Advancement of Western Cooling Efficiency

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WCEC WESTERN COOLING EFFICIENCY CENTER

A Report of the Western Cooling Efficiency Center

RESEARCH • INNOVATION • PARTNERSHIP

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Executive Summary

1.0 Task 1 – Administration/Research Capabilities

1.1 WCEC Steering Committee Meeting

The seventh WCEC Steering Committee Meeting was held February 26th, 2009 at WCEC in Davis, CA. Six steering committee members attended and seven were absent, with two organizations sending alternate attendees. Major topics of the meeting included feedback on the recently held affiliates forum, technology updates on ongoing projects including radiant floor cooling and the western cooling challenge, and strategic planning including the possibility of WCEC spearheading an industry task force. Additional details are available in the meeting minutes (Appendix A).

1.2 Demonstration Room Capabilities

The WCEC physically is composed of offices, a display area for equipment “show and tell” for WCEC visitors, and research/demonstration areas. The research/demonstration areas are used for PIER research projects, as well as for research for California utilities and equipment manufacturers. They will also be used as a platform for outreach to the design and manufacturing community, by providing real-life demonstration of advanced cooling technologies and a location for hands-on training. In order to function in this capacity, there are certain key measurement capabilities that the facility must have.

This PIER program provided some of the basic instrumentation and test apparatus building capabilities necessary to serve this function. Along with funding from other research programs, the WCEC has acquired various laboratory instrumentation and data acquisition equipment (below).

Air Flow Measurement	Orifice Plates	13”, 15”, and 17” Diameter Aluminum Plates
	Pitot tubes	12” and 18” Dwyer Instruments
	Duct Blaster	Energy Conservatory, powered airflow measurement
	Anemometer	“Airflow” Vane Anemometer
Water Flow Measurement	Peristaltic Pumps	Masterflex Drives, Pump Heads, and Tubing
Power Measurement	kWh Transducers	Wattnode WNB-3Y-208-P, with 15- and 5-Amp Solid Core CTs
	Handheld Power Meter	Extech 380976
	Multimeters	Extech 430
Temperature/ RH Measurement	High Quality Air Temperature and Relative Humidity	Vaisala HMD70Y Temp RH Transmitter
	Medium Quality Air Temperature and Relative Humidity	Vaisala HMD50Y Temp RH Transmitter
	Handheld Temp/RH	Extech RH300 Digital Psychrometer
	Air Delta-T (averaging)	Thermopile composed of 24 T-Type thermocouples
	Surface Temperature	Raytek Infrared

Water Quality Measurement	Handheld Water Quality	HM Digital TDS Meter
	In-Line Conductivity	Omega Conductivity Probe (CDE-300) and Transmitter (CDTX-300)
	Water Quality Testing	Hach Digital Titrator, Reagents, and Individual Test Kits for Total Hardness, Calcium Hardness, Alkalinity, Silica, pH
Air-Pressure Measurement	Digital Pressure Gauge	Energy Conservatory DG-500, 2-Channel Automated Performance Testing, 8-Channel
	Analog Manometer	Magnahelic
Datalogging	Multiple Input Dataloggers	Labjack U3-LV USB, up to 16 12-bit analog inputs, up to 20 digital I/O, 2 10-bit analog outputs, up to 2 counters, and up to 2 timers
Signal Conditioning	Thermocouple Inputs	Advantech ADAM-4018+-BE Thermocouple Input Module
	USB > RS232 Converter	Advantech ADAM-4561-AE USB to RS-232/422/485 Converter
	Several Custom Circuits	Adjustable voltage dividers, power supplies
Experiment Control and Monitoring	Dell Workstations	Vostro 200 Mini Tower
	LabVIEW	General Instruments LabVIEW, V8.5
Test Apparatus Fabrication Capabilities	Hand Tools	Variety, including: saws, clamps, wrenches, screwdrivers, pliers, ladders, soldering gun, calipers, hand torch, safety equipment.
	Power Tools	Variety, including: drills, table saw, bench grinder, spiral saw
	Storage/Organization	Asko Mills Hanging Rack System, with casters, industrial wire shelving with casters, shop vacuum, hand truck, utility carts, sawhorses

1.3 Simulation Capabilities

WCEC has invested time and effort of associate engineers and students to develop capacity for advanced building modeling. Four software tools have been used for developing relatively simple building models and ability to simulate complex building systems is progressing rapidly. Details of progress on each of the building simulation tools are as follows:

CONTAM – This software, created by National Institute of Standard and Technology (NIST), is focused on multi-zone airflow and contaminant transport analysis. It is not the proper tool for analysis of thermal loads and heating, ventilating, and air conditioning (HVAC) equipment performance, but allows for detailed analysis of pressure-flow interactions, multi-zone airflow balance, ventilation performance, duct leakage, and infiltration. WCEC has developed a prototype building for a six-story exhaust ventilated multi-family, dormitory, or hotel type building which was used in an analysis of potential energy savings from sealing exhaust leaks.

EnergyPlus – EnergyPlus is the next generation of building energy simulation; it allows for detailed analysis of thermal loads, HVAC equipment performance, building controls, and other energy system components such as photovoltaic electricity generation and thermal energy storage. In the current state of development, EnergyPlus is limited to a particular suite of cooling technologies. Thus, analysis of more advanced next generation equipment such as indirect evaporative + direct expansion hybrid systems may require WCEC to develop custom modules within the EnergyPlus program.

DesignBuilder – This tool uses EnergyPlus as an engine for simulations, but provides a user friendly graphical modeling environment for model development. The software is not as flexible or as powerful as EnergyPlus for the simulation of HVAC systems, and custom modules for advanced HVAC equipment cannot be constructed. However, since DesignBuilder can export an EnergyPlus input definition file, WCEC plans to use the program for rapid prototyping of building construction and general HVAC system architecture and EnergyPlus for refined details about cooling system performance. In June, Jonathan Woolley attended a two day Advanced Building Energy Simulation Workshop at the Pacific Energy Center that focused specifically on interfacing between DesignBuilder and EnergyPlus, and has since been working with students to explore the capabilities for multi-zone building simulation on both platforms.

eQUEST – The QUick Energy Simulation Tool (eQUEST) is a simplified user interface for DOE-2 modeling software. WCEC is in the process of becoming familiar with the tool, and intends to use the program to make parallel comparisons with EnergyPlus modeling efforts. Since the modeling for Database of Energy Efficiency Resources (DEER) 2.2 was conducted in DOE-2, WCEC hopes to use eQUEST as a device to run comparable simulations for advanced cooling systems, and to conduct cross-platform validation of simulation results from EnergyPlus.

2.0 Task 2 - DOE Regional Standards

On June 12, 2008 the United States Department of Energy (DOE) released the “Framework Document” for the next round of residential air conditioner and heat pump standards. WCEC participated in the proceedings by submitting comments advocating for regional standards as allowed by the Energy Policy Act of 2005. Regional standards for hot/dry climates and hot/humid climates would result in more efficient air conditioner design for these regions. However, there continues to be a divide between stakeholders that want to maintain one national standard and those that favor regional standards.

DOE received the comments submitted by participants in the process and will respond to them as part of the next set of documents. A recent check with finds that they plan to release the Advanced Notice of Proposed Rulemaking late 2009 or early 2010. Until then, further public comment is not being taken. WCEC expects regional standards to be included in the proposed rulemaking, but it is not known at this time.

3.0 Industry Support

3.1 ASHRAE and Other Industry Support

Industry support activities over the course of this project included a number of activities with the American Society of Heating, Refrigeration and Air-Conditioning Engineers

(ASHRAE), as well as numerous presentations and interactions with various stakeholders within the California cooling industry.

ASHRAE

The principal ASHRAE activities included Mark Modera's participation on GPC 1.2, SPC 152, and the ASHRAE Handbook Committee. In addition, both Mark Modera and Marshall Hunt attended the ASHRAE winter meeting in Chicago in January. As well as attending the committee meetings associated with the Guideline and Standard, Mark Modera attended multi technical committee meeting associated with the 2011 Applications Handbook. Marshall Hunt attended technical sessions, as well as a number of Technical Committee Meetings including 5.7 Evaporative Cooling, 8.11 Unitary and Room Air Conditioning, and 4.3 Ventilation Requirements and Infiltration. Marshall Hunt also attended the ASHRAE product exposition, contacting Western Cooling Challenge (WCC) participants and searching for candidate technologies for inclusion in the WCC. Both Marshall and Mark also organized and attended a meeting with SCE staff to plan the first meeting on a statewide Hot Dry Air Conditioner (HDAC) program for California.

The GPC 1.2 committee is responsible for developing two guidelines (Guideline 0.2 "Commissioning Process for Existing Buildings", and Guideline 1.2 "The Commissioning Process for Existing HVAC&R Systems". These guidelines could play an important role in processes to improve the performance of cooling systems in existing buildings. The committee will produce protocols for improving HVAC system performance in existing buildings, which can have a significant impact on WCEC demonstration efforts for UC campuses.

The SPC 152 committee (Method of Test for Determining Design and Seasonal Residential Thermal Distribution Efficiency), addresses a key determinant of the energy use of residential cooling systems, thermal energy distribution. Typical forced-air distribution systems waste 30-40% of the cooling provided by the HVAC equipment. Our interests in the current revision process are focused on the treatment of thermal distribution methods other than forced air, including water (radiant cooling), and refrigerants (variable-flow refrigerant systems such as mini-split systems with multiple evaporators). In addition, the committee is considering adding thermal distribution in light commercial buildings to its scope, which is also of particular interest to the WCEC.

Other Industry Support

The WCEC continually maintains close contact with industry. Some highlights of those interactions include:

1. Kristin Heinemeier attended the 2008 Behavior, Energy and Climate Change ("BECC") Conference in Sacramento on November 17, 18, and 19, 2008.
2. Mark Modera made a presentation on the concept of Zero Peak Cooling at the ASHRAE Net Zero Energy Buildings meeting in San Francisco on March 30th 2009.
3. In April 2009, Kristin Heinemeier began developing a preliminary scope of work related to residential AC decision-making and behavior. This will address

choices made upon purchase, service, and replacement of air conditioning systems and components.

4. On April 1st Mark Modera attended a meeting at the U.S. Department of Energy DOE in Washington DC to present the capabilities of the Energy Efficiency Center (EEC) and WCEC.
5. Mark Modera attended a meeting at Southern California Edison to help them plan future Demand Response programs (April 6th)
6. Mark Modera gave a presentation on Radiant Cooling at the partners meeting for the Center for the Built Environment at UC Berkeley on April 23rd.
7. Mark Modera met with Brian Ford from SGL Group on April 27th. SGL Group manufactures various products from graphite, including cooling storage systems for tractor trailers. This technology could prove to be useful for storing cooling in buildings, potentially providing the potential for very quick charging and discharging.
8. On April 28th Mark Modera and Marshall Hunt met with a company from Tennessee (Evaporcool) that is introducing a retrofit product that uses sprayers and pads to cool outside air to web-bulb temperature before it reaches the condenser coil.
9. Mark Modera visited Synapsense on May 8th in order to better understand their technology, and how it might aid in the mission of the WCEC. The Synapsense technology is wireless sensor system that is currently being utilized to map temperatures in data centers.
10. Kristin Heinemeier organized and conducted an HVAC Roundtable meeting held in San Francisco on May 12, 13 and 14. The purpose of the meeting was to initiate a collaborative process to achieve the CPUC goal to transform the HVAC industry in California. The meeting was attended by approximately 70 people, representing a cross-section of groups who impact the performance of the industry, including manufacturers, distributors, dealers/contractors, trainers, code officials, industry associations, and utilities. Both Mark Modera and Kristin Heinemeier attended the meeting, which represents the first step in the process in which the WCEC is likely to play a significant role.
11. On May 15th, Mark Modera visited Portland State University, and gave an invited lecture as part of their seminar series for Green Building Design. Based upon the response to the lecture, and meetings with students and faculty, mutual recruitment of students and research collaborations are likely in the future.
12. Mark Modera attended the EEC Board of Advisors meeting in Washington DC on May 19th. This trip also included a congressional briefing, and a couple of receptions designed to elevate the profiles of the EEC and WCEC. In addition, Mark Modera visited the US Environmental Protection Agency to better understand how their different initiatives might interact with WCEC objectives.
13. Mark Modera presented on Emerging Technologies for Cooling the West at the Association of Energy Engineers meeting in Long Beach on June 10th.

3.2 DEER

The objective of this task was to review the Database of Energy Efficiency Resources (DEER) and how it impacts utility rebates for cooling technologies. DEER contains thousands of DOE-2 hourly simulation runs covering all climates zone, six vintages or ages of buildings, and a set of weighted averages by Investor Owned Utilities (IOU) service territory. If there is a DEER run that matches the technology being considered by a utility, then the DEER values must be used or a strong case made proving why other values are used. There are no DEER runs that match technologies in the portfolio WCEC is researching and developing. Some of the DEER runs are close and others can be used as a starting place for estimates of kWh and kW impacts.

DEER Residential

WCEC reviewed the cooling technologies covered by the current version of DEER and found that baseline residential usage is so low that even technologies savings 50% do not generate large enough rebates based on kWh/yr savings. The chart below exported from the Measure Inspection and Summary (MISer) database manager for DEER shows the impact of the best residential air conditioning technology that is modeled by DEER, which is close to one of the technologies WCEC is assessing (Figure 1).

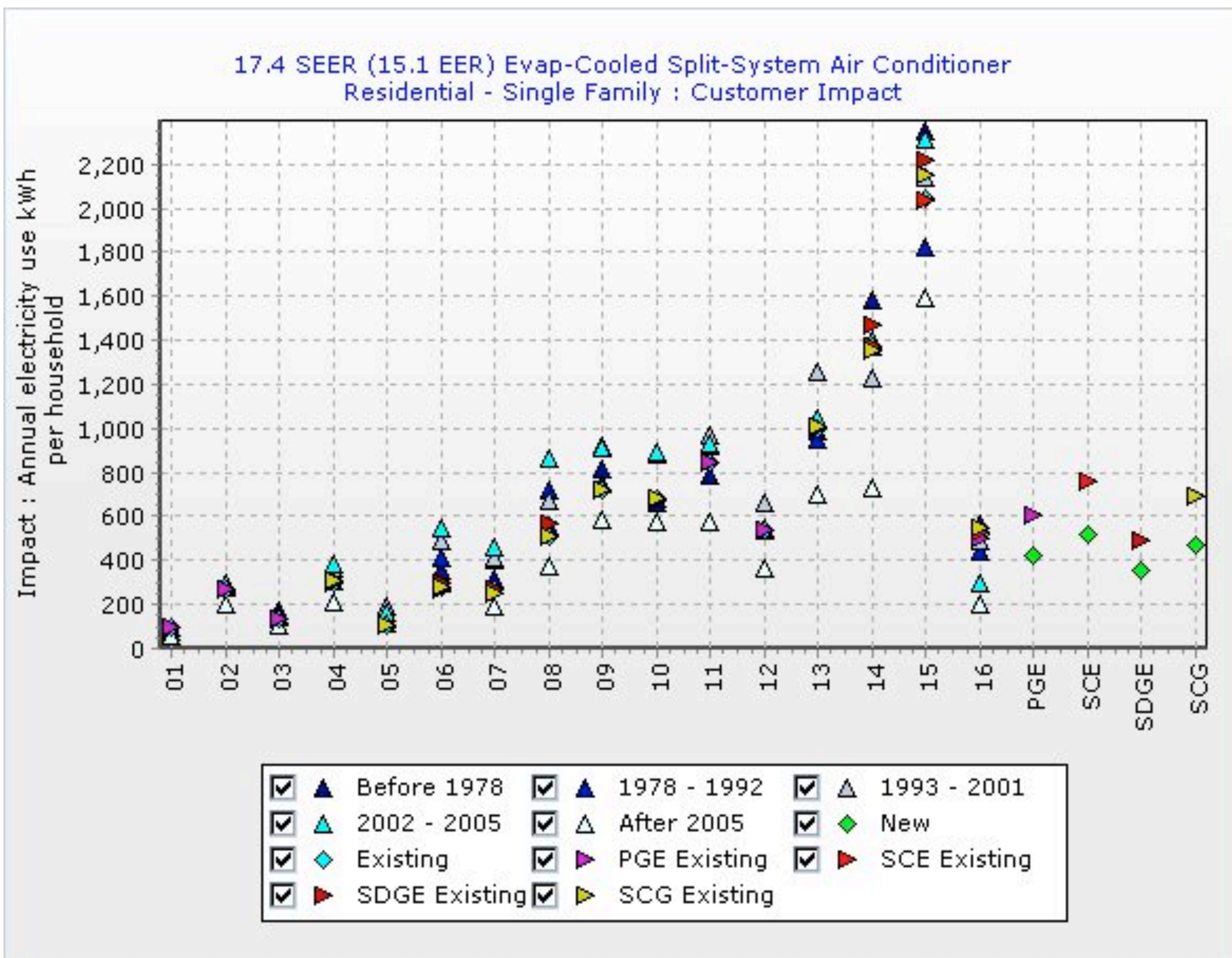

Figure 1 – Impact of efficient residential AC installation from MISer database

In Climate Zone 15 (El Centro) the most savings are generated with a range of 1600 kWh/yr to 2200 kWh/yr depending on the age or vintage of the house. At $0.12/kWh the kWh savings generated rebate would be $192 to $264 for systems that are 3 to 4 tons capacity. In Climate Zones 8, 9, 10, 11 and 13 the savings are half those of El Centro. In the Sacramento and Stockton areas (Climate Zone 12) the savings are even less due to cooling by the Delta breeze. For a house with a three-ton system the incremental cost is $3000 to $4500 per house. Thus, based on kWh per year savings CPUC allowed rebates are less than 10% of the incremental cost and are not large enough to drive energy efficiency decisions.

The IOUs are pursuing a possible solution. Programs targeted to customers with high kWh usage for air conditioning can work if the DEER consultants generate "customized" program impacts. As of July 31st this approach was still in the planning stage and might be applied first to a program that gives incentives for Hot Dry Air Conditioning (HDAC) systems.

WCEC has been making the point that cooling systems that substantially and reliably reduce peak kW demand mitigate the need for building "peaker" power plants. The cost to build small (50 to 100 MW) plants is approximately $1000 per kW. The Anaheim Public Utilities, an municipal owned electric utility, responded to its constrained peak power capacity by paying almost $2000/kw for demand reduction/shifting technologies. The DEER runs for the Evap-Cooled Split AC show a kW demand reduction of around 1.5 kW per system which at $1000/kW would generate a $1500 rebate. Together with a higher a $0.24/kWh rebate that is used in some programs the total incentive for HDAC systems would become large enough to make a difference in the market place. If IOU programs were also allowed to do targeted programs the earned rebate would be even higher.

DEER Nonresidential

A significant part of the Western Cooling Challenge (WCC) project is to develop annual simulations of the energy efficiency and demand reduction delivered by roof top packaged air conditioning and heating Units (RTUs). DEER has simulation runs for RTUs when used on large, single story retail buildings. One of the WCEC affiliates retained Dr. Phil Haves of Lawrence Berkeley National Laboratory (LBNL) to simulate the new generation of stores being built in 2005. For Climate Zone 12 actual energy consumption data was used to calibrate the EnergyPlus simulations and compare to a closely related DEER simulation (Figure 2). The closest DEER simulation case found has nearly identical square footage and EER ratings for the RTUs. The DEER analysis does not have food preservation refrigeration or exterior lighting for the store and parking lot. When these are added to the total DEER kWh/year usage the revised DEER total is 1.94 million kWh/yr which is still 12.8% lower than the EnergyPlus simulation of 2.26 million kWh/yr. The higher actual usage of "Interior Lights" and "Cooling" is about offset by the higher DEER simulated "Elec Equipment". The primary reason that the DEER analysis is low is that the EnergyPlus RTU fan kWh/yr is 0.41million in contrast to the 0.17 million from the DEER simulation. This difference is explained by DEER assuming little, if any, ductwork attached to the RTUs while the calibrated EnergyPlus simulation uses a duct static pressure of 0.7 inches of water column. The calibrated EnergyPlus run had a total of 262 AHRI nominal tons of RTU capacity while the DEER run had 320 tons. This large difference results in a much lower total kWh/yr consumption results for DEER. This discrepancy is on the order of that found in the residential HVAC simulations. With these results the WCC equipment saving 50% of yearly electricity would only generate incentives of $100/ton, which is far below the $500/ton goal of the WCC.

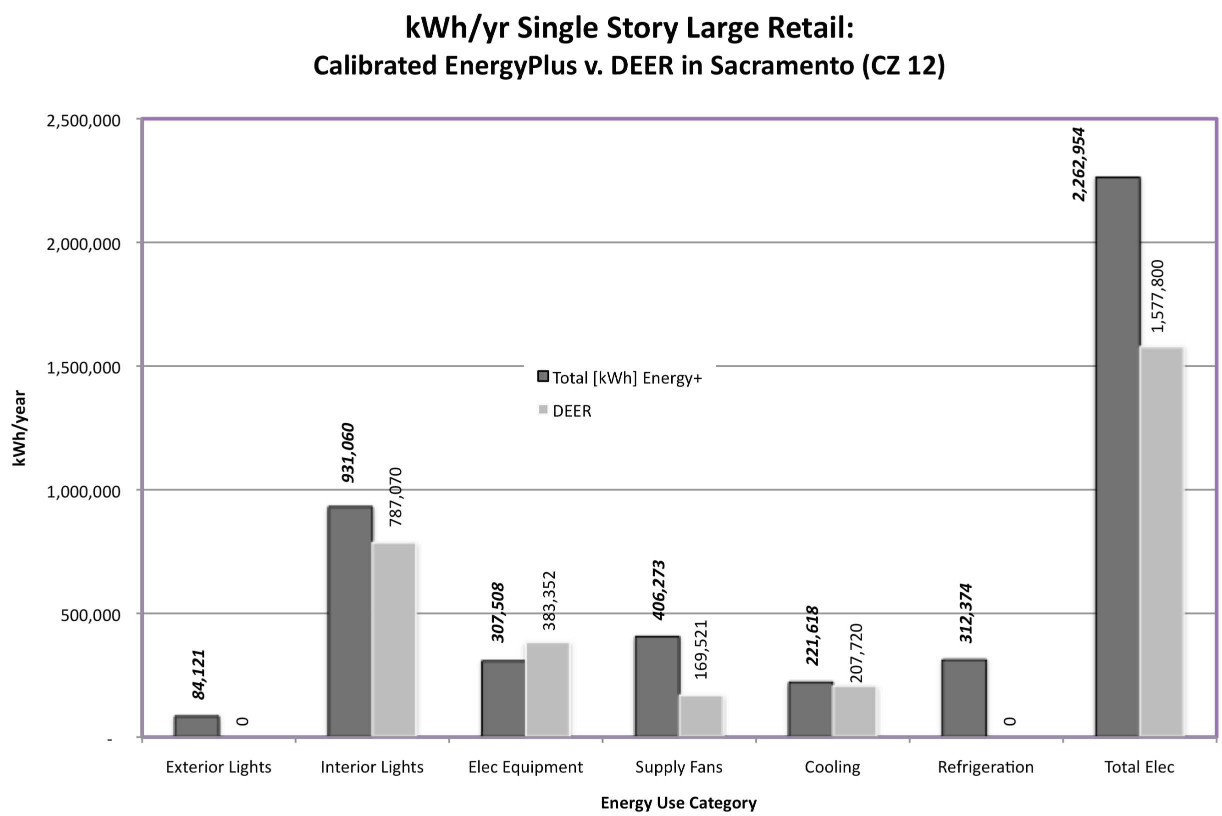

Figure 2- Calibrated EnergyPlus versus DEER Simulation in Sacramento from LBNL consultant Dr. Phil Haves

3.3 E3 Calculator

Each IOU has a version of an Excel based cost benefit analysis simulation tool named “E3”. The California Public Utilities Commission (CPUC) currently requires that the Total Resource Cost (TRC) ratio meet or exceed 1.0 and there are discussions on-going about what will be required for the next three year program (2010-2012). Critical to a good TRC ratio is large kWh/yr savings per dollar of incremental cost for the technology. Incentives that buy down the cost to the consumer do not change that incremental cost to society as a whole. Caught between low DEER kWh/yr savings and high incremental costs due in large part to the immaturity of the market, TRC ratios will not meet the levels required by the CPUC except when the IOUs can use the average

TRC of their whole portfolio of energy efficiency programs to justify inclusion of lower TRC programs.

Thus, as of July 31, 2009, extensive E3 TRC analyses must wait for resolution of the DEER numbers and incremental cost values. Residential programs will have to be targeted at high use customers with Evaluation, Measurement and Verification of results which can then be used in future programs. Nonresidential programs will have to be calibrated to the actual energy use of facilities. Modified DEER simulations need to be made and new algorithms are needed to access the performance of technologies in the WCEC portfolio. Incremental costs will need to be analyzed to generate the equivalent "mature market" cost expected when a technology is part of the HVAC marketplace.

3.4 Behavior Research

The Western Cooling Efficiency Center focuses on the technologies that will be needed to achieve deep reductions in cooling energy and demand use in hot/dry climates. There is clearly a great deal of work to do on the fundamental physics and engineering behind these technologies. However, it has been shown that no matter how advanced a technology is, it will not be successful and will not save energy if it does not accommodate the individual and organizational behavior of the people and firms that use or choose the technology.

This is becoming better recognized in the energy efficiency world. Witness:

- the "Human Factors" panel, which has long been a staple of the American Council for an Energy Efficient Economy *Summer Study on Energy Efficiency in Buildings*, and
- the *Behavior, Energy and Climate Change Conference*, which was originally seen in 2007 as a one-time event, but which generated so much interest that the venue had to be changed to accommodate the 500 attendees, and it became an annual event.

The Western Cooling Efficiency Center has considered the behavioral aspects of all of the technologies with which it works, and developed an outline of questions that would be fruitful topics for future PIER research.

Cooling-Related Behavior Questions

1. Maintenance Behavior
    a. How do homeowners and small commercial maintenance staff typically maintain their systems?

2. Thermostat Behavior
    a. How do homeowners and small commercial tenants use their air conditioners?
    b. What are the different modes of residential AC management?
        - Set thermostat and forget it
        - Night setback/up
        - Use thermostat as on/off switch

c. What are typical AC balance points in CA residences?
d. What are typical thermostat setpoints and schedules for cooling?

3. Service Behavior
   a. What are the advantages to service contracts (such as building trust, and providing the opportunity to upsell more efficient equipment over the years)?
   b. What factors go into a homeowner's decision to purchase or not purchase a service contract?

4. "Run To Failure" Mentality
   a. What factors go into the decision to allow a unit to run to failure?
   b. What happens when a unit is run to failure? Is it replaced with a suitable efficient unit, or with whatever's on the truck?
   c. How quickly must a replacement be made available when a unit fails?
   d. How do contractors view the opportunity to upsell a more efficient unit when a unit fails? Do they have time to make this case?
   e. What kind of materials would help contractors to make a case for improved efficiency or downsizing when they are replacing a unit? (such as a brochure, analysis tool…)
   f. How much does having a history with the customer help in promoting a different choice of replacement unit?
   g. Is the service tech capable of doing the selling? Is a sales engineer able to be brought in effectively?
   h. When do failures occur? Why? (For example, there are always a large number of service calls on first very hot day and the first very cold day of the year).
   i. What is behind the old adage in the industry that if a unit breaks down before the 4th of July, it will be replaced, but if it breaks down after, it will be repaired?
   j. How does the season affect the usefulness of incentives? For example, some manufacturers don't provide upstream rebates during the busy season, because equipment "sells itself." During the swing season, however, they need to do more to convince a homeowner to buy. What impact does this have on the choice to go with high efficiency?
   k. How can we take advantage of the "teachable moment" when a unit fails? Most energy efficiency messaging falls on deaf ears, because most people are not replacing a unit. When a unit fails, it is pretty close to too late to reach that decision-maker with a message. There may be outreach opportunities associated with:
      - The customer standing at the thermostat, thinking "what the heck is going on?"
      - The customer looking at their furnace or water heater, wondering what to do
      - The customer looking in the yellow-pages for a good contractor.
      - The customer using the WWW to find a good contractor.

How can these moments be influenced?

5. Code Enforcement – Pulling Permits
    a. Why do HVAC alteration contractors pull or fail to pull a permit and comply with Title 24?
    b. What influence do owners have on pulling or not pulling a permit?
    c. What would motivate contractors to pull permits more often?
        - making it easier to comply,
        - providing a more credible threat of being caught and penalized,
        - customers requesting it.
    d. What would motivate homeowners to insist on a permit being pulled more often?
        - saving the world,
        - saving money,
        - getting a better quality installation,
        - improving safety,
        - learning that the contractor could lose their license if permit is not pulled,
        - learning that it is illegal if permit is not pulled,
        - more likelihood of being "caught",
        - warranty is voided if permit is not pulled,
        - not eligible for utility incentives if permit is not pulled.

6. Fault Detection and Diagnostics (FDD) (Residential and Small Commercial)
    a. Is a service model the only way to implement FDD, or can a building owner respond to faults?
    b. What would a building owner do if their thermostat annunciated a faulty condition for their AC?
    c. What information needs to be provided to a building owner to cause them to do something?
    d. How much more likely is it that a homeowner would act if the system told them what the best response would be?
    e. What kind of relationship does the homeowner have to have with a service contractor to have confidence in the fault annunciated by the FDD tool?

7. Fault Detection and Diagnostics (Large Commercial)
    a. How is FDD perceived by potential customers? Do customers believe that they have "faults" that need to be detected?
    b. What are the usability and marketability concerns that will influence the success of a FDD tool?
    c. What do facility managers do with alarm data when it's received? How can it be received in a different way to ensure that it is acted upon appropriately?

The WCEC intends to work with PIER Program Managers to develop a scope of work to answer the most important of these questions.

4.0 Western Cooling Challenge

Twelve participants, including eight HVAC equipment manufacturers, signed up to participate in the Western Cooling Challenge (WCC) to design a commercial roof top unit (RTU) with improved efficiency for western climates. The criteria for the WCC are included in Appendix B. This was a monumental effort to get off the ground and industry participation has exceeded expectations during a tough year for HVAC manufacturers that are focused on other efforts, devoting significant engineering resources to meeting the January 2010 US DOE minimum efficiency standards and moving to refrigerant R410a from refrigerant R22. WCEC has provided continued motivation and technical support to the manufacturers that are participating in the challenge. Specific details on this support are available in the monthly chronology of activities (Appendix C).

In June, the first WCC 5-ton unit manufactured by Coolerado (H80) was tested at the National Renewable Energy Laboratory (NREL) and significantly exceeded the WCC criteria (Appendix D). New of this exciting milestone was distributed via press release (http://www.news.ucdavis.edu/search/news_detail.lasso?id=9200). At the end of July 2009 there were 6 active participating manufacturers with participation from more being likely. WCEC continues to work with participants so that there are more WCC qualified units available for customers that cover the RTU range of 3 to 30 tons available by the January 1, 2011 target date. A challenge for the WCC program has been a lack of independent research laboratories that can test cooling equipment up to 20 tons. Currently, NREL can test equipment up to 7.5-10 tons (depending on conditions) and is expanding to 20 tons (expected end of 2010). A renovated PG&E research lab is under construction that can test up to 10 tons. WCEC is working to identify other potential test facilities for large equipment. In parallel with the hardware developments, WCEC is developing the annual hourly simulations needed to assess the climate zone and application specific performance of WCC certified units. The WCEC's efforts on the Western Cooling Challenge will continue through an Interagency Agreement with the California Energy Commission (CEC).

5.0 Water Use Impacts of Evaporative Cooling

Evaporative cooling technologies have been praised for their relatively small energy use in comparison to compressor based air conditioning systems. However, concerns have risen regarding the amount of on-site water used by evaporative technologies. While compressor based systems do not use water on-site, they consume water through use of electricity, which consumes water through evaporation at hydroelectric power plants and cooling of thermal power plants. A paper was written that defines a water use efficiency metric and a methodology for assessing the water use of various cooling technologies (Appendix E). The water use efficiency of several example cooling technologies are compared including direct evaporative, indirect evaporative in two configurations, compressor based systems, direct evaporative for condenser air pre-cooling, and hybrid systems consisting of an indirect evaporative module and compressor based system. Designing cooling systems for California's arid climate is entwined in the close relationship between water and energy and the scarcity of both resources. The solution may be in designing hybrid evaporative and compressor based systems that significantly reduce peak electricity demand and annual consumption while making moderately efficient use of water and delivering desired performance.

6.0 Cooling with Swimming Pool Heaters

In order to explore the capacity for swimming pools to be used as heat sinks for residential cooling, a model was developed to predict pool temperatures as a function of local weather data and time variant thermal inputs. A review of literature was conducted to evaluate existing models of pool temperature response to meteorological conditions, and the mathematical formulae to describe fundamental heat transfer phenomena of evaporation, convection, conduction, and radiation were combined into a complete thermal model. As validation, a residential swimming pool in Davis CA was instrumented to measure the passive heating and cooling effects over a two month period. The experimental findings were compared to simulation results using local meteorological data with very good agreement; the mean absolute error between measured and predicted pool temperatures was less than 0.5°C for the two month period and the maximum error was 1.5°C.

A complete report on the model and experimental validation, pending submission and review for publication, is attached in Appendix F. This research is continuing to develop through an Interagency Agreement with CEC. With this additional funding, the model will be improved and expanded, including the addition of thermal inputs from external mechanical loads. A newly constructed geothermal swimming pool heat pump system in Sacramento will be instrumented and monitored to allow further research and development in the energy efficiency implications of pool heat sinks for cooling.