Improving Market Conditions for Increased Adoption of Ground-Source Heat Pumps

Vinod Narayanan, Antash Najib, Curtis Harrington // Sponsor: CEC

Ground-coupled heat pumps reduce cooling load in summer and heating load in winter by taking advantage of the more stable and moderate ambient temperatures of the ground. By exchanging heat at the mild temperatures found deep in the soil, ground-coupled heat pumps transcend the performance limitations of air-source systems, saving energy and providing a carbon-free way to heat and cool homes.

Purpose

Ground-coupled heat pumps come in a variety of geometries and configurations. The goal of this project is to improve market conditions for increased adoption of ground-source heat pumps in California by identifying optimal designs for low-cost, shallow bore helical ground heat exchangers (GHEs) and providing the engineering information and installation guidance that is needed.

Progress

This past year, WCEC researchers and collaborators developed and calibrated a computational model for the shallow bore helical GHE. The model uses electrical analogies of capacitance and resistance (CaRM) to describe the heat transfer in the ground source heat pump system.

Researchers validated the model by comparing results with those reported in the literature and from field data. In addition, researchers developed a computational fluid dynamics (CFD) model to test other design variables that the CaRM model was unable to simulate.

Path Forward

Once validation of the CaRM model is complete, researchers will prepare and conduct controlled tests of a newly installed GHE design that is based on the model. These tests will be used as a final validation of the model.

Collaborators:
Frontier Energy:
Peter Grant, David Springer

University of Padova, Italy:
Angelo Zarrella

Whitebox Technologies:
Joe Huang, Moncef Krarti

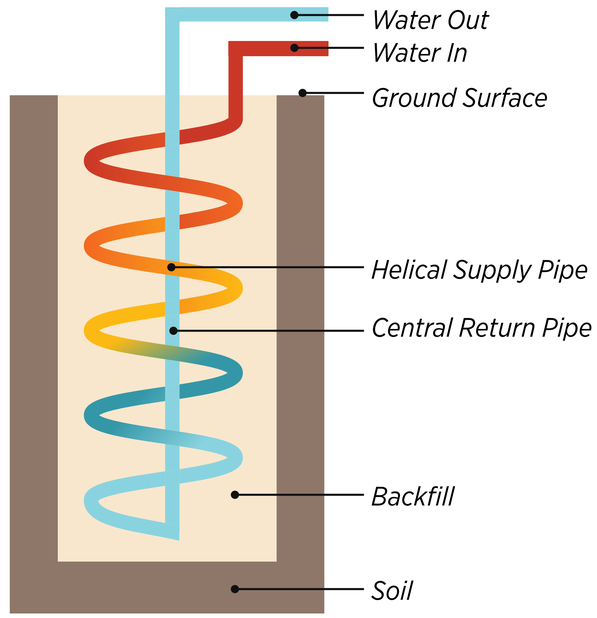
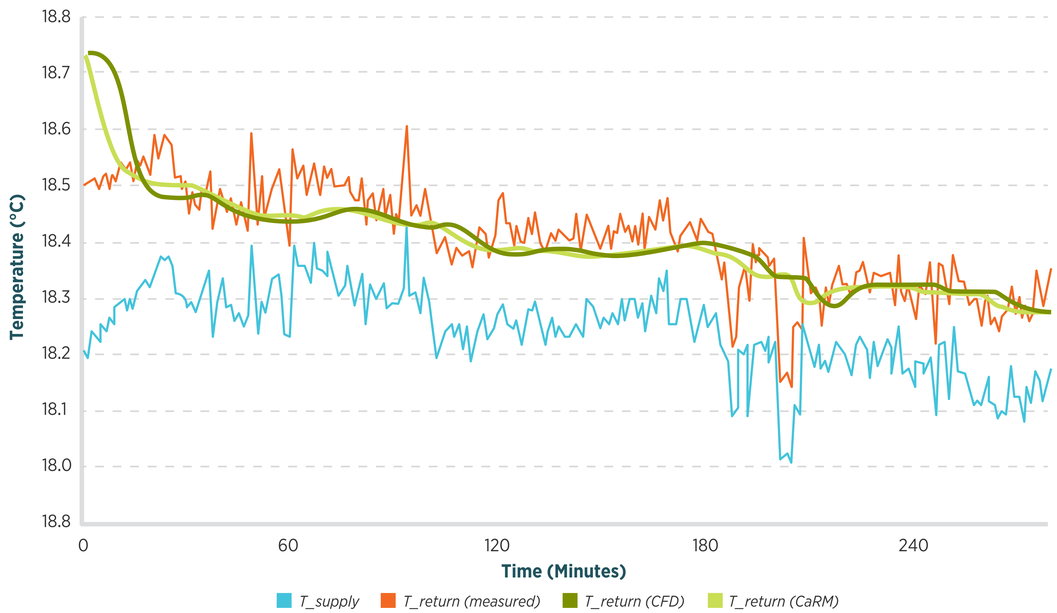


Diagram of the helical GHE modeled in this project. The design corresponds to the existing GHE installation at the field site where data was collected to validate the model. As shown, the heat transfer fluid (water in this case) is supplied to the GHE through the helical section of the pipe and returned through the middle, straight section of the pipe.



CaRM and CFD model predict return temperatures from the GHE within 0.20% of each other

Aerosolized Sealant for Building Envelopes

Curtis Harrington, Mark Modera, Daniel Reif, Jose Garcia // Sponsors: DoD, DoE, Building America

Air leaks in buildings waste energy and can cause moisture and indoor air quality problems. Current methods for tightening building shells have relied primarily on manual sealing methods that are labor intensive and often insufficient, particularly in retrofit applications. The WCEC is testing an aerosol envelope sealing process, AeroBarrier, to improve sealing effectiveness, reduce labor costs, and remove contractor inconsistency. This past year, the WCEC demonstrated AeroBarrier in both commercial buildings and new single-family homes.

How it Works

AeroBarrier involves pressurizing a building while applying an aerosol “fog” to the interior. As the air escapes through leaks in the shell of the building, the aerosolized sealant is transported to the leaks, and seals them as the particles try to escape from the building.

Military Facility Retrofits

WCEC researchers performed retrofit sealing work for a project funded by the Department of Defense ESTCP program. The objective was to validate AeroBarrier as a cost-effective means to meet US Army Corps of Engineers (USACE) tightness requirements for military facilities. Researchers sealed various building types, in varied climates, to show the ability of the technology to be applied on a large scale. The WCEC also conducted lab testing of seal durability and modeled the impact tighter envelopes have on energy use in these facilities. **Seals could withstand 5,000 Pa of pressure.**

Researchers found that AeroBarrier is very effective at sealing building leaks on DoD facilities. **Ultimately, over 50% of the air leakage was sealed over sixteen demonstration buildings.**

New Homes Demonstration

The AeroBarrier demonstrations for the Building America project sealed 79% of the available leakage in the homes. The aerosol process also sealed homes 56% tighter than the homes sealed with conventional open-cell spray foam, allowing the builder the flexibility to choose a more cost-effective insulation material.

The sealing process required access to the home for about four hours with only 1-3 hours of actual sealing time.

Considering the level of air tightness achieved with AeroBarrier and the amount of effort currently employed to reduce air leakage in the homes, it is likely that other manual sealing efforts could be eliminated saving on cost of construction, while also achieving superior and more consistent air tightness.

Using Waste-Heat from an Air Conditioner to Heat a Swimming Pool

Theresa Pistochini, Jose Garcia, Rachael Larson, Robbie McMurry // Sponsor: SDG&E

Air conditioning loads drive peak demand and contribute to overall electric power consumption in California. In the summer, cooling loads are highest in the middle of the day when air conditioners are the least efficient. Rejecting waste heat from an air conditioner to a swimming pool rather than to the outside air can significantly reduce electricity demand. At the same time, pool heating costs can be reduced by supplementing or replacing a natural gas pool heater with heat rejected from an air conditioner.

Purpose

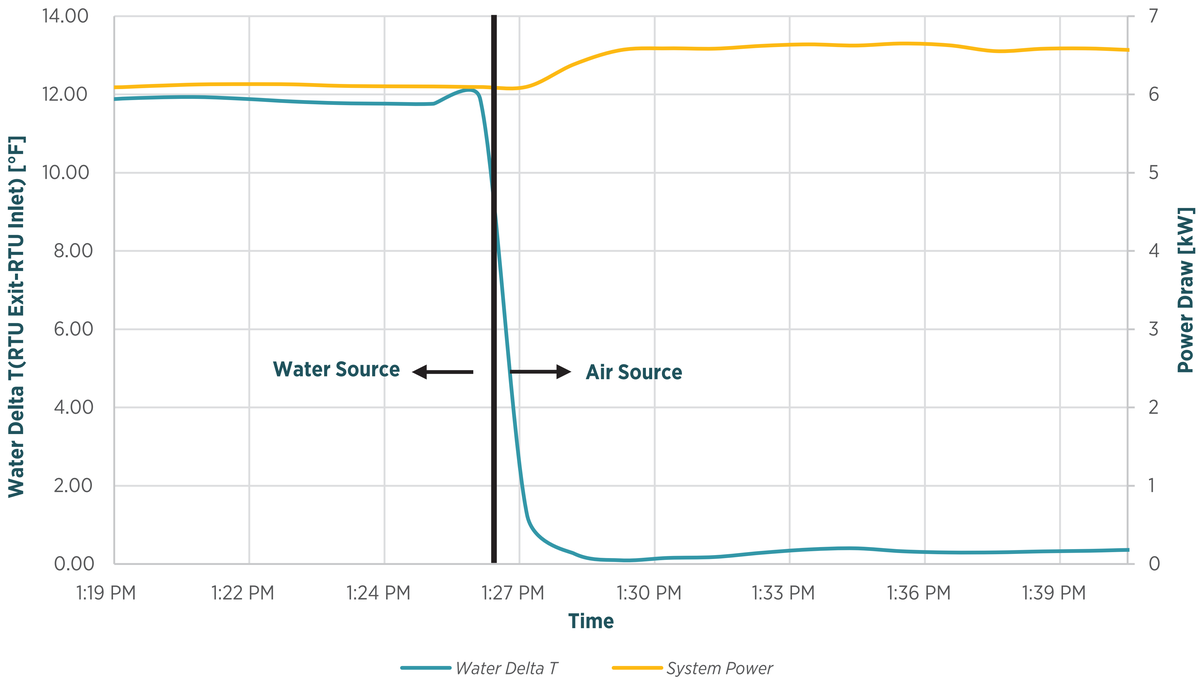
The WCEC examined the impact of rejecting air conditioner waste heat to a swimming pool and compared the results to a conventional system that rejected heat to the air. Researchers built a custom rooftop unit (RTU) at the Wyndham San Diego Bayside hotel. This RTU conditioned a small fitness center while rejecting waste heat to the adjacent pool. The WCEC documented energy savings and demand reduction.

Results

The climate in San Diego was mild compared to many inland locations, with maximum outdoor air temperatures rarely exceeding 90°F during the 4-week study period. Despite these mild temperatures, the electricity demand reduction was as high as 12% when switching from the conventional heat rejection mode to pool heat rejection mode. The average electricity savings was about 5% and the natural gas savings was about 29%.

Path Forward

To increase adoption of technology that rejects waste heat to pools and provide appropriate utility program incentives, modeling the impact of the technology as a function of climate, pool size, air conditioner capacity, and air conditioner load factor is needed. The results from this project could provide an excellent data source to verify model accuracy.



29% REDUCTION IN POOL HEATER GAS USE

5% REDUCTION IN COOLING ENERGY USE

12% REDUCTION IN PEAK DEMAND

WCEC WESTERN COOLING EFFICIENCY CENTER

UCDAVIS

Next Generation Residential Space-Conditioning System

Sreenidhi Krishnamoorthy, Curtis Harrington, Mark Modera // Sponsor: CEC
Collaborators: Daikin, EPRI

Space conditioning systems can have a profound impact on comfort and energy efficiency. The Electric Power Research Institute, funded by the California Energy Commission, is integrating several advanced technologies into a single space-conditioning system for residential buildings that is cost-effectively optimized for California's climatic conditions. As part of this project, the WCEC is testing one of these advanced technologies–a variable speed heat pump system.

Laboratory Testing

The WCEC evaluated the impact that a typical residential duct system, located outside the conditioned space (e.g., in the attic), had on system performance. In Phase I, researchers tested system performance in the laboratory under a single-zone configuration. In Phase II, researchers tested system performance under a multi-zone configuration.

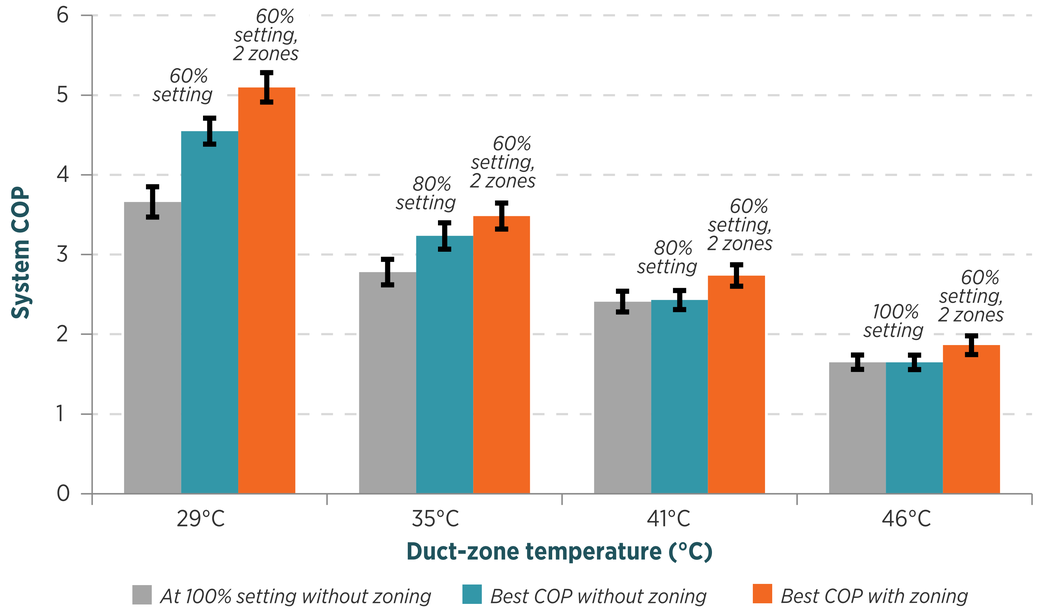
Results

Researchers found that zoning was very effective at maintaining system performance under part-load conditions. With a single-zone configuration, there were significant duct heat gains at lower speeds, and even though equipment performance generally improves at lower speeds, researchers found that at hot duct zone temperatures optimal performance occurred at high speeds. Adding zoning capability significantly improved system performance at lower speeds by essentially maintaining duct velocities by matching the fraction of capacity to the fraction of the duct system served. For example, if the system was running at 50% speed, cooling was delivered to only 50% of the zones.

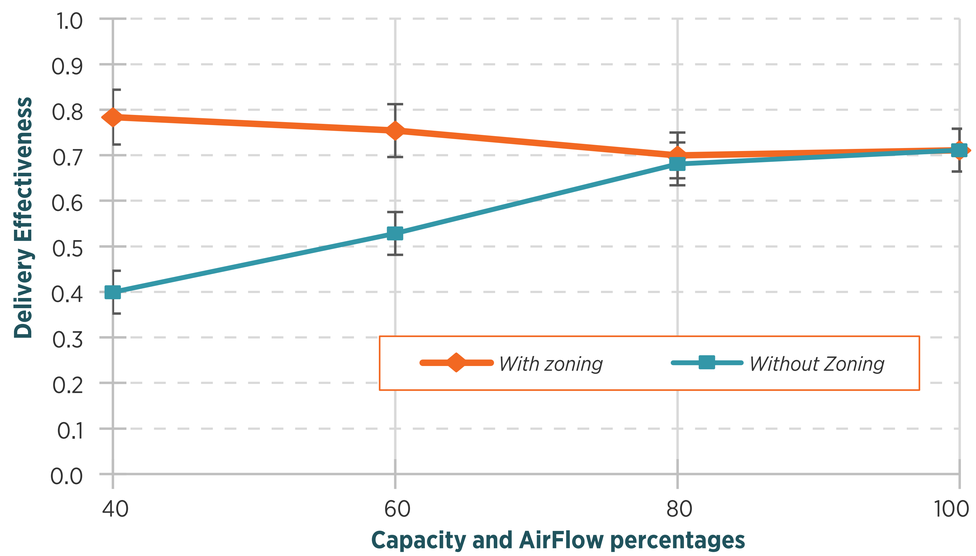
Path Forward

The WCEC will field test the space conditioning system. Researchers will install and monitor three homes in different California climates zones with a variable speed heat pump over the summer of 2018.

Delivery Effectiveness versus Capacity/Airflow percentages for zoning and non-zoning configurations for a duct-zone temperature of 46°C



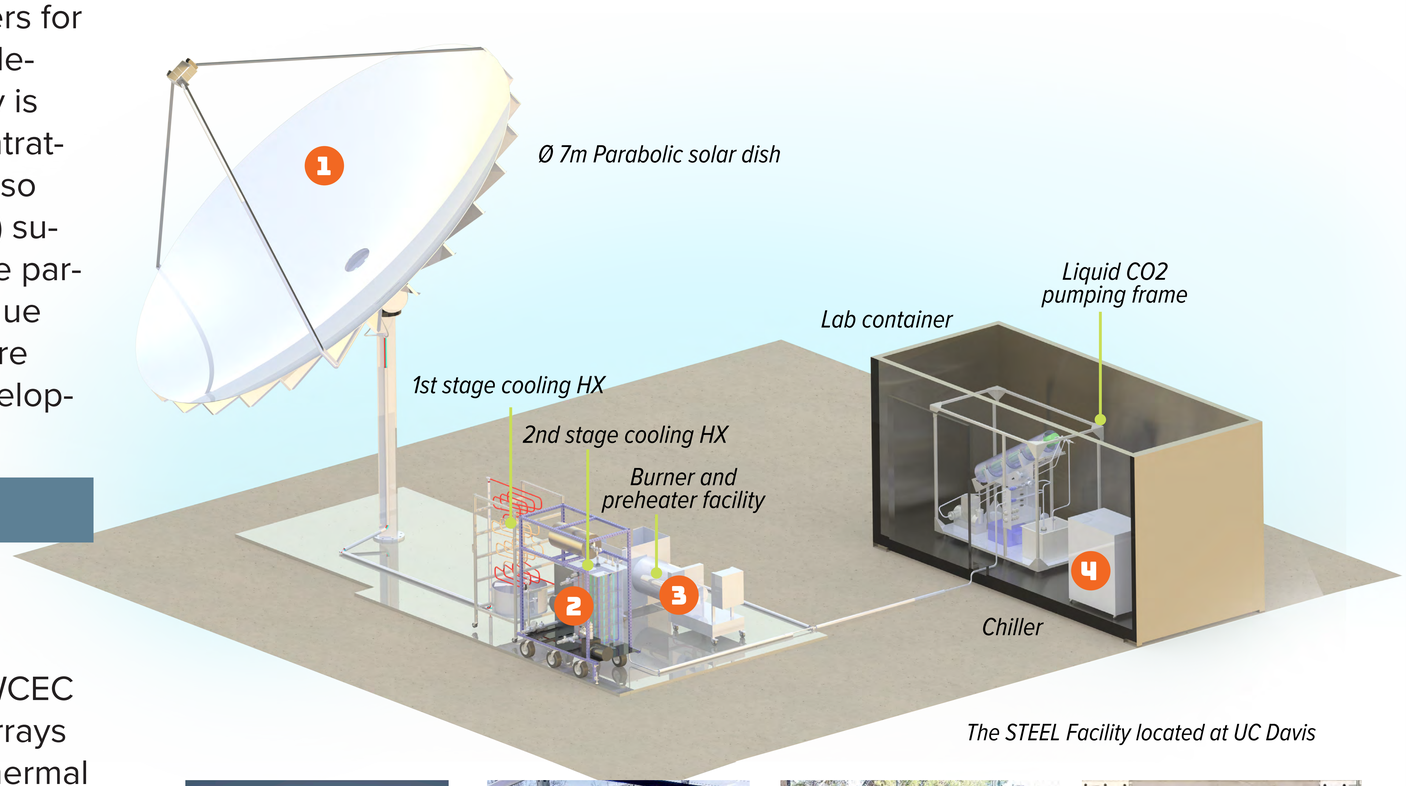
System COP versus duct-zone temperature for different operating modes. Setting refers to capacity/airflow percentages



Solar Thermal and Energy Enhancement Laboratory (STEEL)

Erfan Rasouli, Caton Mande, Matt Stevens, Vinod Narayanan // Sponsor: DoE, ONR

The WCEC is developing the Solar Thermal and Energy Enhancement Laboratory (STEEL) to further research in advanced heat exchangers for a variety of applications such as solar power generation, thermal desalination, waste heat utilization, and solar fuels. The STEEL facility is equipped with a 7-m parabolic solar dish that is capable of concentrating sunlight by nearly 1000 times at the focal area. The facility is also home to a high pressure (200 bar), high temperature (up to 700 C) supercritical carbon dioxide (sCO2) flow loop. The combination of the parabolic dish and the sCO2 loop give the UC Davis STEEL lab a unique set of capabilities in the area of high temperature and high pressure heat transfer research, along with heat exchanger technology development.

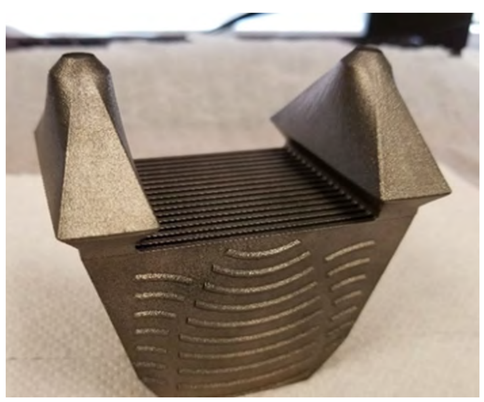


The STEEL Facility located at UC Davis

Ongoing Projects at the STEEL Site

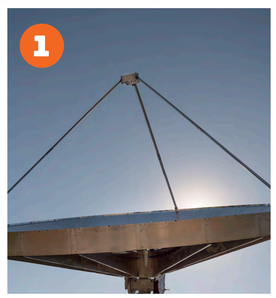
Microchannel solar receiver development

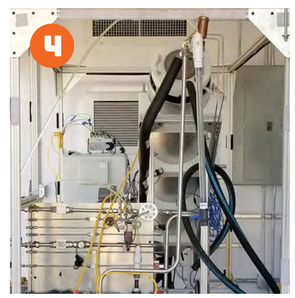
Oregon State University (OSU) developed a solar thermal receiver based on flow of sCO2 through microchannel pin fin arrays. The WCEC characterized the heat transfer performance of flow through the arrays using surrogate fluids and developed correlations to predict the thermal performance. Researchers are currently preparing to test a 15 cm x 15 cm receiver developed by OSU.



Microchannel waste heat recuperator for sCO2 cycles

Through a collaboration between UC Davis and Carnegie Mellon University, researchers designed and fabricated a novel additively-manufactured heat exchanger for application in waste heat recovery and for indirect fossil-fired sCO2 cycles.





Journal Article:
http://bit.ly/PitchAspectMicroscale

Valuation of Thermal Energy Storage for Utility Grid Operators

Nelson Dichter, Mark Modera // Sponsor: Trane

Most air conditioning systems remove heat from a chilled water network or directly from an air stream to produce a cooling effect at precisely the time that cooling is needed. Thermal energy storage (TES) systems operate like air conditioning systems except that they remove heat from an intermediate substance (e.g., water, ice or eutectic salt solutions) at a time when the building doesn't actually need cooling. In this way, cooling is stored before it is needed, giving TES systems the ability to change demand on the electric grid.

To improve information on TES systems, the WCEC used whole-building simulations to evaluate the standard method for estimating the electric grid impact of TES systems. The current method is based on a "10-day average baseline" where the value provided by the TES system for a given hour is defined as the difference between the average energy use of the building for that hour over the past ten similar days and the measured energy use for that hour.

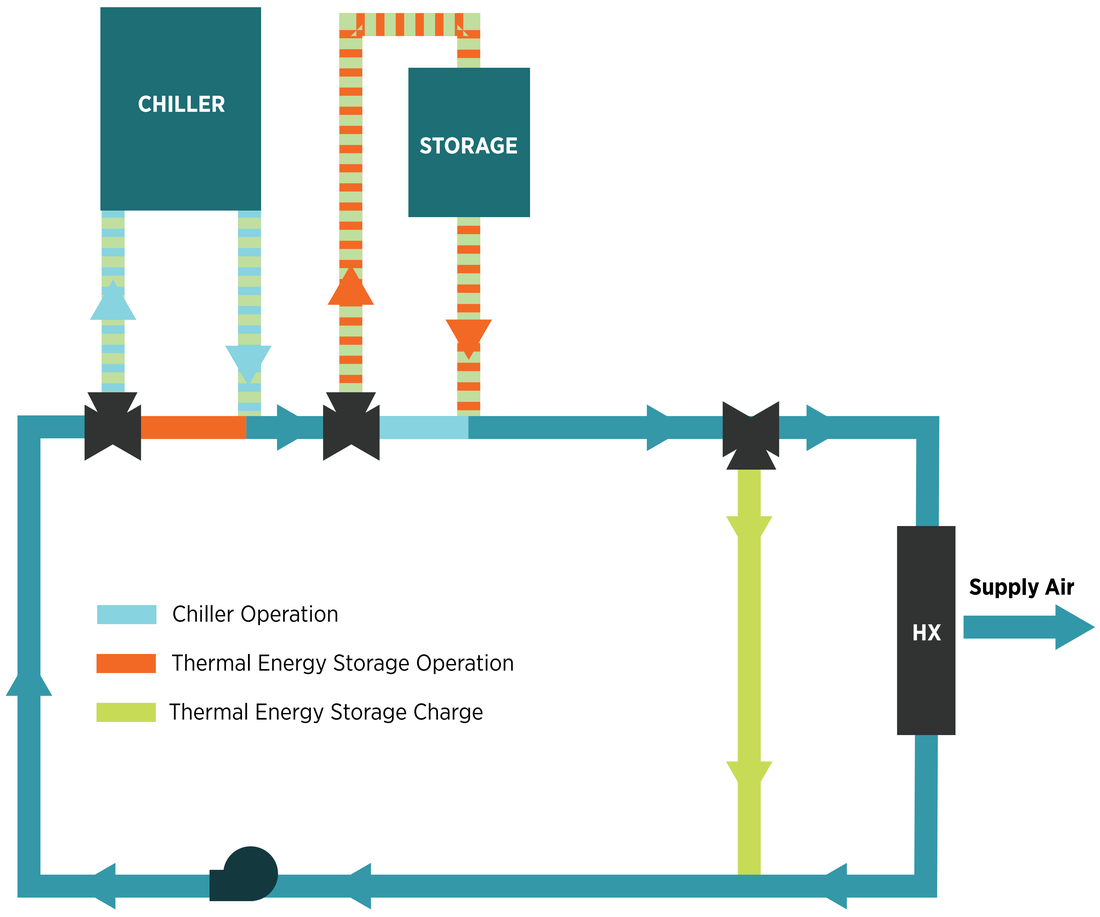
Progress: Simulations

The WCEC performed simulations for four building types and five types of cooling systems in three California climate zones. Researchers input the cooling loads and ambient weather conditions into a post-processor that calculated the electric-grid impacts incurred from meeting the loads for each type of cooling system, as compared to using a TES system. Researchers then applied the "10-day average baseline" method to simulation results and compared the predicted baseline to the "actual" simulated electricity consumption.

Results

The WCEC found that the **10-day average baseline consistently under-predicted the impact that a TES system would have on the electric grid by as much as 77%, between 38% and 57% on average, and by a minimum of 3%.**

Case Study:
http://bit.ly/WCECcaseStudyTES



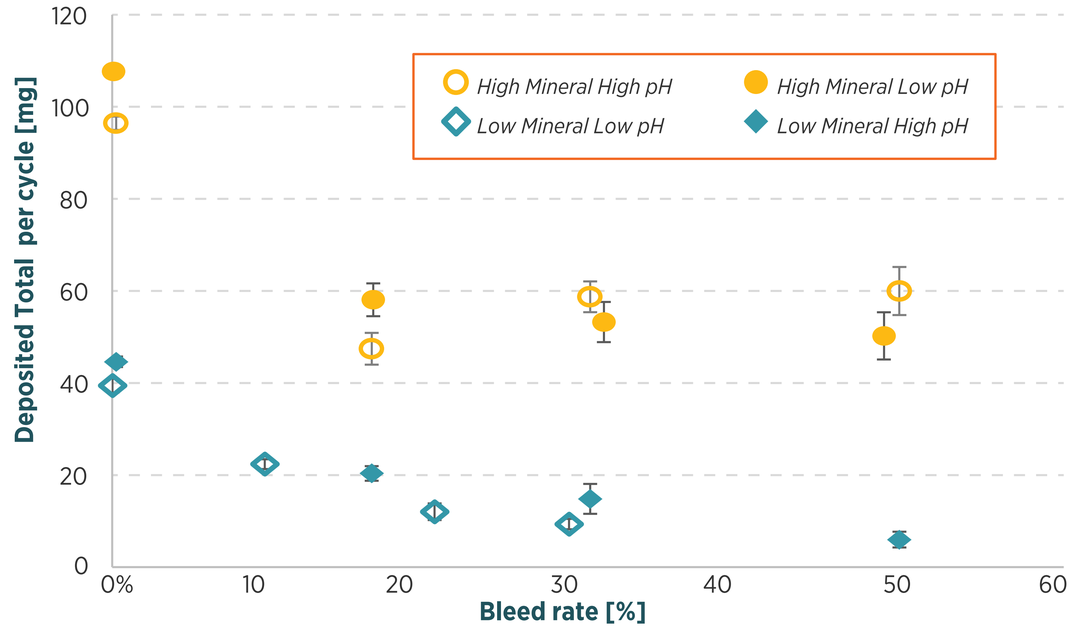
Flow diagram of chiller and thermal energy storage (TES) operation

AVERAGE PREDICTION ERROR OF THE 10-DAY AVERAGE BASELINE

		Direct-Expansion RTU	Air-Cooled Constant-Speed Chiller	Air-Cooled Variable-Speed Chiller	Water Cooled Constant-Speed Chiller	Water Cooled Variable-Speed Chiller
Burbank	Large Office	41%	54%	54%	45%	47%
	Big-box retail	41%	55%	56%	49%	52%
	Hospital	33%	44%	44%	35%	34%
Riverside	Large Office	41%	54%	54%	45%	47%
	Big-box retail	34%	48%	48%	45%	46%
	Hospital	29%	40%	41%	37%	33%
Sacramento	Large Office	38%	54%	53%	47%	57%
	Big-box retail	30%	43%	43%	38%	50%
	Hospital	23%	34%	34%	27%	33%

Water Management for Evaporative Condensing Units

Mark Modera, Nasim Tajmand, Theresa Pistochini // Sponsor: SCE



Total deposited minerals for 25th percentile and 75th percentile water as a function of bleed rate

There is a huge potential for evaporative cooling systems to reduce both peak electricity demand and energy use in California's hot and dry climate, however the technology is not widely used.

Water management of evaporative cooling units is essential and particular care must be taken to reduce the effects of hard water on the system, often resulting in the use of additional water (or a bleed-off) to reduce mineral precipitation and maintain the longevity of these units.

Progress

The WCEC tested four representative water compositions in California, that varied in their pH and mineral content, with four different bleed rates to determine the impact on mineral deposits in the system. Researchers also investigated whether evaporative cooling makes sense in California by analyzing a worst-case scenario where water used for evaporative cooling was produced using desalination, an energy intensive process. Finally, the WCEC analyzed the potential for using rainwater in evaporative cooling systems.

Results

In examining water composition and bleed rates, the WCEC found that: **1) the pH of the inlet water does not impact mineral deposition significantly, and 2) increasing the bleed rate beyond roughly 15% does not reduce deposited minerals for high-mineral-content water, and the deposition decreases are probably immaterial for low-mineral water.**

Researchers also found that evaporative cooling does make sense in California, even when desalinated water is used. Investing 1 kWh of electricity into desalination, followed by reinvesting that water in evaporative condensers, yielded roughly 7 kWh of electricity savings (including 15% maintenance water usage).

Improving Water and Energy Efficiency in California's Dairy Industry

Theresa Pistochini, Cassandra Tucker, Alycia Drwencke, Vinod Narayanan, Matt Stevens // Sponsor: CEC

It is critical to keep dairy cows cool during California's hot summers. Standard cooling methods, however, such as fans and spraying cows with water, require substantial amounts of electricity and water. With the goal of reducing electricity and water consumption, the UC Davis Western Cooling Efficiency Center and the Department of Animal Science tested three novel approaches for cooling dairy cows in California. Researchers measured energy and water use and monitored the cows to determine the impact of the treatments, including body temperature, respiration rate, and milk production.

Results

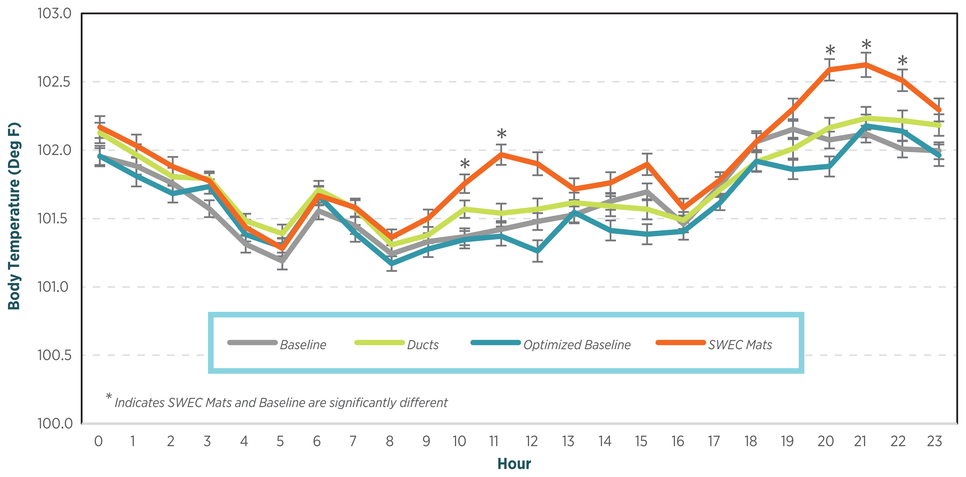
The results indicate that the Conduction Cooling Mats did not effectively reduce early indicators of heat stress in the cows in comparison to the Baseline. In contrast, both Convection Cooling Ducts and Optimized Baseline were effective.

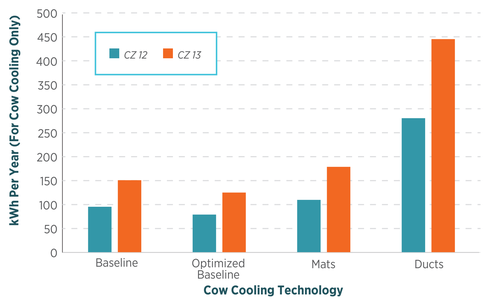
Researchers found that the all cooling methods tested saved water in comparison to the baseline, however, the Convection Cooling "Ducts" used more electricity than anticipated. Researchers are determining if higher efficiency fans could reduce the "Ducts" energy use by at least half.

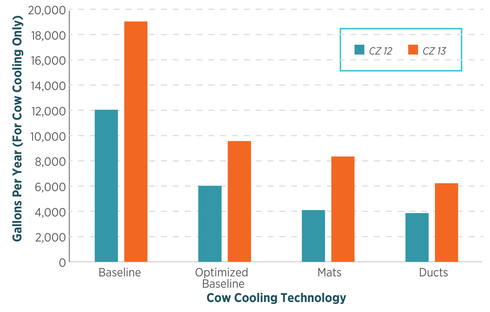
Path Forward

The WCEC will conduct a detailed analysis of the convection cooling "ducts" to determine if energy savings are possible. Researchers will also focus on optimizing traditional fans and sprayers. Additional field testing will take place in summer 2019.

Installation of the convection cooling duct system and direct evaporative cooler

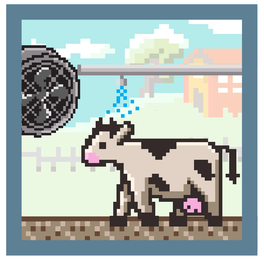






Four Cooling Methods Used

1. Baseline: A fan in the bed area and sprayers in the feed area.



2. "Optimized" Baseline: A fan and sprayers in the feed area.

3. Conduction Cooling "Mats": The bed area is cooled using heat exchange mats. Water flowing through the mats is cooled through a novel evaporative chiller. This method is supplemented by Baseline cooling at high temperatures.

4. Convection Cooling "Ducts": Fabric ducting directs cool air onto the cows in the bed and feed areas. The air is cooled using a high-efficiency direct evaporative cooler. This method is supplemented by Sprayers at high temperatures.

WCEC WESTERN COOLING EFFICIENCY CENTER

UCDAVIS

Using Information to Address Market Barriers to Adoption of Evaporative Cooling Technologies

Sarah Outcault, Paul Fortunato, Jennifer Kutzleb, Angela Sanguinetti // Sponsor: SCE

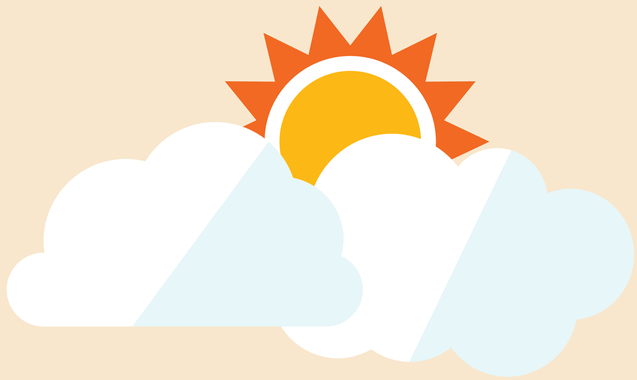
Collaborators: Seeley, ICI, Munters

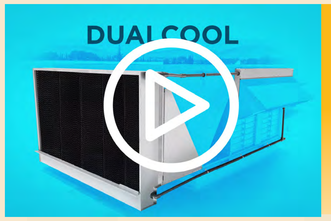
Many stakeholder groups in the HVAC industry have a negative view of evaporative cooling because of low-quality products of the past. One of the barriers to changing these views is the lack of knowledge about today's high-quality evaporative cooling products. The WCEC tested two different information platforms to identify the attributes that best address this knowledge gap.

Progress

Based on previous research, the WCEC created a series of three videos, each featuring a single evaporative cooling technology. The videos provided information on how the technology works, evidence of technical performance, and cost and energy savings estimates. In addition, each video featured one or two testimonials from individuals who work with the technology.

Individuals from across the HVAC industry in California were recruited to participate in the study. Each was asked a series of initial survey questions, and then assigned to review information on one of the three technologies. Each group of three was further split, randomly assigned to either watch a video or review the website featuring the technology. After reviewing the information provided, participants answered another series of questions on their awareness, attitude, and interest in the relevant technology. Results from both groups' pre- and post- information are being evaluated and compared to assess the relative effectiveness of each platform.

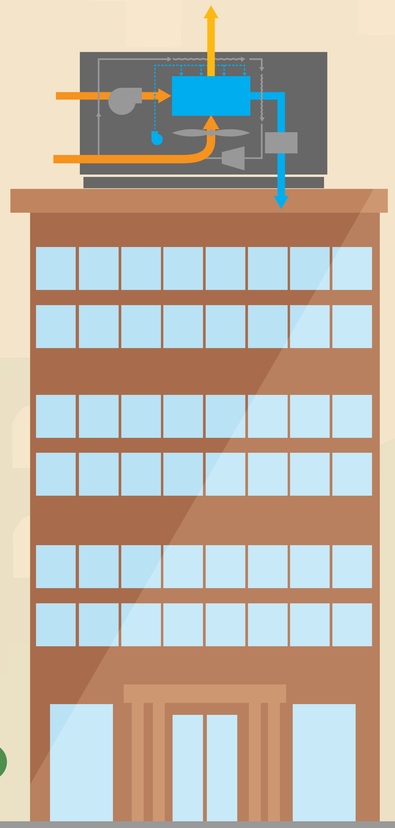




WATCH VIDEO:
http://bit.ly/WCEC_DC

WATCH VIDEO:
http://bit.ly/CWvideo2

WATCH VIDEO:
http://bit.ly/WCEC_Munters



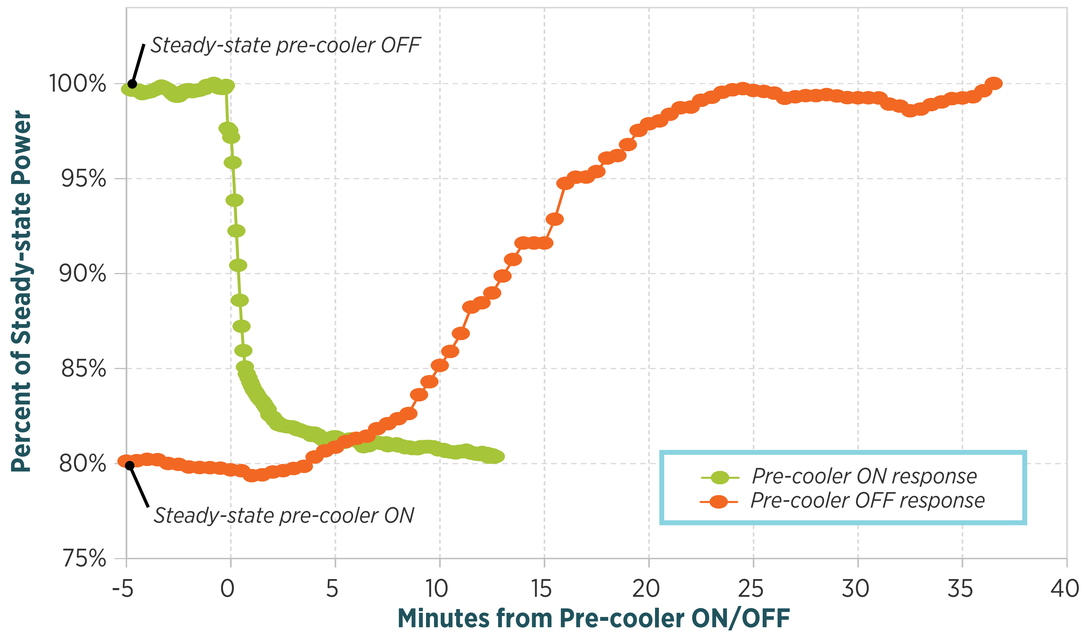
Field Performance of Dispatchable Pre-Coolers

Caton Mande, Theresa Pistochini, Derrick Ross, Robert McMurry // Sponsor: SCE

Condenser-air pre-coolers evaporate water into the airstream used for heat rejection from an air conditioning system. The evaporative process reduces the air temperature and allows the air conditioner to operate more efficiently at higher outdoor air temperatures. WCEC's previous work has illustrated the energy and demand savings potential of condenser-air pre-coolers in the hot-dry California climate. In this project, researchers evaluated the performance of condenser-air pre-coolers being used as a dispatchable asset to reduce electrical demand during peak demand events.

WCEC evaluated the transient response from turning on a condenser-air pre-cooler to achieve load reduction in a laboratory and field setting. The response time is a key factor in deciding if pre-coolers are a practical tool for achieving dispatchable demand reduction. Laboratory testing measured the time response impact of a pre-cooler installed on a 4-ton RTU during startup, operation, and shut down of the pre-cooler. Field testing was conducted between July-October 2017 on a big box retail store in Corona, CA. The store had six RTUs with existing pre-coolers and an additional five RTUs were retrofitted with condenser-air pre-coolers as part of the project. WCEC simulated over 25 demand events that lasted from 60 – 240 minutes at times when outside air temperature was 95°F or greater.

Laboratory testing of transient response from turning the pre-cooler on and off



Results

When the pre-cooler is dispatched, 50% of the total power reduction is achieved within 40 seconds. The remaining 50% required approximately 12 minutes of additional runtime. When pre-cooler was turned off the power response was slower. It took approximately 12 minutes to return to the 50% of the total reduction and roughly 23 minutes to return the pre-dispatch power. The difference in response time is tabulated in the Table.

Response time differences of dispatchable pre-coolers

Test Outdoor Air Dry Bulb/Wet Bulb °F	Time to achieve 50% of maximum power reduction (min)	Time to achieve 75% of maximum power reduction (min)	Time to achieve 100% of maximum power reduction (min)
OA 95/70	0.6	1.6	13.4
OA 105/73	0.6	0.9	12.5
OA 115/76	0.6	1.1	13.3

Path Forward

WCEC will analyze field test data to study the aggregate transient response of dispatching pre-coolers on 11 RTUs on single rooftop.

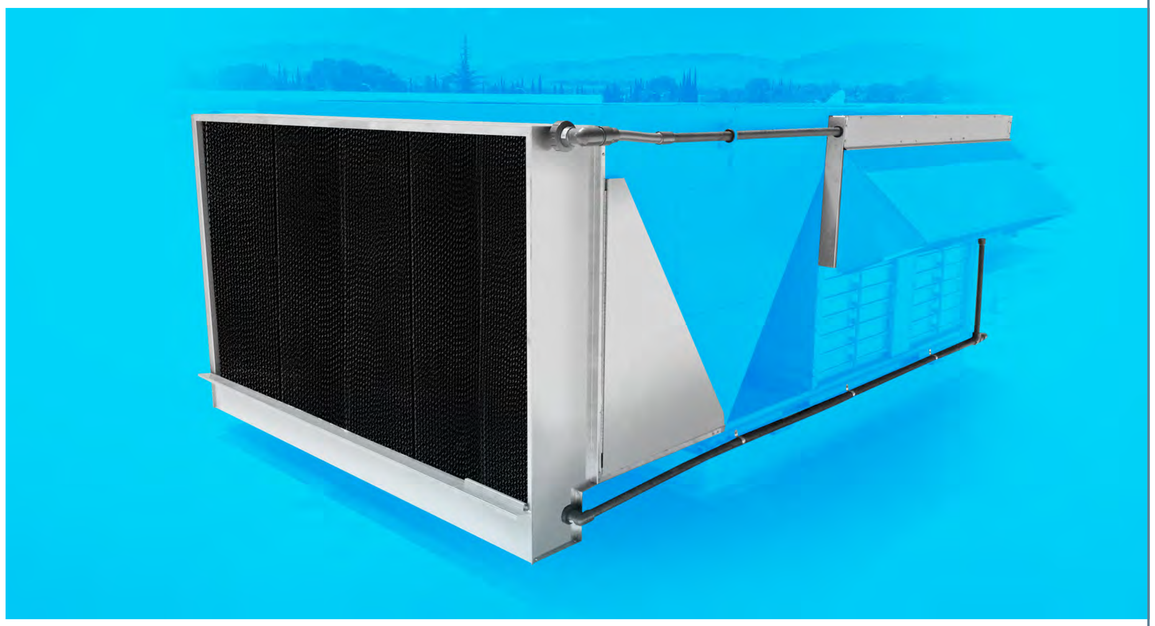
Field Performance of an RTU Optimization Package

Caton Mande, Theresa Pistochini, Derrick Ross, Robert McMurry // Sponsor: SCE

Packaged compressor-based air-condition and heater roof top units (RTUs) provide a significant amount of the cooling for commercial spaces in California. Optimizing the efficiency of RTUs can reduce the strain put on the California electric grid from compressor based cooling.

WCEC has developed a combined retrofit optimization package that can increase the efficiency of a RTUs, reduce peak electrical demand, and maintain net capacity at peak.

The package includes a variable frequency drive (VFD) to reduce the compressor speed and a condenser-air pre-cooler. This package was field tested at a big box retail store in Corona, CA. A 10-ton RTU, that served part of the store room, was selected and retrofitted with two VFDs (one for each compressor) and a condenser-air pre-cooler. The performance of the RTU with optimization package was compared to the performance of the same unit without the optimization package.



Results

The field testing demonstrated the potential for significant energy savings using the combined retrofit. Figure 1 illustrates the difference in the combined retrofit power draw compared to the baseline in stage 1 and 2 cooling. The combined retrofit illustrated a flattening trend as outside air temperature increases. Similar flattening trends were seen in the coefficient of performance (COP), net capacity, and SHR as outside air temperature increased. Averaged over all operating conditions, COP increased by 12 – 23%, net capacity decreased by 9%, power draw decreased by 19-26%, and sensible heat ratio (SHR) increased from -0.5 – 3%.

BASELINE

COOLING STAGE	COP	NET CAPACITY (KBTU/HR)	POWER (KW)	SHR	MODE CHANGES PER HOUR
Stage 1	2.01	38.24	5.58	0.97	2.0
Stage 2	2.24	78.73	10.39	0.91	

COMBINED PACKAGE

COOLING STAGE	COP	NET CAPACITY (KBTU/HR)	POWER (KW)	SHR	MODE CHANGES PER HOUR
Stage 1	2.26 **(+12%)**	34.67 **(-9%)**	4.5 **(-19%)**	0.96 **(-0.5%)**	2.0
Stage 2	2.75 **(+23%)**	72.02 **(-9%)**	7.7 **(-26%)**	0.94 **(+3%)**	

Path Forward

Future work should aim to investigate the performance of the combined package on higher capacity RTUs and the impact to RTU performance when only a subset of the available compressors are reduced to 48Hz.