Thermal resistance of selected thermal reflective insulations

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Abstract. The increasingly stringent requirements of thermal engineering standards lead to ever greater thicknesses of thermal insulating layers in the structures, which makes the insulation of the manufacturer to improve material parameters. Thermally reflective insulation currently occupies only a small volume of products in the building industry, but their use in buildings where a large temperature gradient is created for thermal insulation offers many advantages. The pressure on the thermal insulation efficiency is increasing, so that their thickness is as small as possible.

1. Introduction
Reflective thermal insulation layers are in literature attributed, in contrast to conventional thermal insulation layers, to a significant thermal insulation effect.

Reflective layers have been used in Europe since 2000 in France and Benelux where they were made of aluminium foil sewn together with hollow fibbers and various fabrics. At present, considerable attention is paid to the development of thermal insulation of this kind as it has great potential for use in the building industry, although it is obvious due to their layered layout and the materials used that they will not be as widely used as conventional thermal materials.

In our country, they have been proven to be a vapour-proof thermal insulation after 1990. The fabrics previously used were damp and therefore replaced by a blister foil or a polyethylene foam which was coated with a polished aluminium foil on one or both sides of the blister foil.

The advantage of these insulating materials is that they combine three advantages:

- the relatively high thermal resistance of the insulation layer,
- high reflectivity of the heat of aluminium foil,
- high diffusion resistance for water vapour spread.

The low water vapour permeability of the heat reflective counting stack provides non-porous layers, and the reflective films provide protection against electro smog, which is related to the electrical conductivity of the aluminium and the reflective films provide protection against electro smog, which is related to the electrical conductivity of the aluminium.

2. The current state of thermo-reflective layers on the market
Thermally reflective layers are used in the building industry especially for the insulation of walls, ceilings, roofs, floors, both in residential houses and light buildings, sports and warehouses. On the construction market today, we meet single-layer or multilayer heat-reflective formation.

This group includes vapour-tight single-layer thermal insulation, the thermal insulation of which forms a bubble foil with aluminium foil. In this group we find on the market an AB type - a bubble foil made of polyethylene with a polished aluminium foil or ABA type on one side - a polyethylene film laid on both sides with a polished aluminium foil (figure 1).
Figure 1. Layout diagram of single-layer insulation.

Single-layer heat reflective coatings are used to heat roofing, walls of wooden constructions and, finally, heavy walls with ventilated insulation [1]. Their thermal resistance $R$ ranges from 0.3 m²K/W for type AB to just above 0.5 m²K/W for ABA. The value range is so wide because the prescribed measurement procedures provide worse results (ca. 0.3 m²K/W) than in situ measurements or calculations (0.5 m²K/W or better).

Another group consists of heat reflective foils, the thermal insulation of which is made of aluminium polished foil with fused polyethylene foil such as type AP3 - polyethylene foam of 3 mm thickness with a single-sided polished aluminium foil or AP5 - polyethylene foam of 5 mm thickness with a polished aluminium foil. The use of heat-reflective insulation is suitable for use in roof constructions, wooden walls, underfloor heating systems, heating radiators, etc.

The diffusion resistance factor for water vapour is given for simple reflective insulation $\mu = 3.46.10^5$, for ABA with two Al-foils then $\mu = 3.94.10^5$.

Multi-layered thermal reflection layers in which layers with melted foils or layers without melted foil are laid on top of each other. The thermal resistance $R$ of the base stack AB or ABA is $R \in (0.3-0.6)$ m²K/W, which corresponds to the equivalent value of the thermal conductivity coefficient of the homogeneous material layer $\lambda_{ekv} \in (0.001-0.005)$ W/(m.K). The same coefficient of thermal conductivity can also be considered for a stacked sandwich, so it can be very remarkable values, which can exceed six times the coefficient of thermal conductivity of conventional building insulation.

Figure 2. Layout diagram of multilayer insulation arrangement.

In this group a sandwich arrangement of polished aluminium, foam and blister foils of polyethylene, for example, with 5 layers (figure 2) or sandwich stack of polished aluminium, foam and blister foils of 13-layer polyethylene can be found. Thermally reflective foils are used as an additional or main insulation for thermal insulation of roof structures, walls of wooden buildings, passive and low energy houses, thermal insulation of sports and agricultural halls. These multilayer heat reflective films have the advantage of low thickness, high heat resistance, low bulk density and simple application.

All of the above-mentioned heat reflective films reflect up to 95% of the radiant heat component, thus protecting the object even in the summer against sunlight from the exterior.

The recently of these reflective insulation consists in the use of polished aluminium foils welded to sandwich with bubble or foam foil.

3. Reflective capability of thermal insulations

Building heat insulation is up to 98% filled with air and at room temperature heat is dissipated in about one-third of the radiation, at higher temperatures, for example under heated roof, it is up to 40%.

As a result, in the range of practical temperatures from -30 °C to 60 °C the efficiency of classic thermal insulation changes by up to 30 percent. To do this, we have to add that for conventional thermal insulation, the lambda coefficient increases with temperature. More precisely, when the temperature rises from 15 °C to 60 °C, it will deteriorate by 15%.
With single-layer or multilayer reflective insulations provided with polished aluminium foil, we can almost eliminate the effect of radiant heat transfer mechanisms in isolation and achieve heat conductivity coefficients of isolation at a level close to the non-reflective thermal conductivity of the stationary air, approximately 0.027 W/(mK) [2]. The efficiency of these reflective foils is particularly high when performing roof structures.

4. Methods of heat transmission in thermal insulating materials

Heat dissipation is a typical physical phenomenon that always occurs from higher to lower temperature locations, it is important to have a temperature gradient between two places to spread the heat [3].

The basic ways of spreading heat include:

- conduction - according to Fourier’s law,
- convection - according to Newton’s law,
- radiation - in the sense of Stefan Boltzmann’s law.

Most importantly, this type of reflection is used to characterize the ability of the material to reflect infrared radiation. It depends on the wavelength of the incident radiation, the angle, the type of material, its structure and its surface. For conventional reflective films, it reaches 0.8 to 0.9.

Emissivity indicates the ratio of the amount of light emitted from the material (grey surface) to the quantity that emits an absolutely black body at the same temperature. The intensity of the radiation depends only on the temperature and reaches the maximum value. According to Planck’s radiation law, the spectral intensity of the black-body radiation is given. The emissivity value ε depends on the direction of radiation, the material type, the wavelength, the chemical composition of the material, the structure, and the state of the surface of the material.

Emissivity ε occurs in all directions according to the equation (1) [4]:

\[ \varepsilon = \frac{M}{M_b} = \frac{C \left( \frac{T}{100} \right)^4}{C_b \left( \frac{T}{100} \right)^4} \leq 1 \]  

\text{ }(1)\]

\( M \) radiant intensity [W/m²], \( M_b \) irradiance intensity of black emitter [W/m²], \( T \) thermodynamic temperature [K], \( C \) grey radiant [W/(m² K⁴)], \( C_b \) black radiant = 5.67 W/(m² K⁴).

The absolutely black body reaches the emissivity values \( \varepsilon = 1 \) and emissivity values \( \varepsilon = 0 \) for an absolutely white body.

5. Measurement of thermal insulation properties of heat reflective layers

Thermal reflection layers can’t be used to determine the thermal insulation properties. Only the Hot Box measurement method has been proposed for these insulation. For these insulation, the value of the thermal resistance \( R \) is neither of the decisive factor, not the coefficient of thermal conductivity. The Hot Box method describes a standard issued in 2015 by EN 16012 + A1, Thermal insulation for buildings - Reflective insulation products - Determination of the declared thermal performance [5]. This standard specifies, beyond the Hot Box method, three other options for obtaining a thermal resistance value. Therefore, the most accurate experimental measurement is to determine the thermal resistance of these layers.

The standard describes 4 different thermal resistance measurement methods:

- Method A: The method of a protected heating plate that meets the requirements of ISO 8301, EN 1946-2, EN 12664 and EN 12667.
- Method B: The method of a heat flux meter meeting the requirements of ISO 8301, EN 1946-3, EN 12664 and EN 12667.
- Method C: The Hot Box method, which meets the requirements of EN ISO 8990.
- Method D: Measurement of emissivity and calculations.
For this reason, an XPS expanded polystyrene foam measuring box was designed and assembled to measure the heat resistance $R$ of the samples.

Samples need to be conditioned before testing. When samples delivered in a compressed form, they leave for some time to reach their functional status.

5.1. Hot Box Measurement method
A protected warm case is a measuring device that serves to measure the heat flow passing through the thermal insulation pattern at the given temperature difference, regardless of heat dissipation.

The case diagram is shown in figure 3. The cabinet is made of foamed polystyrene, the outer dimensions of the case are 1200 x 1200 x 1000 mm. In the compensating, measuring and cold parts are placed precision temperature sensors type Pt1000. In the cool part, the low temperature is ensured by the cool air from the cooling unit.

![Figure 3. Scheme of the Hot Box measurement device.](image)

![Figure 4. Photo of a measuring device with control program of a computer.](image)

A 1000x1000 mm reflective insulation sample is attached to the wood frame to avoid heat leakage. Before measuring, it is necessary to determine the temperatures in the hot and cold parts, in which the thermal resistance of individual samples of thermo-reflective insulation will be measured. The temperature difference on the sample is usually 10 K, as well as the temperatures that can occur in the summer and also the temperatures simulating the winter season. The measurement was carried out in a vertical position of insulation with double-sided air cavities of 50 mm thickness.

5.2. Measured samples of thermo-reflective foil insulation
All of the samples used for reflective foil insulation were from a LDPE bubble film with bubbles of 30 mm diameter and 10 mm height. The samples also contained a classic aluminium foil or a golden-coated foil. These are samples of the classic arrangement, ABA (Al foil - bubble foil - Al foil), but also multilayer insulation.

For the following marking of the insulation layer, the abbreviations of the individual layers will be used:

- A - aluminium foil and BB - "big bubble" bubble foil.

Samples used:
- Sample 1 - ABBA - Classic layout (2x Al, 1x BB).
- Sample 2 - ABBABBA - multilayer layout (3x Al, 2x BB).
- Sample 3 - ABBABBABBA - multilayer layout (4x Al, 3x BB).
- Sample 4 - ABBABBABABABA - multilayer layout (5x Al, 4x BB).
- Sample 5 - ABBABBABABBABBA - multilayer layout (6x Al, 5x BB).
- Sample 6 - ABBA - Classic layout, use of a gold-look surface.
After the measured values were entered into the calculation formula, the heat resistance values were plotted against the heat dissipation at a given temperature difference. It should be taken into consideration that these thermal resistance values define only the thermal insulating ability of the thermo-reflective insulation, which does not include unpowered airspaces that occur when the insulation is applied between the wooden grate, which will increase the value of the thermal resistance. The $R_T$ thermal resistances given in Table 1 were found at the highest set temperature gradient of 17 K and are shown.

Table 1. Overview of measured thermal $R_T$ values by Hot Box method for temperature gradient $\theta_{EX} = -2 \, ^\circ C$ and $\theta_{IN} = +15 \, ^\circ C$.

| Reflective thermal insulation sample | $R_T$ [m$^2$K/W] |
|-------------------------------------|-------------------|
| 3 x Al + 4 x BB not melted on surface (Al + BB + BB + Al + BB + BB + Al) | 1.555 ± 0.018 |
| 3 x Al + 4 x BB melted on surface (AlBB + BBAAl + BB + BBAl) | 2.424 ± 0.028 |
| 4 x Al + 6 x BB (Al + BB + BB + Al + BB + BB + Al + BB + BB + Al + BB + BB + Al) | 2.804 ± 0.033 |
| 5 x Al + 8 x BB (Al + BB + BB + Al + BB + BB + Al + BB + BB + Al + BB + BB + Al) | 2.448 ± 0.029 |
| Metallic Al foil ABBA (Al + BB + Al) | 0.760 ± 0.009 |
| 3 x Al + 2 x BB (AlBB + Al + BBAI) | 1.661 ± 0.020 |
| 2 x Al + 1 x BB (gold-look surface) (AlBB + Al/Au) | 1.003 ± 0.012 |

Note: The uncertainty values given are calculated at 95% confidence level.

5.3. Discussion of the results
From the measured values it was found that almost all aluminum foils of silver appearance have very good reflectivity. If the aluminum foil is plastic foiled, the reflectivity is lower, in some cases by tens percent. The gold-look coated aluminum foil has approximately half the worse reflection value on the opposite side of the silver look. The reflectance is also dependent on the thickness of the aluminum foil, the thicker film labelled TL exhibiting lower reflectivity values. It is therefore best to use classical aluminum foils of silver appearance of a smaller thickness for the layer of reflective foil insulation. The highest radiant emitting ability exhibits PE foil BB, thus exhibiting behavior is close to the physically black surface.

6. Conclusion
Experimental measurements of reflex thermal insulations proved the great advantages of these reflective materials and their use in construction. The most important component of heat transfer is radiation. It is because of this phenomenon that the emissivity of reflective surfaces is very important, which should be as low as possible so that the heat loss rate is as low as possible. It follows from the above that the higher the temperature gradient in the building structures, the more thermal insulation properties of the thermal reflective insulation are achieved. If the temperature reaches -15 °C in the exterior, the thermal resistance $R_T$ increases significantly.

Reflective insulation can be applied separately in the building without the use of any other insulators or combined with conventional insulators such as mineral wool. In any case, it is advisable to keep an air gap on both sides of the insulation which contributes little to its favourable thermal insulation properties.

Furthermore, the design, construction and calibration of a new measuring device for the thermal resistance measurement by the Hot Box method were realized. This measurement method serves to determine the thermal resistance $R$ only for reflective bubble insulation, allows the measurement of the samples in various ways of incorporation into the structure and at various widths adjacent to the air cavity. The thermal resistance of the test specimens is highly dependent on the layout of the stack and the type of sub-materials used.

Experimental measurements of reflective foils have shown that they have great potential for building use, but are a new, not thoroughly researched material. Three important physical properties
are combined in one building material: thermal insulation, vapour-proof properties and reflexive properties. The advantage of these materials is total recyclability, reducing the consumption of primary raw materials and reducing the insulation thickness required by current requirements for building structures.

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