Cooling system for hermetic devices based on thermoelectricity

Rafael Palacios, Jorge Vázquez, Miguel A. Sanz-Bobi
Universidad Pontificia Comillas. Escuela Técnica Superior de Ingeniería (ICAI). Instituto de Investigación Tecnológica.
Alberto Aguilera 23, E-28015 Madrid, SPAIN
Rafael.Palacios@iit.upco.es, Tel. +34 91 542-2800 ext 2758, Fax +34 91 542-3176

Abstract

Cooling systems based on a continuous flow of fresh air are typically used in electronic devices. For applications in adverse environment such us underwater applications of industrial applications using air with a great amount of dust, hermetic devices are needed. The major problem when designing hermetic devices is to provide a proper cooling system.

This paper describes different alternatives for cooling hermetic devices. The study was done for a personal computer, evaluating the amount of heat produced during sleep condition and busy condition.

Different cooling alternatives are presented: natural convection using standard radiators (for a noiseless system), and forced convection using radiators and fans.

Both configurations are compared with the equivalent ones using thermoelectricity to increase the heat transfer between the inside of the hermetic box and the outside environment.

It is demonstrated that without thermoelectricity, it is almost impossible to evacuate enough heat because the box of the PC has to be full of radiators. While applying the Peltier effect the heat transfer is highly increased.

Introduction

Electrical equipment such us personal computers or any other electronic devices, typically rely on air as cooling fluid. These devices need to eliminate the heat produced by electronic components in order to maintain the temperatures within certain limits.

For small electronic devices such as mobile telephones, calculators or PDAs the heat generated is so small that there is no need for cooling systems. On the other hand, more powerful devices use cooling systems based on a continuous flow of air through the electronic components. A continuous flow of air eliminates the heat produced at the components of the device. It is very common to find tiny radiators and small fans directly attached to the electronic components that produce higher amount of heat, to warranty enough heat transfer to the airflow.

Devices that rely on airflow cooling systems are for example personal computers (even portable), measurement and control systems and other equipment used in the industry. However, in real industrial application it is possible to have adverse environments with dirty air that could be dangerous for the components. Some equipments have air filters in order to remove the dust, but in some cases hermetic devices must be used. This is clear for special application such as waterproof computers.

Design of the hermetic device

The cooling system of a hermetic device must meet two fundamental requirements:

- Continuous airflow through all electronic components inside the case.
- Enough heat transfer between the inside air and the outside environment.

Non-hermetic systems are usually designed with the air inlet in the front, and the fans with the air outlet in the back. Using this configuration it is easy to warranty a correct airflow through the electronic components of the system (see Figure 1).

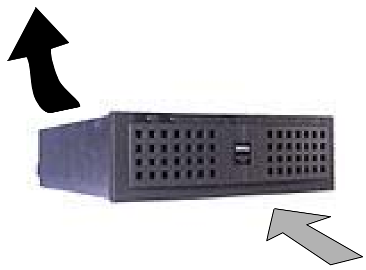

Figure 1: Conventional equipment ventilation

Hermetic devices use airflow to cool circuits, like conventional system, but also a set of internal ducts and heat exchangers. The ducts are used to guide the airflow properly and the heat exchangers are needed to transfer heat to the outside. Schematically, both systems can be represented as in Figure 2.

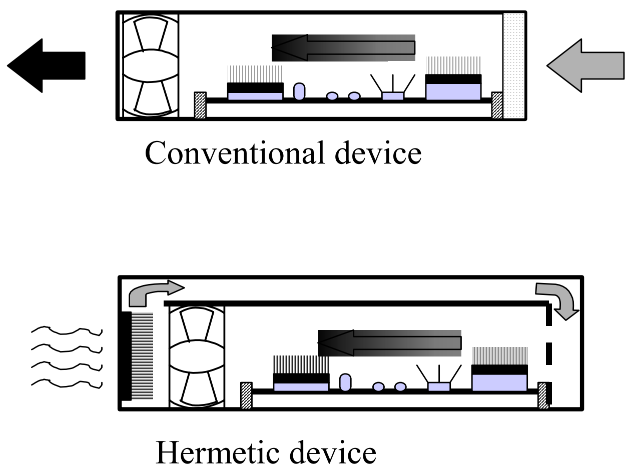

Figure 2: Airflow in conventional and hermetic devices

The hermetic version needs more powerful fans to obtain the same flow rate, mainly because of the flow resistance imposed by the internal heat exchanger.

The hermetic version could be bigger, mainly because of the internal ducts. This is not a serious drawback in personal computer cases where generally there is a lot of free space and some of them already have some internal ducts to better control the flow. Other devices like notebook computers need to be completely redesigned.

One advantage is that using a small coat of insulation, and with the help of thermoelectricity, it is possible to maintain an inside temperature lower than the ambient temperature. This may reduce the size and the number of tiny radiators directly attached to some electronic components. In a normal system, all the components have to be designed for the highest operating temperature (usually 40ºC for domestic indoor devices) leading to big radiators. However having a controlled inside temperature, the size of the circuits and components can be reduced and their reliability can be increased [1]. Therefore, a newly designed hermetic system is not necessarily larger than the original one.

The second requirement of the hermetic device is to be able to transfer all the heat generated at the electronic components, from the circulating air to the external environment. This paper is mainly focused on the study of this problem.

Experimental measurements

The studies described in this paper have been focused on a commercial personal computer. The first step was to measure the operating conditions of the equipment and then design different cooling devices for those operating conditions.

Measurements of temperature, voltage and current were taken while the computer was making intense calculations and while it was just waiting for input (see Figure 3).

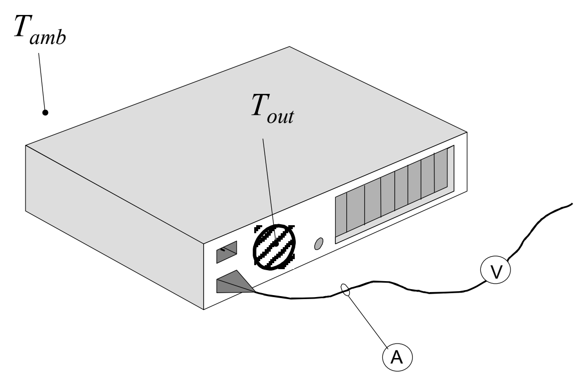

Figure 3: Measurement points

The ambient temperature was 24ºC, but the electric power is higher while the computer is working and therefore the air temperature at the output is also higher. In electronic systems, all the electrical power is converted into heat; hence the electrical power is the same as the heat power. The values are shown in Table 1.

	Not computing	Computing
T_{amb}	24 ºC	24 ºC
T_{out}	29 ºC	31 ºC
Power (Q_c)	35.2 W	46.2 W

Table 1. Experimental measurements

The thermal power and temperature conditions considered for further analysis are the values of the "computing" column. These are the highest experimental values obtained. Although they cannot be considered design specification, these values represent a standard condition to compare different cooling configurations. Four different configurations are presented in this paper, two without thermoelectricity and then the equivalent schemes using thermoelectric modules.

Without Thermoelectricity

Two configurations to cool a hermetic PC are presented in this section. The first proposal is a system with natural convection, therefore a noiseless system. The second proposal is a more efficient forced convection system.

Natural Convection

Natural convection means that the air is not forced to flow with a fan. The air movement is nevertheless produced by density variations due to temperature changes. Obviously, the air inside the case must always be forced; otherwise it will be very difficult to assure good cooling of components and the efficiency will depend on the orientation of the box. The cooling system is depicted in Figure 4.

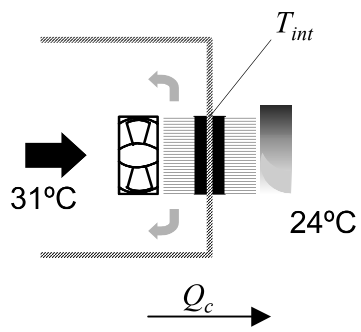

Figure 4: Scheme of the natural convection cooling system

The equation of the heat exchanger is:

$$\dot{Q}_c = \frac{1}{R} \cdot \Delta T \qquad (1)$$

where R is the heat resistance of the radiator that depends on the design and material. For natural convection typical values range from 0.8 to 1.3 W/K and for forced convection around 0.2 W/K.

Applying the general equation (1) to both sides on the case, the intermediate temperature T_{int} and the heat transfer Q_c can be obtained. The results are shown in Table 2.

R = 0.8 W/ºK	T_{int} = 29.6 ºC	Q_c = 7 W
R = 1.0 W/ºK	T_{int} = 29.8 ºC	Q_c = 6 W
R = 1.3 W/ºK	T_{int} = 30.1 ºC	Q_c = 4.7 W

Table 2: Results of natural convection

So using the best kind of heat exchanger, it is only possible to transfer 7 W of heat at the conditions of study. At least 7 heat exchangers will be necessary to transfer 46.2 W.

There is an approximation here because from one heat exchanger to the next one, the air temperature decreases, so the heat transfer in the last radiator is lower than 7 W. However, the steady inside temperature would be higher that

31ºC and the heat transfer at the first radiator will be higher than 7 W. A real example of heat transfer in sequential devices is shown in the next configuration.

Forced Convection

In this case fans are user inside the case and outside the external radiator, greatly increasing the heat transfer a lot. The scheme is shown on Figure 5.

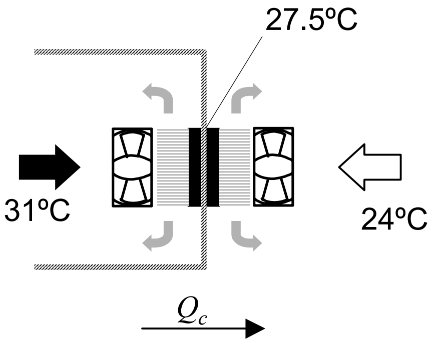

Figure 5: Scheme of forced convection cooling system

Due to the symmetry of the system, the intermediate temperature in this case will be the mean value of the inside and outside air temperatures. The total heat transfer is 17.5W, obtained directly from equation (1) for R=0.2 W/ºC. Therefore this system is more efficient than the natural convection cooling device and only 3 heat exchanger pairs are needed. As explained before, the three heat exchangers do not work exactly at the same conditions as the inside air temperature changes. A more accurate scheme of the hermetic device using a forced convection cooling system without thermoelectric components is shown in Figure 6.

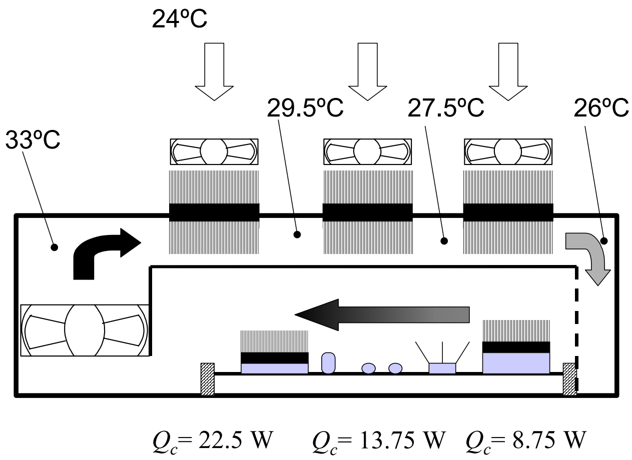

Figure 6: Forced convection solution

Applying Thermoelectricity

Thermoelectricity can be applied to improve the heat transfer of the system bringing more efficient and compact solutions. Based on the Peltier effect, the thermoelectric modules (TE modules) are able to pump heat from the case into the environment [2]. A thermal conductor needs a positive gradient of temperature to transfer heat in the proper direction. However TE modules are active devices able to transfer heat in adverse temperature situations allowing for a greater difference of temperature in the heat exchangers and therefore a higher heat transfer (see Figure 7).

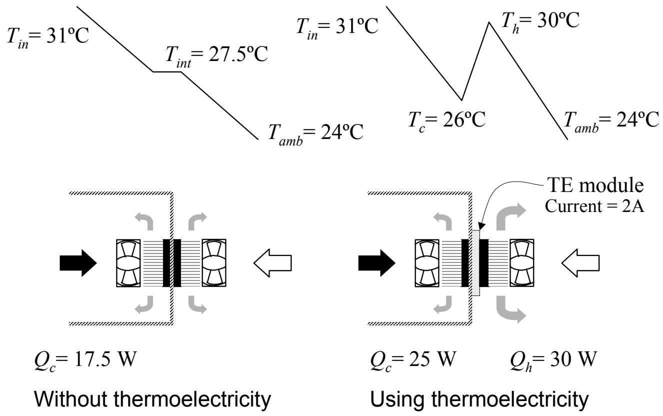

Figure 7: Comparison of the heat power and temperature profiles obtained with/without thermoelectricity

The five equations that rule the behavior of the system are the following [3]:

$$Q_c = n \cdot T_c \cdot I \cdot (\sigma_p - \sigma_n) - \frac{n}{2} I^2 R - k \cdot (T_h - T_c)$$

$$Q_h = n \cdot T_c \cdot I \cdot (\sigma_p - \sigma_n) + \frac{n}{2} I^2 R - k \cdot (T_h - T_c)$$

$$Q_c = \frac{1}{R_{in}} \cdot (T_{in} - T_c) \qquad (2)$$

$$Q_h = \frac{1}{R_{out}} \cdot (T_h - T_{amb})$$

$$Q_e = Q_h - Q_c$$

where the unknown variables are:

- Q_c Heat power at the cold sink (side being cooled)
- Q_h Heat power at the hot sink (side being heated)
- Q_e Electric power
- T_c Temperature at the cold face of the module
- T_h Temperature at the hot face of the module

and the parameters, with the values corresponding to a commercial TE module are:

- n Number of pellets (semiconductor elements) in the module, n=127
- σ Thermoelectric constants, σ_p-σ_p= 4e-4 V/K
- R Electrical resistance of the pellet, R=0.0105 Ω
- k Thermal resistance of the pellet, k=5.487e-3 W/K
- T_{in} Inside air temperature, T_{in} =33ºC
- T_{out} Ambient temperature, T_{out} =24ºC
- I Electrical current through the module
- R_{in} Thermal resistance of the inside heat exchanger
- R_{out} Thermal resistance of the outside heat exchanger

The thermal resistance depends on the configuration, and will be established later. I is considered a control variable, and can be used to adjust the pumping power of the TE module.

Therefore the following matrix equation can be used to represent the thermoelectric cooling system:

$$\left[C(R_{in}, R_{out}, I)\right] = \left(A(R_{in}, R_{out}, I)\right) \cdot \begin{bmatrix} Q_c \\ Q_h \\ Q_e \\ T_c \\ T_h \end{bmatrix} \quad (3)$$

Given the current and thermal resistances of the heat exchangers, equation (3) becomes linear and the five variables can be obtained easily by computing the inverse of matrix *A*. These equations are representative of the real behavior of the TE modules, verified experimentally [4].

Natural convection and thermoelectricity

This configuration will only have a fan for the inside heat exchanger, therefore R_{in} = 0.2 W/K and R_{out} = 0.8 W/K. The amount of the heat transfer obtained depends on the value of the current applied to the module. Solving equation (1) for different values of current *I* gives the maximum power that can be obtained with this configuration. The maximum power is Q_c=24 W for *I*=4.5 A, consequently only two cooling units are needed with the hermetic noiseless system using thermoelectricity.

Forced convection using thermoelectricity

In this case both heat exchangers are using fans to improve the heat transfer, so R_{in} = 0.2 W/K and R_{out} = 0.2 W/K.

The thermal power that can be evacuated with this cooling solution is nearly double of the natural convection solution. (See Figure 8) The maximum cooling power is 50.7 W for a current *I*=6 A. Consequently only one cooling device of this kind is enough to evacuate 46.2 W of heat. This heat power is obtained at *I*=4.9 A which yields to an electric power of 36.2W.

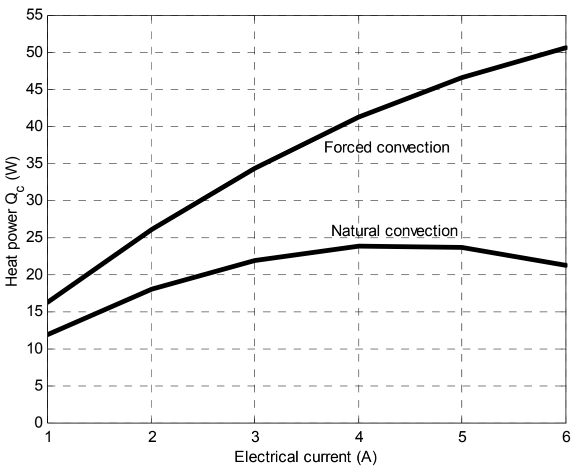

Figure 8: Heat power using thermoelectricity

It is also interesting to remark that the electric power needed for the TE module is a quadratic function of the current. For this reason, it could be more interesting in terms of electrical efficiency to make the modules work at low current. So if suitable space is available, it could be better to use two cooling devices working at 1.7 A with a joint electric power of 8 W to evacuate 46.2 W of heat. This solution, with two thermoelectric devices, is more efficient in the standard condition and is able to transfer 100 W of heat if necessary.

Conclusions

This paper presents different configurations of cooling devices that can be used to refrigerate a hermetic personal computer. It has been shown that thermoelectric modules can help to dramatically reduce the number of heat exchangers needed, as shown graphically in Figure 9.

It can be seen that cooling a hermetic device without external fans is a difficult task due to the large number of radiators needed. It could be impossible in more powerful systems or for hard environmental conditions because the radiators could not fit. On the other hand, using thermoelectricity the heat transfer is so much increased that the cooling device is nearly divided by four.

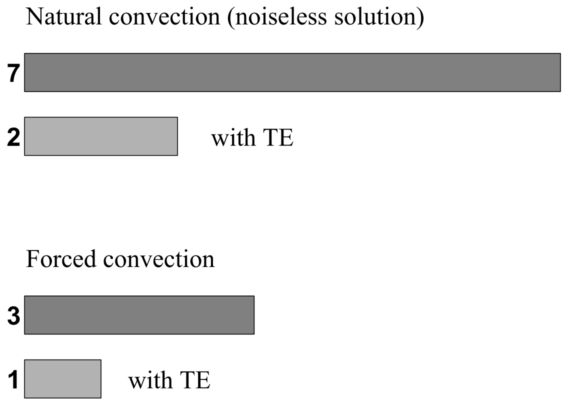

Figure 9: Comparison of solutions, number of heat exchangers

In the different solutions shown, the inside temperature has been kept constant. However using thermoelectricity, it is possible to have the needed heat transfer while maintaining a temperature inside lower than the environment. Adjusting the current of the peltier modules, the temperature of the air can be electronically controlled. The advantage of a temperature control is to reduce the number of radiators directly attached to electronic components or to certify any device for extreme environments.

References

1. Vandersande, J.W., Fleurial, J.P., "Thermal Management of Power Electronics using Thermoelectric Coolers", *Proc XV International Conference on Thermoelectrics,* Pasadena, CA USA, August, 2000. pp. 252-255.
2. Rafael Palacios, Miguel A. Sanz-Bobi, José Villar, Antonio Arenas, "Prototype of heat pump based on Peltier effect. Results of performance tests", *Proc Second european workshop on thermoelectrics.* Nancy, France. Nov, 1995. pp. 93-97.
3. Rowe, D.M., Handbook of thermoelectrics, CRC Press Inc., 1995.
4. Rafael Palacios, Miguel Angel Sanz-Bobi, "Thermal properties of commercial thermoelectric modules", *Proc XVI International Conference on Thermoelectrics.* Dresden, Germany, Agust, 1997. pp. 628-631.