Evaluation of the thermal performance of composite insulated panels with metallic skin through steady-state numerical analysis – Part 2

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Abstract. Although the constructive detail type approach analysis already offers an extensive image about the influence of thermal bridges that occurs in the composite insulated panels with metallic skin, studies of the subject go further, by integrating the detail obtained results into parts of the building analyses, with the purpose to identify how factors such as occurrence frequency of the thermal bridge, or the percent of the glazed surfaces existent in regular facades influence the thermal behaviour of the building part, along with the numerical value of the linear thermal transfer coefficients obtained in Part 1 of the paper. Also, for the identified constructive detail with the lowest thermal performance, framework solutions were identified and analysed through steady-state FEM analysis in order to offer a working tool for building energy auditors.

1. Introduction
In a companion paper, the thermal performance of several common constructive details of composite insulated panels with metallic skin was evaluated, for four different thicknesses of this type of building enclosure solution. The analysed details represent the regular details which constitute the assembly of an industrial hall.
In order to obtain a global perspective on the thermal performance of the composite insulated panels with metallic skin, the study continues with a transition from the constructive detail analysis to the building envelope element analysis.
Otherwise formulated, starting from the local analysis of the effect of thermal bridges, which may cause the intensification of the thermal flux values, analysis which is specific to the constructive detail, with the determination of the linear thermal transmission coefficients that was made in Part 1, study goes further in Part 2 of the paper with the assessment of the impact of thermal bridges in the thermal performance of the facade, respectively of the roof, as building part analysis. This approach allows the identification of the regular constructive details that have a high impact on the energy performance of the studied building element.
The study also aims to optimize the constructive details identified in Part 1 of the paper as being with the lowest thermal performance, by using steady-state FEM analysis.

2. Parametric study of the impact of thermal bridges in the building envelope

2.1. Considered case studies
One of the main steps in the energy performance analysis of a building is the calculation of the heating and cooling demand, in order to determine the heating and the cooling energy consumptions. To calculate that, the building envelope thermal performance analysis is necessary to be done. Therefore, by using the results obtained on constructive detail level in previous paper (Part 1) and also, by using results of paper [1], building envelope analysis level is further pursued, in different scenarios (table 1).
Thus, the corrected thermal resistances for a few facade dimensions were determined, assuming the use
of 10 cm thick wall sandwich panels, a thickness considered to be common for this type of solution, for the outer wall length of 30 m and the height 4 m and 6 m, respectively.

Table 1. Parametric studies depending on the building element type

| Building element type | Case          |
|----------------------|---------------|
| Facade               | A1, A2, B1, B2|
| Roof                 | C1, C2        |

The metallic sheet being really thin (0.0006 m for the exterior side of the panel, respectively 0.0004 m for the interior side of the panel), is considered negligible regarding the thickness of the panel, being considered that the thickness of the panel equals the thickness of the insulation layer, as notation. However, the metallic sheet was taken into consideration in the FEM analysis. Several different scenarios were used with regard to the existence or not of glazed surfaces, respectively with regard to the percentage of glazed surfaces relative to the analyzed facade surface. Also, for the type of constructive detail on which in Part 1 of the paper were analyzed two distinct variants, as is the case of the joint between the wall panels, the wall panel joint with the slab on ground and the joint between roof panels, for the further studies one was chosen. Input data used for the considered facades are centralized in table 2, respectively in table 3 for the roofs.

Table 2. Input data for the analyzed facades

| Case | Used peculiar constructive details | $\delta_{\text{insulation}}$ (cm) | $L_e$ (m) | $L_i$ (m) | $h_i$ (m) | $S_i$ (m$^2$) |
|------|-----------------------------------|----------------------------------|-----------|-----------|-----------|--------------|
| A1   | 3.5.1 | 3.2.1                           | 10        | 30        | 29.80     | 4.00        | 119.20       |
| A2   | 3.5.2 | 3.2.1                           | 10        | 30        | 29.80     | 4.00        | 119.20       |
| B1   | 3.5.1 | 3.2.1                           | 10        | 30        | 29.80     | 6.00        | 178.80       |
| B2   | 3.5.2 | 3.2.1                           | 10        | 30        | 29.80     | 6.00        | 178.80       |

Corrected thermal resistances were determined for roof slab, also for 10 cm panel thickness and outer roof size arbitrary chosen (horizontal projection) of 30x30 m.

Table 3. Input data for the analyzed roofs

| Case | Used peculiar constructive details | $\delta_{\text{insulation}}$ (cm) | $L_e$ projection (m) | $L_i$ projection (m) | $L_i$ slope $\gamma$ (m) | $S_i$ (m$^2$) |
|------|-----------------------------------|----------------------------------|----------------------|----------------------|------------------------|--------------|
| C1   | 3.7.1                             | 10                               | 30                   | 29.80                | 30.22                  | 900.56       |
| C2   | 3.7.2                             | 10                               | 30                   | 29.80                | 30.22                  | 900.56       |

The influence of each thermal bridge on the building elements was analyzed for several undertaken scenarios, depending on the value of the linear thermal transmission coefficient obtained by the type of detail and the length to which it applies ($\psi \cdot l$), as component of the relation (1), and which represents the impact of each thermal bridge that occurs, simultaneously with the frequency of its occurrence in regular constructive facades or roofs. It is also specified that punctual thermal bridges (represented by $\chi$ – the punctual thermal transmission coefficient), such as screws used for mechanical fastening, for which quantitative assessment requires three-dimensional analysis, are not the subject of current investigation.
\[
\frac{1}{R'} = \frac{1}{r} + \sum \frac{\varrho_i}{S_i} + \sum \frac{\chi_i}{S_i} \quad (m^2 \cdot K/W)
\]

\[
r = \frac{R_t}{R} (-)
\]

2.2. Parametric study of the impact of thermal bridges in the building envelope

The obtained results for the facades are presented in figure 1, figure 2, figure 3 and figure 4.

**Figure 1.** Analysis of influence of thermal bridges on analyzed façade – Case A1

**Figure 2.** Analysis of influence of thermal bridges on analyzed façade – Case A2
It is noted that for the building element analysis, for determining the horizontal joint length between the wall panels, the width of each panel was considered to be 1 m. Further, the results of corrected thermal resistances, $R'$, and of $r$-values, which is calculated with relation (2), are centralized in table 4.

Analyzing the results presented in table 4 and, subsequently, in figure 1, figure 2, figure 3 and figure 4, it is observed that the influence of the thermal bridges existing at the joints between the panels (the joints between wall panels, wall panels with roof panels, corners of the building facade) have a relatively low impact in the thermal performance of the facade, but there are two types of common constructive details (joint of the wall panel with window and with the slab on ground), whose geometric and material thermal...
bridges have a major impact on the thermal performance of the building element, significantly reducing it.

### Table 4. Thermal performance of the analyzed facades

| Case     | Results | Percentage of glazed surfaces |
|----------|---------|-------------------------------|
|          |         | 0%   | 10%  | 20%  | 25%  |
| A1, A2, B1, B2 | R       | 2.799 | 2.799 | 2.799 | 2.799 |
| A1       | R'      | 2.096 | 1.958 | 1.856 | 1.820 |
|          | r       | 0.75  | 0.70  | 0.66  | 0.65  |
| A2       | R'      | 2.249 | 2.091 | 1.975 | 1.933 |
|          | r       | 0.80  | 0.75  | 0.71  | 0.69  |
| B1       | R'      | 2.031 | 1.852 | 1.782 | 1.770 |
|          | r       | 0.73  | 0.66  | 0.64  | 0.63  |
| B2       | R'      | 2.175 | 1.970 | 1.891 | 1.878 |
|          | r       | 0.78  | 0.70  | 0.68  | 0.67  |

Similar analysis was undertaken for roofs, with 10 cm panel thickness and outer roof size arbitrary chosen (horizontal projection) of 30x30 m. It was analyzed the influence of each thermal bridge on the roof as building element, for two considered cases, as can be seen in figure 5 and figure 6.

In order to determine the joining length between the roof panels, it is stated that the width of each panel equal to 1 m, and the joining of the panels is considered parallel to the span of the hall (parallel to the width of the considered floor).

### Figure 5. Analysis of the influence of thermal bridges on the analyzed roof floor - Case C1

| Thermal bridge type | Percentage of glazed surfaces [%] |
|---------------------|----------------------------------|
| Detail 3.7: Roof - Roof | 73.19% |
| Detail 3.6: Roof ridge       | 0.00%  |
| Detail 3.3: Wall - Roof       | 26.81%  |
Corrected thermal resistances and r-values were also determined for roof. According to the results obtained in table 5, figure 5 and figure 6, in the case C1 there is a negligible influence of the thermal bridges on the studied building element, but the corrected thermal resistance decrease significantly in case C2, leading to a very low thermal performance for the building element because of the high occurrence of the roof between joints, concurrently with relatively high Ψ-values.

Table 5. Thermal performance of the analyzed roofs

| Case | R (m²K/W) | R' (m²K/W) | r (-) |
|------|-----------|------------|-------|
| C1   | 2.791     | 2.743      | 0.98  |
| C2   | 2.791     | 1.460      | 0.52  |

3. Energetically optimized constructive details

After analyzing several constructive details of sandwich panels and the interpretation of the results from the first part of the paper, respectively in the above presented study, it is concluded that the constructive details that have the potential to significantly improve heat transfer behavior by reducing the effect of thermal bridges are the joining details of the wall panel with the slab on ground. For the identified constructive details with low thermal performance, FEM analysis in the conditions already detailed in Part 1 of the paper is undertaken. Thus, variants of optimization of this type of detail with the purpose to reduce the effect of the thermal bridge were analyzed by: increasing the length of the overlap of the wall panel on the concrete element with the optimization of the fastening (measure types 1), respectively by insulating the base, including the introduction of a horizontal insulation on the perimeter of the building (measure types 2).

For this study, the numerical and analytical calculations for the determination of linear thermal transfer coefficients were performed for the wall panel of 80 mm thickness.

Main solutions and results are presented in the following tables. As can be seen in table 6, following the application of measures type 1, there is a significant reduction of linear thermal transfer coefficients: around 50% in the wall panel, over 40% for the slab on ground. However, there are situations when this
type of solutions is not applicable, because of the low difference between the upper part of the slab on ground and the ground that surrounds the building.

**Table 6.** Linear thermal transfer coefficients for detail 3.5.1, optimized by using measures type 1

| No. | Detail 3.5.1 Measures type 1 | Element | $L_2D$ | $\Psi_{\text{detail}}$ | $\Psi$ | $\Psi_{\text{reduction}}$ |
|-----|-----------------------------|---------|--------|-----------------------|--------|--------------------------|
|     |                             | Wall    | 0.832  | 1.142                 | 0.364  | -                        |
|     |                             | Slab    | 2.789  |                       | 0.778  | -                        |
| 1.a | Overlap 30 cm               | Wall    | 0.628  | 0.622                 | 0.183  | 49.85                    |
|     |                             | Slab    | 2.436  |                       | 0.440  | 43.49                    |
| 1.b | Overlap 30 cm + injected PUR| Wall    | 0.617  | 0.593                 | 0.173  | 52.53                    |
|     |                             | Slab    | 2.416  |                       | 0.420  | 46.03                    |
| 1.c | Overlap 30 cm + EPDM sealing| Wall    | 0.620  | 0.618                 | 0.176  | 51.60                    |
|     | – figure 7                  | Slab    | 2.437  |                       | 0.441  | 43.30                    |

*Figure 7.* Geometrical modeling detail 3.5.1 – solution 1.c

*Figure 8.* Isothermal surfaces detail 3.5.1 – solution 1.c

The results of implemented measures type 2 are centralized in table 7. For optimized details 2.a, 2.b and 2.e (figure 10) there was found a reduction of approx. 25-30% of the linear thermal transfer coefficients relative to the values calculated in the initial detail, for both the wall panel and slab on ground. Regarding the technical solutions 2.c, 2.d (figure 9), respectively 2.f and 2.g, the horizontal thermal insulation layer was proposed with the intention of ensuring a deviation of the temperatures in the perimeter area of the wall-to-ground intersection, in the meaning of executing a "barrier" in passing the heat flow beneath the slab on the ground to the outside, aiming to reduce the flow that dissipates to the surface of the ground. However, the values of linear thermal transfer coefficients obtained by numerical simulations are not much lower than those of solutions 2.b and 2.e, so it is observed that this type of technical solution is
not necessarily justified given the quantities of the works and additional materials necessary for their implementation.

Figure 9. Geometrical modeling detail 3.5.1 – solution 2.d

Figure 10. Isothermal surfaces – detail 3.5.1 – solution 2.d

Figure 11. Geometrical modeling detail 3.5.1 – solution 2.e

Figure 12. Isothermal surfaces – detail 3.5.1 – solution 2.e
Table 7. Linear thermal transfer coefficients for detail 3.5.1, optimized by using measures type 2

| No. | Detail 3.5.1 Measures type 2 | Element | \( L_{2D} \) (W/K) | \( \Psi_{\text{detail}} \) (W/mK) | \( \Psi \) (W/mK) | \( \Psi_{\text{reduction}} \) (%) |
|-----|-----------------------------|---------|--------------------|----------------|----------------|----------------|
| Reference model - Overlap 10 cm | Wall | 0.832 | 1.142 | 0.364 | - |
| | Slab | 2.789 | - | 0.778 | - |
| 2.a | Base insulation with 5 cm XPS down to ground | Wall | 0.806 | 0.845 | 0.273 | 25.04 |
| | Slab | 2.421 | - | 0.572 | 26.52 |
| 2.b | Base insulation with 5 cm XPS + 30 cm vertical insulation of foundation beam | Wall | 0.793 | 0.813 | 0.260 | 28.61 |
| | Slab | 2.259 | - | 0.553 | 28.97 |
| 2.c | Base insulation with 5 cm XPS + 30 cm vertical insulation of foundation beam + 50 cm length horizontal insulation below the ground | Slab | 2.172 | 0.809 | 0.552 | 29.02 |
| | Base insulation with 5 cm XPS + 30 cm vertical insulation of foundation beam + 100 cm horizontal insulation below the ground – figure 9 | Wall | 0.789 | 0.809 | 0.256 | 29.87 |
| | Slab | 2.120 | - | 0.554 | 28.86 |
| 2.d | Base insulation with 5 cm XPS + 60 cm vertical insulation of foundation beam – figure 11 | Wall | 0.789 | 0.806 | 0.256 | 29.85 |
| | Slab | 2.173 | - | 0.550 | 29.26 |
| 2.e | Base insulation with 5 cm XPS + 60 cm vertical insulation of foundation beam + 50 cm length horizontal insulation below the ground | Wall | 0.788 | 0.808 | 0.254 | 30.18 |
| | Slab | 2.128 | - | 0.553 | 28.90 |
| 2.f | Base insulation with 5 cm XPS + 60 cm vertical insulation of foundation beam + 100 cm length horizontal insulation below the ground | Slab | 2.085 | 0.806 | 0.552 | 29.03 |

Finally, the proposals through which was obtained the highest reduction of the thermal bridges effect from each type of proposed solution, were analyzed and the measures have been cumulated. The identifier of combinations of proposed measures and the obtained results are presented in table 8. By combining the proposed solutions, a significant reduction of linear thermal transfer coefficient values is observed, for both the wall panel (over 60%) and the slab on ground, where the \( \Psi \)-value reduction is between 58% and 63%, compared with the initial detail of which thermal performance was studied in Part 1 of the paper.

It is noticed the significant influence of the length of the overlap of the wall panel with the reinforced concrete perimetral base, so as the length of the overlap increases, the effect of the geometric and material thermal bridge is reduced into the constructive detail.

Considering the specificity of this type of constructive detail, characterized by the fixing of the wall panel with the L-shaped metal plate, metallic fastening which is necessary by reasons of strength and stability, the results obtained are considered to be satisfactory.
Table 8. Linear thermal transfer coefficients for detail 3.5.1 using measures type 1+2

| Detail 3.5.1 Measures type 1+2 | Element | $L_{\text{2D}}$ | $\Psi_{\text{detail}}$ | $\Psi$ | $\Psi_{\text{reduction}}$ |
|-------------------------------|---------|----------------|----------------------|--------|-----------------------|
| Reference model               | Wall    | 0.832          | 1.142                | 0.364  | -                     |
|                               | Slab    | 2.789          | 0.778                | -      | -                     |
| 1.c+2.b                      | Wall    | 0.587          | 0.466                | 0.142  | 61.10                 |
|                               | Slab    | 2.174          | 0.324                | 0.140  | 58.35                 |
| 1.b+2.b                      | Wall    | 0.585          | 0.445                | 0.140  | 61.49                 |
|                               | Slab    | 2.154          | 0.304                | 0.135  | 60.88                 |
| 1.b+2.e                      | Wall    | 0.580          | 0.423                | 0.135  | 62.87                 |
|                               | Slab    | 2.076          | 0.287                | -      | 63.06                 |

4. Conclusions
The results presented in Part 2 of the paper offers a comprehensive knowledge about the thermal performance of composite insulated panels with metallic skin from a building element integrated perspective. The results of the undertaken parametric studies highlights that the impact of the thermal bridges on the thermal performance of the building elements, especially for the walls, is significant, similar to the walls of brick masonry with traditionally arranged external thermo-insulation.

The paper highlights that an important effect of the thermal bridge can appear also from the frequent occurrence of a thermal bridge, even though the $\Psi$-values are low or relatively low.

Constructive details optimization for the initial solution with the lowest thermal performance is also made, offering ready to use data for building energy auditors, in case that the energy audit of the building is performed.

The results of the full paper (Part 1, Part 2) offers a great view of the thermal performance of composite insulated panels with metallic skin, which is relative a new technical solution, starting from steady state FEM analyses of common constructive details, which are integrated in studies of real scale parts of building (facades and roofs).

By using advanced calculation methods, the results presented in this paper may be used as working data by building energy auditors and by civil engineering specialists, in order to predict correct information regarding the energy consumption of the building, considering as well the case that energy improvements are being made for an existing building.

5. References
[1] Măgurean A M, Lupan L M, and Moga I 2014 Insulated Sandwich Panels - Thermal performance Proc. of the Second Int. Conf. for PhD Students in Civil Engineering and Architecture (CE-PhD 2014) pp 477–482

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