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Improved heat insulation system (Mirrorpanel) for construction of wood buildings

Abstract: A new thermal insulation system (Mirrorpanel) based on an effective thermal insulation of the air by multiple heat reflection of the radiation heat flux was produced at the Innovation Center of the University of West Hungary. The system was created for wood frame structure buildings where the units of the framework provide the fixing points. In the panels of the new system, there are narrow air fields with high thermal resistance and the lamellae in the field have low surface emission properties, which reflect a considerable part of heat radiation. This system of heat reflection and the narrow air fields was formed with the help of stretched foils. Based on the results of tests gained from the small and medium-sized insulation panels, a life-size test building was constructed, where the performance and conduct of the Mirrorpanel can be continuously studied.

Keywords: energy saving, heat bridges, heat conductivity, recycled paper, wood frame structure, wood houses, wood panels

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Introduction

Increasing the energy efficiency of a building is a pressing need because of the shortage and growing price of energy (Grösche 2009; Omer 2009). Obviously, this goal can be reached at low cost by the improvement of the insulation of wall structures. Besides increasing the thickness of the insulation layers, the elevation of the thermal insulation of the air is a rewarding alternative. New product developments in this field should afford a sustainable development of wood buildings and should be environmentally benign (Perez-Garcia et al. 2005).

The transmission of heat in air occurs by conductivity, convection, and radiation. The most common insulation materials include the little air bubbles inside and block the convection of heat flux effectively. The solid material that surrounds the bubbles form "heat bridges" in the system; thus, the insulation of the material is higher than that of the thermal insulation capacity of the air. Better isolation materials can be developed by lowering the effects of heat bridges and heat radiation (Medina 2000; Pásztory 2007; Kwon et al. 2009). In the past decades, several studies focused on the application of the air layers inside the structures and on the reduction of the heat flux via radiation (Alifanov et al. 2009; Antar and Baig 2009). Besides theoretical considerations, the practical measurements and solutions for the praxis were published (Niemz et al. 2007; Niemz and Sonderegger 2011; Joščák et al. 2012).

The heat radiation in gas has an exceptionally high importance. This property is greatly influenced by the emission property and temperature difference of the boundary layers (Abhishek et al. 2007). The surface emission value characterizes the absorbed energy ratio from radiated thermal energy. The absorption number corresponds to the emission number, which is the emitted ratio of thermal energy. The temperature difference and the thickness of the air layer determine the air circulation effect named convection, which can be characterized by the dimensionless numbers of Grashof and Prandtl (Basak et al. 2011; Ermolaev et al. 2011; Pásztory et al. 2011). Inspired by these factors, the concept of the present article was to form narrow air layers with the help of heat-reflecting foils within the wall structure. The choice of the foil was influenced by the heat reflection quality, the price, the vapor permeability, and the environmental considerations. The importance of vapor movements for wood construction was summarized by Gereke et al. (2010).

With these requirements in focus, the Innovation Center at the University of West Hungary developed a new environment-friendly insulation system based on the improvement of the thermal insulation of the wooden panels in a consortium of three contracting parties. Specifically, the space within the framework should be improved by forming narrow-spaced and parallel air layers, which slow down the heat flux to a minimum by the multiple reflection of heat radiation. The system should reduce the effects of "heat bridges" in the insulation. The present article is a preliminary report on the project.

Materials and methods

Theoretical considerations

The reduction of the heat bridge effect is possible by means of parallel stretched layers perpendicular to the heat flow. As mentioned above, the effectiveness of an insulation system is determined by thermal conduction, convection, and radiation.

The determination of the first one is the simplest, where the heat flow depends on the thermal conductivity of the material (λ) and the thermal difference in the boundary layers (Δt) and the magnitude of the surface (A):

$$\dot{Q}=-\lambda\times A\times\frac{\Delta t}{\Delta x}. \tag{1}$$

The value of λ of normal air under static condition is 0.024 W m^{-1} K^{-1}. Lower values can be achieved only by removing air from the system (i.e., in vacuum) or by replacing air by gases with lower λ, such as argon or krypton. Obviously, this is technically difficult and expensive.

The determination of convection effect is more complicated. Practically, it can be calculated by means of equivalent thermal conductivity (λ_e), which means the combined effect of conduction and convection. The ratio between them is calculated by flow value (e), which is a dimensionless number:

$$e=\frac{\lambda_e}{\lambda}. \tag{2}$$

The flow value depends on the Grashof (Gr) and Prandtl (Pr) dimensionless numbers:

$$e=f(Gr\times Pr). \tag{3}$$

If the product of the Grashof and Prandtl number is <1000, the value of e is 1, that is, the convection effect is zero (Mihajev 1990). For the calculation of the Prandtl number, the coefficient of thermal conductivity (λ), the dynamic viscosity (μ), and specific heat (c_p) are needed:

$$Pr=\frac{\mu\times c_p}{\lambda}. \tag{4}$$

For calculation of the Grashof number, the following parameters are necessary: the thermal coefficient of expansion (β), the gravitational acceleration (g), the thickness of the air layer (δ), the thermal difference of the two boundary layers (ΔT), and the kinematic viscosity (ν):

$$Gr=\frac{\beta\times g\times\delta^3\times\Delta T}{\nu^2}. \tag{5}$$

By means of these equations, the thickness of air layers (δ), which are not affected by convection, can be calculated.

The third physical effect is the radiation described by the radiation coefficient. In the present article, this is a mutual emission coefficient between the two surfaces. The emission coefficient is for the individual surface property. Energy transfer by radiation between two surfaces is described:

$$G_{1,2}=\sigma\times\varepsilon_{1,2}\times(T_1^4-T_2^4). \tag{6}$$

where σ is the Stefan-Boltzmann constant, $\varepsilon_{1,2}$ is the radiation coefficient between two surfaces, and the expression in parentheses is the biquadratic difference of temperatures (T). The radiation coefficient ($\varepsilon_{1,2}$) is the only factor in the equation, which can be modified by changing the property of the foil surface. The calculation method for $\varepsilon_{1,2}$ (i.e., ε between two surfaces) is presented in Equation (7):

$$\varepsilon_{1,2}=\frac{1}{\frac{1}{\varepsilon_1}+\frac{1}{\varepsilon_2}-1}. \tag{7}$$

If the ε of surfaces is low, the mutual radiation coefficient is also low. In the case of aluminum foils, for example, an ε of 0.05 results in 0.025 mutual radiation coefficient between two surfaces. In case of polyethylene foils with ε 0.95, the mutual radiation coefficient is 0.90. This is the reason why high attention was paid for the emission coefficient of the foils applied in the Mirrorpanel system.

Foils in the Mirrorpanel system

Heat reflective foils and the optimal distances between them were tested with small size (500×500 mm) specimens (Figure 1a). The distances 3, 5, and 7 mm were tested; expectedly, the best thermal resistance was reached with 3 mm. However, the distance reduction from 5 to 3 mm almost doubles the numbers of foils (and the material costs), but the thermal resistance is not improved proportionally. Thus, the 5 mm air gap was selected as an economically viable solution. In the experiment, not only the air-field thickness played an important role but also the reflection effects between them.

Recycled paper (260 g m^{-2}) was chosen for the foil material because it has more favorable qualities than aluminum, polyethylene, or textile. The paper surface has an emission value of 0.9, that is, the surface of the paper absorbs 90% of the irradiated energy. A special coating was applied, which reduces mainly the long-wave heat radiation to ε of 0.35. A coating was developed to this purpose, which contains a special pigment and an adhesive. Both sides of the paper surface were covered with aluminum plate-shaped pigments to the highest possible extent. After the surface treatment, the paper has to remain the vapor permeability, which needs a special adhesive. The coating was applicated by painting or by spraying.

The distance between foils in the air fields is kept by a cellulose distance holder, which is fixed to the foils and the wall framework by stapling. The distance holders are small (1.5×0.5 cm) for minimizing the heat bridges and placed on the edge of the foils and one on the middle. The heat conductivity of distance holder is low (0.06 W m^{-1} K^{-1}). The surface of the distance holders is ~8.8% of the whole surface.

The heat bridge effect caused by the wood framework and the covering fiber-reinforced gypsum board was studied on a 2×1.2 m large panel. The framework was made of 6×16 cm spruce and the frame systems were covered with fiber-reinforced gypsum boards on both sides. The wood frame elements built-in at the top and bottom parts of the panel are 6 cm wide but on the long sides are only 3 cm. Wood elements cause significant heat bridges in the system. The other half of the wood frames belongs to the next gypsum board. Large panels were constructed by screwing, whereas the Mirrorpanel system was fixed to the wood frame structure with stapling. Figure 1b shows the cross-section of the wall filled with Mirrorpanel insulation. The properties of wall layers are given in Table 1.

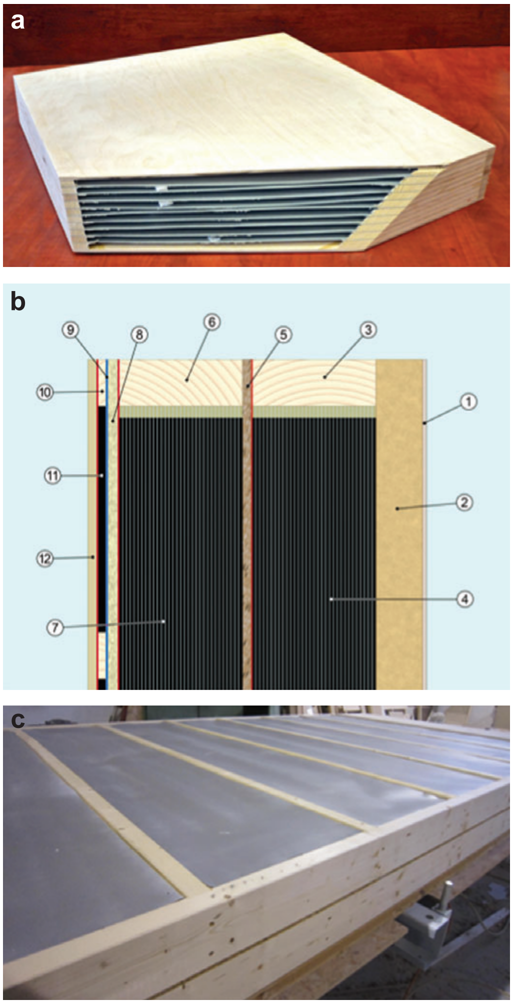

Figure 1 Photography and a scheme of the panels and wall construction. (a) Small experimental panel. (b) Scheme of the cross-section of Mirrorpanel (the detailed captions 1–12 are listed in Table 1). (c) Mirrorpanel wall construction.

Heat conductivity measurements

The heat conductivity of small panel (500×500 mm) was measured by means of a hot plate and a heat flow meter with an effective area of 120×120 mm and with temperature sensors in a heat conductivity measuring instrument. The hot side was set at 40°C and the cooling side around 25°C. The instrument provides the perpendicular heat flow to the specimen surface by means of a 200 mm-thick insulation layer on the side of the specimen. This side insulation forces the heat flow perpendicular to the surface of the small panels. The measurement was started after the temperature distribution had reached the steady-state condition. The instrument performed one measurement every minute, and the last 100 data were used for calculating the average thermal conductivity value.

The heat conductivity of the large panel (2×1.2 m) constructions was tested with the help of hot box method according to the EN 12412-4 standard.

Table 1 Sizes and physical properties of the elements of the Mirrorpanel wall structures (see Figure 1b).

#	Material	Thickness (mm)	Thermal conductivity ($W\ m^{-1}\ K^{-1}$)
1	Lime mortar, fine	5	0.7[a]
2	Panel, natural fiber	60	0.04[a]
3	Wood frame[b] (high density spruce)	160	0.13[a]
4	Mirrorpanel[c]	160	0.029[d]
5	OSB, lined with aluminum foil[e]	12.5	0.13[a]
6	Wood frame (high density spruce)	160	0.13[a]
7	Mirrorpanel[c]	160	0.029[f]
8	Fiber reinforced gypsum board	12.5	0.32[a]
9	Vapor barrier, reflective	0.1	2.3[a]
10	Wood frame (high density spruce)	20	0.13[a]
11	Air[f]	20	0.13[a]
12	Gypsum board lined with aluminum foil[e]	12.5	0.2[a]

[a]Source of the data WUFI Pro 5.0 IBP software: Database Materials (wufi.com).
[b]The Mirrorpanel foils are placed between the wood frame.
[c]The Mirrorpanel system contains also the cardboard distance holders with a higher thermal conductivity (0.06 $W\ m^{-1}\ K^{-1}$).
[d]Data were measured by the Innovation Center at the University of West Hungary.
[e]The lined aluminum foil is not a vapor barrier, because there are free places between the strips and on the edge.
[f]Equivalent thermal conductivity.

Test house

Within the framework of the present study, a large panel construction test house with a ground area of 120 m^2 was built. Instead of an additional insulation, a double panel was applied, which provided space for 31–31 layers of heat-reflective paper in 2×16 cm panel thickness (Figure 1c). In the double panel, the vertical wood frame elements are shifted to each other to reduce the thermal bridge effect.

Discussion and conclusion

The heat conductivity was 0.0291 $W\ m^{-1}\ K^{-1}$ in case of a 500×500 mm Mirrorpanel test specimen with 5 mm foil distances and 0.027 $W\ m^{-1}\ K^{-1}$ with 3 mm gaps. For comparison, the heat conductivity of the widely used polystyrene and rock and glass wool insulation materials is 0.04–0.06 $W\ m^{-1}\ K^{-1}$. Rock and glass wool and other cellulose fiber insulation materials are widely used in wood frame buildings. These materials do not have very low thermal insulation capacity than the Mirrorpanel. Thus, the mutual thermal resistance of the whole panel is also lower in the case of Mirrorpanel than that of other competing insulation materials. The heat conductivity of the complete large panel is 0.038 W m^{-1} K^{-1}, including the thermal bridges of the distance holders and the fiber-reinforced gypsum boards on the sides. This value is better than that of the regularly used fiber and foamy insulation materials. Thus, 1.5 tons of paper was needed to build the test building that is >5700 m^2. Due to the good preparation of the building in technology, it took only 8 days to build the experimental insulation material in the wood frame spaces (Figure 1c). The measure of heat loss of the building elements gives rise to calculated or measured U values. According to the calculations, the U value of wall structure calculated from the layers of the whole panel surface is 0.085 W m^{-2} K^{-1}. The measurement of U value between the studs shows a lower value with 0.0792 W m^{-2} K^{-1} thermal insulation capacity. The heat and vapor range of the Mirrorpanel wall structure can be measured by means of 12 temperature and 6 humidity sensors built in the wall structure.

The new multilayer insulation system fulfilled the requirements of the study. The system is made of renewable and reusable material. The insulation paper is made of environment-friendly recycled material, which helps lower the construction costs. The ordered layer system in Mirrorpanel has a bigger effect in proportion to its volume and mass than the materials placed disorderly between the layers. The heat bridge effect is reduced significantly compared with the traditionally insulation materials. The conclusion is that the Mirrorpanel thermal insulation system could be an advantageous alternative to fill the space between wood frames.

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