FRIGICHIPS TESTING FOR THE HEAT FLOW MEASUREMENTS

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Abstract

There are presented our results with the frigichip Supercool PE-071-10-13-S as the heat flow-measuring sensor. The results are very promising for the possible future of the industrial applications.

Key words: heat flow measurement, frigichips, and thermal conductivity

1 Introduction

Two years ago we have presented [1] our results in the field of the heat flows measurement by usage of the thermoelectrical convertors. We have continued our effort and we allow us to present for the scientific community the device, which is able to measure the heat flows. Its scanning part consists of the Peltier element – frigichip. Initially, in the beginning of our effort we have used the USA Melcor Peltier elements (Cp 1-127-05L) but now we use, for us more accessible, element of the Supercool company from Sweeden (PE-071-10-13-S). Next these our new elements are of one centimeter smaller dimensions (i.e. 2 x 2 cm).
Of course we are not completelly new in this field. According to our knowledges the Dittmann and Schneider 1992 has used the Peltier elements as the heat flow measuring device. Next we are continuing the effort of our former co-worker Kotrik 1994, Bahyl and Marčok 1994 and of us of course Bahyl and Dubnička 2000. We hope that this our scientific effort will impact the technical praxis with the compact measuring device too.

2 Experiments

As it has been mentioned in the introduction we have changed the scanning elements the Peltier chips. So we should to determine newly the optimal load resistors. After deeply consulting this problem [2, 3] we decided to look for quite new methodology, comparing with the one described in our previous paper [1]. The measuring process has been quite similar to the previous one but instead of the eight resistors with different electric resistance values we have used precise resistor decade. This allowed us to measure the voltage only and the electric power of the Peltier element (P) we have evaluated according the form:

$$P = \frac{U^2}{R} \tag{1}$$

Owing to the fact that in this situation we should not to use the ammeter, the resultant load resistor is approximatelly of the value $R_Z = R_{Z1} = 3\Omega$. The nearest decade value resistor is of resistance $R = 3.3\Omega$. After the exact bridge methode of the measurement [3] of the resistor value we have accepted the value $R = 3.29\Omega$. Our basic results of these measurements are demonstrated in the diagram No. 1.

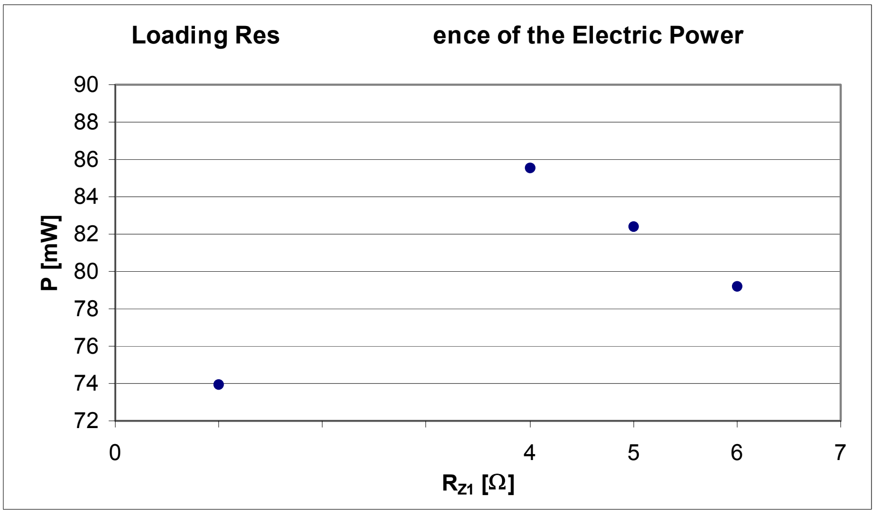


Diagram No. 1: The dependence of the Peltier element electric power (P) as the function of the loading resistor value (R_{Z1})

The usage of the Peltier element in the direct heat flow measurements is not possible until we do not know the effecienci of it. So we should to determine this value too. So our task us to find the function

$$q = f(P) = f'(U.I) = f''\left(\frac{U^2}{R}\right) = f'''(U^2), \qquad (2)$$

where
q [$W.m^{-2}$] – is the heat flow density,
P [W] – is the electric power,
U [V] – is the voltage,
R [Ω] – is the electric resistance.

We have realised the measuring device in which we have been able to measure or to determine the function q in accordance with the form (2). The scheme of this device is given in the figure 1.

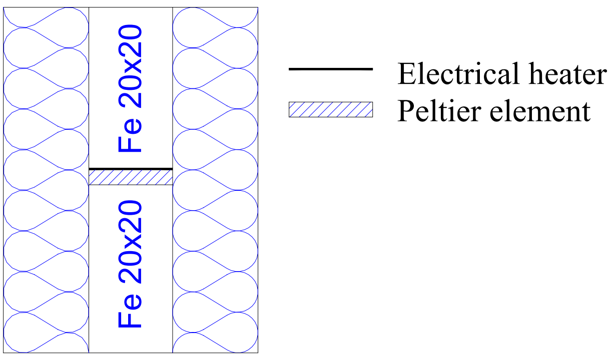


Figure 1: The scheme of the device for the Peltier element efficiency testing.

In our experiment we have supposed that the heat spreads on equally in all directions. As the heat source we have used very thin heating foil so that we can neglect its thickness in comparison with its dimensions. So we can with high precision supposes that one half of the heat amount flows through the Peltier element and the second one is sinking on the opposite side into outside.
So we have measured or watch the dependence of the electric power supplied into the foil and the electric power gained from the Peltier element. The results of measurements are given in the table 1.

Iz [A]	.651	.552	.455	.404	.296	.99
Uz [V]	2.984	2.451	1.929	1.653	1.181	4.8
Pz [W]	1.943	1.353	.878	.668	.35	4.752
Pz/2[W]	.971	.676	.439	.334	.175	2.376
Upc [mV]	108.1	74.5	47.	35.5	17.7	257
Ppc [W]	3.55E-03	1.69E-03	6.71E-04	3.83E-04	9.52E-05	2.01E-02
H [-]	3.66E-03	2.49E-03	1.53E-03	1.15E-03	5.45E-04	8.45E-03

Table 1. The efficiency measurements results

The measurement results have rather surprised us, in the positive sense of course. We have supposed that the power efficiency will not be dependent upon the heat flow going through the Peltier element. As it is clearly seen from the figure 2 the opposite is true.

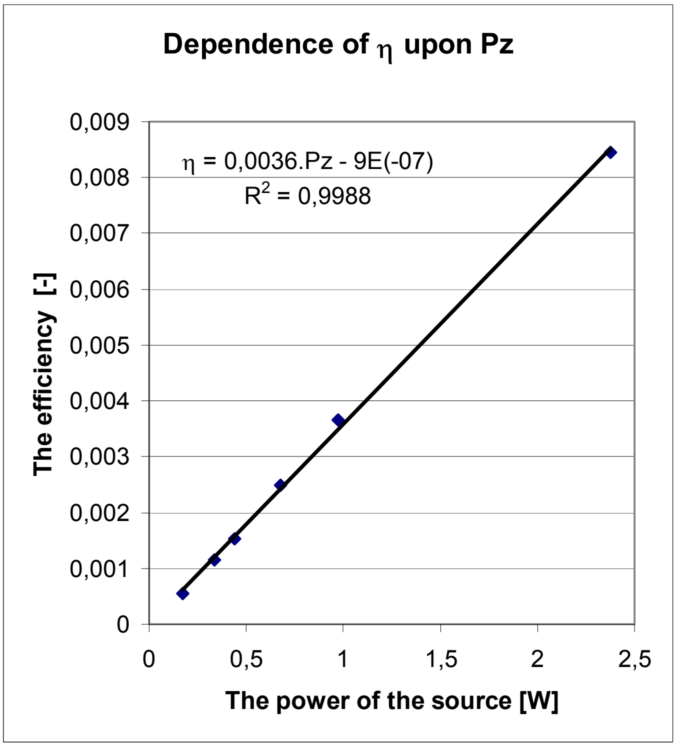


Diagram No. 2. The power efficiency dependence as the function of the heat flow.

This event according to our opinion needs to have deeper theoretical interpretation, but this does not belong to our tasks this time. There is of the crucial importance for us that the calibrating equation (2) is not only a function of voltage but it is s function of efficiency too. In mathematical form we have:

$$q = \frac{\mu.Q_{PC}}{S_{PC}} = \frac{\mu.U^2}{S_{PC}.R} = k.\mu.U^2 , \qquad (3)$$

where
q [W.m^{-2}] – is the heat flow density
μ [-] – is the Peltier element efficiency
Q [W] – is the electric power of the Peltier element
S_{PC} [m^2] – is the Peltier element surface,
U [V] – is the Peltier element voltage,
R [Ω] – is the loading resistor of the Peltier element.

Some partial dependences, which we have obtained in our measurements and experiments are given in the figures 3 and 4. We thing, that they are enough proofing our preciseness and correctness.

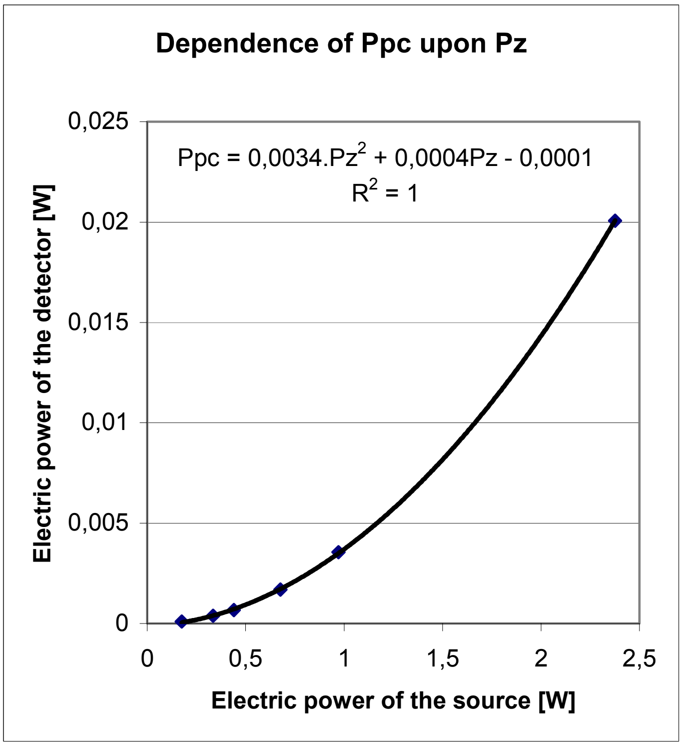


Diagram No. 3. The dependence of the electric power of the detector (Peltier element) upon the loading electric power of the source (planar heater).

After we have ensured us that our results are correct we started the measurements in the real constructions. We have not oriented us upon the exact measurements of the heat flows in the real constructions and the exact heat flow determination. The tests of our very simple looking device in the real conditions have been our preliminary goals.
Our measuring system consists of Peltier element, resistor and milivoltmeter. The first measurements we have realised in the vertically oriented aluminium sash. We tried to compare or control our measurements with the so called Alfameter (Schmidt carpet) produced by the Drutěva Brno, VDI. Though from its technical documentation there have been possible

to suppose the higher heat flows (100 – 5000 W.m^{-2}) as it have been in our case, we wish to find if we will be able to measure something which will to be or which is similar to our future destinations.

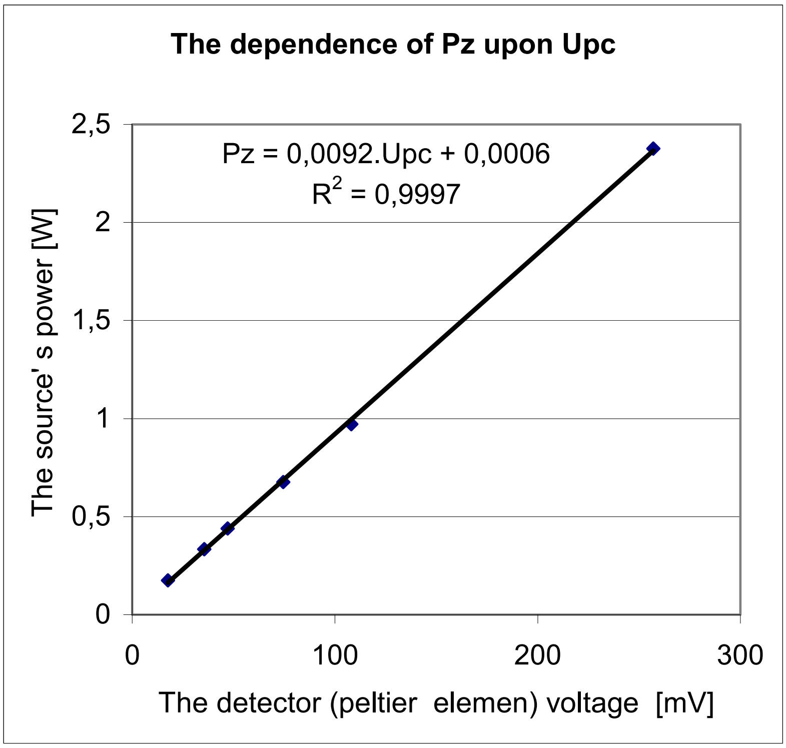


Diagram No. 4. The checking diagram for the heating source voltage.

Really, the alfameter does not answer the heat flow values and on the other side the voltage values of the Peltier element have been very unstable and very strongly dependent upon the compresive forces.

The problem of the thermal contact we have solved with the thermal paste. After some experiments the most suit for us the paste „Wärmepaste T12, Art. – Nr.: 8003513“ of the german producer Jürgen Armack GmbH, 22844 Norderstedt. After application of this heat conductive and adhesive material the voltage values become to be more stabile and the obtained voltage does not answer (react) upon the pressing force.

Besides the better thermal contact on the Peltier element surface we have suggested the other changes too. The first of them interferes with the Peltier element construction. In the heat flow process through the Peltier element there are occuring the thermal field deformations, which influences the results of the measurements. There are two possibilities how to minimalize these temperature field deformations.

1. to do the Peltier element thickness as small as possible
2. to shift the temperature deformations out of the Peltier element.

As the changes of the Peltier element thickness are owing to their construction impossible, we decided, after the consultation [4] for the shift of the temperature field deformations out of the “alive” measuring zone of the sensor. The situation is illustrated in the figure 2.

The perfect stay takes place if the dead zone material is the same as the Peltier element material. In no catalogue [5, 6, 7, 8] we have found appropriate elements i.e. such an elements, which are realised with the non-active strips on their margins. So we decided to realise this zone by ourselves with the main stress to the fact that the dead zone material and the Peltier element should have the same heat conductivity - the same **λ.**

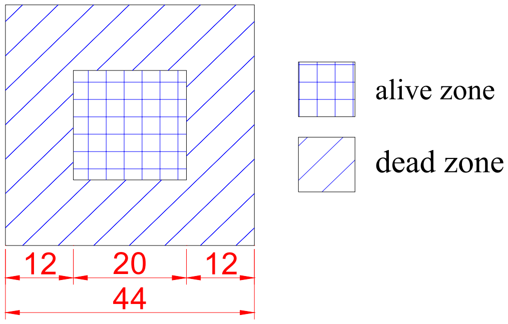
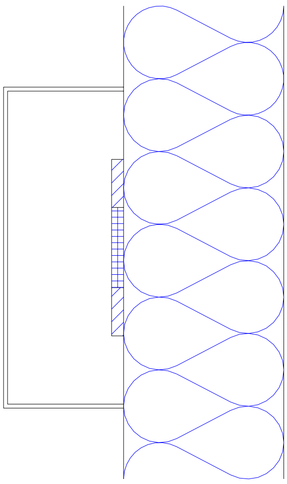


Figure 2. The Peltier element set off.

The dead zone realisation is very important for the whole measurement too. Especially from the point of the Peltier element fixation upon the studied construction.
As we wish our system to be the non – destructive one we should not to use special adhesive in mounting it to the wall. We should to use the usual adhesive tape but never through the alive zone of the sensor. Otherwise we can get very garble results (values), as the tape has its own thermal conductivity.
The output voltage we should to amplify [3]. We have realised the special device, which is stable and the measurements are well reproducible.
To protect the sensor of the spurious heat flows (scuttle, unknown heat sources and so on) we have used the special cower.
And this way suggested and realised measuring device we begin to test it in the drier, which we have adjusted especially for our purposes. See figure 3.



Structure:
- cower
- Peltier element
- heat conductive paste
- sheet
- thermocouple T3
- polystyrene 50 mm
- thermocouple T1.

Figure 3. The scheme of the face wall of the especialy adjusted dryer.

The base of our especially adjusted dryer has been a new door of it. We have dismantled the original door and in the opening we have realised the wall of the polystyrene 5 cm thick. We have steam it well with the mineral wool.
As we designated our heat flow measuring device as the non – destructive one, in such porous materials as the polystyrene is, there is very real the danger to damage the polystyrene surface

with the thermopaste or the adhesive tape. So we tape up a sheet of paper on the polystyrene surface and than we have very easy to mount the Peltier sensor.
The thermocouples (thermoelectrical thermometers) have been mounted on the polystyrene surface.
To protect our detecting system against the spurious heat flows we have covered it with the mentioned special cover.
With this especially adapted drier we have to calibrate our heat flow detecting system. We have maintained the constant temperature in the drier and we have measured the temperatures on the polystyrene surfaces and the Peltier sensor voltage. If these values did not changed in time, we have regarded the temperature stay as the steady one.
From the thickness of the polystyrene (h_{PS}), its thermal conductivity coefficient (λ_{PS}) and from the measured values of the temperatures we have computed the heat flow density going through the system and the Peltier sensor power efficiency. This process we have repeated for six different values of the internal temperature of the polystyrene (30, 35, 40, 45, 50 and 55 ^{o}C – the highest temperatures have not been possible owing to the technical reasons). The results of the measurements have been statistically treated and they are given in the table 2.

Temperature	55 [^{o}C]	45 [^{o}C]	35 [^{o}C]	30 [^{o}C]	50 [^{o}C]	55 [^{o}C]	40 [^{o}C]	45 [^{o}C]
U [mV]	58,3	32	17	4,4	56	70	31,6	45,6
P [W]	1.04E-03	3.11E-03	8.78E-03	5.88E-03	9.53E-03	1.49E-03	3.04E-03	6.32E-03
T1 [^{o}C]	55	45	35	30	50	55	40	45
T3 [^{o}C]	26,7	25,9	24,9	23,8	26,7	26,4	25,4	25,9
q [W.m^{-2}]	19,25	12,98	6,9	4,21	15,85	19,43	9,94	12,98
Q [W]	1040	311	88	6	953	1489	304	632
μ [-]*	0,135	0,06	0,032	0,003	0,15	0,192	0,076	0,122

* the thermal power efficiency has been calculated after voltage amplification

Table 2. The heat flow measuring system calibration data.

The data from the table 2 we have plotted in the picture 5 which can be accepted as the excellent proof of the Peltier element as the heat flow sensor quality. The regression straight line is of form:

$$q = 0.2304.U_{PC} + 2.9246 \quad (4).$$

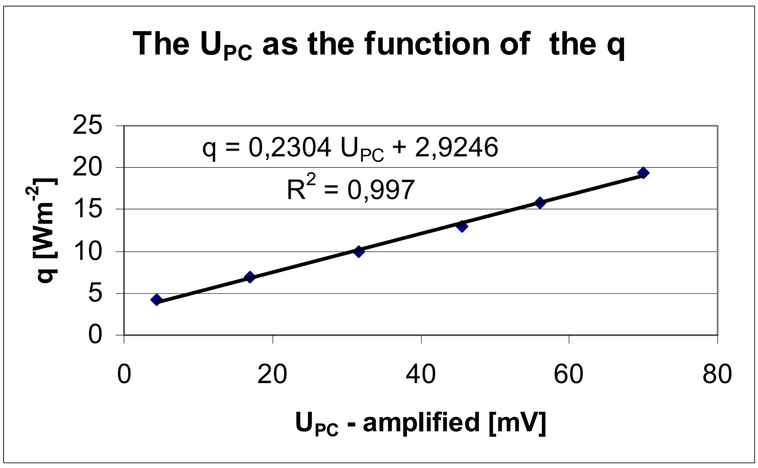


Diagram No. 5. The calibration straight line.

3 The real constructions measurements

After the calibration measurements with the especially adapted drier in the laboratory we have interested us upon the work of our device in the technical praxis. But still we have only tested the our device. We would like to know, the influence of the spurious signals upon the obtained values. Especially we wish to know if our values are the real ones and it they are not to great differences among the repeated measurements. We should to tell the truth that to our regret we do not have any device wit which we can compare our results. We can only to compute in the standard way and to watch very carefully the surrounding of the measuring Peltier sensor.
We will to describe our selected results in the following sections.

3.1 The empty roof

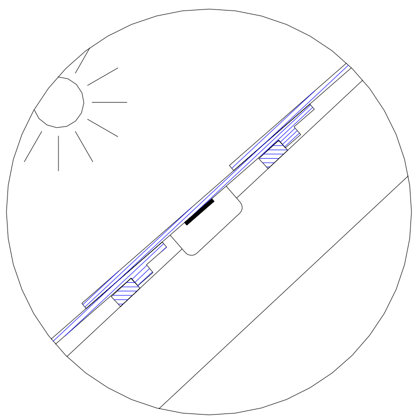


Figure 4. The measurements of the simple tile roof construction.

Our first measurement has been realised on the back side of the simple tile roof. See figure 4. This place has been choosed owing to the possibility of the easiness of the relevant computations. According to the measurement process we have detected the values of the inside temperature and the voltage upon our measuring instrument. The outside temperature has not been measured as this side was very heavy influenced with the direct sun rays. The results of our measurements are given in the diagram 6. We have used the equation (4) for the heat flow computations.
Even if the inside temperature (full line) is the copy of the heat flow curve (dashed line), it is interesting to observe the definite shift of the inside's temperature relative to the heat flow going through the roof. The prolongation is according to our opinion defined with the position of the Sun in the sky.

3.2 The window

Next we have realised the measurements upon the simple window in the course of the whole day. We have realised our measurements from 6 in the morning till 22 at night. The temperature has been measured as near to the window glass as possible with the mercury thermometers. As there was a sunny day, we have eliminated the direct sun rays with the shutter. The daily loss of heat through the window is given in the diagram 7.

We have also determined the function of the Peltier sensor voltage as the function of the temperature difference between the indoor and outdoor temperatures. The results are given in the diagram 8. They can be also take as very clear proof of our access to the heat flow measurements techniques.

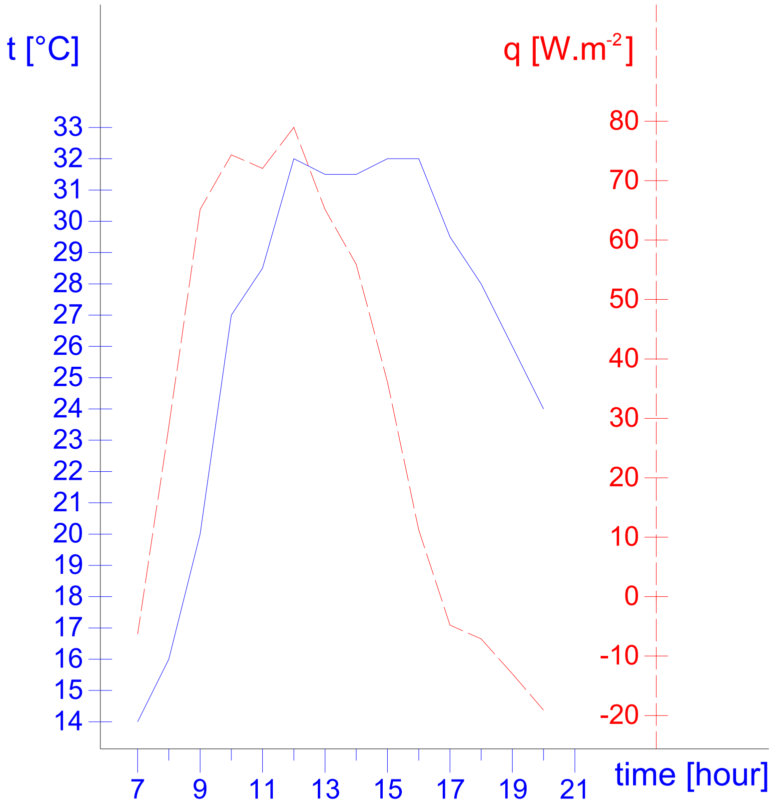


Diagram No. 6. The internal temperature and the heat flow into the room daily variations. The heat flows dashed.

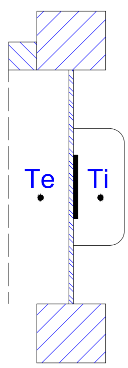


Figure No. 5. The window measurement scheme.

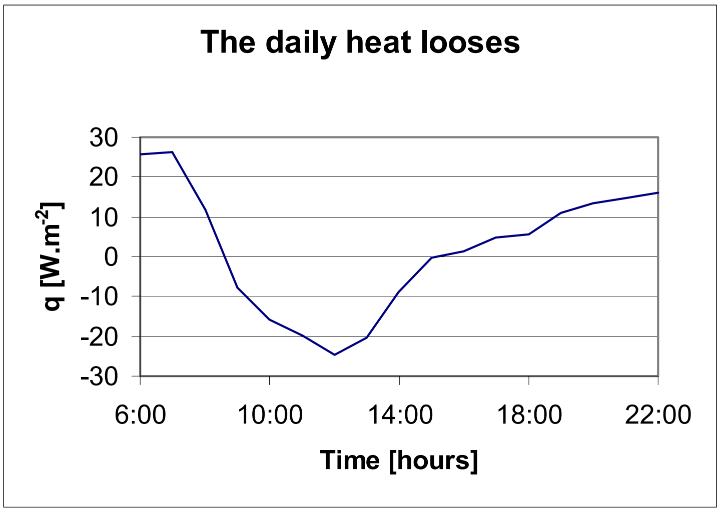


Diagram No. 7. The heat flow looses through a window.

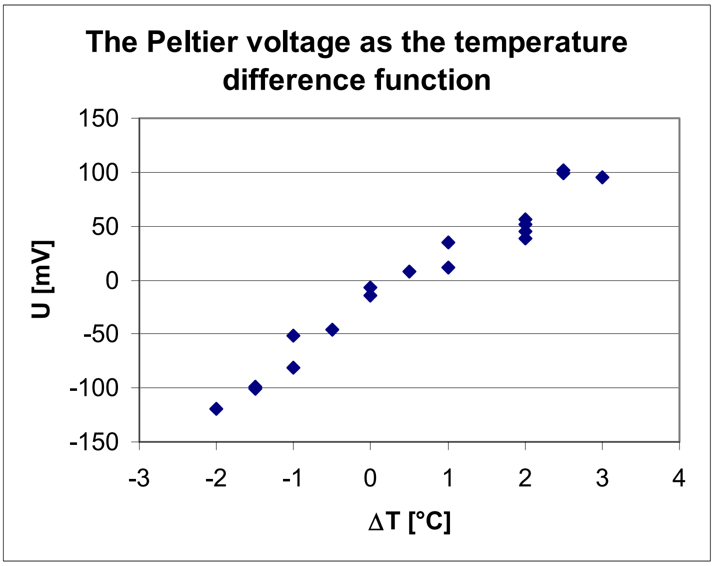


Diagram No. 8. The dependence of the Peltier element voltage upon the temperature slope.

4 Conclusion

As we have mentioned in the beginning of the our work, we are sure that we are successful in the heat flow measuring device construction, testing and realisation. We have also mastered the spurious factors which can negatively influence the results of measurements for which is our system assigned. We would like to stress that we are looking for the reliable, light and compact heat flows measuring instrument in the steady state conditions as we can meet with them in the building constructions.
As the Peltier element is very sensitive device it can be used in the non stationary heat flow measurements too. Of course the heat flow should to reach the detector and this can take place of few seconds.
We think that in the preceding sections we have clearly described not our results only but the problems connected with the measurements too. Very important factor is the excellent contact

of the Peltier sensor with the heat flow through going surface. The usage of the heat conductive paste is quite necessary.
For the future we wish to realise quite automatic electronically calibration procedure, as the high quality and reliable calibration is the crucial point of the measurements too.

Acknowledgement

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