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THERMOELECTRIC COOLING OF CABINETS WITH WATER HEAT REJECTION

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ABSTRACT

The cooling of electronic cabinets that have an air temperature above that of an available liquid is examined to determine temperatures where thermoelectrics increases heat evacuation compared to passive heat exchangers. A non dimensional coefficient is used for the comparaison. The useful range of cooling generally corresponds to cabinet temperatures not exceeding 10 K, that of an available liquid. A thermoelectric air to water cooler that fits into a 19 inch rack is described. Its performances are given. Its provides, efficient cooling for liquid temperatures 5 to 10 K below or above cabinet temperature and has the advantage of being, static, highly reliable and can operate with any type of water, even sea water.

1 - INTRODUCTION

The temperature of cabinets or enclosures with heat generating components depends on the mechanisms of heat transfer to evacuate the heat. When the enclosure temperature is above that of the ambiant available fluid ; the simplist method is by heat exchangers but when temperature differences are small sufficient heat cannot be evacuated and thermoelectrics using electrical power will increase the cooling.

An application is the cooling of cabinets requiring a chilled water circuit. Such cabinets can be cooled thermoelectrically with a water circuit at ambiant temperature.

2 - CABINET COOLING REQUIREMENTS

Enclosures containing electrical and electronic components dissipate more or less heat. The range of specific thermal power goes from 100 W/m3 (of cabinet) to 5000W/m3.

- for specific thermal powers below 300W/m3 natural convection and radiation from the walls of the cabinet are generally sufficient.

- from 300 W/m3 to 1000W/m3 when outside air can be circulated through the cabinet (filtered if necessary). A fan inside or outside the cabinet sucks or blows the air through the cabinet, at the exit its temperature is raised approximately between 8 and 15 °C depending on the heat to be dissipated.

- for the range 1000 to 4000 W/m3.

Generally one has a closed air loop inside the cabinet that contains an air to water heat exchanger as shown in Fig. 1.

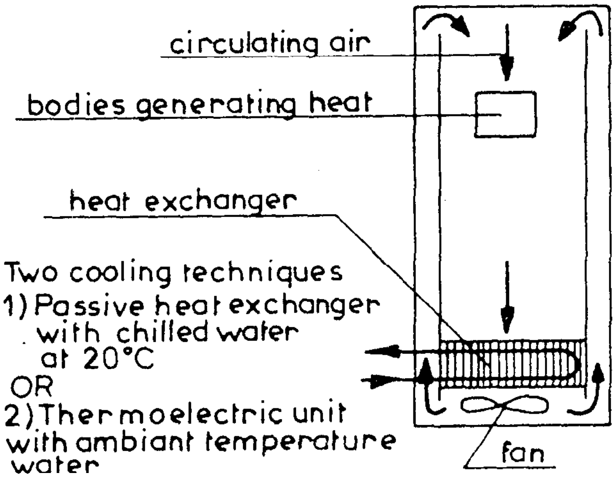

Fig. 1 - Cabinet with water cooling.

- Heat exchanger with chilled water :
The heat generated in the cabinet is hence transfered in a chilled water circuit cooled by an outside refrigeration unit to 20 °C. In the heat exchanger its temperature is elevated around 7 °C.

The air inside the cabinet has the humidity of the outside air the last time the cabinet was opened. Water vapour condensation is not acceptable because of the possibility of electric shorts and corrosion. Therefore the coldest part of the air circuit which is generally the heat exchanger must not be colder than the dew point of an outside air. The practical value is 20 °C which is the reason that cooled water is generally at 20 °C.

- Thermoelectric cooler :
A thermoelectric unit operates with a water circuit at ambiant temperature. This technique is examined and a unit is described. No part of the air circuit is below 20 °C.

3 - COOLING OF BODIES ABOVE AMBIANT

A component or body that generates heat can be cooled by transfering the heat to a circulating fluid, which can be a gas or a liquid, air has been used in the example.

In the following analysis we only consider the heat flow between T(i) and T(o).

Passive heat exchangers

The adjective passive is used here to specify traditional heat exchangers and to distinguish from thermoelectric heat exchangers.

We designate T(b) as the temperature of the body, T(i) the temperature of a fluid in contact with the body and T(o) the temperature of an available ambiant fluid outside the cabinet.

When $T(i) > T(o)$ heat can be evacuated by convection, the heat flux Q to be evacuated can be written :

$$Q = C \times (T(i) - T(o))$$

where C is the conductance of the heat exchanger. The conductance (W/K) defines the size of the heat exchanger and it does not depend much on temperature.

When T(i) - T(o) is small the heat flux is also small, when it is equal to zero it is nil.

Thermoelectric coolers

A very useful approach was presented by Goldsmid (1), who examined thermoelectric cooling of bodies at above ambiant temperature. He shows how the heat exchanger (heat sink) conductance varies with the temperature difference introduced by thermoelectrics.

a) Conductances

We consider a heat flow as shown in Fig. 2. The analysis starts with the enclosure fluid (air) at T(i) and ends with a circulating fluid called ambiance at T(o). We do not take into consideration heat going through cabinet walls because it can be deducted from the initial heat flux.

The temperature at the heat exchanger surfaces are $\Theta(i)$ for the inside (base of fins which are cold) and $\Theta(o)$ for the outside which is hot. The initial heat flux is Q, it becomes $Q\,(1+1/\phi)$ between the thermoelectric unit and ambiance, where ϕ is the coefficient of performance COP.

Let us define the conductances C(i) and C(o) for the inside and outside heat exchangers.

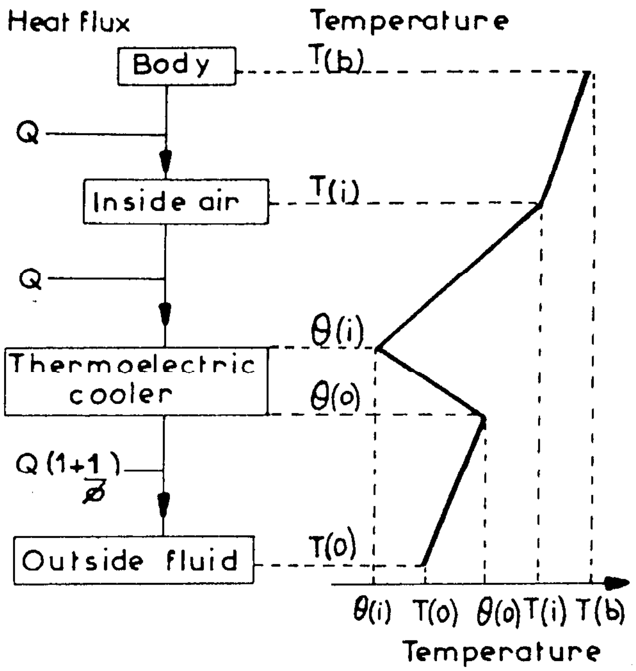

Fig. 2 - Schematic thermoelectric heat flow and temperatures.

$$C(i) = \frac{Q(t)}{T(i)-\Theta(i)}$$

$$C(o) = \frac{Q(t)\ (1+1/\phi)}{\Theta(o)-T(o)}$$

Q(t) depends on the unit and its operating conditions.

The overall conductance of two heat exchangers in series is :

$$C(io) = \left\{\frac{T(i) - \Theta(i)}{Q(t)} + \frac{\Theta(o) - T(o)}{Q(t)(1+1/\phi)}\right\}^{-1}$$

$$C(io) = Q(t) / \left\{T(i)-\Theta(i) + \frac{\Theta(o)-T(o)}{1+1/\phi}\right\}$$

The conductance for the passive heat exchanger is :

$$C = Q / (T(i) - T(o))$$

The ratio of conductances between a thermoelectric unit and a passive heat exchanger is :

$$\frac{C(io)}{C} = \frac{Q(t)}{Q} \times \frac{T(i) - T(o)}{\left\{T(i)-\Theta(i)\right\}+\left\{\frac{\Theta(o)-T(o)}{(1+1/\phi)}\right\}}$$

Goldsmid plots C/Q(t) of dimension 1/K as a function of the thermoelectric difference in temperature $\Theta(o)-\Theta(i)$. When $\Theta(o)-\Theta(i) = 0$ then C(io)/Q(t) has the value corresponding to that of a passive heat exchanger C/Q. We have chosen to consider C* the non dimensional ratio C(io)/Q(t) of the thermoelectric cooler to the C/Q of a passive heat exchanger.

$$C^{*} = \frac{C(io)/Q(t)}{C/Q} = \frac{T(i) - T(o)}{T(i) - \Theta(i) + \frac{\Theta(o) - T(o)}{1 + 1/\emptyset}}$$

The value of C* depends only on temperatures and on Ø which is the COP of the thermoelectric unit. It expresses the relative thermal resistance of a thermoelectric cooler to a passive heat exchanger, is equal to 1 when a thermoelectric cooler has the same thermal resistance as a passive heat exchanger. The efficiency of a thermoelectric cooler increases as C* decreases.

b) Numerical example

An example of cooling the air inside a cabinet and evacuating the calories to a water circuit is examined.

The thermal model of the thermoelectric cooler presented in paragraph 4 is used to obtain Ø as a function of T(i) and T(o). Different values of Θ(o) and Θ(i) are obtained by varying the electrical current I through the thermoelectric unit. C* is calculated knowing T(i), T(o), Θ(i), Θ(o) and Ø. The temperatures were the following ; cabinet air temperature T(i) : 31 °C, 35 °C and 40 °C. Outside water circuit T(o) = 30°C.

The results are plotted in Fig. 3 versus Θ(o)-Θ(i) using ΔT = T(i) - T(o) as a parameter.

The electrical power P required to operate the thermoelectric cooler is equal to :

$$P = Q(t)/\emptyset$$

One sees from Fig. 3 that when the inside air temperature T(i) is close to the outside water temperature T(o), C* is very small so the thermoelectric cooler is very efficient compared to a passive heat exchanger.

c) Useful range

The curve of C/Q given in Ref. 1 shows that for ΔT = 10K a thermoelectric cooler is valid for Θ(o) - Θ(i) equal to about 15 K as C/Q is reduced by over 40 %. In Fig. 3 we find for ΔT = 10 K that thermoelectricity is valid only for Θ(o)-Θ(i) of about 8 K. The difference comes from that Goldsmid dimensions the thermoelectric cooler so that it operates at maximum COP. In our example we are dealing with an industrial unit that is operated well below COP maximum because otherwise it would be too cumbersome. Also he considers the case where there is only one exchanger (heat sink) which is located on the outside, on the inside the thermoelectric cold side is against a body to be cooled. Our example has a heat exchanger on each side of the thermoelectric cooler which increases considerably the value of C*.

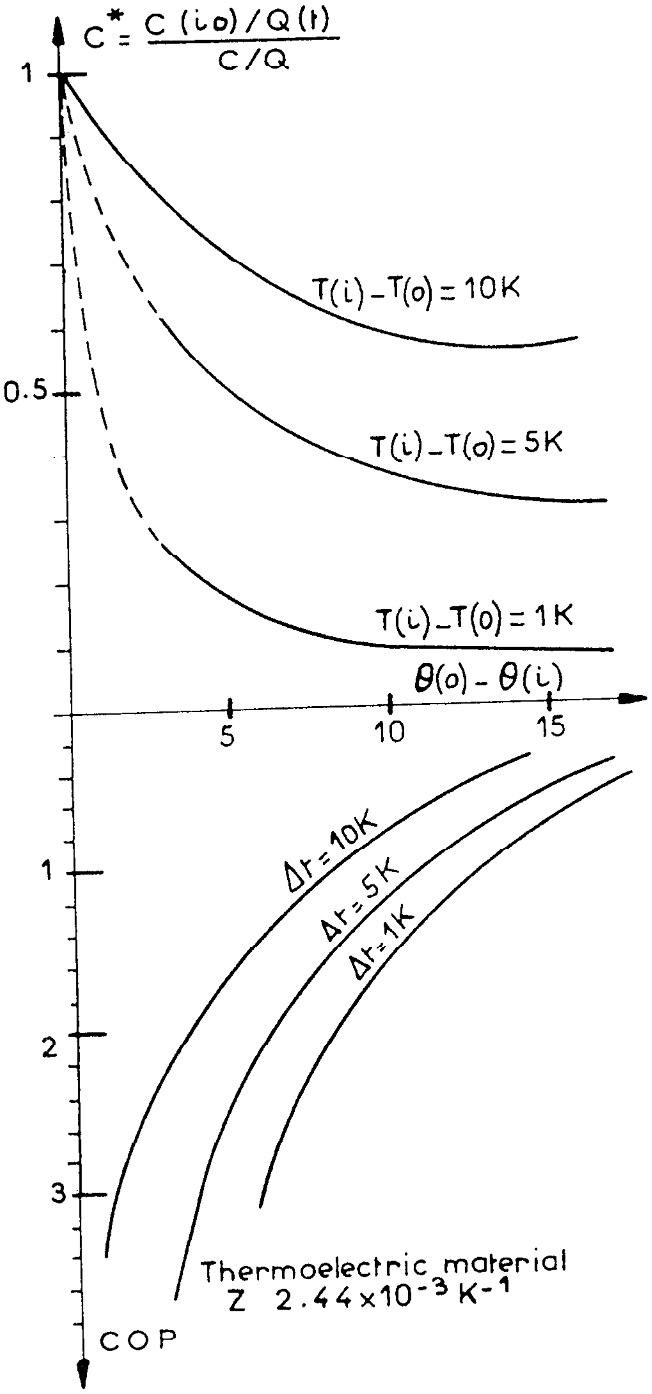

Fig. 3 - Relative thermal resistance C* of thermoelectric cooler.

d) Conclusion

The non dimensional analysis presented in Fig. 3 shows the operating temperature differences where thermoelectric cooling contributes to evacuate heat from enclosures. When Θ(o)-Θ(i) becomes negative one can no longer compare thermoelectricity with heat exchangers because the latter will heat instead of cool the cabinet while thermoelectrics will cool the cabinet.

4. THERMOELECTRIC COOLER

A thermoelectric unit has been designed to fit into electronic 19 inch rack cabinets to replace an air-water heat exchanger that requires a chilled water circuit at 20 °C. The thermoelectric unit uses ambiant water for example at 30 °C or hotter. The technology is very similar to one used for thermoelectric air conditioning with water heat rejection (2) (3). A prototype is being built as a drawer 103 mm high. A description is given then the thermal performances are presented in the form of graphs.

4.1. Description

A drawing of the thermoelectric cooling part is given in Fig. 4 below.

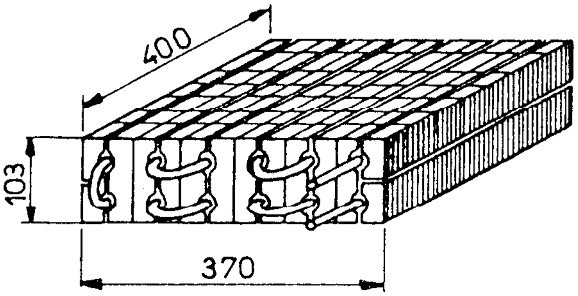

Fig. 4 - Thermoelectric cooler

- Air circuit

The air flow is downward, it can be varied between 0.17 l/s (600 m3/h) and 0.42 l/s (1500 m3/h).

The fins are in aluminum of thickness 1.2 mm with a wave and have a pitch of 4.5mm and heigłt of 27 mm. The total fin area is 3.04 m2.

- Water circuit

The water circuit consists of 12 metallic tubes of 11 mm I.D. which are in series with U bends, they are grounded. The fluid circuit is such that each small horizontal area through which air flows has the same water temperature (taken as the average between the lower and upper tubes). The water flow varies between 0.15 kg/s and 0.25 kg/s.

The heat transfer coefficient for water at 30 °C and at a velocity of 2 m/s is 10.085 W/(m2.K).

- Electrical circuit

The electrical circuit follows each tube and crosses over from one tube to another at the level of the U bends.

4.2. Technology and thermoelectric material

The unit comprises 276 couples (N+P) of cross section 64 mm2 and a thickness 1.5 mm that are soldered on nickel plated copper with a bismuth tin eutectic solder. Thermoelectric material being vulnerable to shear stress, it is necessary to design very carefully thermoelectric units so that a minimum amount of shear stress is transmitted to the material. Shear stress comes from :

- thermal expansion of the tubes and of the heat exchangers due to temperature variations,
- dimensional tolerances of parts.

A technology has been developed and proven by prolonged endurance tests in the laboratory and by units out in the field for many years.

The thermoelectric material resists much better to shear stress when under compression so each piece of thermoelectric material is maintened under a pressure of 10 MPa. The thermoelectric material characteristics are measured on a statistical basis separately for N and for P type material (4).

at 300 K	N Type	P Type
Resistivity $\mu\Omega$.m	10.921	11.730
Seebeck coef. μ V/k	206.48	200.43
Thermal cond. W/(m.K)	1.563	1.41
Coef. merit $Z.10^3$ I/K	2.466	2.429

Average $Z = 2.44.10^{-3}K^{-1}$

4.3. Performances

The cooling power can be plotted as a function of coefficient of performance COP = Ø using $\Delta T = T(i)-T(o)$ as a parameter.

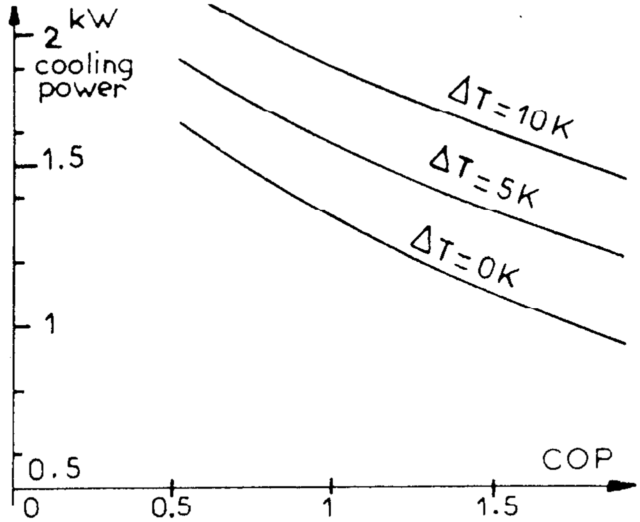

Fig. 5 - Cooling power versus C.O.P.

The influence of the air and water flow rates are given for T(i) = 30 °C. 50 % RH and T(o) = 30 °C which corresponds to ΔT=0. The curves are plotted for a COP = ∅ = 1.5. The variation in cooling power due to water flow rate being doubled is : of 10 %. The air flow rate is important as when it is doubled it increases in a significant way, the heat convection coefficient and the cooling power increases by 30 %.

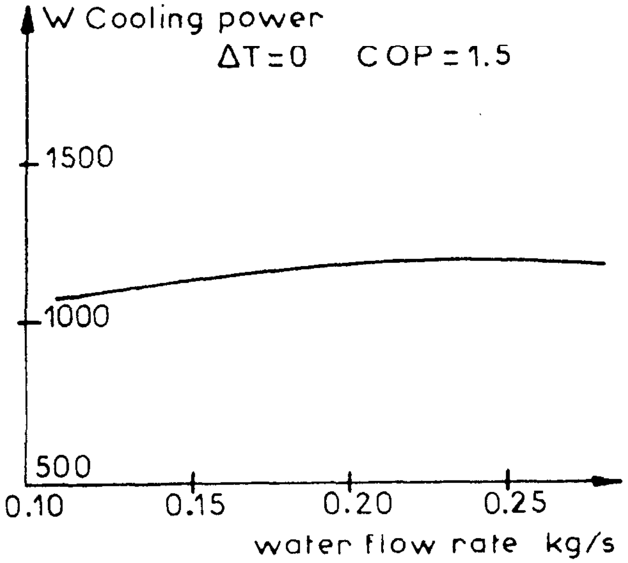

Fig. 6 - Cooling power versus water flowrate

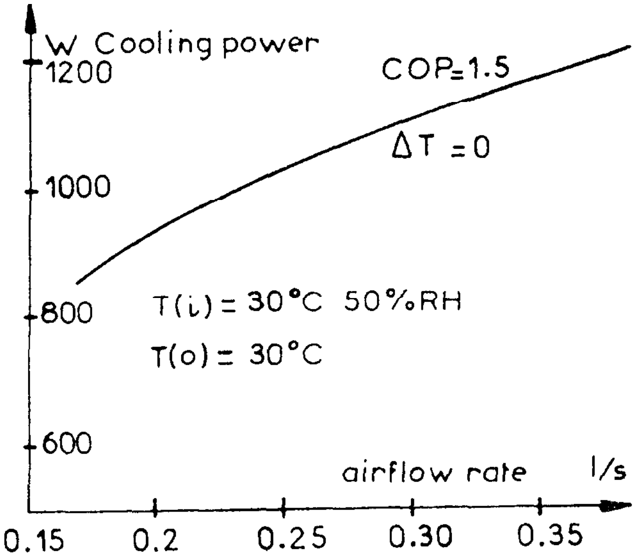

Fig. 7 - Cooling power versus air flow rate

To compare a thermoelectric unit with a passive heat exchanger, some criteria must be chosen. We have chosen volume and have defined a specific cooling power Q* in watts of cooling power per dm3. Fig. 8 below gives Q* for this thermoelectric cooler and gives a range of specific cooling power for heat exchangers.

A passive heat exchanger by definition has a constant conductance (in the small range of temperatures) so is represented by a straight line passing through the origin with a slope equal to its conductance. The limiting lines correspond to conductances per dm3 and per degree K of 12 and 20.

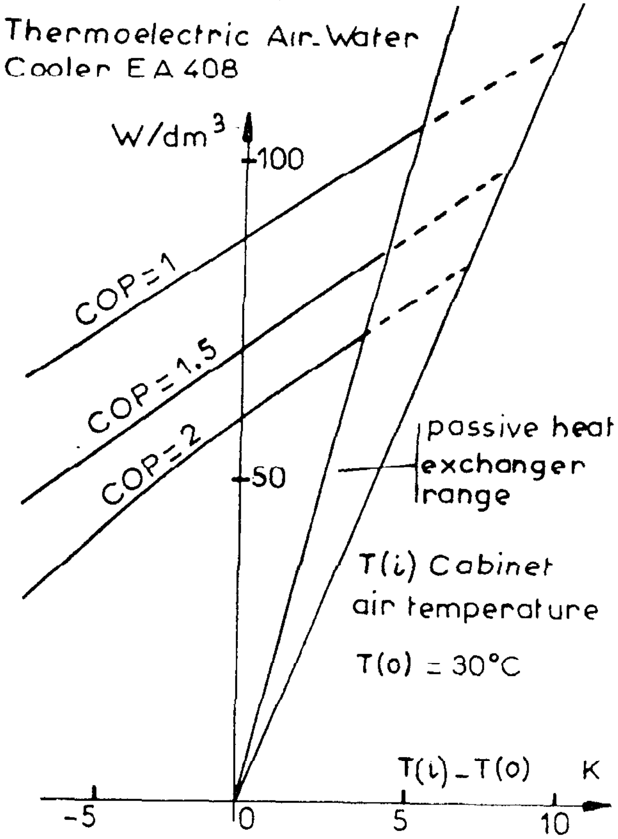

Fig. 8 - Specific cooling power of Thermoelectric unit and passive heat exchangers.

*The curves show clearly when a thermo*electric unit is of interest. The thermoelectric unit described has not been designed for minimum volume nevertheless improvements in Q* will probably only be of the order of 10 or 20 % which would extend the useful range by about a degree C.

5. CONCLUSIONS

Thermoelectricity is very interesting when the temperature is a few degrees around ambiant because in this range passive heat exchangers cannot operate when ambiance is above cabinet temperature and evacuate very little heat when the ambiance is only a few degrees below cabinet temperature.

Thermoelectricity enables a cabinet to be cooled without having a chilled water loop. The system is static and has a very high reliability.

The technology used has been proven by prolonged use of large units based on a similar design. The system is modular and it is easy to increase cooling power by adjoining units. The water circuit is designed to be able to operate with any type of water even sea water.

NOMENCLATURE

Symbol	Unit	Designation
C	W/K	Conductance of a passive heat exchanger
C(i)	W/K	Conductance of heat exchanger on the inside
C(o)	W/K	Conductance of heat exchanger on the outside
C(io)	W/K	overall conductance of the 2 heat exchangers hot side and cold side)
C*		Ratio of $\frac{C(io)/Q(t)}{C/Q}$
I	A	Electrical intensity
P	W	Electrical power
Q	W	Heat to be evacuated from cabinet
Q(t)	W	Heat to be evacuated from cabinet through thermoelectric cooler
Q*	W/dm3	Specific cooling power
T(b)	K	Temperature of body
T(i)	K	Temperature of fluid inside enclosure in contact with body
T(o)	K	Temperature of fluid outside cabinet which is circulating
$\theta(i)$	K	Temperature of base of fins on the inside (cold) of thermoelectric unit
$\theta(o)$	K	Temperature of base of fins on the outside (hot) of thermoelectric unit
$\emptyset$		Coefficient of performance of thermoelectric unit = COP
Z	K^{-1}	Coefficient of merit of thermoelectric material.

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APPENDIX

Conversion of units :

1 cfm = 0.472 l/s

1 gal/m = 0,063 kg/s (water)

1 Btu/hr = 0,293 W

1 Btu/hr.ft^3 = $1,035.10^{-2}$ W/dm3

1 Btu/hr.°F = 0,527 W/K