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Future Energy

Distributed and localized cooling with thermoelectrics

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Thermoelectric semiconductors provide a quiet, refrigerant-free alternative to traditional vapor compression cooling (VCC). It has long been assumed that the figure of merit, ZT, of thermoelectrics is too low to compete with VCC. While this may be true for typical VCC designs where a large temperature drop is required, distributed cooling systems may require only $ZT = 0.5$ which is available today. In this perspective we outline the concept of Distributive Cooling using thermoelectrics to heat or cool only where it is needed and when it is needed. Only the uncomfortable occupant needs heating or cooling, not the entire room, vehicle or building. Such a system level efficiency improvement could revolutionize the way we think about HVAC and provide disruptive technologies that make a real difference to global energy use and climate change.

The energy use and dramatic environmental impact of refrigerants collectively imposes the need to transform cooling technology to address climate change in a significant manner. Heating, ventilation, and air conditioning (HVAC) accounts for over 25% of electricity use in the USA, and by 2060 energy use from cooling could overtake heating. Refrigerant management, i.e., replacing the high global-warming-potential refrigerants themselves, is the largest (10%) component of the climate change solution proposed by Project Drawdown (see Note S1). Enhancing energy efficiency through smart, efficient HVAC systems could transform energy usage and facilitate rapid integration of renewable energy.

In the current centralized architecture for heating and cooling, a large fraction of the energy consumed is simply wasted. HVAC systems are typically designed to heat or cool an entire building or vehicle in the worst-case scenario,[1] and this results in continuous operational inefficiency.[2] Such "overcooling" and then reheating is ubiquitous because platform designs emphasize reliability, simplicity, and initial cost even if energy consumption, user comfort, and health are more valuable to the operators and occupants. Such energy intensive, centralized heating and cooling has been the design theme for many decades even though component technologies have advanced significantly.

Heating or cooling only where and when it is needed (referred to as distributed HVAC) (Figure 1) builds upon the theme of localized as opposed to centralized heating or cooling. Distributed HVAC has the potential to dramatically improve the energy efficiency and reduce the overall energy consumption of a variety of platforms including residential and office buildings, vehicles, storage containers, and warehouses. Instead of heating/cooling an entire building, everywhere, all the time, it can be much more efficient to heat or cool only the occupants or objects that need it, and only when and where discomfort is sensed.[4]

Electric vehicles will likely be an early adopter of distributed HVAC (Figure 1) because every watt spent on climate control results in reduction of the vehicle range or adds to battery cost and weight. Distributed heating and cooling systems are anticipated to sense occupants' discomfort and then automatically control heating or cooling of seats, steering wheel, windows, etc., as well as direct airflow where it is needed. Where today's car can require up to 5 kW for the HVAC system, tomorrow's might only use 100–200 W to cool the car seat and other accessories.[5]

The whole building environment does not need to be at the same temperature; rather, the occupants' local environment and the building's global environment can have separate temperatures. Advances in controls and sensing, supported by the internet-of-things, have reached a level that can address the requirements for implementing distributed HVAC in the built as well as the transportation environment.[6] Examples for these advanced controls would be net-zero commercial buildings such as "The Edge" in Amsterdam, and One Angel Square in Manchester, UK. Smart building control systems can also achieve grid integration, wherein a building can participate in demand response to lower energy costs and/or shift loads to times when electric power is available from renewable resources.

Separate HVAC zones for individual rooms is known to provide better comfort and improved energy efficiency. Distributed HVAC for large buildings typically involves hot and cold water to store heat and move it from room to room. Smaller buildings and individual homes can simply distribute the humidity and temperature-controlled air