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TECHNICAL SPECIFICATION

colour inside

Mechanical structures for electronic equipment – Thermal management for cabinets in accordance with IEC 60297 and IEC 60917 series – Part 3: Design guide: Evaluation method for thermoelectrical cooling systems (Peltier effect)

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Mechanical structures for electronic equipment – Thermal management for cabinets in accordance with IEC 60297 and IEC 60917 series –
Part 3: Design guide: Evaluation method for thermoelectrical cooling systems (Peltier effect)

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MECHANICAL STRUCTURES FOR ELECTRONIC EQUIPMENT – THERMAL MANAGEMENT FOR CABINETS IN ACCORDANCE WITH IEC 60297 AND IEC 60917 SERIES –

Part 3: Design guide: Evaluation method for thermoelectrical cooling systems (Peltier effect)

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Technical specifications are subject to review within three years of publication to decide whether they can be transformed into International Standards.

IEC 62610-3, which is a technical specification, has been prepared by subcommittee 48D: Mechanical structures for electronic equipment, of IEC technical committee 48: Electromechanical components and mechanical structures for electronic equipment.

The text of this technical specification is based on the following documents:

Enquiry draft	Report on voting
48D/401/DTS	48D/414/RVC

Full information on the voting for the approval of this technical specification can be found in the report on voting indicated in the above table.

This publication has been drafted in accordance with the ISO/IEC Directives, Part 2.

A list of all parts of the IEC 62610 series can be found, under the general title *Mechanical structures for electronic equipment – Thermal management for cabinets in accordance with IEC 60297 and IEC 60917 series*, on the IEC website.

The committee has decided that the contents of this publication will remain unchanged until the maintenance result date indicated on the IEC web site under "http://webstore.iec.ch" in the data related to the specific publication. At this date, the publication will be

- transformed into an International standard,
- reconfirmed,
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- replaced by a revised edition, or
- amended.

A bilingual version of this publication may be issued at a later date.

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INTRODUCTION

Besides the conventional compressor cooling there are several alternatives for cooling, for example: absorption cooling, thermoelectric cooling (Peltier), magneto caloric cooling, CO_2 cooling and others.

For the design of thermoelectrical cooling systems, values of the dissipation loss depending on the ambient temperature and internal temperature are necessary.

Thermoelectrical cooling systems performance is a function of ambient temperature, hot and cold side heat exchanger (heat sink) performance, thermal load, of the design of the Peltier device and of Peltier electrical parameters.

Therefore an evaluation method has to be developed. This design guide allows a comparison of thermoelectrical cooling systems.

MECHANICAL STRUCTURES FOR ELECTRONIC EQUIPMENT – THERMAL MANAGEMENT FOR CABINETS IN ACCORDANCE WITH IEC 60297 AND IEC 60917 SERIES –

Part 3: Design guide: Evaluation method for thermoelectrical cooling systems (Peltier effect)

1 Scope and object

This part of IEC 62610 provides an evaluation method for thermoelectrical cooling systems (Peltier effect).With this design guide it is possible to calculate the efficiency of the thermoelectrical cooling system (Peltier effect) and its cooling power depending on the ambient temperature and internal temperature. This design guide can also be used to appraise thermoelectrical cooling systems by its efficiency.

2 Normative references

The following referenced documents are indispensable for the application of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 62194:2005, *Method of evaluating the thermal performance of enclosures*

3 Abbreviations, symbols and indices

For the purposes of this document, the following abbreviations, symbols and indices apply.

3.1 Abbreviations

COP	coefficient of performance [-]
c_P	heat capacity [W/kgK]
D	pipe diameter [m]
I	current [A]
k	overall heat transfer coefficient k [W/ m^{2}K]
n	total number of Peltier devices [-]
Δp	pressures difference [Pa]
Q	energy flow (thermal, electrical, conductivity) [W]
Q_C	effective cooling power of the thermoelectrical cooling system (Peltier) [W]
Q_{cPe}	cooling power of a Peltier device at operating conditions [W]
Q_D	total dissipated heat flow on the hot side [W]
Q_H	heating power inside the cabinet [W]
R_{Pe}	electrical resistance of the Peltier device [V/A]
R_i	thermal resistance [K/W]
S	surface [m^2]
T	temperature [K]
V	voltage [V]

$\dot{V}$ volume flow [m³/s]

ZT Figure of Merit [-]

3.2 Symbols

α Seebeck coefficient [V/K]

ρ density [kg/m³]

λ thermal conductivity [W/m²K]

σ electrical conductivity [S/m = A/V]

φ relative humidity

3.3 Indices

1-7 position marks

A related to an air flow

a ambient

C effective cooling power

c cold side

D total dissipated and removed heat on the hot side

E electrical power applied to the thermoelectrical cooling system

F Fan

H heating inside the cabinet

h hotside

i internal, inside the cabinet

L heat loss

m average

Pe related to the Peltier device

R reverse

S related to the whole thermoelectrical cooling system

4 Theory of the thermoelectrical cooling system

4.1 The Peltier element

The Peltier effect is the direct conversion of electric voltage to temperature differences and the reverse process is called Seebeck effect.

Therefore a thermoelectrical cooling system (Peltier effect) transfers heat from one side of the device to the other side against the temperature gradient, with consumption of electrical energy.

This Peltier effect is described by the following equation:

$$Q_{cPe} = \alpha \cdot I \cdot T_c - \frac{1}{2} \cdot I^2 \cdot R_{Pe} - \left(\frac{\lambda_{Pe} \cdot S_{Pe}}{x_{Pe}} \right) \cdot (T_{4h} - T_{4c}) \quad [W] \qquad [1]$$

The cooling power of one Peltier element Q_{cPe} depends on different phenomena.

The term $\alpha \cdot I \cdot T_c$ is the maximum cooling power based on the Peltier effect, whereas α represents the Seebeck coefficient.

The term $\frac{1}{2} \cdot I^2 \cdot R_{Pe}$ represents the Joule heating, the term $\left(\frac{\lambda_{Pe} \cdot A_{Pe}}{x_{Pe}}\right) \cdot \left(T_{4h} - T_{4c}\right)$ is the heat conduction between the hot and the cold side through the Peltier element.

According to Equation 1 it is a requirement to minimize the terms of the Joule heating and the heat conduction.

For the evaluation of a Peltier element the coefficient Figure of Merit ZT was defined as shown in Equation 2.

$$ZT = \frac{\alpha^2 \cdot \sigma}{\lambda} \cdot T \quad [-] \qquad [2]$$

which represents the ratio between the electrical conduction σ to the heat conduction λ at a given temperature T.

ZT is therefore a very convenient figure for comparing the potential efficiency of devices using different materials. Values of ZT=1 are considered good, and values of at least the 1–3 range are considered to be essential for thermoelectrics to compete with mechanical generation and refrigeration in efficiency.

4.2 Thermoelectrical cooling systems

The thermoelectrical cooling systems (see Figure 1) transport heat Q_c from one medium to another whereas these media can be either gas or liquid. For a better heat transfer, heat sinks are connected to each side of the Peltier device. The material between the Peltier device and the heat sink is called Thermal Interface Material (TIM).

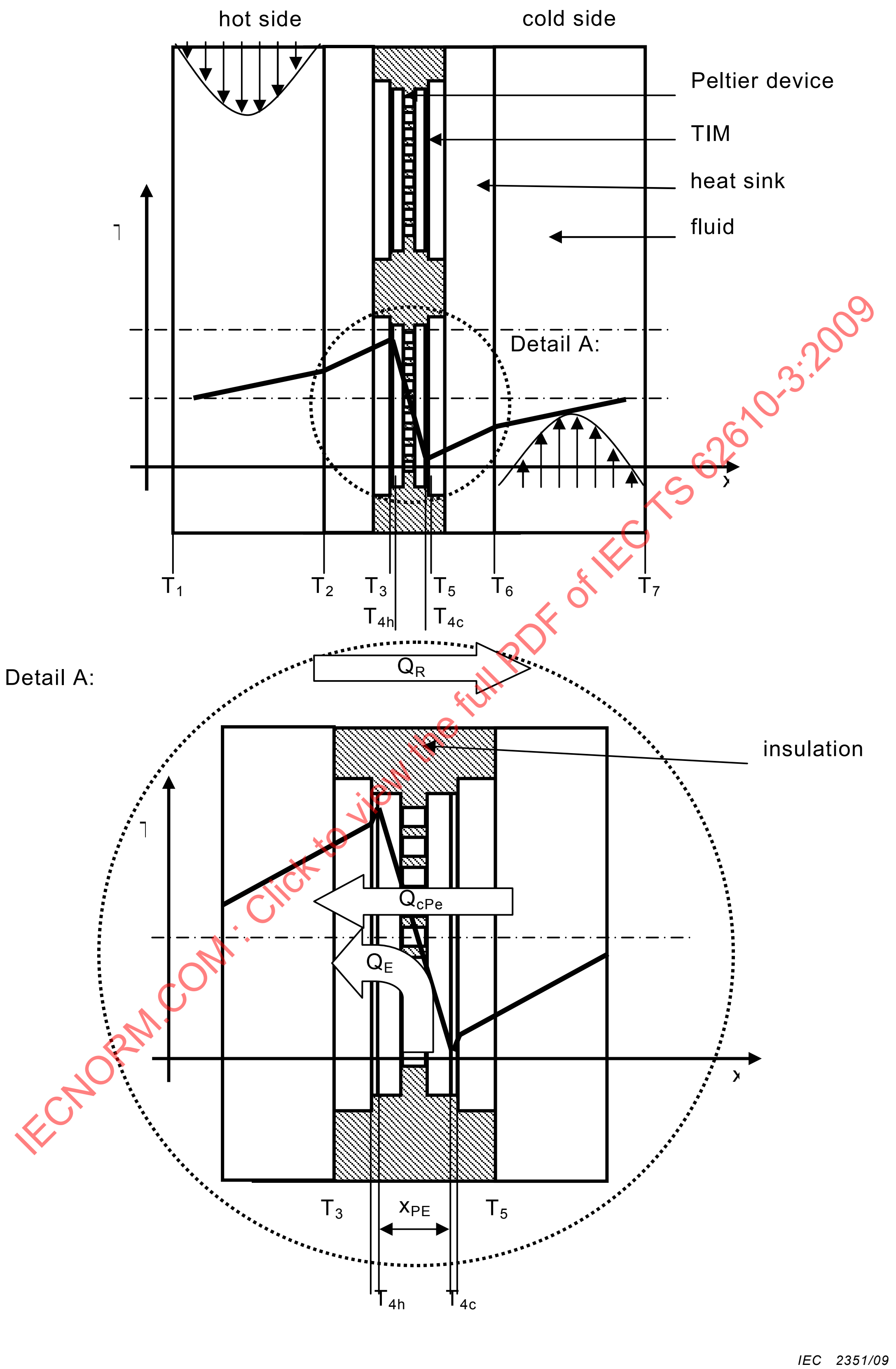

Figure 1 – Principles of the thermoelectrical cooling system

The medium at temperature T_7 passes the heat sink of the thermoelectrical cooling system (Peltier) which has a temperature of T_6 and is cooled by convection. The heat is transferred through the heat sink by conduction at the given temperature gradient between T_6 and T_5. Then the heat flux is transferred through the Thermal Interface Material (TIM) by conduction. The Peltier device is responsible for the main temperature gradient.

On the hot side of the Peltier device the heat flux passes the TIM and the heat sink due to conduction and finally the heat is removed by the medium on the hot side by convection.

The total thermal resistance limiting the total heat flux is a sum of every resistance of each described process (see Figure 2).

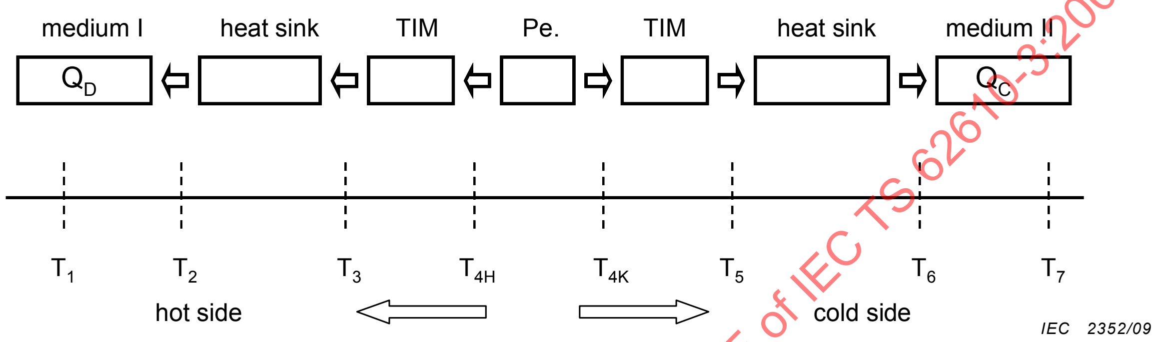

Figure 2 – Thermal resistances

The thermal resistances can be expressed as followed:

$$R_1 = \frac{T_2 - T_1}{Q_D} \quad [K/W] \qquad R_5 = \frac{T_5 - T_{4K}}{Q_C} \quad [K/W]$$

$$R_2 = \frac{T_3 - T_2}{Q_D} \quad [K/W] \qquad R_6 = \frac{T_6 - T_5}{Q_C} \quad [K/W]$$

$$R_3 = \frac{T_{4H} - T_3}{Q_D} \quad [K/W] \qquad R_7 = \frac{T_7 - T_6}{Q_C} \quad [K/W]$$

$$R_{total} = \sum_{i=1}^{7} R_i \qquad [3]$$

Minimizing each resistance is necessary for designing an efficient thermoelectrical cooling system.

As shown in Figure 1 the empty space between the two heat sinks and the Peltier devices is filled with insulation materials to avoid a reverse heat flux Q_R from the hot heat sink to the cold one due to conduction. For an efficient working thermoelectrical cooling system this reverse heat flux through the insulation is to be minimized at all costs. Therefore in further calculation this heat flow Q_R is assumed to be zero.

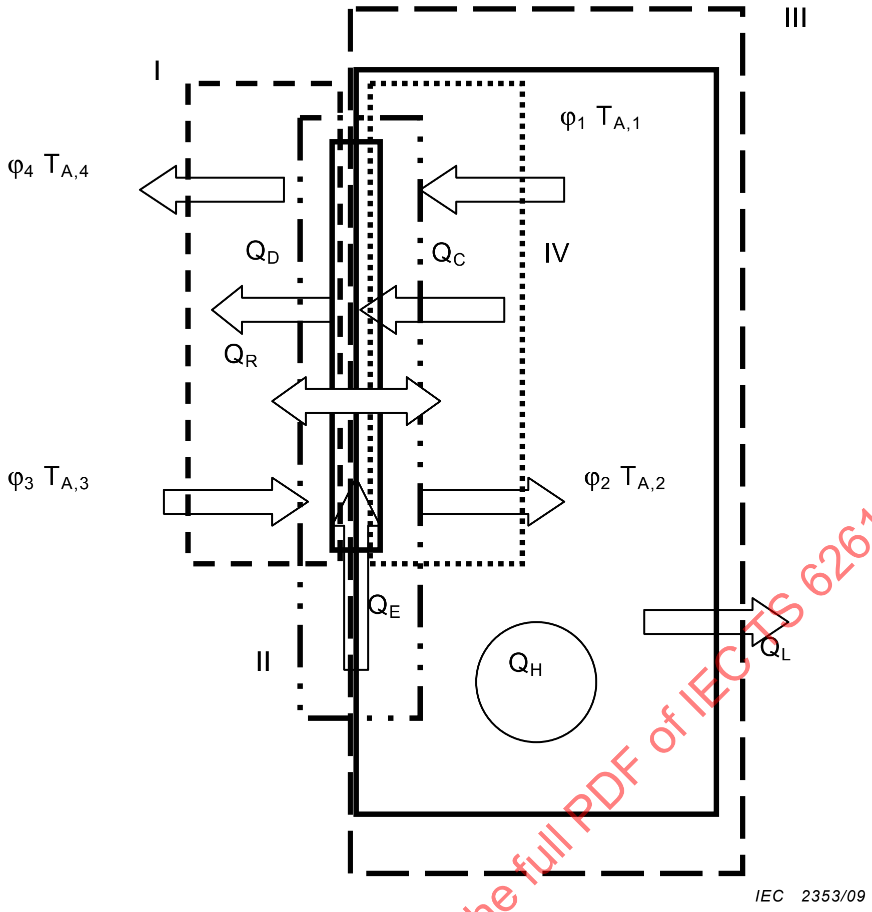

Figure 3 – Thermodynamic system boundaries of a thermoelectrical cooling system attached to a closed cabinet

The power equations for each thermodynamic system according to Figure 3 are as followed:

I: $$Q_C = Q_H - Q_L + Q_{F,c} \pm (Q_R = 0) \qquad [4]$$

II: $$Q_D = Q_C + Q_E + Q_{F,h} \pm (Q_R = 0) \qquad [5]$$

III: $$Q_C = \dot{V}_c \cdot \rho \cdot c_p \cdot (T_{A,1} - T_{A,2}) \qquad [6]$$

IV: $$Q_D = \dot{V}_h \cdot \rho \cdot c_p \cdot (T_{A,4} - T_{A,3}) \qquad [7]$$

$$Q_L = k \cdot S \cdot (T_{i,m} - T_{a,m}) \qquad [8]$$

The heat flux Q_C which is removed from the cabinet is the heating power Q_H minus the heat loss Q_L over the cabinet walls. $Q_{F,c}$ is the heat dissipation from the fan on the cold side and is a function of the efficiency factor of the fan and its rotation speed. The power balances according system boundary II indicates that the heat flux Q_D is the sum of Q_C and the power Q_E that is applied to the Peltier devices and the dissipated heat from the fan on the hot side $Q_{F,h}$ minus the reverse heat flux Q_R through the insulation.

Furthermore it is assumed that no condensation of water vapour occurs while cooling. This implies that the relative humidity φ which is dependent on system temperature and on system pressure has to fulfil certain conditions.

The relative humidity is defined by the ratio between the partial pressure of water vapour in the mixture p_{H_2O} and the saturated vapour pressure of water at the given temperature of the mixture $p^*_{H_2O}$.

$$\varphi = \frac{p_{H_2O}}{p^*_{H_2O}} \cdot 100\% \qquad [9]$$

With disregard of the so-called supersaturated state, water vapour condensation occurs at φ = 100 %. Therefore it shall be ensured that there is no condensation of water vapour during the cooling.

5 Measurement setup

Figure 4 shows the general measurement setup for the evaluation of a thermoelectrical cooling system. It consists of a cabinet that is surrounded by a climate room to keep the ambient temperature constant. In the cabinet a heater is placed to simulate the heat dissipation under operating conditions. The thermoelectrical cooling system (Peltier) is mounted onto the cabinet. It has to be considered that there is no short-circuit of the airflows.

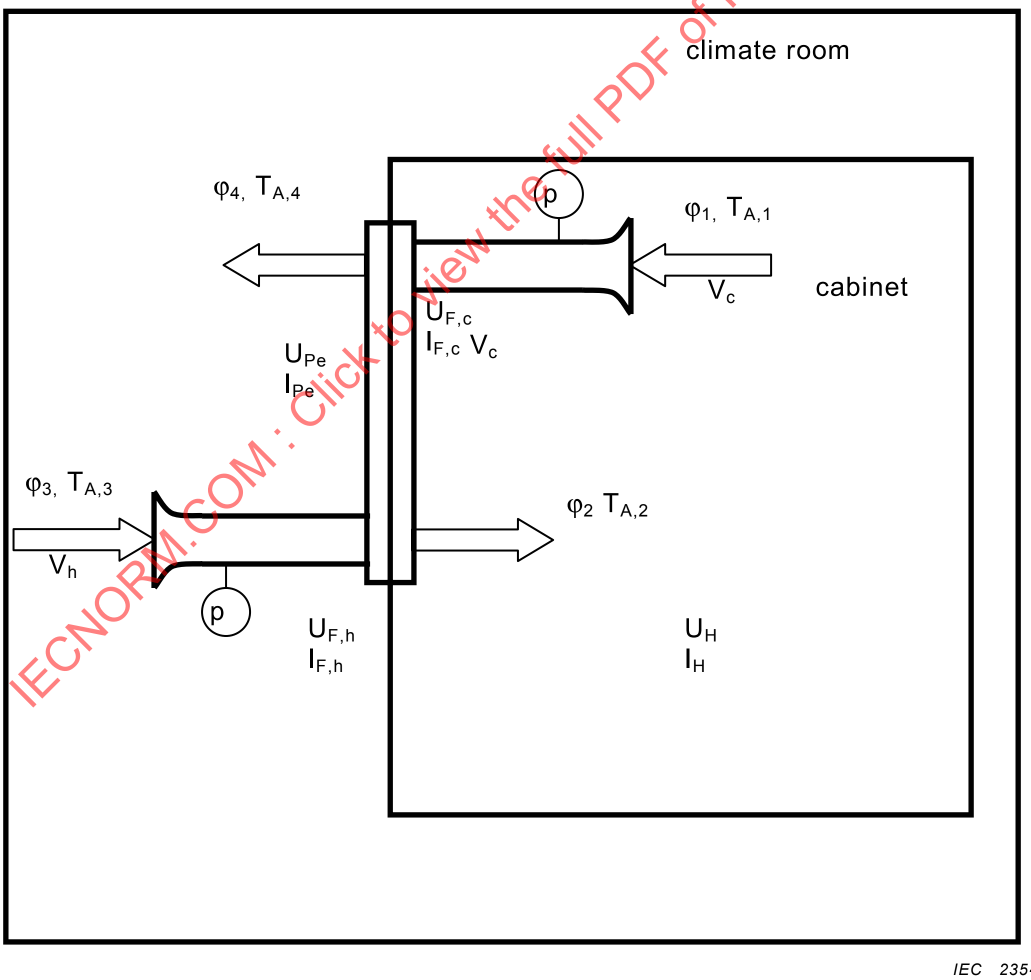

Figure 4 – Measurement setup

The power inlet for the heater, fans and the Peltier devices as well as the ambient temperature shall be independently adjustable for measuring at fixed conditions. The airflow can be easily determined by using a measuring nozzle with defined diameter as shown in Figure 4. By measuring the pressures difference the air velocity w in m/s in the pipe can be calculated with the following equation.

$$w = \varepsilon \cdot \tau \cdot \sqrt{\frac{2 \cdot \Delta p}{\rho}} \quad [m/s] \qquad [10]$$

with $\varepsilon \approx 1$ (compression factor) and $\tau \approx 1$ (value of resistance of the nozzle) for air, the pressures difference Δp in Pa, and density of the air in kg/m^3.

This leads to a total air flow V in m^3/s by a given diameter D_{pipe} of the pipe of:

$$V = \frac{1}{4} \cdot w \cdot D_{pipe}^2 \cdot \pi \ [m^3/s] \qquad [11]$$

6 Interpretation and evaluation

For the evaluation of a thermoelectrical cooling system (Peltier) several measuring points are necessary at fixed operating conditions.

The following list gives an overview of the parameters used in the measurement setup as shown in Figure 4.

operating conditions:

- heater power ($Q_H = U_H \cdot I_H$)
- fan power ($Q_{F,h}$ and $Q_{F,c}$)
- power for the Peltier devices ($Q_{Pe} = U_{Pe} \cdot I_{Pe}$)
- $T_{a,4}$ (ambient temperature)
- measurement data
- $T_{A,1}$, $T_{A,2}$, $T_{A,3}$, $T_{A,4}$
- air flow volumes (V_h, V_c) by determining the pressures differences in the measuring nozzles
- optional parameters
- pressure drop of the heat sinks
- surface temperatures on the heat sink

Optional parameters can be used for optimization of the thermoelectrical cooling system (Peltier) and for determining all resistances mentioned in Figure 2.

The steady state condition is indicated by no changes in temperatures over time.

First, the total heat transfer coefficient k in W/m^{2}K over the cabinet surface S is to be determined according to IEC 62194, Annex A.

The determination of this value has to be done with the measurement setup that is used in further experiments as every single change in the setup may change the value of the overall heat transfer coefficient.

The experimental procedure starts with setting the ambient temperature, the power of the two fans and the power of the Peltier devices. No heating power is applied. After reaching a steady state condition the values of the temperatures $T_{A,2}$, $T_{A,3}$, $T_{A,4}$ are recorded and the airflow is determined. Optionally pressure drop and surface temperature of the heat sinks are determined.

This procedure is repeated at increased heater power dissipation. The heater power dissipation shall be increased until the internal temperature $T_{A,1}$ is higher than the fixed ambient temperature $T_{A,3}$.

The experimental procedure continues the same way as described at different ambient temperatures $T_{A,3}$.

The data evaluation is done according Equation 4 to Equation 7.

To verify the data and the measurement setup the results from the thermodynamic balances shall satisfy the results from the calorimetric calculations and differ by less than 5 %.

$$\left|\frac{Q_D - Q_D^{calo}}{Q_D}\right| \cdot 100\% = \left|\frac{Q_H - Q_L + Q_{F,c} - \left[\dot{V}_h \cdot \rho \cdot c_p \cdot (T_{A,4} - T_{A,3})\right]}{Q_H - Q_L + Q_{F,c}}\right| \cdot 100\% \le 5\% \qquad [12]$$

$$\left|\frac{Q_C - Q_C^{calo}}{Q_C}\right| \cdot 100\% = \left|\frac{Q_C + Q_E + Q_{F,h} - \left[\dot{V}_c \cdot \rho \cdot c_p \cdot (T_{A,1} - T_{A,2})\right]}{Q_C + Q_E + Q_{F,h}}\right| \cdot 100\% \le 5\% \qquad [13]$$

With the obtained data it is possible to create a plot as shown in the following Figure 5.

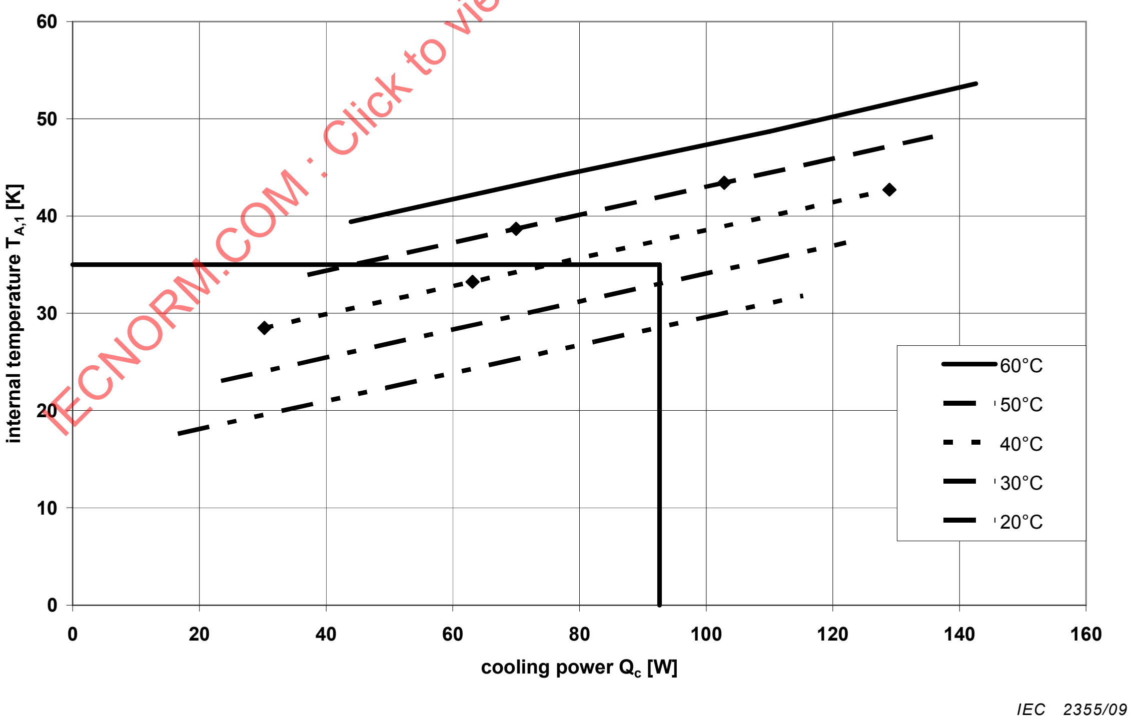

Figure 5 – Results of the measurement

Figure 5 shows the dependency of the cooling power Q_C on the internal temperature $T_{A,4}$ at given ambient temperatures $T_{A,3}$.

For the effective cooling power Q_C of a thermoelectrical cooling system (Peltier) the temperature difference between the internal temperature $T_{A,1}$ and the ambient temperature $T_{A,3}$ is relevant in two ways. First this temperature difference influences the direction of the heat loss (positive if $T_{A,4} < T_{A,3}$, negative vice versa), see Equation 4. Second this temperature difference influences the temperature on the Peltier device hot and cold site itself and this phenomenon directly depends on the global performance of the Peltier device, see Figure 1.

The dependency of the cooling power on the ambient temperature $T_{A,3}$ results from the physical properties of the Peltier device, see Equation 1.

The distance between each curve of different ambient temperatures $T_{A,3}$ is approximately constant.

$$COP_{PE} = \frac{Q_{C,Pe}}{Q_E} \qquad [14]$$

Furthermore it is recommendable to define the COP of the whole thermoelectrical cooling system (Peltier) based on the effective cooling power Q_C and the electrical power applied to the Peltier devices.

$$COP_S = \frac{Q_C}{Q_E} \qquad [15]$$

Finally it is possible to define the COP of the whole thermoelectrical cooling system (Peltier) based on the total applied power. This includes the power applied to the Peltier devices, the power applied to both fans and the power applied to any other electrical device in the thermoelectrical cooling system (Peltier).

$$COP_{total} = \frac{Q_C}{\sum_i Q_{E,i}} \qquad [16]$$

As an important side note, each of those COPs are dependent on the temperatures $T_{A,1}$ and $T_{A,3}$.

In summary, for an objective comparison of thermoelectrical cooling systems (Peltier) it is recommendable to have the following data available.

– the cooling power Q_C at $T_{A,1} = T_{A,3} = 35$ °C with the three corresponding COPs;
– the cooling power Q_C at $T_{A,1} = T_{A,3} = 45$ °C with the three corresponding COPs;
– current that is applied to the Peltier devices;
– current that is applied to the fans;
– additionally useful parameters are airflow and pressure drop.

The following Figure 6 shows an example for a specification sheet of a thermoelectrical cooling system (Peltier).

total number of devices in the thermoelectrical cooling system

current applied to one Peltier device

COP of the advanced cooling system (Peltier) to indicate the thermal resistances of heat sinks, TIMs

n_{Pe}	6	I_{pe}	1,2 A		
35/35	100 W (Q_C)	0,96 (COP_{Pe})		0,78 (COP_s)	0,6 (COP_{total})
45/45	120 W (Q_c)	1,2 (COP_{Pe})		1,1 (COP_s)	0,95 (COP_{total})

$T_{A,1}$/ $T_{A,3}$

COP for the total performance of the advanced cooling system

COP according to the specifications sheet of the Peltier device at the given applied current (I_{Pe}) and given temperatures

IEC 2356/09

Figure 6 – Example for a specification sheet of a thermoelectrical cooling system (Peltier)

Annex A
(informative)

Sample calculation

A.1 Sample calculation

The data used in Figure 5 are listed in the following Table A.1:

Table A.1 – Measurement dataset

$T_{A,3}$	$T_{A,1}$	Q_c
60,0	39,4	43,9
60,0	44,1	76,8
60,0	48,7	110,0
60,0	53,6	142,6
50,0	34,0	37,1
50,0	38,7	70,0
50,0	43,4	102,9
50,0	48,2	135,8
40,0	28,5	30,3
40,0	33,3	63,1
40,0	38,0	96,0
40,0	42,7	129,0
30,0	23,1	23,4
30,0	27,8	56,3
30,0	32,5	89,2
30,0	37,3	122,1
20,0	17,6	16,6
20,0	22,3	49,5
20,0	27,1	82,4
20,0	31,8	115,3

For the following sample calculation the measurement point at the ambient temperature of $T_{A,3}$ = 50 °C, an internal temperature $T_{A,1}$ = 43,4 °C and a resulting effective cooling power Q_C = 102,9 W will be considered.

Pre-experiments determined the overall heat transition coefficient k = 1,5 W/m^{2}K and the surface of the cabinet S = 1 m^3.

The temperatures are as below:

$T_{A,1}$ = 43,4 °C

$T_{A,2}$ = 38,1 °C

$T_{A,3}$ = 50 °C (ambient temperature)

$T_{A,4}$ = 55,9 °C

The initialized heating power Q_H is 80 W, the power applied to the fan on the cold side $Q_{F,c}$ = 13 W and the power applied to the hot side $Q_{F,H}$ = 26 W.

The thermoelectrical cooling system (Peltier) consists of 6 Peltier devices whereas each was applied with a current I_{Pe} of 1,2 A and a voltage U_{Pe} of 14,8 V. That makes a total of 106,56 W for Q_{Pe}.

The air flows are on the hot side V_H = 119 m^3/h and on the cold side V_C = 58 m^3/h.

The power loss through the cabinet walls can be calculated:

$$Q_L = k \cdot S \cdot (T_{A,1} - T_{A,3}) = -9{,}9 \text{ W}$$

Next it is possible to calculate the effective cooling power Q_C:

$$Q_C = Q_H - Q_L + Q_{F,c} = 80 - (-9{,}8) + 13 = 102{,}9 \text{ W}$$

The calorimetric calculation of the cooling power is as follows:

$$Q_C^{calo} = \dot{V}_{ch} \cdot \rho \cdot c_p \cdot (T_{A,1} - T_{A,2}) = \frac{58}{3600} \cdot 1{,}184 \cdot 1005 \cdot (43{,}4 - 38{,}1) = 101{,}6 \text{ W}$$

According to Equation 5 the heat Q_D is calculated by

$$Q_D = Q_C + Q_E + Q_{F,h} = 102{,}9 + 106{,}57 + 26 = 234{,}16 \text{ W}$$

The calorimetric calculation on the hot side is as follows:

$$Q_D^{calo} = \dot{V}_h \cdot \rho \cdot c_p \cdot (T_{A,4} - T_{A,3}) = \frac{119}{3600} \cdot 1{,}184 \cdot 1005 \cdot (55{,}9 - 50) = 232{,}1 \text{ W}$$

Verifying the results can be done by:

$$\left| \frac{Q_C - Q_C^{calo}}{Q_C} \right| \cdot 100\% = \left| \frac{102{,}9 - 101{,}6}{102{,}9} \right| \cdot 100\% = 1{,}26\% \leq 5\%$$

$$\left| \frac{Q_D - Q_D^{calo}}{Q_D} \right| \cdot 100\% = \left| \frac{234{,}2 - 232{,}1}{234{,}2} \right| \cdot 100\% = 1{,}44\% \leq 5\%$$

The definition of the coefficients of performance is done as follows:

The COP of the Peltier devices is to be extracted from the specification sheet of the Peltier manufacture at the given operating conditions.

$$COP_{PE} = \frac{Q_{CPe}}{Q_E}$$ from specifications sheets of the Peltier device.

The COP of the thermoelectrical cooling system is calculated according to Equation 12.

$$COP_S = \frac{Q_C}{Q_E} = \frac{102{,}9}{106{,}56} = 0{,}97$$

The total COP is defined by Equation 13

$$COP_{total} = \frac{Q_C}{Q_E + Q_{F,c} + Q_{F,h}} = \frac{102,9}{106,56 + 13 + 26} = 0,71$$

This calculation can be done for every combination of the temperatures $T_{A,1}$ and $T_{A,3}$ (ambient temperature) whereas linear interpolation between the measurement points is permitted.

This allows to give the required definitions of Q_c, COP_{PE}, COP_s, COP_{total} at temperature of $T_{A,3}$ = 35 °C and internal temperature $T_{A,1}$ = 35 °C and at temperatures $T_{A,3}$ = 45 °C and $T_{A,1}$ = 45 °C for thermoelectrical cooling systems (Peltier) next to all other required specifications as current and voltage applied to Peltier devices, fans, airflows and pressure drops.

For all points it shall be ensured that no condensation of water vapour occurs (see Figure A.1). This can be easily shown with a Mollier h-x-diagram as shown in Figure A.1. Both inlets into the thermoelectrical cooling system have a temperature of 35 °C and a relative humidity of 50 %. The cold airflow is cooled down to 30 °C. Therefore the relative humidity is raised to a value of around 65 %. No condensation occurs. The hot airflow is heated up to 44 °C, the relative humidity is lowered to around 35 %. Again no condensation occurs.

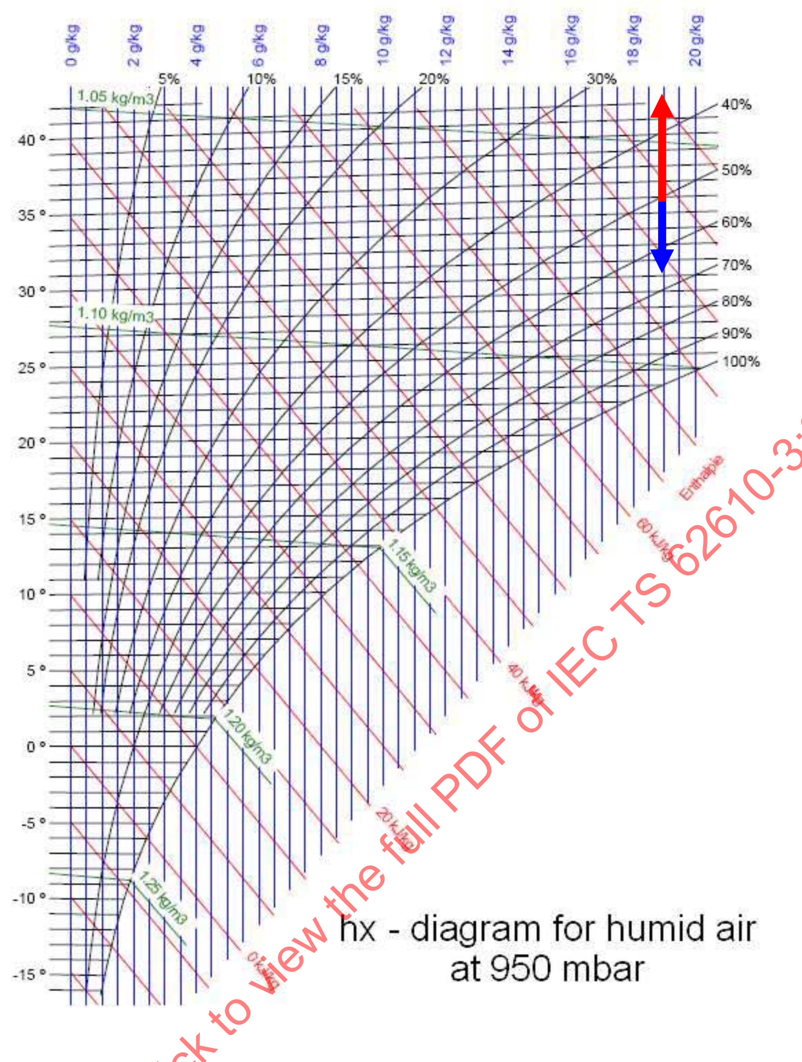

Figure A.1 – Mollier h-x-diagram for humid air

The internal airflow is cooled from temperature $T_{A,1}$ = 35 °C to $T_{A,2}$ of 30 °C whereas the external airflow is heated from $T_{A,3}$ = 35 °C to $T_{A,4}$ = 43 °C. The relative air humidity is 50 % for both air streams.

A.2 Informative remarks

A.2.1 General

According to the Kyoto Protocol and to the directives of the European Parliament and of the Council the usage of coolants with high potential for environmental pollution and global warming (GWP factor, Global Warming Potential) is to be avoided. The most promising alternatives to compressor cooling with e.g. R134a are compressor cooling with CO_2, active cooling based on the Peltier effect and absorption cooling systems. Each of those techniques has its advantages and disadvantages.

The compressor cooling with CO_2 at the current state is more or less efficient, but high installation costs due to working pressures up to 120 bars make this technique less interesting. Another disadvantage of CO_2 cooling systems occurs out of the physical properties of this coolant and requires additional cooling power to run this process. This fact reduces the degree of efficiency enormously.

The Peltier effect seems to be very promising as the cooling effect is highly dependent of the properties of the material. Newly tested materials based on either porous materials or nano-structures show a high improvement of the degree of efficiency. Furthermore Peltier techniques do not need any kind of coolant, have no moving parts but fans and a flat design of the cooling unit is realizable.

The absorption technique is a very intelligent way for cooling but it is only profitable in combination with a heat-regenerator which makes this cooling system only feasible in a very few applications.

A.2.2 The Peltier effect (see Figure A.2)

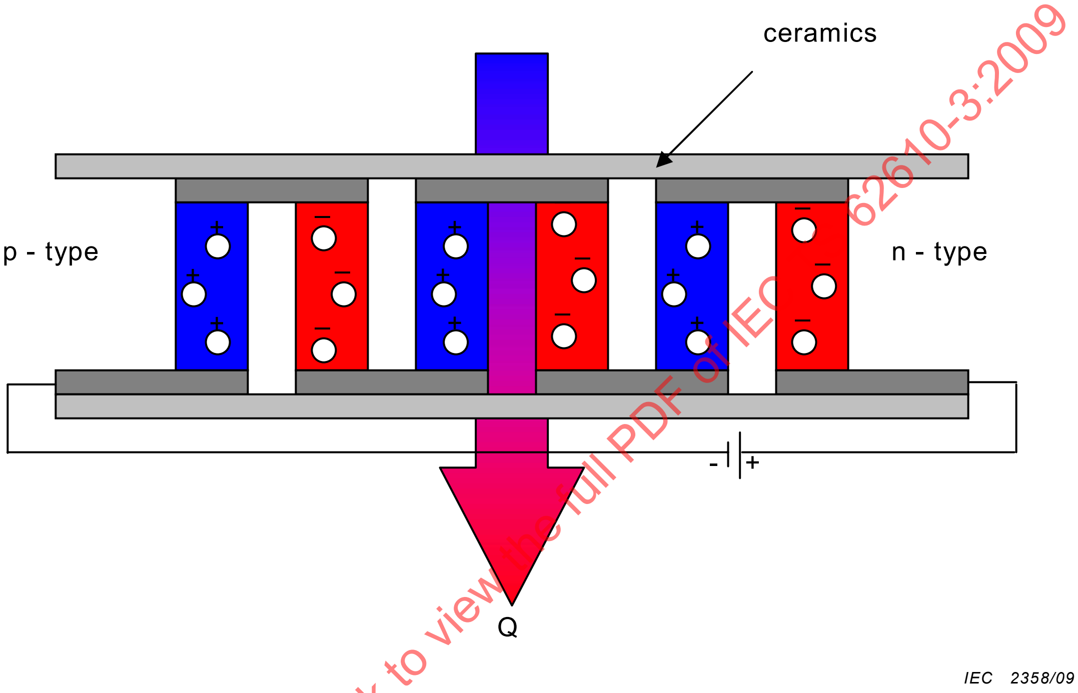

Figure A.2 – Principles of the Peltier effect

Thermoelectric cooling uses the Peltier effect to create a heat flux between the junctions of two different types of materials. A Peltier cooler, heater, or thermoelectric heat pump is a solid-state active heat pump which transfers heat from one side of the device to the other side against the temperature gradient (from cold to hot), with consumption of electrical energy. Such an instrument is also called a Peltier device, Peltier diode, Peltier heat pump, solid state refrigerator, or thermoelectric cooler (TEC). Simply connecting it to a DC voltage will cause one side to cool, while the other side warms. The effectiveness of the pump at moving the heat away from the cold side is totally dependent upon the amount of current provided and how well the heat from the hot side can be removed.

At present the most common materials used in Peltier devices are bismuth telluride (Bi_2Te_3) and silicon-germanium. N-type bismuth telluride is an efficient thermoelectric material due to its high Seebeck coefficient α (voltage per unit temperature difference) of -287 µV/K. Its thermoelectric utility is also assisted by the combination of its high electrical conductivity of 1,1·105 S/m with its very low thermal conductivity of 1,20 W/(m·K), similar to ordinary glass. For the appraisal for materials the Figure of Merit was introduced (see Figure A.3), which represents the ratio between the electrical conductivity σ versus the thermal conductivity λ.

$$ZT=\frac{\alpha^2\cdot\sigma}{\lambda}\cdot K\ [-] \qquad [A.1]$$

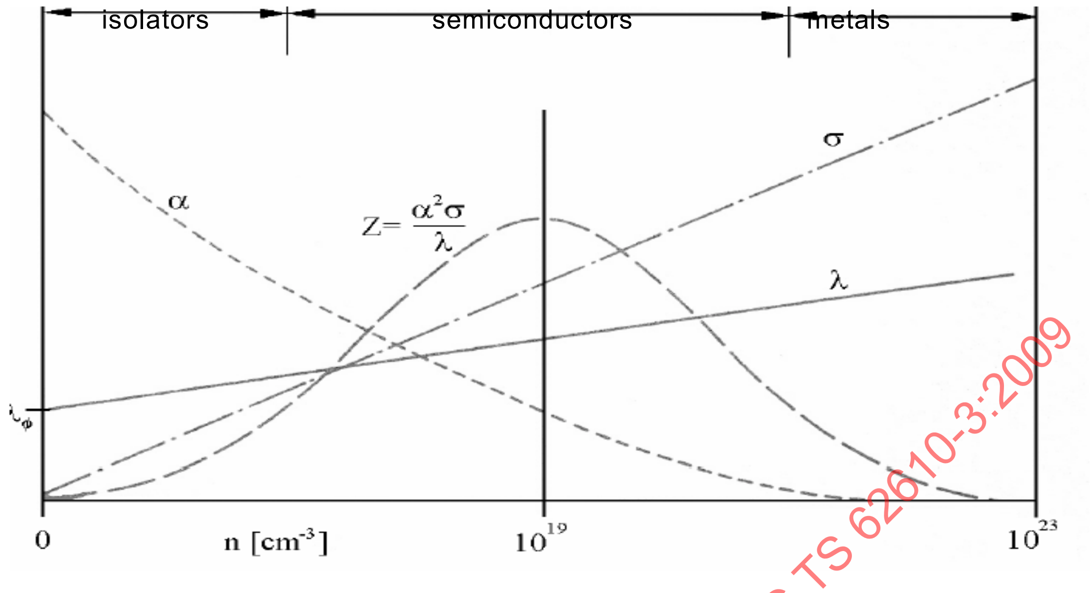

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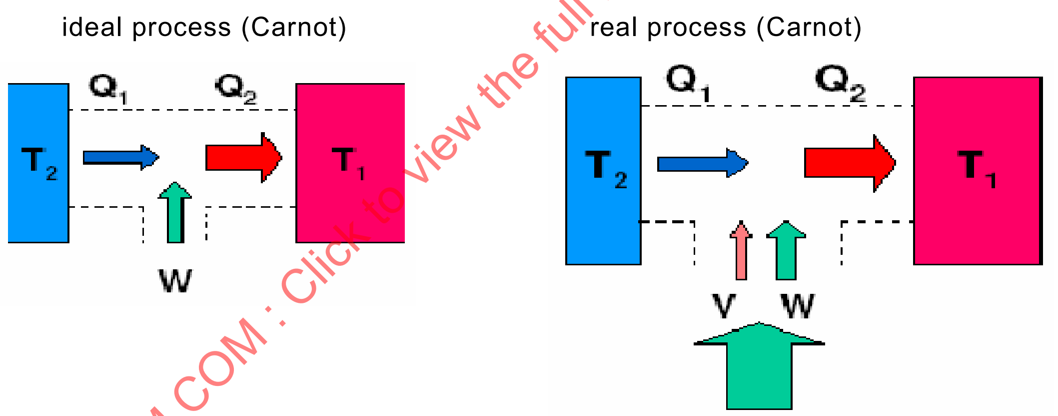
Figure A.3 – Illustration for Z dependent on the number of charge carrier



$$\eta = \frac{Q_1}{W} = \frac{T_2}{T_1 - T_2} = COP \qquad \eta_{th} = \frac{Q_1}{W_0} = \frac{Q_1}{W} \cdot \frac{1}{1 + V/W} = \eta \cdot \frac{1}{1 + V/W} = \eta \cdot \eta_V$$

IEC 2360/09

Figure A.4 – Influence of the Figure of Merit ZT on the efficiency of the Peltier device

The combining of the two equations results in the following equation.

$$\eta_{Th} = \frac{T_2}{T_1 - T_2} \cdot \frac{\sqrt{1 + Z(T_1 + T_2)/2} - \frac{T_2}{T_1}}{\sqrt{1 + Z(T_1 + T_2)/2} + 1} \quad [\;] \qquad \text{[A.2]}$$

Figure A.4 shows the importance of the Figure of Merit (Z·T) on the efficiency of the Peltier device. As mentioned above nowadays research activities are investigating new materials for increasing the efficiency.

Again, the effective cooling power of a Peltier device is described by the following equation (see Figure A.5):

$$Q_{cPe} = \alpha \cdot I \cdot T_c - \frac{1}{2} \cdot I^2 \cdot R_{Pe} - \left(\frac{\lambda_{Pe} \cdot S_{Pe}}{x_{Pe}} \right) \cdot (T_{4h} - T_{4c}) \quad [W]$$

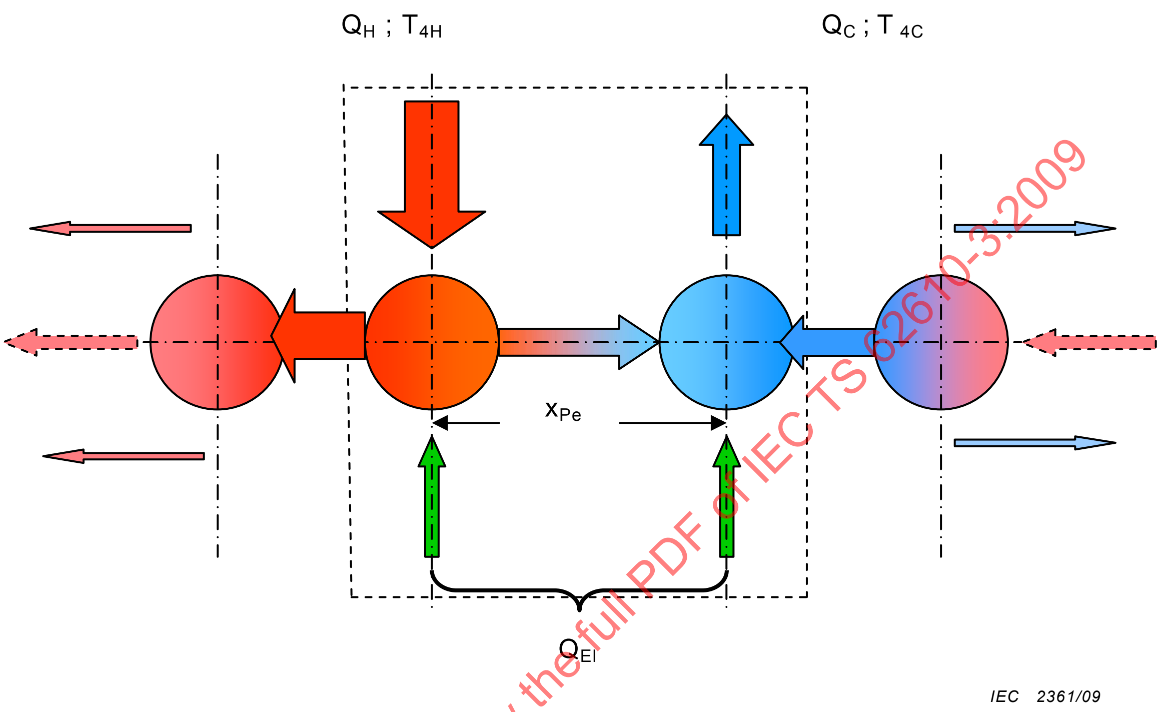


Figure A.5 – Thermodynamic system boundaries of a Peltier device

The cooling power of one Peltier element Q_{cPe} depends on different phenomena. The term $\alpha \cdot I \cdot T_c$ is the maximum cooling power based on the Peltier effect, whereas α is the Seebeck coefficient.

The term $\frac{1}{2} \cdot I^2 \cdot R_{Pe}$ represents the Joule heating, the term $\left(\frac{\lambda_{Pe} \cdot A_{Pe}}{x_{Pe}} \right) \cdot (T_{4h} - T_{4c})$ is the heat conduction between the hot and the cold side through the Peltier element.

A.2.3 Thermoelectrical cooling systems

The thermoelectrical cooling system transports heat Q_c from one medium to another whereas these media can be either gas or liquid. For a better heat transfer, heat sinks are connected to each side of the Peltier device. The material used for this connection is called Thermal Interface Material (TIM).

As shown in

Figure 7, the medium II at temperature T_7 passes the heat sink of the thermoelectrical cooling system (Peltier) which has a temperature of T_6 and is cooled by convection. The heat is transferred through the heat sink by conduction at the given temperature gradient between T_6 and T_5. Then the heat flux is transferred through the Thermal Interface Material (TIM) by conduction. The Peltier device is responsible for the main temperature gradient.

On the hot side of the Peltier device the heat flux passes the TIM and the heat sink due to conduction and finally the heat is removed by the medium I on the hot side by convection (see Figure A.6).

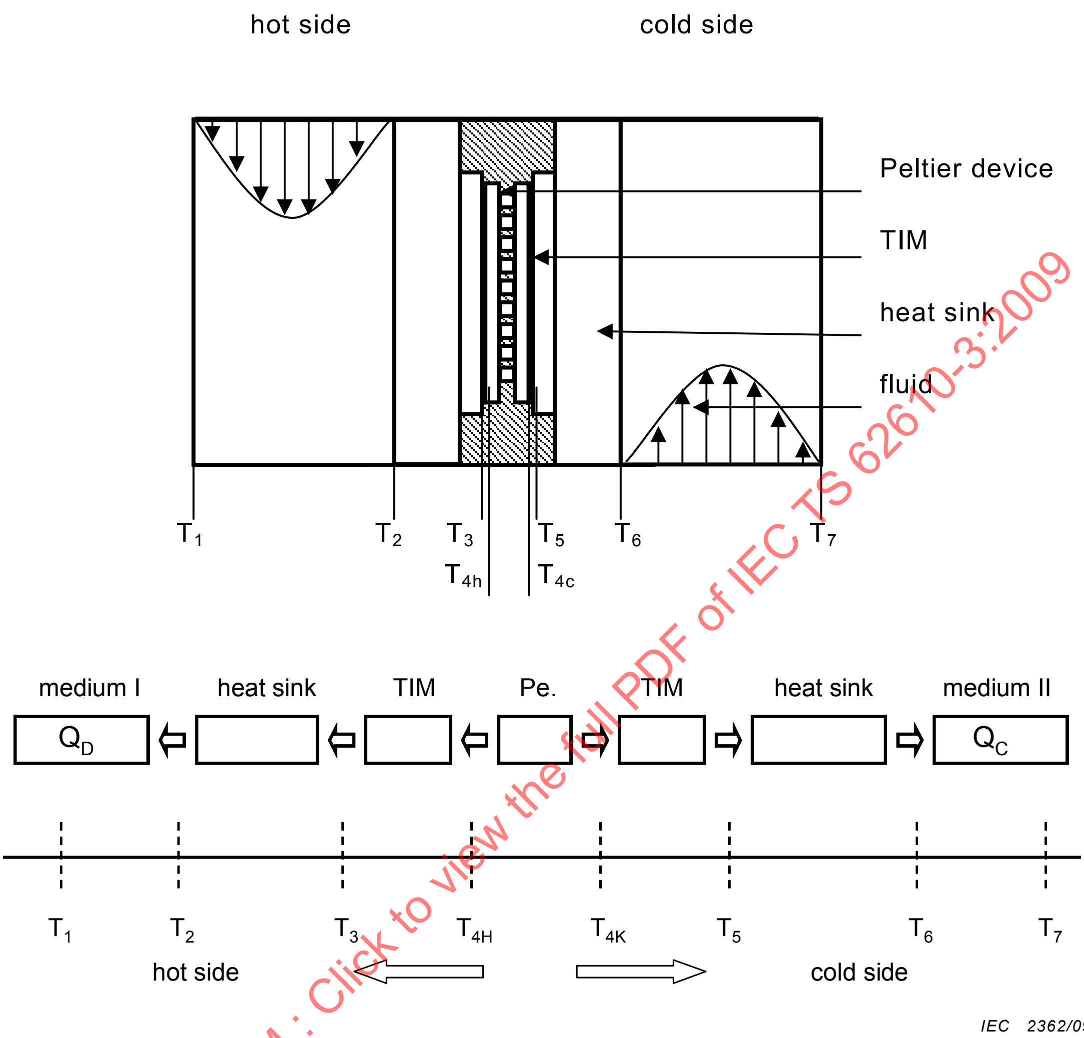


Figure 7 – Thermal resistance of a thermoelectrical cooling system

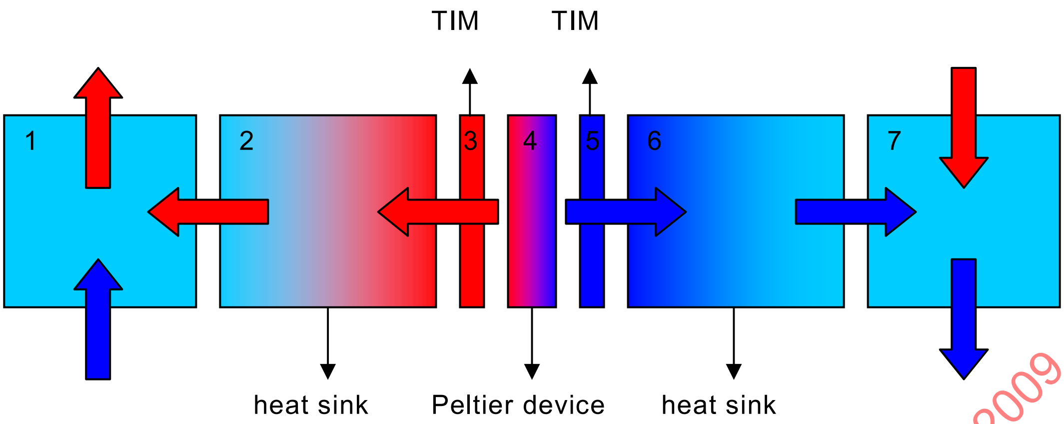
The total thermal resistance that is limiting the total heat flux is a sum of every resistance of each described process (see Figure A.7).

$$R_1 = \frac{T_2 - T_1}{Q_D} \quad [K/W] \qquad R_5 = \frac{T_5 - T_{4K}}{Q_C} \quad [K/W]$$

$$R_2 = \frac{T_3 - T_2}{Q_D} \quad [K/W] \qquad R_6 = \frac{T_6 - T_5}{Q_C} \quad [K/W]$$

$$R_3 = \frac{T_{4H} - T_3}{Q_D} \quad [K/W] \qquad R_7 = \frac{T_7 - T_6}{Q_C} \quad [K/W]$$

$$R_{total} = \sum_{i=1}^{7} R_i \qquad [A.3]$$



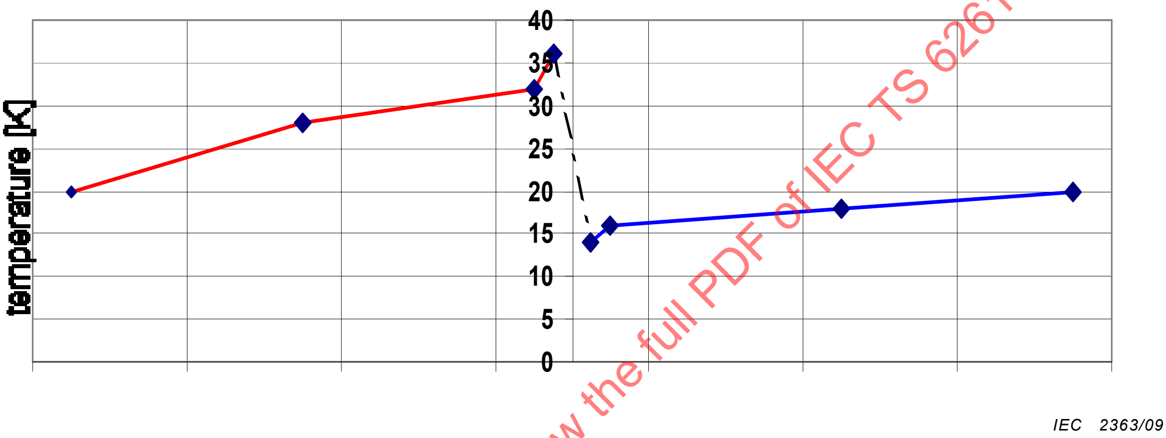


Figure A.7 – Typical temperature curve of a thermoelectrical cooling system

For the evaluation of the efficiency of a thermoelectrical cooling system the coefficient of performance (COP) is used.

$$COP = \frac{Q_C}{Q_E} \quad [A.4]$$

It represents the ratio between the effective cooling power to the total electrical energy applied to the thermoelectrical cooling system.

A.2.4 The thermal resistances

A.2.4.1 Resistance between fluid and heat sink

The heat transfer of a fluid to a heat sink mainly is a function of the velocity and the geometry of the heat sink and can be expressed as the reverse heat transfer coefficient α [W/m²K]. The optimisation of this thermal resistance also influences the fan and their power consumption, the noise emission and the resulting pressure drop over the heat sink. Minimizing the thermal resistance between the heat sink and the fluid, especially air, is essential for an efficient thermoelectrical cooling system (see Figure A.8).