RESEARCH REALIZED

September 2019

UC DAVIS
Western Cooling Efficiency Center

Mark Modera, *Director*

Armando Casillas, *Graduate Student Researcher*

Inside this Issue

Developing a Novel Method for Determining Building Leakage

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WELCOME

Welcome to the Western Cooling Efficiency Center's Research Highlights.

We are excited to share with you some of our recent accomplishments, including our continued efforts to research and demonstrate key technologies and improve market conditions for increased adoption of energy efficient solutions. This review illustrates the diversity and uniqueness of our research—from testing the performance of low global warming potential alternative refrigerants to advancing heat exchangers for HVAC applications and improving ventilation in California schools.

Through our work we strive to maximize our impact and value. We continue to strategically assess our activities, partnerships, and priorities.

This past year, we launched two multi-million dollar projects to: 1) advance solar thermal power generation by developing innovative additively-manufactured heat exchangers (funded by the Department of Energy) and 2) provide large commercial and institutional customers the information they need to purchase advanced distributed energy resource products by evaluating selected products and widely disseminating this information (funded by the California Energy Commission).

We also welcomed arbnco, a Glasgow-based company, as a new affiliate. We are working together on several projects at UC Davis to reduce energy use and greenhouse gas emissions while improving the health and well-being of students, staff, and faculty.

Vinod Naranayan, *Associate Director*

Erfan Rasouli, *R&D Engineer*

Inside this Issue

Our successes and innovations are due in large part to the cooperative interests and combined efforts of our network of partners, collaborators, and research sponsors. We look forward to continuing to work with you to achieve a more sustainable energy future.

Mark Modera // Director

Vinod Naranayan // Associate Director

Our mission is to accelerate development and commercialization of efficient heating, cooling, and energy distribution solutions through innovation, R&D, stakeholder engagement, education, and outreach.

New Staff

Jasen Okunnuga, *Financial Analyst*

Eddie Brutsch, *Affiliate Program Manager*

Erfan Rasouli, *R&D Engineer*

Fred Meyers, *R&D Engineer*

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 U.S. and California recognize the far-reaching implications of greenhouse gas emissions on our environment and changing climate.

HOW WE WORK

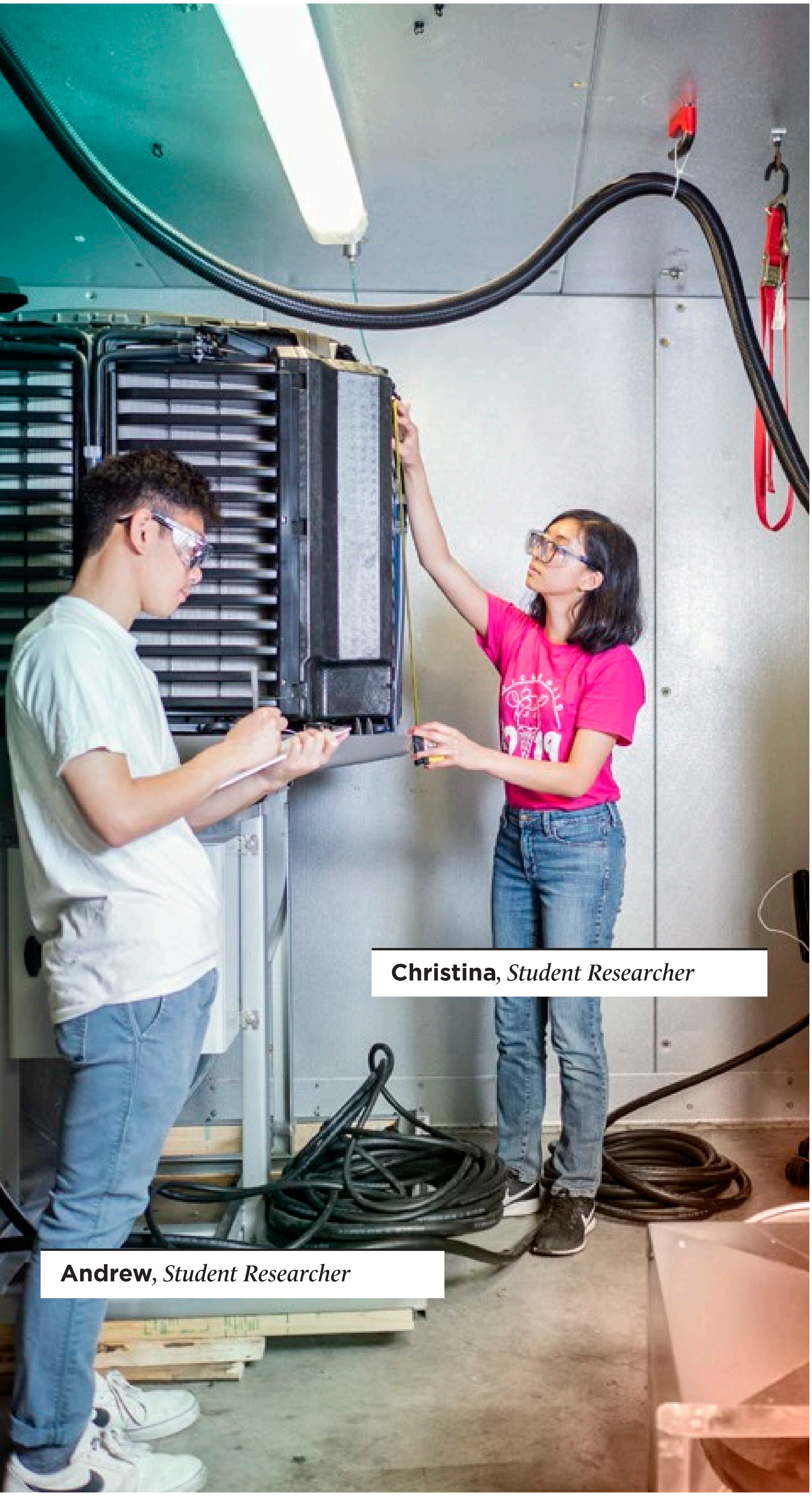
Applied Research

Working closely with manufacturers, policymakers and utilities, WCEC develops and 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



Core Proficiencies

Leaders in climate-appropriate cooling technologies

In-house laboratory with environmental chamber capable of re-creating 95% of California's hot/dry climates

Leaders in automatic aerosol sealing technology for buildings

Extensive Knowledge In

Building Energy Modeling

Technology Evaluation

Cooling Hot/Dry Climates

Codes & Standards

Human Behavior in HVAC

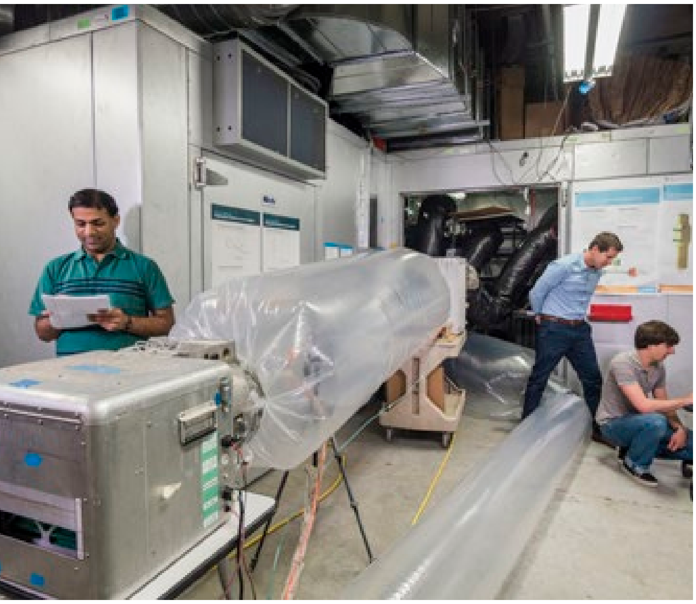
Thermal Energy Distribution

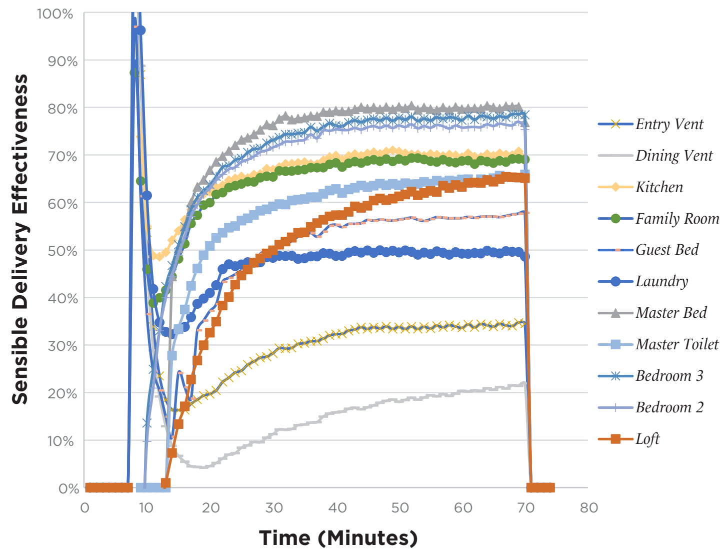
HVAC System Control

Market Barriers

Heat Transfer

NEXT GENERATION SPACE CONDITIONING SYSTEMS





Sensible delivery effectiveness for each grill at field site during a period of full-speed operation with a single-zone configuration and R-6 duct insulation.

Space conditioning systems can have a profound impact on comfort and home energy use. 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 climate. As part of this project, we are testing one of these advanced technologies—a variable speed heat pump system.

Goal

This project is evaluating how the performance of a typical duct system changes as variable-speed equipment modulates its speed.

Progress

We evaluated the impact that a typical residential duct system, located outside the conditioned space (e.g., in the attic), had on variable speed heat pump performance. There were three primary phases of this research:

Phase I: Laboratory testing with a single-zone configuration

Phase II: Laboratory testing with a multi-zone configuration

Phase III: Field testing with a multi-zone configuration

Results

- **Zoning was very effective at maintaining system performance under part load conditions.** With a single-zone configuration, there were significant losses of cooling to the attic at lower speeds. Even though equipment performance generally improves at lower speeds, researchers found that optimal performance of the combined equipment and duct system occurred at high speeds when hot attic temperatures exceed 95°F.
- **Adding zoning capability significantly improved system performance at lower speeds** by maintaining duct velocities. The optimal strategy for achieving this was 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.
- Real-world observations confirmed that **fractional duct thermal losses increased as duct velocity decreased.**

Publications

2017 Journal Article: **http://bit.ly/NextGenHVAC1**
2018 Journal Article: **http://bit.ly/NextGenHVAC2**

EMPOWER PROCUREMENT PRODUCT EVALUATION HUB

There isn't really a great resource out there... There are tons of websites, but most of them are sales-driven. They're not impartial. That's why I was excited about the Hub.
(Survey interviewee)

The Empower Procurement Product Evaluation Hub will provide large commercial and institutional customers (e.g., K-12 schools, universities, local/state government, agriculture, commercial real estate) the information they need to purchase advanced distributed energy resource (DER) products through their procurement processes. DER products include energy efficiency, generation and storage.

Goal

This project, funded by the California Energy Commission, aims to reduce energy use and greenhouse gas emissions by stimulating widespread adoption of proven DER products currently in the early customer adoption phase. Specific project objectives are to: 1) evaluate selected DER products in a rigorous and transparent manner, and 2) widely disseminate evaluation results to large commercial and institutional customers that use a formal procurement process.

Product characterization reports found here:
http://bit.ly/EEIcalEPE

Progress

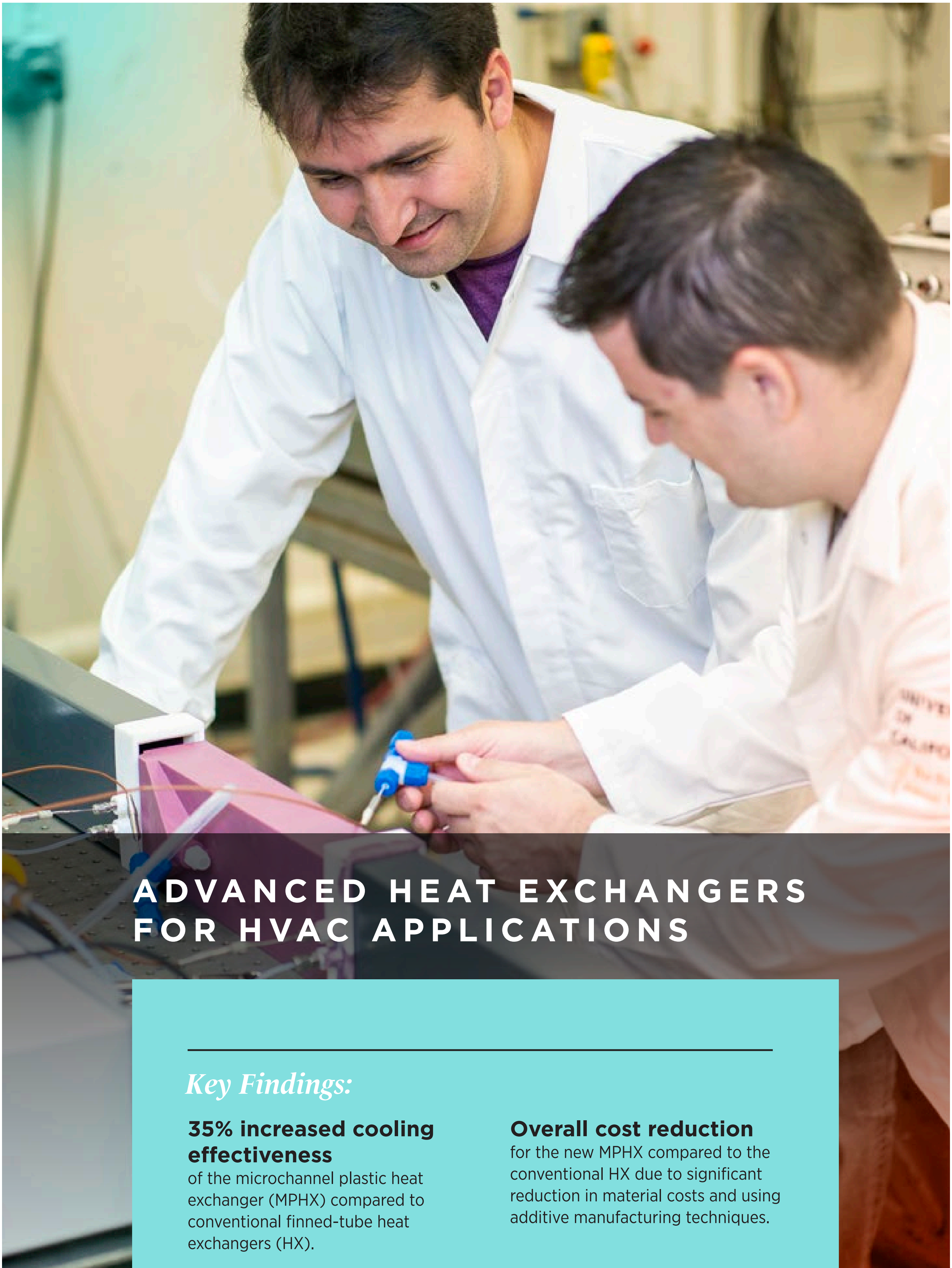
- In the first year (2019), we organized and described **eligible product categories** and prioritized them for evaluation by: 1) completing a customer needs assessment, 2) analyzing potential greenhouse reduction impact, and 3) assessing evaluation feasibility and cost.
- The **customer needs assessment**: 1) identified customers' priority DER products, 2) identified the information they would need from a product evaluation, and 3) outlined pathways for the Hub to influence customer procurement.
- In subsequent years, we will evaluate products and disseminate the results through an **online buyers' guide.**

Results

- We compiled a list of **73 product categories** eligible for evaluation and wrote a product characterization report for each product category.
- We conducted **in-depth interviews with 44 individuals** from across 13 target customer groups. We then implemented an online survey to gather data from a broader sample of customers. Survey data was analyzed to identify DER priorities among customers as a group and across sectors.

Path Forward

Finish the prioritization process and select product categories for evaluation. Begin evaluating products in Fall 2019.

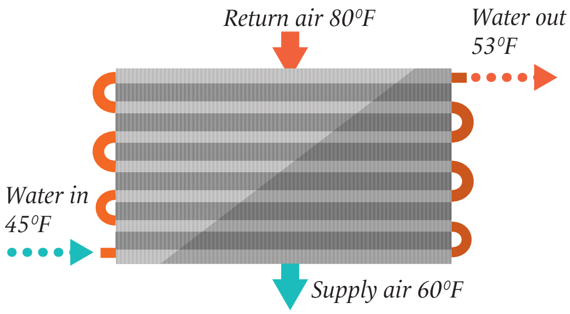


ADVANCED HEAT EXCHANGERS FOR HVAC APPLICATIONS

Key Findings:

35% increased cooling effectiveness
of the microchannel plastic heat exchanger (MPHX) compared to conventional finned-tube heat exchangers (HX).

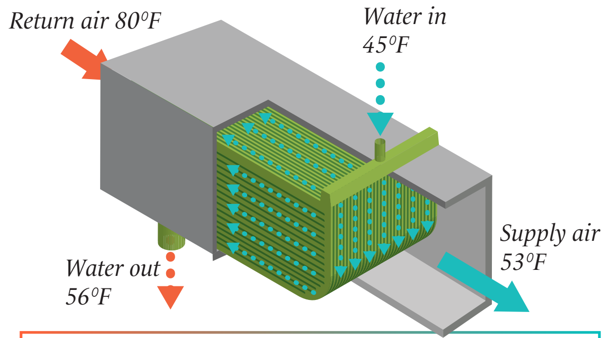
Overall cost reduction
for the new MPHX compared to the conventional HX due to significant reduction in material costs and using additive manufacturing techniques.



Heat load 2.5 ton (9.1kW) // Effectiveness: 57%

Conventional water-to-air heat exchanger

- Low effectiveness
- Additional pressure drop across tube bank
- Made from expensive/heavy metals



Heat load 3.5 ton (12.3kW) // Effectiveness: 77%

MPHX water-to-air heat exchanger

- High effectiveness
- Low pressure drop
- Lighter, less expensive, potentially less noisy
- High corrosion resistance

HVAC refrigerants with low global warming potential have significant environmental benefits, but also have flammability concerns; in the interest of safety they are best kept in hermetically, factory-sealed heat pump packages outside homes. To do this, a secondary fluid, such as water, is needed to transfer heat between the air within the HVAC air handler and the refrigerant outside the home. The configuration of a water-to-air heat exchanger (HX) is critically important in determining its effectiveness in terms of thermal performance. Typical finned-tube HXs in air handlers and current state-of-the-art, chilled, water-to-air HXs have significant limitations.

Goal and Progress

This project, funded by the U.S. Office of Naval Research, uses advances in microchannel technology and additive manufacturing (AM) of plastics to develop a low-cost, highly-effective Microchannel Plastic Heat Exchanger (MPHX). This MPHX could improve conventional air handlers, saving energy and reducing cost.

Based on our prior experience in heat recovery applications, we proposed a conceptual design for a MPHX that consists of multiple “water plates” (WP) in parallel through which cooled or heated water flows. The WPs are joined together by inlet and outlet headers. The internal architecture of each WP consists of a staggered array of microscale pins around which water flows. The WPs are attached together laterally by external fins that form honeycomb air flow passages. Air flows between the WPs and through the fins and exchanges heat with water within the plates.

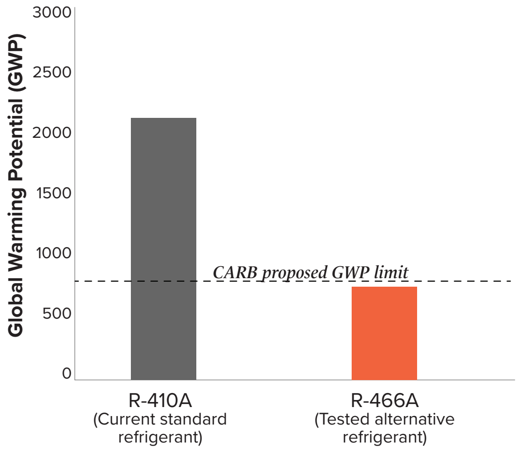
Results

We developed a thermo-fluidic model for performance predictions of this concept. The performance of MPHX is compared with a finned tube HX. The calculations show that for identical approach temperatures and flow rates **the effectiveness of MPHX increased 35% compared to the finned tube design.**

Path Forward

- Fabricate and post-process subscale MPHXs built via selected AM fabrication methods.
- Design and build a test facility for performance characterization of the subscale MPHXs.
- Characterize the pressure drop and thermal performance of built MPHXs.

PERFORMANCE TESTING OF A LOW GLOBAL WARMING POTENTIAL REFRIGERANT



Refrigerants used in vapor-compression air conditioners and heat pumps have a high global warming potential (GWP). To help reduce the effects these greenhouse gasses have on our atmosphere, companies are developing alternative refrigerants with lower GWP. This project evaluates a new lower GWP refrigerant (R-466A) developed by Honeywell that is compatible with R-410A equipment and compares its performance to R-410A refrigerant.

Goal

This project, funded by Trane, compares the performance of a unitary heat pump using the industry standard R-410A and a new low GWP refrigerant R-466A.

Progress

- We tested the performance of the unit at **six outdoor air conditions** using an environmental control chamber at the Western Cooling Efficiency Center.
- The unit was instrumented so its performance could be quantified according to the **ANSI/AHRI Standard 210/240** and compared at each test point.
- We measured the **performance of the heat pump** with R-410A refrigerant, changed the refrigerant out for the new R-466A, and then retested heat pump performance.
- The final performance of the unit using R-410A and R-466A was **compared using capacity, total power, and coefficient of performance (COP).**

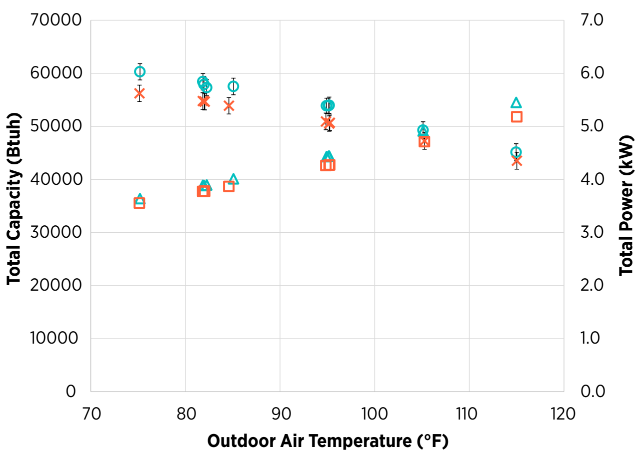
Results

The retrofit R-466A lower GWP refrigerant was able to provide **similar performance** to R-410a.

At higher temperatures the performance was the same while at lower temperatures R-466A capacity and efficiency was slightly lower compared to R-410A. The R-466A refrigerant was also slightly denser and required about 8% more refrigerant charge compared to R-410A.

Path Forward

Future steps include further lifespan analysis. This includes determining if there are any interactions between the new refrigerant blend and unit components and refrigerant performance over time.



Total capacity and total power versus outdoor air temperature

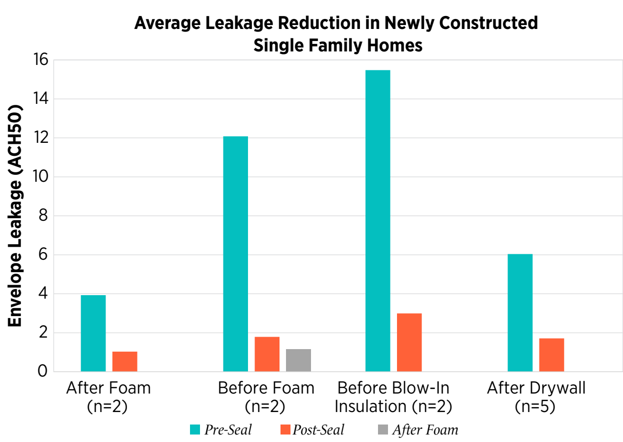
AEROSOLIZED SEALANT FOR BUILDING ENVELOPES

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. We are testing an aerosol envelope sealing process, AeroBarrier—that was developed at UC Davis—to improve sealing effectiveness, reduce labor costs, and improve contractor installation consistency.

Goal

One project, funded by the Department of Energy, is evaluating the labor and material costs and energy efficiency performance of AeroBarrier applied at different stages of the new construction process.

Another project, funded by the California Energy Commission, is evaluating the indoor air quality and energy efficiency performance of AeroBarrier as a retrofit to existing homes.



Progress

This past year, we demonstrated AeroBarrier in both new and existing single-family homes in California. Sealing new homes took place during different stages of construction and with different insulation methods, including rough-in (before and after spray foam insulation, before blow-in insulation) and after drywall. Two existing homes were also sealed as part of a retrofit package aimed at improving energy efficiency and indoor air quality.

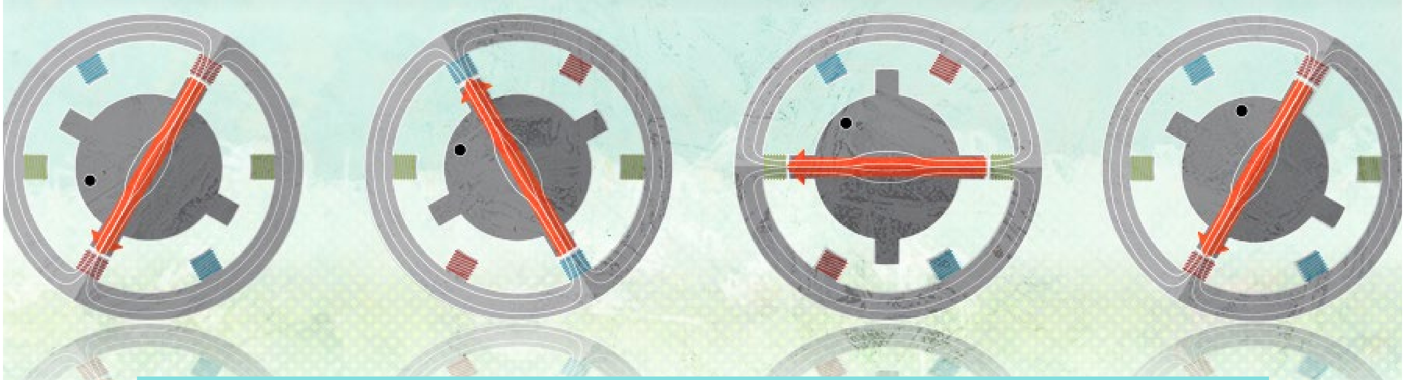
Results

- The entire preparation, sealing and clean up process took 4-7 hours in new construction and 22 hours in existing homes. Of this time, **1-3 hours was spent sealing in each home.**
- New construction homes achieved at least **50% reduction** in air leakage after sealing, with 9 of the 11 homes achieving over **70% reduction.**
- Existing homes achieved between **37% and 64% reduction** in leakage.
- Considering the level of air tightness achieved with AeroBarrier and the amount of effort currently employed to reduce air leakage, 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.

Path Forward

Determine the best approach for sealing existing homes by evaluating new sealant formulations, as well as developing application protocols.

PERFORMANCE EVALUATION OF SOFTWARE-CONTROLLED SWITCHED RELUCTANCE MOTORS



Key Findings:

9-36% less power
for the high rotor pole SRM to generate the same torque on the dynamometer compared to a standard VFD.

Power intensity reduction
for the high rotor pole SRM in the field RTU (11% at 1725 RPM) and laboratory RTU (13% at 1725 RPM).

Additional energy savings
achieved by reducing airflow rate when full airflow was not required.

Packaged air conditioning and heating Roof Top Units (RTUs) provide an estimated 75% of the cooling to commercial buildings in California and can account for more than 50% of peak electrical demand. Power can be saved by reducing indoor airflow when RTUs are only providing ventilation or air circulation. Variable indoor airflow is typically achieved by using a variable frequency drive (VFD). However, VFDs lower the indoor blower system efficiency, which reduces the full energy savings potential.

Goal & Progress

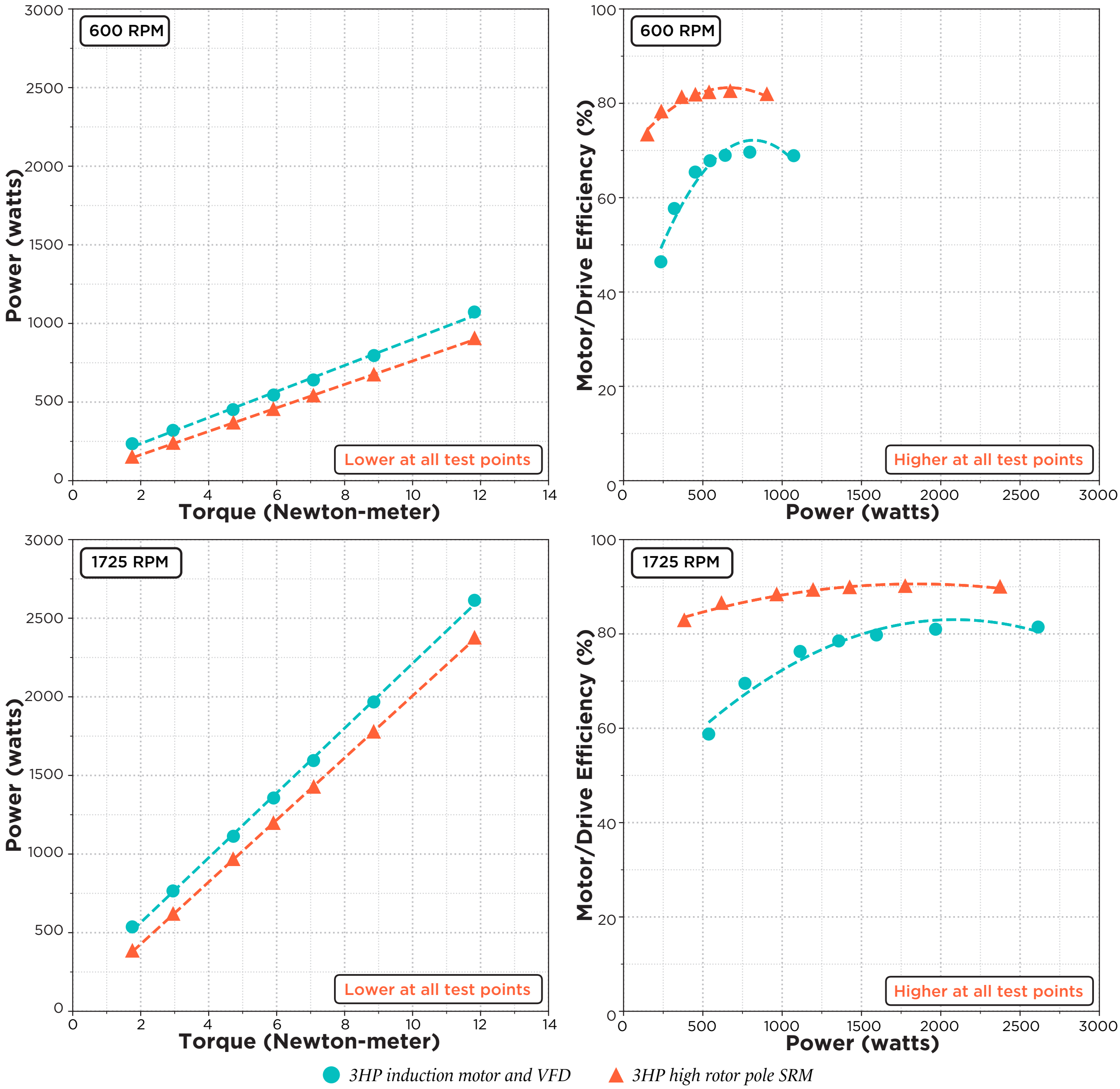
This project, funded by Southern California Edison, evaluated the performance of a high rotor pole switched reluctance motor (SRM) technology to save energy in HVAC systems. This technology reduces power demand associated with indoor fan operation by increasing the indoor blower system efficiency.

We measured and compared the performance of a nominal 3HP high rotor pole SRM with software-controlled inverter to traditional 3HP induction motors with and without VFD.

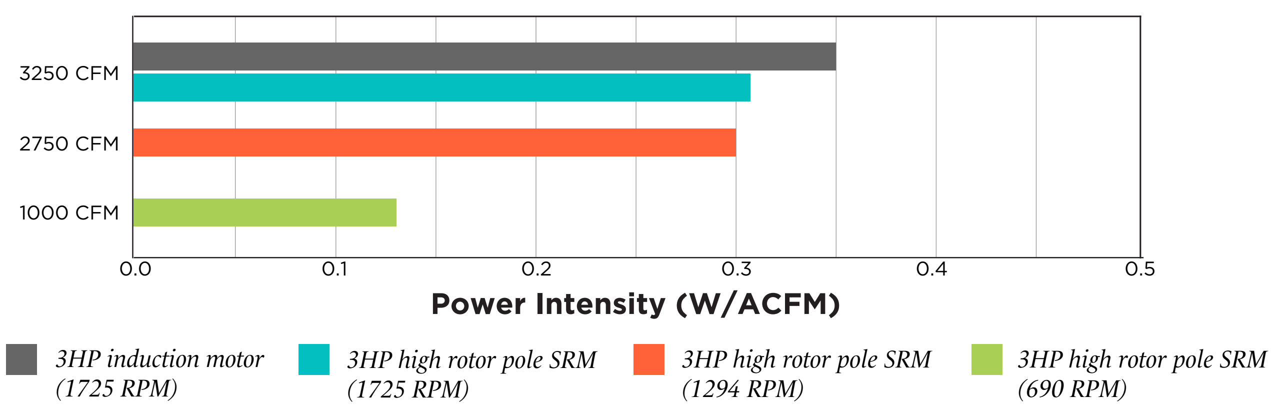
Publications

Case Study: http://bit.ly/WCECCSSMC
Final Report: http://bit.ly/SMCreportETCC

Laboratory dynamometer testing



Field RTU indoor blower power intensity



BUILDING ENERGY AUDIT AND ANALYSIS TOOLS

Most existing commercial buildings do not implement energy efficiency retrofits even when they are a good economic investment due to a lack of information, the high cost of audits and analysis, and the multiple steps needed for implementation. Energy audit tools reduce the cost and hassle for building owners/operators/occupants to find out what efficiency investments make sense for their building(s).

Goal

This project, funded by the U.S. Office of Naval Research, aims to reduce the cost, increase the speed, and streamline the process for building energy audits and recommendations of efficiency retrofits that will have good economic performance.

Progress

We developed a cloud-based building energy audit data collection and analysis tools. Through a partnership with the California Conservation Corps these tools were used to audit over 10,000 buildings in California and make retrofit recommendations for over 5,000 of these buildings.

Currently we are:

- Reviewing existing tools and practices with test audits of campus buildings.
- Developing software specifications, workflows, and user interface mockups to further improve the tools.
- Working with a software development partner to implement the specifications and scale up the tools.

Results

- Audit tools can enable the use of a lower cost workforce to collect high quality data.
- Partnerships with organizations like the California Conservation Corps and California Community Colleges can help achieve scale through workforce development.
- Low cost energy audits and data analysis can reduce barriers to efficiency retrofits.
- Tools can be targeted to auditors of multiple skill levels and to retrofits with different goals.
- Low cost energy audits can lay the ground work for more advanced monitoring and commissioning for deeper efficiency retrofits.
- Military installations benefit from reduced energy consumption enabling them to be more resilient and maintain readiness when supply lines are compromised.

Path Forward

Continue to develop tools and build partnerships with the long-term goal of creating an online marketplace for building energy efficiency retrofits.

Key Progress:

>10,000
Buildings audited

>5,000
Buildings received retrofit recommendations

RECOVER HEATING AND COOLING ENERGY IN THE COLD STABILIZATION OF WHITE WINE

California is the leading wine producing state, selling 283 million cases in 2017. Producing white wine involves a cold stabilization process to keep tartaric acid crystals from forming after the wine has been bottled. This process is energy intensive.

Goal

This project, funded by the California Energy Commission, aims to reduce cooling and heating energy used in the white wine cold stabilization process by using a heat exchanger technology. In the cold stabilization process, a batch of wine is chilled and stored to remove the tartaric acid. The wine is then warmed to bottling temperature and the next batch is chilled. The heat exchanger technology exchanges heat between the wine entering and exiting the stabilization tanks, which reduces both chiller and boiler energy use. The heat exchanger can easily be integrated into existing processes. This project will demonstrate how the heat exchanger is integrated into winery operations, measure the energy savings, and report on the economics of the technology.

Progress

We have been monitoring the system since September 2018, and have characterized how often the technology is used, resource savings due to the technology, and key process parameters that affect the results. We interviewed staff to determine how easily the technology was integrated into the existing process, and to understand operator perception towards the technology. The pilot study will continue until a full year of data is collected.

- **Heat exchanger effectiveness** was measured at 90%.
- Staff interviews showed that the heat exchanger was **easily integrated into the existing process**, and the operators have a **favorable view of the technology.**
- To reduce initial costs, the heat exchanger was designed for half the flow rate of the original process. Despite this, the heat exchanger is expected to **significantly reduce the overall process time** because the cold stabilization setpoint target can be reached much faster with the heat exchanger.
- We highlighted **key process parameters** that could be changed to further improve the energy savings.

Path Forward

- Continue the analysis over a full year of operation.
- Understand how tank energy losses affect savings, as well as the percent of wine that is processed through the heat exchanger.
- Conduct more interviews to understand the evolution of technology adoption at the pilot site.

Key Findings In 3 Months of Monitoring:

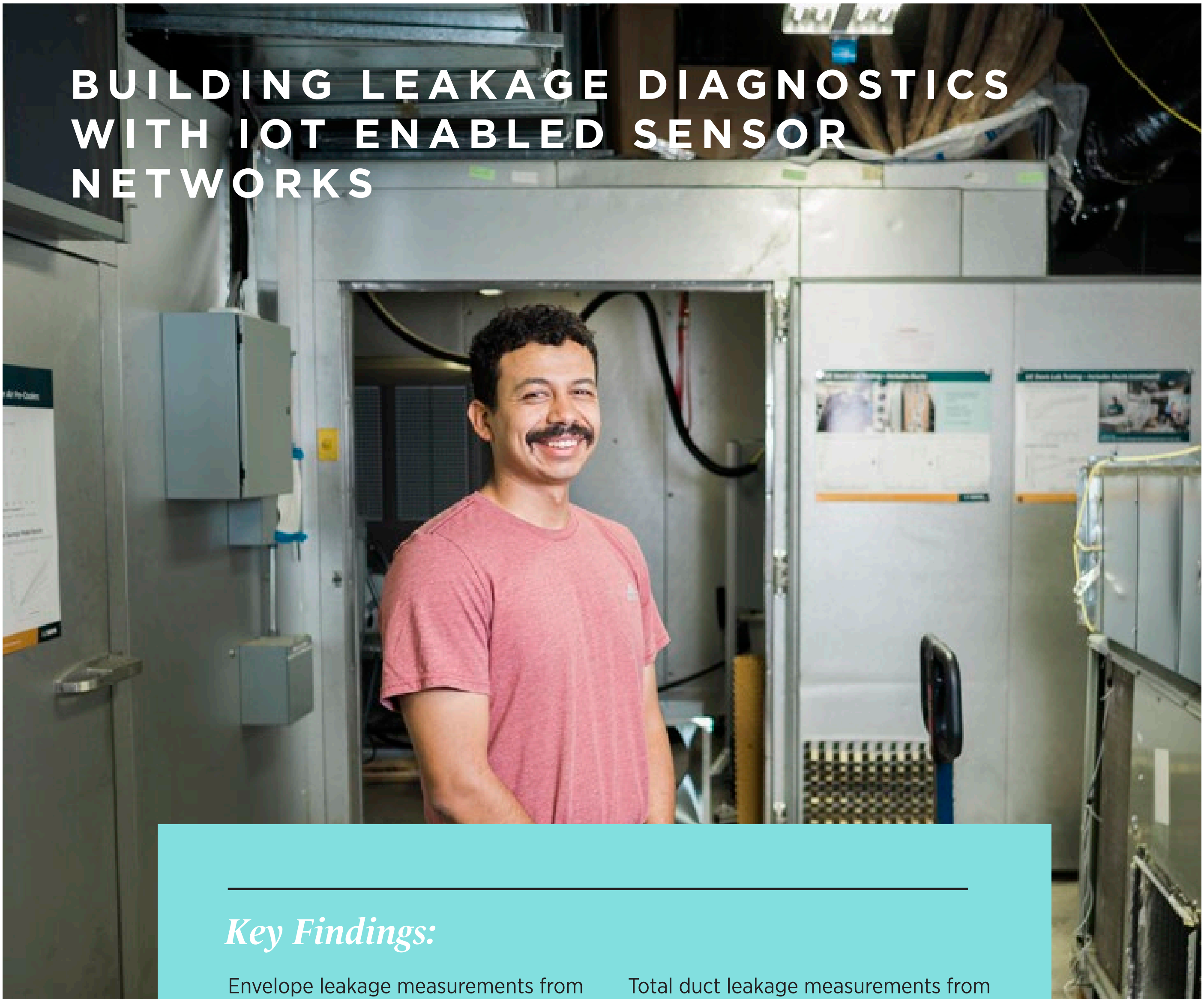
82
hours of operation

63MWh
transferred in primary heat exchanger

1.7 million
gallons of unstabilized wine processed

$4,782
value of to-date resource savings

BUILDING LEAKAGE DIAGNOSTICS WITH IOT ENABLED SENSOR NETWORKS



Key Findings:

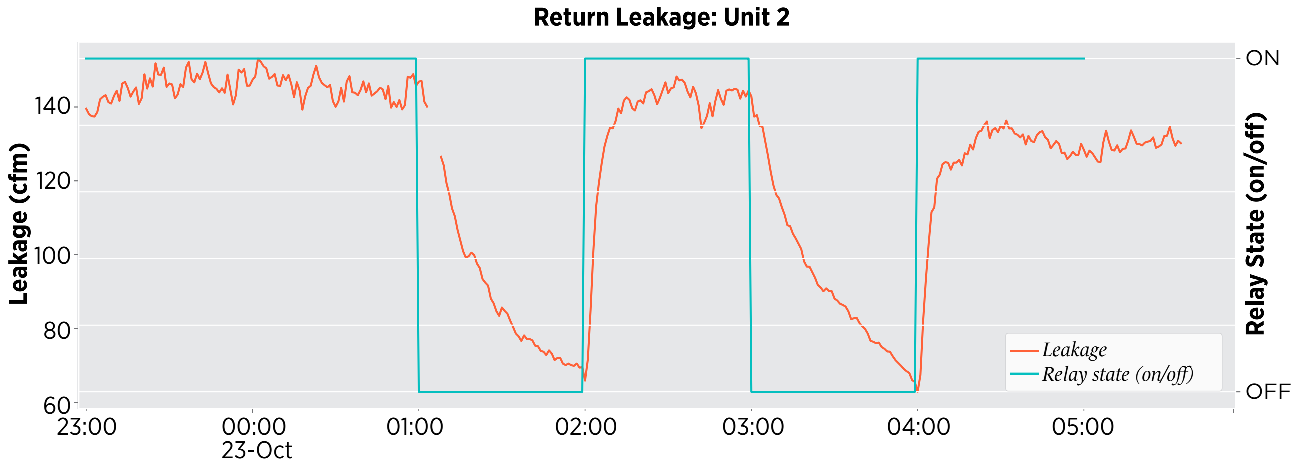
Envelope leakage measurements from the sensor network were within **10% on average of the blower door test.**

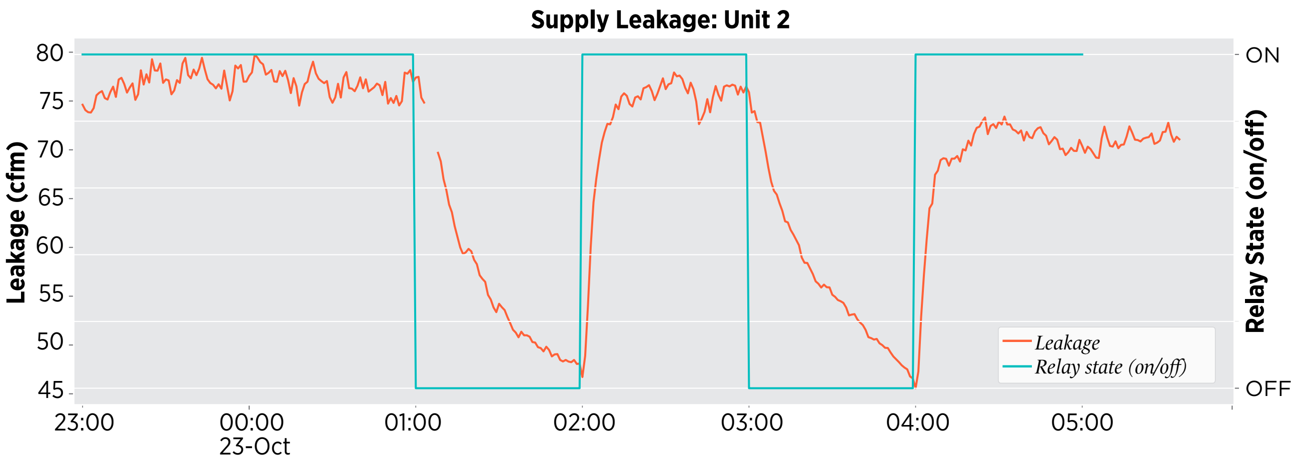
Total duct leakage measurements from the sensor network were within **17% on average of duct blaster tests.**

Building envelope and duct leakage lead to heat loss into unconditioned spaces as well as the need for additional HVAC fan power. Current methods to test for envelope and duct leakage (blower door and duct blaster tests) can be invasive and cumbersome. We propose a new, less invasive method that uses a building's existing fan and a network of deployable sensors to measure: 1) pressure signals to detect envelope leakage and 2) the flow of water vapor through the ventilation system to detect duct leakage.

Goal

This project, funded by the National Institute of Standards and Technology, aims to non-invasively and accurately determine building envelope and duct leakage using a network of deployable sensors that measure absolute and differential pressure, temperature and relative humidity in different areas of a building.





Measured supply and return leakage during 1 hour long test cycles. Return leakage was found to be about 20% of total fan flow, while supply leakage was about 9% of total fan flow.

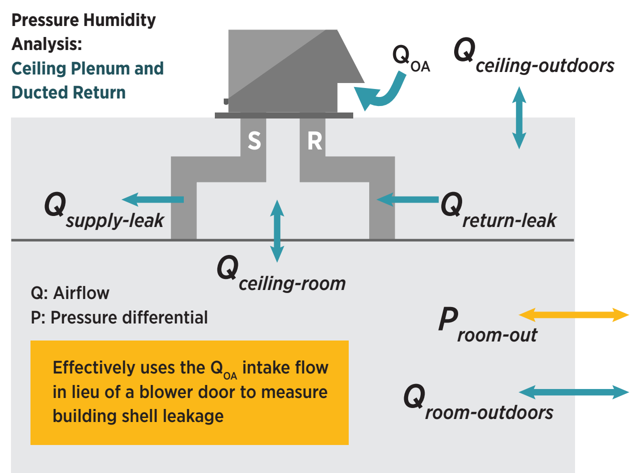
Progress

Lab tests: We determined the accuracy and agreement of sensor readings for absolute pressure, temperature and relative humidity in the WCEC lab.

Field tests: We deployed sensors inside a UC Davis building's rooftop units, office space, attic area and ventilation ducts. Thermostats were controlled remotely through WiFi to conduct tests overnight while the building was unoccupied. Outdoor airflow was determined for the units and ground-truth tests–including blower door, duct blaster and CO2 injection tests–were conducted to corroborate results from the deployed sensor network data analysis. Envelope leakage measurements from the sensor network were within 10% on average of the blower door test. Total duct leakage measurements from the sensor network were within 17% on average of duct blaster tests.

Path Forward

A second field test is planned on another UC Davis building with an actuated economizing unit, which will prove feasibility of a remote multipoint pressurization test using the existing ventilation system.



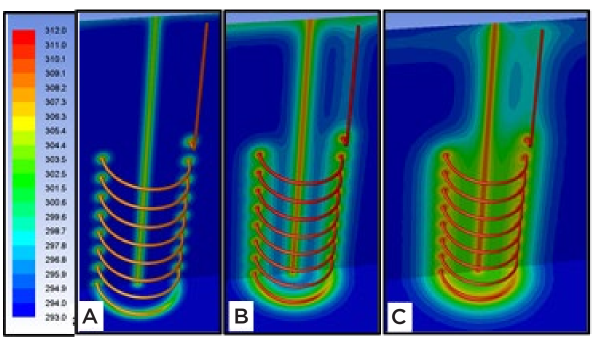
IMPROVING MARKET CONDITIONS FOR INCREASED ADOPTION OF GROUND-SOURCE HEAT PUMPS

This project, funded by the California Energy Commission, aims to increase 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.

Results

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, the researchers developed a computational fluid dynamics (CFD) model to simulate heat transfer phenomena that the simplified CaRM model neglects and to also obtain more detailed results.



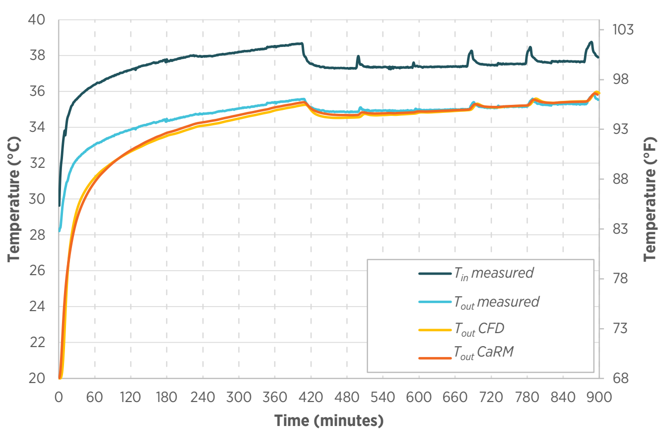
Temperature contours of the GHE and surrounding soil after (a) one hour (b) six hours (c) 15 hours

Benefits

Ground-source heat pumps have shown tremendous potential to improve efficiency over air-source systems, however, cost is a significant barrier to adoption. This project aims to evaluate a lower-cost ground-source system.

Path Forward

Installation of a controlled test facility with a GHE design based on the model is underway. The tests will also provide more information about multiple GHE interactions. The results from the tests and models will be used to generate design parameters (g-functions) that will be incorporated into Energy Plus, a building energy simulation tool.



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

IMPROVING WATER AND ENERGY EFFICIENCY IN CALIFORNIA'S DAIRY INDUSTRY

California is the nation's top milk-producing state. It is critical to keep dairy cows cool during the hot summer months. Standard cooling methods, however, such as fans and spraying cows with water, require substantial amounts of electricity and water.

Goal

With funding from the California Energy Commission, the UC Davis Western Cooling Efficiency Center and the Department of Animal Science tested novel approaches for cooling dairy cows in a small-scale study. Researchers measured energy and water use and monitored the cows to determine the impact of four treatments:

- **Baseline**–a fan in the bed area with sprayers in the feed area.
- **"Optimized" Baseline**–a fan and sprayers in the feed area.
- **Conduction Cooling "Mats"**–the bed area is cooled using heat exchange mats. Water in the mats is cooled through a novel evaporative chiller.
- **Convection Cooling "Ducts"**–fabric ducting directs cool air onto the cows in the bed and feed areas. The air is cooled using a direct evaporative cooler.

Benefits

New approaches to keeping cows cool will help dairies improve their productivity and cow health, while helping California meet its energy, water and climate goals.

Results

- Convection Cooling Ducts and Optimized Baseline were effective at reducing heat stress in cows.
- All cooling methods tested saved water in comparison to the baseline, however, the Convection Cooling Ducts used more electricity in the field test than anticipated. Researchers built and tested a higher efficiency evaporative cooler to reduce the Ducts energy use.

Path Forward

WCEC conducted a detailed analysis and determined that energy savings are possible with the Convection Cooling Ducts and new high efficiency evaporative cooler. However, barriers to adoption of the technology are concerning as it presents a significant change to the types of cooling systems that dairy operators are used to.

Researchers are also optimizing traditional fans and sprayers by developing occupancy sensing sprayers and a heat transfer model that predicts cow cooling needs based on outdoor conditions. These mechanical occupancy sensing sprayers are in the process of being patented.

IMPROVING INDOOR AIR QUALITY IN CALIFORNIA SCHOOLS

Key Findings:

Of the classrooms studied
65% were under-ventilated.

MERV13 filters reduced indoor PM2.5 concentrations by
39% compared to MERV8.

HVAC systems provide necessary mechanical ventilation to classrooms. Ventilation is needed to remove indoor pollutants such as volatile organic compounds and formaldehyde, and carbon dioxide (CO_2). There is increasing evidence that CO_2 exhaled by occupants is an indoor pollutant that can affect decision making performance. This is particularly important in spaces that are densely occupied, such as classrooms. Importantly, studies have found that ventilation impacts student performance and attendance.

Goal

With funding from the California Energy Commission, UC Davis characterized HVAC systems, CO_2 concentrations, and indoor thermal conditions in 104 classrooms that had replaced their single zone HVAC systems within the past three years.

Benefits

Ensuring adequate classroom ventilation will save California school districts money and protect and support the health and well-being of students and teachers. If ventilation in all classrooms met Title 24 requirements, California school districts could see an estimated $33 million in revenue due to fewer student absences.

Results

- Overall, classrooms with recent HVAC retrofits had higher ventilation rates than reported generally in the literature, including in a recent California study.
- **The ventilation rates of many classrooms were below the requirements of the ASHRAE 62.1 standard or California's Title 24.**
- **65% of the classrooms were under-ventilated.**
- Classrooms with wall-mount systems, commonly used in portable classrooms, had higher CO2 concentrations and lower estimated ventilation rates than classrooms with rooftop units.
- Classrooms with economizers, with and without demand control ventilation, tended to have lower mean CO2 concentrations. But, many were still under-ventilated compared to the minimum requirement.
- Inadequate ventilation was found in classrooms at all grade levels.
- Under-ventilation was caused by improperly selected equipment, lack of commissioning, incorrect fan control settings and maintenance issues (e.g., dirty filters).
- Surprisingly, many teachers reported that they were satisfied with their indoor air quality even when indoor CO2 levels routinely exceeded 1700 ppm. This shows the importance of CO2 sensing for monitoring ventilation systems.

Recommendations

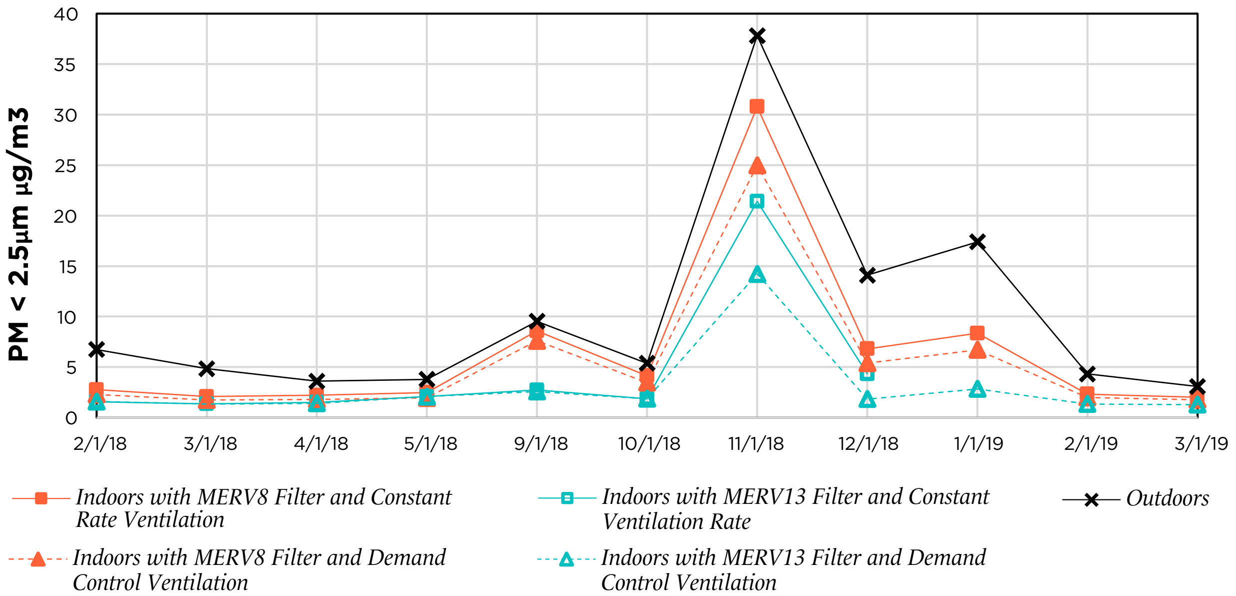
- **Better oversight** to ensure that the right HVAC equipment is purchased, installed, and commissioned properly in classrooms.
- **Performing routine filter maintenance.**
- **Running HVAC fans** as required during occupancy to bring in fresh air.
- **Monitoring classroom CO2** concentrations with a CO2 sensor in the thermostat or as a stand-alone sensor.

Path Forward

UC Davis is conducting two field demonstrations comparing three ventilation system options in two schools:

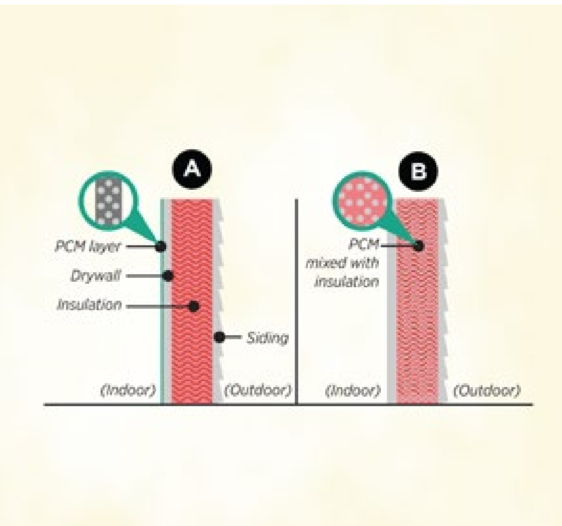
- Standard vs energy recovery vs demand control
- Standard vs high efficiency equipment
- Two filter options (MERV 8 vs MERV 13)

The analysis of results is ongoing and is being used to calibrate EnergyPlus models that will generate equipment recommendations for different regions of California.



Impact of MERV13 filters and demand control ventilation on reducing annual average indoor exposure to particulate matter (PM2.5) measured in a Sacramento region school. Average PM2.5 levels where higher in November due to wildfires.

UPCOMING PROJECTS



Developing a Retrofit Insulation Solution with Phase Change Material

Many homes in California have uninsulated walls and leaky building envelopes, leading to unwanted thermal losses, wasted energy, and the introduction of outdoor pollutants. We will develop and test a Phase Change Material (PCM) enhanced insulation retrofit that will seal and insulate existing homes. This solution will be demonstrated and evaluated in three homes across different climate zones in California. Researchers will assess the solution's market potential and identify opportunities for widespread deployment. We are working with TRC Engineers Inc., industry partners (Insolcorp, Aeroseal, Owens Corning, Senseware, Hearth Labs) and a community-based organization (Merced County Community Action Agency).

Launching Sustainable Communities Pilot Program

Adequate classroom ventilation is critical to supporting student health and performance. UC Davis and the Sacramento Municipal Utility District, in collaboration with a number of partners, will launch an after-school learning program where high school students measure, evaluate, and understand indoor environmental quality and energy use in a few schools located in Sacramento disadvantaged communities. Together, students and researchers will deploy sensors, gather and analyze data, and identify mitigation measures that will improve the learning environment.

Advancing Building Leak Identification

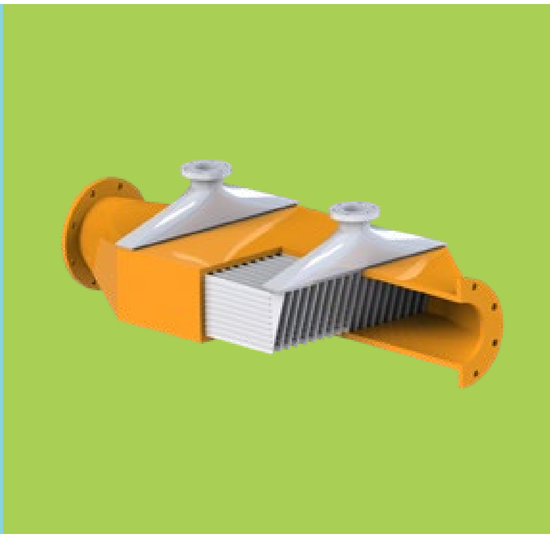
Air leaks in buildings can waste large amounts of energy and cause indoor air quality problems. We are testing a new technology that uses inexpensive, high-accuracy pressure sensors to identify leaks. Researchers will screen multiple buildings and select one building to implement duct and/or envelope sealing. We will measure the building's energy use before and after the retrofit to determine overall energy savings from sealing.

Developing Integrated ZNE Retrofit Packages (REALIZE)

Many low-income households in California do not have access to clean energy options, despite the high potential for energy and emissions savings in their homes. We are part of a research consortium helping to design a cost-effective business model that addresses barriers to zero net energy (ZNE) retrofits in low-income multifamily housing. Researchers will evaluate ZNE retrofit technologies and help develop packages of cost-optimized retrofit solutions. These packages will then be field tested in buildings representative of the housing stock. We will then monitor and verify retrofit solution performance to determine overall project results.

Developing Next Generation Heat Exchangers

We are collaborating with the NEXT Center for Additive Manufacturing at Carnegie Mellon University on two new projects aimed at developing novel heat exchangers for high temperature and high pressure applications. In the first project, the team is developing a molten-salt to supercritical carbon dioxide (sCO2) heat exchanger. Such heat exchangers could be used in next generation solar thermal power plants with thermal storage that are slated to use a high-efficiency sCO2 power cycle. In a second project, the team is developing an ultra-high temperature recuperator for sCO2 cycle. Both projects include multi-disciplinary aspects including material science and engineering, additive manufacturing, corrosion and thermal and fluidic design.



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