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Special. Artificial Intelligence and Information Theory

Modelling and Simulation of the Thermal Performance of Metal Framed Walls

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Abstract—**Recently, in the building practice, steel framed walls have increasingly been used. Such wall structures have a lot of advantages. At the same time, such walls have some disadvantages, and the most important of them is the presence of metal elements which lead to the appearance of thermal bridges and, as a result, to an increase in the overall heat transfer coefficient of the wall structure. The objective of this work was to evaluate and compare the thermal insulation properties of metal framed walls. To achieve the objectives of the study, several configurations of metal framed walls with different levels of thermal insulation and the distances between vertical steel studs were modeled. The heat transfer coefficient of the simulated steel framed walls was determined using the THERM 7.6 software. The simulation results showed that the use of an additional external insulation layer is an effective way to mitigate the adverse effects of thermal bridges caused by the presence of metal frames. Changing the distance between the metal studs also leads to heat losses reduction by almost 15% for a wall without an external expanded polystyrene layer. However, the effectiveness of this reduction is slightly less for walls equipped with additional external insulation. The novelty of the work is that the impact of geometric and thermophysical parameters of steel framed walls on their resistance to heat transfer was established and the ways to increase the thermal performance of such wall structures were outlined.**

Keywords — thermal simulation software, energy consumption, light steel framed wall, thermal transmittance, heat transfer coefficient

I. INTRODUCTION

Residential and non-residential buildings are significant energy consumers [1]. So, there is an urgent need to reduce the energy consumption of buildings, especially in their operational stage, since this accounts for 80%–85% [2] of the total amount of energy consumed during their life cycle. Therefore, it is very important to find solutions and elaborate methods that offer advantages in reducing buildings energy needs.

For Ukraine, the benefits of energy saving are of particular importance in view of its high energy dependence and energy consumption. The domestic economy is energy deficient, meeting its energy needs at the expense of its own production by only 45%. Its fuel and energy balance is dominated by natural gas, which accounts for more than 40%, far exceeding the corresponding indicators of countries such as the United States, the United Kingdom and so on. One of the largest consumers of energy resources is the housing sector - more than 30% of the total energy consumption in the country. The available housing stock of Ukraine, according to the energy classification, belongs to the most energy-intensive class F, which is characterized by energy consumption greater than 250 kWh/m^2 per year. At the same time, in European countries, the energy efficient buildings belong to class A and A+, which means very low energy consumption (from 15 to 45 kWh/m^2 per year).

When designing an energy efficient building such architectural and building principles of enhancement energy efficiency must be followed: optimization of architectural forms of the building with taking into account the possible impact of wind; optimal location of the building relative to the sun, which provides the opportunity for maximum use of solar radiation; increase of thermal resistance of building enclosures (exterior walls, coverings, etc.); minimizing the harmful effect of thermal bridges; increase of thermal resistance of translucent structures; creating an energy efficient ventilation system.

One of the most important factors that affect the energy performance of a building is the value of the heat transfer coefficient of the outer envelope of the building. Various types of thermal insulation may be used to reduce the heat transfer coefficient value.

There are many types of thermal insulation. Their effectiveness is estimated by the degree of thermal resistance. The higher the thermal resistance, the more effective the insulation.

Thermal insulation foams include extruded polystyrene, expanded polystyrene and polyurethane foam.

Granular insulation includes perlite (expanded volcanic rock), vermiculite (expanded mica) and polystyrene foam in granules. Usually they fill cavities, for example, in concrete slabs.

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Foamy insulation is mineral wool and fiberglass. Fiberglass products are obtained from molten glass, and mineral wool is produced from molten rocks.

Filling insulation can be made of mineral wool, glass wool or cellulose.

Reflective insulation consists of one or more layers of aluminum foil.

Foam is a mixture of chemicals that are pumped into the cavity, where the foam is formed, filling them.

Over the last few years, alternatives to the traditional constructive methods have been developed. The so-called frame buildings began to gain more and more popularity. Nowadays, in the construction of frame houses, two types of frames are used - wooden and metal ones. Metal frames are made of lightweight galvanized metal in the form of profiles. Such structures are called lightweight steel framing (LSF) systems. They are made in various shapes and thicknesses. When assembling the frame, they are connected using screws, rivets or bolts, which eliminate welding work. Metal structures are dimensionally stable, do not shrink, and thanks to this, one can immediately order and put doors and windows, and perform any finishing work.

The strength of steel structures allows making openings located between the load-bearing elements wider and use any siding and roofing materials. The service life of such structures, thanks to galvanization, is about a hundred years. But there are also limitations that must be taken into account: metals have thermal conductivities higher than wood, therefore, the correct thermal insulation of the frame is needed, which does not allow the occurrence of so called thermal bridges and gaps in the envelope of the building. And the elements, if any, extending beyond the envelope, need an additional insulation. But all these shortcomings are covered by one biggest plus - the low price per square meter.

Structurally LSF system is a building construction system consisting of dry materials [3]. This system includes three major materials: metals, sheathing panel materials and insulation [4]. Other materials are also needed for fastening and joining. The system must also include air tightness and waterproof membranes and as well as finishing layers. In order to avoid problems related with ground moisture, a frame building needs a ground floor, commonly a concrete slab [5].

As mentioned above, steel framing creates notable thermal bridges and reduces overall thermal performance of steel framed walls. In relation to wood framing steel is much more thermally conductive than wood [6].

Taking into account the disadvantages discussed above, more and more attention has been paid recently to the development of methods that would improve the thermal efficiency of walls with metal frames [7].

The purpose of the work was to determine the thermal properties of the walls with metal frames. To achieve this, three types of walls were considered. The walls differed in the distance between the frame studs as well as the depth of the metal studs. At the same time, three levels of thermal insulation were varied for each type of wall, namely: only with internal insulation as well as with additional layers of external insulation (1.2 cm and 2.5 cm layers of expanded polystyrene). As a result of computer simulation, the thermal characteristics of these walls were determined and proposals were made to improve the thermal performance of such walls.

II. MATERIALS AND METHODS

The general view of steel frames is depicted in Fig. 1.

Commonly, thermal insulation is filled between steel studs and covered with sheathing, for an example, with oriented strand board and layers of external and internal plaster boards. Additional layer of external insulation may also be used.

Fig. 1. Steel frames

The steel framed wall fragment to be simulated is shown in Fig. 2. This structure contains metal studs with a “U” cross-sectional shape. The depth and distance between adjacent metal studs were varied during the simulation.

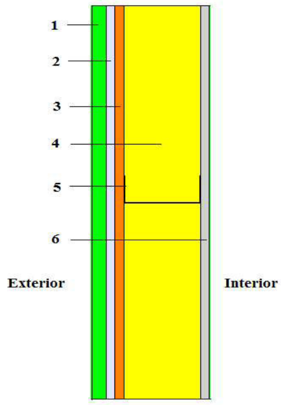

Fig. 2. The scheme of the steel framed wall geometrical model. Materials: 1—external plaster; 2 – external insulation (optional); 3—oriented strand board (OSB); 4 —internal insulation; 5 – steel stud; 6— internal plasterboard

The characteristics of steel framed walls, the thermal properties of which were determined during the simulation, are given in Table 1. And for each type, the level of thermal insulation were varied.

The thermal properties of the materials the walls consisted of were as follows. The thermal conductivity of plaster board, mineral wool, OSB, EPS and steel were assumed to be 0.21; 0.04; 0.13; 0.038 and 50 W/(m·K), correspondingly.

The convective surface heat transfer coefficients were taken according to EN ISO 6946 [8] for a horizontal heat flow. According to this standard, the convective surface heat transfer coefficient between the outer surface of the wall and the external environment was assumed to be h_e=25 W/(m^2·K), and it was taken as h_i=7.69 W/(m^2·K) between the inner surface of the wall and the interior environment.

The rest of the boundary conditions were as follows: the external temperature assumed to be 0 °C and the internal temperature was defined at 20 °C.

The boundary conditions taken for computer modeling are summarized in Table 2.

TABLE 1. Characteristics of walls with metal frames

Wall symbol	Geometrical characteristics of steel studs; distance between adjacent studs	Material used for insulation of wall cavity	Exterior/ interior plaster boards	External insulation
Ia	8.9 mm depth, 4.1 cm flange, 1.2 mm thickness, 40 cm distance between adjacent studs	Mineral wool (MW)	2 cm external plaster; 1.25 cm internal plasterboard; optional external insulation	no
Ib				1.2 cm of expanded polystyrene (EPS)
Ic				2.5 cm of EPS
IIa	8.9 cm depth, 4.1 cm flange, 1.2 mm thickness, 60 cm between adjacent studs	MW	2 cm external plaster; 1.25 cm internal plasterboard; optional external insulation	no
IIb				1.2 cm of EPS
IIc				2.5 cm of EPS
IIIa	10.2 cm depth, 4.1 cm flange, 1.2 mm thickness, 60 cm between adjacent studs	MW	2 cm external plaster; 1.25 cm internal plasterboard; optional external insulation	no
IIIb				1.2 cm of EPS
IIIc				2.5 cm of EPS

TABLE 2. Boundary conditions

No	Parameter	Value
1	Internal temperature	20 ^{0}C
2	External temperature	0 ^{0}C
3	External convective heat transfer coefficient	25 W/(m^2·K)
4	Internal convective heat transfer coefficient	7.69 W/(m^2·K)

The next task was to determine the limiting dimensions of the geometric model of the wall fragment. For a wall with a single layer of vertical metal studs and a distance of 400 mm (or 600 mm) between adjacent studs, standard ISO EN 10211 [9] recommends to take advantage of its symmetry to locate the adiabatic plans.

So, a cross-section of the wall measuring 600 mm (or 400 mm), with a metal stud in the centre, was taken as a geometric model.

Thermal simulation was carried out with THERM 7.6 software [10].

THERM's two-dimensional conduction heat-transfer analysis is based on the finite-element method.

The advantages of the presented program include a convenient graphical interface that allows building models of complex geometry with high accuracy.

III. RESULTS AND ANALYSIS

The results of the thermal simulation (temperature maps) are shown in Fig. 3.

These temperature profiles were used to evaluate average surface heat flux passing through each type of the analyzed walls. This allowed performing calculations of overall heat transfer coefficients (U-values). Fig. 4 represents the values of all overall heat transfer coefficients calculated as a result of the simulation.

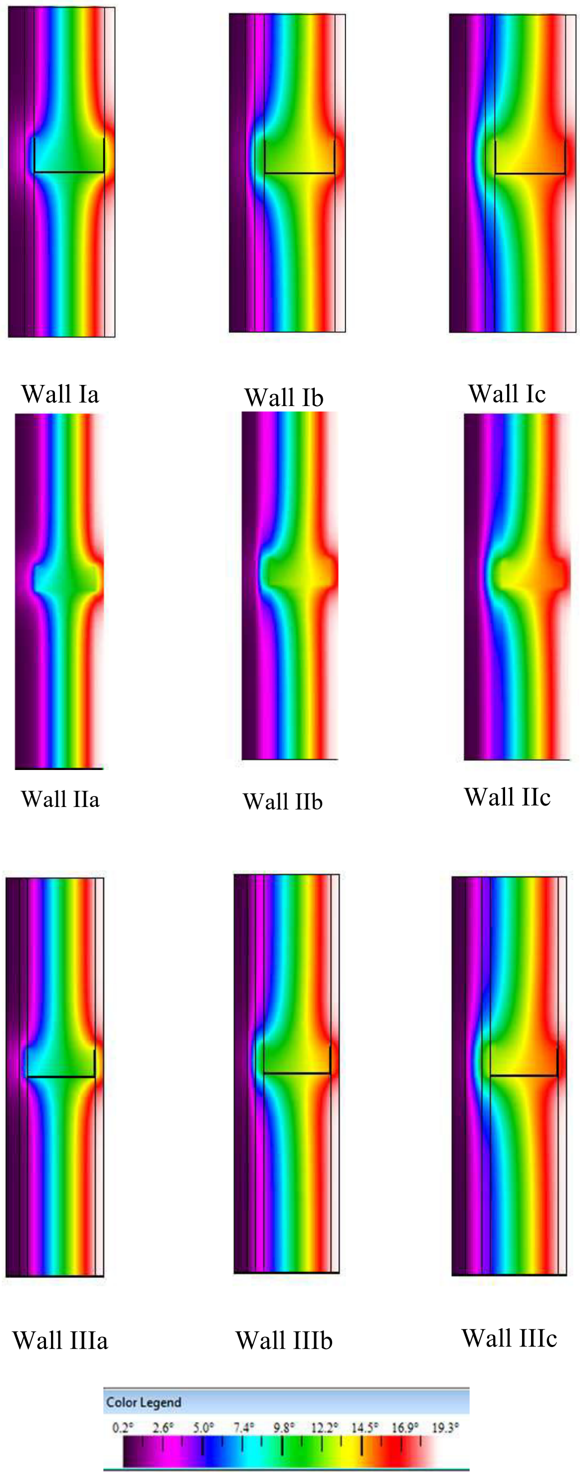

Fig. 3. Temperature maps

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For walls without external insulation overall heat transfer coefficients between 0.55 and 0.69 W/(m^2·K) were obtained as a result of simulation. It can be noticed that installation of addition external layer of thermal insulation results in considerable overall heat transfer coefficient decrease. The values of overall heat transfer coefficients for the walls with additional 1.2 cm layer of external insulation range from about 0.42 to about 0.5 W/(m^2·K), whereas for walls with 2.5 cm of EPS the U-values are within 0.38 and 0.42 W/(m^2·K).

The heat transfer coefficient decreases with distance increase between the metal studs. Moreover, the most noticeable decrease in the heat transfer coefficient was obtained for walls without an additional layer of external thermal insulation. When applying an additional outer layer of thermal insulation, an increase in the distance between the adjacent studs causes less noticeable decrease in the heat transfer coefficient, namely, the decrease is only 9.5% for walls with an additional 2.5 cm layer of thermal insulation and about 11% for walls with a 1.2 cm layer of thermal insulation.

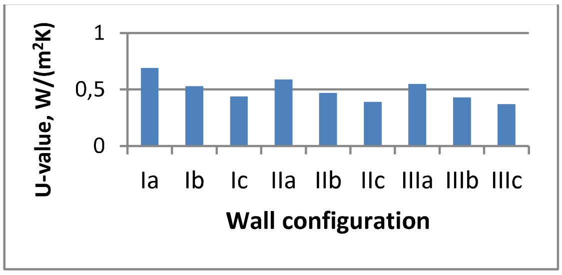

Fig. 4. U-values of simulated metal stud framed walls

It is known that the overall heat transfer coefficient for walls with metal inclusions can be significantly higher than for similar walls if the negative impact of thermal bridges is not taking into account. The data represented in Fig. 5 depict the influence of metal framed wall configuration and level of insulation on the magnitude of so called framing effect.

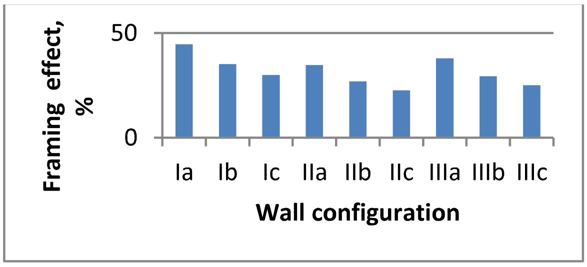

Fig. 5. - The magnitude of framing effect f

The *framing effect,* (*f*) takes into account the increase of wall overall heat transfer coefficient due to the impact of thermal bridges. It can be calculated using the following expression:

$$f = \left(1 - \frac{U_{ideal}}{U_{simulated}}\right) \cdot 100\%$$

where $U_{simulated}$ - simulated overall heat transfer coefficient (all thermal bridges are taken into account) and U_{ideal} – "ideal" overall heat transfer coefficient (thermal bridges are not taken into account).

For the wall structure with 8.9 cm depth metal studs, 1.2 mm thick, and distances between them of 40 cm, without external insulation, the framing effect reaches about 44 %. The magnitude of the framing effect may be lowered with the increase in external insulation layer thickness as well as distances between adjacent studs.

CONCLUSIONS

This work was devoted to the study of thermal efficiency of walls with metal frames. To obtain the thermal characteristics of such walls, a computer simulation was performed. In the analysis, the walls were considered to have different levels of thermal insulation, different distances between the adjacent metal studs, as well as different geometric characteristics of these studs. The results of computer simulation allow us to draw the following conclusions. The use of an additional layer of external thermal insulation results in a significant reduction in the overall heat transfer coefficient of such walls. To some extent, the overall heat transfer coefficient also decreases as the distance between adjacent metal studs increases. As a result of modeling, the relationship between the level of thermal insulation of the walls, their geometrical parameters and the framing effect is also revealed. This framing effect is also greatly reduced when an additional outer layer of thermal insulation is applied.

Obviously, other strategies can be used to mitigate the adverse influence of thermal bridges and enhance thermal performance of walls with metal frames. For example, perforated metal profiles are currently used to reduce the negative effects of thermal bridges. So, further research is needed to optimize the configuration and improve thermal performance of such walls.

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