Thermal analysis of a structure made by using cold formed steel sections

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Abstract. In the last decades, man-made environmental burdens have led to a significant increase of negative effects felt by the human race. Thus, some industrial sectors have developed and implemented a series of solutions with the goal of minimising their negative ecological impact. Taking into account that the construction sector is one of the most important economic players in every national economy, one that has a tremendous negative impact over the environment, in the last years, various recommendations and limitations have been drawn in order to reduce the consumption of non-renewable energy. In order to constantly reduce the impact of the built environment over the natural one, civil engineers should develop and promote sustainable solutions that have a direct effect on improving the environmental performances of the built environment. One such solution is the use of cold formed steel sections (CFS) for building new structures. This paper analyses the linear thermal transmittance of the thermal bridge formed by the vertical steel studs inside the external walls. The results show that these steel elements can be used in order to build energy efficient buildings.

1. Introduction

In the last decades, the issues that are related to the negative effects of the global warming phenomena have significantly increased the level of awareness of how the human race is negatively influencing the state of the Earth’s ecosystem. Another current significant environmental problem, one that is going to affect the development of future generations, is represented by the alarming levels of natural resources consumption. Nowadays, the amount of natural resources that are consumed every year exceeds the Earth’s capacity of renewing the stock of raw materials by 75% [1]. Taking into account that all the ecological problems we are facing are a direct result of our daily activities, different solutions have to be developed and applied in all economic activities at the global scale in order to reduce the load over the natural environment.

Due to the important volume of greenhouse gases emissions into the atmosphere as well as the tremendous amounts of consumed raw materials, the construction sector is considered to have one of the most significant roles in achieving the primary goals of sustainable development at the global scale. Out of the entire quantity of raw materials consumed worldwide, almost 60% is used in the construction sector. At the same, the activities specific to this industry are responsible for emitting more than 40% of the total amount of greenhouse gasses, and for producing around 25% of worldwide waste. Another significant environmental issue concerning this industry is reflected by the fact that
more than 60% of the extracted natural resources are used in the built environment [2-7]. Therefore, the built environment is exerting a significant negative load over the natural one, being one of the most pollutant economic activities. In this respect, all construction sector specialists should increasingly promote solutions with the goal of significantly improving the environmental performances of the construction sector.

The environmental footprint of the building industry is highly influenced by the type and amount of construction materials that are used in order to satisfy the need of a secure and protective indoor space. Thus, optimizing the structural systems and the materials used in building new constructions can reduce the present alarming rates of environmental burdens resulted from all the activities that are characteristic to this industry. Another important influence over the overall ecological impact of the construction sector is represented by the way we use the buildings. There are different studies showing that from the entire life cycle of a construction, one that is not energy efficient, the operation or usage stage is responsible for between 80 and 90% of the total environmental impact of that building [8-12]. By taking this into account, along the years, various solutions have been used in order to reduce this negative environmental impact. Nevertheless, efforts should be intensified in order to improve the energy efficiency of the buildings and thus, improving the overall environmental performances of the construction sector.

The environmental impact over the operation phase from the life cycle of a building is mainly influenced by the level of energy consumption and greenhouse gases emissions used in view of satisfying the optimal indoor condition for the occupants. Related to this issue, at the present moment, the passive house standard is considered to recommend the most restrictive values regarding the thermal performances of a building.

A passive house should have a very thick thermal insulation, highly insulated windows frames, an airtight building envelope, and a high performance ventilation system with efficient heat and/or energy recovering. One of the most important characteristics of this type of buildings is that in order to achieve the passive house limitations, the thermal bridge free design and construction principle must be used. This is a must when it comes to achieving a building with high energy performance, which is formed by using envelope elements (i.e. external walls, floor slabs and roof areas) with a value range from 0.10 W/(m²K) to 0.15 W/(m²K) for the thermal transmittance coefficient (these values are valid for the Central European climate) [12].

Therefore, by taking into account all the above, it is justified to support the idea that reducing the ecological footprint of the built environment represents a very important problem that can be resolved by considering innovative approaches. The use of cold formed sections (CFS) could represent a solution for reducing the environmental impact of the construction sector by building new structures that satisfy the passive house regulations.

The aim of the present paper is to analyse if in the case of a building made by using CFS profiles, the thermal bridges formed inside the exterior walls by the vertical metal studs have an influence over the thermal bridge free design principle of a passive house.

2. Case study
In order to achieve the goal of the study, the authors have used the principles presented in the C 107-2005 Romanian normative [13] and in the international standard ISO 10211:2017 [14] to assess if the value of the linear thermal transfer coefficient (ψ), characteristic to the thermal bridges formed by the vertical metal studs inside the exterior walls, is lower or equal with 0.01 W/(mK). If this restriction is satisfied, then the thermal bridge free design can be used. In order to correctly dimension the thickness of the thermal insulating materials, with respect to the passive house principles, the authors have considered the value range from 0.10 W/(m²K) to 0.15 W/(m²K) for the thermal transmittance coefficient (U). Taking into account that for evaluating the linear thermal transfer coefficient, the value of the specific unidirectional thermal resistance (R) of the considered building envelope element is needed [13], the above mentioned U values have been translated in R values (table 1). The
computation of the specific unidirectional thermal resistance has been completed according to Romanian normative C107-2005 by using the equation (1):

\[ U = \frac{1}{R} \left[ \frac{W}{(m^2 K)} \right] \Rightarrow R = \frac{1}{U} \left[ \frac{(m^2 K)}{W} \right] \]  

(1)

where \( R \) is the specific unidirectional thermal resistance (m²K/W).

### Table 1. U-R equivalence.

| U (W/m²K) | R (m²K/W) |
|-----------|-----------|
| 0.10      | 10        |
| 0.15      | 6.67      |

Figure 1 presents the construction detail of the exterior wall that has been put under analysis. According to C107-2005 [13], before determining the value of the linear thermal transmittance (also known as linear thermal transfer, according to C107-2005), \( \psi \), it is necessary to determine the specific unidirectional thermal resistance of the element (R).

The \( R \) value represents the sum of the thermal unidirectional resistances of the construction element’s layers and the superficial resistance to the radiative and convective heat transfer of the inner and outer surfaces [13], [15-17]. Table 2 shows the computation of the \( R \) value of the considered envelope’s element. Equation 2 has been used in order to determine the specific unidirectional thermal resistance [13]:

\[ R = \frac{1}{\alpha_e} + \sum d_k \frac{1}{\lambda_k} + \frac{1}{\alpha_i} \left[ \frac{(m^2 K)}{W} \right] \]  

(2)

where \( \alpha_i \) and \( \alpha_e \) are the convective and radiative heat transfer coefficients of the internal and external surfaces, in W/(m²K); \( d_k \) represents the thickness of the layer “k” (m); \( \lambda_k \) represents the thermal conductivity of the layer “k” (W/mK).

As mentioned above, the thickness of the thermal insulating materials has been dimensioned by considering the \( R \) values that are recommended to be satisfied by a passive house situated in a European climate. By analysing table 2, it can be observed that the achieved value is between the imposed values.
Table 2. U-R equivalence.

| Nr. | Layer                  | Thickness (d) (m) | Thermal conductivity (λ) (W/mK) | Layers’ thermal resistance (R) (m²K/W) | Thermal resistance (R) (m²K/W) |
|-----|------------------------|-------------------|---------------------------------|----------------------------------------|-------------------------------|
| 1.  | Internal plaster       | 0.005             | 0.87                            | 0.006                                  |                               |
| 2.  | Plasterboard           | 0.025             | 0.21                            | 0.12                                   |                               |
| 3.  | Rock wool (1)          | 0.09              | 0.04                            | 2.25                                   |                               |
| 4.  | OSB panel              | 0.0125            | 0.204                           | 0.06                                   | 8.503                         |
| 5.  | Rock wool (2)          | 0.2               | 0.034                           | 5.88                                   |                               |
| 6.  | External plaster       | 0.02              | 0.87                            | 0.02                                   |                               |

External surface resistance $1/\alpha_e=1/24=0.042$ m²K/W

Internal surface resistance $1/\alpha_i=1/8=0.125$ m²K/W

3. Thermal bridge analysis

According to ISO 10211:2017 [14] a thermal bridge represents a “part of the building envelope where the otherwise uniform thermal resistance is significantly changed by full or partial penetration of the building envelope by materials with a different thermal conductivity, and/or a change in thickness of the fabric, and/or a difference between internal and external areas, such as occur at wall/floor/ceiling junctions”.

The same standard defines the linear thermal transmittance ($\psi$) as the “heat flow in steady-state compared to a reference heat flow rate calculated disregarding the thermal bridge, divided by length and by the temperature difference between the environments on the either side of a linear thermal bridge” [14]. In order to compute the value of $\psi$, the authors have used equation (3) [13]:

$$\psi = \frac{\phi}{\Delta T} - \frac{B}{R} \left[ \frac{W}{(mK)} \right]$$  \hspace{1cm} (3)

where $\Phi$ represents the heat flow rate (W/m); $\Delta T$ represents the difference between the interior and exterior temperatures (K); $B$ represents the width of the modelled linear thermal bridge (m); $R$ represents the specific unidirectional thermal resistance of the element (m²K/W).

Figure 2 presents the considered thermal bridge that is formed by the vertical steel studs in the interior of the analysed construction detail (i.e. external wall).

The value of the heat flow rate, necessary to compute the influence of the linear thermal transmittance, has been determined by using the RDM 6 software.

Table 3 details the characteristics of the materials used for the finite element assessment. Also, in order to complete the model, the authors have considered $T_e=-18^\circ C$ for the exterior temperature boundary conditions (characteristic for climatic zone III) and $T_i=20^\circ C$ for the interior temperature.

Table 3. Properties of the materials considered in the analysis.
Figures 3 and 4 show the heat flow resulted for the considered thermal bridge. It can clearly be observed that the vertical steel stud forms a thermal bridge that has an important influence over the assessed building envelope’s element.

Analysing the figures above, we can also see that the construction detail has been properly developed due to the fact that important values of the heat flow are only registered in the vertical thermal bridge.

Table 4 presents the computation of the linear thermal transmittance ($\psi$). The result clearly shows that the influence of the analysed thermal bridge can be neglected in determining the thermal resistance of the building envelope’s element. The achieved value is lower than the limit of 0.01 W/(mK) imposed by the passive house standard in order to apply the principle of thermal bridge free design and construction.
Table 4. Computation of the linear thermal transmittance.

| Heat flow rate (Φ) (W/m) | Temperature difference (ΔT) (K) | Width of the thermal bridge (B) (m) | Thermal resistance (R) (m²K/W) | Linear thermal transmittance (W/mK) |
|--------------------------|-------------------------------|----------------------------------|--------------------------------|----------------------------------|
| 10.96                    | 38                            | 2.4                              | 8.503                          | 0.006                            |

4. Conclusions

The present state of the natural environment imposes the development and promotion of a series of innovative solutions that can help reduce the ecological footprint of our daily activities. From the consumption rates of natural resources to the volume of greenhouse gases emissions into the atmosphere, year after year, alarming values regarding the impact over the Earth’s ecosystem are registered. While all economic activities have an important negative effect over the environment, the construction sector is considered to be the most pollutant. In the last decade, different solutions have been implemented in order to reduce the impact of the built environment over the natural one, but these efforts must be supplemented in order to significantly improve the ecological performances of this sector. In the near future, it is necessary to reduce the load over the environment of the operation stage from the life cycle of a construction by using different solutions that are related to high energy efficient buildings.

One such solution is represented by the use of the passive house standard which is considered to be one of the most restrictive norms related to the energy consumption of a building. This standard imposes the use of the free thermal bridge design and construction principle, which means that if the value of the linear thermal transmittance of a thermal bridge is lower than a certain value, the effect of that thermal bridge is neglected in the computation of the thermal transmittance of a building envelope’s element. The goal of the present paper was to assess if in the case of using cold formed steel sections, the value of the linear thermal transmittance of the thermal bridge formed by the vertical steel studs inside of an external wall is lower than the one imposed by the passive house standard. The resulted value shows that the ψ value is lower than the limit imposed for considering a free thermal bridge design. Thus, the CFS profiles can be used for high energy efficient buildings.

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