WCEC ANNUAL REPORT

ON COOLING IN THE WEST

2012-2013

UCDAVIS
UNIVERSITY OF CALIFORNIA

BY THE NUMBERS

PEAK

20%
Reduction in whole building HVAC peak demand using a Munters EPX 5000

43%
Demand savings at peak for the Western Cooling Challenge Certified Trane Voyager DC

ENERGY

0
Targeted total amount of energy for the Honda Smart Home including annual electric car energy

60%
Average energy reduction when replacing standard kitchen ventilation with demand control kitchen ventilation

20%
Measured annual savings for evaporative condenser air pre-coolers on chillers

80%
Reduction in pumping power when using phase-change materials in a hydronic system

WATER

Rain Water
Reduces scale formation on evaporative systems compared to tap water

11,000,000
Gallons of free water if each household in Davis harvested just 500 gallons of rainwater

85%
Water reduction in washing machines when using plastic beads

400,000,000
Gallons of water used per day by U.S. for laundry

COOLING

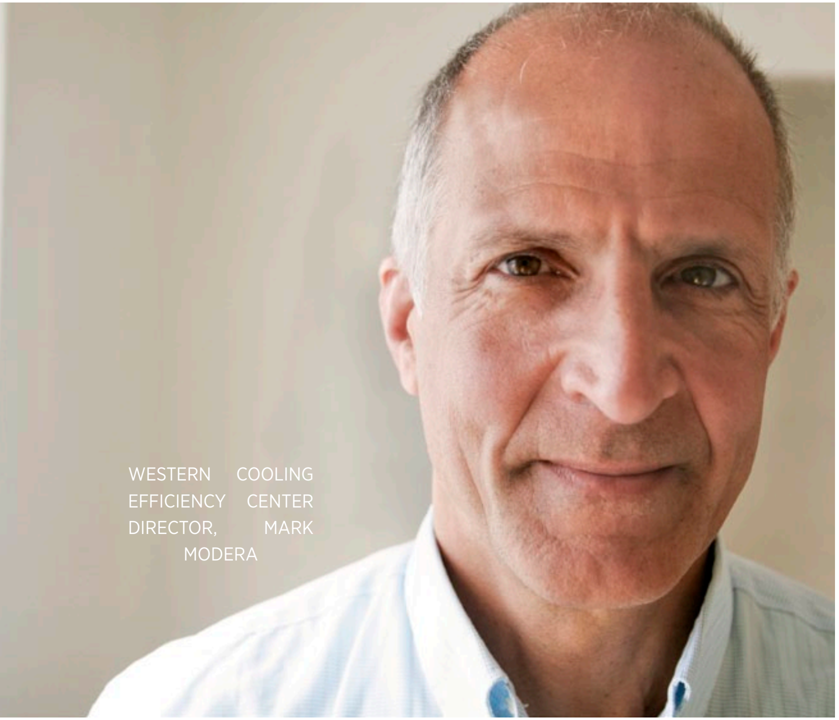
30 tons
Cooling capacity for WCEC's new environmental test chamber

HEATING

1,000,000
BTUs of heating capacity for WCEC's new environmental test chamber

Advancing HVAC energy efficiency through

comprehensive research, industry collaboration, policy-making, and advocacy.



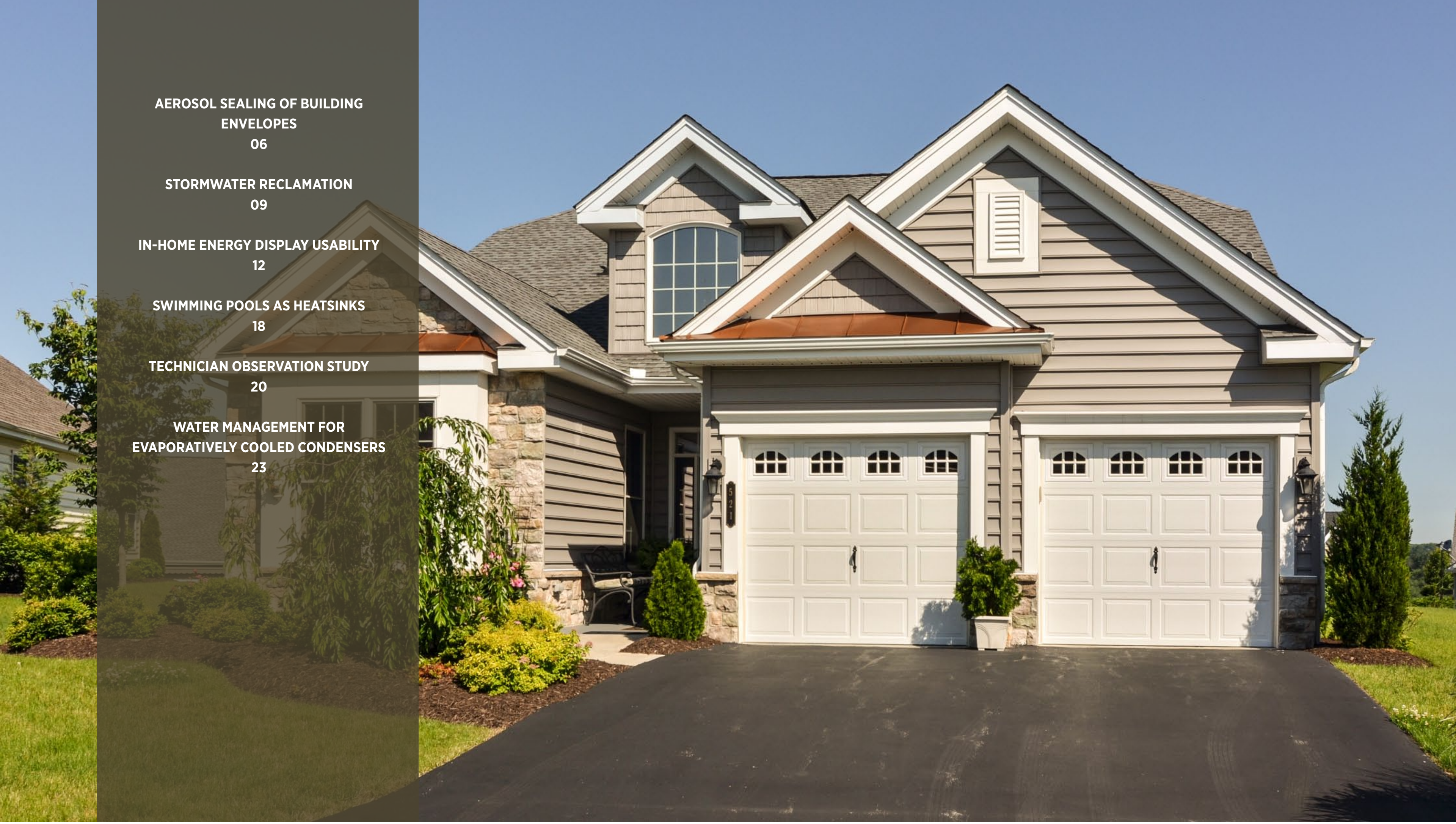
WESTERN COOLING EFFICIENCY CENTER DIRECTOR, MARK MODERA

Welcome to the 2013 edition of the Western Cooling Efficiency Center's Annual Report on Cooling in the West.

This report is the primary requirement for our work on behalf of the state of California and the California Energy Commission, but it also summarizes the research we're doing on behalf of a range of sponsors and is thus the most comprehensive review of the work we've done over the past year. As you'll see, we continue to conduct research, development, and demonstrations across a wide array of HVAC systems, conducting applied research in close partnership with industry and stakeholders, to ensure the results of our efforts can easily transition into HVAC products ready to succeed in the marketplace where they can help California achieve its ambitious energy conservation goals. And we hope and expect these results will help drive efficiencies across the nation and globally as well.

The pages that follow provide a good indicator of the breadth of our work and the advances we've made over the past year. But I'd like to highlight just a couple. First, the CEC-sponsored research on sealing building envelopes with an aerosolized sealant continues to make impressive strides. In short, for the first time, we've sealed multi-family units, learning lessons on how envelope sealing can be used outside the single-family residence market. Moreover, we've conducted substantial work on the process itself, using new nozzles and developing a new multi-point injection system and teaming with a major sealant manufacturer to test a sealant more appropriate for the process. Secondly, we continue to make major inroads with the Western Cooling Challenge, an important rooftop unit efficiency program funded by Southern California Edison and Pacific Gas and Electric. We tested the first submission from a large manufacturer, and the Trane Voyager DualCool met the Challenge's stringent efficiency standards, and units are now being installed around the state for further field testing. And we're encouraged to have two other large manufacturers with candidates as well.

We have also made great strides toward developing standards that will enable a more robust RTU retrofit program. Right now, there are no standards guiding the testing of devices that can make existing, installed RTUs significantly more efficient. WCEC has embarked, as a leader within ASHRAE, down the road of establishing a test protocol that will guide the evaluation of evaporative pre-coolers, work that will, over time, greatly enable the development of this huge but largely untapped market for efficiency.



SINGLE-FAMILY RESIDENTIAL

AEROSOL-SEALING OF BUILDING SHELLS

Automating the process of sealing leaks in buildings

Building shells are notorious for leaking, causing unintended air flows between conditioned and unconditioned spaces, which results in additional heating and cooling loads that the HVAC equipment must remove. A significant effort has been made to reduce the leaks in building shells through current construction practices, but the problem remains one of high labor costs, constant vigilance and quality control. 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.

Last year the WCEC tested the process of sealing envelopes with an automated aerosol-based technology in a small-scale laboratory enclosure. 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 all sealing the enclosure completely from about 42 square inches 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. In addition to the small-scale testing, the WCEC also performed one full-scale test in a single-family home. The first full-scale envelope test was very promising sealing an additional 50% of the available leakage (the leakage after taping windows, doors, and HVAC ducts) beyond the tightness level achieved with the standard methods used by the contractors.

WCEC ENGINEERS IN THE FIELD AT VARIOUS STAGES OF AEROSOL RESEARCH

During this last year we have focused on developing a new aerosol injection system, testing new sealant material, and field testing of the envelope sealing process.

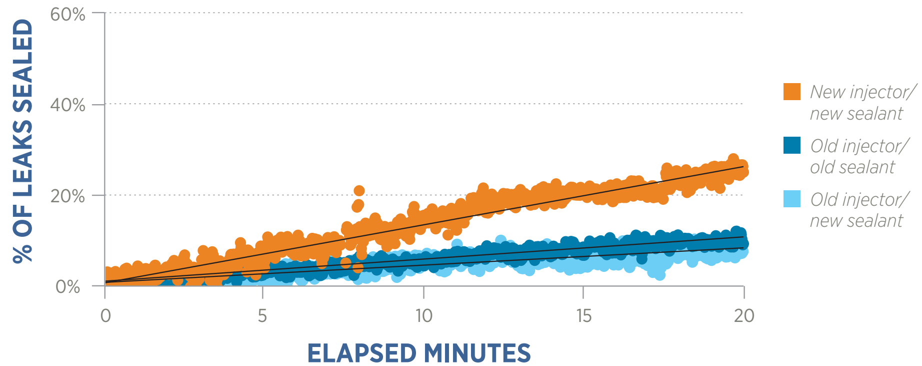
The first full-scale envelope sealing test demonstrated the need for multiple injection nozzles. The system used in the initial testing of the aerosol envelope sealing process was a modified commercial technology for sealing ducts with aerosol particles. This injection system uses a compressed air nozzle that requires a dedicated compressor to operate which limits the practical ability to expand the number of nozzles operating simultaneously. The WCEC has designed a new aerosol injection system that can operate five airless nozzles simultaneously with the option to expand to more if necessary. The new injection system uses compressed gas to pressurize liquid sealant to the appropriate operating pressure of the airless atomization nozzles.

In addition to developing a new injection system, the WCEC is working with a large sealant manufacturer to test alternative sealants that are better suited for whole house applications of aerosol sealing. We have successfully identified and tested a sealant that dries non-tacky while also possessing the characteristics that allow it to be atomized and adhere to leaks. Tests are planned to assess the impact of different additives for improving the sealing effectiveness, maintaining tackiness throughout the sealing process, and strengthening the resulting seal.

Several full-scale tests of the aerosol envelope sealing process have been conducted in the last year which tested an alternative sealant, new nozzle injection system, and application protocols.

Figure 1 compares the sealing rates of the full-scale installations using, 1) existing duct sealing equipment and duct sealant, 2) existing duct sealing equipment and new sealant, and 3) recently develop aerosol injection system with the new sealant. Comparing tests using the old injection system with the new and old sealant gives us an idea of the relative deposition efficiency. The slightly lower sealing rate when using the new sealant indicates that the new sealant has lower sealant deposition efficiency than the old sealant. This result is somewhat expected since the new sealant dries non-tacky preventing particles that dry out before impacting a leak to stick. Figure 1 also shows that the new aerosol injection system using five injection nozzles has a much higher sealing rate nearly four times that of the old injection nozzle. When normalized by sealant injection flow rate however, the new injection system has a lower sealing rate than the existing duct sealing system.

FIGURE 1: COMPARISON OF SEALANT RATES FOR NEW SEALANT AND NEW AEROSOL INJECTION SYSTEM



We have successfully identified and tested a sealant that dries non-tacky while also possessing the characteristics that allow it to be atomized and adhere to leaks.

The most recent full-scale applications tested the process in two multifamily apartments that were essentially identical but at different stages of construction. One test was performed at the pre-insulation phase of construction before drywall was installed allowing the seal to form on the external surface of the unit while another test tested the unit after drywall was installed allowing the seal to form on the inside surface. Sealing the external wall would prevent outside air from entering the wall cavity effectively reducing the thermal exchange between the inside and outside walls, however there is more leakage to seal and the leaks are typically bigger so the process takes more time and material.

Figure 2 shows the sealing profile for the full-scale sealing test of an apartment during the pre-insulation phase of construction. The leakage normalized to 50 Pascal started at 2,500 CFM and was sealed to about 1,000 CFM reducing leakage of the unit by 60%.

Figure 3 shows the sealing profile for the test in a similar apartment after drywall was installed. The leakage normalized to 50 Pascal started much lower than the pre-insulation test at about 950 CFM and was sealed to below 500 CFM reducing leakage by 50%. These tests show that the sealing rate of a leakier building is significantly higher than that of a tighter building. The pre-insulation test sealed 1,500 CFM of leakage at 50 Pascal in about 115 minutes while the test after drywall was installed sealed about 475 CFM in 105 minutes.

The amount of leakage after applying aerosol envelope sealing techniques is not the final leakage of the apartments since part of the process involves taping off doors, operable windows, and HVAC ducts. Ultimately the final leakage of these apartments will be tested by a third party HERS rater and compared in order to analyze the overall impact of sealing the buildings at the different stages.

EXAMPLE OF SEAL FORMED ON EXTERNAL SURFACE (PHOTO TAKEN AFTER INSULATION WAS INSTALLED)

FIGURE 2: SEALING PROFILE FOR TEST PERFORMED ON APARTMENT AT THE PRE-INSULATION PHASE OF CONSTRUCTION (EXTERIOR SEAL)

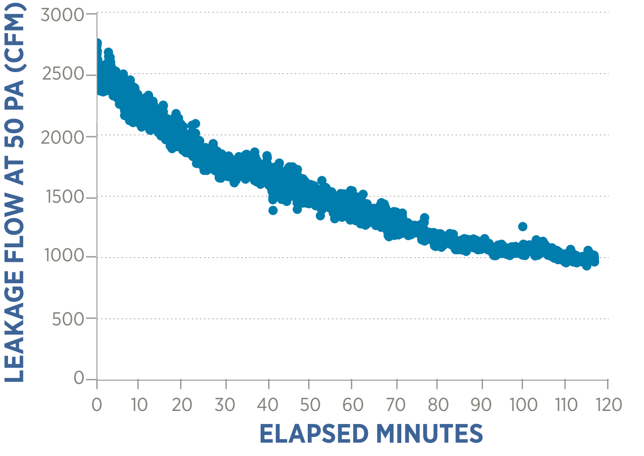
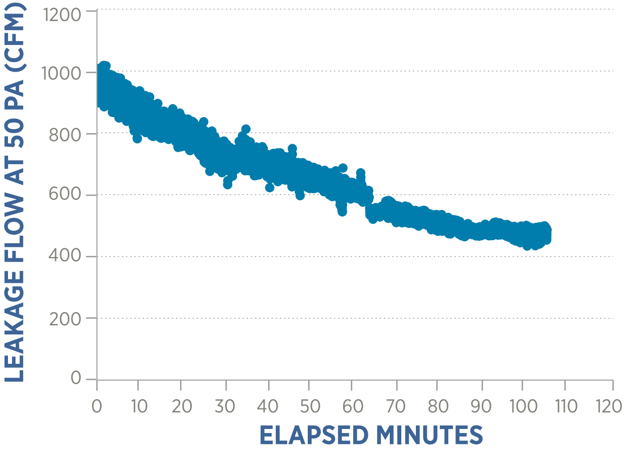


FIGURE 3: SEALING PROFILE FOR TEST PERFORMED ON APARTMENT AFTER DRYWALL WAS INSTALLED (INTERIOR SEAL)



NASIM TAJMAND, PREPARES WATER EXPERIMENTS AT A HOME IN DAVIS, CA

RAINWATER STORAGE FOR THE PURPOSE OF EVAPORATIVELY COOLED AIR CONDITIONING SYSTEMS

Conserve municipal water use through rainwater storage

The cities of California's Central Valley have a climate that is typically very wet in the winter and very dry in the summer. Capturing and storing the abundant winter rainfall for summer use helps to sustain our regional water system. One goal of this project is to outline rainwater harvesting from the perspective of sustainability and public acceptability, placing it within a social science context. Another goal is to understand the value of harvesting rainwater for non-potable use in a residential evaporative cooling application. The following benefits of this application are explored: (**1**) potable water conservation; (**2**) scale prevention in heat exchange units; (**3**) surface water quality protection; and (**4**) reduced risk of flooding.

WATER QUALITY MODELING IN AN OVER GROUND RAINWATER CISTERN

A 2500-Gallon Polypropylene tank was used for the pilot study to demonstrate the quality of the stored rainwater. Over the 6 months from November 2012 to June 2013, as shown in Figure 1, the temperature in the tank followed the trend of the ambient air temperature but experienced significantly less fluctuation. This indicates that rainwater storage can be suitable as a heat source for heating and heat sink for cooling application.

Chemical and physical parameters showed fair stability. Consistent concentrations of organic carbon and metals were found over the course of this experiment. Rainwater has an acidic nature; however, the pH of the harvested rainwater samples from shingle roof was in the near-neutral range of 7. This shows that the risk of potential corrosion for intended use such as evaporative cooling systems decreases because of the buffering capacity of the roofing material. Turbidity, which is often used to represent the presence of particles in water, was low. During the experiments, the turbidity in the rainwater storage averaged 2.5 ± 0.8 NTU. By the end of experiment it was reduced to less than 1NTU.

In this study, biological contamination tests were conducted to investigate the presence of total coliforms, fecal coliforms and E. coli for both samples collected from each rainwater event. Once the tank was full, it was monitored on a weekly basis. Total coliforms, e. coli and fecal coliforms were detected in the initial collected rainwater during the dynamic period but continued to decrease to less than 1 MPN/100 for total coliforms, E. coli and fecal coliforms during the storage period (Figure 2). The decay of indicator bacteria is influenced by several environmental factors. Winter's low water temperature and nitrification inside the tank are a possible reason for the bacteria's inactivation. The results indicate that the microbial concentration without treatment after 6 months storage meets the minimum water quality guidelines and suggested treatment methods for collected rainwater developed by the Department of Planning and Development in the City of Berkley[1]. The guidelines state that the acceptable level of total coliforms should be less than 500 CFU/100 ml, and fecal coliforms level should be less than 100 CFU/100 ml for non-potable water usage.

The result is certainly a promising approach in rainwater storage application and deserves more attention and research in this area. These results were presented at the Interdisciplinary Graduate and Professional Symposium (IGPS) on April 5, 2013. The IGPS 2013 Abstract/Program Book can be found: http://gradstudies.ucdavis.edu/about/IGPS%202013%20Abstract%20Book.pdf

FIGURE 1. WATER AND AMBIENT AIR TEMPERATURE PROFILE IN THE RAINWATER CISTERN

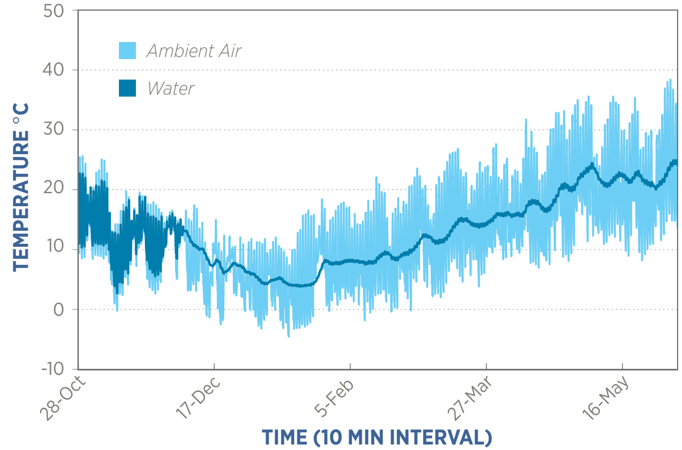
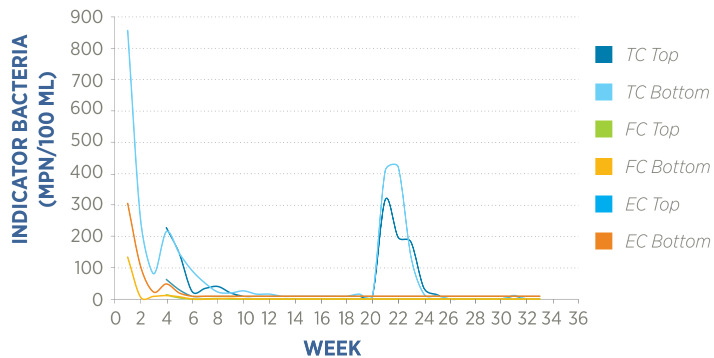


FIGURE 2. LOAD AND DECAY TREND FOR TOTAL COLIFORMS (TC), FECAL COLIFORMS (FC) AND E. COLI (EC) IN THE RAINWATER CISTERN



EXPERIMENTAL RESULTS OF RAINWATER USAGE IN COOLING SYSTEMS

According to the first experiment, stored rainwater will not need treatment to meet the minimum non-potable water quality guidelines developed by the City of Berkeley[1]. However, minimum treatment (filtration and disinfection) before usage is prudent to provide a reliable system against legionella growth in evaporative cooling systems.

It is expected that using rainwater, with very small hardness (17 mg/L as CaCO3), compared to tap water will reduce harmful effects of mineral scaling and bio-fouling on a system with a copper coil condenser. A subsequent laboratory test with small-scale evaporative cooling systems will be used to compare mineral scaling, bio-fouling and bacterial growth in using several water sources: intake rainwater, typical central valley's tap water and a treated mixture of both tap and rainwater.

NASIM TAJMAND, WATER SCIENTIST AT WCEC, STANDS IN FRONT OF THE RAINWATER STORAGE TANKS AT A HOME IN DAVIS, CA

1. Guidelines for Rainwater Harvesting, P.a.D.D.E.a.S.D.B.a.S. Division, Editor. 2010: Berkeley.

USABILITY OF IN-HOME ENERGY DISPLAYS

Assessing the impact of user interfaces on energy savings behavior

This experiment, designed as a randomized control trial, tested responses to simulated home energy feedback interfaces or In-Home Energy Displays (IHEDs). WCEC researchers produced IHED mockup energy feedback interfaces, based on representative market available devices. These simulated interfaces had varying levels of complexity in terms of the quantity and kind of information provided. Experiment participants interacted with the simulated devices, and then responded to questions assessing their ability to retrieve basic information, put that information in a meaningful energy use context, and use that information to make energy use decisions. As part of the experimental design (described in more detail below), different participants were randomly assigned to mockups that presented different features.

Features varied in the devices fell into three categories:

(1) BASIC INFORMATION

Display of basic energy use and cost features, corresponds to the "common" set of features in our heuristic evaluation. Information provided is almost never absent, from even the simplest of devices. All experimental conditions included this basic information, and the condition that included only basic information was the control condition in this study.

(2) CONTEXTUALIZING INFORMATION

The display included information that allowed the user to compare basic information with an external standard, potentially leading to a motivation to reduce energy use. In this study, contextualizing information was presented in the form of either a social comparison with similar households, or a pre-set energy usage goal, or both. Research indicates that social comparisons, or "anchors" (Kahneman, 2011) can act as descriptive social norms that provide a motivation for people to act in accordance with the norm (Jacobson, Cialdini, & Mortensen, 2010; Schultz, Nolan, Cialdini, Goldstein, & Griskevicius, 2007). Goals act as strong motivators for individual action and change, and they have been shown to be effective motivators in the domain of household energy behaviors (Abrahamse, Steg, Vlek, & Rothengatter, 2007; McCalley, deVries, & Midden, 2010; Wilson & Dowlatabadi, 2007) .

(3) DECISION MAKING TOOLS

The display presented either general tips for energy saving that users could have followed if motivated to reduce energy usage, or specific diagnostic tips alerting the user that an appliance (in this case, the air conditioner) was wasting energy because of some form of malfunction that had been detected.

> *"Technologies are only as effective as the people interacting with them."*
>
> CLAUDIA BARRIGA, PH.D
> BEHAVIORAL RESEARCH ASSOCIATE

The experiment varied the quantity and kind of information included in the in home energy display.

STAGE 1 EXAMPLE

In the first stage of the study, participants were randomly assigned to one of the following conditions:

1. *A device with basic information only (Usage in kWh and dollars, current power use)*
2. *A set budget (monthly usage goal)*
3. *Social comparison information*
- **3a**. *Usage is higher than neighbor*
- **3b.** *Usage is lower than neighbor*

STAGE 2 EXAMPLE

In a second stage of the experiment, subjects were randomly assigned to one of three paths

1. *No additional information*
2. *3 General tips for energy saving actions at home*
3. *3 Specific diagnostic information for energy saving actions in their home*

The basic information presented included numerical information (see large white numbers) describing current power use, and energy usage for a day. It also included a graph with “yesterday’s hourly usage” (gray color) and “today’s hourly usage” (orange color). By clicking on “more info” the user could access a second screen, showing daily usage for the month, and cumulative usage for the month (in orange). Budget information included the red alert on the top left of the screen, alerting user to being “over budget” by 15%. It also included a red projected line, in the bottom half graph of the second screen, which represented the budget. Participants in the control condition would have seen no red budget alert and no red line. Social information presented included purple color graph information on the second screen, representing neighbors’ usage. Participants in the control condition would have seen no purple section. Finally, the “take action” screen included three messages recommending either general tips for action, or suggestions based on specific measurements for each users’ system (example shows general tips).

Using the energy feedback interface they are assigned to, participants were asked to complete several rounds of information retrieval tasks (finding and reporting information provided in the feedback interface) and decision making tasks (choosing appropriate actions to reduce energy usage depending on the feedback). After completing three rounds of tasks, participants were asked questions about their experience with the interface and some demographic questions.

Participants in the study were passers-by in public commercial areas around the cities of Davis and Fairfield, in California. They conducted the study in one of six small tablet computers that were programmed to display the mockups as well as the integrated questionnaire. Participants used these tablets to access the energy feedback display and responded to the questions and tasks required by the study. Devices and questions were presented using MediaLab™ experiment software, which allows display of the information, automatic recording of the questions, and tracking of device navigation (hyperlinks followed and time spent at each screen).

Participants were recruited at three field sites in Davis and Fairfield, CA. After removing ineligible participants, 249 responses were saved to a final data table. The respondents were 50% female, and typically college age.

Participants responded to three kinds of questions:

INFORMATION

These questions were intended to gauge whether users could correctly find the information provided in the display and how hard or easy it is for them to access it. They included items such as "according to the display, how much energy has the household spent so far this month?" or "what is the projected electricity bill for the household?" Right and wrong answers to the tasks will allow the researchers to determine whether users can obtain accurate information from the device. Ease of use will be gauged by measuring how quickly respondents were able to answer the questions, and how many navigation screens they had to go through to reach the answer.

MEANING/CONTEXT

These questions are intended to gauge whether the information provided in the feedback interface can be put into a meaningful context by the participants. They included Questions such as, "is the energy use of the house shown in the previous screen low, average, or high?" or, "does the energy use of the house suggest to you that energy use should be reduced?"

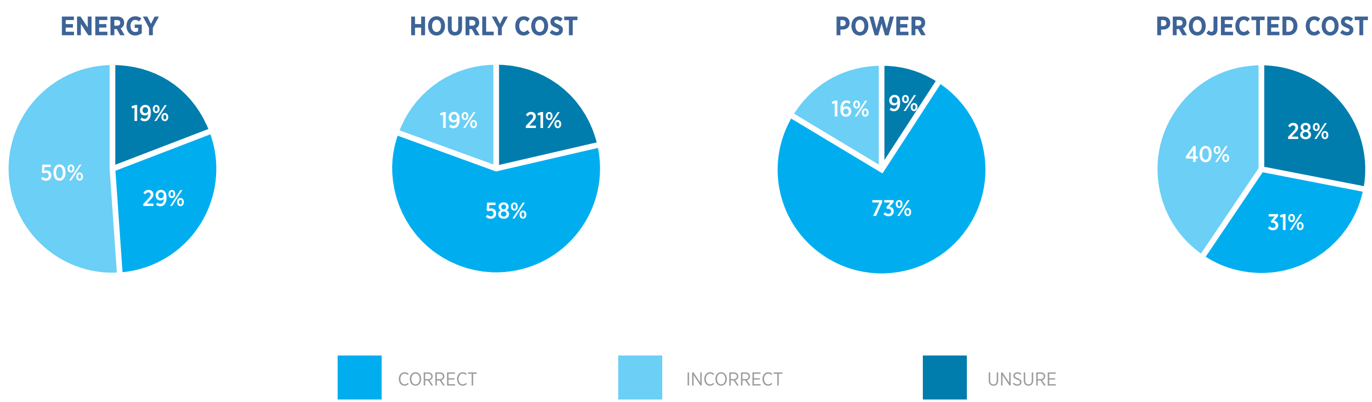
ACTIONS/DECISIONS

Participants were provided with a variety of energy saving options with an increasing cost or effort, and asked which they felt was appropriate given the feedback. These questions are intended to gauge whether information in the device can be used to inform and motivate energy saving decisions.

IHED SELECTED RESULTS » INFORMATION ACCESSIBILITY

One of the primary functions of an energy display is to provide residents with pertinent energy usage and cost data. The ability of individuals to extract simple information about their home energy use and spending on energy is therefore a crucial test of energy feedback usability. To test subject's ability to extract information we constructed four multiple choice questions (one correct answer, three plausible but incorrect answers). The questions asked participants to identify energy use so far this month, cost of energy used in the last hour, current power draw and projected cost for the month. Participants were free to revisit the energy display as many times as they wished to find the information before answering the multiple choice question, and they had the option to answer "I don't know". To analyze the data the answers were coded as Correct, Incorrect, and Unsure. Proportions of correct answers are shown in the pie chart matrix below.

Participants did best (73% correct) when retrieving power, which was presented as a large number (1.1kW) on the first screen, and second best at calculating money spent in the last hour (16 cents), which required finding the cost in the right side y axis on the first screen. However, for this second question, uncertainty was at 21%. Participants fared badly in questions regarding energy use in the month, which required interpreting a cumulative usage chart in screen 2 (50% incorrect) and projecting monthly cost, which required them to project a line from the cumulative graph in the second screen. This last question also includes the highest percentage of "unsure" responses. Results shows a big difference between straightforward numerical information provided upfront and information that requires operations (projecting lines, navigating through screens) to access.



PERCENTAGES OF CORRECT, INCORRECT, AND "UNSURE" RESPONSES TO 4 MULTIPLE CHOICE QUESTIONS TESTING ABILITY OF RESPONDENTS TO EXTRACT INFORMATION FROM ENERGY FEEDBACK INTERFACE.

THE EFFECT OF SOCIAL INFORMATION

Social information plays a potentially important role in IHED design. Neighbors (or similar households) can provide contextualizing information that is otherwise unavailable from a household's energy data on its own. For example, although individual-level data could answer the question: "Has my usage gone up over time?" it cannot answer the question, "is my usage higher than average, or particularly high?" This social information could play a role both in making individuals aware of the potential to reduce their energy use, as well as motivating reductions due to a social normative effect ("my usage should be lower than it is").

To test the importance of social information three social variants were tested in the experiment. The three variants were no social information, an overlay showing neighbors that are 15% higher than the home, and an overlay showing neighbors that are 15% lower than the home. A series of questions in the survey then probed the subject's interpretation of the presented home energy use to determine if the usage of neighbors had an effect.

The first question tested the ability of subjects to correctly interpret the screen, and shows a clear impact of the additional information for most subjects (this can be considered a manipulation check). Neighbors shown using higher energy levels resulted in most subjects indicating that this was the case, whereas lower neighbors resulted in most participants saying they used less or "as much" energy as their neighbors. No neighbor information shown resulted in most subjects indicating that they believed the usage was either similar to neighbors or they could not tell.

The second question probed the normative value of the neighbor information by asking if the household was using more or less energy than it "should be." This distinction indicates that the peer effect could play a role in motivating reductions. Again, subjects responded as hypothesized to the information, and notably responded most strongly when their house was shown as using more than their neighbors. The final question in this set asked for an overall evaluation of energy use in the presented household. The results indicate that when the IHED showed the house as using more energy than the neighbors the subjects felt that their usage was high, but the reverse was not true when the house was shown using less than the neighbors – in this case the subjects felt that the usage was average (not low, as expected).

TAKING ACTION

One purpose of an IHED is to motivate resident action in saving energy, either by taking conservation measures or purchasing or maintaining their equipment. To test the efficacy of the mockup designs in motivating this type of behavior a series of hypothetical questions probed each subject's belief that it would be appropriate to take action to save energy due to the presented information, were it shown in their own home. In addition, subjects were split into two groups to receive either general energy saving tips or specific energy related diagnostic information. The tips and diagnostic groups are additionally compared to test the hypothesis that diagnostic information is more relevant to residents than generic energy saving tips. In these questions subjects were allowed to choose as many energy saving options as they wanted, to better reflect reality.

It is worth noting that there are currently no residential IHEDs that display diagnostic information. This section of the study was testing a hypothetical possibility that the researchers thought might be of potential use to encourage energy saving actions. It is quite interesting to see that both kinds of diagnostic information could significantly increase motivation to engage in energy savings. The trend in each question indicates that tips were more motivating than no information and diagnostics were more motivating still.

ACTIONABLE USABILITY SCORES

To test the projected usability of IHEDs, a combined "actionable usability" score was generated for each kind of IHED (conditions). The score assumes the most usable IHED is easy to use correctly, and provides the required knowledge to transform the information into action, termed "actionable knowledge", and the motivation to act. In the case of our study "actionable knowledge" corresponds to the question asking people whether they would know what to do if they wanted to save energy, and "actionable norms" corresponds to scores on the question asking whether they think, based on the IHED that they should be saving energy.

The score is then based on the formula:

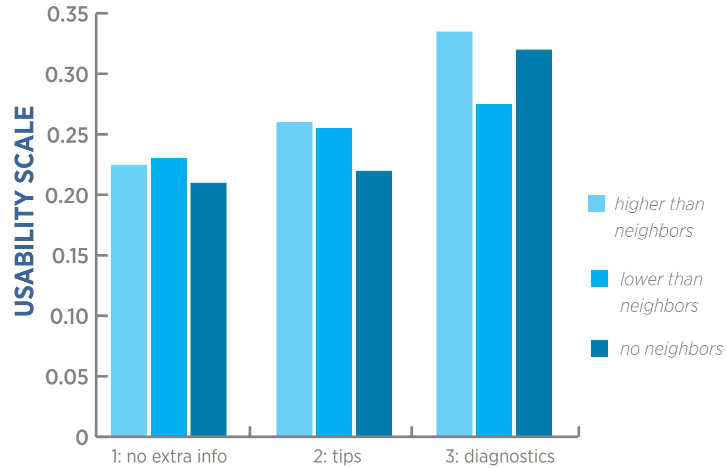
$$Usability\_Score = \left(\frac{Information\_Gained}{Effort\_Required}\right) * (Actionable\_Knowledge + Actionable\_Norms)$$

Translated into the measures recorded in the survey this becomes:

$$Usability\_Score = \left(\frac{Quiz\_Score}{Time\_Spent}\right) * (Actionable\_Knowledge + Actionable\_Norms)$$

The usability score shows two main trends: an increase in usability with additional tips and diagnostics (as shown on the x-axis), and an increase in usability with additional social information (shown in the side-by-side bars). The chart shows that the two information types also interact to improve usability – with the highest scores having both social information and diagnostics. The condition in which the house was shown to have a higher energy use than its neighbors was always more usable than the opposite – most likely due to the normative effect. The case with no neighbors was much more usable in the diagnostic scenario. This is likely because the diagnostic information largely plays the same role as social information in motivating improvements, but it was also easier to complete the quiz when there was less social information on the screen. Finally, the highest usability score (.34) is more than a 50% increase over the lowest score (.22), suggesting that IHED design can have a large impact on resident actions.

USABILITY SCORES COMPARED ACROSS KIND OF ACTIONABLE INFORMATION PROVIDED (NONE, GENERAL TIPS, SPECIFIC DIAGNOSTICS), AND KIND OF SOCIAL COMPARISON PROVIDED (USAGE HIGHER THAN NEIGHBORS, USAGE LOWER THAN NEIGHBORS, NO SOCIAL INFORMATION)



RESEARCH RECOMMENDATIONS

» Expand research on the impact of general energy saving tips, diagnostic information, and messages that are provided directly in the IHED while people check their energy usage.

» Expand research on the effects and desirability of social comparison information, paying particular attention to the possibility of "boomerang" effects, in which a comparison decreases motivation to save energy.

» Expand research on the impact of complex, graphic and information rich IHED devices, focusing in particular on users' ability to extract correct and actionable information from it.

» IHED Usability scores, like the one proposed here, should combine traditional usability measure (ease of navigation, ability to gather correct information) with an effectiveness usability measure, gauging whether the IHED provides information that facilitates energy saving actions.

SWIMMING POOLS AS HEAT SINKS

Reduce air conditioning costs and pool heating costs at the same time

When a homeowner has a pool and an air conditioner, they are often rejecting heat from the air conditioner condensers to the atmosphere while burning natural gas to heat their swimming pools. This project aims to utilize the synergy of these two energy consuming activities 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

Using swimming pools as heat sinks can reduce air conditioning energy use by 25-30% and cut peak electricity demand by 30-35% in California.

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 the WCEC published a paper in Energy and Buildings Journal on the feasibility of rejecting condenser waste heat to a residential swimming pool in California. The analysis suggested that using swimming pools as heat sinks can reduce air conditioning energy use by 25-30% and cut peak electricity demand by 30-35% in California. The paper also discusses the potential for cost effective methods for cooling pools and the dependence of the calculated energy savings based on pool temperature and climate zone.

The WCEC also sponsored a CAPSTONE design team at UC Davis for studying the potential use of hydrosols in pools to reduce solar heat gain to the pool. Water temperature has a significant influence on the potential energy savings when rejecting waste heat to the pool, but additionally, and perhaps more importantly, impacts a homeowner's enjoyment of the pool. Many of the simulations suggested that pools can overheat when absorbing air conditioner waste heat. One method conceived for mitigating this problem is to use hydrosols to increase the reflectivity of a pool when pool temperatures become too high.

The senior design team used the model to show that having the ability to increase pool reflectivity by 15% results in a 2°C decrease in pool temperature which could offset the impact of rejecting air conditioner waste heat to the pool in many circumstances. An experiment was conducted in an attempt to measure the increased reflectivity of a pool with micro-bubbles injected. The experiment compared the heat required to maintain the temperature of a small pool with hydrosols injected to a similar pool that did not have hydrosols injected. The amount of heat to maintain the same temperature could then be directly attributed to the added solar reflectivity of the pool. Unfortunately, the students did not account for the heat added by the hydrosol machine which ended up being more than the amount of heat reflected. This project demonstrated that using hydrosols to reduce solar heat gain to a pool, resulting in an overall net decrease in heat gain to a pool, is unlikely with the technology tested in our tests. While hydrosols have been shown to decrease pool absorptivity, the power required by the hydrosol generator exceeds the impact of the added reflectivity.

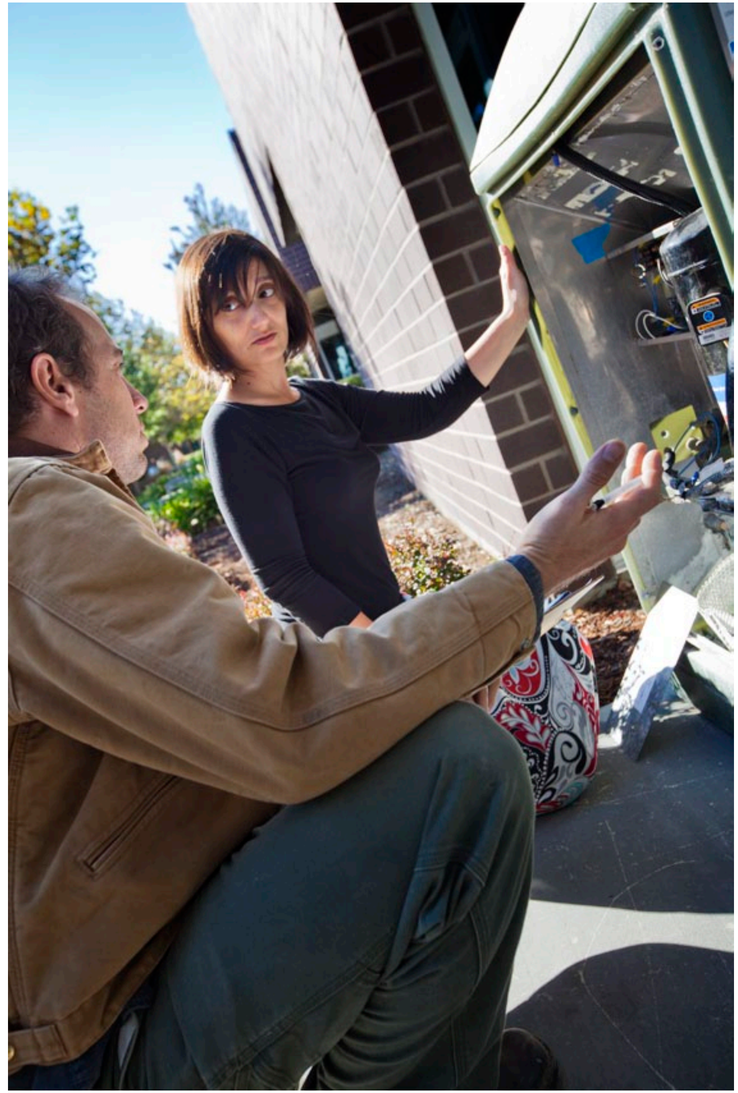
TECHNICIAN OBSERVATION STUDY

Determining the human factors in HVAC maintenance

HVAC technicians are there on the front lines when an air conditioning system goes kablooie, or when end of life decisions are being made (is it time to pull the plug, or should we fix it yet again?). Technicians thus have a great deal of influence over whether a unit is replaced or not, and whether the customers will get whatever the dealer has in the yard, or whether they have time to fully analyze all the options and go with the lowest life cycle option. Hence, HVAC technicians serve the role as "ambassadors" for energy efficiency. How well do they play this role?

WCEC decided to investigate this with funding from the California IOUs and CPUC. We used the home of one of our research colleagues, and called 16 contractors and invited them to send out a technician to provide maintenance services. Each of the technicians provided what they considered to be maintenance services, and after being paid for their services, they were informed that it was a part of a research study. They were then interviewed to find out why they did the things they did. A technical expert "scored" what they did from a technical perspective, and a social-psychologist evaluated how they related to the "homeowner" and how they played the role as ambassadors for energy efficiency. Figure 1 shows the number of technical tasks that were completed correctly as a function of the duration of the service. The longer the service took, the more tasks they were seen to do correctly. Figure 1 also shows some characteristics of the technicians, and technician certification (NATE or NCI) was likely to result in a fuller servicing (although one of the poorest performances was also by someone with NATE certification). How did they do as ambassadors for energy efficiency? None of the technicians promoted energy efficiency, even when prompted by the "homeowner." They were proud of their skills and training, and felt that they had provided a "quality" job.

There are policies that affect the development of industry standards and utility programs for maintenance. For example, the California Long Term Energy Efficiency Strategic Plan and its associated HVAC Action Plan set the goal to make



quality maintenance the norm. Attempts to achieve this goal have had limited success in the marketplace—early attempts at fielding utility programs that provide rebates for maintenance services were not totally successful. Utility programs utilize contractors and technicians as trade allies and rely on them to recruit participants and deliver efficiency services. Human factors and the performance of the technician are significant determinants of successful maintenance programs and measures. Policies that promote the performance of technicians in the field will increase the savings from these programs as well as transform the market for HVAC maintenance. These policies include a call for development of a new type of service offering that is based on accurate measurements and standards, and requires competent technicians to "push" measures with well-established savings, and early-adopter customers to pull these measures.

But are HVAC Technicians good ambassadors for energy efficiency? The quick answer is no, not currently. In this study, the HVAC technicians did not carry out some of the basic maintenance tasks correctly, and they didn't spend the time required to do so. Technical performance was below the standards of ACCA 4 and "Quality Maintenance" goals. Technicians recommended expensive improvements that were not justified by measurements or observations. They also did not promote energy efficiency or service contracts.

Yet, technicians had more training and were more knowledgeable than their technical performance scores would suggest, and technicians that were NATE or NCI certified were more likely to score well on the task checklist. Technicians work hard to achieve their perceived company and customer goals:

- **Perceived Company Goals:** Their company goal is to sell and accomplish as many service calls as possible each day.
- **Perceived Customer Goals:** Customers are interested in only two things: in making sure the equipment is working when needed, and in spending as little time and money as possible to achieve that goal.

Many technicians seemed to be proud of their training and their work, and also of their ability to achieve these two goals. These goals are closely tied to the industry's traditional practices around the term "maintenance." Indeed, previous research by WCEC has shown that homeowners think of HVAC as "low-maintenance" and "low-tech," matching the characteristics of a refrigerator: you plug it in, it works, someday it dies and you get a new one. Thus it can be difficult to convince homeowners that they should partake in detailed and expensive maintenance services, and most technicians would prefer not to try, in order to maintain a trust relationship with the customer. The word "Quality" similarly has a dual meaning, and as most technicians believe that they are already providing a "quality" service, it is difficult to sell "quality maintenance." (What is the other kind of maintenance called?).

This new type of HVAC service would share many characteristics with maintenance, but would focus more on measurement, performance and workmanship.

INDUSTRY TRANSFORMATION IS NEEDED: Develop a way to make technicians see the goals of their employers and customers as consistent with the non-traditional goals of quality technical performance. A new category of service other than "maintenance" or "tune-up", is required…perhaps "optimization." This new service would share many characteristics with maintenance, but would focus more on measurement, performance and workmanship. This type of service can be marketed directly, although it can be reinforced by being included in utility programs, and even included in point-based recognition systems for existing buildings. Policies should promote HVAC optimization in existing buildings.

If this type of optimization is to be distinguished from maintenance, are maintenance technicians the right people to be doing this work? In utility programs and other developments, HVAC contractors are being positioned as the logical provider of integrated whole-building energy services, which includes such areas as insulation, infiltration, and windows, in addition to HVAC. Their knowledge of HVAC system operation is unequalled, and those technicians who are certified by organizations such as NATE, NCI, or other certifiers are, for the most part, well qualified. But this work would have to be delivered in a different way than traditional maintenance. The service must be allowed to take several hours, and adherence to ACCA Standard 4 and other industry standards for quality workmanship must be mandatory. Accurate and well-documented measurements and observations must be the basis for all adjustments and recommendations. Training on how to take the required measurements and what they mean may be necessary in some cases. The role of measurements in service trainings and certifications such as NATE and NCI should be explored. Technicians also must be aware of the value that they are providing-- take pride in this new service, and enthusiastically offer it to their customers. This service should be viewed as an opportunity to teach and change customers' attitudes about AC maintenance.

For this to work, customers must value HVAC performance. "Early adopters" with an interest in environmental concerns have been found to be a coherent group that responds well to energy-savings claims for maintenance services. The industry will need to find a way to focus on these "early adopters" who already value this technical performance. Market segmentation strategies should be developed that identify the characteristics of these early adopters, and allow for marketing to be targeted. Once optimization has become business-as-usual for this category of customer, it will be much easier to make the sale to the general populace. Solid data on the energy- and non-energy benefits, both for the industry at large and for individual buildings, is also critically needed. Without this evidence, it will be impossible to sell this type of optimization. Research is also needed at the state or national level into the impacts of faults in residential HVAC and their prevalence.

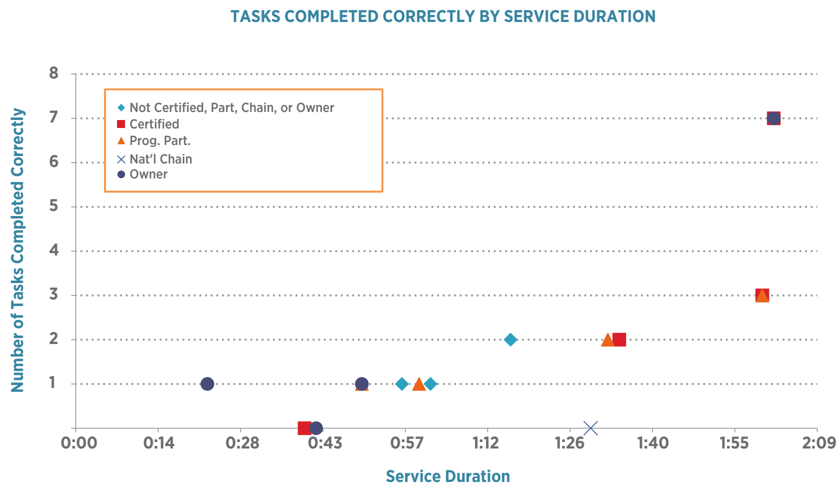


FIGURE 1: NUMBER OF TASKS COMPLETED CORRECTLY AS A FUNCTION OF SERVICE DURATION

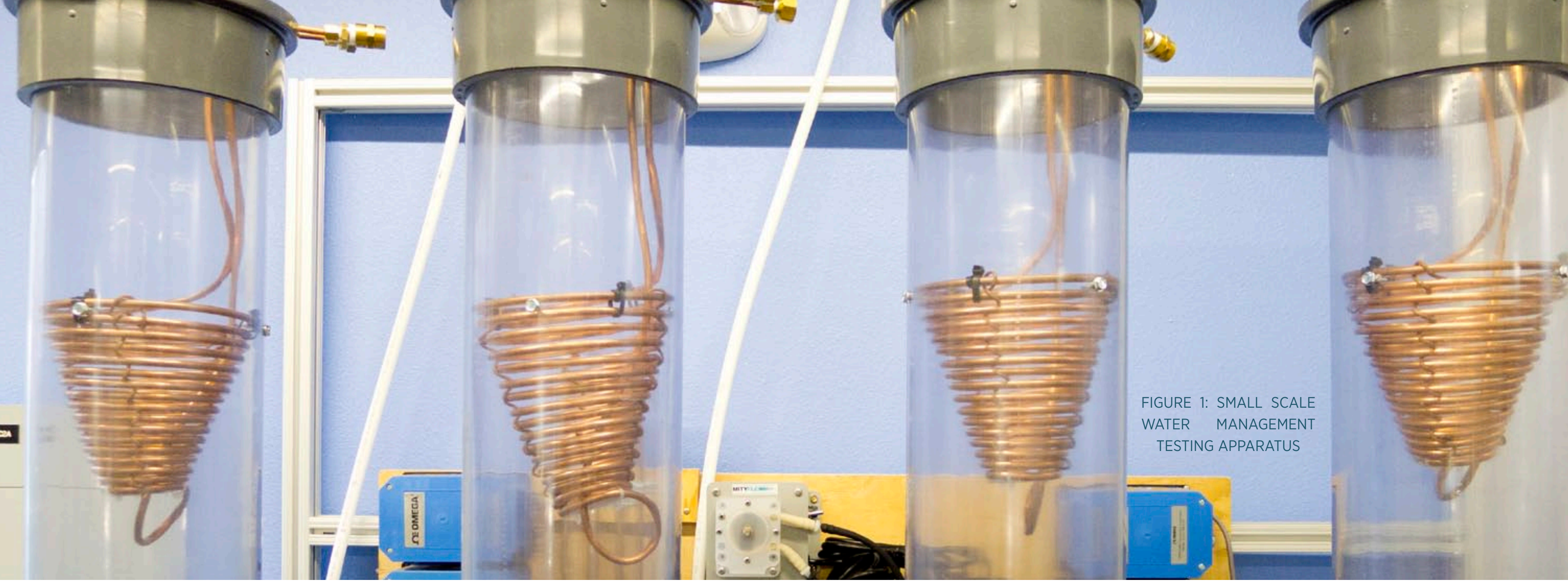


FIGURE 1: SMALL SCALE WATER MANAGEMENT TESTING APPARATUS

WATER MANAGEMENT FOR EVAPORATIVELY COOLED CONDENSERS

Improving the longevity and reducing water use in evaporatively cooled condensers

An evaporatively cooled condensing unit (ECCU) sprays water over the condensing coil where water droplets evaporate into the condenser air stream. ECCUs are highly efficient in dry climates and their operating efficiency is closely tied to the outdoor air wet bulb temperature as opposed to the outdoor air dry bulb temperature. However, water management of ECCUs is essential and 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, scaling the condensing coil, pumps, piping, and other surfaces. In residential system, a bleed system is generally used to bleed sump water and replace it with fresh water. While this consumes additional water it is thought to decrease maintenance and improve system performance. The manufacturer of a residential ECCU recommends bleeding up to 40% additional water above what would be evaporated for cooling. The recommended bleed rate is a function of tap water hardness.

WCEC completed small scale testing of an evaporatively cooled hot water coil at approximately 1/20 scale of the ECCU was used to test two bleed strategies simultaneously in comparison to a no bleed control. Hard water from the Davis, CA municipal supply was used as the source water for the experiments.

The small scale ECCU testing apparatus consisted of a copper coil supplied with 130°F water, a sump supplied with Davis, CA tap water, a recirculation pump and nozzle system that sprayed the copper coil, and a fan that supplied approximately 50 cfm of outdoor air heated to 95°F to each test chamber. The water spray operated for a 60 minute on period followed by a 30 minute off period to allow the coil to dry. The influent tap water was sampled periodically to measure temperature, pH, calcium and magnesium concentrations. The sump water was sampled weekly to measure temperature, pH, calcium and magnesium concentrations. The total calcium and magnesium precipitated over the course of the experiment was calculated based on a mass balance approach at steady state conditions. The results show that Calcium and Magnesium behaved very differently in the evaporative system (Table 1).

Calcium was observed to be largely or entirely precipitated in all systems. In the two no-bleed systems, calcium was not detected in the sump water indicating that it had entirely precipitated (100% precipitation). In the low and high bleed systems, the sump concentrations of calcium were actually lower than that of the tap water. The calcium concentration in the low bleed sump was 16.0 mg/L, the high bleed sump was 8.4 mg/L, and the tap water was 34.1 mg/L. Therefore, increasing the bleed rate actually increases the total amount of calcium available to the system and also the mass of Ca deposited in the system (i.e., as mineral scale). Conversely, sump concentrations of magnesium were higher than that of tap water. The magnesium concentration in the low bleed sump was 350 m/L, the high bleed sump was 185 mg/L, and the tap water was 48.6 mg/L. Therefore, increasing the bleed rate reduced the total amount of magnesium available to the system and reduced the amount of magnesium depositions in the system.

In the high and low bleed systems, the mass of precipitated calcium compared to the no bleed system increased (~4% increase for the low bleed and ~14% increase for the high bleed) and the mass of precipitated magnesium compared to the no bleed system decreased (~100% decrease for the low bleed and ~52% decrease for the high bleed). These results indicate that increasing the bleed rate may actually contribute to calcium-based scale formation. By increasing the bleed rate, more makeup water is required, and therefore a greater amount of calcium is supplied to the system. Because of its low solubility at the elevated pH values that are observed in the ECCU system, a majority of the calcium is then converted into mineral scale. 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 maybe be more detrimental than beneficial).

Carbonate-based solids are commonly observed to foul water heaters, cooling towers, and ECCUs. However, magnesium carbonate is far more soluble than is calcium carbonate. Under no-bleed conditions, a vast majority of the magnesium precipitated out; however, when a bleed was introduced the mass and percentage of magnesium precipitated dropped off quickly. At the high bleed condition, magnesium was not found to contribute to mineral scale. The difference in the behavior is due to the differences in solubility limits and the effect of the increased bleed on the solution pH. This indicates that, unlike calcium-based scale, the bleed is an effective approach for controlling magnesium-based scale. Among calcium and magnesium concentrations that are typically observed in drinking water, magnesium is less likely to significantly contribute to mineral scale formation than is calcium.

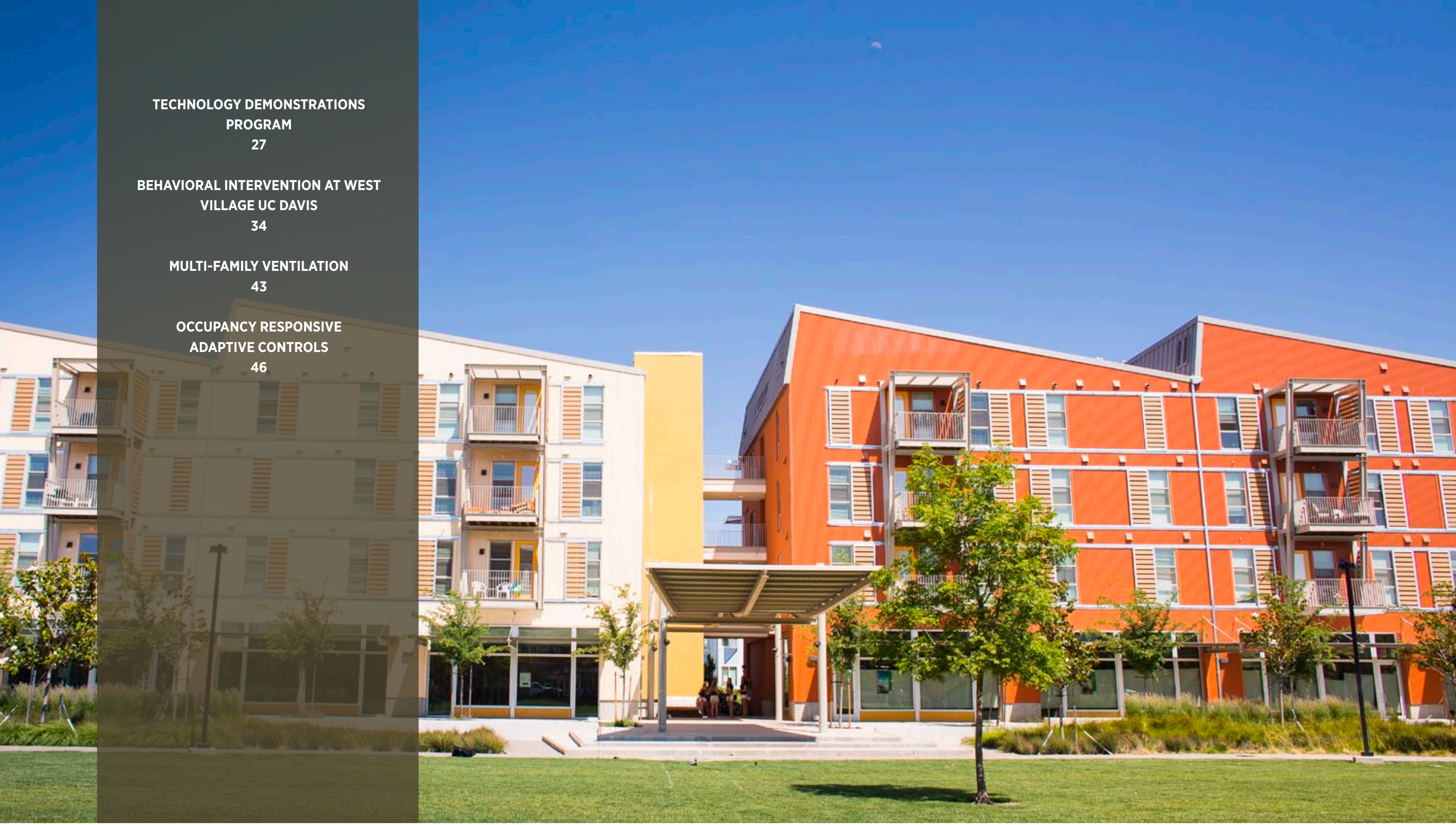
Calcium and magnesium react to water-based purge treatments differently. So it is important to first know which of these minerals is more prevalent in the water used for a given evaporative application.

System	pH	Ca Sump (mM)	Ca Precipitate (mols)	Ca % solid	Mg Sump (mM)	Mg Precipitate (mols)	Mg % solid	Mineral phase
Influent (tap)	8.11	0.85	-	-	1.97	-	-	-
Control (no bleed)	9.46	0	1.13	100	11.04	2.57	98.41	N/A
8% bleed	9.19	0.40	1.17	95.4	14.41	1.23	43.3	$MgCO_3$
40% bleed	8.99	0.21	1.29	81.1	7.64	0.00	0.0	$CaCO_3$ (arag)

TABLE 1: PH, CALCIUM AND MAGNESIUM CONCENTRATIONS IN TAP WATER AND SUMP WATER OF THREE EXPERIMENTS

FUTURE WORK

WCEC has proposed future work to run several sets of small scale experiments with manufactured water to represent the wide breath of water quality available throughout the state of California. The results of the experiment would be used to develop a model to calculate an optimized bleed rate based on the local water quality information. Detailed water quality information in an already existing database from the California Department of Public Health would be used to correlate location (zip code) with water quality information. A chart would be developed to provide ECCU installers with a recommended bleed rate based on location.



MULTI-FAMILY, HOSPITALITY & INSTITUTIONS

TECHNOLOGY DEMONSTRATIONS PROGRAM

Accelerating the deployment of energy efficient technologies through real world demonstrations

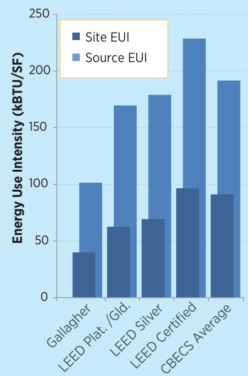
LEED PLATINUM BUILDING, GALLAGHER HALL AT UC DAVIS WAS A FOCUS OF STUDY FOR THE DEMONSTRATIONS PROGRAM

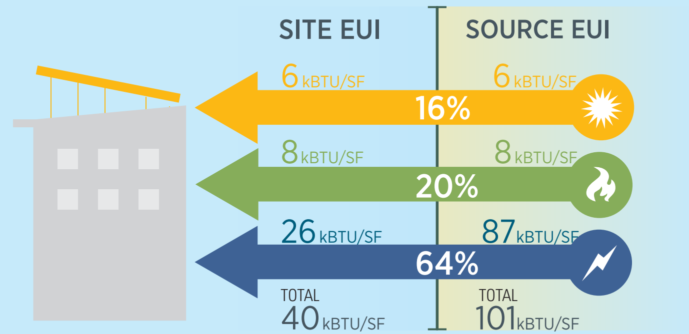
As part of WCEC's mission to accelerate the successful application of energy efficient HVAC technologies, the Center engages in a variety of technology demonstrations and beta-testing activities. The sheer breadth of market-available efficiency products creates a daunting task for institutional decision makers who have neither the time, nor the 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.

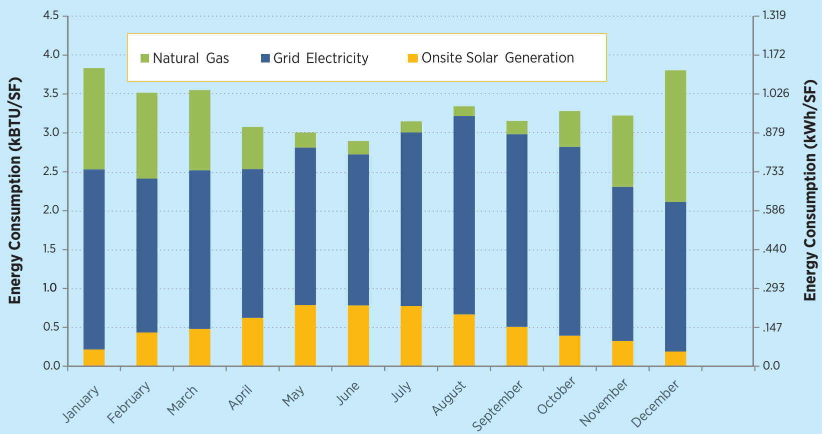
SITE EUI AND SOURCE EUI



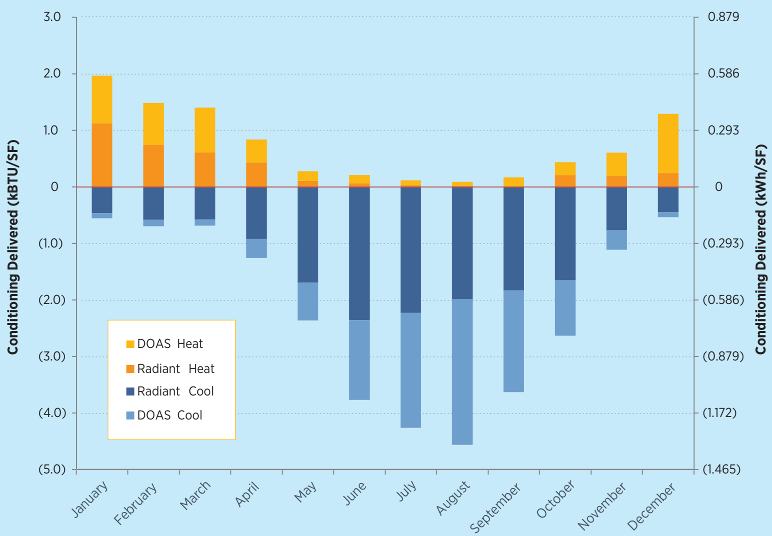


Davis' Gallagher Hall houses the Graduate School of Management. This 89,000 SF building has earned a LEED Platinum rating and stands out on campus as an example of smart building design. Innovative engineering including radiant heating and cooling, a dedicated outside air system, and solar management 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.

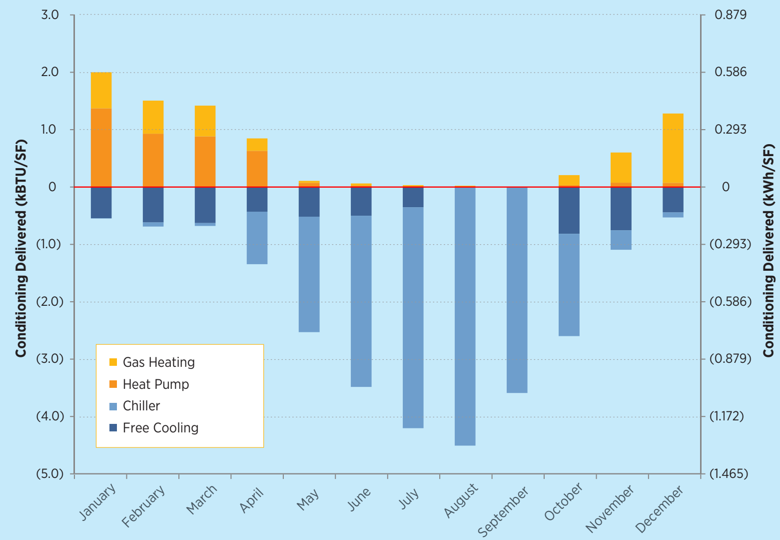
BUILDING SITE ENERGY



RADIANT VS. DOAS CONDITIONING

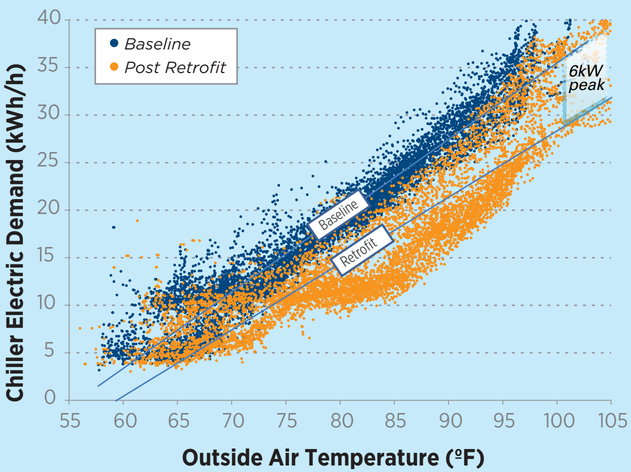


BUILDING CONDITIONING SOURCE

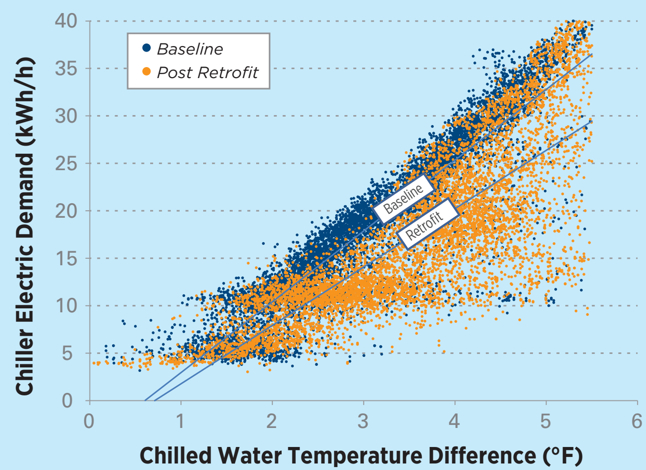


Evaluation of the EvaporCool™ pre-cooler took place at Beale Air Force Base on a 50-ton chiller. Initial results showed roughly a 22% reduction in energy consumption over the standard chiller without the pre-cooler.

CHILLER ELECTRIC DEMAND AS A FUNCTION OF OUTSIDE AIR TEMPERATURE

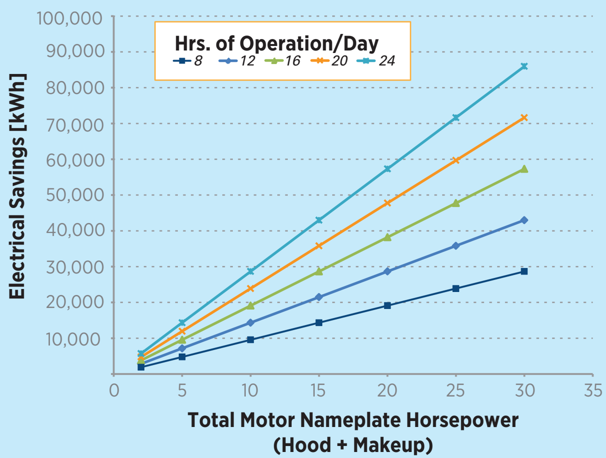


CHILLED ELECTRIC DEMAND AS A FUNCTION OF CHILLED WATER TEMPERATURE DIFFERENCE

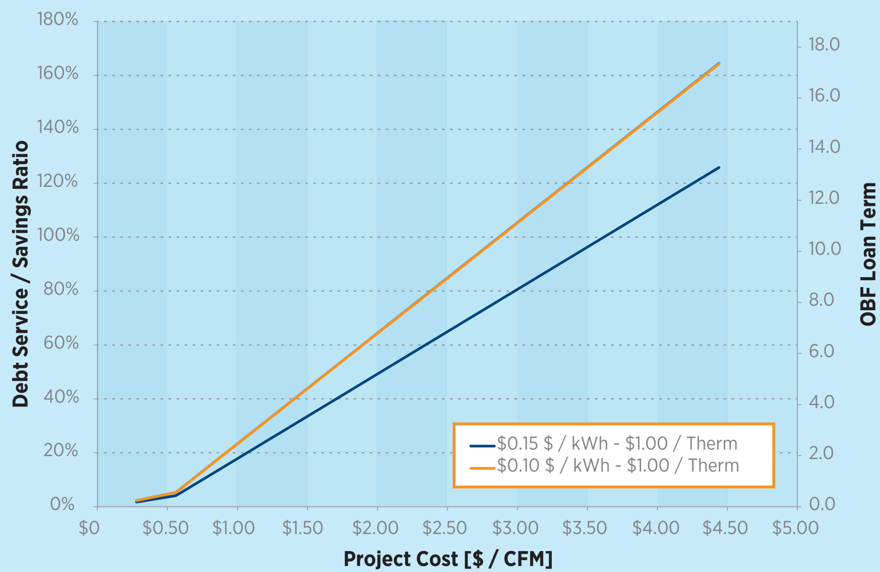


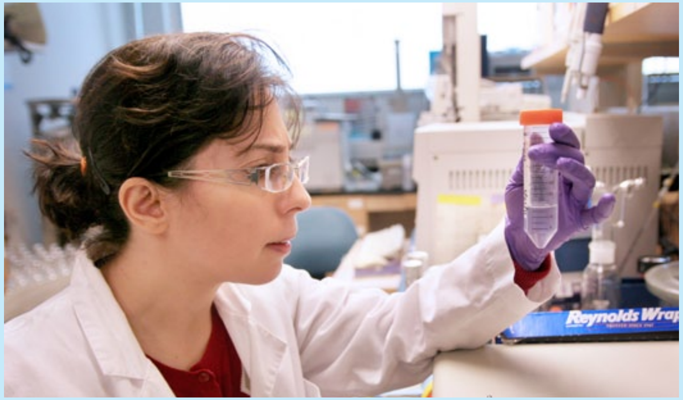
By sensing when kitchen cook surfaces are being used and adjusting the exhaust ventilation to match, energy expended by kitchen fume hoods can be reduced significantly. Fan energy savings on the order of 60% are typical and additional savings are had when the energy to condition the air is taken into account.

ANNUAL FAN SAVINGS



FINANCE METRICS FOR DEMAND CONTROL KITCHEN VENTILATION





TECHNOLOGY DEMONSTRATIONS » 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.

TECHNOLOGY DEMONSTRATIONS » RTU RETROFIT CONTROLLERS

Packaged air conditioners typically utilize inexpensive and antiquated control technology. New advances and falling costs in the field of electronics and motor controllers 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 CSULB will retrofit a 10 ton RTU and then monitor the energy savings.

Continuing work includes:

- Field demonstration of aerosol duct sealing for central exhaust systems in the Art Building at UC Davis
- Evaluation of energy impacts for Telkonet's occupancy sensing thermostats at residence halls at UC Davis
- Evaluation of climate appropriate RTUs at China Lake NAWS and the UCD University house.

BEHAVIORAL INTERVENTION AT WEST VILLAGE UC DAVIS

Assessing the use of 'tiny steps' behavior ideas in everyday HVAC energy use

The main goal of the study was to test a specific behavior change model for the domain of energy saving behaviors. This behavior change model had not been tested for household energy savings in the past.

In short, the Behavior Model tested claims that in order for any behavior to occur, 3 things need to happen: a person must be Motivated (want to do the behavior), have the Ability (be capable of perform-ing behavior), and be Triggered (be prompted or reminded to perform the behavior). A relationship exists between Ability and Motivation, such that a high level of Motivation can overcome even a low Ability to accomplish a behavior. Conversely, a person can be persuaded to perform a behavior they have low motivation for if it is very simple to ac-complish. Most behavior change efforts focus on propping up a person's motiva-tion; however, this model focuses first on making sure a reminder (Trigger) is always in place and then simplifying the behavior (thus ensuring the presence of Ability) as much as possible. This is often

WEST VILLAGE COMMUNITY AT UC DAVIS

sufficient to produce a behavior change and is much easier to implement and more universally applicable than increasing a person's motivation.

In order to enhance the ability to perform a new behavior, the model advocates the use of "tiny steps", establishing a scaled-down version of the desired behavior as a habit first and then growing that over time into the full behavior. For example, if you want to adopt the habit of flossing your teeth, start by establishing the tiny habit of flossing just one tooth. Once flossing one tooth becomes automatic, it is less work to expand that toward the full behavior (flossing all your teeth). For the energy domain, if you want someone to hang-dry all their clothing, start by having them hang-dry just one towel, establish that as a habit, and then expand to all towels, then all towels and shirts, etc. The model also encourages the pairing of positive reinforcers with the completion of the target behavior. Congratulating the participant on their specific energy savings in that moment should generate positive affect in the participant which will accelerate the pace of habit formation.

CONTEXT: THE WEST VILLAGE COMMUNITY DEVELOPMENT

The West Village Community Development (West Village) at the University of California, Davis (UC Davis) is the largest planned Zero Net Energy community in the United States. West Village is a mixed-use development that includes housing for UC Davis students, faculty, and staff; academic research and office space; retail space, and the first community college centre located on a University of California campus.

The original impetus for the West Village Community Development was to provide desirable housing to UC Davis faculty, staff, and students. Environmentally-sound design was always part of the vision, and the zero net energy goal came to be incorporated during project development. At completion, the community will include 662 apartments, 343 single-family homes, and 3950 square meters of commercial space. In the fall of 2011, the first residents –about 800 students, faculty, and staff– moved into 315 apartments. As of fall 2012, the 662 apartments have been completed and are currently occupied by approximately 1470 students, faculty, and staff.

Energy efficiency measures at West Village are projected to reduce energy demand by approximately 50 per cent compared to current building code requirements. These measures include solar-reflective roofing; radiant barrier roof sheathing; high efficiency light fixtures, air conditioning and appliances; thick exterior walls for added insulation, and external window sunshades. On-site energy generation is designed to meet the community's energy demand. A four megawatt PV system is designed to meet the needs of the first 1980 apartment residents and commercial occupants. In the future, a biogas generator based on UC Davis technology may be developed to convert table scraps from campus dormitories, animal waste from the campus dairy, and plant waste from agricultural research fields into energy for the community.

The main approach of West Village to residential engagement in the ZNE goals is to provide In-Home and Online Mobile energy use feedback to residents, so that they can monitor and potentially control and reduce their energy use. West Village included, in its design, the planned installation of identical In-Home-Energy-Displays (IHEDs) in all apartments. These IHEDs would track and display energy usage at the appliance level (thanks to plug-load monitoring), and enable remote control of plug-loads through apps or other online interfaces. West Village monitors solar panel production at the apartment level (solar panel surface is assigned to each apartment), and can provide combined production/consumption feedback, at the apartment level, through an online interface available to residents.

West Village student residents do not directly pay energy bills; instead, the renewable and efficiency investments are incorporated into their rents. That said, the developers intend to promote energy savings through a series of rewards programs and other incentives.

METHODS

46 West Village residents were recruited during October 2012 to participate in a two month trial of a behavior change intervention.

Participants were asked to participate in a study that would require them to commit to trying three different energy saving actions (take shorter showers, hang dry part of their laundry and turn off their PC at night), and respond to surveys at the beginning and the end of the study. All participants received tools to assist them in these tasks: drying racks for clothes, and five-minute shower timers. Half the participants also received 3 tracking devices (buttons) that they pressed whenever they completed the action. The tracking devices provided encouraging feedback ("great job", "keep it up") and also, occasionally, provided information about the cumulative amount of energy saved by doing the actions.

The initial brief survey, conducted in early November before devices and tools were distributed, gauged a baseline of energy saving behavior patterns, and motivations to save energy. The final survey assessed reported frequency of completed actions, and the perceived role and experience with the tools and the tracking devices. The 46 participants were offered 150 dollars for their commitment to complete the study. It was clear in all instructions that the 150 dollars would be given regardless of success in completing the energy saving actions: they just needed to try to do them, and complete all study surveys.

At the end of the study period, a separate group of residents was asked to respond to a survey similar to the initial study survey, to establish a second baseline or reference point. This group received no intervention or instructions whatsoever. They are referred below as the "No Intervention Condition". This group received 20 dollars for their participation in the survey.

TRACKING DEVICE WITH THE ENCOURAGING FEEDBACK MESSAGE "KEEP IT GOING!" FOR THE ACTION OF TURNING OFF THE PC AT NIGHT.

SELECTED RESULTS

Below is a report on relevant results for the study. A full report of all study results was submitted to Toyota ITC and is available from the WCEC on request. Results from this study will also be presented at the 2013 Behavior, Energy and Climate Change conference, in Sacramento.

EFFECTS OF CONDITION ON PRE-POST TARGET BEHAVIOR CHANGE

This section addresses “pre-post” changes in the target behaviors; this is, differences between the target energy saving behaviors at the beginning of the study, and their performance throughout the study, as reported by the participants. To establish comparison reference points, the analyses use two standards. The first comparison point is the reported level of energy saving actions by participants before the beginning of the study, which is then compared to their reported level of energy saving actions at the end of the study. The second reference point used is a set of responses by a sample of residents who did not participate in the study, but were asked about their reported level of energy saving actions (a control group). These participants were not instructed to engage in any saving energy actions. They were invited, separately than the rest of the participants, to a one-time brief survey. Again, analyses were conducted using SPSS21 software. Tests were ran as ANOVAs (ie: analysis of variance), with three conditions (Device, Control and No Intervention), with pairwise comparisons used to test the differences between each pair of groups.

INCREASE OF REPORTED SHORTER SHOWER BEHAVIOR

Experimental participants were asked, in the initial survey, how often they took the energy saving action of shorter showers. At the end of the survey, they were asked how often they had taken shorter showers throughout the study period. Both questions were asked using a 7 point scale, where “1” meant “Never” and “7” meant “Always.” The difference between responses to this question at Time 2 (Final Survey) and Time1 (Initial Survey) was used to create a score of increase in the energy saving action. Positive scores indicate an increase in the action, and higher scores indicate a higher rate of increase in the action. A difference of 0 is used for the No Intervention group, which was only measured at Time 2.

The ANOVA for the increase in reported short shower behaviors shows a significant effect of condition on increase of desired behavior ($p < 0.001$) for the whole model. The pairwise comparisons indicate that all differences are significant: the Control condition reported increases of shorter shower that are significantly larger than increases in the Device Condition. Both the Device and the Control condition are significantly different from “0” (no change) which would be expected if there had been no intervention. Increases in shorter shower behavior were statistically significant, and the increase was significantly higher in the control than in the device condition.

Although initial reported frequency of behavior is not significantly different across groups, the control condition had slightly lower scores to begin with. The significant difference in increase that we report here, between the device and control conditions, may be due to the fact that the device condition had less space to move up to (only had to move half a point to reach a level of 6, which is pretty high; whereas the control condition could move a whole point to reach the same level –see Figure 1). Interpretation of this result, which makes the control condition look superior, should be done with this caveat in mind.

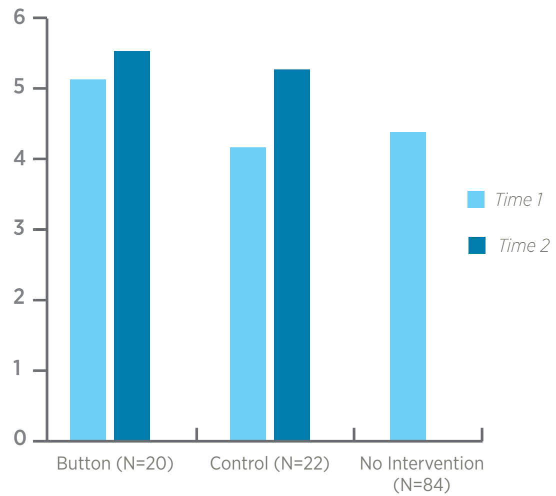


FIGURE 1: REPORTED FREQUENCY OF SHORT SHOWERS, AT TIME 1 (BEFORE INTERVENTION) AND TIME 2 (AFTER INTERVENTION), BY CONDITION, USING A 0-6 SCALE, WHERE 0 MEANS “NEVER” TOOK SHORTER SHOWERS, AND 6 MEANS “ALWAYS” TOOK SHORTER SHOWERS.

[1] It may be important to note here that scores for reported pre- study short shower behaviors were not significantly different across the three conditions, that is to say, the three groups can be considered initially equivalent.

It is important, also, to contrast this self-reported measure of behavior, with a different measure of behavior: the one provided by the recording tracking button, in the devices group. To make this easier, we developed a "Tracking Device Score" of completed behavior that uses a 1-7 scale, allowing comparison with the 1-7 score scale used for the self-report of behavior. Since the self-report scale assesses a proportion of times in which people conducted the behavior (what proportion of all opportunities to conduct the behavior did you actually conduct it, with 7 meaning "every time" and 1 meaning "never"), we needed to create s similar proportional measure for the button pushes.

The tracking device provided an absolute number of button pushes, or "clicks". In order to create a proportional measure, we assumed a total number of opportunities for the behavior that was the total number of days for the study. The maximum number of days in the study was 58. From this we subtracted, for each participant, the number of days they had been away for Thanksgiving and Christmas Break (they were asked this in the survey), and the number of days that their installation of the device was delayed (some participants got the device installed a few days after others.

Thus, we created an individualized number of "study days" for each participant. We divided the number of button pushes by the number of study days, to obtain the "Tracking Device Score", and transformed it into a proportion for a 1-7 scale by multiplying it by a constant of 6.

The resulting score corresponds to the proportion of times that participants took shorter showers and clicked the button, of all the days that they were at home during the study. This score assumed that participants did not leave during any non-holiday weekend during the study period, but we consider this to be an unrealistic scenario. It is common for students to leave during weekends and visit their family. Because of this, we calculated two other versions of the Tracking Device Score: one assuming that students had left for half of the weekends during the study period (3 weekends) and one assuming that they had left every weekend. The three versions are presented in Figure 2, in contrast with the self-reported measures at Times 1 and 2. Figure 3 shows the mean Tracking Device Score for the Shower Actions.

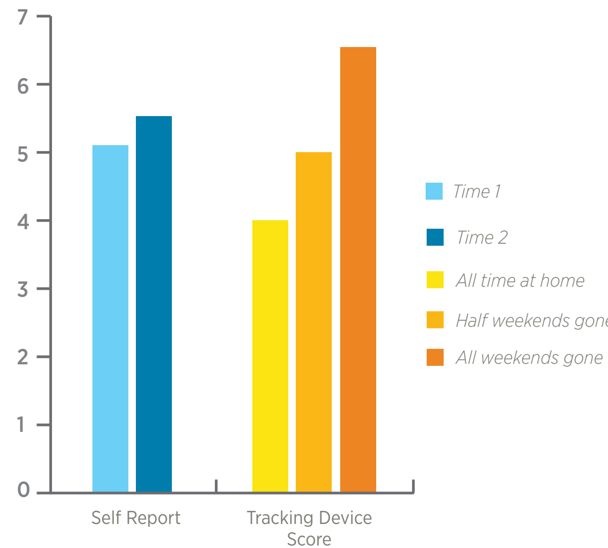


FIGURE 2: COMPARISON OF SELF REPORT AND DEVICE TRACKING SCORES FOR SHORT SHOWER ACTIONS – DEVICE GROUP ONLY (N =22)

EFFECT OF CONDITION ON FINAL SHOWER TIMES

Participants in the experimental part of the study had provided estimates of both their typical shower times, and their shower time reduction throughout the study. These measures were combined to create an "End of Study Shower Time", in minutes, which we compare with typical shower times in the no-intervention group, as a baseline. As noted earlier, typical shower times previous to the study were statistically equivalent across all three groups. Statistical analysis shows a significant effect of Condition on final shower times, with the pairwise analysis showing that both the Device and Control groups final study times are significantly different from the shower times of those in the No-Intervention group. Final shower times were the shortest for the Device condition, but the difference between Device and Control conditions is not significant.

Both the Device and Control conditions had significantly shorter shower times at the end of the study, than a no intervention reference group.

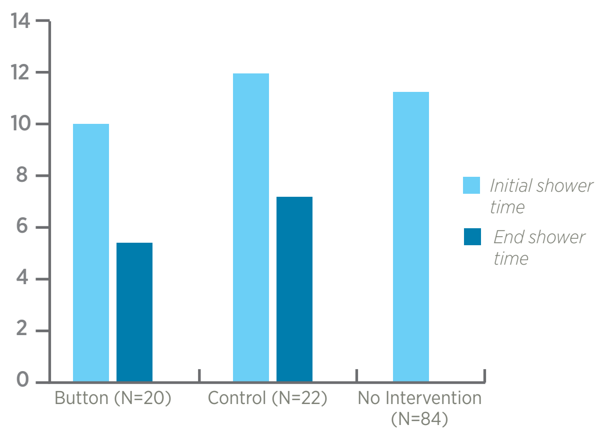


FIGURE 3: PRE AND POST INTERVENTION AVERAGE REPORTED SHOWER TIMES, IN MINUTES, BY CONDITION, SHOWING THE SIGNIFICANT DECREASE IN REPORTED SHOWER TIMES IN BOTH THE DEVICE (BUTTON) AND CONTROL GROUPS.

INCREASE OF REPORTED HANG DRYING LAUNDRY BEHAVIOR

This analysis addresses the difference between reported frequency of "hand drying laundry" before the study and "hang drying laundry" throughout study. Both use the 7 point scale where "0" means "Never" and "6" means "Always". The difference between Time 2 and Time 1 was used as a score of increase in behavior. The No Intervention group is used as a reference point. Increase in behavior is assumed to be "0" for the no intervention group. Again, statistical analysis using ANOVA shows the control and device groups are not significantly different from each other, but they are both significantly different from the no intervention group (see Figure 4, they both show significant increases in reported rates of hanging laundry compared to the no intervention group, or to a "0 change" value).

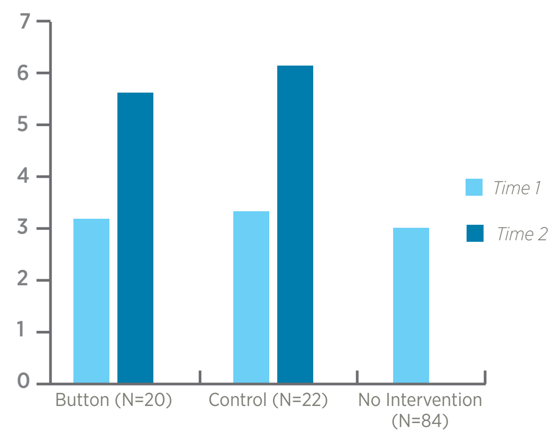


FIGURE 4: REPORTED FREQUENCY OF HANG DRYING LAUNDRY, ACROSS CONDITION AND TIME.

INCREASE OF REPORTED PC-OFF BEHAVIOR

This analysis addresses the difference between reported frequency of "turning off computer at night" before the study and throughout the study. Both use the 7 point scale where "1" means "Never" and "7" means "Always". The difference between Time 2 and Time 1 is used as a score of increase in the behavior. The No Intervention group is used as a reference point. The No Intervention group was asked the same question, and their responses were not statistically different from the experimental groups at Time 1. Increase in behavior is assumed to be "0" for the No Intervention group. Again, there are no significant differences between the device and control groups, but they are both statistically different from the "No Intervention" condition (Figure 5), which represents an expected change in behavior of 0.

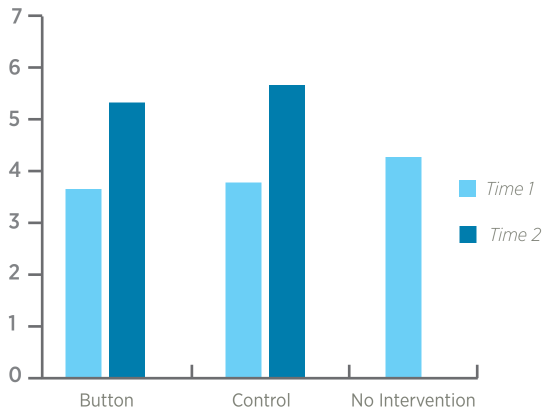


FIGURE 5: AVERAGE REPORTED FREQUENCY OF TURNING OFF COMPUTERS, BY CONDITION GROUP AND TIME

To contrast this self-reported measure of turning PC-off frequency, with the one provided by the recording tracking button in the device group we calculated a "Tracking Device Score" of completed behavior using a 1-7 scale, allowing comparison with the 1-7 score scale used for the self-report of behavior. To do so, we used the same method as described for the shower behavior. The resulting score corresponds to the proportion of times that participants turned their computer off and clicked the button, of all the days that they were at home during the study. As with the shower behavior, we include here three possible scores, depending on different assumptions regarding students' permanence at West Village during the weekends. These are shown in Fig. 6.

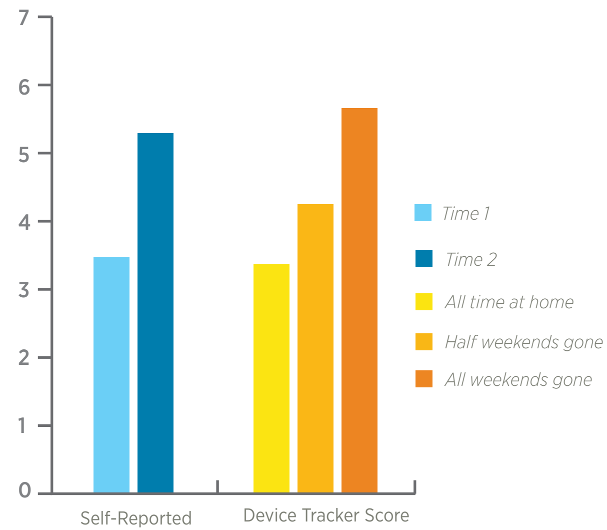


FIGURE 6: COMPARISON OF SELF REPORT AND DEVICE TRACKER SCORES FOR COMPUTER OFF ACTION. DEVICE TRACKER SCORES ARE SHOWN FOR THREE DIFFERENT ASSUMPTIONS ABOUT APARTMENT OCCUPANCY.

EFFECTS ON NON TARGET BEHAVIORS

Besides checking for the effects of the devices and tools on the target energy saving actions, the study examined whether the devices could, or not, have an effect on other energy saving behaviors that were not directly addressed when communicating with participants. Participants were not asked to do these behaviors (or attitudes) or given any information about them. In the end of the study, however, they were asked whether they had noticed any changes in these behaviors throughout the study period.

These changes in behavior and attitudes were presented in the form of eight statements, and participants were asked to record their level of agreement with each, using a 6 point scale, where "1" meant "strongly disagree, and "6" meant "strongly agree. SPSS ANOVA models were ran to test for condition effects for each of these 8 statements. None of the analyses show significant differences between the device and control conditions, nor were they affected by environmental attitudes. Increased Attention to Electricity Use at Home (4.8) , Other Small Energy Saving Actions(5,1) , Reported Other Large Energy Saving Actions (3.8), Increased Attention to Water Use at Home (4.6) Increased Attention to Energy Use Outside the Home (3.8) Increased Attention to Water Use Outside the Home (3.9), Increased Conviction that Saving Energy is Important (4.9), Increased Conviction that Saving Water is Important (5.0).

DISCUSSION AND RECOMMENDATIONS

The discussion below is based on the previous results and others stemming from open ended responses that study participants provided in the surveys, and that are analyzed in detail in the full report.

Commitments of people to engage in temporary energy saving actions was successful in creating awareness and desired behavior changes. This also produced motivation to persist in energy saving behaviors in the long term.

Engagement in the actions seemed to act as a trial period during which residents could see that the behavior was possible, and that it had positive consequences beyond energy savings or environmentalism (saving time, protecting clothing, etc.). Engagement with the actions also seemed to trigger positive feelings about energy savings and the individual's capability to do something.

Even when the tracking and feedback devices did not have a significant advantage over simple commitments and tools (drying racks, shower timers) to produce behavior changes, participants who had them responded to them positively, had difficulty finding any disadvantages to having such a device, and appreciated learning from the feedback messages. On the negative side, it is possible that the devices were too distracting and/or called too much attention to themselves rather than the energy saving actions. They may have acted more as reminders that participants were in a study than as reminders about energy savings: participants in the device condition were more likely than those in the control condition to say that they performed the actions because of the experimental rewards.

Results in this study may be a warning sign about favoring gadgets and devices over simple commitments and accountability in behavioral change interventions.

That said, the sample size and the time frame may have conspired against the effectiveness of a device that triggers and rewards action, as predicted. These two limitations on the study (based on project funding and administrative limits) may have reduced the study's final findings. In particular, the time frame during which the experiment was conducted was too short to detect lasting differences in action patterns (laundry, showers) as responses to incremental feedback messages, like the ones the devices were providing.

More research with longer time periods that can gauge whether energy savings and attitude changes can be obtained from interventions is necessary if we are to understand behavioral change thoroughly. 8 months to a year seems a minimum. More than a year would be ideal. After all, a model based on incremental change through time, requires more than a brief period to be tested. Likewise, technical obstacles in gathering actual energy data could have been overcome in the project's time frame had allowed for a lengthier observation period. Practical concerns of this study also led to modifications in the original design (elimination of a device condition without feedback messages, and a no device/no tools condition) that might have provided relevant insights into the pattern of results we finally found. It may well be that the most important insight stemming from this project lies not in the results, but in the evidence that behavioral field experiments in energy use require lengthier timelines and increased funding to provide truly solid and compelling results.

A follow-up of participants in the study is strongly recommended in order to check for persistence of the effects in the absence of monetary incentives.

A replication of the study with an extended design (including the two eliminated conditions) and an appropriate study period (9 to 12 months) is strongly recommended if stronger conclusion regarding the specific effectiveness of the tracking devices is desired. Such a design, which would be easy to implement at West Village considering the current team's expertise and initial experience with this study, would also allow for a more thorough exploration of energy impacts of the devices.

Were more resources to be available, the ideal research scenario would include plug level monitoring of energy use by the appliances/activities studied, and inclusion of all residents in a household. These two scenarios would allow us to explore how residents may interact with each other in the presence of tracking devices, and whether energy is saved at the appliance level.

The unique characteristics of multi-family buildings are either unaddressed or forced to adhere to guidelines developed for entirely different purposes

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.

PROPOSED CHANGES TO MULTI-FAMILY VENTILATION CODES

Previous stages of the Multi-Family Ventilation project assessed codes and standards for areas of potential improvement. The assessments of California's building and energy code, primarily Title 24, as well as national standards like ASHRAE 62.1 and ASHRAE 62.2, were conducted through administering several surveys to gather perspectives of industry practitioners and experts. At the heart of these investigations were the two distinct sets of 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. Interestingly, no discernible technical rationale supported the specification of two distinctly different ventilation requirements for essentially identical buildings whose only difference is an additional story.

As a result of researching the foundation of the low-rise vs. high-rise discrepancies the WCEC developed the following potential recommendations for improving Title 24 with respect to ventilation in multi-family buildings:

FOR ALL VENTILATION SYSTEMS:

- » Code Consolidation: Combine all residential buildings, including multifamily high-rise buildings, under a single 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 CENTRAL SHAFT VENTILATION SYSTEMS:

- » Ventilation Duct Sealing: reduce ventilation duct leakage
- » Automatic Continuous Balancing: minimize over- and under-ventilation

EVALUATING PROPOSED CODE CHANGES THROUGH MODELING

In order to evaluate the impacts of the WCEC's proposed recommendations, the WCEC has created a variety of models and simulation scenarios to test the impacts these changes may have on energy consumption of multi-family buildings. The materials and constructions the model consists of are based on typical steel frame buildings that satisfy California Title 24 requirements and the geometry of the building model is comprised of four apartments. Each apartment can either be ventilated directly outdoors or to a central shaft that serves similar apartments above and below. In the middle of the building, surrounded on all sides by apartments, is a common area that represents a landing for elevator access (see Figure 1).

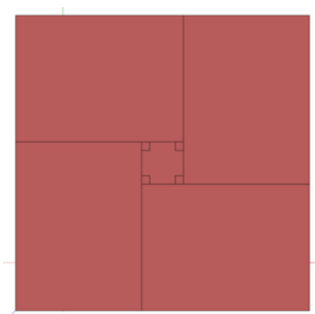


FIGURE 1: MULTI-FAMILY VENTILATION MODEL FLOOR PLAN

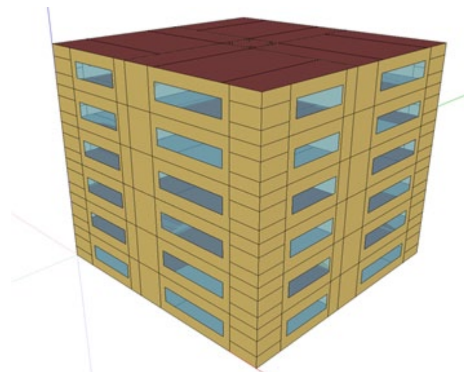


FIGURE 2: ISOMETRIC VIEW OF 6 STORY MULTI-FAMILY VENTILATION MODEL

All possible combinations of the proposed changes under evaluation are illustrated in Table 1. The preliminary outputs of the heating, cooling, and total energy loads predicted by the model for a 6 story building, shown in Figure 3([1]), illustrate the relative effects of the proposed changes. For example, a leaky building with a poorly commissioned and leaky central shaft (6S CS T24 LE LD unbalanced) consumes nearly twice the energy as a tightly sealed unit with an individual exhaust ventilation system. Similar simulations will be performed for models ranging from 1 to 6 stores as well as a variety of California climate zones.

TABLE 1: MODELING SCENARIOS TO EVALUATE POTENTIAL CODE CHANGE PROPOSALS

HIGH-RISE																LOW-RISE			
Individual Unit				Central Shaft												Individual Unit			
				LD				TD				TD + B							
T24	T24	J	J	T24	T24	J	J	T24	T24	J	J	T24	T24	J	J	T24	T24	J	J
LE	TE	LE	TE	LE	TE	LE	TE	LE	TE	LE	TE	LE	TE	LE	TE	LE	TE	LE	TE

EVALUATING POTENTIAL VENTILATION SYSTEM IMPROVEMENTS THROUGH FIELD STUDIES

Lastly, the WCEC is conducting a field study to demonstrate alternative approaches to improving the performance central shaft ventilation systems. The demonstration site is an eight story apartment building that contains several centralized ventilation shafts with nearly identical configurations. In total, three shafts will be instrumented to continuously monitor the amount of ventilation each apartment is experiencing. One of these shafts will be the comparative baseline representing an existing and unaddressed scenario. The other two shafts will be retrofitted with two potential improvements; **(1)** orifice plates and a balanced commissioning or **(2)** shaft sealing and constant airflow registers. We expect to see significant performance improvements, both in reduced energy use as well as more consistent ventilation.

FIGURE 3: PRELIMINARY OUTPUTS OF 6 STORY SIMULATIONS

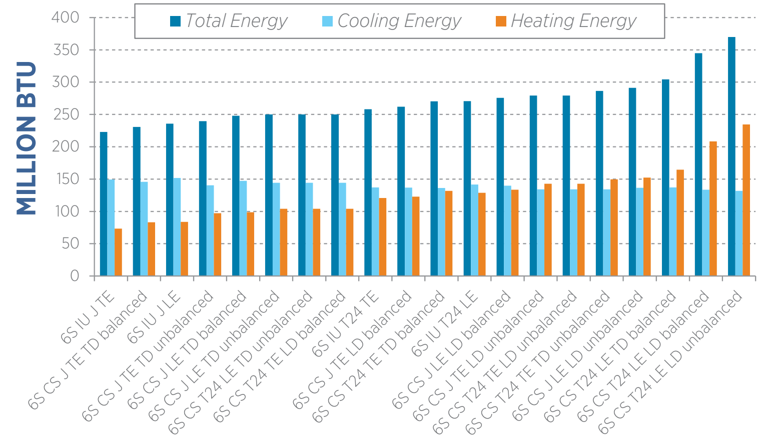
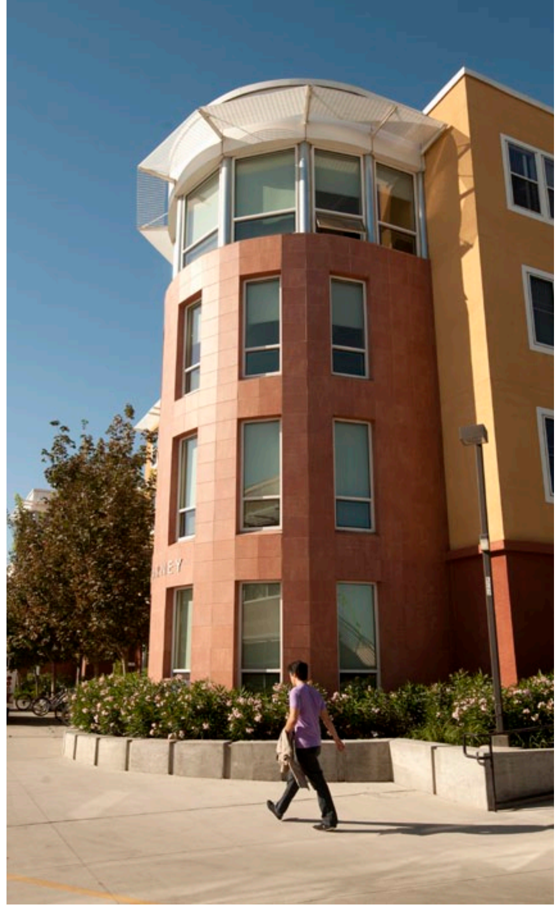


FIGURE 3[1]: BUILDING MODEL NOMENCLATURE KEY

LABEL	DEFINITION	DESCRIPTION/DETAILS
6S	Number of Stories	6S = 6 Stories
CS	Ventilation system type	IU = Individual unit CS = Central Shaft
J	Ventilation Rate Specification	T24 = Title 24 (ASHRAE 62.X) J = ASHRAE 62.2 addendum j
LE	Envelope Leakage	LE = Leaky Envelope (0.35cfm/ft^2)* TE = Tight Envelope (0.2cfm/ft^2)*
LD	Duct Leakage	LD = Leaky Duct (25%)** TD = Tight Duct (5%**)
unbalanced	Commissioning	unbalanced balanced

** ft^2 refers to total envelope area including walls, floor, & roof*
*** % refers to percentage of total flow that is due to leakage*



OCCUPANCY RESPONSIVE ADAPTIVE CONTROLS

Field study of adaptive thermostats in 4 residence halls at UC Davis

Occupancy sensing thermostats have the capability to adjust temperature set-points or ventilation system operation when a space is vacant. Adaptive control algorithms can use occupancy state, user feedback, and measure environmental variables to learn about use patterns, occupant comfort preferences, and system dynamics. This information can be used to adjust operating schedules, and to automate temperature settings during occupied and vacant states. These capabilities, coupled with networked control, and internet-based user interfaces, promise a variety of energy efficiency opportunities while at the same time improving comfort and level of service.

Conventional programmable thermostats are often setup with inappropriate schedules and set-points. Some facilities are 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. Although occupancy sensing thermostats are relatively new to market, they have made significant inroads in hotels, where room occupancy is low, and schedule predictability is low.

Not all occupancy sensing controls are equal. Some technologies apply adaptive algorithms while others rely on fixed programs with user-managed inputs. Some technologies will evolve operating schedules and predict the duration of vacant periods, while others only switch modes once occupancy is recognized. Further, products in this sphere incorporate a smattering of other useful features that are neither adaptive, nor occupancy responsive. For example, these devices may limit the range that a tenant is allowed to adjust set-points, or they may extend fan run-time after conclusion of a call for cooling in order to extract additional thermal energy from a coil. It is difficult to establish a baseline against which these technologies should be compared, and complicated to decouple what savings should be attributed to one feature or another.

Importantly, the energy savings impact for these technologies should differ significantly by application, by climate zone, and by season. Obviously, an assembly hall or conference room would benefit more than a retail facility. Less obvious, when a building has separately controlled zones, a temperature set-back in one zone may increase load in adjacent zones. These dynamics should be considered in any prediction of energy savings for the technology.

FIELD RESEARCH

Since 2011, WCEC has been collaborating with UC Davis Student Housing to observe and assess the impact of an occupancy responsive adaptive thermostat system installed in the University's residence halls. The product studied is the Telkonet EcoInsight™ which incorporates an array of features, including networked controls that allow facility personnel to manage and schedule thermostat settings in all rooms from a robust web interface. The technology has now been installed in every residence hall on campus.

Telkonet applies a learning algorithm called Recovery Time™ which continually adapts the set-back temperature for vacant periods such that a room can recover quickly upon the occupant's return. Facility managers select an acceptable recovery time, and the thermostat learns how quickly the 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. Further, the set-back response is tiered such that after a long period of vacancy, temperature is allowed to drift even further.

We believe that occupancy responsive adaptive controls hold potential for great energy efficiency improvements, but that savings is very sensitive to application

WCEC's study has focused on the measured system dynamics and chilled water energy consumption in four high rise residence halls in the Segundo complex. Analysis thus far covers operation in the cooling season and has revealed some fascinating results. Principally, we note that the technology enables a substantial reduction in room fan coil run-time during vacant periods. In fact, for the period of study in Bixby, fan coils operated on average 25% of the time in occupied rooms, while fan coils in vacant rooms remained off near entirely. However, the pre-post comparison of data records does not indicate a significant reduction in whole building chilled water energy consumption.

WCEC is compiling a paper and report on this study, which thoroughly explores the dynamics that may contribute to a mismatch between room fan coil run-time and whole building chilled water consumption. The effort employs a linear break point regression model to describe chilled water energy consumption during pre and post-retrofit periods in each building. As recommended by ASHRAE Guidline 14 "Measurement of Energy and Demand Savings", these regression models are used to compare a projected baseline energy consumption against the energy use measured after the technology was installed.

To complicate matters further, while the study does not indicate chilled water energy savings during the academic year, we do observe a clear relationship between vacancy and reduced chilled water energy consumption. This is especially apparent during the non-academic period, when the buildings are only used occasionally for conference housing. It is not clear what portion of this reduction can be attributed to the occupancy sensing function, and what portion may be related to reduced thermal loads associated with building use and occupancy.

Following on the conclusions of the effort thus far, further research aims to measure energy impacts during the heating season, and to better isolate for the impact of the occupancy responsive adaptive control algorithm, separate from other thermostat features. Additionally, we aim to incorporate a modeling aspect to this work which may better explain the apparent mismatch between fan coil run time and whole building chilled water energy consumption. We believe that occupancy responsive adaptive controls hold potential for great energy efficiency improvements, but that savings is very sensitive to application, and that any effort to advance the technology more broadly should be considerate of these differences.

LIGHT COMMERCIAL & RETAIL

FAULT DETECTION & DIAGNOSTICS

Increase efficiency through maintenance awareness

Remote and automated Fault Detection and Diagnostic (FDD) tools have the potential to save considerable energy in existing commercial rooftop air conditioning units (RTUs). However, the market for these systems has not yet materialized. Tools have been available for larger systems for some time, although even these have not enjoyed a significant market share. For RTUs, there are still fewer tools available, and little to no market share. Since RTUs cool about 60% of the commercial square footage in the United States, they are a significant source of energy consumption and peak demand. Under the best of circumstances, RTUs are not as efficient as larger built up systems. However, in reality, they are even less efficient than that. Many market failures have led to a lack of quality in installation and maintenance of these units, and performance is suffering. Many RTUs have some sort of faulty operation that is increasing their energy use. If these faults could be found and addressed, then significant energy savings could be realized.

WCEC has conducted a study of the use of FDD on RTUs. The objectives of WCEC's research into FDD:

- » Summarize input from industry stakeholders on desired capabilities of FDD tools and service models for making best use of FDD tools.
- » Identify appropriate technology for detecting and diagnosing faults in commercial building RTUs. This is achieved by cataloging the faults that occur in RTUs and their energy performance impact and frequency. A set of criteria are developed for the attributes and a desired approach must have a relatively high chance of success in the market place, or to be successfully implemented in California's Title 24 energy code. The potential approaches are evaluated according to these criteria and potentially successful approaches are identified.

- Define the requirements for tools in each category in our framework, by analyzing the types of tools that would be found in each category. We sought out examples of FDD tools that are available on the market and categorized these tools. We also determined what faults each can identify, and what kinds of data are required for each tool.
- Describe the process of gaining industry input on the implementation of FDD by developing a mock-proposal for incorporating FDD in Title 24 and holding an FDD Industry Roundtable workshop, with key stakeholders.
- Outline the analysis used to determine how much energy could be saved in California RTUs by using FDD tools, and the cost-effectiveness of this use.
- Describe an industry-centric consensus approach to develop a draft FDD requirement for the 2013 version of California's building code, submit this measure, support its adoption, and provide whatever follow-up is needed post-adoption to ensure field compliance.
- Describe a process of developing laboratory methods of testing RTU FDD, through an ASHRAE standards process.

We worked closely with industry to develop and support an FDD measure for California's Title 24 for 2013 which is palatable to manufacturers and cost effective for customers. To prepare for this, we interviewed contractors to learn something about the requirements for FDD tools. We developed a framework for describing the tools that deliver FDD, evaluated the different approaches according to a set of criteria we developed. We identified the tools that were available in 2010 and estimated the energy savings and cost effectiveness of various FDD measures. We worked closely with manufacturers, including large HVAC OEMs and smaller third-party developers to review the draft Title 24 proposal, and made various changes to improve the measure. We submitted the proposed language to the CEC and the requirements were adopted. Finally, we are involved in developing an ASHRAE Standard Method of Test for RTU FDD.

Since inserting requirements for FDD into California's building code, the International Code Council has included the same requirements in the proposed International Energy Conservation Code. ASHRAE's Standard 90.1 Mechanical committee is also considering FDD requirements for future versions of ASHRAE Standard 90.1 Energy standard. Although the requirements have been adopted in the California Building Code, work on this measure is not complete. Through the WHPA FDD Subcommittee and other industry actors, the requirements will be supported by:

- Making manufacturers and end users aware of the measure.
- More clearly defining the requirements in the measure.
- Developing a certification program (leveraging ASHRAE efforts for standardization).
- Creating acceptance tests (field verifications).
- Conducting behavioral work to ensure that functionality is enabled in the field and that alarms are heeded and acted upon.
- Researching fault incidences by collecting field data.
- Proposing reach code FDD requirements that go well beyond the mandatory measure adopted.

LEARN MORE ABOUT THIS RESEARCH:
GOT WCEC.UCDAVIS.EDU FOR THE FAULT DETECTION AND DIAGNOSTICS CASE STUDY

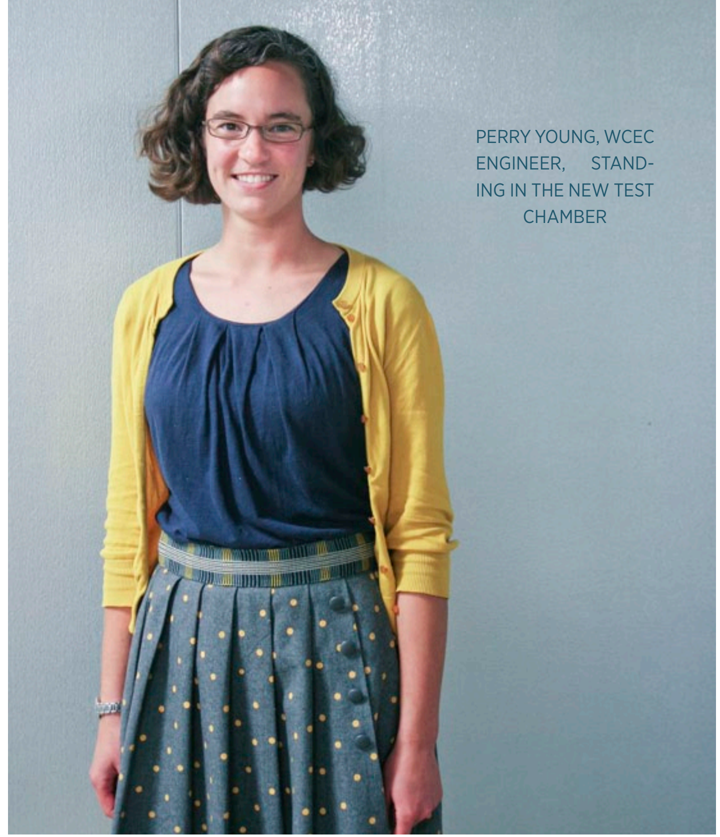
DEVELOPMENT OF A LABORATORY TEST PROTOCOL FOR CONDENSER AIR EVAPORATIVE PRE-COOLERS

Creating benchmarks to objectively assess performance of evaporative pre-coolers

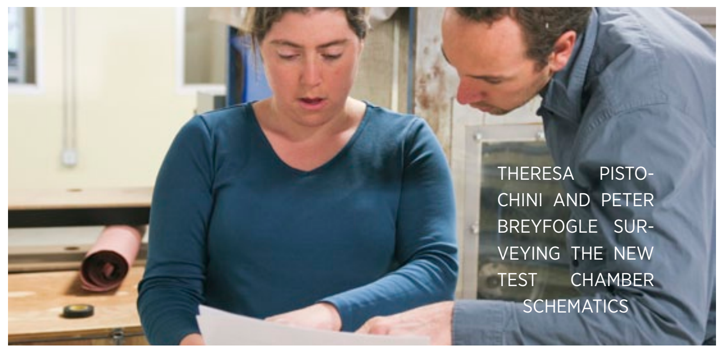
Evaporative pre-coolers are available to retrofit air-cooled air conditioning systems often used in residential and light commercial sectors. These systems operate by evaporating water into the condenser air stream, cooling the incoming condenser air. This pre-cooling of the condenser air stream allows the air-cooled system to perform more efficiently. Evaporative condenser-air pre-coolers are of special interest in dry arid climates such as those in the western United States.

While there are well-established test standards for rating the performance of air-cooled systems, a test standard to objectively compare the performance of condenser-air evaporative pre-coolers is not available. Establishing a specific protocol for measurement of evaporative pre-cooler performance allows end-users and utilities to make objective comparisons between products. Without such a standard, each developer will evaluate their product differently in a way that puts their product in a better light. Since this technology is growing in the market, and utilities are interested in a methodology to determine values for rebates and deemed savings, it is imperative to put a standard protocol in place.

WCEC developed the first draft of a laboratory test protocol and objectively tested three evaporative condenser-air pre-coolers. Various methods to measure and analyze performance were tested in order to determine the most reliable and accessible way to measure and analyze the performance of the pre-coolers. The pre-coolers tested were designed to be installed on small air-cooled air conditioning units often used in residential and



PERRY YOUNG, WCEC ENGINEER, STANDING IN THE NEW TEST CHAMBER



THERESA PISTOCHINI AND PETER BREYFOGLE SURVEYING THE NEW TEST CHAMBER SCHEMATICS light commercial environments. Each design can easily be installed on an existing air conditioning unit, and each design employed a slightly different water delivery method. Pre-cooler A utilized nozzles with a flat spray pattern that sprayed directly onto the condenser coils (Figure 1, left). In this test, the water spray was partially blocked by the exterior grate of the air conditioner which partially covered the condenser coil. One nozzle was installed on each of the two larger sides of the condensing unit. Pre-cooler B utilized a fiberglass filter media that wrapped around a small condensing unit (Figure 1, middle). A spray manifold with three nozzles created a mist of water droplets surrounding the condensing unit. The application tested used one manifold on each of four sides for a total of 12 nozzles. Pre-cooler C utilized an airflow-actuated valve on top of the condensing unit; when the fan turned on, water sprayed from three nozzles into the air stream, one on each of three sides of the condensing unit (Figure 1, right). The coil was not protected from water droplets.

Tests were conducted with each design in order to calculate the coefficient of performance (COP) of the retrofit air conditioning system. Coefficient of performance is a metric representing the ratio of cooling capacity provided by the air conditioner over the power delivered to the unit. A higher COP indicates that the unit is performing more efficiently. It was found that all three units performed more efficiently with the retrofits than without the retrofits installed (Figures 2). The three pre-coolers tested all showed a general trend of increasing performance improvement with increasing wet bulb depression, which is the difference between the dry bulb and wet bulb temperatures of the outdoor air. A larger wet bulb depression indicates drier air conditions and allows for greater impact of the pre-cooler. The products tested had modest energy efficiency benefits and should not be interpreted to represent the range of all products available. Field tests of products not tested in this laboratory test show efficiency increases in the range of 20-30%.

An equivalent performance method was developed in order to determine the temperature drop in the air entering the air-conditioner. This is a very

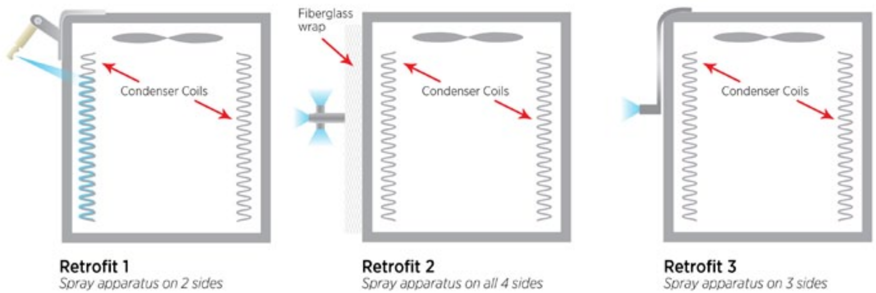


FIGURE 1: RETROFIT DESIGNS

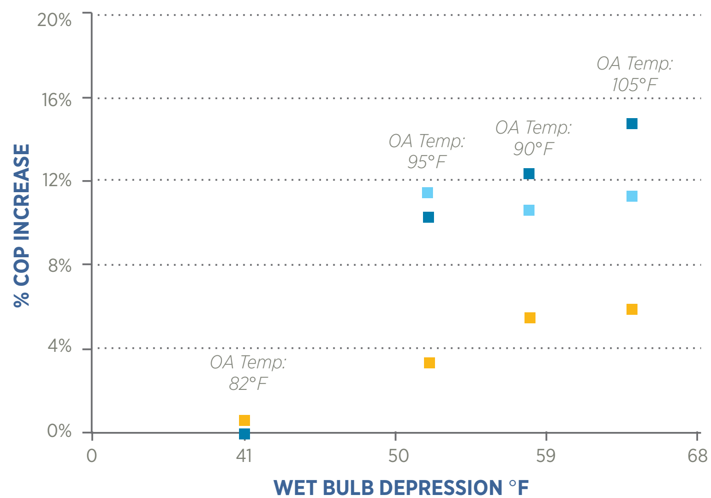


FIGURE 2: % COP INCREASE WITH RESPECT TO WET BULB DEPRESSION FOR ALL THREE PRE-COOLERS

difficult metric to measure because of the water vapor in the air as a result of the pre-cooling process; when water vapor lands on a temperature sensor, it may evaporate and therefore cool the sensor, which causes it to report a lower dry bulb temperature than there actually is. In addition, the air is not well mixed, making it difficult to pick a location for the temperature measurement. The equivalent performance method assumes that the air-conditioning unit performs comparably for the two following scenarios:

- The outside air temperature is 86°F and there is no evaporative pre-cooler installed, or
- The outside air temperature is 104°F, the installed evaporative pre-cooler cools the air to an average of 86°C, and supplies this air to the condenser coil

Using this assumption, it is possible to back out the temperature of the air after leaving the pre-cooler apparatus but before entering the condenser coil as shown in Figure 3. In this figure, the baseline performance represents the performance of the unit before the pre-cooler apparatus was installed. The test result with pre-cooler performs more efficiently. The temperature leaving the pre-cooler apparatus but before entering the condenser coil is indicated in Figure 3 by $T_{dB,equivalent}$ which represents the temperature on the baseline curve that has a performance equal to that of the test result with the pre-cooler. The difference between $T_{dB,test\ point}$ and $T_{dB,equivalent}$ is the cooling delivered by the pre-cooler.

Using this novel method to calculate the temperature delivered by the pre-cooler offers a high-accuracy objective method to compare pre-cooler performance. The pre-cooler results can be used to calculate potential energy savings using building energy consumption data and climate modeling.

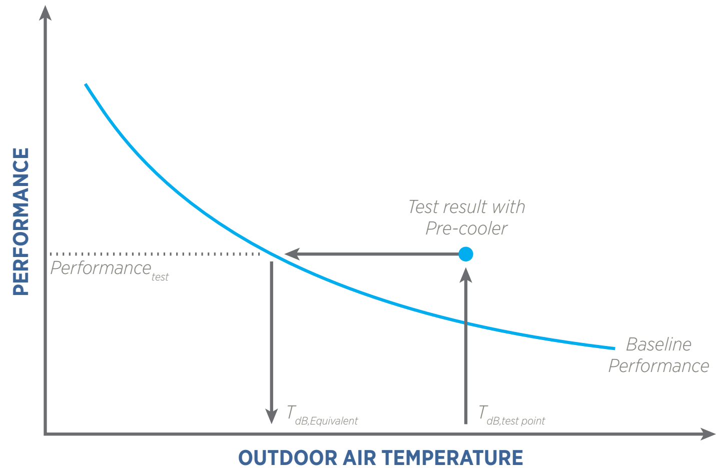


FIGURE 3: EQUIVALENT PERFORMANCE METHOD

FUTURE WORK

This work has informed a committee of members of the American Society of Heating and Air-Conditioning Engineers (ASHRAE) that is working to formalize the protocol as an ASHRAE method of test. WCEC is currently building a new environmental chamber for testing HVAC equipment and associated retrofits up to 5-ton capacity. The chamber will have the capability to replicate outdoor air conditions representative of a large range of weather conditions, including the hot and dry air conditions observed in the western United States. This laboratory is expected to be operational in the fall of 2013. Initial testing is planned for a 4-ton roof top air conditioning unit with evaporative pre-cooling retrofits. These tests are expected to provide further information about how to refine the test protocol, and also to provide information on the viability and effectiveness of these pre-cooler retrofits.

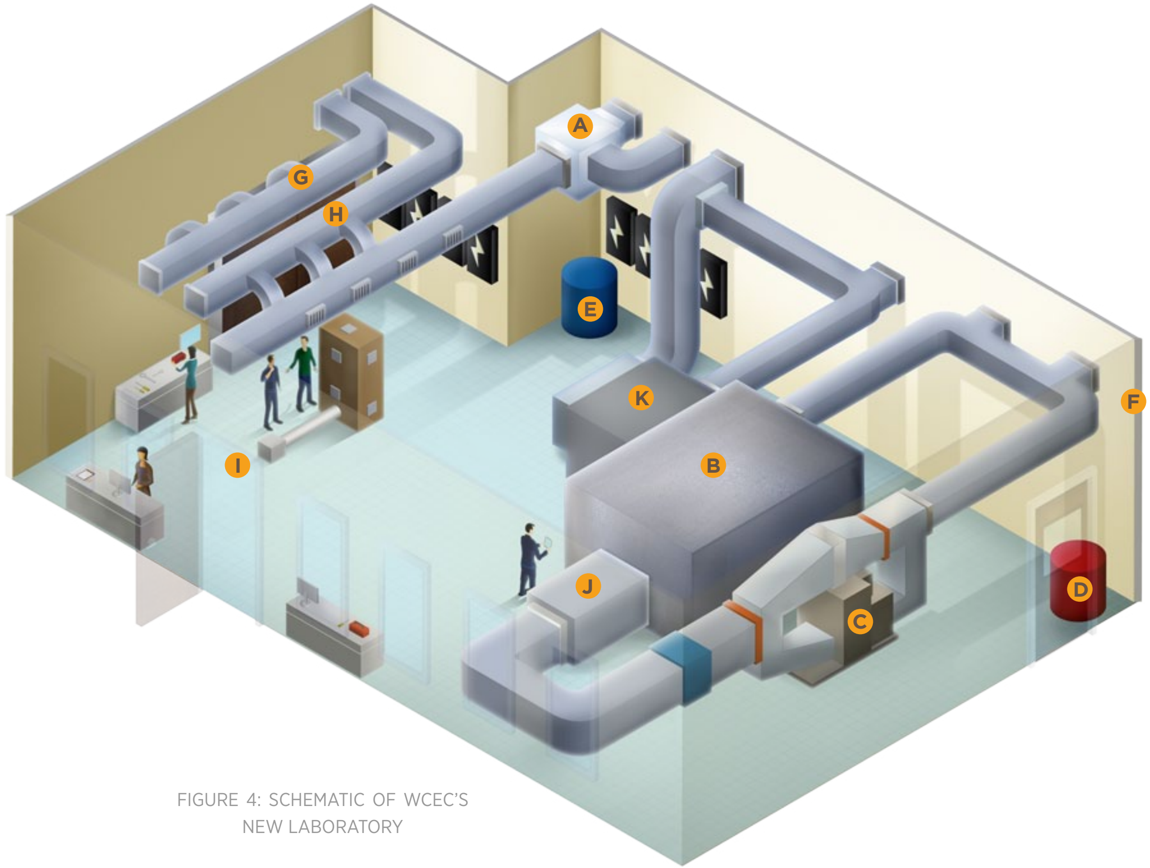


FIGURE 4: SCHEMATIC OF WCEC'S NEW LABORATORY

A. *Coolerado® C60 IDEC to cool the lab*
B. *Hot side test chamber*
C. *MUNTERS® HCD-4500 dessicant dehumidifier*
D. *Process hot water buffer tank*
E. *Process chilled water buffer tank*
F. *General laboratory exhaust (not pictured)*
G. *Outdoor air Intake for test stations*
H. *Test station exhaust*
I. *Test stations*
J. *Flow nozzle airflow measurement*
K. *Cold side test chamber*

ADVANCED SYSTEM CONTROLS BEHAVIORAL RESEARCH

Assessing the everyday usage efficacy of advanced thermostats

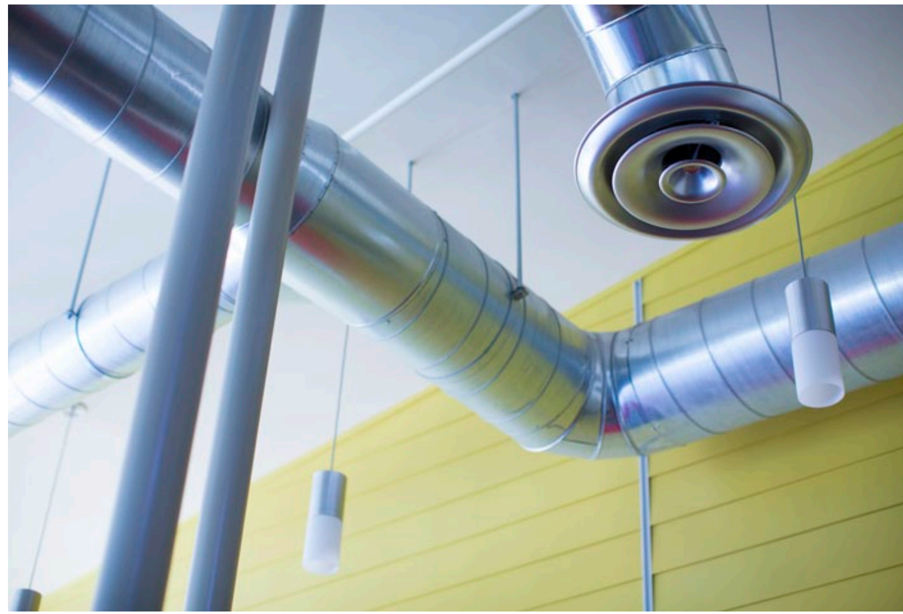
In this study, participants will respond to surveys and conduct assigned tasks related to the use of newly installed advanced thermostats in their workplace. The thermostats differ from traditional programmable thermostats in their increased usability and functions, and access to a thermostat web portal, through which thermostats can be remotely controlled. As with most technologies, thermostats often have a learning curve. Negative first impressions with the technology can be lasting, and decrease motivation to adapt and even interact with the new technology. Confusion or mistakes made at the beginning of the interaction with the thermostat can affect long term usability.

The study's goal is to evaluate users' interactions with the new advanced thermostats, and compare those with users' interactions with the more traditional thermostats they had been using so far. We assume that each thermostat may be used by more than one person. The study is now in early stages of data collection in three commercial settings: a private elementary school, a golf clubhouse, and a restaurant.

In this report we describe the methodology of the study, and a few preliminary results from the initial evaluation survey.

INITIAL EVALUATION SURVEY

Before installation of the new thermostats, researchers conducted a first survey of occupants of the areas to be controlled by the new advanced thermostats. The survey was conducted online. This survey assesses responses of users to their prior thermostat, and will provide a baseline of user past experience with thermostats, to be later compared with user experience with the newly installed thermostats.



The first survey addressed the following issues:

- **Perceived product usability:** The ease with which users can manipulate the current ("old") thermostats
- **Perception of efficacy:** Users' perceived effectiveness of the thermostats in doing what the occupants want to do
- **Perceived value:** The monetary worth and other non-monetary value that occupants assign to the thermostats
- **Barriers to use:** Technical and non-technical aspects of thermostats which make them difficult to use effectively
- **Comfort:** Self-report of thermal acceptability using sensation (very cold > very hot) and comfort (very comfortable > very uncomfortable) scales
- **Recommended features for potential new thermostats:** new features, features to be eliminated, features to be modified.
- **Intent to adopt:** assessment of whether or not the occupant would buy the same thermostat in the future, at what price and in what context.

TESTING USABILITY VIA TASKS AND DISCUSSION BOARD

After installation of the new thermostats a subset of the participants will be interviewed to assess their initial perceptions and use of the thermostats on site. This subset of observations will provide a first screening of usability problems and experiences of satisfaction or frustration. In addition, all participants will have been encouraged to submit any comments or issues they have with the thermostat to the researchers. Participants will be able to do so via email or using a discussion board set up specifically for the study.

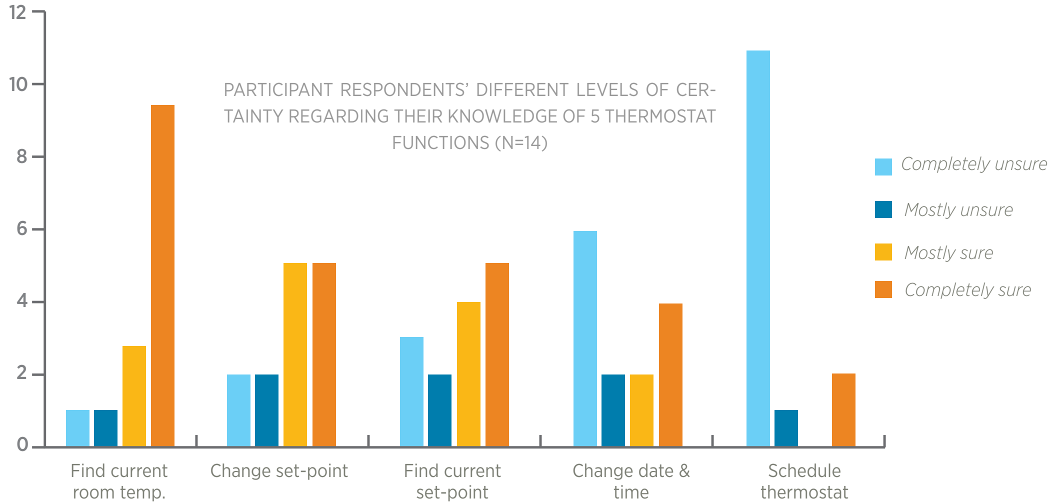
At this point of data collection, new thermostats have been installed in one of the three commercial settings chosen, and participants have already reached out to the research team (via email) to make comments about issues with the new thermostats.

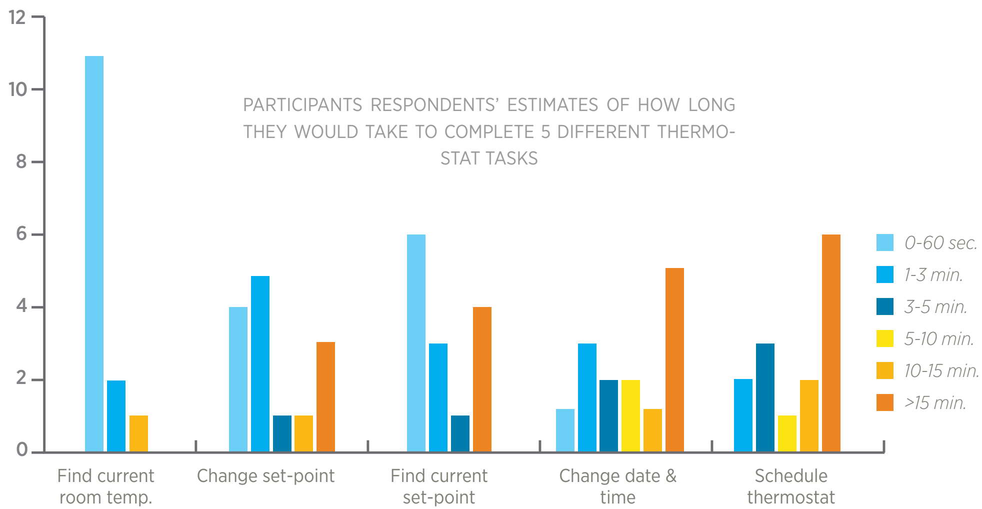
Most of the usability testing in this study will be conducted via an online discussion board for study participants. At different points throughout the study period (approx. every three weeks), the research team will post thermostat task requests (for example "set the thermostat to a 65 degrees set-point for the next two hours) and participants will be able to post the results of their attempt, discuss difficulties they had completing the task, questions they have, and solutions they found to complete the task requested. Users will also be encouraged to post experiences, positive or negative, that they may have while using the newly installed thermostats, including problems with comfort. Users will be asked whether they are sure they accomplished the tasks successfully. Since researchers have access to the thermostat actual functioning logs, participants' responses will be contrasted with actual thermostat changes.

Tasks assigned to participants will include the following operations:

1. Read and report thermostat display (current temperature, set-point, time and date)
2. Turn thermostat on and off
3. Change time and date in thermostat
4. Confirm that time and date in thermostat have changed and are correct.
5. Create a thermostat schedule for usual occupation periods.
6. Override the thermostat schedule for a temporary period.
7. Schedule the thermostat to turn on during a one-time-only 8 hour period during the weekend, when it would usually be off ("special event").

Depending on the situation at different locations, tasks may also include creating and accessing the online web portals.





FINAL EVALUATION SURVEY

After some time, users should have become stabilized the use of their thermostats. At this point, we will again survey all of the users who received new thermostats and participated in the study using the same set of measures used in the survey for the "old" thermostats, and adding new questions regarding the learning curve, operations through the web portal and comparisons with the old thermostat. Satisfaction with the old thermostats will be compared with satisfaction with the new thermostat, and satisfaction with the new "standard" thermostats will be compared with satisfaction with the advanced thermostats.

Throughout this time, we expect that each participant will be required to use at most five hours addressing study related activities, as detailed below:

» 30 minutes initial survey
» 30 minutes per thermostat task assigned. (Maximum of 4 tasks = 120 minutes)
» 30 minutes board reporting and discussion per task assigned (Maximum of 4 tasks = 120 minutes)
» 30 minutes final survey

PRELIMINARY RESULTS

At this early stage of data collection, data analysis would be superfluous, but it may be interesting to note that, consistent with other findings, participants seem to be knowledgeable only about very basic thermostat functions (see clear differences between easy tasks, like reading current temperature, and "hard, energy saving" tasks, like scheduling the thermostat). More initial survey data is available by request, but full analyses will only be conducted when data collection at all stages is completed.

MULTI-TENANT LIGHT COMMERCIAL

Working to increase energy efficiency in the largely under-served mixed-use retail market

WCEC is working to address the traditionally underserved marked termed Multi-Tenant Light Commercial (MTLC). MTLC buildings are defined as having 2-25 small tenants and are owned by a single landlord. Example of MTLC buildings are strip malls, office parks and mixed use properties. Retrofitting these buildings represent a real challenge for several reasons. Low access to capital, principal-agent problems, short-term leases, and a large variety of end-use types are some of the barriers identified for this market.

Together with CLTC and EEC, WCEC is adopting an integrated approach that tackles lighting, envelope and HVAC in MTLC buildings. Goal of this project is to reduce energy and peak consumption of these buildings by at least 30% in an economically effective way.

The project is now pursuing two goals:

(1) COLLECT BETTER INFORMATION ON MTLC BUILDINGS

Available information on MTLC buildings is unreliable and incomplete. WCEC together with EEC and CLTC collected field data on MTLC buildings that include physical characteristics of the buildings, technology currently installed and energy use. Energy audits in more than 50 commercial MTLC buildings in California are planned to be completed by the end of the summer. Energy audits have been performed in partnership with California Conservation Corps (CCC). Corps members have been trained by WCEC, CLTC and EEC staff at the beginning of the summer and sent to different locations in Northern California to perform ASHRAE level 1 audits and collect energy bills and smart meter data. Data will be transcribed and analyzed during the fall. In addition, WCEC is monitoring several technologies of interest for MTLC buildings through other concurrent projects. HVAC controls, evaporative pre-coolers, hybrid evaporative units, advanced RTU retrofit kits and duct sealing are among these technologies.

The MTLC project aims to reduce energy and peak consumption by at least 30%.

CALIFORNIA CONSERVATION CORPS WORKER TRAINING FOR THE MTLC PROJECT AT UC DAVIS

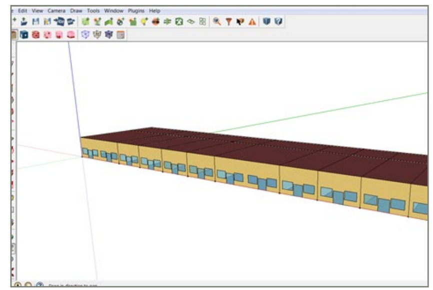
(2) SELECT TECHNOLOGIES FOR RETROFIT PACKAGES

When several retrofit technologies such as lighting, controls and HVAC are installed in the same building, their potential interaction must be considered. WCEC is modeling the interaction of these technologies using several simulation software tools: Energy Plus, Open Studio, JEPlus and R. Technologies are grouped into packages and each retrofit package is tested against the others in different scenarios. Several variables influence the baseline including climate zone, orientation of the building, geometric characteristics, envelope and existing equipment. Several thousand simulations are run and an optimization tool finds the packages that maximize the return on investment or the amount of energy saved.

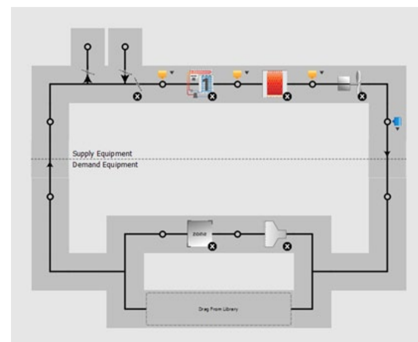
PATH FORWARD

WCEC will be analyzing field data this fall to calibrate simulations. The overall performance and cost of different packages will be further analyzed and verified. Once the performance and cost analysis research is finalized, WCEC, EEC and CLTC will work with manufacturers and utilities to help craft economically viable, energy efficient turnkey packages for the MTLC market.

CCC CREW MEMBERS IN THE FIELD



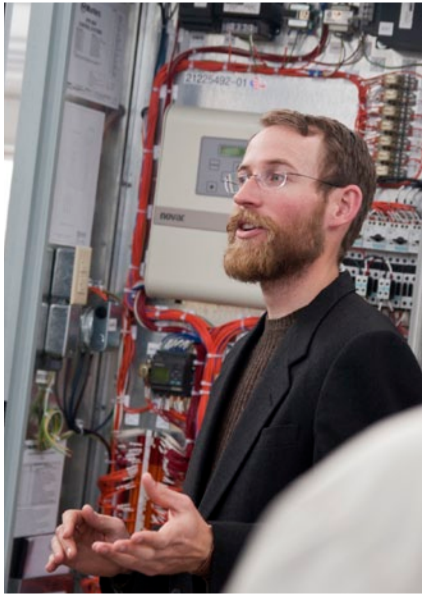
MTLC BUILDING SIMULATION IN ENERGY PLUS



HVAC LOOP SIMULATED IN OPEN STUDIO

WESTERN COOLING CHALLENGE

JONATHAN WOOLLEY, WCEC ENGINEER, SPEAKING AT PG&E'S LAB ABOUT THE WESTERN COOLING CHALLENGE'S NEW ENTRANT, THE MUNTERS EPX 5000



Climate-appropriate air conditioning systems capture substantial energy savings at peak

Cooling and ventilation can account for more than 50% of the summertime peak electrical demand from commercial buildings. Rooftop packaged air conditioners are predominantly responsible for this load. Energy saving features such as variable speed fans and multi-stage compressors promise substantial reductions for annual electricity consumption from rooftop air conditioners, however, since all components must operate at full tilt during peak periods, they do not offer significant savings when electrical demand reduction matters most.

The Western Cooling Challenge advances development and commercialization of climate-appropriate air conditioning systems that capture substantial energy savings at peak. Recognizing the public benefits of reducing sate wide peak electrical demand, The California Public Utilities Commission Energy Efficiency Strategic plan calls for a market shift toward climate appropriate air conditioners. Climate appropriate cooling technologies may take any format that works in concert with local meteorological conditions to achieve savings over code minimum equipment. However, all of the technologies currently advanced through the Western Cooling Challenge utilize some form of indirect evaporative cooling, usually in combination with a vapor compression system.

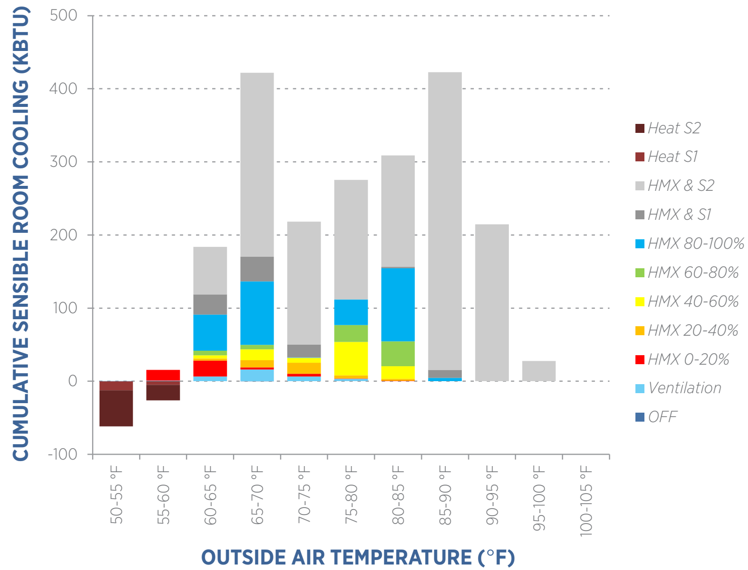
The Western Cooling Challenge has been in motion since 2008, and quickly drew the first formal entry from Coolerado. That equipment, the Coolerado H80 surpassed Challenge performance requirements by a large margin – laboratory testing indicated 65% energy savings at peak cooling conditions.

In 2012 and 2013, the Western Cooling Challenge has made significant strides and seen growing participation from multiple manufacturers. Notably, WCEC has recently completed laboratory testing of hybrid unitary equipment from Trane and Munters. In collaboration with these and other manufacturers, we are studying the performance of roughly 30 pilot systems installed with various customers throughout California. While the Challenge initially focused on characterizing performance for packaged hybrid rooftop units, study has expanded to evaluate various other climate appropriate methods for commercial cooling. This includes indirect evaporative dedicated outside air systems designed to cover the ventilation cooling load for a whole building , and indirect evaporative coolers installed as retrofit additions to existing rooftop air conditioners. The sections that follow outline a handful of our current work with specific technologies.

COOLERADO H80

Two summers of data from the Coolerado H80 installed in light commercial settings show efficiency that is about 25% improved over baseline measurements when outside air temperature is above 95°F. Following installation of the first of these units, UC Davis worked extensively with the manufacturer to troubleshoot a number of control related troubles, but since that time both systems have functioned reliably.

Notably, we found that the indirect evaporative cooling component covered a significant portion of the total cooling load through the year. For mild conditions (below 85°F) roughly 40% of the room cooling load was covered without compressor operation at all. When compressors did operate, indirect evaporative cooling provided 30-60% of the cooling capacity – load that the compressors did not have to carry. Although the Coolerado H80 supplies more than the code minimum amount of fresh air, it was always able to carry the entirety of ventilation cooling loads, even at very high outside air temperatures.



AMOUNT OF COOLING DELIVERED BY EACH STAGE OF THE COOLERADO H80'S SYSTEMS BASED ON OUTSIDE AIR TEMPERATURE.

HMX X-X%: INDIRECT EVAPORATIVE ONLY COOLING AT A PERCENTAGE OF SUPPLY AIRFLOW

HMX & S1 OR S2: INDIRECT EVAPORATIVE COOLING COMBINED WITH COMPRESSOR STAGE (S1: STAGE 1, S2: STAGE 2)

The most significant operational difficulties observed through these pilots were related to unanticipated loss of cooling capacity after the indirect evaporative heat exchanger dried out. Coolerado's current systems require that if ever started from a dry state, the heat exchanger must be primed with a surfactant (dish soap) so that the surfaces will wick moisture properly. During the regular operating season, the heat exchanger must remain wet, even during periods when there is no call for cooling. If the heat exchanger dries out, it must be primed with surfactant again, or it will not perform adequately. On occasion, both installations experienced grid water outages for long enough that the heat exchanger dried and lost its wicking prime. This caused the system to operate with reduced capacity until service personnel re-applied surfactant. Coolerado's newest stand-alone indirect evaporative coolers will automatically recover from an unanticipated dry out event, as long as service personnel keep the soap reservoir filled in sequence with regular filter changes.

Overall, we predict that the H80 installed in Davis reduced annual electrical energy consumption for cooling by 10% compared to baseline measurements. This is significantly less than the savings predicted by Laboratory measurements. We attribute the difference mainly to fan power measured for these installations, which was roughly twice what was recorded by NREL in the technical report "Coolerado 5 Ton RTU Performance: Western Cooling Challenge Results" .

TRANE VOYAGER DC

In Summer 2012, WCEC conducted laboratory tests of the Trane Voyager DC. The report, "Western Cooling Challenge Laboratory Results: Trane Voyager DC Hybrid Rooftop Unit" describes function of the factory-integrated hybrid rooftop unit, and documents peak demand savings of more than 40%. This equipment uses the DualCool technology, which provides direct evaporative pre-cooling for condenser air, and circulates evaporatively cooled water through an air to water heat exchanger to cool ventilation air. This strategy reduces ventilation cooling load for the vapor compression system, and improves operating efficiency by reducing condensing temperature.

Trane's participation in the Western Cooling Challenge represents a major step toward California Public Utility Commission's goals for climate appropriate HVAC. In the past several months WCEC has facilitated the installation of five Voyager DC systems for pilot study. Three 12-ton systems were installed in Southern California, one 25-ton system, and one 35-ton system were installed in Northern California. We are currently logging performance data for these systems, and preliminary results indicate savings on the same order as was measured in laboratory tests. Importantly, these pilot installations are allowing an opportunity to learn about the broader range of operating characteristics for the system, in order to best understand annual energy savings potential. For example, while it is clear that DualCool provides significant savings at high outdoor air temperatures, we aim to better describe the tradeoffs between these evaporative components and conventional economizer operating modes at lower outdoor temperatures.

MUNTERS EPX 5000

We are happy to announce that Munters has submitted equipment for evaluation by the Western Cooling Challenge. In collaboration with PG&E Applied Technology Services, UC Davis directed the laboratory testing of the Munters EPX 5000, a 5000 cfm Dedicated Outside Air System, designed to cover the ventilation cooling load for large format commercial buildings. The equipment uses a polymer construction tube-in-flow indirect evaporative heat exchanger, in combination with a multi-stage vapor compression system to supply a constant volume of cooled fresh air ventilation to a space. Notably, the equipment can use return air from the space as working air for the indirect evaporative cooler. Since room air generally has a much lower wet bulb temperature than outdoors, this substantially improves wet bulb effectiveness for ventilation air cooling.

Results from the laboratory tests will be published late in 2013, but preliminary findings are compelling. According to calculated comparisons, using the Munters' technology for the entirety of ventilation air cooling in a large format commercial space should reduce whole building HVAC peak electrical demand by more than 20%. Following on the laboratory test, WCEC is currently facilitating two pilot field evaluations for the technology, both installed at grocery stores in California.

WESTERN COOLING CHALLENGE FIELD INSTALLATIONS AND TESTING OF THE COOLERADO M50 (LEFT) AND THE SEELEY CLIMATE WIZARD CW-H15 (RIGHT) INDIRECT EVAPORATIVE COOLERS

HYBRID RETROFITS – COOLERADO & SEELEY CLIMATE WIZARD

In light of the fact that commercial HVAC equipment has a long operating lifetime, and that energy consumption for cooling is therefore entrenched within existing building infrastructure, the Western Cooling Challenge is seeking to advance climate-appropriate cooling technologies that can be installed as retrofits to existing rooftop packaged air conditioners. Beyond condenser air pre-cooler additions, we are investigating a range of strategies to install indirect evaporative air conditioners that operate in sequence with existing commercial equipment. These indirect evaporative systems can serve cooled air into the ventilation air stream for a standard rooftop unit, or they can deliver air directly to the space in parallel with existing equipment. In both approaches, indirect evaporative cooling can cover ventilation loads very efficiently, and will cover a portion of the room cooling loads. The fraction of room cooling served without compressor operation will depend on the size and number of indirect evaporative coolers, compared to the total cooling capacity of conventional equipment on the rooftop.

The strategy employed for integrating these systems will significantly impact energy savings potential. For example, economizer function must be maintained, since this mode of cooling is still more efficient than indirect evaporative cooling at low temperatures. Through various pilot field studies, WCEC is collaborating with manufacturers, installers, customers, and utilities to explore and compare alternative application strategies. For a restaurant in Northern California, we've facilitated installation of one Climate Wizard, installed with separate supply ductwork to operate in parallel with three existing conventional machines. A pre- and post-installation comparison by PG&E indicated that this retrofit reduced cooling energy consumption during occupied hours by 60%. WCEC is studying the system to characterize equipment performance explicitly, and to assess the implications and success of the control strategy that was installed.

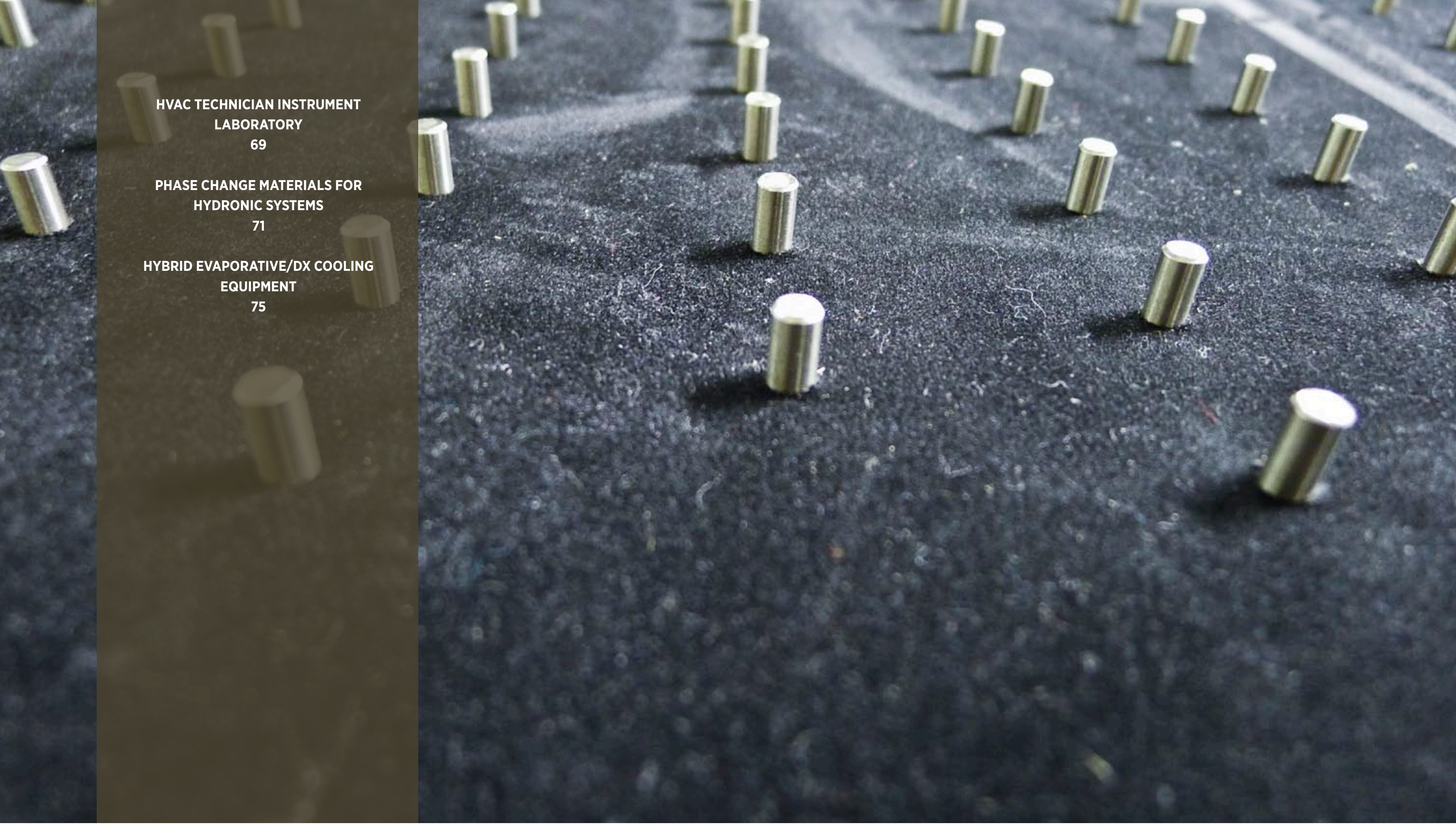
In collaboration with Walmart, WCEC directed the installation of three Coolerado M50 and three Seeley Climate Wizard CW-H15 systems at a store in Bakersfield. For this pilot, the indirect evaporative systems were installed to deliver chilled air through existing rooftop units, utilizing existing ductwork distribution. The equipment was selected to cover the total ventilation rate for the store, and allowed all other rooftop units to operate as recirculation only. To accomplish this, we developed an inexpensive programmable controller that manages when each component in the combined system will operate. All six systems are controlled similarly, which provides an unmatched opportunity to compare field performance for these two innovative indirect evaporative air conditioners.

PATH FORWARD

In the coming year, with support from CEC, Southern California Edison and PG&E, WCEC will turn toward comparing and publishing the performance results from the laboratory and field results currently underway. We aim to collaborate with manufacturers, utilities, trade associations, engineers and contractors to provide educational tools, informational resources, and technical guidelines related to the technologies. We intend that these tools will be accessible and useful to inform customers, installers, policy makers, and the general public about the benefits and tradeoffs of the technologies.

Further, since the broad market adoption of emerging technologies is not solely a technical challenge, WCEC is integrating a behavioral research element into the Western Cooling Challenge program. This effort aims to better understand and characterize the interests and motivations of the market actors and decision makers that play critical roles in the path toward uptake of climate-appropriate cooling technologies. Alongside our pilot field studies that investigate the technical nuances for these machines as applied in various applications, this market research promises to recommend policy levers and market opportunities that California might follow in order to motivate the smart use of climate-appropriate cooling techniques.

A pre- and post-installation field test comparison by PG&E indicated that the Climate Wizard reduced cooling energy consumption during occupied hours by 60%.



CROSS-CUTTING TECHNOLOGY

HVAC TECHNICIAN INSTRUMENT LABORATORY

Quantifying the accuracy of HVAC technician equipment & behavior

HVAC (Heating, Ventilation, and Air Conditioning) systems are fundamental to the comfort of people inside buildings. Consequently, a significant amount of electricity consumption in buildings comes from maintaining this comfort. Some of that energy consumption has less to do with the initial equipment's efficiency, and more to do with how well it's maintained over the useful life of the machine. These systems need to be installed correctly and maintained to operate at optimal performance and efficiency.

One lab study has found that addressing several very common refrigerant and airflow related faults can save over 30% of an air conditioner's energy consumption. This is an important energy-related issue to address because HVAC accounts for 12% of the electricity use and 43% of natural gas use in residential and small commercial buildings.

INSTRUMENT TESTING APPARATUS AT WCEC'S LABORATORY IN DAVIS, CA

Several attempts to address this issue have been made through utility Refrigerant Charge, Airflow, Duct Test and Seal programs, and also through requirements for new buildings in Title 24. However, these initiatives can only succeed up to a point: one recent Evaluation Measurement and Verification study found that only 20-30% of the expected savings were actually achieved. It was suggested in a recent study that uncertainties in instrumentation accuracy could account for at least some of the failure to produce these expected savings.

The current crop of performance measurement tools used by technicians may not be sufficiently adequate. As the "HVAC Energy Efficiency Maintenance Study" shows, technicians can only measure subcooling (SC) and superheat (SH) (basic measurements to monitor refrigerant charge of the AC system) to within about a 4°F range. The contractor generally stops adding charge when the SC or SH is within 3-5°F of the target value, which means the reading can be off by up to 9°F from the optimal temperature, leading to an inaccurate charge.

While ASHRAE publishes a standard for measurement of the required factors in the laboratory (ASHRAE Standard 41), it does not address measurement issues in the field. There is also no third-party evaluation or procedures to evaluate HVAC service instrumentation accuracy, reliability, and usability. Instrument suitability goes far beyond manufacturers' stated accuracy. It also includes the in-field accuracy, ease of installation and calibration, and robustness of the instrument. There are also human factors that go into measurement accuracy, such as methods to install the instrument, measurement locations, and insulation of sensors. The "HVAC Energy Efficiency Maintenance Study" identified the need for research in instrumentation requirements, and called for the establishment of a lab test that will be described here.

The objective of this project is to develop and launch a laboratory test 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
- Provide instrument tests, reach out to the industry to ensure that the research is meeting commercialization needs, and solicit funding from industry entities for subsequent activities

The experimental apparatus for this project consists of a HVAC system operating as if it were installed in a residence or a small business, where technicians from companies and private practices can use their instruments as they would if they were in the field. The accuracy of their measurements will be tested by comparing the values they find to the values acquired by the calibrated instrumentation installed in the system.

This system makes use of a water-to-refrigerant heat exchanger that provides the same heat to the refrigerant line and is an appropriate substitute to a standard residential A/C system that does not take as much space as a conventional air conditioning system would.

The system is provided with several electronic controls that will be used to maintain the desired conditions (95°F condenser inlet air temperature, 80°F evaporator inlet water temperature). Resistance Temperature Detectors (RTDs) are used to monitor water, refrigerant, and air temperatures throughout the system and to control hot water flows.

We have completed construction on the laboratory apparatus and commissioning of the mechanical system and instrumentation. We are currently going through the process of characterizing the dynamics of the system (condensing unit and "evaporator"). We have purchased an initial set of instruments and are currently preparing them for testing. After completing the instrument testing, we will begin with the human factor elements of the tests.

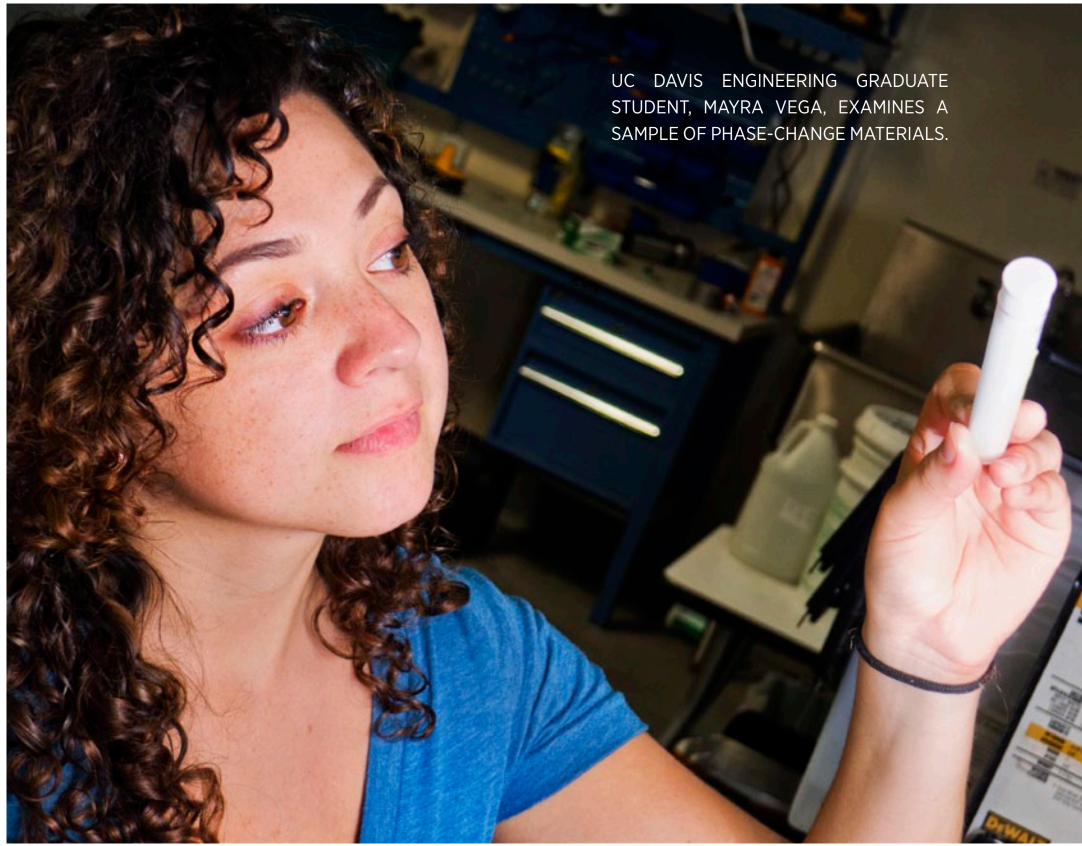
Uncertainties in instrumentation accuracy could account for at least some of the failure to produce expected HVAC savings.

PHASE CHANGE MATERIALS FOR HYDRONIC SYSTEMS

Dramatically reduce pumping power in hydronic systems

This project is investigating the feasibility of adding microencapsulated phase change materials (mPCMs) into hydronic cooling and heating systems to reduce the energy needed to circulate the fluid in the system. The capacity of a hydronic system is primarily a function of the fluid flow rate, the heat capacity, and the temperature differential across the heat exchanger. Adding mPCMs will increase the effective heat capacity of the water, allowing for a reduction in water flow rate while providing the same amount of heat transfer. Since the pumping power is roughly proportional to the cube of the flow rate, reducing the flow rate leads to significant power savings.

The specific heat of water (4.2 kJ/kg/ºC) is low compared to the latent heat of fusion for commercialized PCM beads (up to 180 kJ/kg). As an example, a heat exchanger in a fan coil unit providing cooling with a water temperature differential of 5ºC at a water flow rate of 5 kg/min, the cooling capacity is 1.8 kW. Replacing just 10% of the water volume with mPCMs would deliver the same capacity at a flow rate of only 3 kg/min. This reduction in flow rate of 20% equates to nearly an 80% reduction in pumping power. For the same example heat exchanger in heating mode using water only, the capacity of the system is approximately 3 times greater than for cooling because of the larger temperature differential between the entering water and entering air temperature.



UC DAVIS ENGINEERING GRADUATE STUDENT, MAYRA VEGA, EXAMINES A SAMPLE OF PHASE-CHANGE MATERIALS.

FRENCH FOREIGN EXCHANGE ENGINEERING STUDENT, SAMSON VAYSSEIRES, IN FRONT OF THE PCM TEST APPARATUS HE HELPED CONSTRUCT

Replacing 10% of the water volume with mPCMs would allow a flow rate reduction of 10% and a pumping power reduction of 27%. Commercially available PCM beads have selectable phase change temperatures that would potentially allow this concept to succeed in both cooling and heating applications.

There has long been interest in using PCMs for thermal storage with the current primary focus being on load shifting for peak load reduction. While the only widely available commercial system uses ice as the phase change material, this work has resulted in a significant body of literature on the properties of bulk (or macroencapsulated) PCMs, much of which is relevant to our work here.

PCMs fall into two categories: organic and inorganic. The inorganic PCMs are typically salt hydrates and organic PCMs are typically paraffins and fatty acids.

Based on the properties of the candidate materials, we have been using commercially available PCMs made from paraffin waxes in our tests. The wide range of melting points of the different chain length paraffins make them suitable for use over a wide range of temperatures covering both heating and cooling in hydronic systems

Replacing just 10% of the water volume with mPCMs can reduce pumping power in hydronic systems up to 80%.

The selected mPCMs need to possess thermal and mechanical stability. The mPCMs must be capable of experiencing multiple cycling through a pump with a minimal amount of capsules rupturing. In addition, they should be able to experience multiple thermal cycling without rupturing and without degradation in the thermal properties; specifically the phase change temperature, the degree of super-cooling, and the latent heat. In order to separate thermal effects from mechanical effects, we have been carrying out two separate tests:

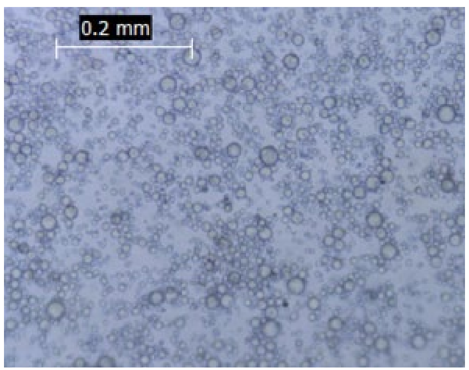
THERMAL CYCLING

Using a freezer and electrical heating tape, we have thermally heated an 8oz container containing a concentrated slurry of mPCMs with a nominal melting temperature of 6°C. Prior to any thermal cycling these mPCMs showed super-cooling of approximately 3°C. This experiment is ongoing, and to date, after hundreds of cycles there is no sign of a shift in the melting point, or in the degree of super-cooling. Microscopy shows no sign of ruptured particles after 100 cycles.

MECHANICAL DAMAGE

mPCMs as a hydronic system technology does face potential challenges, most notably, what kind of damage could they cause to the system. If the mPCMs break, they could foul up the pump from wax released by ruptured capsules, deposition of the wax on the heat exchanger leading to loss of efficiency, and loss of capacity due to the reduced fraction of PCM in the slurry. Previous work has shown varied results but suggest that small particles, with diameters of less than 10 microns, are less subject to damage than larger particles, most likely because of the smaller change in shear forces across the particles.

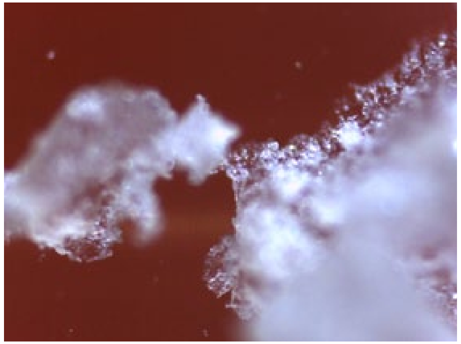
Our test for mechanical damage has involved pumping a slurry containing mPCMs with a range of diameters round a closed loop and periodically removing and examining a sample of the slurry. The images below show clearly that damage has occurred to the PCMs. There is evidence of wax deposited on the impellor, and there are large (up to 1mm) 'clumps' of waxy material deposited in the system.



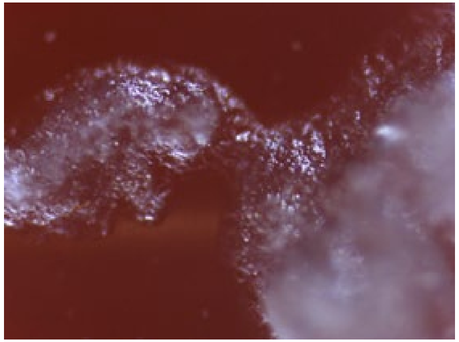
MICROSCOPE IMAGE OF MPCMS AFTER 100 CYCLES SHOWS NO EVIDENCE OF BROKEN CAPSULES

THE IMPELLER OF THE PUMP WITH WHAT SEEMS TO BE WAX FROM BROKEN MPCMS

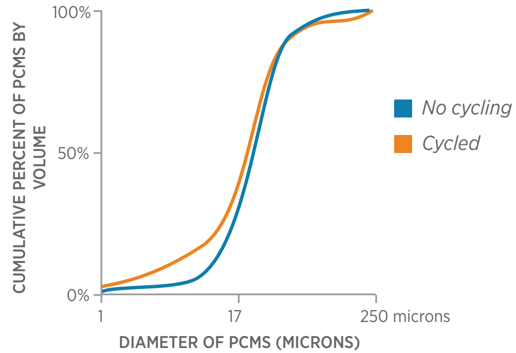
THE MPCMS IN POWDER FORM SHOWN BEFORE THE MECHANICAL CYCLING (LEFT) AND THE CLUMPS FOUND AFTER PUMPING (RIGHT)



MICROSCOPE IMAGE OF WAXY CLUMP FOUND AFTER MECHANICAL CYCLING OF THE MPCM SLURRY



THE SAME CLUMP AS ABOVE AFTER HEATING TO MELT THE WAX—THE UNDAMAGED MPCMS FORMING THE CLUMP ARE CLEARLY VISIBLE



PARTICLE SIZE DISTRIBUTION BEFORE AND AFTER MECHANICAL CYCLING THROUGH A CLOSED PUMPING LOOP

On close examination the clumps appear to be mainly composed of PCM capsules embedded in wax, suggesting that, appearances notwithstanding, the fraction of capsules that have broken is small.

Using a heated microscope stage, images were taken of a clump in the solid form and then after heating above the phase change temperature. The intact capsules can clearly be seen in the molten wax.

To help understand which capsules are being damaged we have made measurements of the particle size distribution using a Laser In-Situ Scattering and Transmissiometry measurement. The graph below shows the cumulative particle size distribution measured before and after cycling through the closed loop pumping system for approximately 3 days. The samples used did not contain any of the clumps, as these were too large for the system to measure. The volume of the loop is approximately 0.5gal and the flow rate is 7gpm, so during the test each capsule would be expected to pass through the pump some 60,000 times.

The graph shows that the cycling has skewed the distribution towards smaller capsules, showing that the larger capsules are being preferentially removed from the slurry. We are currently working to quantify this effect, and to determine what fraction of the particles are breaking and what fraction are being trapped in the clumps.

Summary of current results:

- Microencapsulated paraffin is thermally stable for this application
- Mechanical damage suggests smaller capsules are less susceptible to damage

UPCOMING WORK

In the coming months we will be further studying the effects of capsule size on breakage rates by performing a closed loop pumping test on smaller capsules. We will also study the heat transfer properties of PCM slurries in a hydronic system we have built in our laboratory. The hydronic system contains a slurry loop, in which the PCMs are circulated through an air to water heat exchanger, with the air supply being heated or cooled by the laboratory water supply. By measuring the pumping power, the slurry flow rate, the air flow rate, and the air and water inlet temperatures, we will be able to determine the relationship between slurry concentration, flow rate, heat transfer, and required pumping power.

HYBRID EVAPORATIVE/DX COOLING EQUIPMENT

First principles-based research for effective Indirect evaporative technology progress

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.

ZHIJUN LIU, USING GREEN-DYED WATER TO VISUALLY SEE POINTS OF TURBLENCE AND THE BEHAVIOR OF WATER IN AN INDIRECT EVAPORATIVE EXPERIMENT.

We have continued our work on developing a model for indirect evaporative heat exchangers. The model is intended to be used for heat exchangers made using channels with thin plastic walls. The plates are kept apart, and the channels are kept from collapsing by pins, which also act as turbulence promoters. The simplest manufacturing technique is for the pins to be formed from the same sheet as the plate (Figure 1).

The pressure drop in the channels is caused by a number of effects, which are not independent. At this stage of our research, we are keeping the channel height (spacing between the plates) and channel width constant to minimize the variables to study. In order to remove some of the variability in size/shape that were found in the tapered pins, we have constructed plates with cylindrical pins (Figure 2) that are significantly more consistent.

FIGURE 1: HEAT EXCHANGER WALL WITH TAPERED PINS.

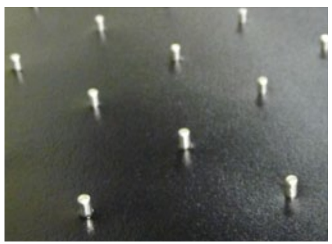
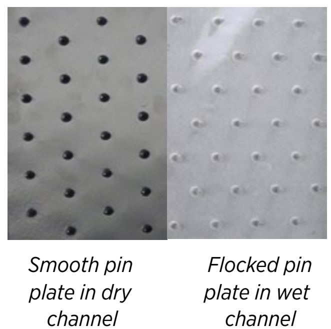
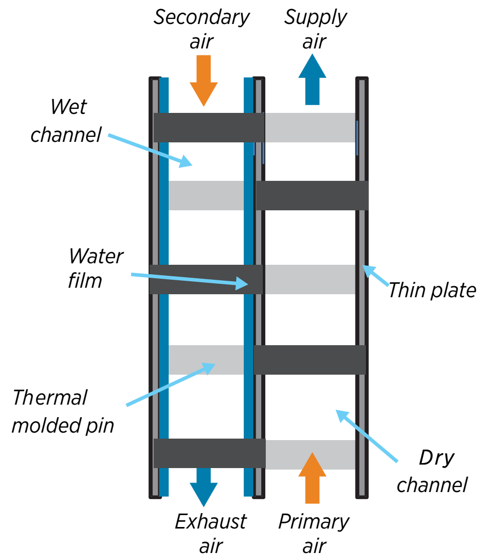


FIGURE 2: PLATE WITH CYLINDRICAL PINS



THE PLATE IN THE DRY CHANNEL IS SMOOTH, WHEREAS IN THE WET CHANNEL THE PLATE IS COATED WITH FLOCKING MATERIAL TO PROMOTE AN EVEN DISTRIBUTION OF THE WATER



SCHEMATIC OF THE GEOMETRY OF THE HEAT EXCHANGER BEING MODELED

EFFECT OF INDIVIDUAL PINS

In a simple model, we can divide the pressure drop into drag caused by two main components: the plates and the pins. The effect of the plates would be proportional to their surface area (all other things being equal) and the effect of the pins would be proportional to their cross sectional area. As the number and size of the pins increases, their effect becomes larger and the effect of the plates is reduced. However, this picture is complicated by the way in which the flow around the pins is disrupted (Figure 3).

There is a quiescent area, or 'shadow', in the flow behind each pin, which will have the effect of reducing the effective area of plate surface over which the air is flowing. The size of this area will depend on the flow rate and the pin size. This effect is further complicated by the proximity of other pins: if the pin spacing is such that subsequent rows of pins fall in the shadow their effect on flow will be smaller than that of wider spaced pins. In order to understand the importance of this effect we are measuring the pressure drop in channels with a range of pin sizes and separations. This aspect was started recently and the results are still being analyzed. Further measurements are planned for the upcoming months.

EFFECT OF WATER ON PRESSURE DROP

The wet channel has a flocked surface, which has a higher roughness than the smooth surface of the dry channel. Introducing water into the channel is necessary to provide cooling, but excessive water flow will disrupt the airflow in the channel. An example is given in the graph below, for a water flow rate of 60ml/min, the airflow is disrupted when the Reynolds number reaches 6000 (Figure 4).

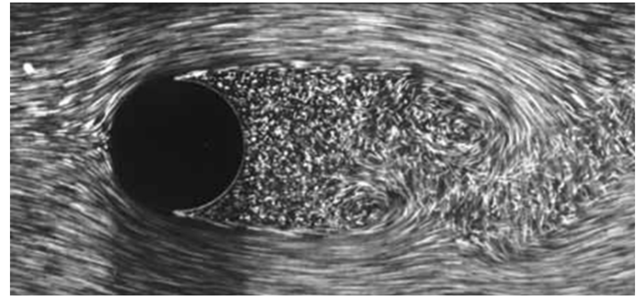


FIGURE 3: TYPICAL PATTERN OF FLUID FLOW PAST A CYLINDRICAL PIN

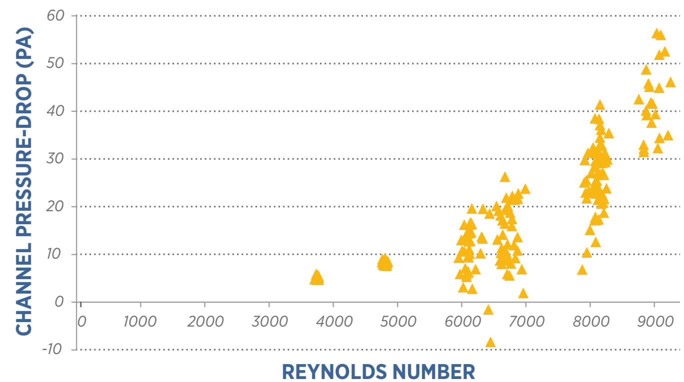


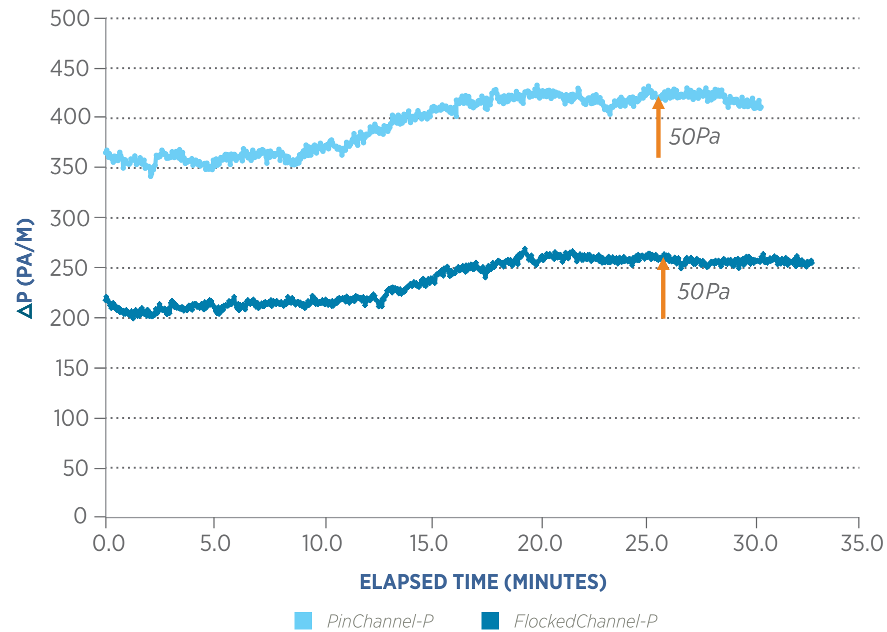
FIGURE 4: EFFECTS OF WATER ON PRESSURE DROP

Recent tests have focused on the low flow regime, to determine the effect of minimal water flow on the pressure drop. To study this, a channel was built with a flocked surface and water was flowed through the channel for several minutes to completely wet the surface. The water flow was then stopped and the pressure drop was monitored at a constant air flow rate. The test has been carried out for surfaces both with and without pins.

Figure 5 shows that in both cases the channel starts to dry after approximately 12 minutes, and is fully dry within 20 minutes. The difference in pressure drop between the wet and dry states is roughly 50Pa in both cases, even though the actual pressure drop is higher in the channel with pins, as would be expected. The similarity in the change in pressure drop suggests that the effect of drag on the plates can be de-coupled from the effect of the pins, which is promising for the development of our model.

In addition to the experimental work and the modeling described, a separate model based on the effectiveness-NTU method was developed. Using some approximations, the governing differential equations that describe IEHX heat/mass transfer behavior were modified 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 numerically. The model was compared to existing data from the literature and found to be in good agreement. This work was published in HVAC&R Research[1].

FIGURE 5: PRESSURE DROP DIFFERENCE BETWEEN WET AND DRY STATES



FUTURE WORK

In the coming months we will continue to refine the model and will carry out further experimental work on the effect of pin size and spacing, as well as further work to understand the effect of plate roughness and water coverage.

[1] *Zhijun Liu, William Allen, Mark Modera. Simplified thermal modeling of indirect evaporative heat exchangers. HVAC&R Research. Vol.19,Issue. 3,2013*

INDUSTRY SUPPORT

HVAC PERFORMANCE ALLIANCE

Partnering HVAC stakeholders to curb energy waste in mechanical systems

With over 170 member organizations, the Western HVAC Performance Alliance (WHPA) is a fusion of HVAC, energy efficiency, facility, and property management organizations whose decision-maker-level appointees work with one another, utilities and with government to curb energy waste.

Collectively and individually, member organizations foster expert HVAC system specifications, sizing, installation, commissioning, operation, service, and maintenance. In addition to increasing efficiency, this collaborative effort aims to increase 1) comfort, air quality, system reliability and equipment lifespan, 2) the value proposition for high performance HVAC becomes more apparent to consumers, and 3) work towards achieving the goals of the California Energy Efficiency Strategic Plan (CEESP).

The WHPA Launched in 2009 in response to that portion of the CLTEESP that reads: "An HVAC Advisory Group should be chartered to involve high-level HVAC industry stakeholders—such as manufacturers, distributors, and contractors—to coordinate industry sponsorship of and participation in HVAC strategies. Membership should also include other key players, such as the CPUC, Energy Commission utilities, building owners/managers, consumers, and the Federal government."

WCEC facilitated the May 2009 Roundtable that resulted in the formation of the WHPA, and facilitated its early steering committee meetings. WCEC activities have varied over time, and recent activities include chairing the Fault Detection and Diagnostics Committee and preparing for the Summit for the Advancement of Functioning Economizers.

EDUCATION AND OUTREACH

Advancing and promoting HVAC energy efficiency at home and abroad

WCEC OUTREACH ABROAD

This year, the WCEC engaged the broader HVAC industry on an international scale. WCEC Director, Mark Modera, spent two weeks in China meeting with HVAC industry leaders and academics. While there, he discussed the potential application and WCEC collaboration for two energy efficient technologies. The first technology (Figure 1) is a fluid cooling tower that combines indirect evaporative and direct evaporative cooling to efficiently chill water below incoming air wet bulb temperatures. WCEC will be acquiring one of these new fluid coolers for testing. The second technology (Figure 2) is a modification to radiant ceiling panels that can increase the overall surface area and increase convective thermal transport.

Modera's next stop was at the Hong Kong Polytechnical University where he gave a presentation to the Hong Kong chapter of ASHRAE. Modera spoke on the recent research findings at WCEC including RTU retrofits, the use of aerosolized sealant to seal building envelopes and encapsulated phase change materials to improve the carrying capacity of hydronic distribution systems.

In Beijing, Modera presented to BUCT (Beijing University of Chemical Technology) on the economics and management of getting energy efficiency projects funded. Modera detailed the diverse challenges from policy-makers down to the end user, and the solutions to these challenges from his experience running the Western Cooling Efficiency Center.

MODERA RECEIVED AN HONORARY VISITING PROFESSOR AWARD AT BEIJING UNIVERSITY OF CHEMICAL TECHNOLOGY (BUCT)

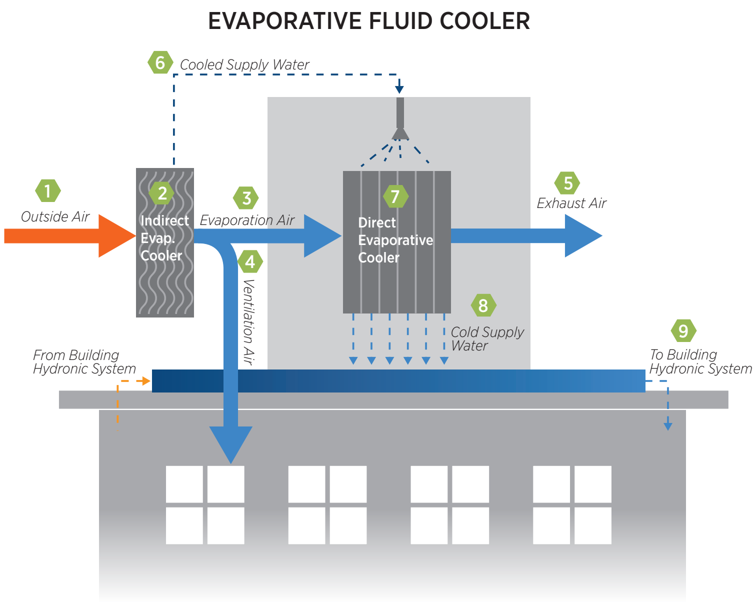


FIGURE 1: EVAPORATIVE FLUID COOLER SCHEMATIC

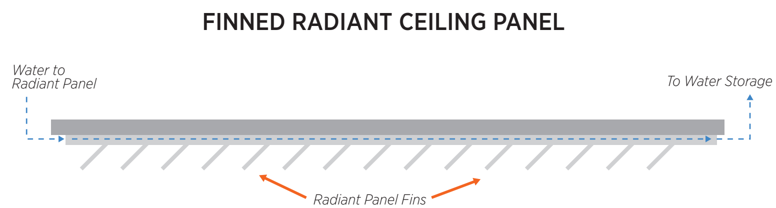


FIGURE 2: FINNED RADIANT CEILING PANEL

WCEC OUTREACH AT HOME

Part of our outreach goals is to bring sound HVAC energy efficiency ideas to stakeholders that can directly act on them. WCEC, along with SWEEP (Southwest Energy Efficiency Project), hosts a webinar once a month on various HVAC efficiency topics. These topics range from evaporative pre-cooler results, advanced RTU controls, HVAC behavioral research and new HVAC utility programs to name a few. The presenters are professional leaders in their industry that include energy consultants, manufacturers, utility managers, research partners and academics. Each webinar reaches between 30-50 industry professionals, most notably utilities who can take this vital information and apply it to their utility programs.

Another important focus for WCEC's outreach is to meet and collaborate with the industry in a variety of capacities. WCEC met directly with companies to discuss current and future research including but not limited to: Trane, Daikin, Siemens, Wells Fargo, Danfoss and Honda. The success of these meetings can be realized in the various projects we are currently collaborating with these companies on that include the deployment of over 12 Trane DC Voyager Units, and the design and monitoring of the Honda Smart Home; a Net Positive Home being built at West Village, UC Davis.

WCEC also meets regularly to present and work with HVAC policymakers and organizations. A few notable events include a meeting with the California Energy Commission on natural gas initiatives, three separate ASHRAE conferences, ACCA and the ETCC meeting at SMUD. Much of the work at these meetings involve shaping policy for HVAC efficiency and creating protocols for standards testing.

Our annual Affiliate's Forum this year brought together policy makers, manufacturers, utilities, and HVAC contractors for presentations and discussion on the upcoming changes and future changes to policy, utility programs and research in HVAC.

STEVE SLAYZAK FROM COOLERADO (LEFT) AND RICHARD SWANK FROM TRANE (RIGHT) ACCEPT THE WESTERN COOLING CHALLENGE AWARD FOR MEETING THE REQUIREMENTS OF THE COOLING CHALLENGE

VIRGINIA LEW OF THE CALIFORNIA ENERGY COMMISSION PRESENTED ON POLICY ISSUES AT WCEC'S AFFILIATES FORUM

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.

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Los Angeles Department of Water & Power

Munters® Corporation®

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