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Considerations on the Thermal Modelling of Insulated Metal Panel Systems

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ABSTRACT
The very strict regulations imposed by the European directives regarding low energy consumptions of buildings imposes the availability of thermal and energy efficient solutions for the building envelope. One common solution is given by insulated metal penal systems, which are typically used for industrial buildings but lately also used for other types of buildings (e.g. residential buildings, hotels, hospitals). These types of solutions must be properly addressed from the thermal modelling and simulation point of view considering a different thermal behaviour due to its detail components. For insulated metal penal systems the typical calculations are done by considering only the current field area without the impact of the thermal bridges. This means that the value used in calculations is just a 1D, and not a 2D or a 3D simulation which are closer to the real heat transfer phenomena for this types of constructive details. Thus, the paper addresses a study regarding the manner by which metallic building components can be thermally evaluated and optimized in order to improve their thermal performance and reach the imposed thermal transmittances-U values imposed for the market of high performant energy efficient buildings. The paper brings a complex approach in evaluating the thermal performance of insulated metal penal systems.

KEYWORDS
Metal panels, thermal bridges, heat transfer, modelling, simulation

INTRODUCTION

On an international level the development of high performance buildings (i.e. nearly Zero Energy Buildings – nZEB, passive buildings) is one of the main focuses aimed on achieving important decreases of the energy consumptions and greenhouse gas emissions. On a European level a decrease in the energy consumptions level of 20% is expected by 2020 (2020 Energy Strategy) and of 27% by 2030 (2030 Energy Strategy). Thus, the construction of new buildings offers the best opportunity to implement thermally optimised solution for the building envelope components, solutions that are able to meet the European targets regarding energy consumptions.

The building envelope plays a very important role in establishing both the energy demand for heating or cooling the building and also the interior comfort level of that building. The construction market offers several solutions described as optimal solutions for meeting the nZEB target imposed by the European directive (Directive 2010/31/UE). Among traditional solutions, the insulated metal panel systems (i.e. sandwich panels) typically used for industrial buildings are becoming popular among builders as an alternative solution for other types of buildings (e.g. office buildings, hospitals, residential buildings). Although that the metal panel has an interior layer of thermal insulation, this is covered on both sides by a corrugated metal sheet, thus decreasing the thermal performance of the ensemble. Also, several thermal bridges occur in the joints area, thermal bridges that must be addressed with at least a 2D calculation approach.

In many situations the calculations are done by a 1D approach, without considering the negative effect of the thermal bridges. Thus, an inaccurate thermal assessment can lead to code compliance issues and a poor thermal performance in the operating phase of the building. The study aims to analyse the thermal performance of insulated metal penal systems by approaching 3D calculations with the help of CÎMPSPAT program. The adjusted thermal resistance R' (i.e. thermal resistance that considers the effect of the thermal bridges) and the adjusted thermal transmittance U' are calculated and compared with the standard values for traditional and values for nZEB.

METHODS

A heat transfer computing software called CÎMPSPAT is used for the numerical modelling and simulation of the 3D heat transfer phenomena that takes place in insulated metal penal systems. The CIMPSPAT computing software is similar to other tools like THERM, Physibel, Antherm and others. Similar to mentioned tools, CIMPSPAT was developed in the last 35 years by our research staff. The finite-differences method is used for solving the third order heat transfer differential equations. The boundary conditions for the simulated cases are set in accordance to national and European standards. The program does 3D calculations by employing the heat conduction equation in a stationary thermal regime:

$$\frac{\partial}{\partial x}\left(\lambda(x,y,x)\cdot\frac{\partial\theta(x,y,z)}{\partial x}\right)+\frac{\partial}{\partial y}\left(\lambda(x,y,x)\cdot\frac{\partial\theta(x,y,z)}{\partial y}\right)+\frac{\partial}{\partial z}\left(\lambda(x,y,x)\cdot\frac{\partial\theta(x,y,z)}{\partial z}\right)=0 \quad (1)$$

where: θ is the temperature variable in time, in the (x,y,z) node, λ is the thermal conductivity of the body [W/(m·K)]

The geometry of the panel was discretized using a discretisation network in accordance with the stipulations of the standard EN ISO 10211. The digitization network is done automatically by the program, until the conditions for the heat flow between the inner and outer surfaces of the wall give a difference under 0.001W and in each node of the spatial mesh the obtained differences are under 0.000001 W (EN ISO 10211).

The input of data is done with the help of a graphical module. The required data is the spatial geometry of the component, the physical characteristics of each material that is forming the building component, the boundary conditions, the ambient temperatures, the exterior temperature, and the interior and exterior air humidity. The library of the program contains climatic data in accordance with the SR EN ISO 13790 standard and other specific standards.

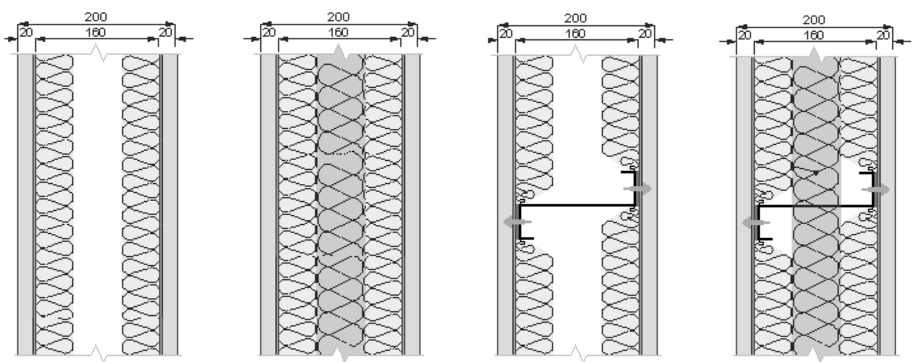
The analysed components are specific details for walls made with insulated metal panel systems existing in the construction market. The component is described by three layers: i.e. an exterior and an interior profiled sheeting and an inner layer of thermal insulation having a thermal conductivity λ=0.04 [W/(m·K)].

The simulated case scenarios are described as it follows: in current field area without the purlin (1) and in the area with the purlin (2). Thus, results are given considering both areas of a metallic component. Two hypotheses were simulated for each studied case:
- hypothesis (a): an air layer exists between the two thermal insulation layers that are in contact with the interior and exterior sheeting;
- hypothesis (b): a thermal insulation layer is placed between the two thermal insulation layers in contact with the interior and exterior sheeting.

For case scenario I is presented a wall with a thickness of 150 mm in two variants, the first in the current field area (a) and the second in the purlin area (see figure 1), the Z purlin having a length equal to 150 mm. For case scenario II is presented a wall with a thickness of 250 mm with an interior layer of thermal insulation between the existing thermal insulations (b), in the current field area (i.e. 1.II.b) and in the Z purlin area, purlin with a length of 200 mm (i.e. 2.II.b). For case scenario III is presented a wall with a thickness of 300 mm with an interior layer of thermal insulation between the existing thermal insulations (b), in the current field area (i.e. 1.III.b) and in the Z purlin area, purlin with a length of 250 mm (i.e. 2.III.b). The Z, C and U purlins have a thickness equal to 1.5 mm, while the profiled sheeting has a thickness equal to 0.5 mm. The mentioned case scenarios are briefly described in table 1. Also, the geometrical model of the constructive details is presented in figure 1.

Table 1. Studied case scenarios

	Case Scenario					
	(1)			(2)		
	150 mm	200 mm	250 mm	150 mm	200 mm	250 mm
Hypotheses	I	II	IV	I	II	III
a.	1.I.a	1.II.a	1.III.a	2.I.a	2.II.a	2.III.a
b.	1.I.b	1.II.b	1.III.b	2.I.b	2.II.b	2.III.b



1.I.a 1.I.b 2.I.a 2.I.a

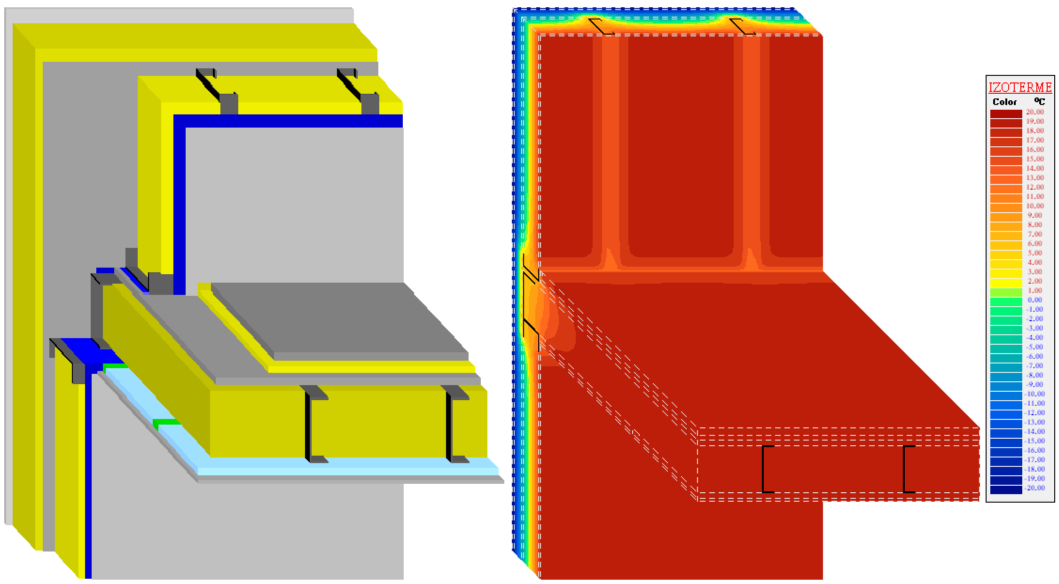
Figure 1. Extract from the analysed case scenarios

RESULTS

As mentioned before the European Directive 31/UE/2010 defines new types of energy efficient buildings starting by 31 December 2021. The nZEB require significantly improve thermal performances that will lead to higher thermal resistances (i.e. lower thermal transmittances) in accordance to what a building envelope can be described as having nearly zero energy consumptions. Although that the term of “nearly zero” is understood as more related to building systems than the building envelope, the reality is that the envelope still plays a key role in reaching that zero level.

The Romanian Governmental Order (GO 2641/2017) that came into force in April 2017 imposes more strict requirements for reaching the nZEB levels. Minimum adjusted required values for thermal resistances of building envelope components are given for both of residential and other types of buildings. The adjusted thermal resistances values refer to the ones obtained by applying the thermal bridges effect described by the linear and punctual thermal transmittance coefficients. In the case of an exterior wall for residential building the minimum adjusted required values is R’=1.80 [$m^2 \cdot K/W$], that being an adjusted thermal transmittance U'≤0.56 [W/(m^2·K)]. For other types of buildings the values for exterior walls are not higher but even smaller than the one mentioned for residential buildings, e.g. for category I of building going from R'=1.10 to 1.8 [m^2·K/W] while for category II of buildings going from R'=1.0 to 1.7 [m^2·K/W], category being defined based on the main usage of the building. Unfortunately, the minimum required values for both residential or other types of buildings, do not meet the values defined for a nZEB that should be around R'≥6,67 [m^2·K/W], which means an U'≤0,15 [W/(m^2·K)].

Thus, the values obtained through 3D calculations were compared to the above mentioned values in order to evaluate if the analysed case scenarios comply with them. It is good to mention that in current design practice thermal performance of metal insulated panels is evaluated mainly in the current field area and not in the area purlins area.



a) b)

Figure 2. The 3D geometrical model (a) and the spatial temperature field (b)

Table 2. Simulation results and compliance to design norms

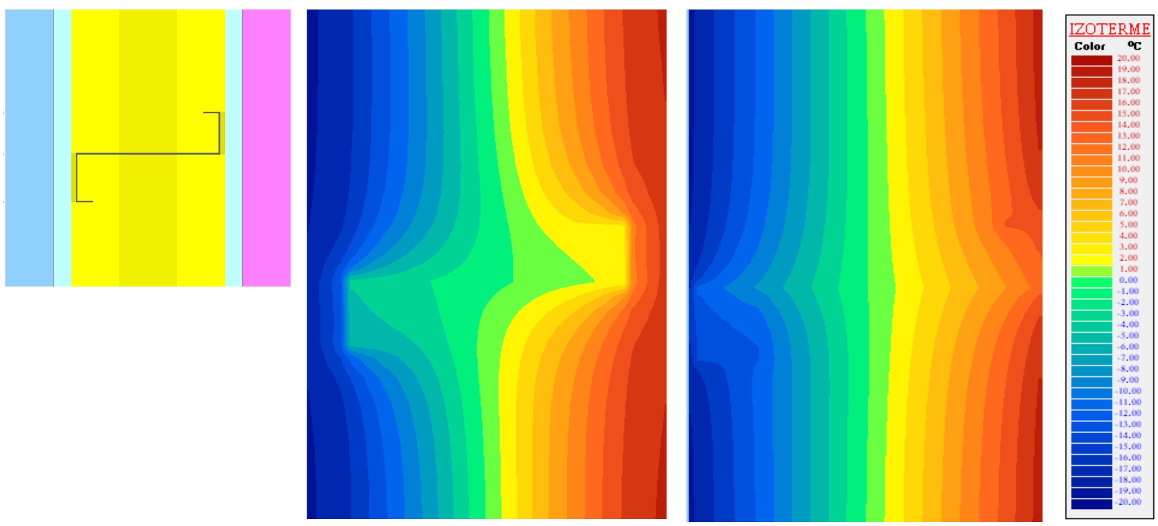
		Values		Calculation		GO 2641/2017	nZEB
				R'	U'	U'	U'
				[m^2·K/W]	[W/(m^2·K)]	[m^2·K/W]	[W/(m^2·K)]
Studied Cases	Fig.1	I	1.I.a	2.647	0.378	yes	no
			1.I.b	3.930	0.254	yes	no
			2.I.a	1.921	0.520	yes	no
			2.I.b	2.487	0.402	yes	no
		II	1.II.b	5.125	0.195	yes	no
			2.II.b	2.844	0.352	yes	no
		III	1.III.b	6.331	0.158	yes	no
			2.III.b	3.329	0.300	yes	no
	Fig.2			2.835	0.353	yes	no

DISCUSSIONS

Table 2 gives an accurate image of the thermal behaviour of the studied cases. As it can be observed for all examined cases the adjusted thermal transmittances U' have lower values

compared to national norms (GO 2641/2017) but much higher values compared to the ones described by the nZEB targets. When 1D calculations are done for the presented details, the results obtained, without considering the negative effect of the thermal bridges, is somewhere equal to a thermal resistance of 4 [$m^2 \cdot K/W$] for case scenarios I, value higher than all results (see table 2) obtained by implementing complex calculations (i.e. 2D or 3D). A 1D calculation approach does not consider the negative effect of the thermal bridges, thus giving a thermal performance even two times better than the actual (i.e. real) performance of a component. Therefore, such complex details should always be analysed by a 3D approach, using a spatial discretization network associated with the analysed case. Thus, the mesh will describe the exact shape of the corrugated sheet (i.e. the spatial shape), and also the presence of the steel purlins and of the fixing elements.
An example of the geometrical model and the spatial temperature field for an exterior wall in connection with an intermediate metallic thermal insulated flooring, is presented in figure 2. Such complex details that beside the material layers have several metallic elements (i.e. purlins) in its structure, placed in various positions (e.g. horizontal or vertical) and orientations, impose a 3D calculation procedure that can evaluate the spatial volume of the analysed detail. The metallic purlins give a spatial thermal effect of the heat flows that are passing through the building component. Doing 2D calculations for several defined areas of the geometrical model and overlapping the plane effects will not lead to accurate results for these type of complex details. The results will be overestimated compared to the actual thermal behaviour of the building envelope.

The simulated model and the temperature field for case 2.I.b and case 2.III.b are presented in figure 3. All simulated models started from the geometrical model presented in figure 1, that was described and modelled based on the real dimensions for each constructive detail. Figure 3 presents (a) the generic modelling in the purlin area.



a) Case 2 b) 2.I.b 2.III.b

Figure 3. The geometrical model (a) and the spatial temperature field (b) - with purlin

CONCLUSIONS

Meeting the required energy efficiency targets imposed by the European Union is a very hard task considering than even nowadays, some of the solutions offered on the construction market are not able to fulfil the thermal performance values imposed by design norms. When calculating complex details (e.g. insulated metal panels), the approach is usually done 1D instead of a 2D or more accurate a 3D calculation procedure. Therefore, the final thermal and energy performance of a building is quite different than the performance obtained during the operation phase of the building, case usually met in current practice at metallic structures. This has significant economical implication for the owners or operators of that building, from the energy consumption point of view. Even for the case of thermally optimized details (i.e. case scenario for all studied dimensions)) the thermal performance still does not comply with required values for nZEB. That means that several solutions could be employed to improve their thermal performance: thicker thermal insulation layer, an extra thermal insulation system on the exterior side of the panel, or better thermal performing materials (e.g. nanoinsulating materials) (Lakatos, 2014, 2017) and fasteners made of non-super conductive materials.

To conclude, beside the reduction of the energy consumption also a reduction of the greenhouse gas emission must be obtained, which means a low CO_2 emission index for the analysed building. With building envelope components with a thermal performance far worse than the modelled scenario in design phase, will set a trend opposite to what is needed, not only on a European but also on a worldwide level. The "A" energy class buildings or nZEB obtained on "paper" must behave likewise in operating phase. A 3D complex approach of the calculations for the insulated metal panel systems is able to offer accurate results for what means a real operation of a building.

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REFERENCES

2020 Energy Strategy accessed at https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2020-energy-strategy

2030 Energy Strategy accessed at https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/2030-energy-strategy

Directive 2010/31/EU of the European Parliament and Of the Council of 19 May 2010 on the energy performance of buildings (recast)

CÎMPSPAT. 2017 Computer program for 3D steady –state heat transfer calculation, Building Physics Research Team, Cluj-Napoca, Romania.

EN ISO 10211. 2007. Thermal bridges in building construction- Heat flows and surface temperatures- Detailed calculation.

SR EN ISO 13790. 2005. Thermal performance of buildings. Calculation of the energy necessary for heating, Romania.

Governmental Order 2641/2017 for the modification and addition of the technical regulation "Calculation methodology of the energy performance of buildings"

Lakatos A. 2014. Comparison of the Thermal Properties of Different Insulating Materials, *Advanced Materials Research*, Vol. 899, pp. 381-386.

Lakatos, Á. 2017. Comprehensive thermal transmittance investigations carried out on opaque aerogel insulation blanket, *Materials and Structures,* Vol. 50: 2. https://doi.org/10.1617/s11527-016-0876-7

Zabcik R.A. 2014. Thermal Performance of Insulated Metal Panels per ASHRAE 90.1-2010, Research and Development NCI Group Inc., 6 pages.

Jung-Min Oh et al. 2016. Analysis of building energy savings potential for metal panel curtain wall building by reducing thermal bridges at joints between panels, *Energy Procedia*, vol. 96 , pp. 696 – 709.