Thermal Flux Measurements with a Compensated Heat-Flow Meter

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ABSTRACT

Measurements with heatflow meters are used to check the thermal protection of buildings or installations in situ as a nondestructive testing method.

Putting the heatflow meter on the partition that is measured disturbs the measured thermal flux passing through this partition. The thermal resistance of the heatflow meter affects the partition like a heat source or heat sink. The heatflow meter's surface is smaller than that of the partition and this nonlinear heatflow produces a systematical error in thermal-flux measurement.

This error can be eliminated with a new kind of heatflow meter described here. This hetflow meter compesates for this disturbance of temperature field through the partition with one auxiliary source (or sink) of heat. So the measurement becomes one null method, faster and more precise than the former more common method. The heatflow meter can be smaller and can function without a guard ring.

Several experiments are made and some of the results are presented.

INTRODUCTION

In order to control the quality of thermal protection of buildings and other objects in situ, it is necessary to know the thermal loss of their partitions (walls, floors, roofs, etc.), i.e.,thermal fluxes passing through these partitions. For the measuremend of an unknown thermal flux, the method of auxiliary walls[1] or hetflow meters[2] is used. This is a nondestructive testing method.

The measuremend is made by putting the auxiliary wall,i.e. , the heat-flow meter, on the partition that is to be measured. When the same thermal flux passes linearly through the partition and the heatflow meter, the thermal flux passing through the partition is determined from the temperature gradient (thermal flux is proportional to the temperature gradient).

By putting the heatflow meter on the partition that is being measured,thermal flux is disturbed in two ways. First, the thermal ressistance of the heatflow meter affects the partition like additional thermal insulation. Second, assuming that the heatflow meter is placed only on one part of the partition surface, its thermal resistance produces a nonlinear heat flow passing through the partition and the heatflow meter. This phenomenon produces a systematic error in thermal flux measurements, whi ch is known as thermal shunting.

A further refinement to reduce the first type of error is made by reducing the thermal resistance of the heatflow meter by reducing its thiskness. This prevents the reduction of the sensitivity of the heatflow meter. The number of thermocouples (which measure the gradient of temperature through a cross-section of a heatflow meter) must be in creased. In order to eliminate shunting around the edges of the hetflow meter, a guard ring is placed around the meter.

To eliminate these errors, anew kind of thermal flux measuremend has been developed that uses a heatflow meter that compesates for the disturbance of the temperature field through the partition. The compesation is made by a separate surface heater placed on the meter's surface.

PROCEDURE AND PRINCIPLE OF MEASUREMENTS

The distribution of temperature through the cross-section of one isotropic and homogeneous plate (partition) in steady-state heat transfer is shown in Fig.1. Figure 2 shows new temperature distribution through this partition in steady--state heat transfer which occurs when a new layer (auxiviary wall-heatflow meter) is aded to the warmer side of the whole surface of the partition. At the same temperatures of the air and the same conditions of heat transfer (in relation to the Fig.1) the temperature distribution through the partition plate will be changed. In the plane 2-2, the temperature decreases from θ_2 on θ_2'. The auxiliary wall affects the partition like the superposition of one additional source of cold (source of heat with minus sign), which decreases the temperature in plane 2-2 for a value of $\theta_2 - \theta_2'$ and whose acting is superposed to the initial flux through the whole cross-section of the partition.

To compensate for this disturbance caused by the auxiliary wall, it is necessary to increase the temperatures of the partition to their initial values, θ_1 and θ_2, which can be attained by placing an additional source of heat* in plane 2-2 (for example, in the form of heating foil) or preferably, on the outer surface of the heatflow meter (in the plane 3-3). Then the souce of heat is out of the partition-heat flow meter system.

The auxiliary wall is usually smaller in area than the surface of the measured partition. Then the lines of thermal flux passing the partition (at measurement without compensation) becomes convergent towards the heat-flow meter, i.e., the thermal flux has a radial component (proportional to the temperature difference $\theta_2 - \theta_2'$ on the surface of the partition). There fore the temperature of the partition surface under the heat-flow meter will be lower than θ_2 and higher than θ_2'. In Fig.3 these temperatures are shown and maked as θ_s (average) and θ_m (under the center of the flux meter).

If there is an additional source of heat (i.e., equivalent source of cold) producing the whole thermal flux passing through the meter and the partition, the principle of measuremend is not changed. The control of this theat source has to be adjusted so that the same thermal flux passes trough the partition as without the heatflow meter, i.e., trough the partition out of the surface covered with heatflow meter (when the partition is homogeneous). Greater or less heating of the heater causes a radial flow of heat through the partition, which belongs to the same law as a radial component caused bay additional thermal resistance of the heat flow meter. This radial conduction of heat is greatest on the surface of the partition covered by the heatflow meter and appears fist, so it can be used for the control of the compensation heater.

Figure 4 is a schematic of heatflow meter with an additional source of heat, its insulating envelope, and thermocouples, which measure the radial component of thermal flux (this is in the shape of a star in the differential couple).

RADIAL FLOW OF THERMAL FLUX

Radial flow of thermal flux is solved by many authors 3,4 on the basis of Maxwell's 5 solution of Fourier's equations 6. However, the author used Loewen

*If the auxiliary wall is put on the colder side of the partition analogous relations hips are obtained. The auxiliary wall acts as a source of heat and for its compensation the "cooling foil" is needed.

and Shaw's solution for continuous rectangular sources of heat on the surface of semi-infinite solids in steady-state heat conduction 3. This is because heat-flow meters with rectangular surfaces were used.

An average temperature increase, $\Delta\theta_s$, from a heat source of areal intensity q" and dimensions of sides m and ℓ, is

$$\Delta\theta_s = \frac{q''\ell}{\lambda_1} A_s \tag{1}$$

where

q"	= reduction of thermal flux because of thermal insulation of the heatflow meter
ℓ	= length of heatflow meter
λ_1	= thermal conductivity of the partition

The maximal temperature increase, $\Delta\theta_m$, from the same source is

$$\Delta\theta_m = \frac{q''\ell}{\lambda_1} A_m \tag{2}$$

The factors A_s and A_m are functions only of m /ℓ (Fig.5), and λ_1 is the thermal conductivity of the partition.

If the equation of equilibrium for the partition with the heatflow meter is formulated according to the distribution of the temperature in Fig.2, we have

$$t_2 - t_1 = q' \left(\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{1}{\alpha_2} \right) \tag{3}$$

where

q'	= thermal flux passing through the partition with heatflow meter
t_1, t_2	= temperatures of the air
α_1, α_2	= coeficients of surface (air film) conductance
λ_2	= thermal conductivity of the heatflow meter (auxiliary wall)
δ_1, δ_2	= thickness of the partition, heatflow meter

If the equation is formulated according to the distribution of the temperature in Fig.3, we have

$$t_2 - t_1 = q' \left(\frac{1}{\alpha_2} + \frac{\delta_2}{\lambda_2} \right) - q \left(\frac{\delta_1}{\lambda_1} + \frac{1}{\alpha_1} \right) - (q - q') \frac{\ell A_s}{\lambda_1} \tag{4}$$

where

q	= thermal flux passing through the partition without heatflow meter

For the partition without the heatflow meter (Fig.1), we have

$$t_2 - t_1 = q \left(\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{1}{\alpha_2} \right) \tag{5}$$

From Eq. 3 and 5 we have

$$\frac{q}{q'} = 1 + \frac{\frac{\delta_2}{\lambda_2}}{\left(\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{1}{\alpha_2} \right)} \tag{6}$$

From the Eq. 4 and 5 we have

$$\frac{q}{q'} = \frac{\frac{1}{\alpha_2} + \frac{\delta_2}{\lambda_2} + \frac{\ell \Lambda_s}{\lambda_1}}{\frac{1}{\alpha_2} + \frac{\ell \Lambda_s}{\lambda_1}} = 1 + \frac{\frac{\delta_2}{\lambda_2}}{\frac{1}{\alpha_2} + \frac{\ell \Lambda_s}{\lambda_1}} \tag{7}$$

where

$$q'' = q - q' = \frac{\frac{\delta_2}{\lambda_2}}{\frac{1}{\alpha_2} + \frac{\ell \Lambda_s}{\lambda_1}} q' \tag{8}$$

EQUATION FOR CORRECTION OF COEFFICIENT OF THERMAL CONDUCTIVITY

The basic equation for heat conduction through the flat plate of homogeneous material (thermal properties independent of temperature) is given by Fourier

$$Q = Aq = \frac{A}{\delta_1} \lambda_1 \Delta\theta \tag{9}$$

where

Q	=	total heat flow through the surface
A	=	the surface area of the plate
$\Delta\theta = \theta_2 - \theta_1$	=	the temperature difference between two surfaces of plate perpendicular to the heat flow

From Eq. 6 and 9 we have

$$\lambda_1 = \frac{q\delta_1}{\Delta\theta} = \frac{q' \left[\frac{\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{\delta_2}{\lambda_2} + \frac{1}{\alpha_2}}{\frac{1}{\alpha_1} + \frac{\delta_1}{\lambda_1} + \frac{1}{\alpha_2}} \right] \delta_1}{\theta_2 - \theta_1} \tag{10}$$

If this equation is solved for λ_1 we have

$$\lambda_1 = \frac{-B \pm \sqrt{B^2 + 4(\theta_2 - \theta_1)\left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} \right) q' \delta_1^2}}{2(\theta_2 - \theta_1)\left(\frac{1}{\alpha_1} + \frac{1}{\alpha_2} \right)} \tag{11}$$

where

$$B = \delta_1 \left[(\theta_2 - \theta_1) - q' \left(\frac{1}{\alpha_1} + \frac{\delta_2}{\lambda_2} + \frac{1}{\alpha_2} \right) \right]$$

From Eq. 7 and 9, we have

$$\lambda_1 = \frac{q\,\delta_1}{\theta_2 - \theta_1} = \frac{q' \left(\dfrac{\dfrac{1}{\alpha_2} + \dfrac{\delta_2}{\lambda_2} + \dfrac{\ell A_s}{\lambda_1}}{\dfrac{1}{\alpha_2} + \dfrac{\ell A_s}{\lambda_1}} \right) \delta_1}{\theta_2 - \theta_1} \tag{12}$$

If this equation is solved for λ_1, we have

$$\lambda_1 = \frac{-B \pm \sqrt{B^2 + 4 q' \delta_1 \ell A_s (\theta_2 - \theta_1) \frac{1}{\alpha_2}}}{2(\theta_2 - \theta_1) \frac{1}{\alpha_2}} \tag{13}$$

where

$$B = (\theta_2 - \theta_1)\, \ell A_s - q' \delta_1 \left(\frac{1}{\alpha_2} + \frac{\delta_2}{\lambda_2} \right)$$

If the temperature is only measured (Fig.3) in the center of the surface covered with a heatflow meter, it is necessary to replace $\theta_2 - \theta_1$ in the denominator of Eq. 12 with

$$\theta_2 - \theta_1 = \theta_m - \theta_1 + \Delta\theta_m \tag{14}$$

If the average temperature of that part of the surface covered by a heatflow meter is measured, we have

$$\theta_2 - \theta_1 = \theta_s - \theta_1 + \Delta\theta_s \tag{15}$$

Eq. 1 and 2 give $\Delta\theta_s$ and $\Delta\theta_m$. When q" from Eq.2 is replaced with q - q', we have definitively

$$\lambda_1 = \frac{-B \pm \sqrt{B^2 + 4 q' \delta_1 \ell A_s (\theta_m - \theta_1) \frac{1}{\alpha_2}}}{2(\theta_m - \theta_1) \frac{1}{\alpha_2}} \tag{16}$$

where

$$B = \ell A_s (\theta_m - \theta_1) + q' \left[\ell A_m \frac{\delta_2}{\lambda_2} - \delta_1 \left(\frac{1}{\alpha_1} + \frac{\delta_2}{\lambda_2} \right) \right]$$

When q" from Eq. 1 is replaced with q - q' , we have an identical expression to Eq. 16, only instead of index "m" there will be an index "s". The values for A_s or A_m are taken from Fig.5 for appropriate geometry of the heatflow meter.

Because λ is never negative, only the positive roots in Eq. 11, 13 and 16 are used.

MEASUREMENT

The aim of the measurement is to establish first the possibility of heatflow measurement with thermal compensation; second, if this measurement is more advantageous than measurement without compensation; and finally the cause of some phenomena in these measurements.

Hundreds of measurements have been made in steady and variable states of heat conduction through the samples, using two kinds of chambers and three kinds of heatflow meters. The same samples and heatflow meters are used for comparative measurements with and without thermal compensation.

Apparatus

The first kind of chamber consists of a square box. Its thermal insulation is panels of expanded polystyrol. A heating aluminium plate is placed under the chamber's cover and identical cooling plate is placed on the floor. Thermostats are connected with both plates. These thermostats maintain the temperature of the plates at the desired values. A plate made of soft rubber is placed over the lower (cooling) plate, to improve thermal contact between the cooling plate and the sample.

The sample is placed over the layer of soft rubber. The heatflow meter (with and without a device for compensation) can be lowered or lifted from the sample by a handle, which is manipulated outside the chamber. The temperature measurements are made by Cu-Const and Fe-Const thermocouples.

The other chamber is of the hot-box type. The constant difference of temperature between its rooms is maintained by thermostats. The sample to be measured is built into the vertical partition between the rooms. The conditions of measuremant the hot-box apparatus correspond to the conditions existing in buildings in situ.

The dimensions of the heatflow meter (Schmidt's belt used in the first chamber) are 512 x 58 x 6 mm. The meter is made of vulcanized natural rubber and is used with about 100 Ag-Const thermocouples.

A mica plate with a Cr-Ni wire is used as a compensating heater. Its surfaceis coated with thin aluminium plates to equalize the temperature of the heater surfaces. The heater and heatflow meter are placed in an insulated box made of expanded polystyrol. A serpentine cooler is placed behind the heater for the measurement of the flux passing through the sample of expanded polystyrol which has a polished aluminium sheet.

Calibrated commercial heatflow meters are used for measurements in the hot-box-type chamber.

they are:

1. heatflow meter Z 70, dimension 500 x 500 x 8 mm, made in Forschungsinstitut fuer Waermeschutz, e.V. Muenchen, W. Germany

2. heatflow meter WS AP 80-1, dimension 110 x 110 x 1,2 mm (for measurements) and heat-flow meters 31561 and 31563, diameter ϕ = 106 mm, thickness 3,3 mm, all produced by Tech. Phys. Dienst TNO-TH, Delft, Netherlands (for control of compensation).

The heater for thermal compensation of heatflow meter Z 70 has a cross-section identical to the heater for Schmidt's belt. The heater for heatflow meter WS AP 80-1 is made by printed circuits. The plates are of soft, expanded polyurethane of a thickness of 5 mm. They are glued as the thermal insulation on the surfaces of these heatflow meters.

The Schmidt's-belt heatflow meter used in first chamber is much longer and thicker in relation to its width. Its characteristics are different in practice from the heatflow meters used for measurement on the partitions.

The conditions of heat transfer (diffusion, convection, radiation) are changed during experiments in the chamber. The state of heat transfer is made variable by changing the temperature of the water in the lower cooling plate (more drastically than it happens in practice).

The following wall samples are used for the measurements:

1. concrete of normal granulation;
   density 2100 kg/m^3;
   dimension 750 x 750 x 50 mm

2. a wall of hollow brick (36% cavity) with a total of 1 cm of plaster on both sides;
   density 1300 kg/m^3;
   dimension 750 x 750 x 75 mm

3. expanded polystyrol;
   density 15,3 kg/m^3
   dimension 750 x 750 x 20 mm

4. expanded polystyrol with glued polished sheet aluminium (thickness 1 mm). The sample of expanded polystyrol is the same as used above.

Procedures of measurements

The output signal $K\Delta\theta_{so}$ of the differential temperature thermopile is measured in steady state on the surface of the sample in both chambers before the heat flow meter is applied. After applying the heatflow meter, the output signal becomes $K\Delta\theta_s$. Then the output signal is adjusted on the value $K\Delta\theta_{so}$ by the compensating heater. In this way the radial component of the thermal flux is annulled. The radial component is caused by surplus or shortage of thermal flux through the heatflow meter relative to the size of the flux before applying the heat flow meter.

The measurements of the thermal flux of the temperature and heating control are made like with an automatic data acquisition system. Each of the values is measured or changed again every 5 minutes. The measurements with compensation usually last 1 to2 hours.

The measurements of the heatflow meter with no compensation are made by putting the same heatflow meter on the same place on the sample. The measurements are made over several hours until the values become established (this usually happens more than 24 hours after applying the heatflow meter).

It is much more difficult to obtain the initial output signal $K\Delta\theta_{so}$ of the differential temperature thermopile during the variable state of heat transfer passing the sample than during its steady state. An integration of temperature $K\Delta\theta_s$ is made during at least one full cycle of oscillation of the temperature of the sample in order to obtain the output signal $K\Delta\theta_{so}$.

Measurements are performed in the hot-box type chamber with compensation only by steady-state heat transfer. This is measured in normal room conditions and appeare as measurements on the spot of the walls between the rooms in the building. The measurements are only made on the concrete sample and in long intervals (several days and nights). In this way the influence of transient conditions on heatflow meter and thermocouples are eliminated.

The apparatus control of thermal fluxes are made with the independent heatflow meters I and II.

The way that the arrangement of the thermopiles influences the sample or heatflow meter have been examined as have their shape and position on control of the compensation heater.

The sample of concrete with the arrangement of hot-box controls (marked I and II) is given in Fig.6. Figure 7 gives shape and position of the piles of thermocouples related to the surface of the sample covered by heatflow meter Z 70 with compensation.

The measurement is performed in this way: the values $K\Delta\theta_{so}$ and the values for fluxes I and II are taken before placing the heatflow meter. From day to day, thermopiles are slowly adjusted separately to the same $K\Delta\theta_{so}$ (only are the thermopiles on samples that have a value $K\Delta\theta_{so}$. That is, heatflow meters I and II are adjusted on the same fluxes as before the placing of heatflow meter Z 70. All the piles of thermocouples are separately controlled with compensation to the value $K\Delta\theta_{so} = 0$. This means that the compensation measurements are made for two separate values of $K\Delta\theta_s$ (initial and zero).

RESULTS OF MEASUREMENTS

Results of measurements of the heatflow meter with thermal compensation and without it in the form of thermal conductivities are given in Tab. 1 and 2 for steady and variable states of heat transfer (for samples in the one room chamber). The measurements given in Tab. 1 compare the steady and variable state of heat transfer through the corresponding samples (other conditions were identical). Table 2 gives results for these same samples, and for the additional sample of expanded polystyrol with sheet aluminium, that were obtained with heatflow meter in steady-state heat transfer and with the guarded hot-plate apparatus. These results serves as an etalon. Figures 8-11 givethe diagram of variation of measured values in the steady and variable state of heat conduction with and without compensation, as a function of time. The results of measurements in steady-state heat conduction passing the sample in the hot-box-type chamber are given in Tab.3. The typical cource of this measurement for heatflow meter Z 70 is presented on the diagram in Fig.12. Almost identical diagrams are obtained for the heatflow meter WS AP 8/-1.

As can be seen in Tab.1, higher thermal conductivities are obtained in the measurements with compensation than without it. These differences can be considerable. Fewer mutual differences are obtained with the sameway of measurement (with and without compensation) between thermal conductivities in steady and variable states of heat conductivity for the same samples. These differences are practically inside the limits of accuracy of measurement with heatflow meters.

Relatively few deviations from the true values are obtained in all cases in the measurements with compensation. However, these deviations are higher in tjree of four samples in the measurements without compensation. The deviation is especially high in the case of the sample of expanded polystyrol with sheet aluminium (+237%). This error corresponds practically to the case given by Cammerer 9 for this sample. This large error shows that without compensation, there is a significant thermal flux shunted around the heatflow meter by radial conduction through the sheet aluminium.

The results of measurements given in Tab.3 confirm the results given in Tabs. 1 and 2.

The first line in Tab.3 shows the values of output signal or thermal flux used for the compensation with the heater. The second line gives the results obtained for such output signals for heatflow meter with compensation. The third line gives results obtained for the heatflow meter I, and the fourth one is the same heatflow meter II.

ANALYSIS OF THE RESULTS OF MEASUREMENTS

The majority of measurements of thermal fluxes are per-formed in the steady or quasi-steady state of heat transfer through the sample. It can be seen that such measurements are the function of the homogeneity of the sample material. The measurements in the quasi-steady, e.g., slow variable state of heat transfer demands the measurements during a larger number of cycles 10 with assistance of so-called integrators 11 or scanners, which measure in definite time intervals.

It is proved with these experiments that the measurements with a compensating heatflow meter in a variable state of heat transfer can measure at least as well as with no compensation. In fact, the problem of measurement in variable heat transfer with the compensation heatflow meter leads to the statistical measurement of cyclic variable value.

The results obtained in measurements with thermal compensation deviate less from the results obtained by the guarded hot-plate apparatus than with no compensation (except when the partitions with big thermal resistance are measured).

The results of measurements of thermal flux for samples of different materials are presented in Tab.2. These results are obtained from steady-state conditions. The results obtained by heatflow meter with thermal compensation agree in the limit of error of apparatus with the results obtained in the guarded hot-plate apparatus. The results obtained with no compensation are out of the limit of error (except in the sample of expanded polystyrol, which has a high thermal resistance relative to the thermal resistance of the heatflow meter).

From this we can conclude that a systematic error exists in the measurements with no compensation. This error depends on homogeneity and thermal resistance of the sample's material. The results obtained in Tab.2 are used for checking Eq. 11, 13, and 16 for correction of the error of measurements for the heatflow meter with no compensation. Equation 11 relates to the correction of measurements when the flux passes only linearly through the sample and heatflow meter. The values $\theta_2 - \theta_1$ are taken for the difference of temperature obtained out of the heatflow meter, but reduced for the temperature drop through the heatflow meter.

Equations 13 and 16 relate to the correction of measurement when the flux caused by thermal resistance of heatflow meters passes radially through the sample. In Eq. 13 the measured difference of temperature through the sample under the center of the heatflow meter is taken as values $\theta_2 - \theta_1$. The same value is taken in Eq.16 as the difference of temperatures marked as $\theta_m - \theta_1$. It can be seen that the correction according to Eq. 11 depends on the kind of measured material. The deviation in correction according to Eq. 16 depends on the accuracy of measurements of maximum temperature drop under the heatflow meter.

CONCLUSION

A new kind of measurement of thermal flux is suggested in this paper. This kind of measurement consists of thermal compensation of thermal flux alterations caused by the thermal resistance of the heatflow meter itself.

The compensation heatflow meter eliminates a systematic error made by measurements without compensation. It is established that the thermal resistance of the heatflow meter af-fects the partition as a corresponding source of cold. An auxiliary source of heat can compensate for the influence of the source of cold. Conversely, an auxiliary source of cold can compensate for a source of heat, which is the case when the heatflow meter is placed on the cold side of the partition.

The auxiliary source of heat increases the flux through the partition back to what its original value would be if the heatflow meter were not put on the partition. In this case, the gradient of temperature through the heatflow meter is not made on account of gradient temperature across the partition but on account of the auxiliary heat source. In this way, the systematic error in thermal flux measurements introduced by the heatflow meter acting as additional thermal insulation is removed. The method of measurement, in principle, becomes a null method.

Because of the observed similarity of the additional nonlinear heat conduction caused by the thermal resistance of the heatflowmeter and heat conduction caused by a source of heat, it will be possible to replace the influence of thermal resistance with equations for nonlinear heat condùction. The satisfactory results have not been obtained by experimental check of these equations, because of the conditions (for a semi-infinite body) of equation derivation and temperature measurements.

The compensation method of measurement gives results faster then the method without compensation. The compensation method does not demand a new distribution of temperature through the partition. It demands only the adjustment of temperature of relatively small and thin heatflow meters. In this case the temperature of the partition remains unchanged.

The compensation method gives more accurate results than the method without compensation in almost all conditions of measurements. The compensation method is practically independent of partition material and of the method of heat transfer.

The sample of expanded polystyrol with aluminium sheet was measured with the compensation method and has given results within the accuracy limits of applied instruments. Without compensation, the error was +237%.

The compensation method results do not depend on the size of the heatflow meter applied on relatively homogeneous samples. Also, it is not necessary to have a guard ring around the measuring surface of the heatflow meter. The measuring surface of the meter can be very small and thus can also measure so-called thermal bridges.

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TABLE 1
Steady and Variable State Measurements

Material of Sample	Quantity	Unit	Heatflow Meter with Compensation		Heatflow Meter with no Compensation	
			Steady State	Variable State	Steady State	Variable State
1	2	3	4	5	6	7
Concrete	λ	W/mK	1,19	1,23	0,924	0,919
	θ_{sr}	^oC	11,8	10,23	10,9	9,8
	$K\Delta\theta_{so}$	mV	+0,064	+0,016	-0,134	-0,134
	$K\Delta\theta_s$	mV	+0,065	+0,015	-0,062	-0,071
Hollow Brick	λ	W/mK	0,436	0,490	0,371	0,337
	θ_{sr}	^oC	30,3	29,7	30,3	29,6
	$K\Delta\theta_{so}$	mV	+0,236	+0,555	-0,070	-0,070
	$K\Delta\theta_s$	mV	+0,236	+0,556	-0,006	-0,009
Expanded Polystyrol	λ	W/mK	0,0411	0,0430	0,0388	0,0387
	θ_{sr}	^oC	31,5	30,9	31,5	30,9
	$K\Delta\theta_{so}$	mV	+0,415	+0,511	+0,065	+0,065
	$K\Delta\theta_s$	mV	+0,415	+0,335	+0,208	+0,230

TABLE 2
Heatflow Meters and Etalon Measurements and Corrections

Material of Sample	Quantity	Unit	Heatflow Meter With Compensat.	Heatflow Meter Without Compensat.	Hot-Plate Apparatus with G.R.	Equations for Correction Number (11)	Equations for Correction Number (13)	Equations for Correction Number (16)
1	2	3	4	5	6	7	8	9
Concrete	λ	W/mK	1,092	0,895	1,151	2,58	1,04	0,717
	θ_{sr}	^oC	+27,5	+27,5	+28,0	+27,5	+27,5	+27,5
	$K\Delta\theta_{so}$	mV	+0,505	+0,142	-	-	-	-
	$K\Delta\theta_s$	mV	+0,505	+0,273	-	-	-	-
Hollow Brick	λ	W/mK	0,475	0,371	0,490	0,571	0,427	0,358
	θ_{sr}	^oC	+23,2	30,3	32,8	30,3	30,3	30,3
	$K\Delta\theta_{so}$	mV	+0,880	-0,070	-	-	-	-
	$K\Delta\theta_s$	mV	+0,881	-0,006	-	-	-	-
Expanded Poly-styrol	λ	W/mK	0,0390	0,0371	0,0398	0,0403	0,0374	0,0349
	θ_{sr}	^oC	24,7	31,2	30,2	24,2	24,2	24,2
	$K\Delta\theta_{so}$	mV	+0,584	+0,594	-	-	-	-
	$K\Delta\theta_s$	mV	+0,585	+0,731	-	-	-	-
	λ	W/mK	0,0385	0,134	0,0398	-	-	-
	θ_{sr}	^oC	32,3	29,8	30,2	-	-	-
	$K\Delta\theta_{so}$	mV	+0,409	+0,017	-	-	-	-
	$K\Delta\theta_s$	mV	+0,409	-0,185	-	-	-	-

TABLE 3
Hot-Box Type Chamber Measurements

Quantity	Heatflow Meter Z 70			Heatflow Meter WS AP 80-1		
ϑ, $\Delta\theta_s$	0	$\Delta\theta_{so}$	$\varnothing_o$	0	$\Delta\theta_{so}$	$\varnothing_o$
λ (W/mK)	1,20	1,215	1,228	1,20	1,223	1,21
λ_I (W/mK)	1,01	1,065	1,145	1,105	1,137	1,08
λ_{II} (W/mK)	0,835	0,85	0,885	1,00	1,027	0,99

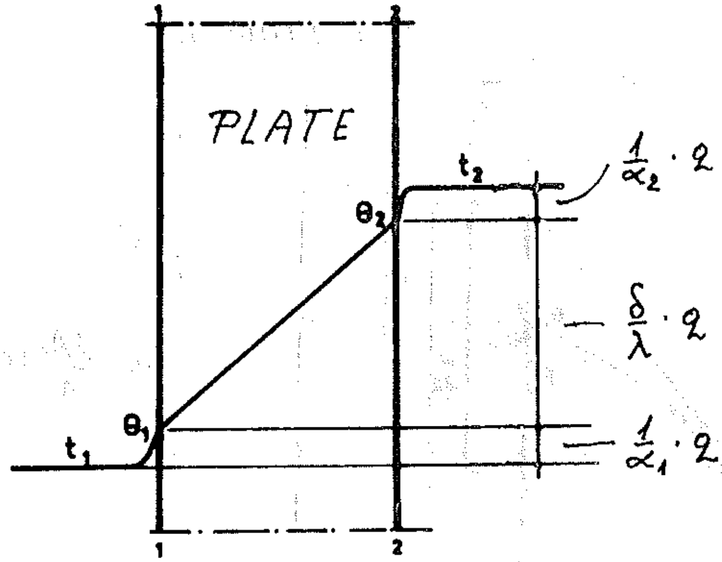

Figure 1. *Schematic presentation of distribution of temperature through the plate in steady state heat transfer*

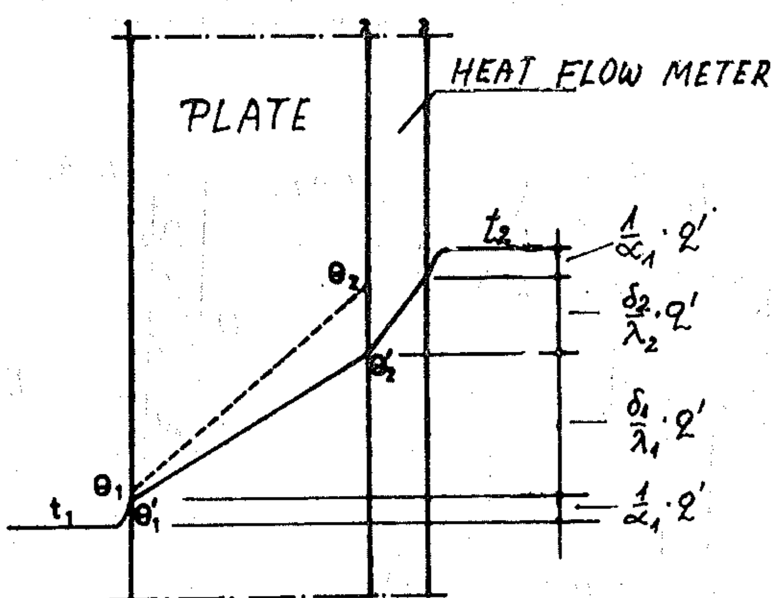

Figure 2. *Schematic presentation of temperature distribution through the plate and the heat flow meter in steady state heat transfer*

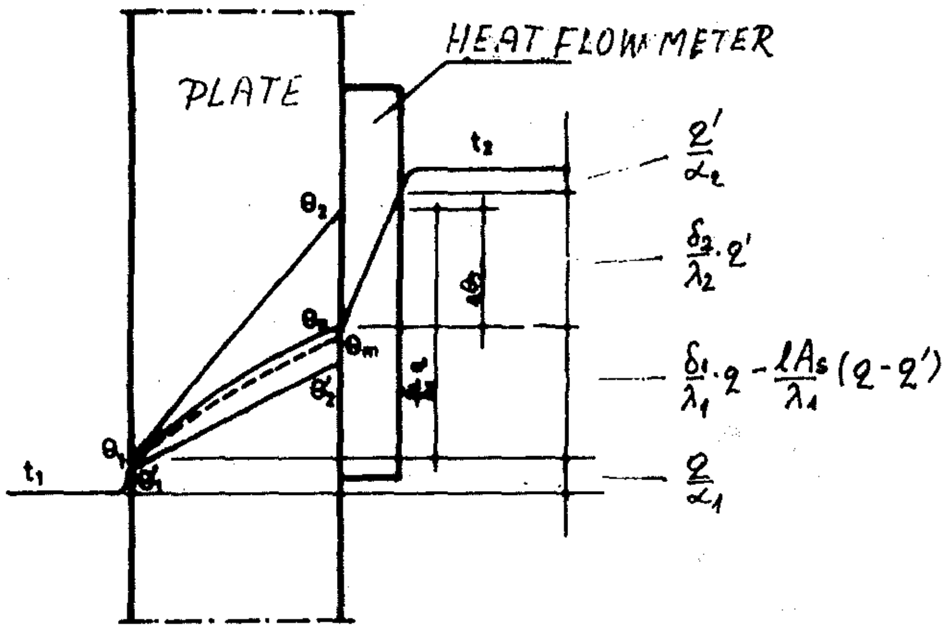

Figure 3. *Schematic presentation of temperature distribution through the partition and the heat flow meter on one part of the partition in steady state heat transfer*

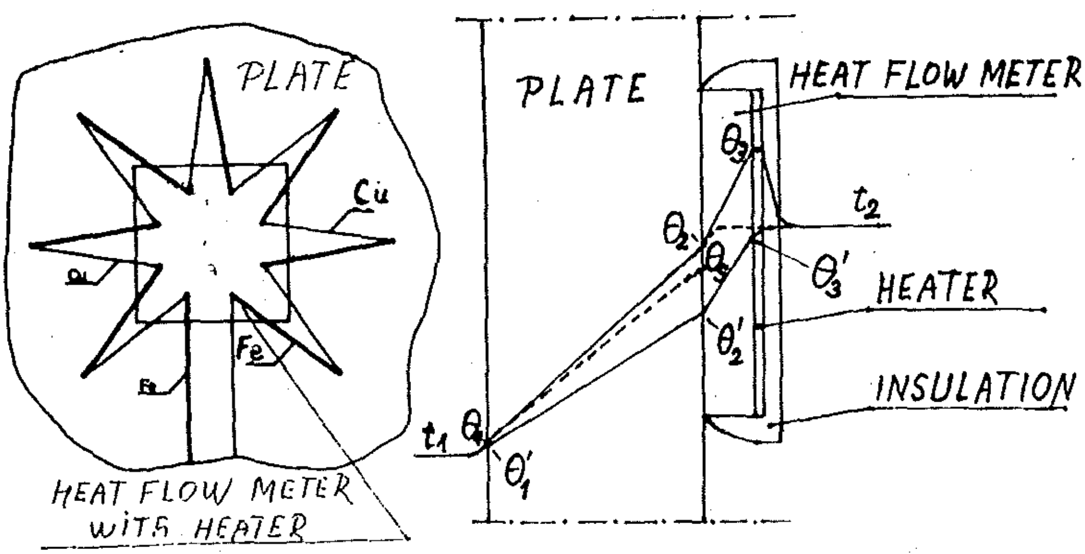

Figure 4. *Schematic presentation of the heat flow meter placed on the partition (a face and cross-section)*

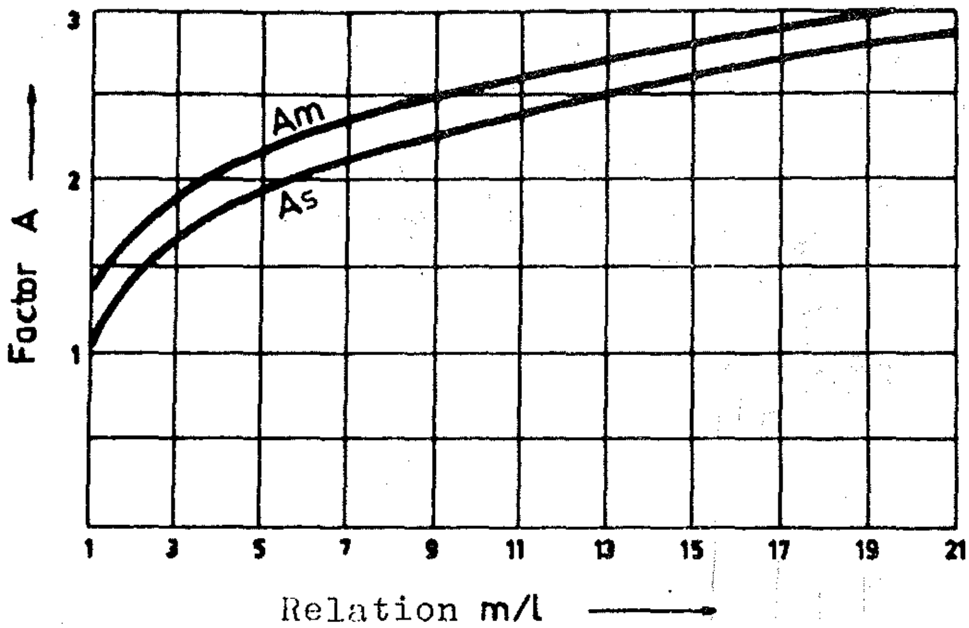

Figure 5. The curves of function A = f(m/l)

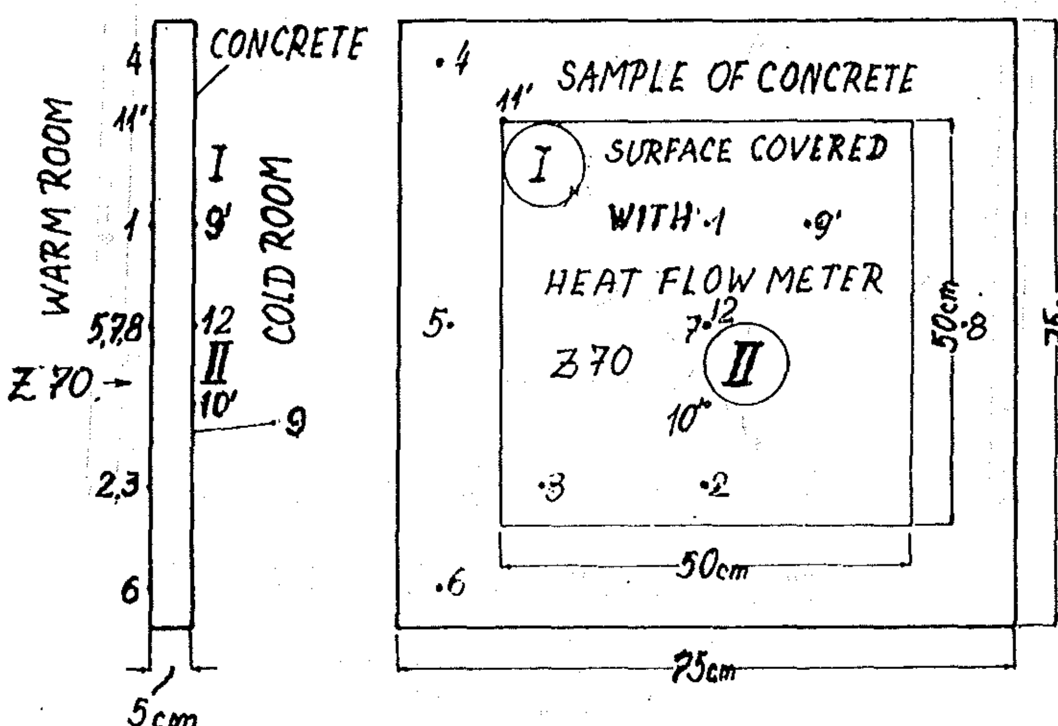

Figure 6. The sample with the arrangement of heat flow meter.

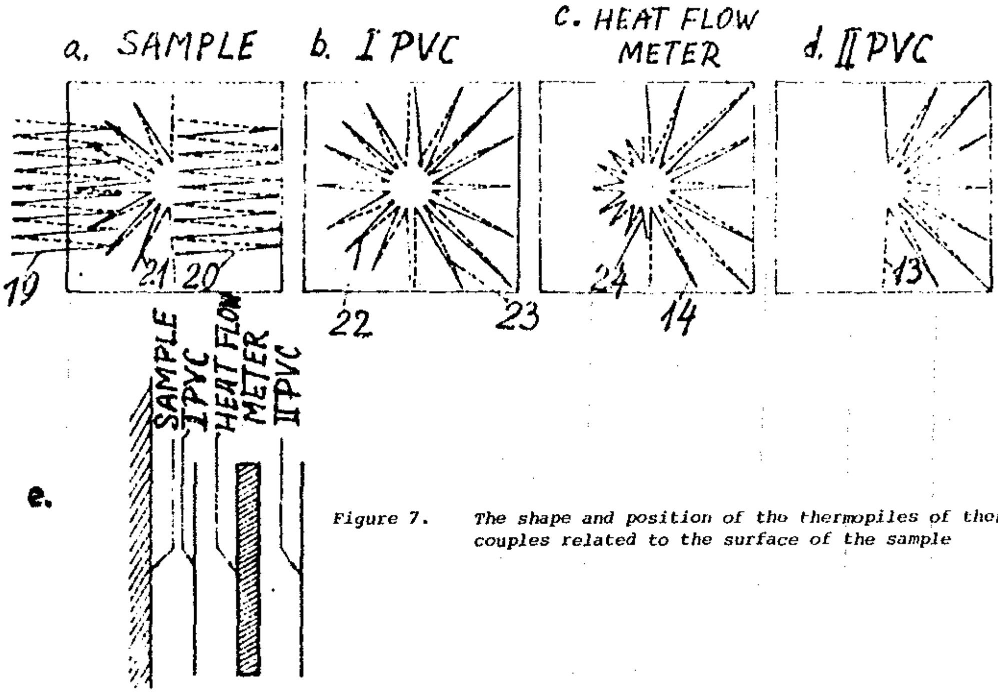

Figure 7. *The shape and position of the thermopiles of thermocouples related to the surface of the sample*

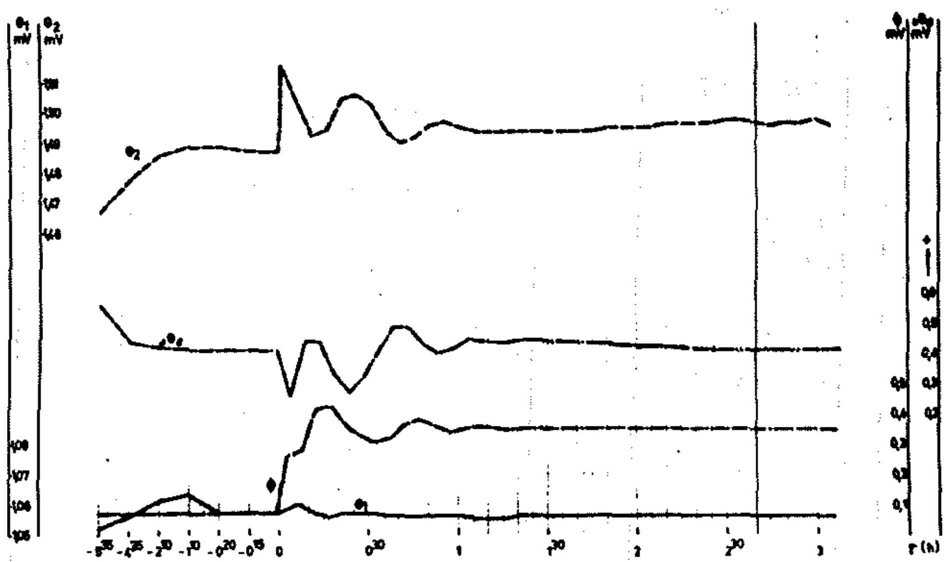

Figure 8. *Variation of the values measured with compensation in steady state, in function of time (the measurements start at time t=0)*

θ_1, θ_2 - *surface temperatures*

$K_\Delta \theta_s$ - *value proportional to the difference of the sample's surface temperature*

ϕ - *thermal flux*

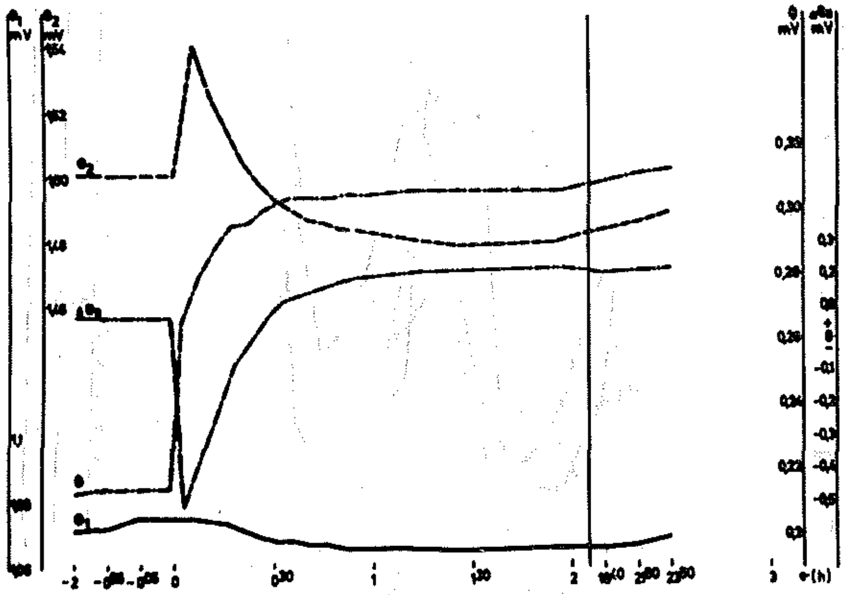

Figure 9. Variation of the values measured without compensation in steady state, in function of time (measurements start at time t=0)

θ_1, θ_2 - *surface temperatures*

$K_\Delta \theta_s$ - *value proportional to the difference of the sample's surface temperature*

ϕ - *thermal flux*

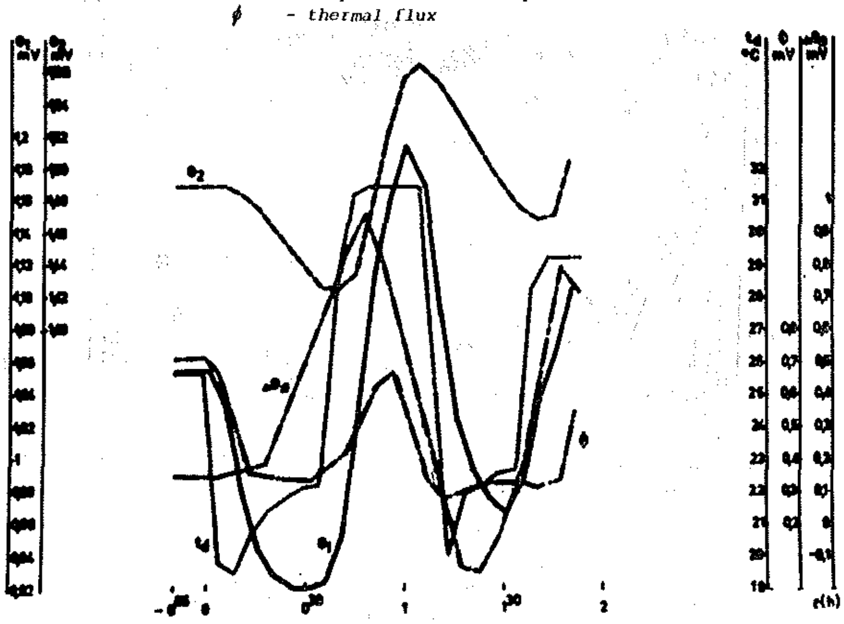

Figure 10. Variation of the values measured with compensation in variable state in function of time (measurements start at time t=0)

θ_1, θ_2 - *surface temperatures*

$K_\Delta \theta_s$ - *value proportional to the difference of sample's surface temperature*

t_d - *temperature of cooling plate*

ϕ - *thermal flux*

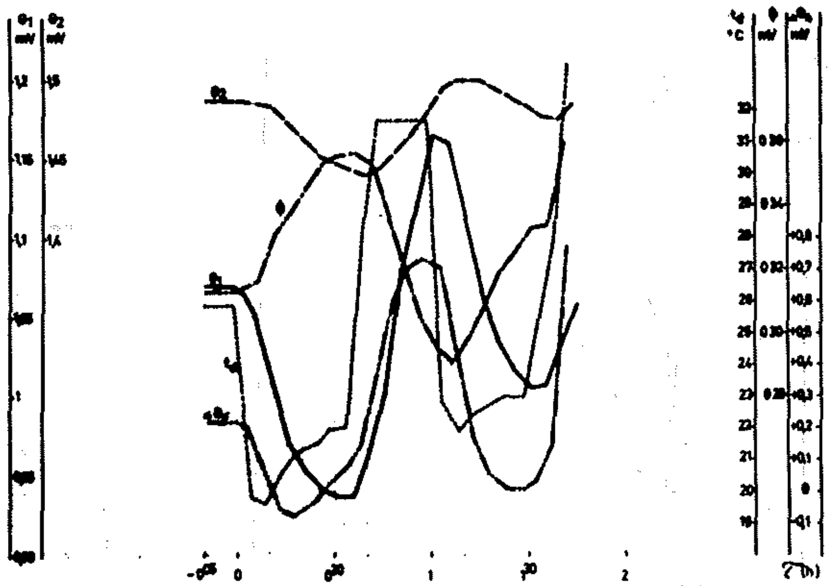

Figure 11. Variation of the values measured without compensation in variable state in function of time (measurements start at time t=0)

θ_1, θ_2 - surface temperatures
$K_\Delta \theta_s$ - value proportional to the difference of sample's surface temperature
t_d - temperature of cooling plate
ϕ - thermal flux

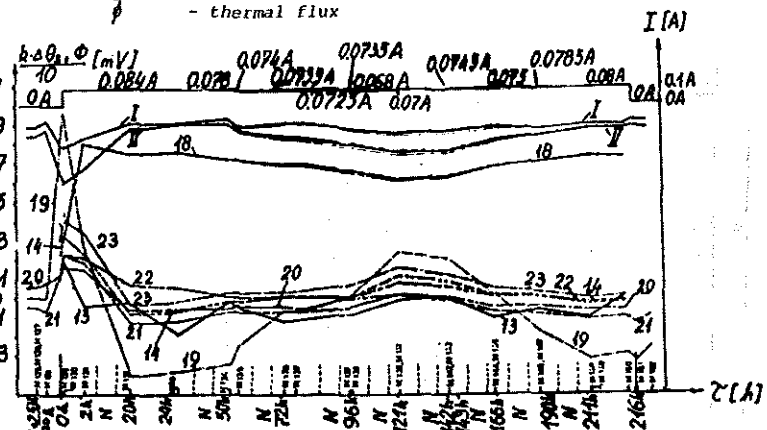

Figure 12. Variation of the values measured with compensation in steady state in function of time (start of measurements at time t=0)

$K_\Delta \theta_s$ - value proportional to the difference of the sample's surface temperature
I(A) - current of compensation heater (in upper side of diagram)
$\phi/10$ - values of thermal flux diminish ten times
18 - mark for the flux of the heat flowmeter Z70
I - mark for the flux of the heat flowmeter 31563
II - mark for the flux of the heat flowmeter 31561
N - mark for the ordinal number of measurements
(h - number of hours passing from the beginning of measurements, Oh is a start of measurements)

*Vertical dotted lines on the absciss and designation n denotes the shortness of diagram during the night