Temperature and Moisture Dependence of the Thermal Conductivity of Insulation Materials

F. Ochs[1)], H. Müller-Steinhagen[1)2)]
[1)] Institute of Thermodynamics and Thermal Engineering, working group SuN, www.itw.uni-stuttgart.de
[2)] DLR Stuttgart, Institute for Technical Thermodynamics

1. Temperature dependence of the thermal conductivity

The effective thermal conductivity (k_{eff}) of insulation materials is measured according to DIN 52616 /1/at a mean sample temperature of 10 °C with a protected heating plate device (see figure 1). For the building sector this is sufficient, but insulation materials for heat stores are in general exposed to higher temperatures, in the case of hot water stores up to 95 °C.

The effective thermal conductivity increases with temperature. For dry insulation materials this effect can be described with a linear approach:

Figure 1: Protected heating plate with stainless steal bulk container

$$k_{eff} = k_0 + a \cdot (T - 273.15)$$

Different kinds of insulation materials have been tested. Since the main focus lies on pit heat stores, only stress resistant types have been selected.

Measured values of the effective thermal conductivity are compared in figure 2. Best linear fit coefficients are listed in table 1:

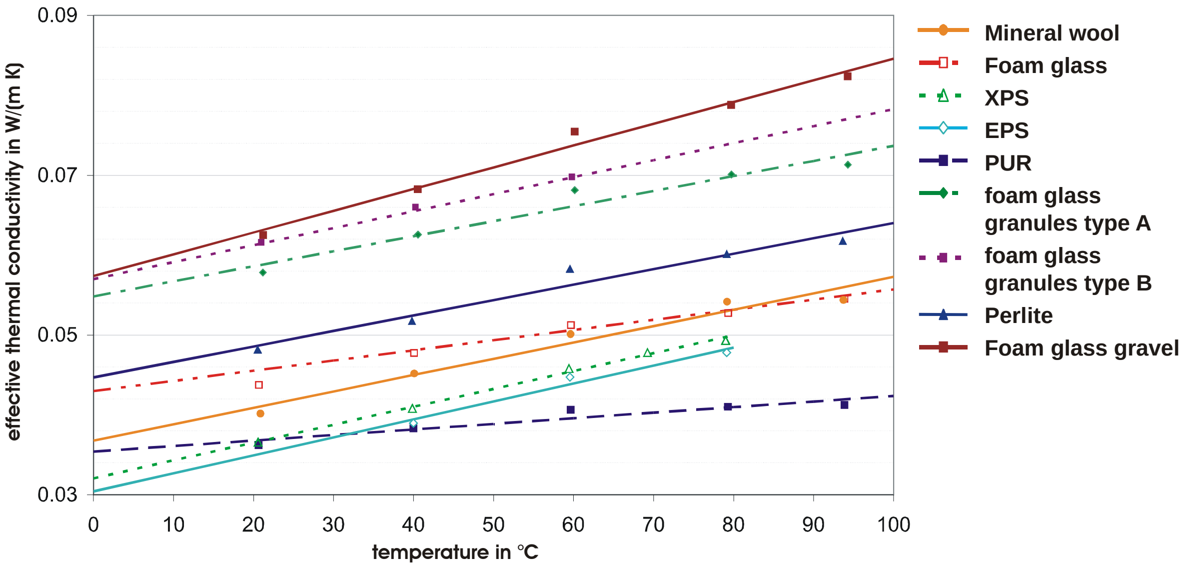

Figure 2: Thermal conductivity of the measured insulation materials as a function of the mean temperature.

Table 2: Manufacturer or literature data of density (ρ) and bulk density (ρ_b), permanent service temperature ($T_{max,perm}$), as well as thermal conductivity at 10 °C (k_{10}) and best linear fit coefficients (k_0, a) of the tested insulation materials.

	ρ in kg/m³	ρ_b in kg/m³	$T_{max,perm}$ in °C	k_{10} in W/(m K)	k_0 in W/(m K)	a in W/(m K²)
Boards						
Mineral wool	160	--	250	0.040	0.037	2.0E-04
Foamglas	100-150	--	430	0.045	0.043	1.3E-04
XPS	40	--	70	0.035	0.032	2.2E-04
EPS	40	--	85	0.030	0.030	2.3E-04
PUR	80	--	110	0.035	0.035	7.0E-05
Bulk						
Foam glass granules type A	320	200	700	0.070	0.055	1.9E-04
Foam glass granules type B	310	190	700	0.065	0.057	2.1E-04
Perlite	100-300	90	100	0.050	0.045	1.9E-04
Foam glass gravel	250	160-190	430	0.066	0.057	2.7E-04

2. Thermal conductivity as a function of temperature and moisture content

Insulation materials are exposed to environmental influences (i.e. rain or humidity). Due to diffusion processes as a consequence of gradients of the temperature or the humidity, the moisture content of the insulation can increase. High temperatures at high moisture contents lead to a strong increase of the effective thermal conductivity because of pore diffusion.

The effective thermal conductivity increases with temperature and moisture content. The moisture content depends mainly on the pore ratio and the pore structure of the insulation.

Exemplarily the effective thermal conductivity of foam glass granules (figure 3) and of mineral wool (figure 4) is plotted as a function of the temperature for different moisture contents.

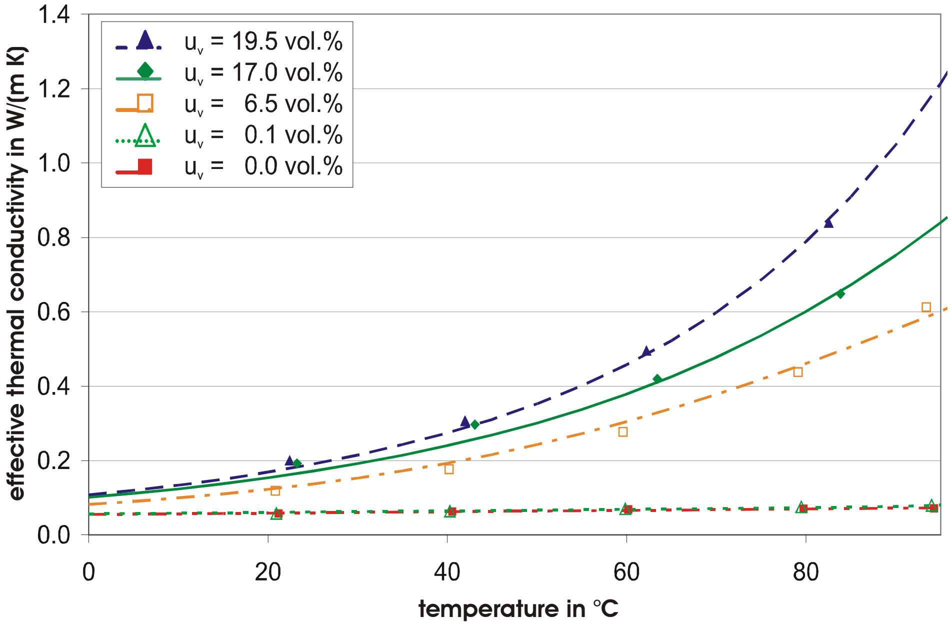

Figure 3: Measured thermal conductivity of recycled glass granules (type A) as a function of the temperature for different moisture contents (uv).

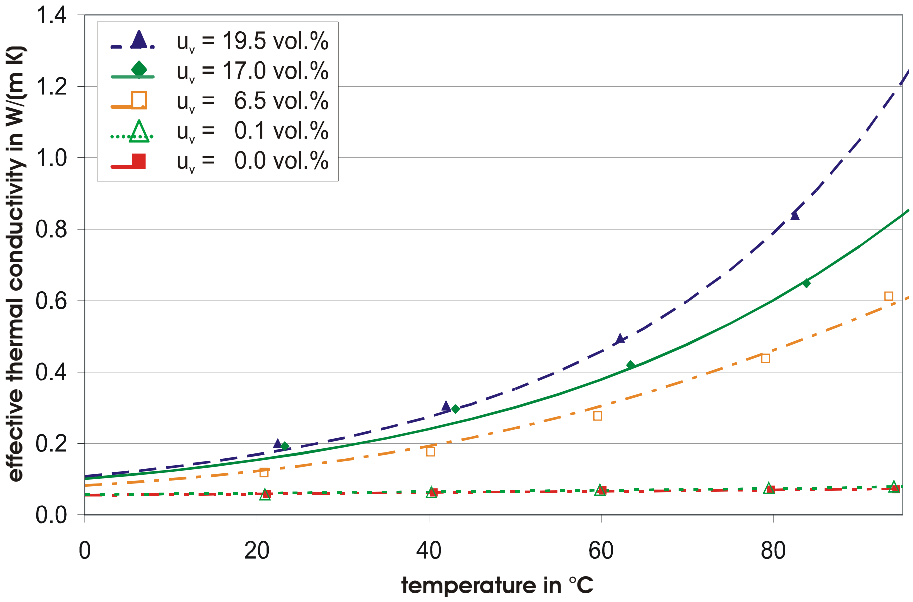

Figure 4: Measured thermal conductivity of mineral wool as a function of the temperature for different moisture contents (uv).

In figure 5 it is shown that for low temperatures the trend of the measured thermal conductivity can be described with a linear approach.

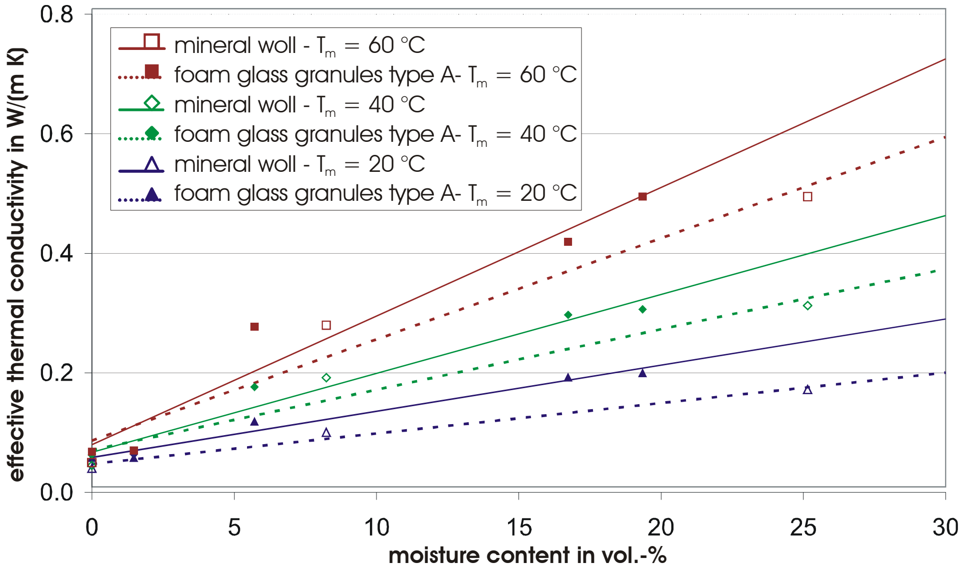

Figure 5: Thermal conductivity of mineral wool and foam glass granules as a function of the volume related moisture content and the temperature.

Figure 6 shows a plot of the calculated effective thermal conductivity as a function of the volume related moisture content (uv) and the temperature according to the layer model suggested by Krischer /2/.

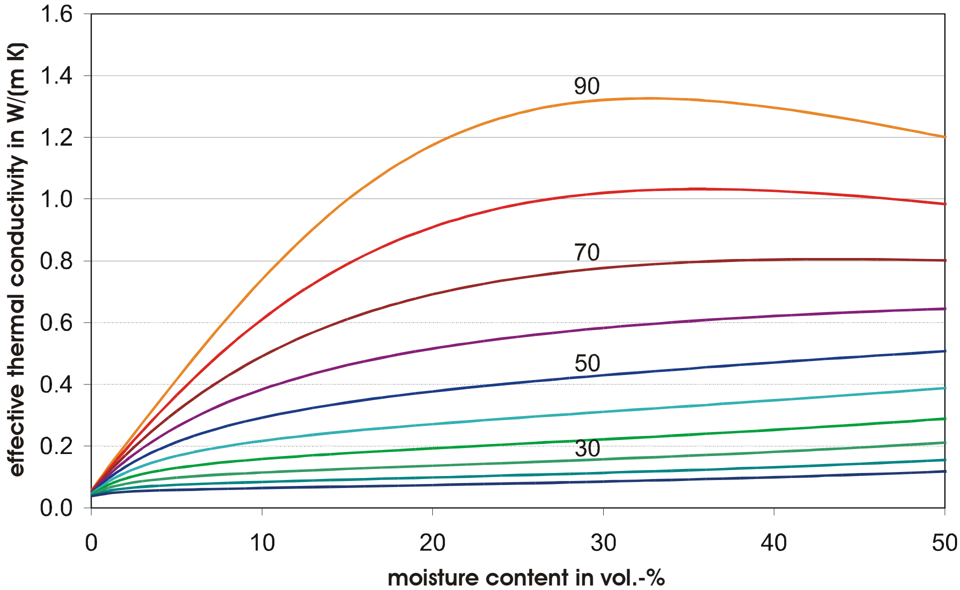

Figure 6: Thermal conductivity of mineral wool as a function of the volume related moisture content with the mean temperature as parameter according to the layer model.

3. Conclusions

1) If insulation materials are applied for operating temperatures considerably above ambient temperature, the dimensioning of the insulation thickness should not be performed with the thermal conductivity according to the DIN 52616 /1/.

2) Furthermore the values indicated in DIN 4108 part 4 /03/ are not sufficient for applications with higher operating temperatures.

3) Insulation materials are not always completely dry after delivery (depending on the kind of insulation, moisture contents between 0.5 and 5 Vol.% are possible)

4) Insulation materials exposed to environmental influences show increased moisture contents.

5) The dimensioning of the insulation of components of heating systems (i.e. heat stores) with a linear relation between the thermal conductivity and the temperature and moisture content is more accurate, than with DIN or ASTM values.

6) In the range of higher temperatures (> 50 °C) as well as for detailed calculations and simulations the effective thermal conductivity according to a layer model (e.g. suggested by Krischer /2/) should be considered.

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Literature

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