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Medium-Scale Cooling: Thermoelectric Module Technology

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54.1 Introduction

Medium-scale cooling is defined as the range in which thermoelectric modules are most suited for producing the cooling. This technology is used extensively for industrial equipment requiring small cooling powers, and where one or several modules are sufficient (see Chapter 52). This chapter will only address the technology that uses ten or more thermoelectric cooling modules.

The fundamental characteristic is that the modules are electrically insulated from the heat exchangers, so this technology is simpler than the technology in which thermoelectric elements are integrated to the heat exchangers (see Chapter 53).

54.2 Fundamentals

Types of Thermoelectric Modules

A thermoelectric module consists of a number of pieces of thermoelectric material referred to as thermoelectric elements. They are of n-type and of p-type semiconductor and are generally connected electrically in series inside a thermoelectric module (see Chapter 49).

There are two types of thermoelectric modules, as shown in Figure 1. Those with two ceramic plates, which support the thermoelectric elements, and those without ceramic plates, in which the thermoelectric elements are held together by a resin. Historically the first modules did not have ceramics, the electrical insulation between the copper connectors which link consecutive thermoelectric elements was achieved by placing a sheet of organic insulator such as Mylar (c)* between

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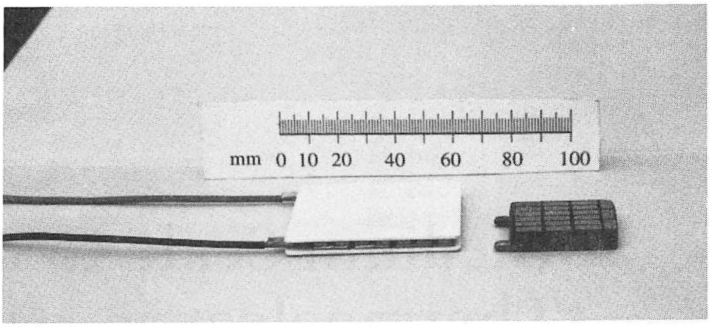


FIGURE 1 Photograph of a module without and with a ceramic insulating plate.

the thermoelectric module and the heat exchanger. Nowadays it is more economical to manufacture modules that use ceramic. The advantages are: (1) the ceramic is a good electrical insulator for low voltage operation, and (2) the ceramic, when used with a thermally conducting grease, provides a relatively low thermal resistance between the ceramic and the heat exchanger and allows easy assembly of the thermoelectric modules to the heat exchangers.

Thermal

The thermal requirements are not difficult to satisfy but the heat exchangers must be designed with a base plate to interface with the thermoelectric module. The thermal resistance of the base plate must be small compared to the overall thermal resistance. In addition the thermal resistance at the interfacing of the ceramic must be compatible with the rest of the thermal resistances. Heat losses between the two sides (cold and hot) must be minimized and the tightening screws must have thermally insulating washers.

Mechanical

The main problem with modules is that their structure, which today generally uses a ceramic on each side, cannot withstand any bending. Shear must be limited to the weakest shear component of the structure, which is the interface of the thermoelectric elements.

When several modules are assembled between two plates, the modules must all have the same thickness and the ceramics plates must be parallel to 0.02 mm. The heat exchanger plates must also be parallel, otherwise bending will occur and the thermoelectric modules damaged.

To decrease this problem, a large heat exchanger plate can be employed which holds n-modules on one side while on the other side there are several plates which are tightened separately. This reduces the number of modules that must have exactly the same thickness.

Electrical

The modules can be connected through their leads, either in series, in parallel, or any combination of both. The objective is to enable the total system to operate under a given voltage. The ceramic plates usually used are of alumina, although in very special circumstances beryllium oxide has been used because of its higher thermal conductivity. Aluminum nitride has also been used as it is a good thermal conductor and an excellent dielectric insulator; however, it is very expensive.

Alumina is excellent theoretically, but under severe operating conditions microcracks can develop over a long period and serve as the source of high-voltage breakdown. In the case of high-voltage operation requiring dielectric tests of several kilovolts, it is necessary to add to the alumina an organic insulator such as Mylar (c)™ or Kapton (c)*. In this case there is no advantage in using a ceramic unless the thermoelectric module is cheaper.

4.3 Heat Exchangers

There are two categories of heat exchangers, those using a gas such as air and those using a liquid such as water. Both will be examined briefly.

Air Heat Exchangers

Straight Fins

The cheapest fins are extruded fins (heat sinks), which are sold by many companies. The extrusion process does not produce thin, closely spaced fins. Consequently some companies manufacture heat exchangers by machining a flat plate with grooves into which the fins are stuck using epoxy resin. A higher fin surface is obtained but a drawback is the thermal resistance at the interface between the fins and the base (see Figure 2). Data on the performance of these fins are provided by some manufacturers.[1]

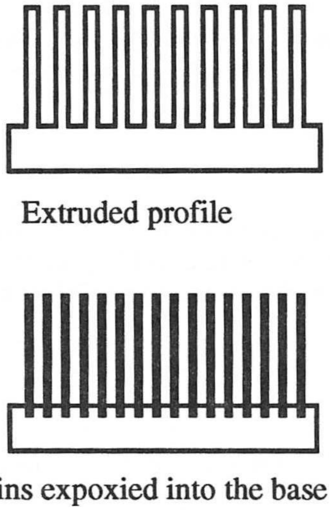


FIGURE 2 Detail of extruded fins and epoxied fins.

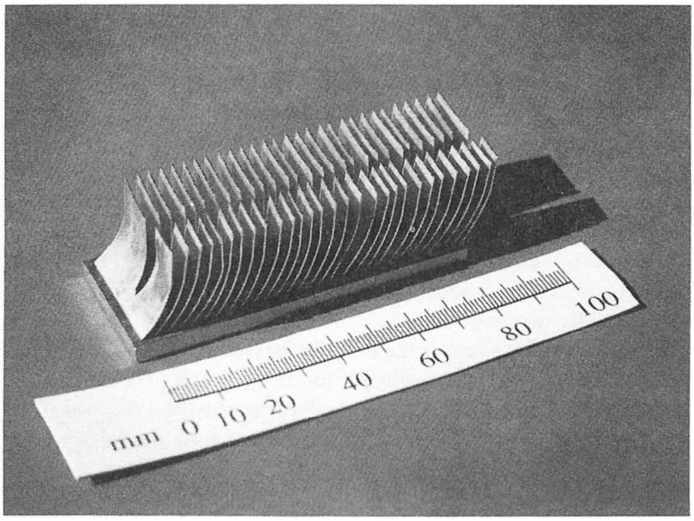
Straight fins can also be manufactured by a shaving process called "skyving." The initial patent belongs to Peerless of America, although several companies are licensees. Unfortunately, this process can only make straight fins.

Part of a skyved heat exchanger made by Showa of Japan is shown in Figure 3.

Other Types of Heat Transfer Surfaces

There are many heat transfer geometries for fins. The best reference is the book by Kays and London.[2] The surfaces can be flat, such as fins, or like pins. Efficient pins are difficult to manufacture and will not be discussed further.

Fins come in a great variety of shapes and sizes. There are two types, which both need to be attached to a base: (1) individually stamped fins, and (2) folded fins. The advantage of folded fins is that a group of fins are located together which simplifies the attaching process. The fins can be louvered, lanced, and perforated (see Figure 4).



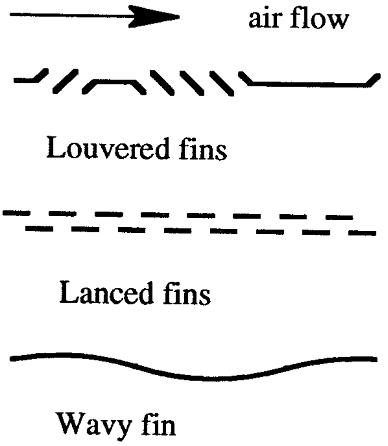


FIGURE 4 Schematic of fins: louvered, lanced, and wavy.

Fin-to-Base Attachment Processes

The process or material used to attach the fins to the base must have a low thermal resistance. The ideal solution is to have continuity of the material, but machining the fins out of a thick plate is very expensive. There is also the "skyving" process previously mentioned.

Fins are generally made of copper or aluminum. Aluminum is generally preferred because of the lower weight. Copper is easy to solder, whereas aluminum is more difficult. The techniques generally require that at least one of the parts be clad with an alloy of aluminum-silicium, which melts at a slightly lower temperature than pure aluminum. The parts can be bonded by: (1) dipping in a salt bath, which creates a pollution control problem; (2) brazing in a vacuum, which is expensive; or (3) brazing in a controlled-atmosphere oven with a special flux—the Nokolox process from Alcan is the best-known process.

Water Heat Exchangers

The water heat exchanger can consist of a copper or aluminum plate with holes drilled through it. Tubes can be used, manufactured out of copper, aluminum, or titanium. Stainless steel tubes constitute a thermal resistance that generally cannot be neglected. The convection coefficients are well known.[3]

54.4 Structures

There are three basic types of structures: planar, column, and linear (see Figure 5). Thermoelectric modules have two parallel surfaces traversed by thermal powers. These two surfaces have manufacturing tolerances on the thickness and the parallelism, these tolerances influence the choice of structure.

Planar Structure

The planar structure is the only one which employs a big plate on one side onto which many modules can be attached. A big heat exchanger is always cheaper than many small ones. This is probably the reason why all systems built to date use the planar structure. The most frequent method is to tighten two plates of the same size together (see Figure 6). There is a big plate on one side. The other plate serves to tighten several modules together, which reduces the number of modules that must have exactly the same thickness.

The ideal solution is to tighten the modules individually. However, the disadvantage of this is that on one side there are as many individual heat exchangers as there are modules and for each module there are generally two screws.

The best tightening method is to apply the force in the middle of the module and have individual heat exchangers on one side of the thermoelectric modules. When a system contains many modules there are several ways of tightening them individually with the force applied in the middle of each module. Two examples are given in Figure 7, where two or four modules are tightened with one

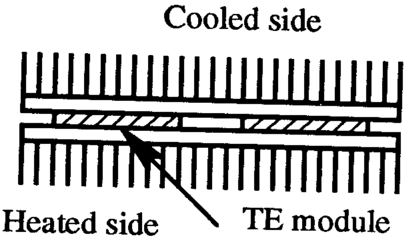


Figure 5a Planar structure.

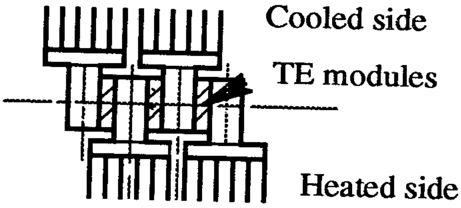


Figure 5c Linear structure.

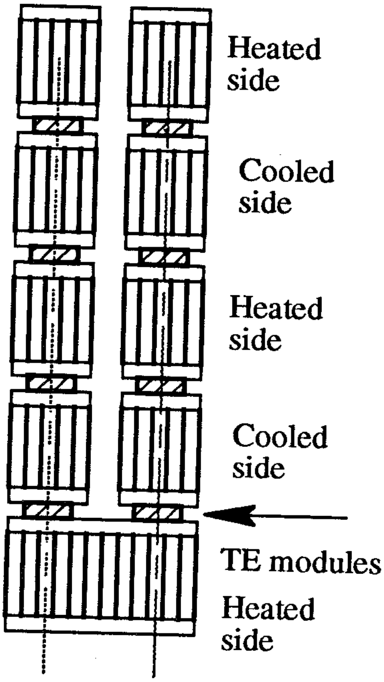
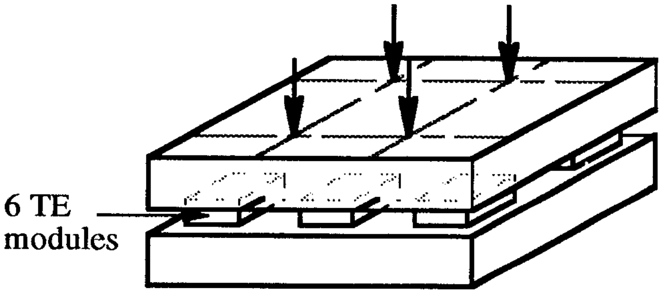


Figure 5b Column structure.

The wiring between modules is not shown.

FIGURE 5 Structures with thermoelectric modules.



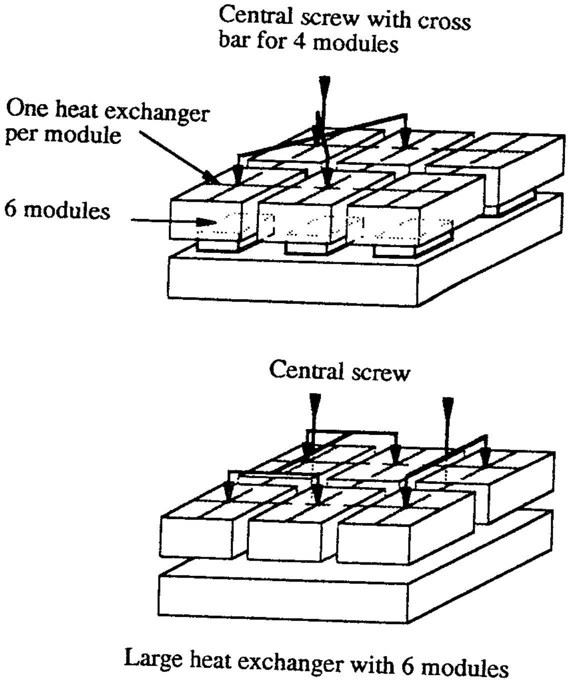


FIGURE 7 Central tightening mechanisms. (With permission of the Institute of Electrical Engineers of Japan, Tokyo, Japan.)

Linear and Column Structures

The difficulty with linear and column structures is the same as that of stacking a pile of bricks; if the top and bottom surfaces of the bricks are not parallel, then the pile is unstable and will topple over. It is similar when stacking TE modules. A disadvantage of this system is that each module requires an individual heat exchanger.

The tightening mechanisms are located alongside the lines or columns and it is practical to tighten four lines or four columns together.

4.5 Industrial Applications

Past Applications

Radio Corporation of America (RCA)

RCA was one of the first companies to invest heavily in thermoelectrics. They manufactured many small consumer-type products. In particular they made a 30-kW air-conditioning unit for the U.S. Navy[4] based on thermoelectric modules.

Carrier Corporation

This company worked on naval applications,[5,6] for example a 3.5-kW air-conditioning unit with heat rejection to water. The unit consists of six subunits, each one containing four thermoelectric modules. Each thermoelectric module is 13.7 × 17.8 cm and has 130 thermoelectric elements with an individual area of 1.13 cm^2 and a thermoelectric element height of 2.54 mm. This is much bigger than present-day commercial thermoelectric modules.

In the mid-1960s Carrier built a thermoelectric air-conditioning and heating system for the

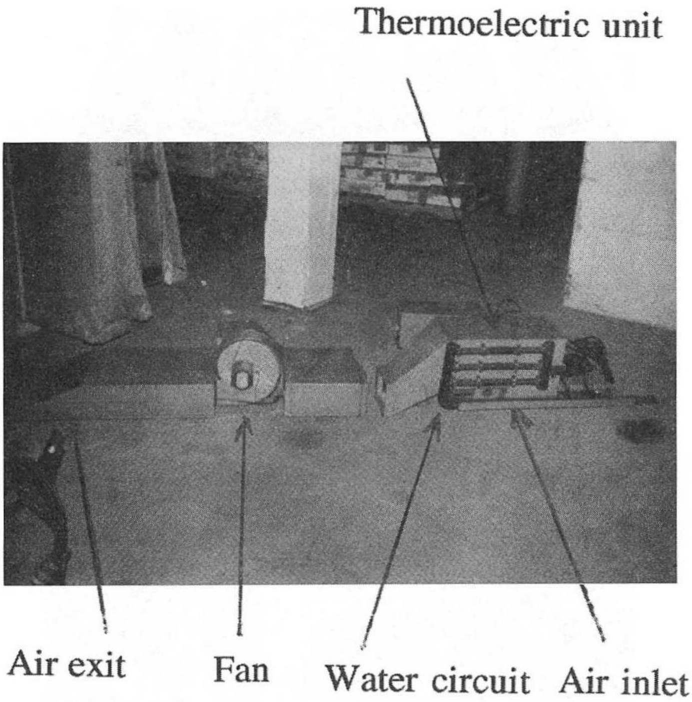


FIGURE 8 Photograph of Carrier Corp. unit at S. C. Johnson.

nonavailability of spares, especially concerning the power supplies and controls. A photograph of a unit when taken down for repair and laid out on the floor is shown in Figure 8. The cooling power of each unit is 1.5 kW and the heating power 1.8 kW.

The thermoelectric modules were made by Carrier. They are 12 × 12 cm, with 64 elements and a thickness of 2.5 mm. The exact thermoelectric element area is not known but is estimated to be around 60 mm^2. The maximum electrical current was 80 A in the cooling mode.

Carrier stopped all activity in thermoelectrics after completing this installation.

Borg-Warner Corporation

This company was very active but published practically nothing.[7] Their main activity was in small compact systems which used ceramic thermoelectric modules.

U.S. Navy

The U.S. Navy was a major driving force in developing thermoelectrics in the early 1960s. A very interesting paper describes a frozen and a chilled stores box.[8] The units produce cold air and reject the heat into a water circuit at 7°C. The cooling power is 0.7 kW for the chilled stores at -1°C and 2.5 kW for the frozen store at -18°C. The systems consist of subunits each containing 36 modules.

The thermoelectric modules are 8.4 × 8.4 cm and 15 mm high. Each module contains 48 thermoelectric elements of a diameter of 7.1 mm (area = 40 mm^2), with a height of 9.9 mm.

Present Applications

TECA

Today TECA of Chicago is the only company manufacturing multimodule cooling systems. A typical product is the C4000 air-conditioner. The heat is rejected to air and it has a cooling power of 400 W when the inlet temperatures on the cooled side and on the heated side are equal to 60°C.

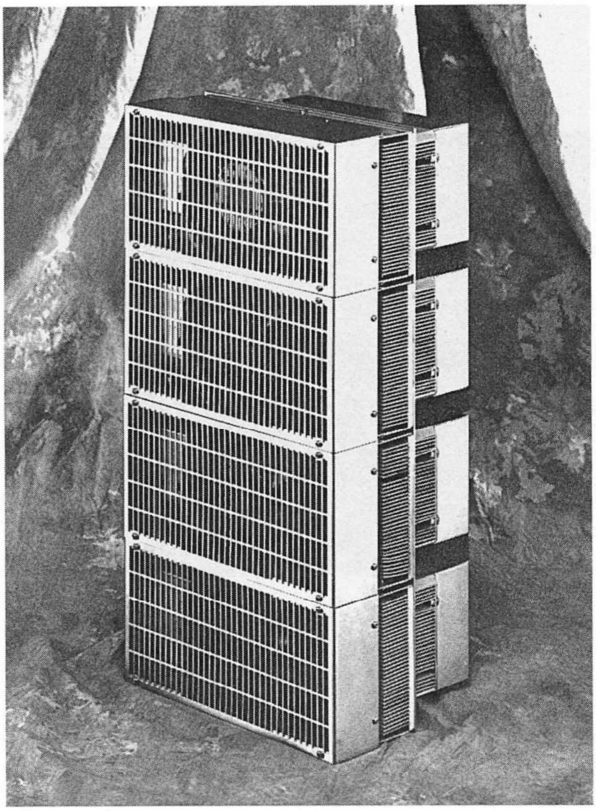


FIGURE 9 Photograph of a TECA Americool R4000 series unit.

It consists of four subunits joined together. All the air circuits are in parallel. A subunit is a proximately 15 × 30 × 24 cm and cooling is obtained using commercially available thermoelect modules. The number of modules and their characteristics is proprietary. A photograph of o unit is given in Figure 9 and the performances of a model Americool R4000 series are given Figure 10.

Midwest Research Institute

Midwest Research Institute of Kansas City, Missouri, has developed a microclimate thermoelect air-conditioning unit for the pilots of helicopters.[9] The unit has a cooling power of 1000 W. contains 96 ceramic commercial modules, each one containing 254 thermoelectric elements. T size of the elements is proprietary. The thermoelectric modules are assembled six at a time betwe two continuous plates with folded lanced fins. They have developed a unit for ground vehicles and also a liquid microclimate conditioner system.[11]

Future Applications

Equipment developed by the Midwest Research Institute will become commercial in the n future. Development work is ongoing on thermoelectric cooling systems with thermoelect modules.

There are essentially two domains, space cooling for electronics and air-conditioning. The a plications are numerous but are limited by the high cost. Prototypes have been built for a conditioning telephone booths and feasibility studies have been undertaken for t

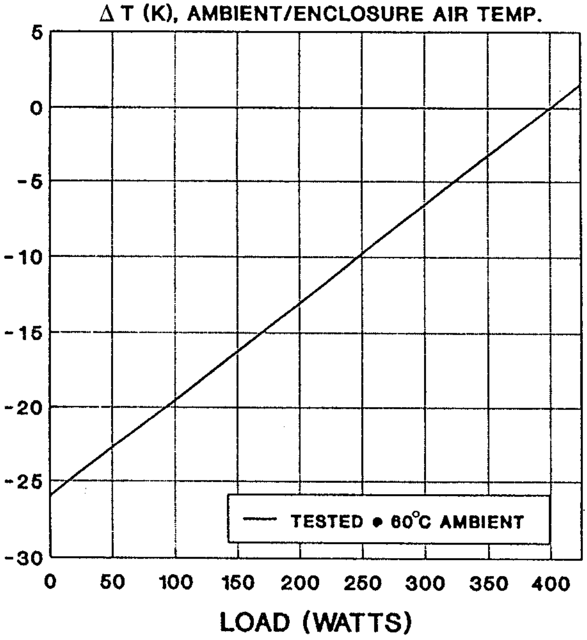


FIGURE 10 Performances of Americool R4000 series unit.

Although specifications change with time the basic difficulties remain the same. Fortunately nology has progressed and today's systems can meet specifications that were unobtainable 3(ago.

6 Advantages of the Thermoelectric Module Technology

Thermoelectric cooling systems today are essentially made with thermoelectric modules. Th nology of integrating thermoelectric elements into the heat exchangers has only been used fc large systems (see Chapter 53).

Commercial thermoelectric modules have been available for over 30 years and their cc decreased regularly. In cases where the number of systems is small, thermoelectric modul nology is the most economic, for several reasons: (1) thermoelectric modules are standard o shelf components; (2) the operating voltages are such that a system can contain series p electrical circuitry and commutation in the electrical circuits gives flexibility in the cooling (3) the parallel circuitry gives built-in redundancy; (4) they are relatively easy to install; and (heat exchangers can be associated to several thermoelectric modules.

Integrated thermoelectric element technology is only appropriate for very large systems o the equipment justifies mass production, which is not the case today.

7 Conclusions

Looking back 30 years history is seen to repeat itself. In the 1960s people expected to see m improvement, they wanted to have systems that would be as efficient power-wise as the pression cycle systems. When it was realized that this would not materialize all work on th moelectric cooling in the Western world stopped.

It is accepted that a thermoelectric system at full power cannot have an efficiency which approaches that of a compression cycle system but a thermoelectric system has a much more flexible cooling power than a compression cycle and a thermoelectric system can have an adjustable current (or voltage) DC power supply. The peculiarity of thermoelectrics is that the coefficient of performance (COP) increases very fast when the electrical current passing through the system is reduced which cannot be done with a compression cycle system where it is necessary to bypass some of the fluid flow around the compressor. This is far less efficient than decreasing the voltage of a thermoelectric system. It is interesting to note that at half power a thermoelectric system can often compete "electrical power wise" with a compression cycle system.

The applications of systems in the Kilowatt range that were studied then are now starting to be studied again.

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