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Improving Thermal Performance of the Wall Panels Using Slotted Steel Stud Framing

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Abstract

Nowadays application of cold formed steel framing as structural elements had experienced a great development, and currently this system is met in almost all aspects of modern life [1]. There are many more advantages than might appear at first glance. Their development is highlighting the need to build as easy and as safe in a short time, all at top quality and affordable price. This paper proposes a study of hygrothermal behavior of panel sections made of slotted light steel framing, in order to improve thermal performance. Hygrothermal characteristics of the sections were determined using tridimensional computer programs UNORM and ABAQUS 6.11. Starting from a basic pattern, there have been developed twelve cases of perforation. The new profiles were obtained through variation of certain parameters defining the slotted segments, seven versions that had rectangular shape and five versions where the geometrical shape of the slots has been other than the rectangular one (oval, diamond, etc.).

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Keywords: Slotted steel framing; numerical simulations; thermal performance; heat flow; equivalent thermal conductivity.

1. Introduction

Significant share of the construction industry in the consumption of fossil fuels requires concern for energy efficiency and establishing high levels of thermal protection requirement for new buildings [2]. To this end, the progressive convergence over several years, in terms of existing new construction would provide energy savings, reduce operating costs of buildings and reducing emissions of greenhouse gases.

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A favorable solution regarding this problem is promoting new techniques, different and innovative needs and requirements arising lately over other methods of construction less environmentally beneficial. One of the latest and advanced technologies in the field developed today are those based on the use of light steel framing. The construction technology is widely used in countries with cold climates, because of the good thermal performance and structural behaviour. The fact that the steel structure is 100% recyclable is becoming increasingly important in a world where good management of natural resources is indispensable.

2. Establishing geometric model and calculation methods

2.1. Geometric model

Numerical calculations for determining the heat flow are applied for a panel made of cold steel framing C150, having a thickness of 1.5 mm (Fig. 1). For the closure the space between the uprights is filled with mineral wool of 15 cm which provides thermal insulation layer. After that, layers of plywood are mounted inside and outside. The inner cladding is formed of plasterboard plates 0.9 cm, and the outer cladding is made of OSB board 1.5 cm.

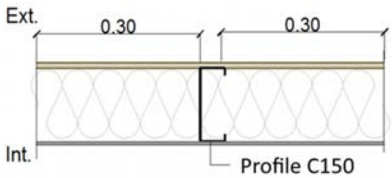

Fig.1. Geometric model analyzed

2.2. Thermal conductivity of the used materials

The thermal conductivity of the materials is considered as follows:

- Plasterboard : $\lambda = 0.30$ W/mK,
- Mineral wool :$\lambda = 0.042$ W/mK,
- OSB plates : $\lambda = 0.14$ W/mK
- Steel: $\lambda = 60$ W/mK.

For slotted steel framing with perforation an equivalent thermal conductivity has been determined using computational calculations UNORM or manual calculation depending on the case.

2.3. Boundary conditions and dimensions

In analysing construction systems, heat transfer coefficient values are considered as it follows: interior $\alpha_{si} = 8$ W/ m² K and outdoor $\alpha_{se} = 24$ W / m² K. Superficial thermal resistance values of heat exchange between inside and the inside face is $R_{si} = 0.04$ m² K / W, respectively heat exchange between the outer and the outer face is $R_{se} = 0.13$ m² K / W (Fig.2). The size of the geometric model is considered according to demand of international standard EN ISO 10211 [2], adiabatic plans (zero heat flow) being located at 0.30 m of the core. The length of the profile was considered 1000 mm .

Fig. 2. Boundary conditions regarding interior and exterior temperatures in UNORM

2.4. Meshing elements

Since the heat flow is determined in programs using numerical methods, an important step is the mesh of the elements. In ABAQUS software [4] the mesh of the spatial geometric model (Fig. 3) is achieved by choosing the right type of meshing element and finite element model division. In the studied cases the dimension of the finite element values was 0.015 m. For linkage between nodes, to achieve the most efficient way on dividing (since the analysed models were three-dimensional and the size of the sections components showed large variations) the meshing type chosen was HEX.

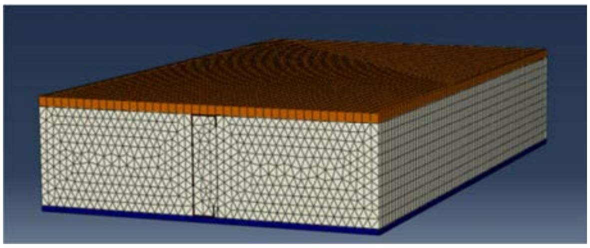

Fig. 3. ABAQUS mesh pannel section

In UNORM [5] spatial geometric pattern mesh is performed automatically by the computer program (Fig. 4), resulting spatial mesh network. The degree of subdivision is controlled by introducing the number of cells. In the stud framing area mesh network was increased, which leads to the rising of nodes number. The nodes are positioned taking into account physical and geometrical discontinuities of the item.

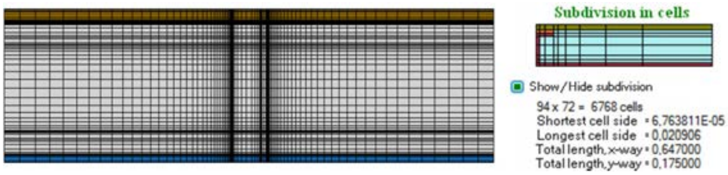

Fig. 4. UNORM mesh panel section

2.5. Calculation methods

As the analysed construction elements are three-dimensional bodies, the real thermal field is spatially and variable. In order to simplify volume of current design calculations for determining termotechnical characteristics real field was replaced with constant thermal field.

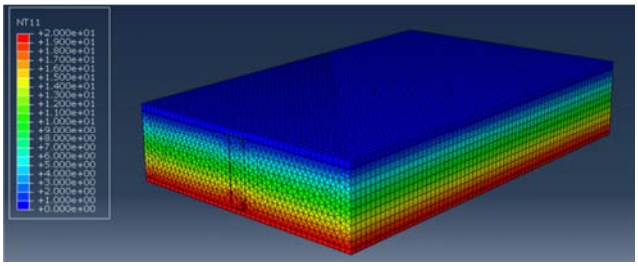

Fig. 5. The distribution of temperatures in the pannel section according ABAQUS

To calculate the heat flow in the considered sections, UNORM is using as numerical calculation method the finite difference method and ABAQUS is using finite element method. Fig. 5 and Fig. 6 are showing temperature distribution simulated in wall sections generated in ABAQUS respectively UNORM software.

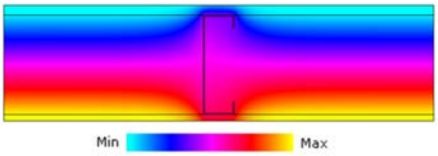

Fig. 6. The distribution of temperatures in the wall section according UNORM

3. The calculation of equivalent thermal conductivity

In the paper there have been studied multiple cases of the way the profile were perforated. All the results were compared with a reference model which was choosen randomly. The chosen basic model was a profile C 150, having 1.5 mm thickness and dimensional characteristics as shown in Fig. 7. The size of removed slots are : width d=5 mm, length l=80 mm and are arranged at intervals of e=20 mm on vertically direction and c=10 mm on horizontally direction. The number of rows of perforated segments is n=6 and the distance on wich the profile is not perforated is f=20 mm.

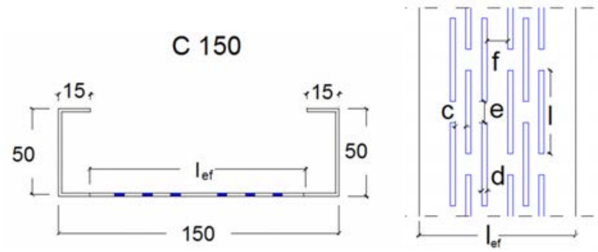

Fig. 7. Geometric description of reference model

Starting from the basic model, there have beeen developed twelve cases of perforation obtained by varying certain parameters which are defining the perforated segments: seven versions where the shape has been rectangular and five versions where the geometrical shape of the slots has been other than the rectangular one (oval, diamond, etc.).

In the first seven cases (for segments having a rectangular geometric shape) the equivalent thermal conductivity of the profile were determined using UNORM program, which has a special calculation module for determining the value. For other geometric shapes developed (Unorm program options are limited and the only geometric shape that can be developed is the rectangular one), equivalent thermal conductivity was calculated using the following formula:

$$\lambda_{eq} = \lambda_{perf} = \frac{b}{\frac{1}{U} - \frac{1}{\alpha_i} - \frac{1}{\alpha_e}} \tag{1}$$

where: λ_{perf} - equivalent thermal conductivity value [W/mK] ;
α_i - superficial heat transfer coefficient on the inner surface [W/m^{2}K];
α_e - superficial heat transfer coefficient on the outer surface W/m^{2}K];
b - distance on which the profile was perforated [m];
U - thermal transmittance determined in ABAQUS software [W/m^{2}K].

4. Calculation of the heat flow

4.1. Perforated profiles having rectangular geometric shape slots

The following cases are describing the seven cases of perforation considered:
Var. I – is characterizing the profile in which the distance “e” two perforated sections in vertical direction is between 10 mm and 30 mm
Var. II – is characterizing the profile in which length of the “l” varies between 60 mm and 120 mm.
Var. III - is characterizing the profile in which the “f” on which the profile is not perforated and varies between 10 mm and 30 mm.
Var. IV - is characterizing the profile in which the “c” between two perforated sections in the horizontal direction varies between 8 mm and 20 mm.
Var. V - - is characterizing the profile in which the width “d” varies between 2 mm and 6 mm.
Var. VI - is characterizing the profile in which the number of rows varies between 4 and 8.
Var. VII - is characterizing the profile in which the thickness varies between 0.7 mm and 2 mm.

The results after analyzing seven curves trends relating to changing ways of perforation are summarized in the Fig. 8 - Fig. 11.

4.2. Perforated profiles having other shapes than rectangular one

Var. VIII….**Var. XII**– is characterizing steel profiles in which the areas of perforated segments were preserved as the basic model but the geometrical shape is varied (Fig. 12).

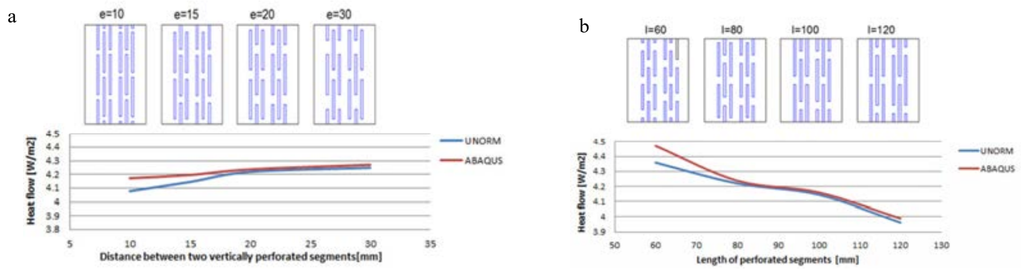

Fig. 8. (a) Effect of modifying distance “e” between two vertically perforated segments; (b) Effect of modifying length perforation “l”

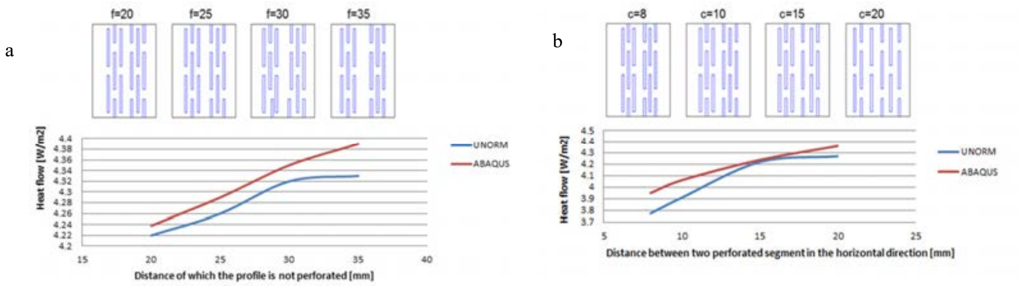

Fig. 9. (a) Effect of modifying the distance “f” of which the profile is not perforated; (b) Effect of modifying distance “c” between two perforated segment in the horizontal direction ;

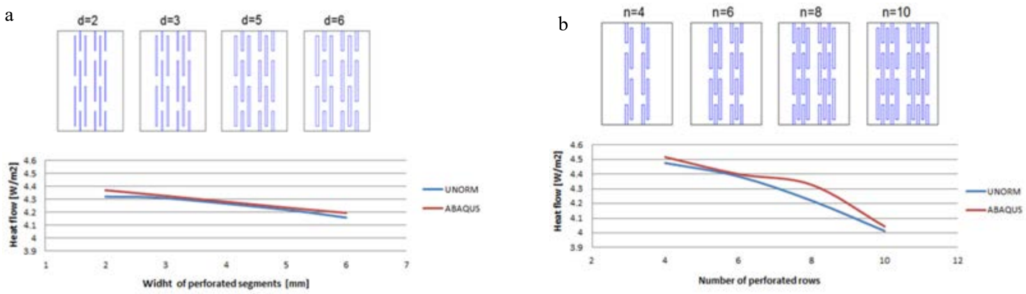

Fig. 10. (a) Effect of modifying width “d” of the perforated segment; (b) Effect modifying the number of perforated lines “n”

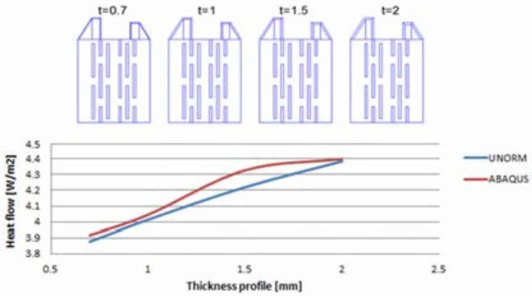

Fig. 11. Effect of modifying thickness “t”profile

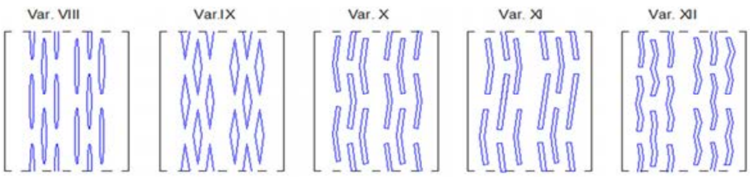

Fig. 12. Perforated profiles having other shapes then rectangular one

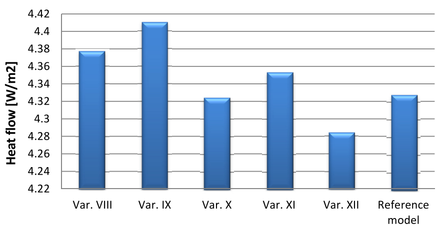

Fig. 13. Heat flow values obtained using perforated profiles having other shapes then rectangular one

4. Conclusions

The results show that there is a correlation between perforated geometry of steel profiles and the amount of heat flow passing the element. Thermal conductivity and thermal resistance is being influenced. For trends of curves analyzed in seven options of perforation, calculation results showed that the energy efficiency section of the wall rises with:

- Decrease of distance between perforation both vertically and horizontally;
- Location perforations to the heart profile;
- Decreased of thickness profile;
- Increasing the number of rows of holes and their length;
- Increasing the dimension of perforation;

Among the solutions the best behavior in terms of thermal profiles were obtained for variations in geometric shape which was the most diverse Var. XII (Figure 13). The differences between thermal performance achieved by these models developed in comparison with classic rectangular shape are between 1.6 % and 5.6 %.

As the developer of profiles that have variations of slots carrying various panel would be a difficult one in terms of the technological process, it is recommended the development of a geometric model that takes into account each of the seven curves obtained, thus developing an optimal way in the drilling mode profile. In ABAQUS the heat flow value obtained for the optimised model based on the seven criteria was 3.60 W / m^2, and in UNORM 3.55 W /m^2. As shown in Fig. 14, the heat flow characterizing the proposed model is much smaller than other alternatives we evaluated, leading to a better thermal efficiency. The higher heat flow passing through the element is the lower, the thermal resistance increases.

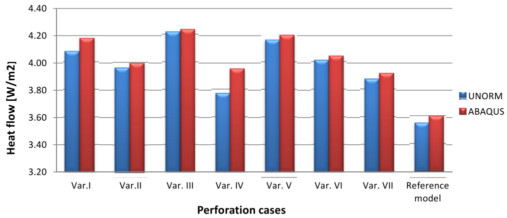

Fig. 14. Tabulation of the seven cases analysed

Due to lack of experience in our country, this type of structure was less used in residential area and there was a restraint both from the designers and the companies executing the practical application of these constructive systems.

Recently, motivated by technical and economic advantages of using steel structures compared to those the traditional materials, the number of companies that promote this type of structure has increased considerably. The trend of reducing costs, improving the thermal performance of building envelope elements in Romania and the emergence of manufacturers who have the range of such products are likely to increase interest in this segment, expecting growth in the near future of the share use of cold formed profiles for small structures to the detriment of classic business systems [6].

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