MICRO-ENVIRONMENTAL CONTROL SYSTEM

PROJECT TITLE: Micro-Environmental Control System
PROGRAM: Delivering Efficient Local Thermal Amenities (DELTA)
AWARD: $3,199,963
PROJECT TEAM: Syracuse University (Lead), United Technologies Research Center, Air Innovations, Bush Technical, LLC, and Cornell University
PROJECT TERM: May 2015 to April 2018
PRINCIPAL INVESTIGATOR (PI): Prof. H. Ezzat Khalifa

GRAND CHALLENGE

Heating, Ventilation, and Air Conditioning (HVAC) accounts for 13% of energy consumed in the United States. Even though more energy-efficient HVAC technologies are being adopted in both the commercial and residential sectors, these technologies mostly focus on heating or cooling large areas. Building operators have to tightly manage temperature for an average occupancy comfort level throughout the entire addressable area, although the occupants only occupy a small fraction of the building’s interior. Localization of thermal management can relax the temperature settings in buildings, reduce the load on HVAC systems, and enhance occupant comfort. Localized thermal management could be achieved by tailoring the thermal environment around the individual, thus saving energy by extending temperature set points within the building itself. ARPA-E estimated that relaxing building temperature set point requirements from 70°F for heating and 75°F for cooling to 66°F and 79°F, respectively, could reduce annual HVAC energy consumption by 15%. To ensure occupant comfort and maintain productivity in this expanded temperature range, ARPA-E’s Delivering Efficient Local Thermal Amenities (DELTA) program set performance metrics that localized thermal management systems (LTMS) should remove 23 W of energy from human skin in a cooling setting, and provide 18 W of energy in a heating setting.1

TECHNICAL OPPORTUNITY

Despite many years of commercial availability, most state-of-the-art LTMS are still too expensive, inefficient, or inconvenient for widespread adoption. Almost all LTMS developed or sold commercially to date have relied on air that has been previously conditioned in central Air Handling Units (AHUs). The pre-conditioned air is then delivered to the environment either through ducts descending from the ceiling, or less frequently, through underfloor plenums. Both delivery mechanisms suffer from drawbacks such as intrusiveness, noise, high cost, and in some cases, high energy consumption. Local thermal storage using phase change materials (PCM) provides a more convenient, cost-effective approach. PCMs allow the system to discharge heat at

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1 Detailed calculations of the energy savings and program metrics were laid out in the DELTA Funding Opportunity Announcement (FOA). A synopsis of the FOA can be found at: https://arpa-e.energy.gov/sites/default/files/documents/files/DELTA_ProgramOverview.pdf.
night when the area is unoccupied, avoiding noise and heat emissions during occupancy period, and shifting the electric load to off-peak hours. Using a thermal storage module containing PCMs can provide local cooling without any connections to building services other than connection to an electric outlet, or limitations on placement (i.e. not in a window).

**INNOVATION DEMONSTRATION**

The Syracuse University team’s goal is to develop an advanced micro-environmental control system, named μX, which is compact, efficient, quiet, and ergonomic. μX can enable local climate control to keep the occupant comfortable and facilitate expansion of thermostat setpoints, thus significantly reducing energy consumption for building HVAC. μX utilizes a thermal storage module containing PCM that freezes at about 60°F to store 10 hours worth of “cooling.” This cooling capacity is produced in approximately eight hours at night by a novel, high-performance micro vapor-compression system (μVCS) whose evaporator is embedded in the PCM module. During the day, small, quiet fans blow about 20 cfm (ft³/min) of room air at a room temperature of 79°F through the frozen PCM module, cooling the air to a comfortable 71-72°F, delivering no less than 50 W of cooling to the near-range environment. By freezing PCM at night, the system avoids releasing noise and heat when the workstation is occupied. In the heating season, a heat delivery device is used to add 18 W of heat to a person.

A focus of the project was to design and fabricate a high-performance micro-compressor to enable system functionality. Among the many compressor types, the team chose scroll compressors because they are valveless, quieter, more efficient, and have fewer moving parts (i.e., more reliable). Scroll compressors have a built-in compression ratio, which can be optimized to match the narrow operating conditions needed for the system to meet DELTA metrics. Scroll compressors can deliver the best efficiency at that condition without the performance, cost, and reliability penalty of the valve mechanisms needed in reciprocating and rolling piston rotary compressors, or the spring-loaded sliding vanes in the latter. Because of the small size (<5 cm diameter) and tight tolerances required for high efficiency, designing and developing the micro scroll compressor represented one of the most significant challenges in this project. The successful execution of this task required a combination of rigorous design and precision machining. Syracuse University worked with Bush Technical to design a micro-compressor, and validated its performance experimentally and against the predictions of a proprietary compressor simulation tool developed by strategic partner United Technologies Research Center (UTRC). The prototype compressor features a very small cooling capacity of about 60 W, consumes less than 11 W of electricity, and has fewer moving parts than traditional rotary or reciprocating compressors.

A second key challenge was to design and fabricate a PCM/evaporator module. The size and efficiency requirements of μX dictates that all three critical design aspects of the module – heat exchanger, refrigerant, and PCM – be carefully selected and engineered. Guided by numerical models, the team successfully designed the PCM/evaporator module to meet thermal capacity and size requirements. The team optimized air and refrigerant channel sizes and spacings through computational analysis and experimentation in order to achieve desired heat transfer and refrigerant and air flow rates. Experiments confirmed that the optimized PCM/evaporator can meet its specified performance targets.

Preliminary test results using a prototype of the integrated system with a thermal manikin illustrate that the prototype is able to remove more than 32 W of heat from the manikin, surpassing the DELTA target of 23 W.

**IMPACT PATHWAY**

The innovative design of the envisioned μX is compatible with automated, high volume, cost-effective manufacturing techniques similar to those used for mini-refrigerators. Such refrigerators employ larger VCS, but retail for less than $70. The first market envisioned is for peak demand reduction in offices that integrate this technology into high-end desks. Because of the technology’s potential in load shifting, New York State Energy Research and Development Authority (NYSERDA) provided Syracuse University a follow-on grant of $400,000 to apply the technology in demand reduction prototypes aimed primarily at New York City.

Syracuse University has formed strategic partnerships with Air Innovations (AI) and UTRC and its affiliate, Carrier. AI and UTRC have agreed to terms defining market thresholds for exclusive licenses to the μX technology. Both companies bring multiple distribution channels, extensive experience, and strong relationships with suppliers and subcontractors necessary for both niche and high-volume markets. The current price point of μX is likely to first suit niche applications, such as mission-critical facilities and historic buildings. Mass production will reduce the price to suit high-volume markets.
LONG-TERM IMPACTS
A low-cost LTMS using μX technology can reduce electricity consumption associated with HVAC, thereby saving consumers on energy costs, reducing greenhouse emissions, and enabling more sustainable heating and cooling architectures for energy-efficient building design. The thermal storage technology can also potentially enable shifting of the electric load to off-peak hours, further improving the stability of the electric grid.

INTELLECTUAL PROPERTY AND PUBLICATIONS
As of October 2017, the μX project has generated two invention disclosures to ARPA-E, and two provisional patent applications have been filed on the disclosed inventions. The Syracuse University team has also published the scientific underpinnings of this technology extensively in the open literature. A list of publications is provided below:

