WLiK Faculty of Heat and Material Transfer
Rheinisch-Westfälische Technische Hochschule, Aachen
Professor R. Kneer (Dr. Ing)

Calculations of thermal transmission by radiation with the use of “Aluthermo Quattro” composite insulation mat

Expert Report commissioned by
Aluthermo AG, Burg Reuland, Belgium

Edited by: B. Hilemacher (Dr.-Ing)

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1. Introduction

The thermal insulation quality of construction elements is today an increasingly important criterion in evaluating the overall technical execution quality of buildings. In response to the various requirements for specific properties that are often defined by the nature of the construction, the current market is characterised by a wide variety of thermal insulation materials, both for new buildings and for retrofitting in the renovation of old buildings.

Certain innovative concepts for the thermal insulation of construction elements utilise the radiation reflection effect provided by the highly reflective surfaces of certain insulation materials, which have generally been specially coated for this purpose. The result is reduced heat transfer through the construction shell, meaning in practice that in summer less heat enters the building and in winter less heat is lost through the structure, thereby making a major contribution to energy saving.

2. Problem description

For the present Expert Report, a thermal insulation material of this type with a highly reflective surface on both sides was analysed by means of heat transfer calculations. The object of the tests was the thermal insulation material named “Aluthermo Quattro”, manufactured by the company Aluthermo AG of Burg Reuland, Belgium.

Two test reports from the Fraunhofer Institut für Bauphysik (Fraunhofer Institute for Construction Physics) of Stuttgart, Germany, are available for the “Aluthermo Quattro” product, namely Test Report P15-013.1/2005 dated 07.02.2005 “Determination of the emission coefficient of the outer surfaces of a multi-layered composite thermal insulation mat” and Test Report P1-003/2005 dated 13.01.2005 “Determination of resistance to heat transfer conforming to DIN EN 12667”. The present Expert Report makes reference to the results published in the above test reports.

The “Aluthermo Quattro” composite thermal insulation mat studied here consists of 7 layers with a total of 13 interfaces between different materials. The core layer, consisting of a 3 mm thick polyethylene (PE) foam (material weight 75 g/m^2), is sandwiched between two layers of aluminium foil coated on both sides with PE (material weight 20 g/m^2), which are in turn enclosed by 4 m thick PE air-bubble films (diameter of the air chambers: 10 mm). This inner package of layered materials is covered by aluminium foil (material weight 81 g/m^2) coated on both its exterior surfaces with a nitrocellulose coating (material weight 3 g/m^2). On their interior surfaces, these cover layers of aluminium foil are again coated with PE (material weight 20 g/m^2). The aforementioned Test Report P15-013.1/2005 specifies that the overall thickness of the “Aluthermo Quattro” composite thermal insulation mat is 11.2 mm and gives a value of 0.08 for the emission coefficients of the outer surfaces.

Test Report P1-003/2005 specifies a heat transfer resistance of R = 0.279 m^{2}K/W for the “Aluthermo Quattro” thermal insulation mat.

Figure 1 below illustrates a typical application for this type of thermal insulation material: the “Aluthermo Quattro” composite thermal insulation mat is laid directly on the rafters of a roof construction.

The illustration shows a sloping roof inclined at an angle of 35˚, viewed both from the side and in cross-section. The “Aluthermo Quattro” thermal insulation mat (4) was laid in strips parallel to the direction of the gutter, and it was fixed with the aid of cross-battens (3) on the rafters (5). The cross-battens (3) support the battens (2), which are spaced in accordance with the requirements of the final roof covering (1), for example concrete tiles or clay bricks. As is often the case today for loft conversions, an interior cladding of plasterboard panels (6) was fastened underneath the rafters on the inside of the roof.

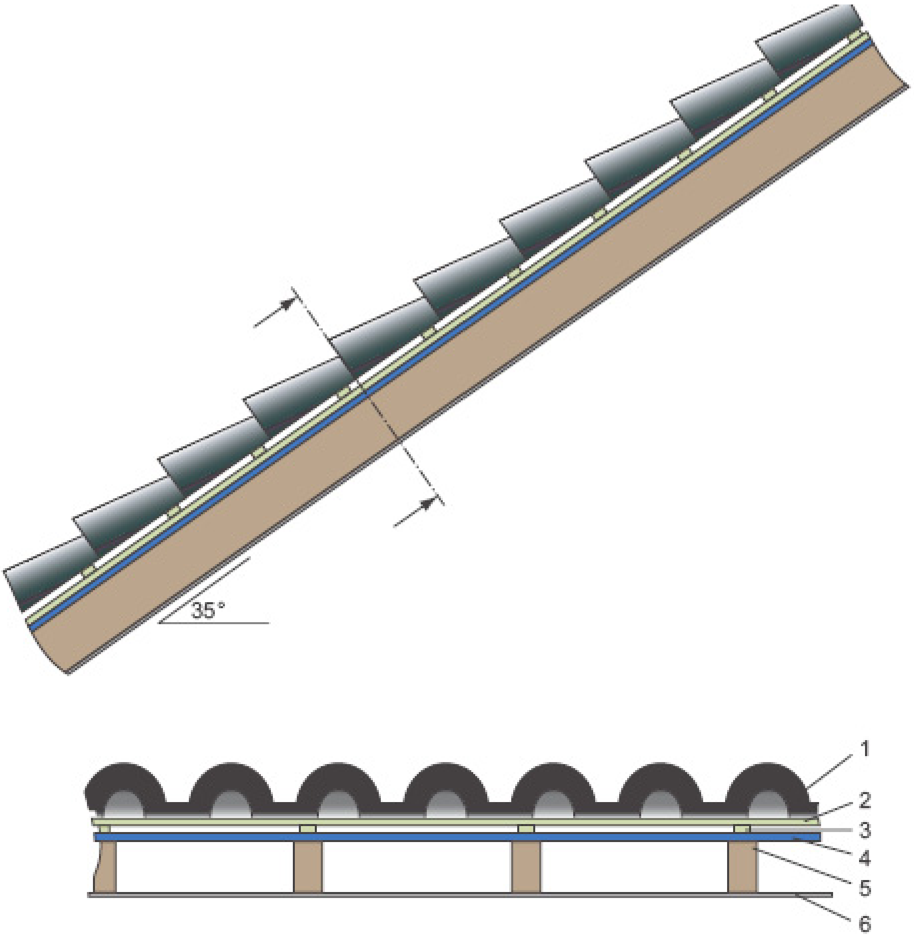


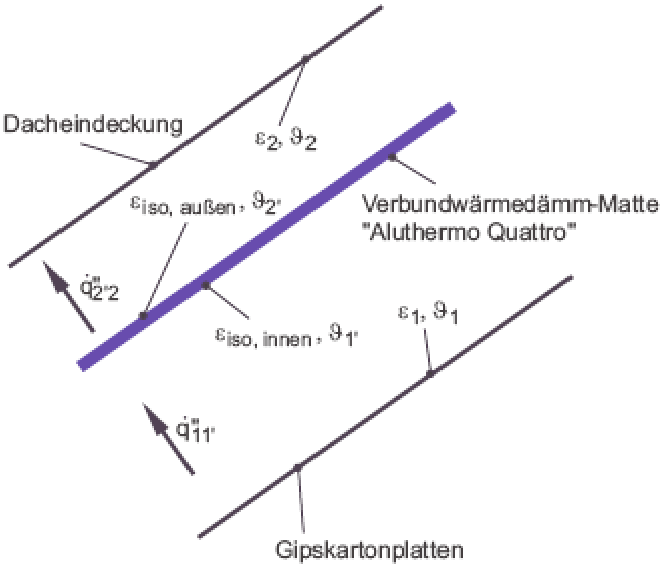
Figure 1: Typical installation situation for the “Aluthermo Quattro” composite thermal insulation mat on a sloping roof, gradient 35˚, shown in side view and cross-section

1. Rear-ventilated roof covering material, e.g. concrete tiles or clay bricks
2. Battens
3. Counter-battens
4. “Aluthermo Quattro” composite thermal insulation mat
5. Rafters
6. Plasterboard

The aim of the present Expert Report was to analyse the extent to which heat transfer by radiation between the two limiting surfaces (plasterboard on the inside and roofing material on the outside) is influenced by the installation of “Aluthermo Quattro” composite thermal insulation mats, and in particular to determine the overall thermal resistance between the plasterboard and the roof covering, assuming certain specified conditions.

To illustrate the process of heat transfer by radiation in the above installation example for the “Aluthermo Quattro” composite thermal insulation mat, Figure 2 shows a simplified outline diagram of the principle behind the present problem:

Between two parallel, infinitely extended plane surfaces at different temperatures (plasterboard inside, roof covering outside), the “Aluthermo Quattro” composite thermal insulation mat is laid to form an intermediate parallel plane, so that heat exchange by radiation occurs between the “Aluthermo Quattro” composite thermal insulation mat and the two surfaces facing it, i.e. the plasterboard or roofing material.



Roof covering material
ε_{ISO} outer
“Aluthermo Quattro” composite thermal insulation mat
ε_{ISO} inner
Plasterboard panels

Fig. 2: Diagram of the principle underlying the problem studied

The surface temperatures of the plasterboard panels and roof covering with respective emission coefficients ε_1 and ε_2 on their inner surface (i.e. the side facing the insulating material) are ϑ_1 and ϑ_2 respectively. The “Aluthermo Quattro” composite thermal insulation mat is characterised by the heat transfer resistance $R_{ISO} = 0.279$ m^2K/W, an emission coefficient of $\varepsilon_{ISO} = 0.08$ for the outer surfaces and a thickness δ_{ISO}.

The calculations below are based on a specified uniform temperature for the plasterboard panels – corresponding to a proportionately higher room temperature (depending on the wall structure) – of $\vartheta_1 = 20^\circ C$.

For the temperature ϑ_2 at the inner surface of the roof covering, we have assumed a value of $\vartheta_2 = -20^\circ C$ in the present calculations.

For the emission coefficients of the plasterboard panels, a value of $\varepsilon_1 = 0.9$ has been assumed in the calculations.

The emission coefficient of the inner surface of the roof covering, i.e. the surface facing the "Aluthermo Quattro" composite thermal insulation mat, varies from 0.90 to 0.94 according to the material used (concrete roof tiles, clay bricks, roofing felt or full timber planking. For the calculations, we have assumed a conservative higher estimate of $\varepsilon_2 = 0.94$.

3. Defining equations

According to the specified framework conditions, we should assume that for both interface zones, i.e. between the plasterboard panels and the "Aluthermo Quattro" composite thermal insulation mats and between the "Aluthermo Quattro" composite thermal insulation mats and the roof covering, any thermal transmission due to the specified temperature differences will occur exclusively by radiation. Taking into account the Stefan-Boltzmann law, the following equations can therefore be derived for the net radiation exchange between two infinitely extended flat surfaces i and j, which can assumed to be "grey bodies":

$$\dot{q}^{*}_{ij} = \frac{1}{\left(\frac{1}{\varepsilon_i} + \frac{1}{\varepsilon_j} - 1\right)} \cdot C_s \cdot \left[\left(\frac{T_i}{100}\right)^4 - \left(\frac{T_j}{100}\right)^4\right] \qquad (1)$$

where the radiation constant $C_s = 5.67\ W/m^2K^4$.

On the other hand, assuming single-dimensional heat conduction in a solid body of thickness δ and thermal conductivity λ, the following equation applies to the heat flow over the surface area:

$$\dot{q}^{*}_{ij} = \frac{\lambda}{\delta} \cdot \left(\vartheta_i - \vartheta_j\right) \qquad (2)$$

with the thermal resistance

To determine the unknown thermal resistance values R_i for the relevant zone i or the overall

$$R = \frac{\delta}{\lambda}. \qquad (3)$$

resistance R_{tot} between the plasterboard panels and the roof covering, the heat flows transmitted by radiation or conduction in the relevant zones are calculated using equations (1) and (2). With indexing corresponding to Figure 2, the following equations are obtained:

$$\dot{q}^{*}_{11'} = \dot{q}^{*}_{1'2'} \qquad (4)$$

$$\dot{q}^{*}_{1'2'} = \dot{q}^{*}_{2'2} \qquad (5)$$

Applying the above defining equations (1) or (2), the unknown temperatures $\vartheta_{1'}$ and $\vartheta_{2'}$can initially be determined iteratively for the equation system (4) and (5). Assuming thermal radiation resistance values equivalent to thermal conduction resistance of

$$\dot{q}''_{11'} = \frac{1}{R_{11'}} \cdot (\vartheta_1 - \vartheta_{1'}) \text{ bzw.} \qquad (6)$$

$$\dot{q}''_{2'2} = \frac{1}{R_{2'2}} \cdot (\vartheta_{2'} - \vartheta_2) \qquad (7)$$

the thermal resistance values $R_{11'}$, $R_{12'}$ and $R_{2'2}$ can be determined. The overall thermal resistance R_{tot} relative to the driving temperature potential (ϑ_1 - ϑ_2) is therefore determined by:

$$R_{ges} = R_{12} = R_{11'} + R_{1'2'} + R_{2'2} \qquad (8)$$

Finally, a heat transfer coefficient u_{12} – again based on the driving temperature potential (ϑ_1 - ϑ_2) and equivalent to the thermal radiation – can be calculated from:

$$u_{12} = \frac{1}{R_{12}} \qquad (9)$$

4. Results

The calculated results are summarised in Table 1 below:

Characteristic	**“Aluthermo Quattro” composite thermal insulation mat**
Temperature ϑ_1 [˚C], specified	20
Temperature $\vartheta_{1'}$ [˚C]	3.11
Temperature $\vartheta_{2'}$ [˚C]	1.15
Temperature ϑ_2 [˚C], specified	- 20
Overall thermal resistance R_{12} [m^2K/W]	5.70
Heat transfer coefficient u_{12} equivalent to the thermal radiation [W/m^2K]	0.175

Table 1:

Specified data and calculated results for the Aluthermo Quattro” composite thermal insulation mat.