Combining research, demonstrations, policy and deployment to advance energy efficient thermal systems.
Welcome to the Western Cooling Efficiency Center’s Year-In-Review for the 2015-2016 year. We are excited to share with you some notable developments from this past year, including new technologies developed in-house that are moving to the market. This Year-In-Review also displays the diversity and uniqueness of not only our latest research and findings; but also an increased range of new partnerships that greatly expand our impact in California and beyond.

This year, WCEC partnered with over 20 groups from both private industry and the public sector; including government organizations such as the Department of Energy, Department of Defense, Lawrence Berkeley National Laboratory, and the Electric Power Research Institute. We’ve also taken greater steps to partner with other prominent research divisions right here at UC Davis, including the Energy Efficiency Center, the Department of Public Health Sciences and the Department of Animal Science.

Testing technologies and writing research reports is an important step to move the energy efficiency needle forward. WCEC goes one step further by searching for new, sometimes unconventional perspectives to our energy issues, challenging long standing precedents, and engaging policymakers and standards organizations.

This year, WCEC made progress on creating a new standard to test evaporative pre-coolers through ASHRAE Standard 212, and we are creating training videos on 2016 Title 24 Building Energy Efficiency Standards for residential HVAC systems to help unravel some of the complexities in building standards. These efforts have the potential to increase adoption rates of both new technologies and existing best practices for buildings.

LOOKING TOWARD OUR ENERGY FUTURE

Our research successes and innovations are owed largely to the cooperative interests and combined efforts of our valued network of industry partners, collaborators, and research sponsors. In light of the growing energy and environmental challenges we face, we know these upcoming years are important. WCEC is proud to be a part of this movement to advance a more sustainable energy efficient future.

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What is WCEC?

The Western Cooling Efficiency Center is an authoritative and objective research center at UC Davis that accelerates the development and commercialization of efficient heating, cooling, and energy distribution solutions.

Our work is increasingly important as energy policies in the US and California recognize the far-reaching implications of greenhouse gas emissions on our environment and changing climate.

HOW WE WORK

APPLIED RESEARCH

Working closely with manufacturers, policymakers and utilities, WCEC tests new and existing HVAC technologies in our laboratory. We also deploy real world demonstrations that provide objective technology evaluations of field performance. Our engineers recommend and implement performance improvements for the technologies tested.

HUMAN FACTORS & POLICY RESEARCH

We understand that even game-changing technologies face considerable barriers to adoption that include policy, market and human interaction. WCEC works with policymakers, supporting codes and standards that will save energy and promote new, efficient technologies. We also work closely with our utility partners, to evaluate technologies for market incentives, and in parallel, address human behavioral factors.

Learn more » wcec.ucdavis.edu
Performance Testing of a New Refrigerant

The modernization and economic growth in countries like China and India have led to an even larger marketplace for vapor compression cooling—and a larger overall carbon footprint and global warming potential (GWP). Because of the inevitable increase in vapor compression cooling throughout the world, solutions to reduce the global warming potential of each of these units can have a significant impact on our environment.

One part of that solution is to reduce the global warming potential of the refrigerants used in these systems. To that end, WCEC laboratory tested a new refrigerant, R-452B under a variety of conditions and compared the results to the standard refrigerant, R-410A. This refrigerant is claimed to have a 70% smaller GWP than R-410A. R-452B is also a drop-in replacement for R-410-A, requiring no more than a possible TXV replacement to account for the change in operating pressures and refrigerant mass flow rate.

RESULTS

The results show that the equipment operating with R-452B refrigerant achieved similar capacity to the equipment operating with R-410A but used less total power in each test performed. The combination of providing comparable cooling capacity using less power is what results in the better efficiency observed for the unit operating with R-452B. R-410A showed a 5% improvement in the equipment coefficient of performance at the AHRI rated condition (95°F) and 4% improvement in coefficient of performance on average across all tested conditions.

PUBLICATIONS

Download WCEC’s laboratory performance test case study for R-452B:

bit.ly/RefrigerantCS

Aerosolized Sealant for Building Envelopes

Building envelope leaks are a significant factor in energy consumption, accounting for over 30% of the total energy used for HVAC. Sealing buildings by means of aerosolized sealant particles is a promising technology, providing a comprehensive solution that can dramatically reduce the total leakage in buildings. Sealing building envelopes saves energy by eliminating infiltration of unwanted, unconditioned air, reduces the loss of conditioned air and reduces the demand for cooling and heating. Existing envelope sealing practices require many contractor hours, manually sealing leaks with no guarantee that the majority of leaks have been found or sealed. Sealing building envelopes with aerosol particles eliminates the guess-work—sealing leaves a person to unknowingly—while providing instantaneous feedback and verified results.

EFFICIENCY SAVINGS

Greater efficiency at Ambient conditions than R-410A

5% Savings

DISCHARGE PRESSURE

Lower discharge pressure than R-410A

7% Savings

REFRIGERANT CHARGE PERFORMANCE

Less refrigerant charge than R-410A

9% Savings

NON-RESIDENTIAL DEMONSTRATIONS

Completed first year of Department of Defense demonstrations, to demonstrate this technology in non-residential applications including existing classrooms and office buildings. Up to 65% Available leaks sealed in large commercial buildings.

MUTILFAMILY SEALING DEMONSTRATIONS

Finished testing aerosol technology in 18 new construction apartments and 18 existing apartments. Up to 50% Available leaks sealed in multifamily buildings.

DEPARTMENT OF ENERGY PROJECT

Single family home-based project focused on working closely with developers to determine several optimal options for application of aerosol sealing. Direct collaboration with National Center for Energy and Environment.

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Advanced Heat Exchangers

WCEC has three projects underway related to advanced heat exchangers for power cycles. Specifically, the power cycle under consideration is a supercritical carbon dioxide (sCO₂) cycle. The sCO₂ cycle is being considered by DOE for power generation from fossil, solar, nuclear and high temperature waste heat sources. A key aspect of this cycle is the high efficiencies (on the order of 50%) obtained at moderate temperatures at the turbine inlet (on the order of 550°C) and compact turbomachinery. The efficiency of these cycles is heavily dependent on effective heat exchangers. To further this effort, WCEC is focusing on developing compact, high efficiency heat exchangers for these cycles. Unique test facilities are being developed to permit characterization of these heat exchangers at cycle operating pressures and temperatures.

PROJECT 1: MICROCHANNEL SOLAR THERMAL RECEIVER DEVELOPMENT

In this project, the team is developing the next generation of solar thermal receivers that are capable of absorbing up to 1000 suns of thermal flux at exit sCO₂ fluid temperatures of 720°C. This new solar thermal receiver, combined with smaller turbines designed to use sCO₂, take up much less space and generate more overall electricity than traditional receivers—absorbing and transporting 100W per cm². Traditional receivers can only absorb up to 60W per cm², and the turbines used in combination with traditional receivers are larger and have larger energy losses.

At UC Davis, thermal characterization of flow through such microscale passages of the receiver was performed in Phase I of the project. In Phase II, UC Davis will be characterizing the performance of a 20 kW microchannel receiver on the newly commissioned 7-meter parabolic solar dish.

PROJECT 2: MICROCHANNEL RECUPERATOR FOR INDUSTRIAL PROCESSES

In this project, a high temperature recuperator that exchanges heat between two high pressure sCO₂ streams is being developed. A 1-2 kW recuperator will be characterized in WCEC’s test facility in the coming year.

PROJECT 3: MICROCHANNEL RECUPERATOR FOR GAS TURBINES

In this project, we propose that the waste heat from the exhaust of a gas turbine be recovered and used to generate power using a sCO₂ cycle. The emphasis of this project is on design and characterization of a heat exchanger that can be placed within the exhaust stream of the turbine to recuperate heat into the sCO₂ stream.

In order to improve reliability of the heat exchangers during multiple thermal operating cycles, a monolithic recuperator using additive manufacturing is proposed. In Year 1 of the project, WCEC completed the design of a heat recuperator. A key constraint on the design is the available pressure drop on the turbine exhaust side. In order to validate the design for this constraint, a plastic 3-D printed recuperator was tested and the pressure drop results compared against the model predictions. In Year 2, performance of an additively manufactured recuperator will be characterized with sCO₂ fluid through microscale passages within the plates of the recuperator structure.
VENTILATION RATE REQUIREMENTS

EXHAUST 100CFM

EXHAUST 50CFM

Much of the behavioral work on HVAC technology adoption focuses on customers, but it is crucial to consider other stakeholders as well. The study funded by Southern California Edison, and aims to fill that gap – and look beyond the issue of high costs. This research was also presented at the 2015 Behavior, Energy and Climate Change Conference in Sacramento, CA, and at the 2016 WCEC Affiliates Forum, which can be viewed here: bit.ly/WCECMarketBarriers

A publication for the academic press is in progress.

DISSEMINATION

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Next-Generation Residential Space-Conditioning System

The focus of this project, funded by the California Energy Commission and led by the Electric Power Research Institute (EPRI), is to integrate several advanced technologies available worldwide or in the RD&D phase into a single space-conditioning system for residential buildings that is cost-effectively optimized for California’s climatic conditions.

The full project team will evaluate several technologies including automated demand response, alternative refrigerants, and heat recovery ventilators. The WCEC is under subcontract to EPRI to specifically test the performance of a variable-speed heat pump system connected to typical ductwork that is located outside of the conditioned space. The lab testing for this project is measuring the performance of the duct system and determining appropriate strategies for controlling variable-speed equipment based upon the overall system performance.

TWO-PHASE LABORATORY TESTING

In Phase I the WCEC looked at system performance for a standard single-zone duct system, and Phase II will implement zoning controls on the same duct system to reduce thermal losses in the ducts. In both cases, the air-tight ductwork experiences the same conditions as the outdoor condensing unit. These duct-zone temperatures roughly represent an average of the conditions seen by ductwork in an attic (hotter than outdoors) and in a crawlspace (cooler than outdoors). The Phase I testing for this project has shown an improved COP for the equipment when running at low speeds; however, during hot outdoor conditions the duct losses increase at lower fan speeds. In some cases the thermal losses through the duct system can negate the improvement in efficiency of the equipment when running at lower speeds.

Figure 1 and 2 present some of the results of Phase I testing. Figure 1 shows that at lower outdoor (i.e. duct-zone) air temperatures the optimal system COP occurs at lower system speeds, and as temperatures get warmer around the ductwork the optimal speed increases all the way to 100% for the hottest temperatures. Figure 2 shows the delivery effectiveness of the duct system, which is the fraction of cooling supplied by the unit that makes it to the grilles in the conditioned space. Clearly the efficiency of the duct system is strongly dependent on the speed of the system and the temperature of the space in which the ducts are located. Increasing the amount of duct insulation or locating the ducts in conditioned space would significantly improve the delivery effectiveness of this duct system.

Phase II of this project is scheduled to begin in early 2017 and will look at control strategies for improving delivery effectiveness and overall system performance, particularly at low-speed operation. The results from Phase II will also develop recommendations for appropriate automated demand response control actions. We expect that the use of zoning will be able to counteract the duct efficiency penalties associated with reduced compressor and fan speeds.
Does Evaporative Cooling Make Sense in Arid Climates?

Conventional wisdom on evaporative cooling says this technology only makes sense in hot and dry climates. And in those climates, water is scarce, particularly during periods of drought, which makes the question of whether it is worthy using evaporative cooling in the first place. Conventional wisdom does not take into account new evaporative products and cooling accessories that broaden the climatic reach of this technology. Likewise, new research shows that evaporative cooling yields, even when taking water-use in drought-prone regions into account.

To fully answer this question about evaporative cooling in arid climates, there are three phases of research this project delves into:

1. A performance metric that reflects water and energy efficiencies, the water energy performance of evaporative pre-coolers and evaporative condensing units.
2. The energy and economic cost for three different water resources (tap water, rechargeable, and produced water) before and after desalination, new evaporative products and cooling accessories that broaden the climates.
3. The energy and economic cost for three different water resources (tap water, rechargeable, and produced water) before and after desalination, new evaporative products and cooling accessories that broaden the climatic reach of this technology. Likewise, new research shows that evaporative cooling yields, even when taking water-use in drought-prone regions into account.

3. ENERGY AND ECONOMIC COST FOR THE MOST ENERGY/ COST INTENSIVE WATER GENERATION: DESALINATION

The WCEC mapped the water-use of evaporative technologies onto the most expensive form of water generation: desalination. Desalination produces 80-280 liters of potable water for every 1 kWh used. For every 1 kWh used to make water with Desalination, that same water used in evaporative cooling can save 2-10 kWh.

In terms of cost, water produced from desalination costs $1.65 per 1,000 liters. In contrast, water with desalination can save $1.25-$25 in electricity cost savings, depending on the technology employed and the local cost of electricity.

DEMAND RESPONSE WITH EVAPORATIVE PRE-COOLERS

Evaporative pre-coolers process the largest energy savings impact during peak electricity demand times, and water use efficiency is highest during those hours of the day. A holistic solution could be to run evaporative pre-coolers as part of a demand response program in the day where demand peaking results in pinch point demand reduction. Likewise, desalination can operate at right when electricity demand is low. WCEC is currently working on a project to test evaporative pre-coolers as a utility-dispatchable demand reduction technique.

Every $1 invested in creating water through desalination can yield $1.20-$25 in electricity cost savings using evaporative technologies.

Sub Wet-Bulb Evaporative Chillers (SWEC) for Building Cooling Systems

The SWEC technology uses an evaporative cooling process to chill water for use in building cooling systems. The SWEC designs tested utilized multi-stage indirect evaporative cooling designs to chill water below the wet-bulb temperature for the supply water temperature. The results reveal that under higher wet-bulb temperatures, the SWEC technology can produce chilled water at temperatures between 60 and 67°F, which is desirable for serving a radiant cooling system with efficiency as much higher than vapor compressor air conditioning systems.

The performance of the tested SWEC chillers illustrates a large energy savings potential in hot dry climates. The results also revealed that, under a wide range of weather conditions, the SWEC technology can produce chilled water at temperatures between 60 to 67°F, which is desirable for serving a radiant cooling system with efficiency as much higher than vapor compressor air conditioning systems.

COST INTENSIVE WATER GENERATION: DESALINATION

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Energy-Efficient Clothes Dryers: Automatic Cycle Termination Controller

In the interests of promoting energy efficiency and satisfying consumers, there has been a move toward automatic termination controllers in residential dryers, which use some method of sensing to determine when the load is dry. However, available test data shows that these control systems do not fare well when their energy efficiency performance is measured.

This project, funded by the California Energy Commission’s Energy Innovation Small Grant Program, developed an automatic dryer cycle termination controller that utilizes the relationship between dryer drum inlet temperatures and outlet temperatures to accurately predict the end of the drying cycle. The technology promises to be more accurate and robust in performance under different load and environmental conditions in comparison to existing technology. The low-cost automatic controller was demonstrated in the laboratory to reduce energy use in gas clothes dryers by accurately terminating the drying cycle. In addition, information obtained in the drying cycle can be used to predict real-time energy efficiency metrics to track dryer performance over time as a means for fault detection and to provide information to the consumer.

PERFORMANCE RESULTS

In a standard DOE test conducted three times, the controller shut-off the dryer when 2% remaining content was predicted and measured results showed a remaining moisture content of 1.62%, 1.89%, and 1.93% for the three tests. For drying the DOE standard load, the controller used between 5-15% less total energy in comparison to three similar gas dryers tested by DOE. The research team calculated that the controller shut-off the dryer within seven seconds of when the dryer reached the desired 2% remaining-moisture target.

The research team ran 16 additional tests evaluating the controller over a variety of conditions in which room temperature conditions were varied and load type and size were varied. One test was excluded because a large amount of lint was collected in the drying process which affected the ability to accurately weigh the load at the end of the cycle. For these 15 tests, the results varied between 1.3 - 6.7% remaining moisture content. All but one test had a remaining moisture content between 1.31 - 5%, where 5% is higher than the DOE test standard of 2%, however, would still be considered “dry” by consumers. The energy consumed for the drying cycles varied between 1.40-4.13 kWh, where the energy consumption was a function of the size and composition of the load. More details are available in the case study, “Energy Efficient Clothes Dryers: Automatic Cycle Termination Controller” available here: bit.ly/dryercasestudy

PATH FORWARD

WCEC seeks a commercial partner to license the technology and implement it in commercial dryers. WCEC has received additional funding from Sacramento Municipal Utility District to test the controller in electric dryers to supplement the testing completed with a gas dryer. The research team also plans to develop the real-time energy efficiency reporting metrics and fault detection capabilities of the technology.
Hybrid air conditioners incorporate the advantages of various cooling components in variable speed, multi-mode, machines. These systems are climate appropriate energy measures that recognize how cooling needs and efficiency opportunities are different in each region. With funding from the Department of Energy and Southern California Edison, and in collaboration with several industry partners, UC Davis students are developing modeling tools to support broader application of climate appropriate hybrid air conditioners.

- Developed a standard format for representation of performance data for unitary hybrid air conditioning equipment.
- In collaboration with industry partners, we developed custom models for three hybrid air conditioning systems (Seeley ClimateWizard, Munters EPX5000, Trane Voyager DC).
- Developed an EnergyPlus module for “Unitary Hybrid Air Conditioners.” Currently we have a development branch of EnergyPlus with a functional prototype for the model.
- Facilitated a three day project workshop at NREL in September:
  - Undergraduate research fellows presented about custom models they developed for indirect evaporative and hybrid air conditioning equipment
  - Introduced students and manufacturer collaborators to low energy building design concepts
- Sponsored a capstone mechanical engineering design project which developed an EnergyPlus model of Zero Net Energy office building and explored the optimization of design parameters.
- Facilitated a graduate-level journal review seminar on building energy efficiency research and technology.

Field Performance Test of Indirect Evaporative Coolers on Cellular Sites

Through funding from Southern California Edison, WCEC installed two different Indirect Evaporative Coolers (IECs) at two different cellular sites in Placentia and Cudahy, California and monitored these installations over a 9-month period. Indirect evaporative cooling is an efficient method of cooling in California’s hot and dry climates. It is different from a direct evaporative cooler in three significant ways, including:

- It does not add moisture to the conditioned space;
- It can cool to a lower temperature; and
- It exhausts a portion of the air moved.

RESULTS

Results from this field test compare the conventional air conditioners installed on these buildings to the indirect evaporative coolers. The indirect evaporative coolers showed a coefficient of performance increase of 2x - 10x the efficiency of the traditional, installed DX systems.

RECOMMENDATIONS

The research team recommends IECs as an impactful measure to reduce energy consumption and peak demand for cooling in commercial buildings. However, the team also recommends that utility efficiency programs, and other efforts to advance the technology, should remain cognizant of some of the challenges that can hinder performance and limit the persistence of savings. It is especially important that any installation of this measure be paired with a quality service agreement. For this specific field test, the cellular telephone company had a standing service contract.

Read the full report: bit.ly/IDECcellular

DATA AND INFORMATION FLOW

Manufacturers input performance data into the Technology Performance Exchange including nominal info and performance maps for each mode. Then the data is compiled, and translated into a format for use in EnergyPlus. The data’s performance curves will be transferable to modeling users on the Building Component Library.

THE HYBRID AIR CONDITIONER MODELING TEAM: (LEFT TO RIGHT) YUANXIAN CHEN, YITIAN LIANG, NICHOLAS CABREN, JONATHAN WOOLLEY, & KYLE CHEUNG

The Hybrid Air Conditioner: Industrial to Smart, Sustainable Cooling. Keynote Remarks & A Call Out
Indoor farming operations do not require the typical ratio of sensible cooling (which maintains air temperature) and latent cooling (which maintains humidity levels) required for residential or commercial buildings. In order to meet these specialized requirements, dehumidification systems are often necessary.

Traditional dehumidification systems provide dehumidification and increase the air temperature, as opposed to the desired dehumidification and reduction of air temperature. An alternative is MSP Technology’s dehumidification system that uses a plate air-to-air heat exchanger and a cooling coil that is part of a split-compressor-based refrigeration system. This process results in a ratio of sensible to latent cooling that is well suited for indoor farming applications.

Through a project funded by Xcel Energy, experimental laboratory testing and numerical modeling were performed to estimate the annual energy savings produced by using MSP Technology’s dehumidification system over a traditional dehumidification system. The results of this project forecast that implementation of MSP Technology’s system has potential to save 30% or more of the energy used for dehumidification and cooling in indoor farming applications.

Download the Case Study: http://bit.ly/mspcasestudy

WHAT’S NEXT
Field Testing – WCEC recommends conducting field testing of the technology to further assess and quantify the energy savings that can be achieved with the new MSP Technology’s dehumidification system.

Indoor Agriculture Industry – Due to the recent legalization of recreational cannabis in California, there will be an increase in indoor cultivation of the crop. Therefore, this technology will become more important than ever to reduce the high energy consumption associated with indoor cannabis cultivation.
Pacific Rim Thermal Engineering Conference: Design of Compact Heat Exchangers for Supercritical Carbon Dioxide Cycles

Pacific Rim Thermal Engineering Conference: Dynamics of Heat Transfer During Bubble Ebullition from a Microheater

Department of Defense Presentation: Automated Annual Sealing of Buildings Envelopes

Mandela Washington Fellowship Tour

ASHRAE Conference, Orlando: Subcommittee Chair SPC312, SPC315, ASHRAE Standards Committee, Technical Committee 5.7

Pacific Rim Thermal Engineering Conference: Directional Condensate Motion of Highly Wetting Fluids on An Asymmetrically Structured Surface

Singapore Meeting: Annual Sealing of Ducts, Buildings and Other Enclosures

ASHRAE Conference, St. Louis: Subcommittee Chair SPC312, SPC315, ASHRAE Standards Committee, Technical Committee 5.7

ACEEE Conference: Cooling Strategies: Japan vs. the U.S.

Delegation from Japan

Department of Defense Presentation: Automated Annual Sealing of Buildings Envelopes

ACEEE Conference: Annual Sealing

ACEEE Conference: Outside the Box: Climate Appropriate Hybrid Air Conditioning as a Paradigm Shift for Commercial Building Packaged Units

ACEEE Conference: Cooling Strategies: Japan vs. the U.S.

Delegation from Ukraine

BECC Conference: Cooling Strategies: Japan vs. the U.S.

Presentation and WCEC Tour for California Assemblymember Bill Quirk

U.S. Navy: Design of Compact Heat Exchangers for Supercritical Carbon Dioxide Cycle / Dynamics of Heat Transfer During Bubble Ebullition

Mansour Information: Design of Highly Wetting Fluids on An Asymmetrically Structured Surface

Center for the Built Environment, UC Berkeley: Scholarly Sensing Learning Thermostats

Mark Modera
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WCEC YEAR-IN-REVIEW 2014-2015

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Thank you to our Affiliates & Partners

Aeroseal®
Air2O
American Honda Motor Co, Inc.*
California Energy Commission
Carel®
Carrier Corporation®
Coolerado®
Daikin Industries, Ltd.*
Davis Energy Group*
E-Source
Evaporcool®
Integrated Comfort, Inc.*
Los Angeles Department of Water & Power
Munters® Corporation*

Pacific Gas and Electric Company®
Sacramento Municipal Utilities District
Seeley International Pty. Ltd.*
Sempra Energy® Utilities
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