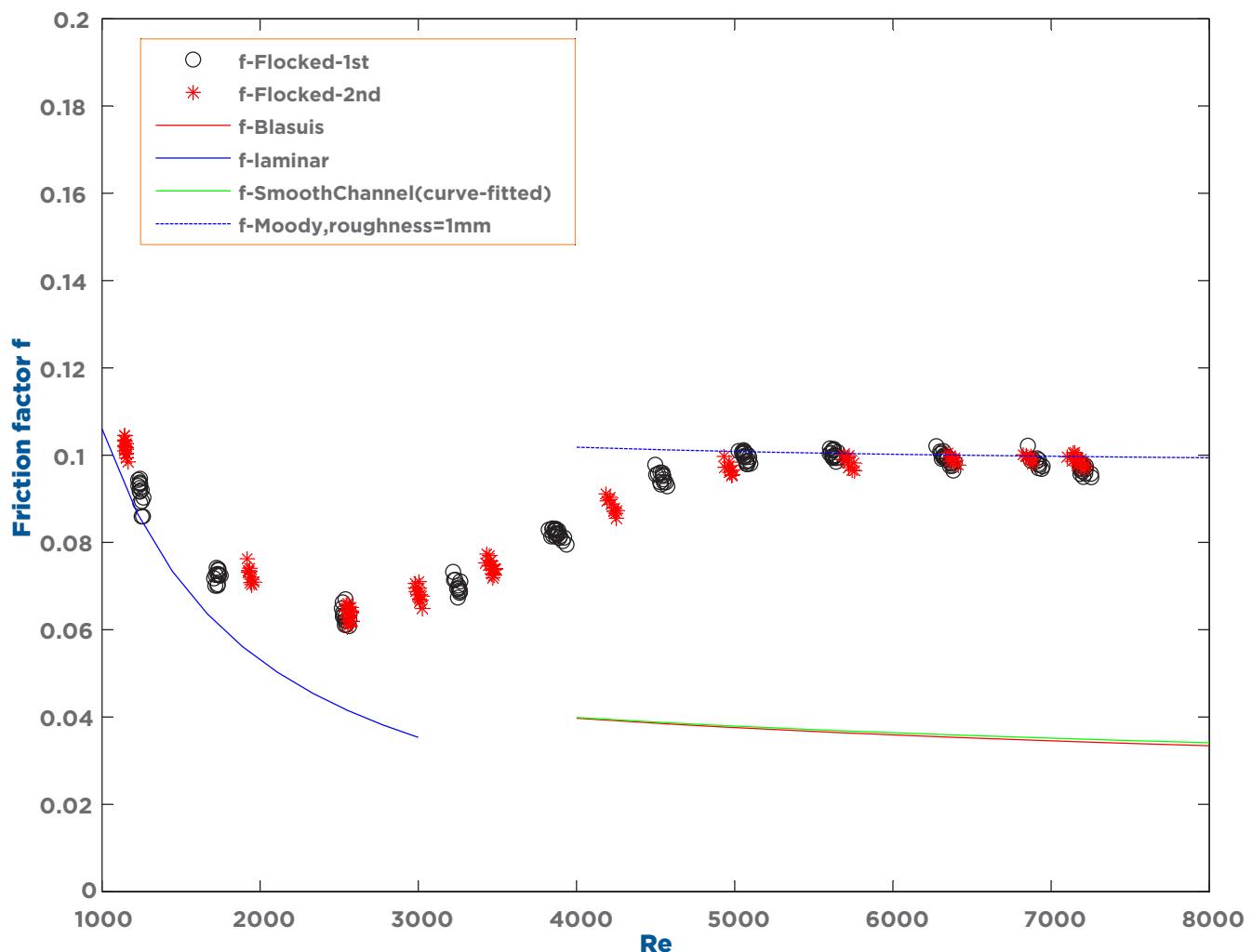


Figure L3: Friction test results of a flocked surface in dry condition and compared with theoretical predictions

As seen in figure L3, initial results on a dry channel show a clear division of the flow regimes into laminar, through the transition region and finally fully turbulent flow. The next stage of the experiment will compare results for different surfaces and for wet and dry conditions. These results will feed back into the model which will be used to predict the heat transfer behavior of different channel and material configurations. These predictions will then be tested in a second series of experiments.

## PATH FORWARD

Next steps for the modeling work include:

- » Utilize the verified model (modified effectiveness-NTU method for IEHXs) to conduct a more thorough parametric analysis to quantify the factors that influence cooling performance and energy efficiency of the IEHXs so as to provide recommendations for optimizing the design
- » Expand the model to encompass different IEHX air arrangements, including cross-flow, regenerative type, and quasi-counter flow
- » Embed the IEHX model as a module to a system-level model for hybrid IEC/DX cooling systems to analyze the combinations of component configurations and the energy saving potentials

Next steps for the experimental study include:

- » Study additional IEHX surface materials from current industrial designs to account for the impact of surface geometry on IEHX hydraulic performance
- » Continue the friction test on the sampled IEHX surfaces in dry and wet condition to get sufficient empirical data for comparison
- » Summarize the test data and analyze it for future publication ☈



## M. AEROSOL-SEALING OF BUILDING SHELLS

Building shells are notorious for leaking, causing unintended air flows between conditioned and unconditioned spaces, which result in additional heating and cooling loads on the HVAC system. 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. The WCEC has received funding from Build America and the California Energy Commission 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 building leaks, and as they escape, seal them.



### LABORATORY TESTING

The first round of funding for this project was restricted to small scale laboratory tests of the sealing process. The WCEC constructed an 8' x 8' x 4' enclosure with leak panels distributed at various locations around the shell of the enclosure. Nine tests were performed in the test box, with all tests sealing the enclosure completely from about 42 square inches of leaks to less than 1 square inch. The objective of the tests was to determine the sensitivity of the sealing performance to various independent variables including: enclosure pressure, sealant flow rate, and particle size. Figure M1 shows the conditions under which each test was performed. Figure M2 shows the leakage profiles for each of the nine tests in the enclosure. All tests successfully sealed the enclosure to nearly zero leakage in less than 30 minutes. Note that, at the beginning of each test, the sealant lines were first purged of water before sealant reached the injection nozzle, causing a slight delay at the beginning of each test, which for 25 ccm tests was about 5 minutes and for the 100 ccm test was about 2 minutes.



## TEST PROTOCOLS

Test Number	Box Pressure (Pa)	Sealant Injection Rate (ccm)	Sealant Dilution to Reduce Particle Size
1	No pressure/flow control	100	No Dilution
2	100	25	No Dilution
3	No pressure/flow control	25	No Dilution
4	50	25	No Dilution
5	100	25	No Dilution
6	50	25	No Dilution
7	100	25	No Dilution
8	50	25	No Dilution
9	100	25	1 part sealant/1 part water

Figure M1

## LEAKAGE PROFILES

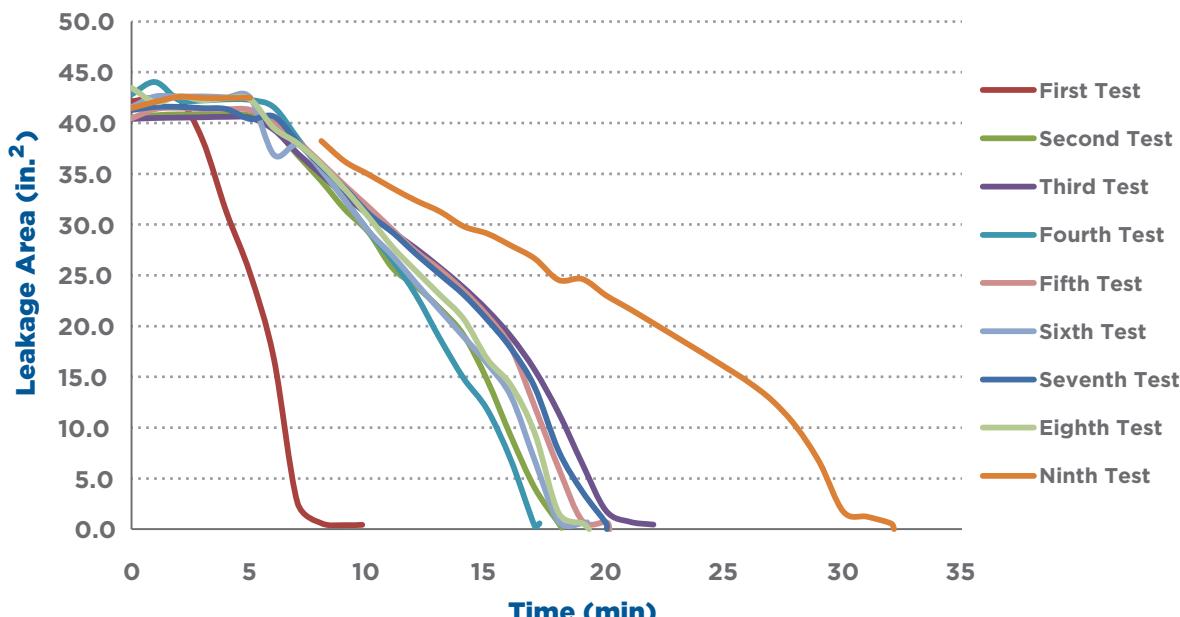


Figure M2

The leakage profiles show that the sealant injection rate has a significant impact on sealing time, whereas controlling the pressure inside the enclosure was less important. Tests performed at a 25 cubic centimeters (ccm) injection rate at various pressures all sealed the enclosure in 13-15 min, whereas injecting sealant at 100 ccm sealed the enclosure in 6 min. Reducing sealant particle size by diluting the sealant with water also significantly extended the sealing time. This is due to the reduced solid sealant injection rate associated with diluting without adjusting the pump rate. In the

test with diluted sealant, the enclosure sealed in approximately 28 min (Figure M2, 9th test).

### FIELD TESTING

One full scale test of the technology attempting to seal the building shell of a single-family home has been completed with promising results. The test was performed at the rough-in stage of construction (drywall, but no texture or paint) on a 1330 square foot home in Stockton, CA.

A blower door was used to pressurize the building during injection and to monitor leakage throughout the sealing process (Figure M3). The technology successfully sealed 50% of the leakage area that was available, after taping up the HVAC ductwork, double-hung windows (up to the outer edge), and door seams (Figure M4). A pre- and post-blower door test showed that the total building leakage was reduced by 27%, and a third party HERS test after construction was completed showed a 25% reduction in leakage compared to a similar home that was not sealed with the aerosol technology. Figure M5 shows an example of the seal formed around a typical junction box in the wall.

We expect that future results will improve significantly due to problems experienced with equipment and the low sealant flow rate used during the initial field tests. The injection was completed in two hours using a 25 cubic centimeter per minute (ccm) sealant flow rate, which we calculate to be one quarter of the injection rate that could have been utilized. In addition, the sealing process was stopped prematurely for unrelated reasons, and the leaks were still being sealed when the process was halted. No sealant was observed on the walls and very little was noticeable on the concrete floor. One important discovery during this test was that the sealant fog would not completely distribute throughout the building during a single-point injection, therefore moving the sealant injection nozzle from room to room was needed. Increasing the sealant flow to 100 ccm and distributing the sealant injection around the house would reduce the installation time and improve sealing significantly. This demonstrates the need to further develop the technology for building and attic applications, which includes investigating alternative atomization systems that can practically perform multi-point injections.

Recent efforts have focused on investigating alternative sealing hardware specifically for whole building applications of aerosol sealing. This includes testing airless atomization technologies that reduce the cost and weight of the equipment needed for the sealing process and increase the realistic number of simultaneous injection points within a building. We are also looking into a number of different, custom sealant compositions that may aid in distribution, and will harden as it dries.

The WCEC is currently developing and validating Computational Fluid Dynamics (CFD) models to track sealant particle distribution in a space, as well as the sealant deposition process for various types of leaks. In general, the modeling will be used to improve the application protocol for building shells. It will be used to investigate the number of injection points and the best spray angles for the injectors needed for different size spaces and aspect ratios. It will also be used to understand the flow patterns and turbulence created by installing a blower door in an attic-access hatch, and to quickly assess and optimize potential application protocols. 



Figure M3: Blower door used to pressurize the house



Figure M4: Preparing the home for aerosol sealing

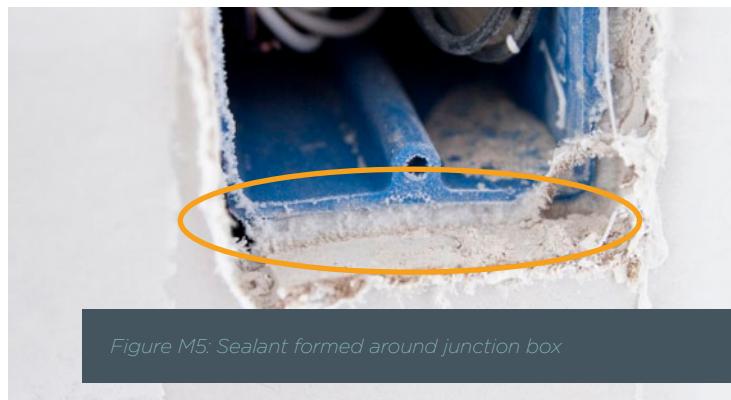


Figure M5: Sealant formed around junction box

## N. PHASE-CHANGE MATERIALS FOR HYDRONIC SYSTEMS

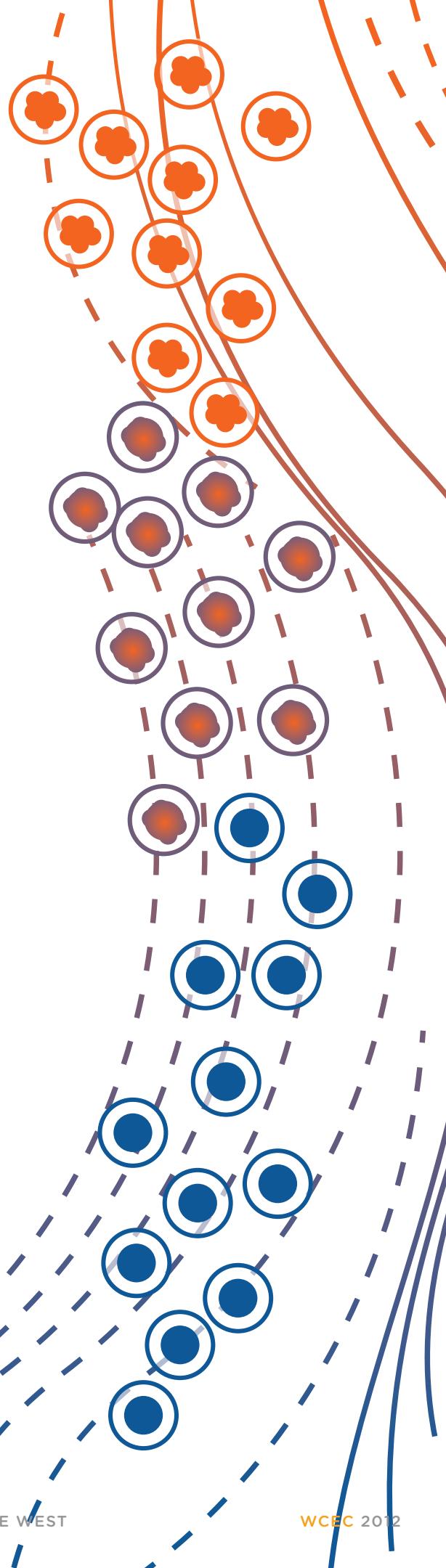
This project aims to reduce the running costs of hydronic heating and cooling systems in commercial buildings by reducing the pumping power. Pumping power can be reduced by lowering the required flow rate of the heat transfer fluid. However, maintaining capacity while reducing the flow rate requires an increase in the heat capacity of the fluid. Ice slurries have been used to do this in cooling applications, but while ice has a high latent heat of fusion (334 kJ/kg) and effectively increases the heat capacity of water, its use is limited by its fixed melting temperature. In order to address this limitation, we are investigating the use of phase change materials (PCMs) in hydronic systems.

PCMs have great potential for thermal energy storage. There are a wide range of applications of PCMs, ranging from building materials to clothing. The advantage of using PCMs rather than ice is that they can be engineered to melt at any desired temperature which facilitates their integration into existing systems.

The most promising PCMs are based on paraffin waxes due to their combination of a wide range of melting temperatures, high latent heats, low cost, and chemical stability. To use these waxes in hydronic systems, we need to know how they behave when mixed with water. The simplest way is to create an emulsion, but this is likely to result in the wax depositing on the pipes, valves, and pump, causing loss of efficiency and capacity, as well as possible equipment failure. So the PCM needs to be physically isolated from the fluid. This is accomplished by encapsulating it.

Microencapsulation is generally classified as encapsulation of a substance with a diameter between 1-100 microns. Larger than this and the particles are considered to be macroencapsulated. The benefits of PCM microencapsulation in hydronic systems are multiple:

1. The smaller size helps maximize the surface to volume ratio thereby reducing the time it takes for the particles to melt or freeze. This is particularly significant in view of the poor thermal conductivity of solid paraffin wax.
2. Smaller particles are less likely to be trapped by pump impellers or valves, and so are less likely to rupture and release paraffin into the water, leading to potential failure



## BEHAVIOR OF SLURRIES

A mixture of microencapsulated PCM and water will act like a slurry. The increased viscosity of the slurry may offset some or all of the pump energy savings due to the lower flow rate, and the heat transfer behavior will be different from pure water. We have modeled the behavior of PCM slurries with varying fractions of PCM. Typical behavior is shown in figure N1 where we have modeled a 4 ton system.

The reduction in pumping power is easy to see. The sharp drop in slurry flow rate and pumping power at a concentration of  $\approx 0.08$  is due the transition from laminar to turbulent flow. The model uses data for a commercially available microencapsulated PCM (made by Microtek) which has a melting point of 133°F and a latent heat of 73BTU/lb.

## HYDRONIC SYSTEM WITH ONE FAN COIL DELIVERING 4-TONS OF HEATING OR COOLING

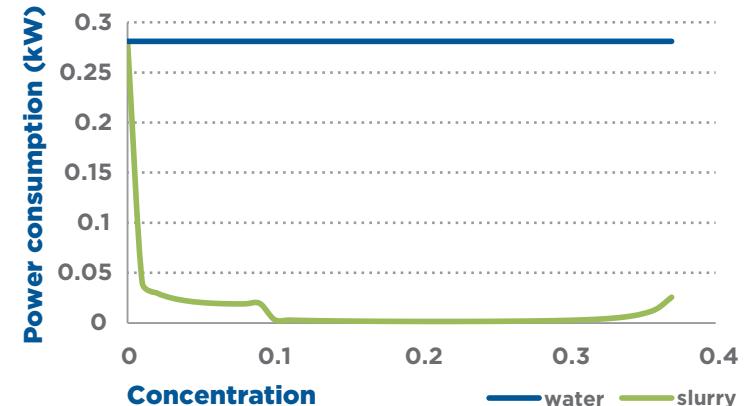
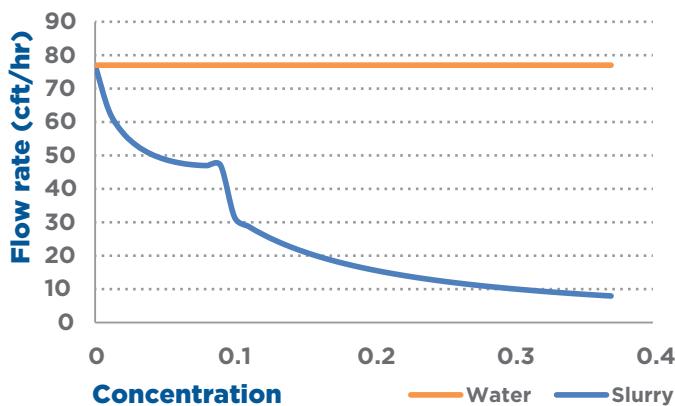


Figure N1

## PATH FORWARD

### Hydronic System Model

The goal of this experiment is to determine the performance of PCMs in a hydronic system. We are building a test set up in our laboratory which will replicate the behavior of a 2 ton heating and cooling system, shown in Figure N2. A supply of conditioned air will provide a load to a fan coil, and a water to slurry heat exchanger will regenerate the PCM. The experiment will consist of 4 phases. The first phase will consist of pumping pure water to determine the pumping power required if the system did not include PCMs. The second phase consists of testing

the slurry under heating conditions using a PCM with a phase change temperature of approximately 140°F. Then a different PCM with a lower phase change temperature (~50°F) will be used to create another slurry which will be tested under cooling conditions and finally a slurry containing PCMs with both high

and low melting points will be used to simulate a 2 pipe system. The slurry will pass through a loop where it will go through a conditioning phase in the first heat exchanger. In the second heat exchanger the slurry will exchange heat with air which will be delivered to the room. The air will also need to be pre-conditioned to meet the standard temperatures for HVAC testing. Cold and hot water supplies on site will be used to pre-condition the slurry and the outdoor air.

During this experiment we will subject the PCM microcapsules to both thermal cycling and mechanical stresses. In order to separate any effects, we will also conduct two other experiments in which we subject the PCM capsules to only one variable: thermal or mechanical stress.

#### Pumping experiment:

To determine the mechanical stability of the PCMs, a test will pump the PCM slurry in a closed loop. Samples will be taken periodically and studied to determine if any capsules have ruptured. The samples will be photographed, and imaging software will be used to determine the range of diameters before and after the pumping test. This will give an indication as to whether different sizes of capsules are more susceptible to rupture than others.

#### Thermal Cycling experiment:

In order for the PCMs to remain useful in our application, their thermal properties need to remain constant after repeated cycling. The literature suggests that paraffin based PCMs are generally thermally stable. A thermal cycling test

will measure the change in thermal properties such as melting temperature and heat of fusion, after repeated cycling. A sample of the slurry will be placed in a sealed container and thermally cycled between temperatures 10°F above and below the phase change temperature. Samples will be periodically removed from the container for testing by Differential Scanning Calorimetry. ☑

## HYDRONIC SYSTEM MODEL SCHEMATIC

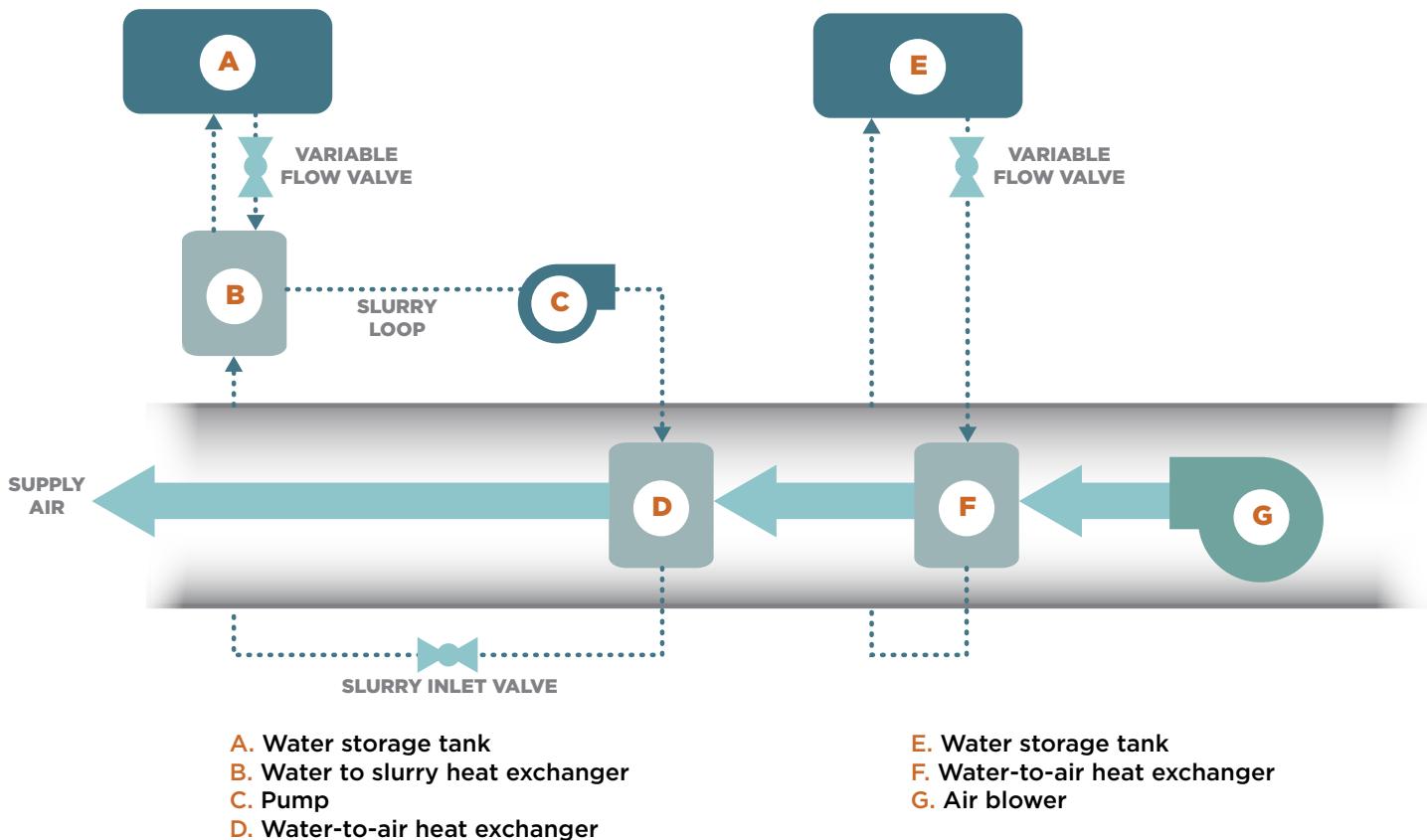


Figure N2



Iowa Energy Center

## O. HVAC TECHNICIAN INSTRUMENT LAB

One of WCEC's ongoing 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, 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 the WCEC, showed 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 actual 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 testing and seal and quality installation testing equipment..

The ultimate goal of this project is to facilitate the adoption of more suitable instrumentation for HVAC installation and maintenance, and methods of using these instruments, thereby increasing energy savings from utility programs as well as devising better methods. 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.

The 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 more accurately maintain HVAC systems in order to achieve significant energy savings.

The main 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 industry to ensure that the research is meeting commercialization needs, and to solicit funding from industry for subsequent activities.

The HVAC Technician Instrument Laboratory (HTIL) will be located at WCEC's new facility at West Village, although some testing may be done through partnerships with other laboratories.

## ACCOMPLISHMENTS

In the first year of development, effort focused on forming a project advisory committee. This committee met once to discuss the project objectives and methods, and to prioritize which instruments are most in need of testing. The project staff also visited three other similar labs, to get ideas on layout and instrumentation.

Alan Meier, LBNL  
Bill Spohn , Truetech Tools  
Bob Wiseman , IHACI  
Chris Scruton, CEC/PIER  
Gary Fagilde, PG&E  
Golam Kibrya, CEC/PIER  
Iain Walker, LBNL  
James Schaefer, ASHRAE

Jim Bergmann, Truetech Tools  
John Proctor, PEG  
Jon Schoenfeld, kW Engineering  
Jonathan Zeh, Sac City College  
Marshall Hunt, PG&E  
Rick Chitwood, Chitwood Energy  
Management

Robert Davis, PG&E  
Robert Mowris , Verified  
Russ King , CALCERTS  
Sean Gouw, SCE  
Warren Lupson, AHRI

Since the lab space will not be available until WCEC moves to its new home at West Village, design work during this first year focused on the laboratory that will house the HTIL. This lab will supply conditioned air, as well as heated and chilled water to a thermal experiment chamber, as well as to a number of smaller experiments—including the HTIL.

## THE PATH FORWARD

In the upcoming year, the project team will engage in the following activities:

- » Propose test procedures for refrigerant pressure gauges and temperature sensors
- » 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
- » Test multiple makes and models of various 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 ☎

## INDUSTRY SUPPORT

P. HVAC Performance Alliance	59
Q. HVAC Behavioral Research Initiative	61
R. Education & Outreach	67





## P. WESTERN HVAC PERFORMANCE ALLIANCE

WCEC has continued to support the Western HVAC Performance Alliance (“the Alliance”) over the last year. The Alliance 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, in order to promote energy efficiency and peak load reduction.

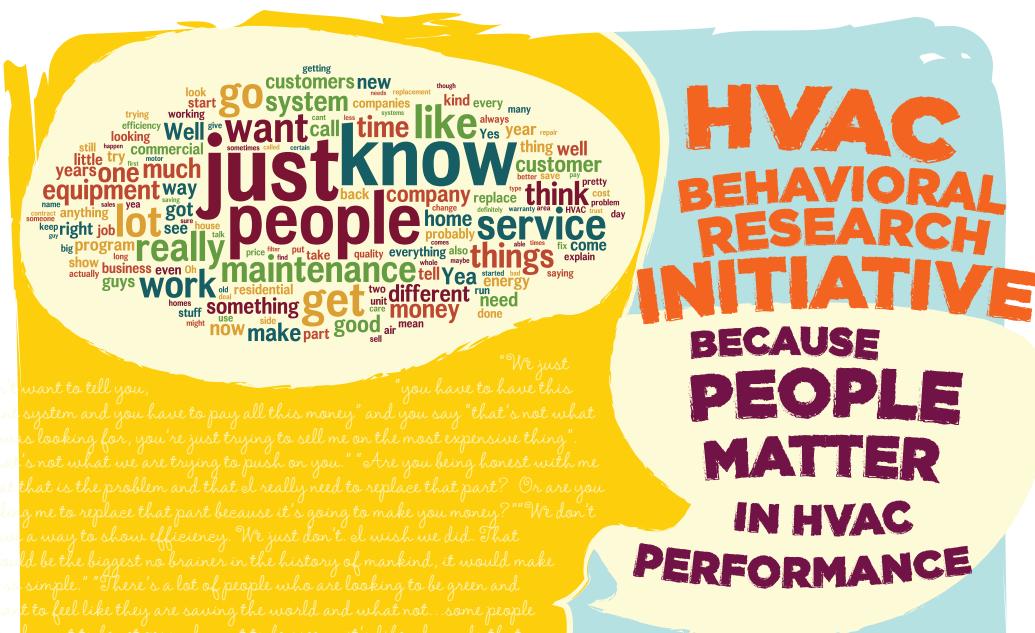
The CLTEESP sets four goals for the HVAC sector, which form the framework for the Alliance’s objectives. They are:

- » Consistent and effective compliance with enforcement, and verification of applicable building and appliance standards
- » Quality HVAC installation and maintenance becomes the norm. The marketplace understands and values the performance benefits of quality installation and maintenance
- » Building industry design and construction practices that fully integrate building performance to reduce cooling and heating loads
- » Develop new hot/dry climate HVAC technologies (equipment and controls, including system diagnostics) and greatly accelerate their marketplace penetration

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 Figure P1 for a breakdown of the 131 organizational 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. ☑

Figure P1: Organizational Members of the HVAC Performance Alliance

<b>California IOU</b>	Pacific Gas & Electric (PG&E), San Diego Gas & Electric (SDG&E), Southern California Edison (SCE), Southern California Gas (SoCalGas)
<b>California Public Utilities Commission</b>	California Public Utilities Commission (CPUC)
<b>Certifying Body</b>	Building Performance Institute, Inc. (BPI), CalCERTS, Inc., HVAC Excellence, NATE, Northern California / Hawaii NEBB, RESNET
<b>Codes and Standards Official (Association or Jurisdiction)</b>	CALBO, IAPMO, International Code Council (ICC)
<b>Contractor – Nonresidential</b>	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.
<b>Contractor – Residential</b>	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
<b>Contractor Association</b>	ACCA, ACTA, CAL SMACNA, IHACI, SMACNA Los Angeles
<b>Controls – Manufacturer, Distributor</b>	Honeywell
<b>Distributor</b>	Indio Cooling & Heating Supply, Specialty A/C Products, TruTech Tools, US Air Conditioning Distributors
<b>Distributor Association</b>	HARDI
<b>Educator, Trainer</b>	American Trainco, Inc., Delmar, Cengage Learning, Ecology Action, El Camino College, Energy Analysis Technologies, HVACRedu.net, JJATC 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
<b>Engineering Society</b>	American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE)
<b>Government (Other than CPUC)</b>	California Energy Commission (CEC), U.S. EPA Region 9
<b>HVAC Manufacturer</b>	Carrier Corporation, Danfoss, Ingersoll Rand, Trane Residential Solutions, Johnson Controls , Lennox Industries, Rheem Manufacturing, Williams Comfort
<b>HVAC Manufacturer Association</b>	AHRI
<b>Organized Labor</b>	Joint Committee on Energy and Environmental Policy (JCEEP), PIPE Trust Fund, SMWIA Local 162 and Local 206, Southern CA Pipe Trades, District Council 16
<b>Other Stakeholder</b>	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)
<b>Owner, Facility Management, or Property Management Association</b>	
<b>Owner, Facility Management, or Property Management Company</b>	American Realty Advisors, Irvine Company, Jack in the Box, PM Realty Group
<b>Publicly Owned Utility</b>	SMUD
<b>Third Party Quality Assurance Provider</b>	American Commissioning Group, LLC, Enalasys Corporation, Field Diagnostic Services, Inc. (FDS), Proctor Engineering, Verified, Inc.,



# HVAC BEHAVIORAL RESEARCH INITIATIVE BECAUSE PEOPLE MATTER IN HVAC PERFORMANCE

## Q. HVAC BEHAVIORAL RESEARCH INITIATIVE

Has it ever occurred to you that air conditioners would work much more efficiently if it weren't for the people involved? Always twiddling with the thermostat, or installing things incorrectly, or choosing the wrong technology for the application or failing to maintain things as manufacturers specify. If this thought has occurred to you, then you may have an appreciation for WCEC's HVAC Behavioral Research Initiative (HBRI), which believes that people behave the way they do for a reason, and understanding that reason is key. WCEC has assembled a team of behavioral and social scientists to address some of these issues . This innovative team is beginning to look at the ways in which human factors influence the performance of AC systems in the field. By understanding these factors, we can both design better systems and buildings, and find ways to influence performance-defining behaviors. WCEC is working with other researchers to ensure that technologies developed and demonstrated are aligned with the goals and aspirations of users and providers, as manifest in their behavior. The team is also undertaking several discrete research projects to shed light on human behavior and how it can be influenced.

## WORK TO DATE ON THE HVAC BEHAVIOR RESEARCH INITIATIVE

**Roadmap for Behavior in HVAC:** CEC's PIER program has long understood the importance of human behaviors on energy consumption. Seed funding from PIER has allowed the WCEC HBRI team to identify some of the questions that can be addressed including:

- » How do homeowners and small commercial maintenance staff typically maintain their systems?
- » What are the advantages to service contracts (such as building trust, and providing the opportunity to sell more efficient equipment over the years), and what factors go into a homeowner's decision to purchase or not purchase a service contract?
- » What happens when a unit is run to failure? Is it replaced with a suitable, efficient, unit, or with whatever's on the truck? How do contractors view the opportunity to sell a more efficient unit when a unit fails? Do they have time to make this case? How much does having a history with the customer help in promoting a different choice of replacement unit?
- » Why do HVAC contractors pull or fail to pull a permit and comply with Title 24?
- » What would a building owner do if their thermostat alerted them about faulty conditions in their AC? What information needs to be provided to a building owner to make them take the right course of action?
- » How is Fault Detection and Diagnostics perceived by potential customers? Do customers believe that they have "faults" that need to be detected and fixed? What do facility managers do with alarm data when it's received? Can it be conveyed in a different way to ensure that it is acted upon appropriately?

**The Motivation behind Behavioral Research:** With funding from the California IOUs (via the Davis Energy Group), WCEC participated in developing the [HVAC Maintenance Energy Efficiency Study](#). Quality Maintenance programs in the past have had uneven success, and part of the reason for that is the wide range of uncertainties involved in defining what quality maintenance is and the programs that deliver it. This study identified the need to better understand the behavior of homeowners, tenants, small business owners and managers, contractors and technicians, in order to then produce Quality Maintenance services that respond to the stakeholders' needs. This work was also documented in an [ASHRAE Conference Paper](#) and was presented at the ASHRAE Conference in San Antonio in June, 2012.

**Behavior and Residential Attitudes towards Air Conditioner Maintenance: When AC is not cool enough.** The California Long Term Energy Efficiency Strategic Plan calls for Quality Maintenance of HVAC systems to become the norm by the year 2020, envisioning that by that time, users will understand and value the benefits of maintaining Air Conditioners regularly. Quality Maintenance of residential and small commercial air conditioners is expected to reduce energy use by up to 30%, while providing a series of other non-energy benefits, such as improved indoor air quality, increased equipment life, reliable performance, and safety.

That said, users' motivation to procure professional maintenance for their Air Conditioners is low. A recent survey on attitudes towards AC maintenance services, conducted by the WCEC, gathered data from a representative random sample of 270 Southern California Edison residential customers. Respondents evaluated, among other things, the importance and relevance to them of AC maintenance benefits, the characteristics that they value in professional AC services, and the influence that monetary incentives from utility programs would have in their decision to procure a maintenance service agreement for their AC system.

53% of respondents said they regularly maintain their ACs but only 12% say they have professional maintenance agreements. The discrepancy is an indication that most people probably think of AC maintenance as a "do it yourself" kind of thing. Indeed, when asked what you need to do regularly to keep the AC working well, the most common answers provided were "changing filters" and "keeping the equipment clean". 61% of users said they would not hire professional maintenance unless it was urgent: an indication that professional maintenance would only follow repairs and that preventative maintenance is not really on the radar. In fact, 43% of those surveyed claimed they would require rebates of at least 50% from utilities or other programs, to consider doing preventative maintenance through an HVAC contractor.

Users' intentions to procure professional maintenance through service agreements increased significantly after respondents read some information on the benefits of regularly maintained equipment. Still, the majority of respondents persisted in saying they were not likely to procure such services in any circumstance.





What about those 12% that have professional maintenance agreements? According to our analyses, those respondents cared significantly more than others about the way in which maintenance improves energy efficiency, air quality and the reliable performance of their AC. It is possible that having service agreements has been the way in which users, in connection with expert technicians, have learned more about energy and environmental benefits of maintenance, and have witnessed the reliable performance of their equipment.

WCEC also found that the terms "Quality" and "Maintenance" did not have resonance with potential customers and technicians. Worse, the terms may actually be a barrier from implementation. "Quality" implies that what the technician normally does is not quality, and "Maintenance" seems to suggest only filter changes and coil cleaning to most respondents.

A more extended report of the survey results, which will include a thorough analysis of the ways in which people's values and beliefs influence their AC maintenance choices, is currently being prepared by our team.

**Maintenance Behavior and Commercial Decision Makers:** WCEC is also investigating behaviors related to Quality Maintenance with small commercial decision-makers, also with funding from SCE. In April 2012, our researchers conducted four focus groups in SCE territory, with the participation of more than 40 small business owners or managers. They were asked a series of questions about the importance of AC in their business and the role that they perceive maintenance plays in AC performance. Very few of these small business owners have professional maintenance contracts, and their interest in AC performance was driven by its impact on the bottom line. A full analysis of this research will be available by the end of 2012.

**Behavior and In-Home Energy Displays:** SCE is also interested in influencing residential customers' behavior by providing them with feedback on their energy use. WCEC has been conducting a three-part study to find out how real-time energy feedback influences usage behavior:

- » Evaluation of a set of In-Home Energy Displays available in the market, to categorize their features and functionality. This work has shown that the market for IHEDs is in constant flux, that the functionality of IHEDs varies substantially, that many important feedback features are promised but not currently available in the IHED interfaces, and that there is no agreed upon standard for the best features to be included in a feedback device, or for the best way in which to integrate IHEDs into the household.
- » There are several key functionality issues that can be generalized and this is the basis of the next step in the research. A survey is being conducted to show a "generic" energy feedback display to participants, and gauge their understanding of the information presented and their response to feedback, including real time energy use, energy used by peers, and diagnostic feedback. This study will be completed this fall. Preliminary findings are that there is a delicate balance between too much information and not enough context with which to interpret the information.
- » The UC Davis campus houses a "Net-Zero Energy Community" which gives tenants the opportunity to access feedback on their energy consumption. Our team is surveying a sample of community residents before and after accessing this feedback, thus gauging their attitudes and intentions towards energy use, and attempting to find a correlation with energy use. This study will be completed next year.



**Behavior and Technicians: The California Utilities' interest in Quality Maintenance includes an interest in the behavior of technicians, in addition to homeowners and small business owners.** Contractors, and the technicians they hire, have a great deal of impact on the performance of existing AC units, as well as an impact on the decision to replace a unit that is performing poorly with a more efficient unit. Understanding their attitudes and drivers can shed light on both Quality Maintenance programs and the overall performance of AC units in the field. With funding from the California IOUs and CPUC (via Energy Market Innovations), WCEC has conducted an observational study of residential field technicians, wherein contractors were contacted and invited to come to a study house to provide a tune-up. The technician's work was observed prior to being informed that the observation is part of a study (and they were given the opportunity to opt out of the research if they do not wish to participate). Findings suggest that technicians seldom do a complete quality maintenance job as defined by ACCA standards, and so far only one technician has detected the fault that was known to be in the system. Conclusions from this work will be published this fall. Figure Q1 shows the impact that the service duration has on the number of tasks completed correctly, for different types of technician. This illustrates that it is difficult to complete a quality maintenance service in much less than 2 hours. Most technicians are not given that amount of time, because they have a set number of calls they need to make to make a profitable day's work. The contractor mindset needs to change to reflect this new type of service that is required to significantly improve the performance of HVAC systems.

## TASKS SUCCESSFULLY COMPLETED BY DIFFERENT TYPES OF TECHNICIANS

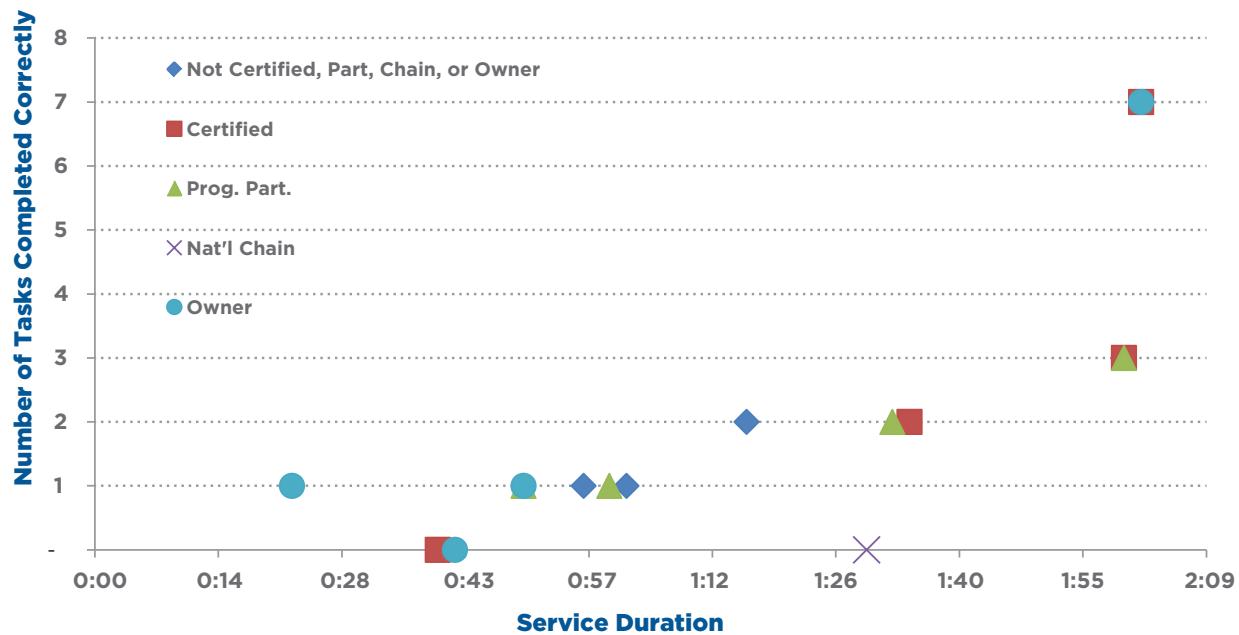


Figure Q1

**Contractor Behavior and Code Compliance:** California's Title 24 building code is a model for other states. However, its scope and complexity make it difficult to comply with, and it is estimated that contractors only take out permits in about 5-10% of the HVAC replacement jobs that require them, so Title 24 requirements are probably not implemented in the vast majority of cases. The California IOUs have funded the [Western HVAC Performance Alliance](#) to investigate some of these types of barriers to energy efficiency. WCEC conducted a survey of contractors to find out how they assess the risk of being caught when not taking out a permit. The findings of the survey were that contractors for the most part do not believe that there is a credible threat that they will be caught if they do not take out a permit: 81% of contractors believe that they would definitely or probably not be caught. They also believe the consequences of being caught without a permit are not substantial: 86% felt that the consequences would be a small fine, requirement to go back and take out a permit, or other such slap on the wrist. The reasons why one would take this risk are primarily financial: half of respondents felt that they would either lose a bid to someone who was not including the expense of taking out a permit, or would be forced to lower their own bid to be competitive. This work is documented in a paper and presentation for the [ACEEE Summer Study on Energy Efficiency in Buildings](#).



## PATH FORWARD

Work on the HVAC Behavioral Research Initiative will continue throughout the next year. What follows are some of the research objectives we intend to work on.

### **The Role of “Middlemen” in Understanding Maintenance Behavior:**

We learned in the 2011-2012 Understanding Maintenance Behavior project about the important role that contractors play in promoting or inhibiting the uptake of Quality Maintenance in residential and small commercial owners. By better understanding the contractors' motivations as they communicate with their customers, we will identify ways to encourage customers to engage in Quality Maintenance. But this goes beyond contractors: technicians and distributors, the “middlemen” in this process, also play a role in HVAC decision making. This potential also goes beyond Quality Maintenance: these actors are there when a decision is being made whether to repair or replace a failing HVAC system, and they can influence the decision and the choice of replacement system. Understanding the role these actors play in HVAC decision-making should be tapped in the design of Quality Maintenance programs, as well as upstream and other HVAC replacement programs and Quality Installation programs. WCEC will investigate the “teachable moments” when a unit fails.

**Behavior of Commercial Quality Maintenance Technicians in California (and New York):** In another Maintenance-related project, WCEC will learn how closely commercial QM contractor activities align with the requirements of ASHRAE/ACCA Building Maintenance Standard 180, by conducting a covert observation of technicians in Quality Maintenance programs in both California and New York. California IOUs have implemented Quality Maintenance programs as a non-resource part of their Energy Efficiency portfolios in 2010-2012, and are planning to expand and extend these programs in the 2013-2014 bridge period. At the same time, NYSERDA (New York State Energy Research and Development Authority) is running a Quality Maintenance program that differs somewhat from the California Programs, in that they do not provide a customer or contractor incentive, but rather rely on contractors to be able to sell an advanced maintenance service for a premium price. Although all of these programs utilize Standard 180 to define “Quality Maintenance,” it is not known how fully the contractors implement the Standard.

WCEC will engage in a covert field observation of maintenance ac-

tivities, designed to look at how diagnostics and remediation are actually accomplished by field technicians in California commercial Quality Maintenance programs. We will identify variation among contractors and differences between actual activity and ASHRAE /ACCA Standard 180 as well as program requirements and processes. We will also capture customer service, marketing, and sales observations. We will do this by covertly observing a number of technicians in California. We will aim to partner with DNV/KEMA Energy & Sustainability to conduct a similar study in New York with their Quality Maintenance programs.

**Behavior Related to Adoption of Emerging Technologies:** Emerging technologies must undergo a thorough evaluation of their energy savings and market potential before being incorporated in utility programs. This ensures that potential incentives for the technologies would provide cost-effective savings. However, some of the barriers to installing emerging technologies are behavioral and are not easily addressed without first understanding the objectives, knowledge, aspirations, and intentions of the building staff, occupants, contractors, and sales engineers. For example, it can be expected that the way that technicians communicate about water (wasting water vs. wasting energy) can have a big impact on customer decisions to adopt evaporative technologies. Also, understanding what drives early-adopter attitudes will help to promote emerging technologies. This project will provide information needed to promote emerging cooling technologies in commercial and residential buildings.

This project will include research into the behavior of both users and non-users. A mix of individual interviews, focus group discussion and survey of SCE commercial customers, contractors, and distributors will be used to identify the current degree of penetration of emerging cooling technologies, attitudes toward the use of the technology, including comfort considerations, and other critical factors in the adoption of the technology, such as installation and maintenance considerations. WCEC will conduct a broad survey of a stratified sample of buildings (by size, energy use, location, business-type, and other factors that point to buildings with potential for different emerging technologies). Questions would relate to determinants of adoption or non-adoption, satisfaction or dissatisfaction, and comfort level; assessment of distribution channels; understanding buyer/non-buyer decision process; price elasticity issues; comfort (tolerance)/cost tradeoffs; impact of reliability and ease of maintenance issues; role of financial incentives; and demand response behavior under different scenarios. What drives their choice of technologies? What makes a good technology (beyond technical merit)?

**Behavior and Technician Instrument Use:** Finally, in the HVAC Technician Instrument Laboratory (described elsewhere in this report), WCEC will be investigating another behavioral aspect of installation and maintenance technicians: how they use their instruments. While part of the project will focus on laboratory testing of new technician instruments to determine their accuracy, the remainder of the project will look at existing technician tools (taken from the back of participants' pickup trucks) and behavioral aspects of how technicians use these tools. ☐





2012 WCEC Affiliates Forum

## R. EDUCATION AND OUTREACH

WCEC staff made numerous presentations, gave tours to prominent stakeholders and presented research findings at a myriad of HVAC events and meetings this year. Just to name a few, WCEC presented and led/attended technical committee meetings at the ASHRAE Winter Meeting and Annual Conference, made four presentations at the ACEEE Summer Study, attended hearings and discussed HVAC policy issues with legislative staffers, and spoke at the Compliance Improvement Advisory Group. WCEC researchers also presented at the i4Energy Talk at UC Berkeley, discussed system air leakage test standards at a SMACNA Meeting, and gave multiple presentations and had a booth at the ACCA conference in Las Vegas. Professor Modera also spoke at the UC Davis Policy Institute's Green Build Forum in Sacramento.

In the media, WCEC engineer Jonathan Woolley conducted a training session for over 100 contractors, consultants, CEC members, and various other HVAC efficiency experts within SMUD's Energy and Technology training program and was featured in an article in the Sacramento Business Journal discussing Indirect Evaporative cooling and, more specifically, the merits of the Seeley Climate Wizard. WCEC Director Mark Modera was featured on a PBS show called Office of the Future: Energy-Efficient Office Space where he discussed the Center's origin, briefly explained the impetus of the Center and highlighted some technologies being researched at the center including envelope sealing with aerosol particles.

WCEC experts also presented on Fault Detection & Diagnostics at the High Performance Buildings Conference, spoke at the Carrier Global Engineering Conference, ACI Conference, and Daikin Forum, gave multiple presentations at CHESC (CA Higher Education Sustainability Conference) and presented at the California Emerging Technologies Coordinating Council. WCEC also hosted a diverse range of stakeholders including Siemens, SCE, Sempra, SMUD, LAWDP, Danfoss, Lockheed Martin, Honda, Wells Fargo, and Amory Lovins. Finally, Mark Modera taught his new course on Building Energy Performance for the second time this year. ☀



**THANK YOU TO THE CALIFORNIA ENERGY COMMISSION  
AND OUR AFFILIATES. YOUR SUPPORT IS INTEGRAL TO THE  
SUCCESS OF THE CENTER'S WORK AND TO THE GREATER  
GOAL OF REDUCING ENERGY USE.**

AIRMAX®

BEUTLER CORPORATION®

CALIFORNIA ENERGY COMMISSION

CARRIER CORPORATION®

COOLERADO®

DAIKIN INDUSTRIES, LTD.®

DAVIS ENERGY GROUP®

INTEGRATED COMFORT, INC.®

LENNOX INDUSTRIES, INC.®

MUNTERS® CORPORATION®

NovaTURQUE, Inc.®

NV ENERGY

OCTUS ENERGY

PACIFIC GAS AND ELECTRIC COMPANY®

SACRAMENTO MUNICIPAL UTILITIES DISTRICT

SEELEY INTERNATIONAL PTY. LTD.®

SEMPRA ENERGY UTILITIES®

SOUTHERN CALIFORNIA EDISON®

TARGET®

TRANE®, INC.®

UPONOR®

VIEGA®

WALMART®

XCEL ENERGY®



If you would like to learn more about our work, please visit our website: [wcec.ucdavis.edu](http://wcec.ucdavis.edu)

**Questions or Inquiries regarding partnership opportunities with WCEC?**

Paul Fortunato, Outreach Coordinator: 530.752.0280 | [pfortunato@ucdavis.edu](mailto:pfortunato@ucdavis.edu)  
Jim Rix, Program Manager | 530.752.0799 | [jcrix@ucdavis.edu](mailto:jcrix@ucdavis.edu)