ISSN 2029–1213

KAUNAS UNIVERSITY OF TECHNOLOGY

ADVANCED CONSTRUCTION 2012

PROCEEDINGS OF THE 3RD INTERNATIONAL CONFERENCE

The conference is dedicated to
the 90th Anniversary of the Establishment of
Kaunas University of Technology

18–19 October, 2012 Kaunas, Lithuania

TECHNOLOGIJA
KAUNAS • 2012

Conference is organized by:
Kaunas University of Technology, in cooperation with
Lithuanian Academy of Sciences.

The proceedings of the 3rd International Conference ADVANCED CONSTRUCTION contain selected papers and extended abstracts.

All papers were reviewed.

The style and language of authors were not corrected. Only minor editorial corrections have been carried out by the Publisher.

Proceedings of the
3RD INTERNATIONAL CONFERENCE ADVANCED CONSTRUCTION

18-19 October, 2012, Kaunas, Lithuania

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Heat Insulation Panels with Multilayer, Low-Emissivity Aluminum-Polyethylene Sheets

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Abstract. Buildings are large consumers of energy in all countries. The proper use of thermal insulation in buildings does not only contribute in reducing the required air-conditioning or heating size, reducing the thickness of walls but also in reducing the annual energy cost. As the heat flows through the building envelope (walls, roofs, floors) in the way of radiation, conduction and convection, there are buildings in which the radiation is the dominant method of heat transmission. Reflective Insulation System is formed by a combination of low emittance surfaces and air spaces that provide reflective cavities which have low levels of radiant energy transmission. In this research insulation panels with multilayer, low-emissivity aluminum-polyethylene sheets were prepared and investigated with a thermal box. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, as well as the number and thickness of air spaces, within the same total insulation thickness (40 mm). This study showed that surface emissivity and convection have important influence on heat flow. The aluminum-polyethylene sheets were effective in reflecting heat and reducing heat transfer by radiation.

Keywords: thermal insulation, reflective insulation system, insulation panels

INTRODUCTION

One of the most important research areas today is energy-efficient technologies such as heat insulation in buildings. Heat transfer in walls, windows, roofs and floors of both residential and nonresidential buildings such as shopping centers, supermarkets and factories have been investigated intensively since the first oil crisis (de Brito Filho *et al.* 2011). The investigations deal with the different concepts of external walls (Lindberg *et al.* 2004), double glass windows (Yang *et al.* 2006), ground heat exchangers (Kyriakis *et al.* 2006), building's orientation (Mingfangm, 2002), green roofs (Lazzarin *et al.* 2005), thermal-insulation thickness (Comahli *et al.* 2004), and other aspects.

Heat transfer occurs in three different ways: conduction, convection and radiation. Heat conduction is the transfer of heat due to molecular collisions. In solid materials, the molecules are nearly in contact with each other. This close proximity results in an easy transfer of thermal energy. Convection is the process whereby heat is transferred by the mass movement of molecules from one place to another. In free convection, the formation of convection currents depends on the property of the gas, the temperature difference, and the size of the air cavity. Radiation is heat transfer involving the change in energy form from internal energy at the source to electromagnetic energy for transmission then back to internal energy at the receiver. It plays a very important role in the heat transfer process both in gases and in vacuum (Incropera *et al.* 2007). Heat flow by radiation is commonly used with the term "Low E". The "E" stands for emittance and the values range from 0 to 1, with 0 being no radiation and 1 is the highest measure of emittance or radiation RIMA-I (2002). Mass insulation such as fiberglass, rock wool, and polystyrene foam use the high insulation capacity of air by segmenting it into small compartments. The heat conductivity of air is 0.025W/mK at 20ºC if the air molecules are not moving in the same direction (the convection effect is zero), and if the size or thickness of the air layer is more than 1mm (Zhang *et al.* 2009). Despite the relatively high insulation value of air, the above-mentioned insulation materials have heat conductivity value of around 0.04W/mK. The difference between the insulation values of air and of the insulation materials comes from the higher heat conductivity of the solid component (filament of fiber glass, rock wool, and polystyrene) of the insulation materials acting as heat bridges. Thus, one possible solution to decreasing the heat conductivity of an insulation material is to decrease the effect of heat bridges (Pasztory *et al.* 2011). Standard types of insulation, such as fiberglass, foam, and cellulose primarily reduce heat transfer by trapping air or some type of a gas. Thus, these products or technologies reduce convection as a primary method of reducing heat transfer. They are not as effective in reducing radiant heat transfer, which is often a primary mode of heat transfer in a building envelope, in fact, these products, like most building materials, have very high radiant transfer rates. In other words the surfaces of standard types of insulation are good radiators of heat.

Most building materials, including fiberglass, foam and cellulose have surface emittances or "E" values in excess of 0.70. Reflective insulations typically have "E" values of 0.03. Therefore, reflective insulation is superior to other types of insulating materials in reducing radiant heat. The term reflective, in reflective insulation, is in some ways a misnomer, because aluminum either works by reflecting heat (reflectance of ~ 0.97) or by not radiating heat (emittance of ~ 0.03). Whether stated as reflectivity or emissivity, the performance is the same RIMA-I (2002).When reflective insulation is installed in building cavities, it traps air (like other insulation materials) and therefore reduces heat flow by convection, thus addressing all three modes of heat transfer.

Reflective insulation is a thermal insulation with low levels of radiant energy transmission and consists of one or more low emittance surfaces, bounding one or more enclosed air spaces. In all cases, the reflective material must be adjacent to an air space. Aluminum, when sandwiched between two pieces of plywood for example, will conduct heat at a high rate. In fact, the metalized and foil materials commonly used in reflective insulation will reduce radiant heat transfer by as much as 97% RIMA-I (2002). Layers of aluminum or a low emittance material and enclosed air spaces, which in turn provide highly reflective or low emittance cavities adjacent to a heated region, typically form a reflective insulation system. Some reflective insulation systems also use other layers of materials such as paper or plastic to form additional enclosed air spaces. The performance of the system is determined by the emittance of the material, the lower the better, and the size of the enclosed air spaces. The smaller the air space, the less heat will transfer by convection. Therefore, to lessen heat flow by convection, a reflective insulation, with its multiple layers of aluminum and enclosed air space, is positioned in a building cavity (stud wall, furred-out masonry wall, floor joist, ceiling joist, etc.) to divide the larger cavity into smaller air spaces. These smaller trapped air spaces reduce convective heat flow RIMA-I (2002).The resistance of air space is a function of its thickness. Thinner air spaces have less resistance due to greater conduction. Thicker air spaces, on the other hand, have less resistance due to heat transfer from convection currents. Therefore, the optimum air space thickness in reflective insulation system should be used $\approx 20mm$ (Nisson *et al.* 1985).

Reflective insulation products incorporate trapped air spaces as part of the system. These air spaces, which may be layered or closed-cell, can be included in the system either when the product is manufactured or while it is being installed. In either case, the advertised performance of the insulation requires that these air spaces be present after the product is installed. The labeled resistance to heat flow (R-value) will not be achieved if the product is not installed correctly.

The thermal performance of the reflective system varies with the size and number of enclosed reflective spaces within the building cavity. Most reflective systems range from one to five enclosed air spaces. There are other beneficial considerations for using reflective insulation. Generally, these products have a very low water vapor and air permeance. When installed properly, with joints taped securely, reflective insulation materials are efficient vapor retarders and an effective barrier to air and radon gas RIMA-I (2002).

Most insulating materials work by creating miniature air spaces. Reflective insulation, on the other hand, uses larger air spaces faced with foil on one or both sides. The performance of reflective insulation depends on a number of factors (Budaiwi *et al.* 2002):

- The radiation angle of incidence on the reflective surface. The best performance of reflective insulation is achieved when radiation falls at a right angle of incidence on the reflective surface (perpendicular to the surface).
- The temperature difference between the spaces on both sides of the reflective material. The greater the temperature difference, the greater the benefits of the reflective insulation.
- The emissivity of the material. The lower the emissivity (the higher the reflectance) the better.
- The thickness of the air space facing the reflective material. Air space must exist on at least one side of the reflective insulation.
- The orientation of the air space.
- The direction of heat flow.

In addition to the reflective performance characteristics of reflective materials, other characteristics such as strength, flammability, availability, and oxidation should be considered (Dr. Al-Homoud, 2005). Aluminum is the material of choice to produce low-emittance facings with the emittance as low as 0.03, but as with many metals, oxidation can occur. (Budaiwi *et al.* 2002) Aluminum oxidation is a chemical reaction between oxygen and aluminum. If bare aluminum is exposed to an oxygen-rich environment, then a process called passivation will occur. Passivation is the spontaneous formation of a thin, protective oxide film which limits the potential for further corrosion. The rate at which aluminum-oxide forms, depends upon a number of factors including: metal purity, atmospheric conditions, and the presence of an existing oxide film. A low-emittance surface is the key component in any reflective insulation system; as such, the preservation of a facing's emittance value is essential in maintaining optimal thermal performance RIMA-I (2002).

Reflective insulation materials are designed for installation between, over, or under framing members, used together with or without mass insulation and as a result, are applicable to:

- Residential construction, new and retrofit – walls, basements, floors, ceilings, roofs, and crawl spaces;
- Commercial construction, new and retrofit – walls, floors, basements, ceilings, roofs, and crawl spaces;
- Manufactured housing construction, new and retrofit – walls, floors, roofs, and crawl spaces;
- Other uses in new and retrofit – water heater covers, cold storage units, poultry, and livestock buildings, equipment sheds, pipe insulation and recreational vehicles RIMA-I (2002).

The use of low-emissivity surfaces for reducing heat radiation has been well known for decades. This technology has been developed for space applications, like the heat insulation of spacecrafts. Heat reflection is important in space: there is no air pocket that is used in traditional heat insulation materials and radiation energy is higher than on Earth. Alifanov et al. (2009) investigated the modeling and other technical issues related to multilayer insulation systems. The multilayer reflecting foil as core material was used in vacuum insulation technology and it was found that when using multilayer reflecting foils, the radiation heat transfer decreased significantly (Known *et al.* 2009). The effect of radiant barriers with the combination of different insulation materials was investigated both theoretically and experimentally in hot climates and it was found that the foils could reflect a high percentage of heat energy and the effectiveness of foils at higher temperature was higher (Suehrcke *et al.* 2008). The reflected energy ratio can be increased on a light color roofing membrane after cleaning its soiled surface (Levinson *et al.* 2005). In addition, increasing the number of air cavities in a hollow block (building unit) increased the thermal resistance. However, the number of air cavities used did not increase the thermal resistance linearly (Antar *et al.* 2009).

In this study insulation panels with multilayer, low-emissivity aluminum-polyethylene sheets were prepared and investigated. The overall objective of this research is the development of an economical, high-efficiency heat insulation system for residential and public buildings by using different reflecting materials. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, within the same total insulation thickness.

METHODS

Reflective insulation reduces heat transfer by radiation. Materials react to radiant energy falling on them through the following ASHARE (2001):

- Absorptance (α): fraction of incident radiation absorbed through the material.
- Transmittance (τ): fraction of incident radiation transmitted through the material.
- Reflectance (ρ): fraction of incident radiation reflected by the material.

Therefore,

$$\alpha + \tau + \rho = 1 \quad (1)$$

For opaque surfaces: $\tau = 0$ and $\alpha + \rho = 1$; for a black surface $\tau = 0$; $\rho = 1$ and $\alpha = 1$. Reflective (polished) surfaces are characterized by high reflectance and, therefore, low emittance (ε); material's ability to diffuse radiant energy ($\varepsilon = \alpha$, for gray surfaces), which makes them effective in reducing radiant heat transfer in buildings. The emittance is a function of the material, and the condition and temperature of its surface.

The reflective insulation works as follows (Lechner, 2001):

- Heat from hot surfaces radiates in a straight line to other cooler surfaces surrounding them. The reflective insulation (radiant barrier) reduces radiant heat transfer from such hot surfaces (e.g., roof or wall) to cooler spaces (e.g., attic or living space).
- The reflective insulation must be both a poor emitter (≤ 0.1 emittance) and a poor absorber (good reflector, ≥ 0.9 reflectance) of thermal radiation.
- The first layer of reflective insulation is the most effective (stops about 95% of radiant heat flow). Additional layers of reflective insulation create additional air spaces that reduce convection heat flow.
- Although radiation is independent of orientation, convective heat flow depends greatly on both the orientation of the air space and the direction of heat flow.
- The resistance of air spaces and reflective insulation varies with their location in the structure and the time of the year (direction of heat flow).

White color is also effective in minimizing heat transfer into buildings because it is not only a poor absorber of energy but also a good emitter.

To increase heat resistance, it is better to use a surface with a very low emissivity (e.g. aluminum). A thin aluminum foil has a higher reflecting property than that of an aluminum plate (Kostic *et al.* 2010), but the foil has a very low tensile strength. An aluminum foil reinforced with polyethylene is commercially available and was used in this study. The aluminum–polyethylene sheet has the mechanical integrity to withstand rough handling during manufacture and construction, while retaining low emissivity. The aluminum side of the sheet has a surface emissivity of 0.05 while the polyethylene side has a surface emissivity of 0.5.

For Latvia's climate conditions multi-layer structure with n layers of the resulting thermal resistance can be calculated as the sum of the individual layers of thermal resistance and adding to the resulting value also the thermal resistances of outdoor R_a and indoor R_i thermal boundary layers.

$$R = R_a + R_1 + R_2 + ... + R_n + R_i (m^2 K / W) \tag{2}$$

The resistances of thermal boundaries are determined by standard LVS ISO EN 6946. Their values depend on whether the heat flow direction is directed horizontally or vertically, upward or downward. Vertical heat flow (upward), for example, R_i=0,10 m^{2}K/W and R_a=0,04 m^{2}K/W.

Homogeneous k-layer thermal resistance is calculated using the thickness d_k (m) and the heat conduction λ_k (W/mK), according to the formula:

$$R_k = \frac{d_k}{\lambda_k} \tag{3}$$

If the layer is not homogeneous, for example, hollow bricks, frame construction, Keraterm blocks etc., then an effective thermal conductivity is used in calculation, which is determined by measurements or calculations:

$$R_k = \frac{d_k}{\lambda_{ef.k}} \tag{4}$$

Thus, opaque structures, through which is no air flow and where there are no microscopic air inclusions, the resulting heat resistance can be calculated relatively easily.

If constructions single k-layer is made of air gap or with any other gas-filled gap, then the layer's thermal transmittance U_k (W/m^{2}K) and it's correspond thermal resistance R_k=1/U_k are determined by three physical mechanisms of heat transfer:

- gas convective movement in a gap, which intensity depends on the properties of gas thermal expansion and temperature differences;
- infrared radiation from surfaces, which are in contact with the transparent medium (gas);
- gas thermal conductivity.

The gas thermal conductivity usually has a minor role in the heat transfer of these layers, for example, air's thermal conductivity is 0.027 (W/mK). Generally, if the materials' surface emission coefficient ε values are greater than 0.9 (concrete, bricks, plasterboard), the most important is the heat transfer through radiation. If the material's, which is facing the gas gap, surface emission coefficient value decreases (for polished aluminum surface $\varepsilon \leq 0.1$), it also reduces the radiant heat exchange intensity. The convective heat exchange can be reduced using gas with a low thermal expansion coefficient for gap filling. This method is used in glass packets, which are hermetically sealed. However, in practice, in lamellar constructions (except the mentioned glass packages) the filling gas is air LU FMF (2005).

Thus, practically the only way how to reduce heat exchange between these layers is the use of surface coatings or materials with low heat emission factor. Since the radiation intensity varies in proportion to the absolute temperature's fourth grade (T^4), then the heat resistance of these layers is a nonlinear function of surface temperature and convective flow, as already mentioned above:

$$R = \left(E \cdot h_r + h_c\right)^{-1} = \frac{\Delta T}{Q} \tag{5}$$

where h_r and h_c (W/m^{2}K) are during the heat exchange (permeability) of radiation and convection towards characterized parameters. [Reflective Insulation Manufacturers Association International]

Convective heat transfer coefficient is determined through experimental measurements and tabulated as a two-argument (surface temperatures' difference and mutual surfaces' distance) function: $h_c = h_c\left(T_2 - T_1, d\right)$.

Radiation heat transmission parameter h_r is calculated according to the formula:

$$h_r = 0,5 \cdot \sigma \cdot E\left(T_1 + T_2\right)^3 \tag{6}$$

where $\sigma = 5,67032 \cdot 10^{-8} (W / m^2 \cdot K^4)$ - radiation characterizing Stephan-Bolcman constant LU FMF (2005).

According to Reflective Insulation Manufacturers Association the mutual radiation factor E of two parallel surfaces is calculated from the opposite surface emission factors ε_1 and ε_2 RIMA-I (2002):

$$E = \left(\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1 \right)^{-1} \tag{7}$$

Thus, to determine such multi-layered constructions the resulting thermal resistance has to be tasked with the air temperature on both sides of the buildings (T_i- inside and T_a – outside) and then the nonlinear equation systems, that are showed above, have to be solved, assuming that the parameters, which are characterizing the construction's layers: d_k, λ_k, R_i, R_a and ε_i are given LU FMF (2005).

To investigate the effect of the number of reflecting aluminum–polyethylene sheets within the same insulation thickness, a series of experiments has to be conducted using a panel with the same shape and size. The size of the panel is limited to 300mm×300mm for it to accommodate the heat conductivity measuring device. Each panel contains three parts: the bottom plate, the top plate, and the space between the two plates (which henceforth will be referred to as the air field). The bottom and top plates of the panel are made from 3.2 mm thick pressed cardboard. The side elements are made from 15mm×40mm pine lumber. Thus, the distance between the bottom and top plates is 40mm and has to be kept constant throughout the series of experiments.

The temperatures of:

- heating plate (lower plate) + 20 ºC;
- cooling plate (upper plate) 0 ºC.

The heat transfer through each of the panels was modeled using Hot Box FOX600, the experimental duration for one panel was 2 to 3 hours.

The heat flow was organized in normal direction from lower plate to upper plate, one – dimensional.

For the investigation 6 different panel types were made, respectively:

Panel 1: The 40-mm air field is bordered by pressed cardboard surfaces with 0.9 emissivity.

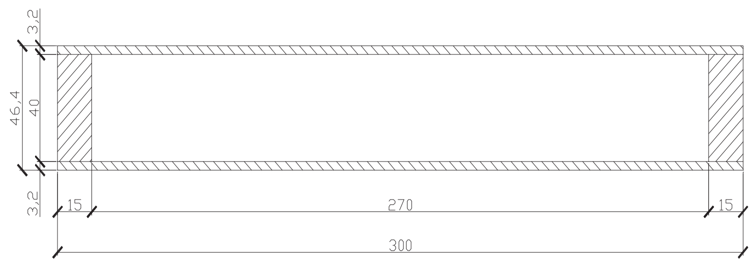

Figure 1. Panel №1

Panel 2: The inner surfaces of the bottom and top plates are lined with a 0.05 emissivity aluminum foil. In comparison to the previous panel, only the surface emissivity property is changed.

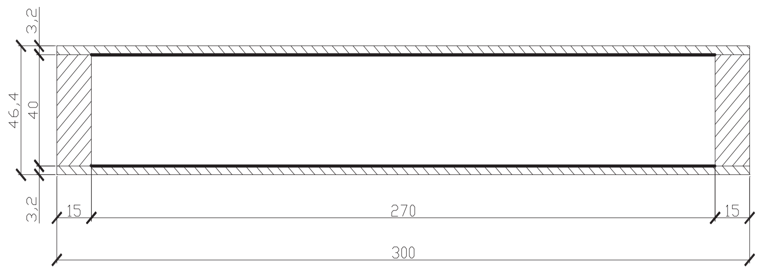

Figure 2. Panel №2

Panel 3: The side elements of Panel 2 are cut into two parts and an aluminum–polyethylene sheet (2mm thick) is fastened in between. Thus, the sheet divides the 40 mm distance between the top and bottom plates into two equal air cavities that are parallel with the plates. Henceforth, the terms "air cavity" and "air space" will be used interchangeably to refer to the space between a sheet and a plate, or the space between sheets (see description for Panels 4–6). This is different from the term "air field", which as mentioned earlier is the whole space between the top and bottom plates. Aluminium foil is with 0.05 emissivity; polyethylene – with 0.5 emissivity.

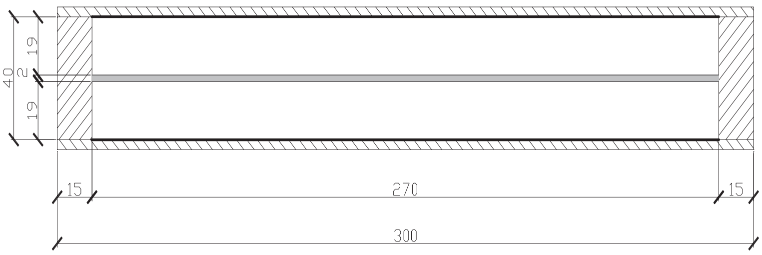

Figure 3. Panel №3

Panel 4: The air field is divided into four equal cavities using three aluminum–polyethylene sheets. Thus, the panel consists of three stretched sheets and four air cavities.

Panel 5: The air field is divided into six equal air cavities using five aluminum–polyethylene sheets.

Panel 6: The air field is divided into 8 equal air cavities using seven aluminum–polyethylene sheets.

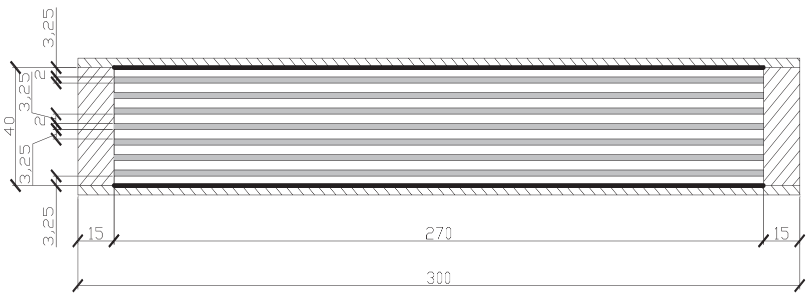

Figure 4. Panel №6

RESULTS

In this research insulation panels with multilayer, low-emissivity aluminum-polyethylene sheets were prepared and investigated with a thermal box. This study was intended to determine the effect of radiation in a heat insulating system that uses multiple thermal reflection sheets to divide the cavity within the wall. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, as well as the number and thickness of air spaces, within the same total insulation thickness (40 mm). Also this study showed that surface emissivity and convection have important influence on heat flow. The aluminum-polyethylene sheets were effective in reflecting heat and reducing heat transfer by radiation.

Table 1. Experimental and calculated R-Values

Panel Type	Inside surface of bottom & top plates	Number of AL-PE sheet	Number of air cavities in the air field	Thickness of each sample (mm)	Thickness of each air cavity (mm)	R – Value, m^2K/W		
						Experimental R - Value; AL sheet facing lower plate	Experimental R - Value; AL sheet facing upper plate	Calculated R-Value
1	Pressed card board	0	1	45.54	40	0,3677	0,3677	0,3449
2	Aluminium foil	0	1	45.21	40	0,6057	0,6057	0,6766
3	Aluminium foil	1	2	46.73	19	0,9144	0,8855	1,3577
4	Aluminium foil	3	4	46.22	8.5	1,3194	1,4250	1,3863
5	Aluminium foil	5	6	46.12	5	1,3129	1,2893	1,4141
6	Aluminium foil	7	8	46.07	3.25	1,3165	1,3153	1,4793

After analyzing the effects of changing the number of reflecting layers within the same insulation thickness, the following results can be summarized:

1. Surfaces with low emission properties (aluminium foil, polyethilene sheets) were found to influence heat flow and heat radiation existing in building construction significantly. As shown in figure 5, more than 50% of heat flow decrease was observed when the inner surfaces of the bottom and top plate were lined with aluminium foils. In European wood frame residential buildings, polyethylene foil is commonly used as vapor barrier with 0.9 to 0.95 surface emissivity. Replacing the polyethylene foil with aluminum foil or aluminum-polyethylene sheet could result in an increase in the thermal resistance of the wall construction.

2. Increasing the number of reflective sheets between the plates resulted in lower effective heat conductivities. By increasing just one sheet, it was possible to obtain a thermal resistance equal to those of commonly used insulation materials. The thermal resistance of insulation system approached that of stagnant air as more sheets were inserted. The relationship between the thermal resistance and the number of sheets is not linear (see figure 5). The first inserted sheet had the highest effect (the result of panel 4 is not taken in account) and each additional sheet had less influence on heat resistance.

3. The relationship between the thermal resistance and the number of air cavities is also not linear.

The number of the air cavities varied from zero to seven, and their thickness according to the amount from 40 mm to 3,25 mm. The optimal number of sheets and the air cavity width should be further investigated for different wall constructions. Finite element modeling (FEM) and experiments should be used.

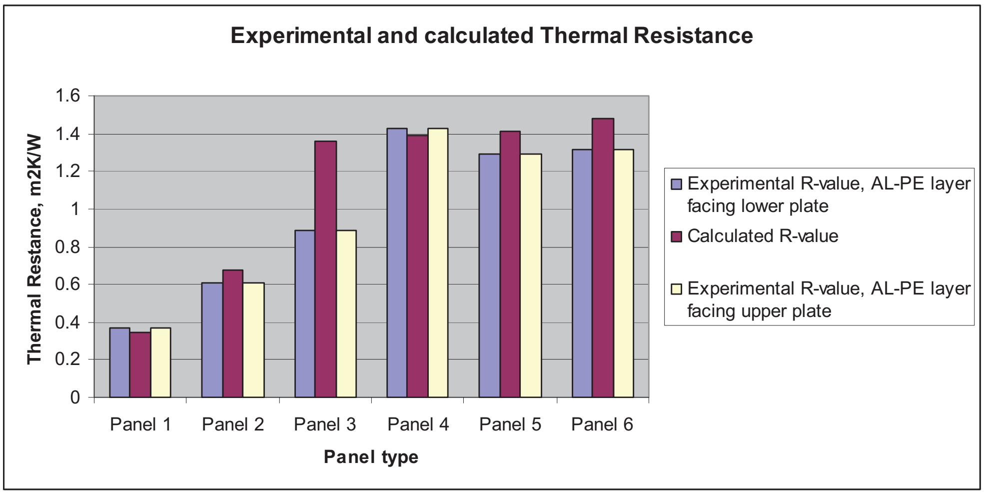

Figure 5. Experimental and calculated thermal resistance

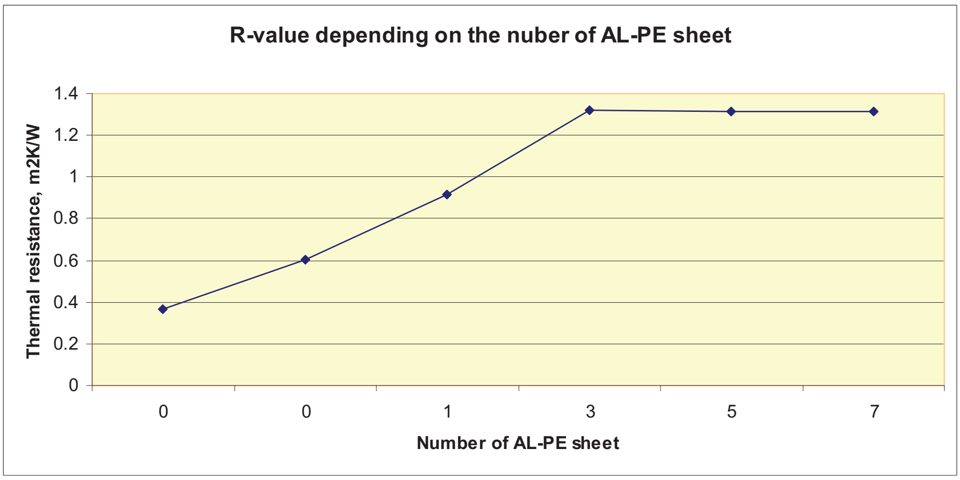

Figure 6. R-values depending on the number of AL-PE sheet

4. The material reflectivity has influence on thermal resistance. Aluminium foil has a lower emmitance 0.05 than polyethylene sheet 0.5, that's why the thermal resistance for AL-PE sheet facing lower plate is higher than

the resistance, where AL-PE sheets are facing upper plate (except Panel 4). So as the heat is moving from warmer surface to a colder surface, a higher reflective surface has to face the side, where the temperature is higher.

DISCUSSION

According to the results, Panel 4 has the highest R-value. Theoretically it's not right because as more aluminum polyethylene sheets are used in panel construction as higher is the thermal resistance. Also looking at the results of Panel 4, the thermal resistance for AL-PE sheet facing upper plate is higher than the resistance, where AL-PE sheets are facing lower plate, but it should be opposite. Aluminum foil has a lower emmitance 0,05 than polyethylene sheet 0,5. So as the heat is moving from warmer surface to a colder surface, a higher reflective surface has to face the side, where the temperature is higher. The incorrect results for the panel 4 can be explained with the aluminum foil unstick from pressed cardboard plates during the experiment. Additional air gaps were created and this could cause the false measurements.

As shown in figure 4, Panel 3 has the highest difference between theoretical and experimental values. This can be explained that the aluminum sheets that were glued to the cardboard plates hadn't the emmitance of aluminum surface 0.05. Also heat flow leakages could have occurred during the experiment.

The amount of formulas that were used for the theoretical calculation, doesn't give exact results and precise description of the material workability. Because the mathematical calculations in multilayer insulation don't involve surface changes according to heat flow direction, that's why the theoretical results for aluminum-polyethylene sheet facing lower plate and upper plate are the same. Here a Finite element modeling (FEM) should be used to get appropriate results; it would also show the working properties of a multilayer insulation by changing the reflective material sheet amount and direction.

CONCLUSIONS

This study has resulted in the development of an efficient heat insulation system by simply using aluminum-polyethylene sheets to divide the air field within a residential and public building envelope. This approach proved effective in reducing heat transfer by radiation, convection and conduction by decreasing surface emissivity, minimizing convection currents, and eliminating micro heat bridges, respectively. Full size heat insulation panel systems with multilayer-aluminum sheets need to be built in order to analyze the feasibility of production, to determine the heat resistance of this system in practice, and to compare the results with other insulation systems. Also FEM modeling should be used to get better view of reflective insulation material working properties.

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HEAT INSULATION PANELS WITH MULTILAYER, LOW-EMISSIVITY ALUMINUM-POLYETHYLENE SHEETSS

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Kaunas University of Technology
3rd International Conference
ADVANCED CONSTRUCTION
18-19 October 2012
Kaunas , Lithuania

1. INDRODUCTION

Buildings are large consumers of energy in all countries. The proper use of thermal insulation in buildings does not only contribute in reducing the required air-conditioning or heating size, reducing the thickness of walls but also in reducing the annual energy cost. As the heat flows through the building envelope (walls, roofs, floors) in the way of radiation, conduction and convection, there are buildings in which the radiation is the dominant method of heat transmission. Reflective Insulation System is formed by a combination of low emittance surfaces and air spaces that provide reflective cavities which have low levels of radiant energy transmission.

In this research insulation panels with multilayer, low-emissivity aluminum-polyethylene sheets were prepared and investigated with a thermal box. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, as well as the number and thickness of air spaces, within the same total insulation thickness (40 mm). This study showed that surface emissivity and convection have important influence on heat flow. The aluminum-polyethylene sheets were effective in reflecting heat and reducing heat transfer by radiation.

2. OBJECTIVES

The overall objective of this research is the development of an economical, high-efficiency heat insulation system for residential and public buildings by using different reflecting materials. The investigation includes the analysis of the effects of changing the number of reflecting layers, ranging from zero to seven, within the same total insulation thickness.

3. MATERIALS AND METHODS

To investigate the effect of the number of reflecting aluminum–polyethylene sheets within the same insulation thickness, a series of experiments has to be conducted using a panel with the same shape and size. The size of the panel is limited to 300mm×300mm for it to accommodate the heat conductivity measuring device. Each panel contains three parts: the bottom plate, the top plate, and the space between the two plates (which henceforth will be referred to as the air field). The bottom and top plates of the panel are made from 3.2 mm thick pressed cardboard. The side elements are made from 15mm×40mm pine lumber. Thus, the distance between the bottom and top plates is 40mm and has to be kept constant throughout the series of experiments. The heat transfer through each of the panels was modeled using Hot Box FOX600, the experimental duration for one panel was 2 to 3 hours. The heat flow was organized in normal direction from lower plate to upper plate, one – dimensional.
For the investigation 6 different panel types were made, respectively:

Panel 1: The 40-mm air field is bordered by pressed cardboard surfaces with 0.9 emissivity.

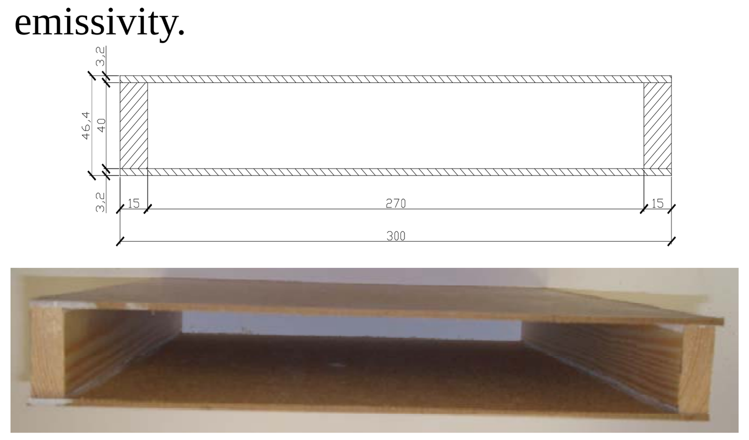

Figure 3.1. Panel №1

Panel 3: The side elements of Panel 2 are cut into two parts and an aluminum–polyethylene sheet (2mm thick) is fastened in between. Thus, the sheet divides the 40 mm distance between the top and bottom plates into two equal air cavities that are parallel with the plates. Henceforth, the terms “air cavity” and “air space” will be used interchangeably to refer to the space between a sheet and a plate, or the space between sheets (see description for Panels 4–6). This is different from the term “air field”, which as mentioned earlier is the whole space between the top and bottom plates. Aluminium foil is with 0.05 emissivity; polyethylene – with 0.5 emissivity.

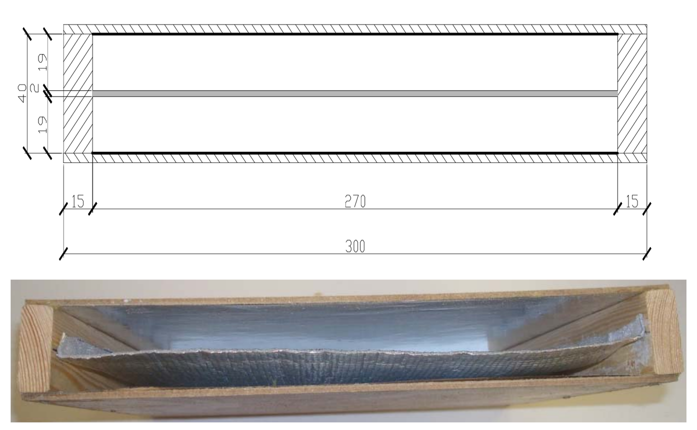

Figure 3.3. Panel №3

Panel 2: The inner surfaces of the bottom and top plates are lined with a 0.05 emissivity aluminum foil. In comparison to the previous panel, only the surface emissivity property is changed.

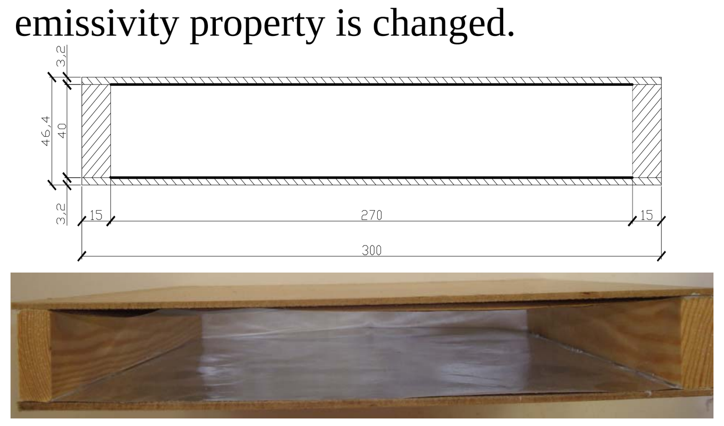

Figure 3.2. Panel №2

Panel 4: The air field is divided into four equal cavities using three aluminum–polyethylene sheets. Thus, the panel consists of three stretched sheets and four air cavities.

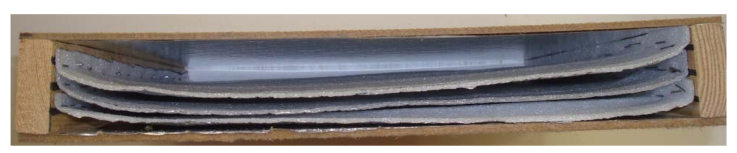

Figure 3.4. Panel №4

Panel 5: The air field is divided into six equal air cavities using five aluminum–polyethylene sheets.

Figure 3.5. Panel №5

Panel 6: The air field is divided into 8 equal air cavities using seven aluminum–polyethylene sheets.

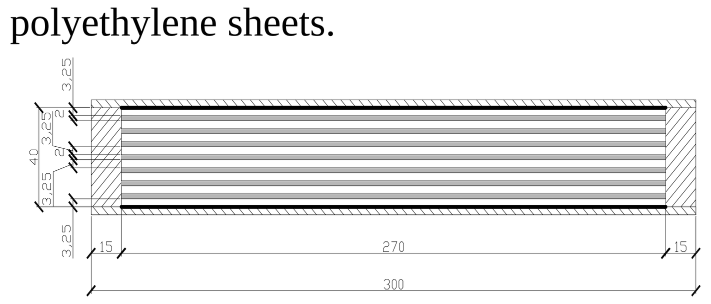

Figure 3.6. Panel №6

4. RESULTS AND DISCUSSIONS

Table 4.1. Experimental and calculated R-Values

Panel Type	Inside surface of bottom & top plates	Number of AL-PE sheet	Number of air cavities in the air field	Thickness of each sample (mm)	Thickness of each air cavity (mm)	R – Value, m^2K/W: Experimental R - Value; AL sheet facing lower plate	Experimental R - Value; AL sheet facing upper plate	Calculated R-Value
1	Pressed card board	0	1	45.54	40	0,3677	0,3677	0,3449
2	Aluminium foil	0	1	45.21	40	0,6057	0,6057	0,6766
3	Aluminium foil	1	2	46.73	19	0,9144	0,8855	1,3577
4	Aluminium foil	3	4	46.22	8.5	1,3194	1,4250	1,3863
5	Aluminium foil	5	6	46.12	5	1,3129	1,2893	1,4141
6	Aluminium foil	7	8	46.07	3.25	1,3165	1,3153	1,4793

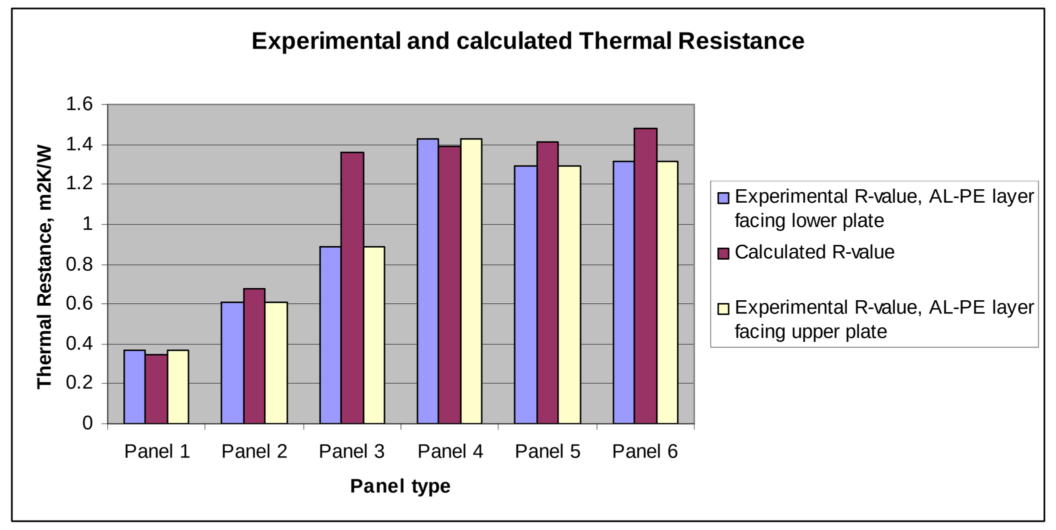

Figure 4.1. Experimental and calculated thermal resistance

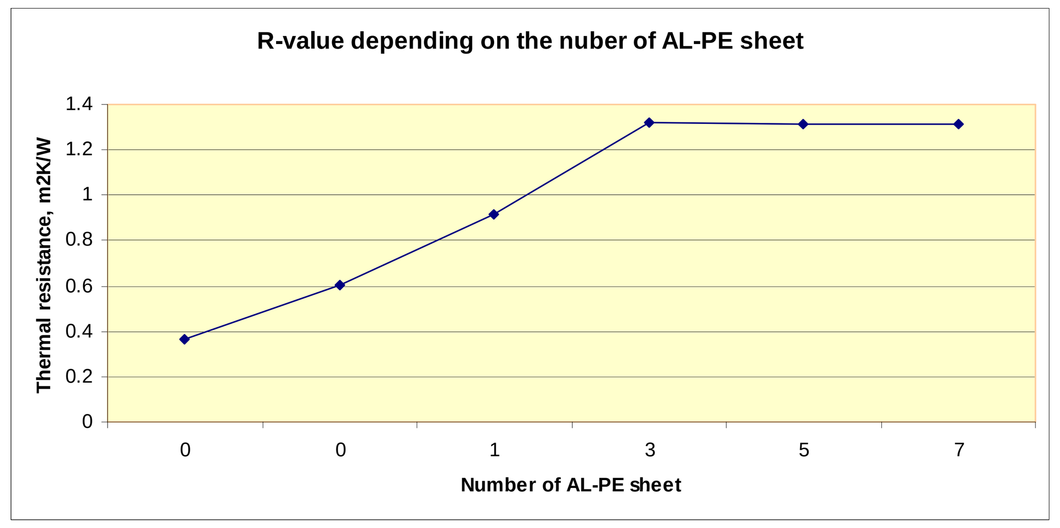

Figure 4.2. R-values depending on the number of AL-PE sheet

This study showed that surface emissivity and convection have important influence on heat flow. The aluminum-polyethylene sheets were effective in reflecting heat and reducing heat transfer by radiation.
After analyzing the effects of changing the number of reflecting layers within the same insulation thickness, the following results can be summarized:

1. Surfaces with low emission properties (aluminium foil, polyethilene sheets) were found to influence heat flow and heat radiation existing in building construction significantly. As shown in figure 5, more than 50% of heat flow decrease was observed when the inner surfaces of the bottom and top plate were lined with aluminium foils. In European wood frame residential buildings, polyethylene foil is commonly used as vapor barrier with 0.9 to 0.95 surface emissivity. Replacing the polyethylene foil with aluminum foil or aluminum-polyethylene sheet could result in an increase in the thermal resistance of the wall construction.
2. Increasing the number of reflective sheets between the plates resulted in lower effective heat conductivities. By increasing just one sheet, it was possible to obtain a thermal resistance equal to those of commonly used insulation materials. The thermal resistance of insulation system approached that of stagnant air as more sheets were inserted. The relationship between the thermal resistance and the number of sheets is not linear (see figure 5). The first inserted sheet had the highest effect (the result of panel 4 is not taken in account) and each additional sheet had less influence on heat resistance.
3. The relationship between the thermal resistance and the number of the air cavities is also not linear. The number of the air cavities varied from zero to seven, and their thickness according to the amount from 40 mm to 3,25 mm. The optimal number of sheets and the air cavity width should be further investigated for different wall constructions. Finite element modeling (FEM) and experiments should be used.
4. The material reflectivity has influence on thermal resistance. Aluminium foil has a lower emmitance 0.05 than polietylene sheet 0.5, that’s why the thermal resistance for AL-PE sheet facing lower plate is higher than the resistance where AL-PE sheets are facing upper plate (except Panel 4). So as the heat is moving from warmer surface to a colder surface, a higher reflective surface has to face the side where the temperature is higher.

According to the results, Panel 4 has the highest R-value. Theoretically it’s not right because as more aluminum polyethylene sheets are used in panel construction as higher is the thermal resistance. Also looking at the results of Panel 4, the thermal resistance for AL-PE sheet facing upper plate is higher than the resistance, where AL-PE sheets are facing lower plate, but it should be opposite. Aluminum foil has a lower emmitance 0,05 than polyethylene sheet 0,5. So as the heat is moving from warmer surface to a colder surface, a higher reflective surface has to face the side, where the temperature is higher. The incorrect results for the panel 4 can be explained with the aluminum foil unstick from pressed cardboard plates during the experiment. Additional air gaps were created and this could cause the false measurements.
As shown in figure 4, Panel 3 has the highest difference between theoretical and experimental values. This can be explained that the aluminum sheets that were glued to the cardboard plates hadn’t the emmitance of aluminum surface 0.05. Also heat flow leakages could have occurred during the experiment.
The amount of formulas that were used for the theoretical calculation, doesn’t give exact results and precise description of the material workability. Because the mathematical calculations in multilayer insulation don’t involve surface changes according to heat flow direction, that’s why the theoretical results for aluminum-polyethylene sheet facing lower plate and upper plate are the same. Here a Finite element modeling (FEM) should be used to get appropriate results; it would also show the working properties of a multilayer insulation by changing the reflective material sheet amount and direction.

5. CONCLUSIONS

Heat transfer occurs in three different ways: conduction, convection and radiation. Most building materials, including fiberglass, foam and cellulose have surface emittances or “E” values in excess of 0.70. Reflective insulations typically have “E” values of 0.03. Therefore, reflective insulation is superior to other types of insulating materials in reducing radiant heat. The term reflective, in reflective insulation, is in some ways a misnomer, because aluminum either works by reflecting heat (reflectance of ~ 0.97) or by not radiating heat (emittance of ~ 0.03). When reflective insulation is installed in building cavities, it traps air (like other insulation materials) and therefore reduces heat flow by convection, thus addressing all three modes of heat transfer.

This study has resulted in the development of an efficient heat insulation system by simply using aluminum-polyethylene sheets to divide the air field within a residential and public building envelope. This approach proved effective in reducing heat transfer by radiation, convection and conduction by decreasing surface emissivity, minimizing convection currents, and eliminating micro heat bridges, respectively. Full size heat insulation panel systems with multilayer-aluminum sheets need to be built in order to analyze the feasibility of production, to determine the heat resistance of this system in practice, and to compare the results with other insulation systems. Also FEM modeling should be used to get better view of reflective insulation material working properties.

6. ACKNOWLEGEMENT

Access to the laboratory of Professor Group of Building Materials and Products is acknowledged. Author would like to thank master thesis supervisor Patricija Kara for advices and support during research work.

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