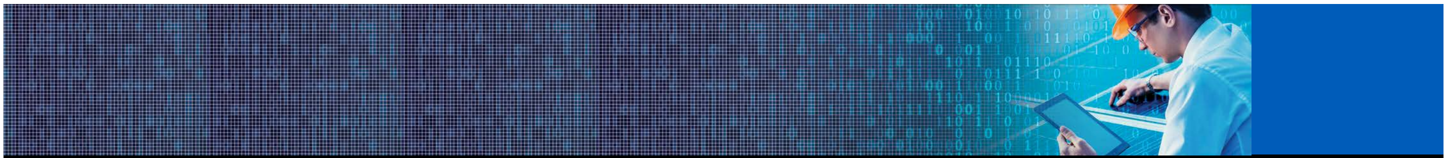
ELECTRIC POWER RESEARCH INSTITUTE

PROGRAM ON TECHNOLOGY INNOVATION: DISRUPTIVE INNOVATIONS FOR HEATING, VENTILATION, AND AIR CONDITIONING (HVAC) SYSTEMS – 2017

May 2018



Executive Summary

End-Use devices have presented themselves as Distributed Energy Resources (refer to EPRI's Integrated Energy Network white papers) [1]. As utilities seek practical and creative ways for energy and power demand side management, established and emerging Heating, Ventilation and Air Conditioning (HVAC) systems have developed versatility to serve as valuable resources for demand-side management, mainly with connectivity and adjustable speed features. Connectivity features include Wifi-enabled systems where customers can control and monitor their HVAC system operation using apps on their smart phone and/or demand-response (DR) capabilities for utilities to send a signal to HVAC systems and reduce their capacity during peak demand. Variable capacity compressors and fans further enable the energy efficiency (EE) savings of the systems and can operate at part-load capacity (ex. variable capacity heat pumps) while satisfying the customer's thermal comfort needs and delivering EE and DR results.

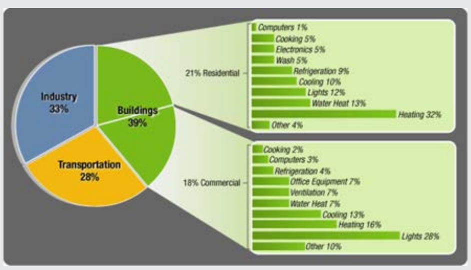


Figure 1 – Buildings in the U.S. today consume 72 percent of electricity produced, and 55 percent of U.S. natural gas use. They account for about 40 percent of total U.S. energy consumption (costing $350 billion per year) and greenhouse gas emissions. Reducing the GHG emissions associated with buildings is essential to reducing overall U.S. emissions [2].

As illustrated in Figure 1, building HVAC systems account for 42% of residential buildings' energy consumption and 36% of commercial buildings' energy consumption, which includes both electric and gas consumption. Reducing greenhouse gas emissions due to the energy footprint of building HVAC systems, and reducing the global warming potential of the refrigerants used in refrigeration and HVAC systems, continue to be the primary drivers for innovation and market transformation needs in the HVAC industry, across all sectors – residential, commercial and industrial. Government policies have been driving the market to address the environmental impact factor of HVAC systems, though the commercialization process and market adoption has been slow.

Application/Use Case Overview

Needs, Opportunities, and Challenge

HVAC systems provide space conditioning to serve thermal comfort needs, especially in commercial and residential applications; and for thermal management needs, especially for processes in industrial and commercial sectors. The newly commercialized "smart" HVAC systems have expanded from diagnostics to monitoring and control features, enabling the user to access the thermostat settings via smart phone apps. Some recent examples are described in EPRI's summary of the 2017 ASHRAE Winter Conference and AHR Expo [3]. Additionally, the integration of controls would enable more customized strategies for supporting Demand Response objectives through the collaboration of manufacturers.

Opportunities for innovation to address primary industry needs and challenges are being monitored in emerging HVAC-related technologies. Key innovations should address the following research gaps. We include examples of the scouted emerging technologies that fall in each area.

a) Reducing building load through non-HVAC means: While HVAC systems are designed to meet the building's conditioning needs, the building attributes could be varied such that the HVAC load would be reduced. This is primarily done through the building envelope with insulation, thermal mass, fenestration/windows (multi-pane) or through waste heat recovery. Examples: SHARC Energy Systems, Inc.; RoCo (Mobile Comfort, Inc.)

b) Expanded electric heating capacity to meet lower ambient temperature conditions with reduced or eliminated back-up heating (ex. electric resistance or gas) across more climate zones. This is typically done by improving the system efficiency for specific ranges of operation, using adjustable speed drives, variable capacity compressors, ground-coupled heat pumps and waste heat recovery. Examples: Treau Isothermal Compressor, Treau Membrane Heat Exchanger

c) Improved efficiency at high ambient temperatures (mitigates peak demand) and/or high humidity. Strategies include using make-up air units (100% outdoor air conditioning units), also called DOAS (Dedicated Outdoor Air Systems), which separate the sensible cooling and dehumidification loads, thus addressing hu-

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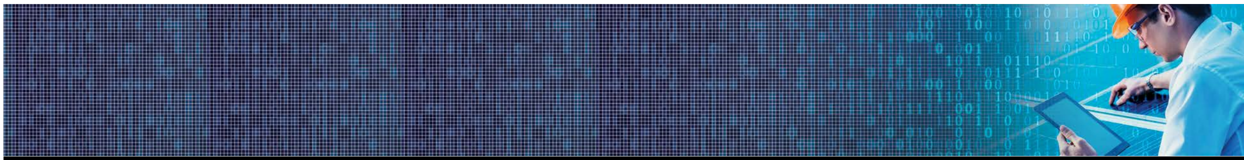
This white paper was prepared by EPRI



midity removal more efficiently and allowing independent control of sensible cooling. Example: ClimateMaster, Munters

d) Improved component efficiency, such as improving motor or compressor efficiency or reducing the defrost cycle penalty, especially for commercial refrigeration and residential heat pumps (outdoors units) applications. Examples: Interphase Materials, Nelumbo, SkyCool Systems, Software Motor Corporation

e) Thermal energy storage and/or integration of energy efficiency with energy storage which support peak demand shifting. Examples: Element 16 Technologies, Inc. and SunAmp

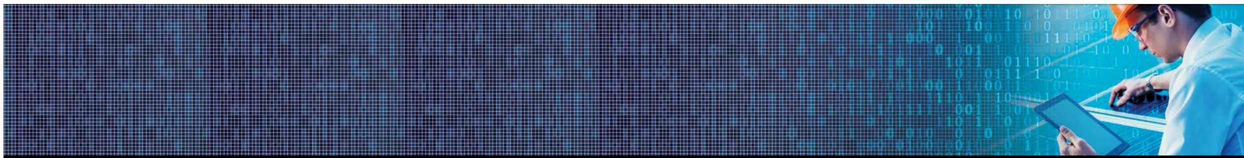
f) Alternative refrigerants to reduce or eliminate the use of current environmentally-harmful refrigerants, and replace them with safe alternative refrigerants or alternative heating and cooling technologies. For example, because of its high ozone depletion potential (ODP), R-22 refrigerant is being phased out. Many hydrofluorocarbon (HFC) refrigerants are also being targeted for phase out because of their high global warming potential (GWP). For residential space conditioning, the most common example is R-410A, which has become the common "alternative" to R-22. R-410A is a blend of R-32 and R-125, and has a GWP of about 2,100. As a comparison, R-22 has a GWP of about 1,800. While R-410A does not have high ODP, it actually has higher GWP. Residential space conditioning requires extra caution with regards to flammability and toxicity. For the long-term, the HVAC&R industry may use very-low GWP refrigerants, which may include a limited number of refrigerant options applicable to different applications. Natural refrigerants, such as ammonia, CO_2 and hydrocarbons, can each fit well into some applications. Thus, it may be the case that some applications may have HFCs/HFOs as refrigerants, in blends or similar. Example: Treau Isothermal Compressor; Mayekawa; Emerson Propane Conditioning Units

g) High efficiency chillers for higher chilled water temperature. Most chillers are tuned for 45°F supply, while certain applications are requiring warmer supply temperatures of 55°F or above, thus compressors fine-tuned for higher temperatures would be beneficial.

Technology Overview

When evaluating any HVAC component or system, there are several metrics to consider and compare performance across different products. The table below provides the definitions/taxonomy of the key metrics for evaluating HVAC technology.

Brand	**Company name**	**Model**	**Unit model version**
TRL	Technology Readiness Level [4]	**MRL**	Manufacturing Readiness Level
COP	Coefficient of Performance - ratio of energy delivered to the energy input	**HSPF**	Heating Seasonal Performance Factor – ratio of total heating output (Btu) to total seasonal input energy (watt-hours)
EER	Energy Efficiency Ratio – ratio of system's heating or cooling output (Btu/hr) to the input (watts)	**SEER**	Seasonal Energy Efficiency Ratio – ratio of total seasonal cooling output measured (Btu) to total seasonal watt-hours of input energy
System Capacity (heating)	System heating capacity with temperature ranges	**System Capacity (cooling)**	System cooling capacity with temperature ranges
Compressor type and specifications	Identify compressor mode	**Fan type and specifications**	Identify fan mode
Refrigerant Type, GWP, ODP	HVAC system working fluid, its Global Warming Potential and Ozone Depletion Potential	**Refrigerant safety, maintenance needs**	Refrigerant flammability/toxicity level and associated maintenance provisions
Connectivity options	Ex. OpenADR 2.0 for Demand Response; AHR 1380 specifications; Thermostat control with phone app	**Thermostat or Controller**	Customer interfacing device for setting user preferences
Footprint; Sizing	System dimensions; Area footprint	**Acoustics**	Sound level from equipment operation
System Packaging	Number of components; Delivery	**Modular Design**	System integration for expanded capacity or options
Control features	Ex. thermostat settings; operational accessibility for user vs. maintenance personnel	**Accessory components**	Ex. ducting, dampers, refrigerant piping/charging needs



Overview of Emerging Electric Technologies

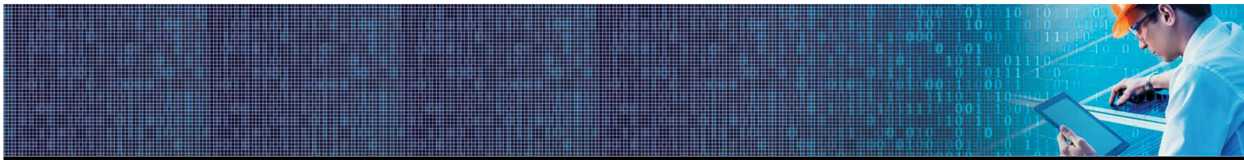
The following is a summary of a short list of emerging electric technologies which were evaluated and for which preliminary due diligences were conducted in 2017. The technologies span different components, features or types of HVAC systems, offering innovations to improve HVAC system efficiency and cost-effectiveness, at varying Technology Readiness Levels (TRL). These companies were identified through the TI Scouting network, which include:

a. Incubate Energy Network: The Incubatenergy Network is a consortium of clean energy focused incubators across the United States that have supported over 500 companies to date and have a significant future pipeline. The success of companies supported by Incubatenergy Network members is represented by their metrics, securing more than a $1.6 billion in funding, $440 million in revenue and over 3,300 direct jobs. These companies represent an important element of the EPRI Technology Innovation and Scouting programs, connecting emerging entrepreneurs with our utility members for increased collaboration in the energy industry.

b. Caltech FLOW/Rocket Fund: Caltech FLOW/Rocket Fund: Housed at the Resnick Sustainability Institute at the California Institute of Technology Caltech, FLOW (First Look West) [5] is a program that supports young entrepreneurs starting cleantech companies through a competition program sponsored by the Department of Energy's Cleantech UP (CUP), with follow-on training, mentoring and networking for funding. FLOW winners are eligible to compete in the DOE National Cleantech UP. FLOW's Rocket Fund, in partnership with a consortium of California's major utilities, the California Emerging Technologies Coordinating Council (ETCC) [6], provides non-equity grants for companies to build their first commercial prototype and field test with customer.

c. University and National Laboratories: Significant cleantech innovation begins in the university and national laboratories, supported by NSF and/or ARPA-E awards to advance their development. Some universities and labs have their own innovation and entrepreneurship programs which cultivate the advancement of the technologies and start-ups.

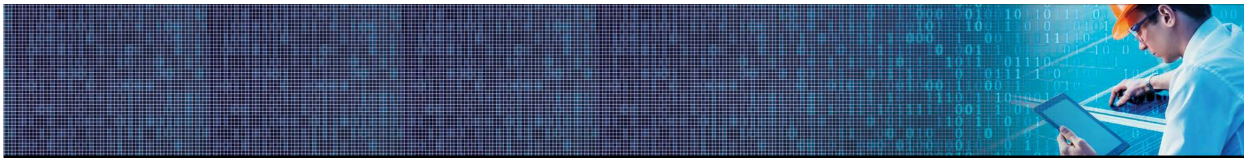
Company	TRL	Description	Differentiator/Value to Power Utility
Element 16 Technologies, Inc. element 16 TECHNOLOGIES http://www.e16tech.com/	5	Element 16, established as a company in 2016, has developed a novel thermal energy storage system (TES) based on molten sulfur that is installed as a retrofit to boost the performance of combined heat and power (CHP) systems. In 2016, they were awarded $1.5 million grant funding from the California Energy Commission (CEC) to build a demonstration unit at CSUN (California State University Northridge) to install and operate the first commercial combined cooling, heating and power plant with high temperature Thermal Energy Storage (TES). Unit size lower limit is 540kW.	Element 16 replaces traditional storage media in combined heat and power systems (molten salt, thermal oil, solid storage, water) with molten sulphur, which has demonstrated high temperature performance (up to 600°C) that matches molten salt but is 1/10th cost of competition. Molten salt freezes around 220-240°C so when it is discharged after producing steam ~ 200°C, electricity (heaters) must be used to keep it from freezing. This waste may be avoided using sulfur because it doesn't solidify until 120°C and won't require much, if any, electrical heating. This could open up opportunities in new commercial building sectors, in hotels and hospitals. Flexibly produces either heat or water chilling. Offers load shifting energy during the "spikes".



Company	TRL	Description	Differentiator/Value to Power Utility
Interphase https://www.interphasematerials.com/	5	Interphase Materials, founded in 2015, has developed a proprietary, non-toxic, low-cost chemical surface treatment (single molecule thin coating) that prevents fouling due to corrosion, scale deposits and biological growth, thus boosting system efficiency by 5-10%. Interphase Materials' heat transfer enhancer (HTE) decreases the need for water treatment, improving the efficiency of heat exchangers, resulting in lower CO_2 emissions. There are many potential applications: in the power industry (condenser loop operation), oil and gas (offshore rig heat exchangers), and commercial HVAC. The chemistry is under an NDA restriction but functionally it increases the heat transfer of cooling systems (heat exchangers, condensers, etc.) by 5-10%. This is achieved by changing the physics of cooling water interaction with the hardware (i.e. pipes) on a molecular level, turning the surfaces "slippery". The method of application is as follows: the products are flushed as powders into the cooling system during regular operation, either at targeted injection points or system-wide through a sump, where they automatically bind to the surface system hardware. There is no need to shutdown, drain, coat, or dry – all of which are expensive procedures currently used.	The company currently has a pilot project through EPRI on condenser tubes. The technology has opportunity to be piloted in heat exchangers for commercial HVAC systems. Interphase Materials' main challenge in commercialization is transitioning the technology from medical applications to serving industrial sectors.
Nelumbo http://www.nelumbo.io/	5-6	California Bay Area-based, Nelumbo develops and deploys advanced coating products Omniphobe and Ice-Nein to improve energy efficiency in commercial air conditioning and refrigeration equipment by reducing defrosting timing and maintaining cleaner operations for cooling coils. They developed the first droplet ejection technology, where the droplets jump before they freeze, which vastly delays frosting. Commercially available with low through-put. Applicable on aluminum and expanding onto copper tubes with aluminum fins as well as micro-channel heat exchangers. They are a new member of Lawrence Berkeley National Laboratory Cyclotron Road (3rd cohort).	Energy efficiency gains through reduced defrosting needs for coils in refrigeration systems. No surface preparation is needed beyond the existing industry process; Dip coating process like e-coat, which is currently performed on Aluminum fins.

Company	TRL	Description	Differentiator/Value to Power Utility
RoCo (Mobile Comfort, Inc.) Mobile Comfort Inc. www.mobilecomfort.us	5	Roving Comforter Personalized Space Conditioning Technology (aka RoCo) provides local thermal comfort instead of whole space, to reduce HVAC costs- in line with ARPA-E program DELTA Delivering Efficient Local Thermal Amenities (APRA-E awardee). It's distributable (portable) dual-storage device with its on-board battery and phase-change material, which can re-charge at off-peak hours. Current prototype operates 8hrs continuously to provide heating/cooling (5°F cooling). Phase change material is the heat sink, so system doesn't need a fan or vent.	Technology provides load shifting, flexibility and portability features to the customer. Two key impactful scenarios for its application are: 1. For average 5 workers/52,000 ft^2 (4831m^2) in warehouses and 100 workers/50,000 ft^2 (4645m^2) in manufacturing buildings ▪ Workers lost 10% productivity when temperature in working environment temperature increases from 77°F to 86°F (25- 30°C) ▪ Spot coolers requires power of the order of 1kW each; RoCo requires power of the order of 50W each ▪ *Efficient Electrification opportunity. Improves worker productivity substantially.* 2. Places where central AC is not necessary and window AC is almost exclusively used ▪ Window AC unit (10.7 SEER) consumes roughly 3.5 times more energy than four RoCo units ▪ For a family of four, daily energy savings are 1.3 kWh ▪ *Demand Response and reduced HVAC energy use opportunity*
SHARC Energy Systems Inc. SHARC ENERGY SYSTEMS www.sharcenergy.com	8	Canadian-based, Sharc Energy Systems (formerly International Wastewater Systems, Inc.) designs and develops renewable energy systems that extract thermal energy from wastewater, promoting energy efficiency for residential and industrial buildings (wastewater heat recovery). Two product lines are SHARC (10MW of recovered heat: space heating, cooling and water heating) and Piranha (self-contained unit that can generate 100% of domestic hot water heating load; suitable for commercial and 50-200 multiunit residential applications). Installations have been done in Scotland, Canada, New Jersey and Washington DC.	With Sharc heat rejection system, cooling towers can be eliminated. Installations are done as a Power Purchase Agreement. As technology picks up traction, building codes may implement sanitary energy exchange guidelines.
SkyCool Systems SkyCool Systems http://skycoolsystems.com/	5-6	Passive fluid cooling panels with an optical/photonic film coating (controls thermal radiation and light absorption), that save energy and water use for building cooling by implementing sky cooling natural phenomenon. SkyCool technology is an Add-on to cooling systems that cools the refrigerant, thus reducing electricity used by compressor which improves system overall efficiency. The system can be installed by solar installers and connected to the refrigeration system by HVAC contractors. Currently conducting first pilot demonstration in CA of small-scale system integration (1kW) and began a 10kW scale demonstration in 2017 in Davis, CA.	Energy Efficiency technology that reduces cooling electricity usage 24hrs a day (including peak hours). It has zero water use, and is a simple add-on to new or existing cooling systems. Key applications are commercial refrigeration, data center cooling and commercial building A/C. Addresses the phase-out of conventional refrigerants (HFCs) by 2021 and Zero Net Energy targets.

Company	TRL	Description	Differentiator/Value to Power Utility
Software Motor Corporation https://www.softwaremotorcorp.com/	8	SMC's new motor Vulcan Smart motor system uses a patented software based controller to operate a switched reluctance motor to improve the energy efficiency of electric motors (world's #1 consumer of electricity) by up to 75% when compared to baseline single-speed induction motor. This efficiency gain is feasible for less than 50% load on the system. Inherently, the switched reluctance motors do not use any permanent magnets and the rotors are controlled by the application of magnetic field generated thorough the passage of current in the stator windings. The SMC has made great technical strides in the coil winding techniques as well as controlling the motors with or without a position sensor (hall effect sensor typically used on the rotor to determine the rotor position) using their proprietary algorithms and software. The motor operates with their SMC inverters which can also be connected to the Internet and can be controlled through cloud.	The SMC controller's ability to be an Industrial Internet of Things (IIoT) device and the ability to control the motor with an Internet based software controller offers the flexibility to control multiple motors from one central control with additional options to have a decentralized control. The utilities could benefit by adjusting the motors speed and reduce the speed (as well as the load) as allowable by the companies and make these motor applications ready for DR applications.
SunAmp https://www.sunamp.com/	7	Sunamp's platform technology is a heat battery with patented phase change material (non-flammable, non-toxic) for space heating/cooling and water heating. The excess power generated by solar is stored in the heat battery, which then provides heat in residential and commercial building, as and when needed (for space heating and water heating). The technology competes with batteries for energy storage.	As a platform technology, SunAmp's technology offers solution features for demand-response, load-shifting, water heating, space heating and cooling. Additionally, it provides both customer engagement features as well as smart interaction with the grid and behind-the-meter renewables.
Treau Isothermal Compressor http://www.cyclotronroad.org/treau/	3	Treau, which came out of Otherlab, has developed a technology can eliminate refrigerants from heat pumps, air conditioners, and refrigerators. It is a nearly isothermal compressor and expander that can be integrated into heat pump cycles that do not use refrigerants, but benign gasses like nitrogen, CO_2, or helium. Currently a proof-of-concept demonstration has been built and the team is establishing business and strategic partners. They are a new member of LBNL Cyclotron Road (3rd cohort).	This technology has the potential to enable more efficient and *refrigerant-free* heat pumps for air conditioning, space heating, and water heating.
Treau Membrane Heat Exchanger http://www.cyclotronroad.org/treau/	4-5	Treau, which came out of Otherlab, has developed a very low-cost and high surface-area, polymer-based heat exchangers. High surface-area heat exchangers can reduce the temperature lift of heat pump and air conditioning systems and allow them to run at a higher COP. This technology addresses HVAC challenges related to fouling, corrosion, weight and performance advances. They are a new member of LBNL Cyclotron Road (3rd cohort).	This technology would provide reductions in system size and maintenance needs for building HVAC systems. Estimated reductions in system cost would be from $\$2/m^2$ to $\$0.3$-$\$0.5/m^2$.



Next-Steps

While EPRI's Technology Innovation Scouting efforts continue to monitor the progress and development of emerging technologies and companies, we invite feedback from the member utilities on their interest to pilot test any of the technologies (laboratory or field demonstrations) with EPRI's third-party Measurement and Verification expertise.

EPRI's team continues to explore government funding opportunities that would support pilot testing and advancing the commercialization of emerging technologies, especially with respect to the utilities' needs for customer engagement and effective integration with the grid's evolving nature towards the Integrated Energy Network.

Critical research gaps that EPRI is engaged in are linking the HVAC innovations with progress on advanced manufacturing as well as system integration, where the focus is not just on the technology component, but improving the infrastructure and framework that it serves.

References

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