Advanced Heat Exchangers for HVAC Applications

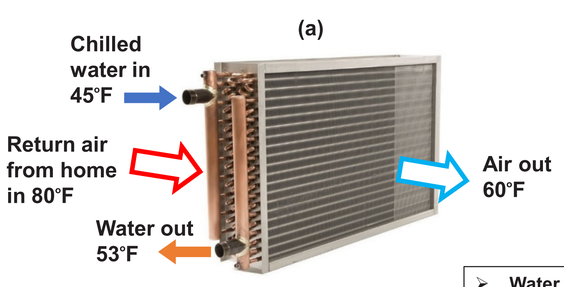
Erfan Rasouli, Matt Stevens, Caton Mande, Vinod Narayanan
Sponsor: Office of Naval Research

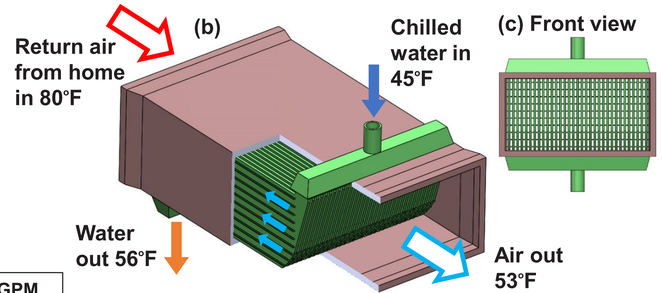
HVAC refrigerants with low global warming potential have significant environmental benefits, but have flammability concerns; in the interest of safety they are best kept in hermetically, factory-sealed heat pump packages outside homes. To do this, a secondary fluid, such as water, is needed to transfer 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 (see Fig. 1a) and current state-of-the-art chilled water-to-air HXs have significant limitations.

Goal and Progress

To use 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 (Fig. 1b). 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 (Fig. 1c). Air flows between the WPs and through the fins and exchanges heat with water within the plates.





- Water flow rate: 8 GPM
- Fan flow rate: 1500 CFM
- HX size: 2 x 2 x 1 ft³

Current state of the art- Cross flow tube-fin
- ☹ Low effectiveness
- ☹ Additional pressure drop across tube bank
- ☹ Made from metals- heavy; expensive

Innovations:
- Eliminate tubes; flow through microscale passages within each “fin”
- Near counter-flow configuration
- Use plastic; less expensive, lighter, more chemically resistant

Proposed Microchannel Plastic HX
- ☺ High effectiveness
- ☺ Low pressure drop
- ☺ Lighter, less expensive, potentially less noisy

Figure 1

Results

We developed a thermo-fluidic model for performance predictions of this concept. The performance of MPHX is compared with a finned tube HX in Fig. 2. The calculations show that for identical approach temperatures and flow rates **the effectiveness of MPHX is up to 20% higher** than that of a finned tube design.

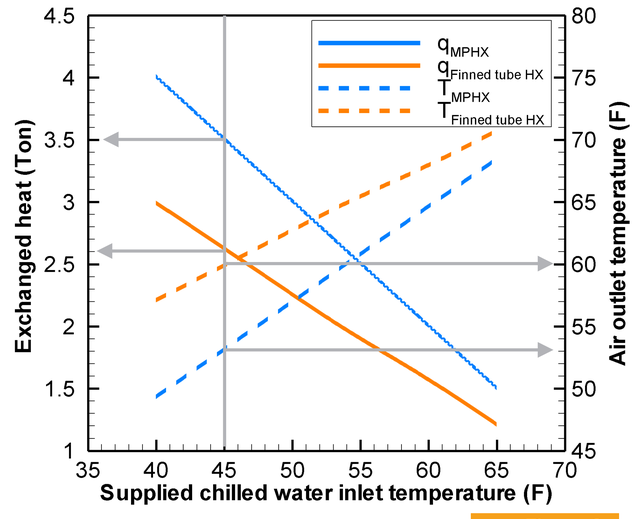


Figure 2

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.

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PROJECT RESULTS:

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

Vinod Narayanan, Antash Najib, Curtis Harrington, Rachael Larson

Introduction

Ground-source heat pumps (GSHP) reduce energy required for cooling in summer and heating in winter by taking advantage of the more stable and moderate ambient temperatures of the ground. GSHPs come in a variety of geometries and configurations.

Goal

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.

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

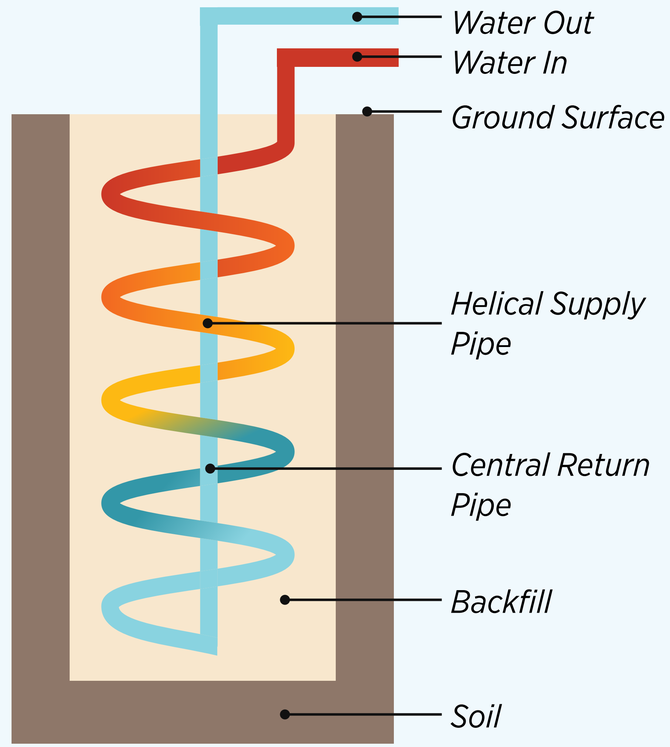
Benefits

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.

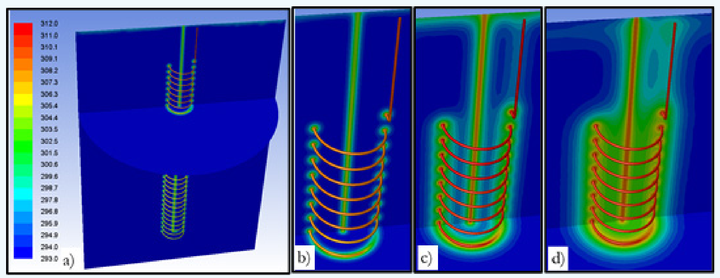
Path Forward

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.

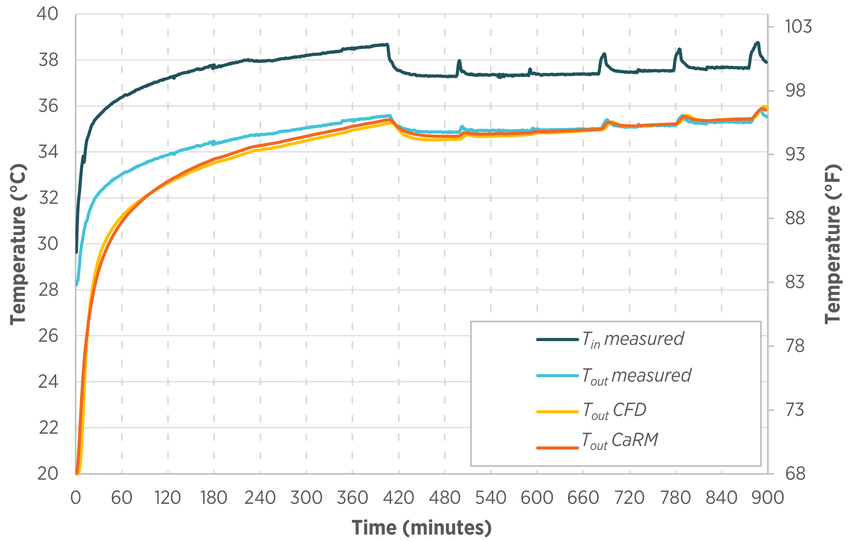
Diagram of the helical GHE modeled and installed at the field site.



Temperature contours of the GHE and surrounding soil after (a) one hour, complete model (b) one hour, top portion (c) six hours, top portion (d) 15 hours, top portion (e) 15 hours, bottom portion.



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



FUNDING PROVIDED BY THE CALIFORNIA ENERGY COMMISSION

Performance Testing of a Low Global Warming Potential Alternative Refrigerant

Derrick Ross, Curtis Harrington
Sponsor: Trane // Collaborators: (Trane) Steve Kujak, Honeywell

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 it to R-410A refrigerant.

Goal

To compare 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 it's performance could be quantified according to the **ANSI/AHRI Standard 210/240** and compared at each test point.
- We measured the **performance of the RTU** with R-410A refrigerant, changed the refrigerant out for the new R-466A, and then retested RTU performance.
- The final performance of the unit using R-410A and R-466A was **compared using capacity, total power, and coefficient of performance (COP).**

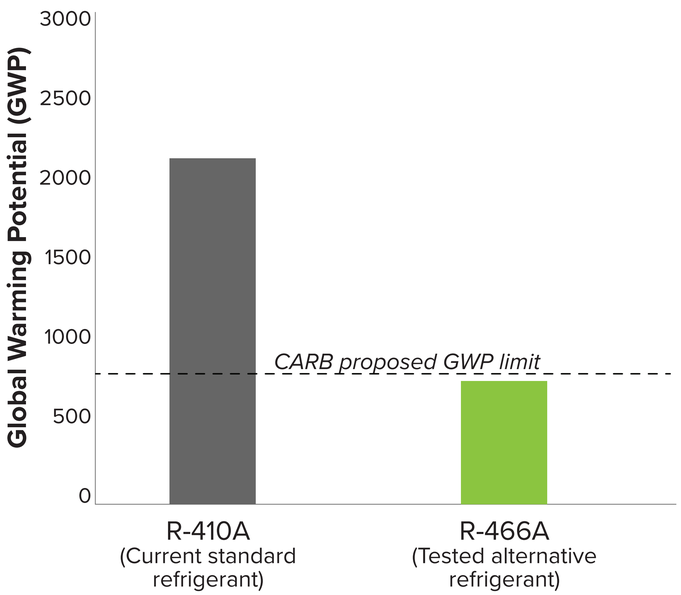
Results

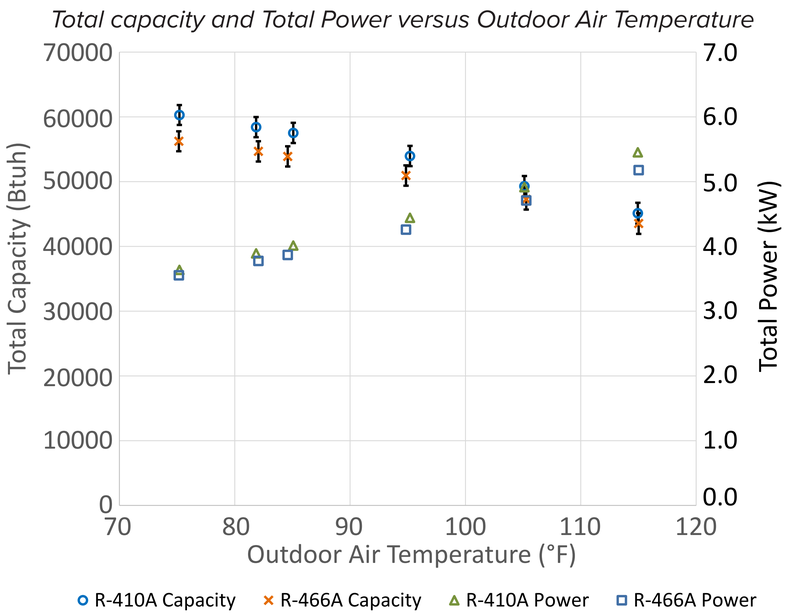
The retrofit R-466A refrigerant was able to provide **similar performance** to R-410a refrigerant while also having a **lower GWP**.

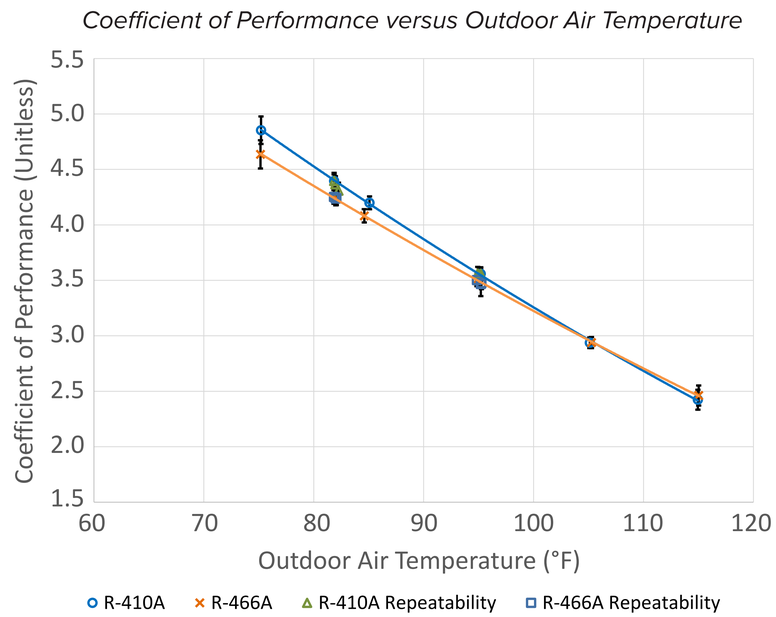
At higher temperatures the performance was the same while at lower temperatures R-466A capacity and efficiency was slightly lower compared to R-410A. The R-466A refrigerant was also slightly denser and required about 8% more refrigerant charge compared to R-410A.

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.







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Next Generation Space Conditioning System

Curtis Harrington, Caton Mande, Mark Modera, Sreenidhi Krishnamoorthy
Sponsor: California Energy Commission // Collaborators: (EPRI) Sara Beaini, Aaron Tam, Ammi Amarnath

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 climate. As part of this project, we are testing one of these advanced technologies–a variable speed heat pump system.

Goal

To evaluate 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 system performance. There were three primary phases of this research:

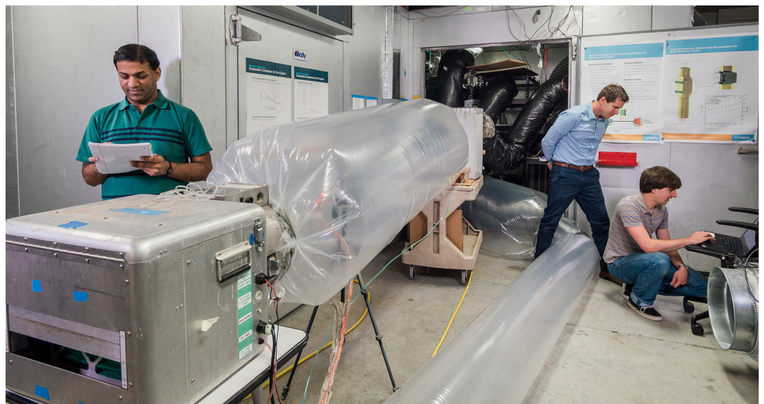
Phase I: Laboratory testing under a single-zone configuration

Phase II: Laboratory testing under a multi-zone configuration

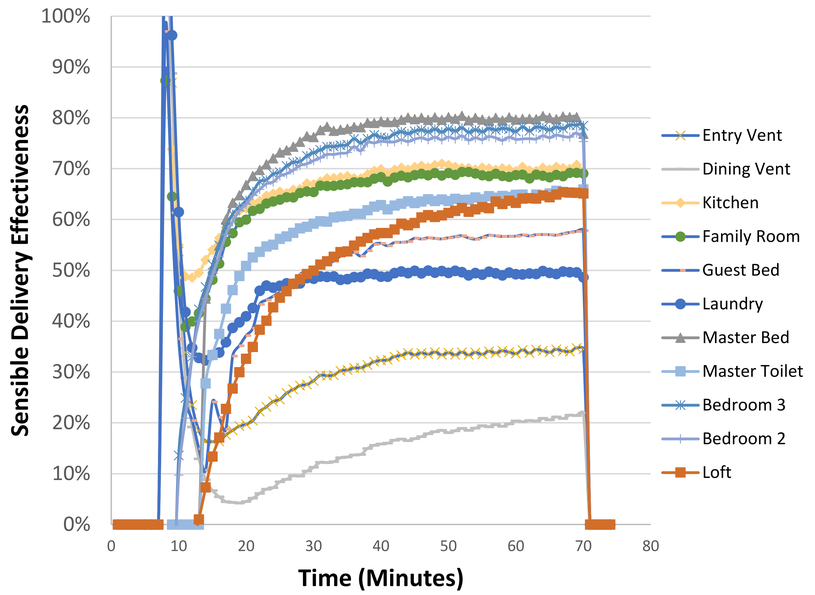
Phase III: Field testing of variable-speed heat pumps under a multi-zone configuration

Results

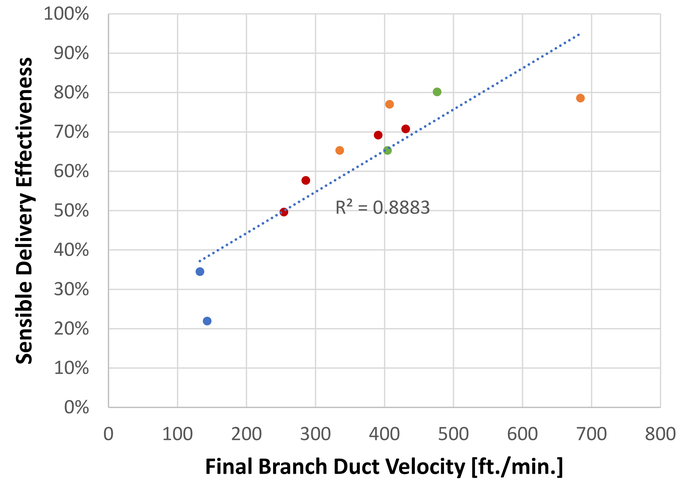
- **Zoning was very effective at maintaining system performance under part load conditions.** With a single-zone configuration, there were significant duct heat gains at lower speeds. Even though equipment performance generally improves at lower speeds, researchers found that optimal performance of the combined equipment and duct system occurred at high speeds when hot attic temperatures are present.
- **Adding zoning capability significantly improved system performance at lower speeds** by maintaining duct velocities and 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.
- **Field testing verified the overall system performance implications** when changing heat pump speeds.
- Real-world observations confirmed that **fractional duct losses had a significant dependence on duct velocity.**



Sensible delivery effectiveness for each grill at PG&E field site during a period of full-speed operation



Sensible delivery effectiveness versus final branch duct velocity for each grill at PG&E field site



Publications & Reports

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

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Performance Evaluation of Software-Controlled Switched Reluctance Motors

Caton Mande, Matt Stevens, Theresa Pistochini
Sponsor: Southern California Edison

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

To evaluate 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 & Reports

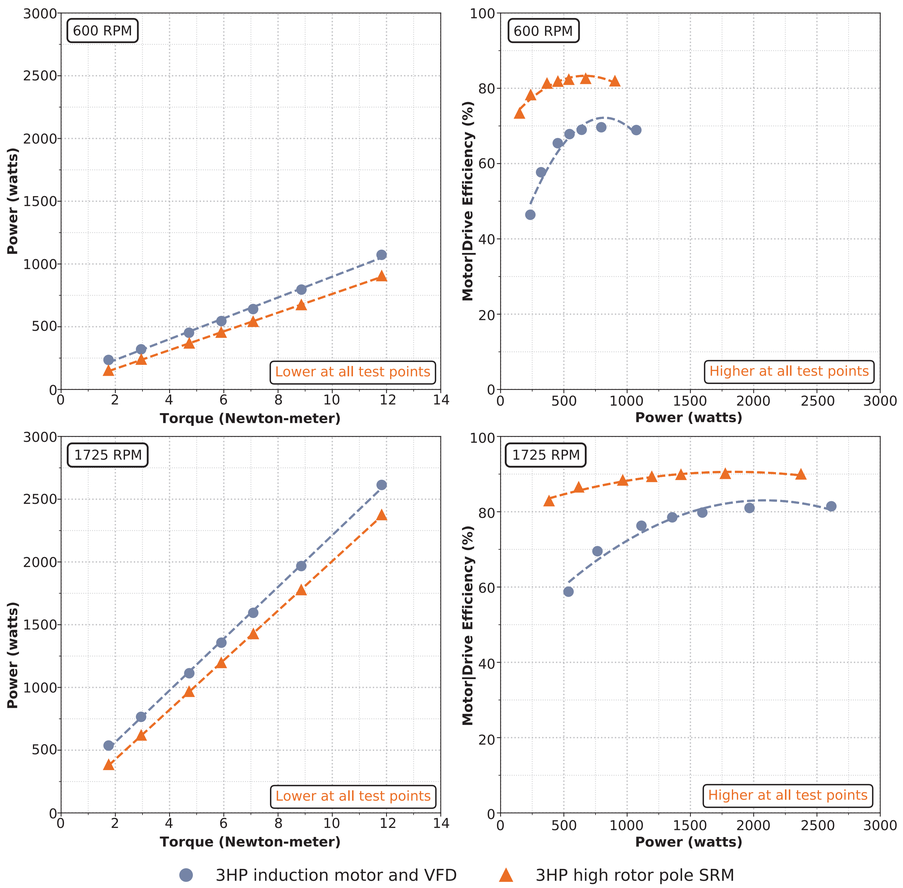
Final report:
http://bit.ly/SMCreportETCC

Results Summary

- High rotor pole SRM used **9% to 36% less power** to generate the same torque on the dynamometer.
- On average, the high rotor pole SRM **reduced the power intensity by 17% to 22% in the lab RTU and 11% in the field RTU.**
- **Operating at variable speed achieved additional savings** by reducing the airflow rate when full airflow was not required.

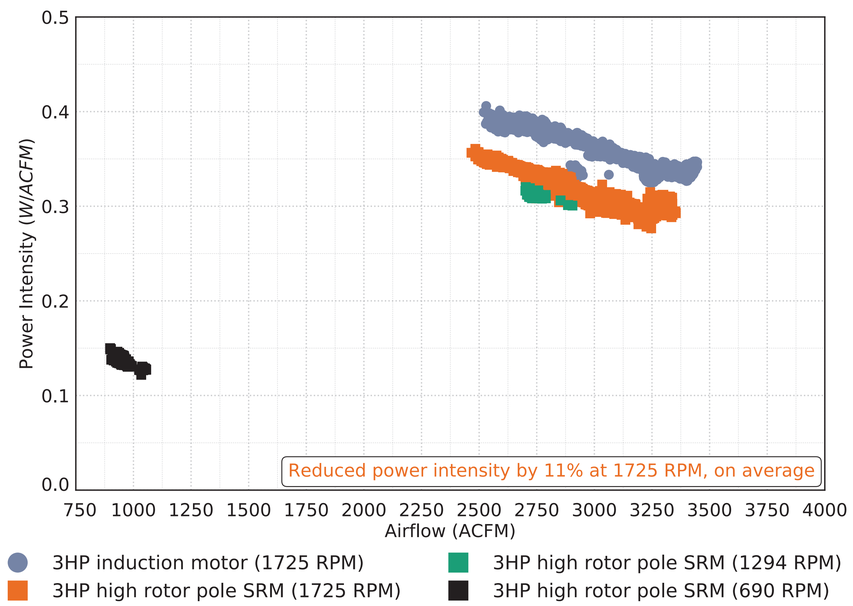
Lab Dynamometer Results

Laboratory dynamometer testing

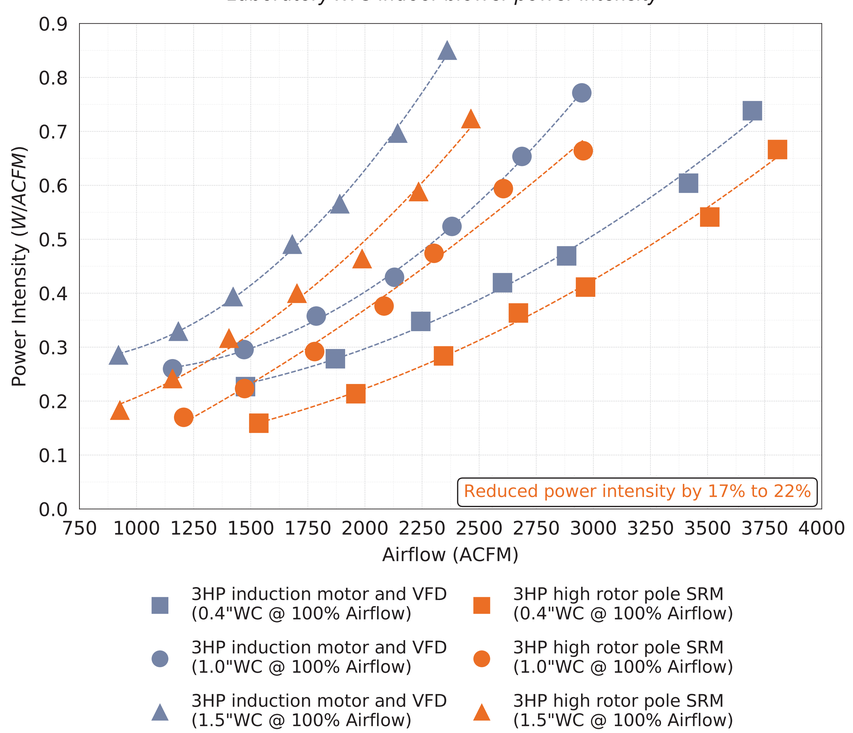


Lab & Field RTU Results

Field RTU indoor blower power intensity



Laboratory RTU indoor blower power intensity



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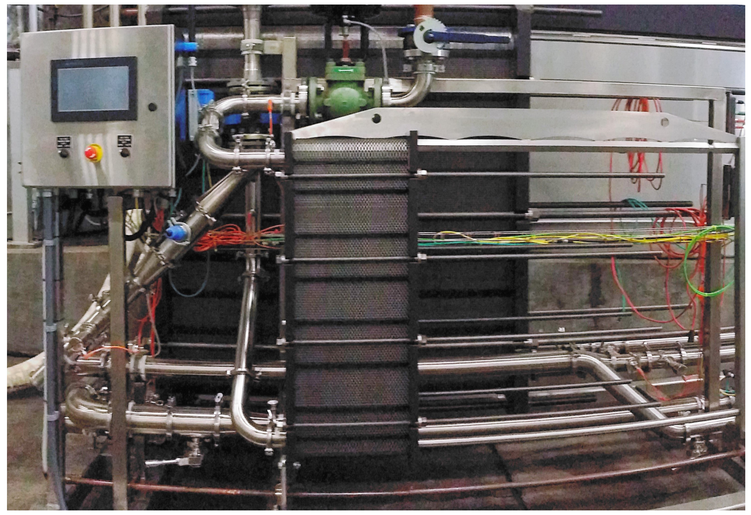
Using a Heat Exchanger to Recover Heating and Cooling Energy in the Cold Stabilization of White Wine

Frank Loge, Kendra Olmos, Jose Garcia, Robert Good

Sponsor: California Energy Commission // Collaborator: Jackson Family Wines



In 3 months of monitoring:

- **82 hours of operation**
- **1.7 million gallons of unstabilized wine processed**
- **63 MWh transferred in primary heat exchanger**
- **$4,782 value of to-date resource savings**

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

To reduce cooling and heating energy used in the white wine cold stabilization process by using a heat exchanger technology. In the cold stabalization 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 beetween the wine entering and exiting the stabalization 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.

Aerosolized Sealant for Building Envelopes

Curtis Harrington, Mark Modera, Daniel Reif

Sponsors: Department of Energy, California Energy Commission // Collaborators: Center for Energy and the Environment, AeroBarrier

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.

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. 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

To determine the ideal stage of construction to apply the AeroBarrier process, reduce labor and material costs, and measure improvements in energy efficiency and indoor air quality.

Progress

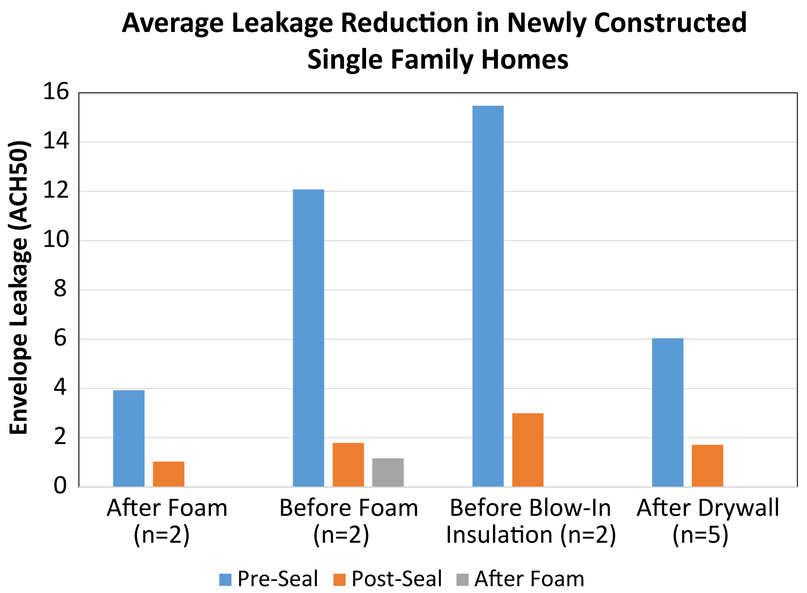
This past year, we demonstrated AeroBarrier in both new and existing single-family homes in California. Sealing new homes took place during different stages of construction and with different insulation methods, including rough-in (before and after spray foam insulation, before blow-in insulation) and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

Path Forward

Determine the best approach for sealing existing homes by evaluating new sealant formulations, as well as alternative spray configurations.

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.



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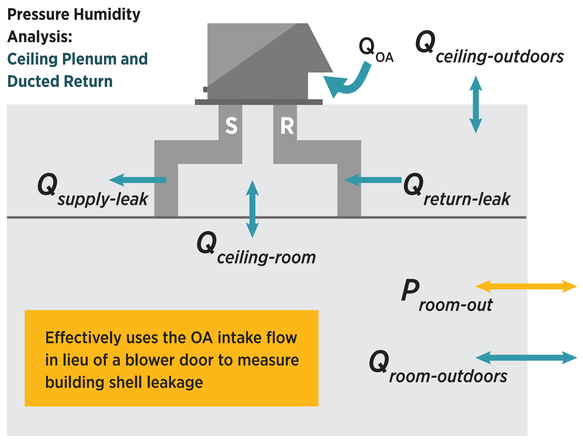
Building Leakage Diagnostics with IoT Enabled Sensor Networks

Armando Casillas, Mark Modera, Curtis Harrington
Sponsor: National Institute of Standards and Technology // Collaborators: (XCSPEC) Janet Peterson, Peter Peterson

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 pressure signals to detect envelope leakage and the flow of water vapor through the ventilation system to detect duct leakage.

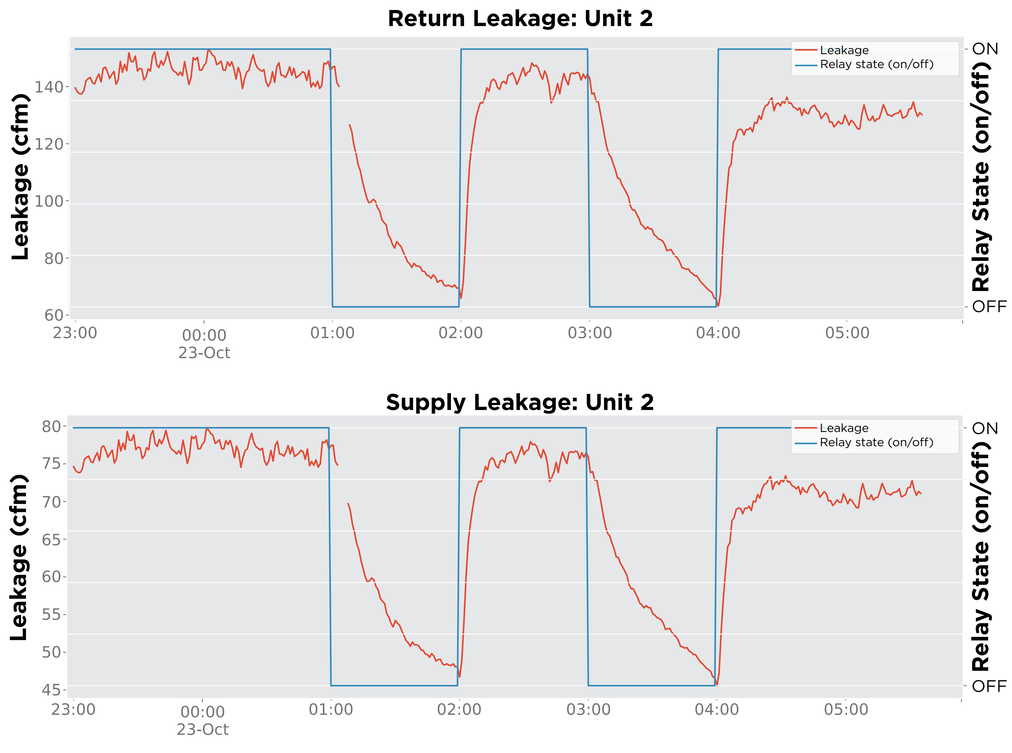
Goal

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.



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.



Measured supply and return leakage flow 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.

Results

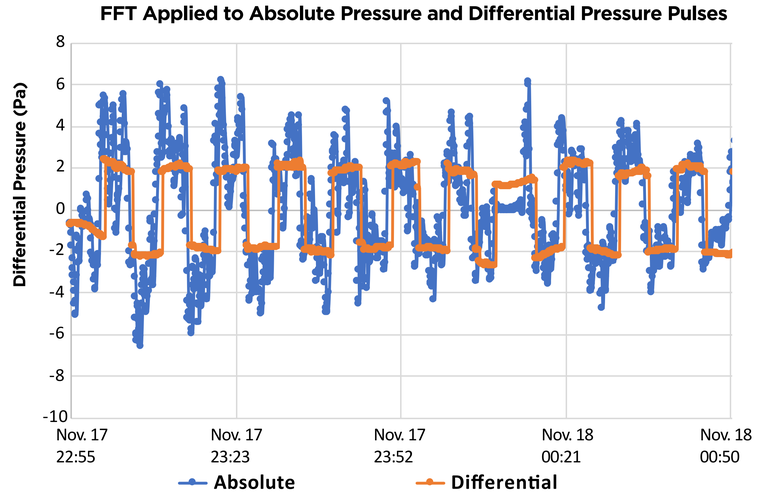
- Envelope leakage measurements from the sensor network were within **2%** of the blower door test.
- Total duct leakage measurements from the sensor network were within **10%** of duct blaster tests.

	Blower Door Test	Field Sensor Network
Envelope Leakage	1250 CFM_25	1240 CFM_25

	Duct Blaster Pressurization	Field Sensor Network
Supply Leakage	250 CFM_25	230 CFM_25
Return Leakage	450 CFM_25	430 CFM_25

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.



Fast Fourier Transform (FFT) Filter applied to absolute and differential pressure measurements between inside and outside the building.

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PROJECT RESULTS:
Improving Indoor Air Quality in California Schools

WCEC: Theresa Pistochini, Robert McMurry, Sarah Outcault
LBNL: Wanyu R. Chan, Xiwang Li, Brett C. Singer

Introduction

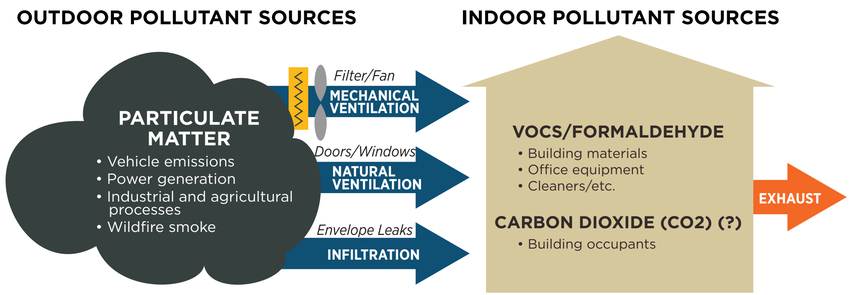
HVAC systems provide necessary mechanical ventilation to classrooms. Ventilation is needed to remove indoor pollutants such as volatile organic compounds and formaldehyde, and carbon dioxide (CO2). There is increasing evidence that CO2 exhaled by occupants is an indoor pollutant that can affect decision making performance [1]. This is particularly important in spaces that are densely occupied, such as classrooms. Importantly, studies have found that ventilation impacts student performance and attendance [2].

Goal

During the 2016-2017 school year, UC Davis characterized HVAC systems, CO2 concentrations, and indoor thermal conditions in 104 classrooms that had replaced their single zone HVAC systems within the past three years.

Results

- Overall, classrooms with recent HVAC retrofits had higher ventilation rates than reported generally in the literature, including in a recent California study [3].
- **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.



Mechanical ventilation systems deliver filtered outdoor air to a space to reduce indoor pollutants

References
1) *U. Satish, M. Mendell, K. Shekhar, T. Hotchi, D. Sullivan, S. Streufert and W. Fisk, "Is CO2 an Indoor Pollutant?" Environmental Health Perspectives, vol. 120, no. 12, pp. 1671-1677, 2012.*
2) *W. J. Fisk, "The ventilation problem in schools: literature review," Indoor Air, International Journal of Indoor Environment and Health, vol. 27, no. 6, pp. 1039-1051, 2017.*
3) *Mendell, M.J, et al., "Association of classroom ventilation with reduced illness absence: a prospective study in California elementary schools," Indoor Air, vol. 23, no. 6, pp. 515-528, 2013.*

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 [3].

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.

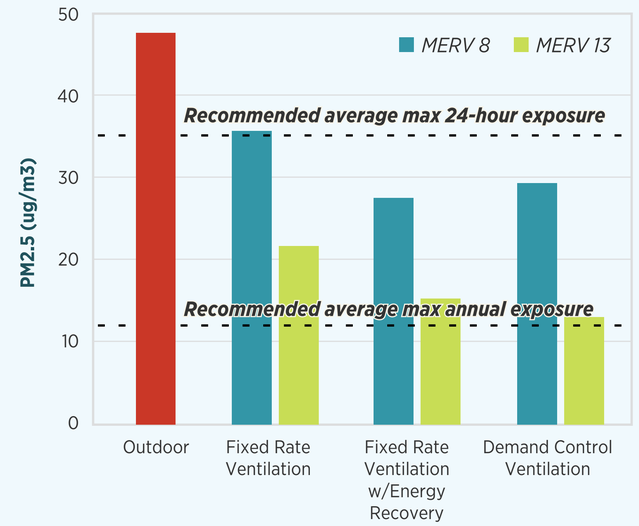
Path Forward

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

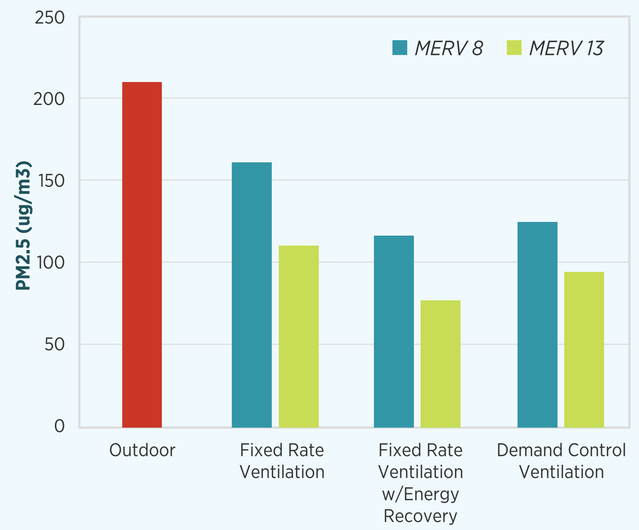
- Standard vs energy recovery vs demand control
- Standard vs high efficiency equipment
- Two filter options (MERV 8 vs MERV 13)

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

November 14, 2018: "Moderate" outdoor air quality



November 15, 2018: "Very Unhealthy" outdoor air quality



Recent smoke days resulting from the Camp Fire showed the benefits of MERV13 filters. Poor air quality from the Camp Fire resulted in school closures in the Sacramento and Bay Area regions. In Sacramento area classrooms, MERV13 filters reduced indoor PM2.5 concentrations by 30-50% compared to MERV8.

FUNDING PROVIDED BY THE CALIFORNIA ENERGY COMMISSION

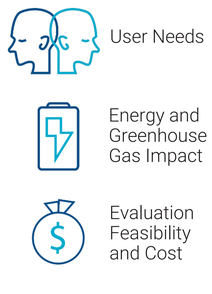
California Energy Product Evaluation Hub

Mark Modera, Theresa Pistochini, Sarah Outcault, Rachael Larson
Sponsor: California Energy Commission

Product Categories

- Electric Space Conditioning
- Electric Water Heating
- Commercial Refrigeration
- Energy Management and Information Systems
- Buildings Fenestration and Windows
- Plug-load Products
- Lighting
- Agricultural Irrigation Systems
- Energy Storage

PRIORITIZE



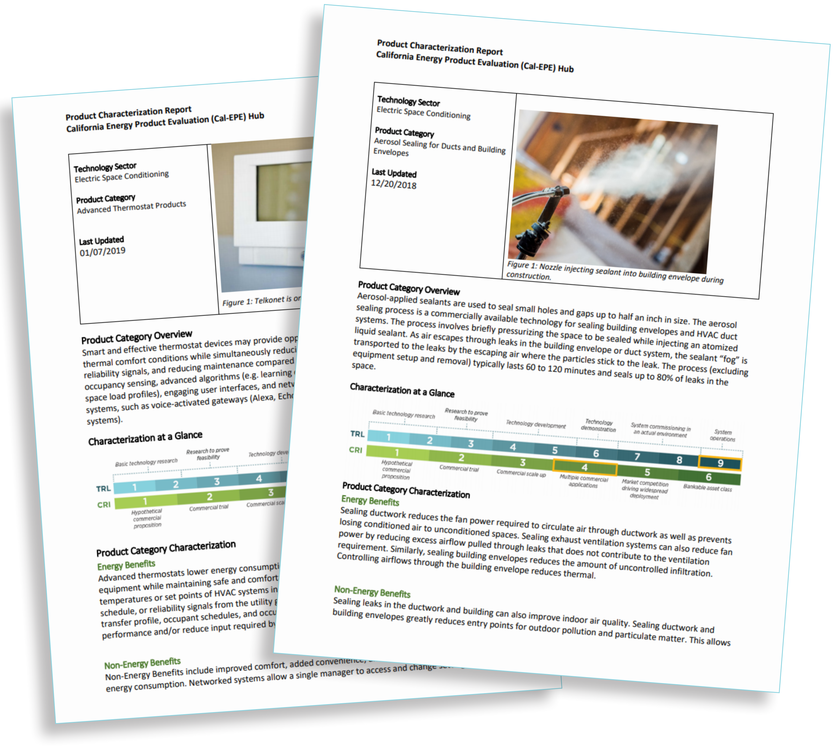
The California Energy Product Evaluation (Cal-EPE) Hub (or Hub) will provide large commercial and institutional customers (e.g., K-12 schools, universities, local/state government, agriculture, commercial real estate) the information they need to purchase advanced distributed energy resource (DER) products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

Goal

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.

Progress

- In the first year (2019), we are organizing and describing **eligible product categories** and prioritizing 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**, which is currently in process, will: 1) identify customers' priority DER products, 2) identify the information they would need from a product evaluation, and 3) outline pathways for the Hub to influence customer procurement.
- In subsequent years, we will evaluate products and disseminate the results through an **online buyers' guide.**



Product characterization reports can be found online at: http://bit.ly/EElcalEPE

> *"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)*

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 in fall 2019.

Collaborators and Contributors: UC Davis California Lighting Technology Center, Energy Storage Lab, Russell Ranch, Facilities Energy and Engineering; Lawrence Berkeley National Lab; UC Berkeley Center for the Built Environment; Energy Solutions; Local Government Commission; Coalition for High Performance Schools

UCDAVIS
Western Cooling Efficiency Center

Building Energy Audit and Analysis Tools: Supporting Market Transformation of Energy Efficiency Retrofits

David Vernon, Benjamin Finkelor, Joshua Morejohn, Kiernan Salmon, Alex Malm

Sponsor: Office of Naval Research // Collaborators: UC Davis Energy Conservation Office, arbnco

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

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.

>10,000
Buildings Audited

5,000
Building Retrofit recommendations made

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.

UCDAVIS Western Cooling Efficiency Center

UCDAVIS Energy and Efficiency Institute