Air-Conditioning and Refrigeration Technology Institute

Executive Summary

ARTI Project 10120-01

THERMOELECTRIC TECHNOLOGY ASSESSMENT

Beginning around 1990, a combination of factors–notably environmental concerns regarding refrigerant fluids and interest in cooling electronics–led to renewed activity in alternative cooling technologies. Thermoelectric cooling may be the most well established of these technologies. Other cooling mechanisms, such as thermomagnetic effects, thermionic emission, and thermoacoustic effects, are less established but may soon have their day.

Thermoelectric coolers are solid-state devices that convert electricity directly to temperature differentials. The concept of solid-state refrigeration dates back almost to the very beginning of the field of thermoelectrics itself. Since the discovery of the Peltier effect in the early 19th century, the ability to construct a solid-state cooling mechanism existed. The Peltier effect is the principle at work behind thermoelectric coolers or refrigerators. So thermoelectric coolers are also called Peltier coolers. The effects related to the Peltier effect are the Thomson effect, Joule heating and heat conduction. The Peltier, Seebeck and Thomson effects are reversible (in fact, the Peltier and Seebeck effects are reversals of one another); Joule heating and heat conduction cannot be reversible under the laws of thermodynamics.

The energy conversion efficiency, or Coefficient of Performance (COP) of thermoelectric cooling devices, is determined by thermoelectric figure-of-merit, commonly denoted by ZT. The highest ZT to date is reported in Bi_2Te_3/Sb_2Te_3 and PbSeTe/PbTe superlattice thin films. Coolers based on such materials typically have a COP of ~2, which is lower than the COP of 3-4 vapor compression refrigerators. However, there is no known theoretical impediment to significant increases in thermoelectric energy conversion efficiency, and given a breakthrough in materials, thermoelectric technology might offer the possibility of a safe, efficient, and affordable alternative to fluorocarbon compression equipments.

This project has performed a literature search on thermoelectric technology and populated the 46 criteria that pertain to thermoelectric technology in the ARTI's Database. Some observations on thermoelectric technology, especially those relevant to large scale air conditioning and refrigeration, have been made, as discussed below:

- Thermoelectric coolers are solid-state electronic devices that directly convert electricity to temperature difference. Without moving parts, thermoelectric coolers are inherently more reliable and require little to no maintenance. The lack of refrigerants carries obvious environmental and safety benefits.

- The use of thermoelectric devices and systems has been limited by their relative low energy conversion efficiency. Present commercial thermoelectric devices operate at about 10% of Carnot efficiency, whereas the efficiency of a compressor-based refrigerator increases with size: a kitchen refrigerator operates at about 30% of Carnot efficiency and the largest air conditioners for big buildings operate near 90%.

- A broad search for thermoelectric materials with high efficiency has been conducted. There is no known theoretical impediment to significant increases in thermoelectric energy conversion efficiency, and given a breakthrough in materials, thermoelectric technology might offer the possibility of a safe, efficient, and affordable alternative to fluorocarbon compression equipments.

- Today's thermoelectric devices are particularly useful when the efficiency is a less important issue than small size, low weight, or high reliability. For example, thermoelectric devices are suited for situations where the heat load is small (say, <25W) or the temperature lift is small (say <10C) or the variation of the heat load is large (e.g., train passenger cabin). It is important to note that the COP of thermoelectric coolers increases significantly with decreasing the temperature lift, as shown in Figure 3 in Section Device, Coefficient of Performance (COP) of thermoelectric coolers with different ZT.

- Instead of utilizing a full-fledged thermoelectric cooling system, it is possible to use a thermoelectric heat pump to improve the performance of an existing vapor compression system, so called "hybrid system." For example, a hybrid vapor compression – thermoelectric cooler systems could use thermoelectric heat pumps to enhance the outlet subcooling of a condenser, in which thermoelectric heat pumps operate at small ΔT and high COP. Theoretical analysis predicted the cooling capacity and COP of the hybrid system could be significantly improved. More detailed information can be found in the section "Hybrid Systems."