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The influence of polyisocyanurate (PIR) facing on the heat transfer through the corners of insulated building partitions

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Abstract. Prefabricated products made of polyisocyanurate (PIR) thermal insulation material covered with cardboard, plastic, aluminium or composite facings are used for thermal insulation of building envelopes. The facing of these products is selected according to their conditions of use, and the effect of the facing on the declared thermal properties of the product depend only on water vapor diffuse properties of the facing. However, at the corners of the building where these products are joined, facings can be in the direction of the heat flux movement and significantly increase heat transfer through the longitudinal thermal bridge formed in the corner of the building. After analysing the solutions for installation of PIR thermal insulation products on the walls and roof corners of buildings, calculations of the heat transfer coefficients of the linear thermal bridges were made, and the influence of various facings and different structural solutions on the heat transfer coefficient value of the thermal bridge was determined. Aluminium foil facing have the greatest influence, but other facings must also be considered. The structural solutions with the greatest increase in the heat transfer due to the effect of the facing were selected, and the influence to the thermal and air tightness properties of the structural solution when facing is removed were analysed, the stability of thermal properties of the thermal insulation material were analysed as well. Proposals for joining PIR thermal insulation products with heat-conductive facings in the corners of buildings were prepared.

1 Introduction

The use of rigid polyisocyanurate-polyurethane foam (PIR/PUR) in construction has increased due to their excellent mechanical properties and low thermal conductivity [1]. PIR insulation is the most widely used insulation material in low-slope roofs in the U.S. (≥ 70 % of the market share) [2].

Figure 1 shows the common manufacturing of PIR boards. The largest volume of rigid PIR boards is produced in sheet form on machines known as laminators that are essentially double conveyors, between which foam rises to a controlled thickness. The faced sheet products obtained on laminators are widely used for construction applications such as roofing or insulated facades [3].

The flexible facings are generally made of mineral fleece, glass fleece, aluminium foil or composite film [4]. Depending on the type of facings on the panel, we can distinguish flexible-faced or rigid-faced foam panels [3].

The choice of facing usually depend on the wall construction where the PIR thermal insulation will be installed. For example, PIR faced with thin aluminium foil is commonly used as exterior or interior continuous insulation for masonry or concrete wall systems, including exterior masonry cavities, in commercial and residential wood stud construction. The facers protect the foam core from UV degradation [5].

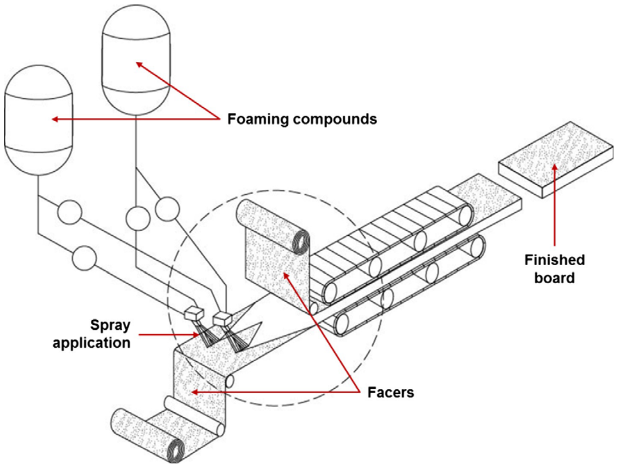

Fig. 1. PIR board manufacturing process [2]

PIR with plastic facing is usually used in production of precast insulated concrete sandwich panels, as continuous insulation in concrete wall systems, and as insulation for use in precast, tilt-up and cast-in-place insulated concrete wall panels. The same applications are for PIR faced with composite paper foil.

Different facings are chosen to suit the intended application of the PIR insulation boards. Facers and facing materials serve a variety of functions in the production and use of PIR insulation. They are used to contain the foam core during the production process,

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create stability to the finished insulation board. Facers and facing materials also may serve several functions during working life of the product beyond contribution to strength and dimensional stability [6]. Different facings can serve as vapour barrier, moisture lock, optical surface or protection against mechanical damage [4].

Foil and plastic facings on rigid PIR foam panels can help stabilize the R-value of the product, slowing down thermal drift and maintain the long-term thermal resistance of the insulation [7]. When PIR is manufactured, a number of small, closed cells are created. This means that the blowing agent vaporized during the foaming reaction fills these small cells as a gas [8]. To reach equilibrium, the air migrates into the cell and the blowing agent migrates out of the cell [9], as a result, the composition of the gas in the pores and the thermal properties of the entire thermal insulation product change over time [10]. Therefore, in order to maintain the thermal properties of polyurethane foam, the aim is to minimize the damage to these facings during the installation of building insulation.

However, at the corners of the building where these products are joined, facings can be positioned in the direction of the heat flux movement and might increase heat transfer through the longitudinal thermal bridge formed in the corner of the building. A lot of research was carried out to investigate the reduction in heat transmittance of wall constructions due to the influence of linear and point thermal bridges [11]. Typically, when evaluating the heat transfer coefficient of a partition and modelling longitudinal (and point) thermal bridges, the joints passing through the thermal insulation are evaluated [11-13] and the influence of facings is not evaluated. In some cases, it is recommended to remove the facings from the joints, to bond the products by gluing at the corners, but in practice polyurethane products are often bonded without removing the facings. Therefore, this study is conducted to evaluate the extent to which a facing can influence heat transfer through partitions, especially when the facing is made of aluminium foil.

2 Methodologies

2.1 Parameters of wall fragments

The construction of the ventilated wall is shown in Fig. 2. The structure consists of a 10 *mm* plaster layer, a 200 *mm* aerated concrete block, a 10 *mm* thick PU glue layer and a 200 *mm* PIR insulation layer (thermal properties are given in Table 1), as well as ventilated air gap and exterior finish. The different facings of PIR insulation are chosen to be diffusion-proof, so that the declared thermal conductivity can be obtained.

PIR thermal insulation with four different facings is used in these fragments: composite facing with aluminised surface, thin aluminium tin facing, composite paper facing and plastic facing, as well as unfaced PIR and PU glue at the joint of PIR boards. The influence of studs and fasteners is not evaluated for the modelled wall fragment. The inner layer made of aerated concrete blocks is modelled without the influence of mortar joints, the layer has been considered as solid material.

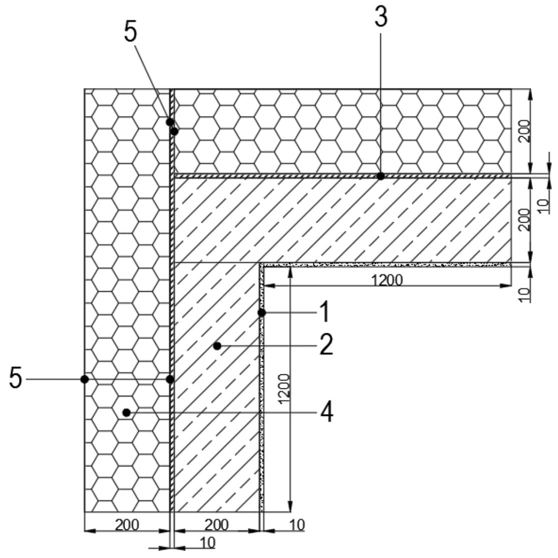

Fig. 2. Wall corner fragment: 1 – plaster, 2 - aerated concrete blocks, 3 – PU foam, 4 – PIR insulation, 5 – PIR facings (see Table 1) (dimensions in *mm*).

The heat transfer coefficient of this wall structure, calculated in accordance with EN ISO 6946:2017 [14], is $U = 0{,}09$ $W/(m^2 \cdot K)$.

Table 1. Wall materials

No.	Material	Thickness, *mm*	Thermal conductivity λ, *W/m·K*
1	Plaster	10	0,9
2	Aerated concrete blocks	200	0,13
3	PU foam	≤ 10	0,04
4	PIR boards with facing:	200	0,022
	a) aluminium foil	100 μm	211
	b) multilayer aluminized facing	155 μm	0,125
	c) composite paper facing	132 μm	0,066
	d) plastic facing	103 μm	0,125

2.2 Numerical modelling of heat transfer in building corner joints insulated with faced polyurethane products

Computer program THERM 7 developed at Lawrence Berkeley National Laboratory (LBNL) which complies with the standard EN ISO 10211:2017 [15] is used for modelling of heat transfer in building corner joints.

Using this program, the heat transfer coefficient of the longitudinal thermal bridge of each modelled building wall corner is calculated and compared to the heat transfer coefficient of the longitudinal thermal bridge of the same corner insulated with a single layer of PIR without facing and PU glue in the joint. The differences in the result values obtained are proportional to the magnitude of the heat loss per corner, while the thermograms of the temperature distribution of the modelled structures and the heat flux intensity show the influence of different facings on the heat transfer through the insulated corner of the building.

For this numerical calculation boundary temperatures $\theta_{int} = 20$ *°C*, $\theta_e = 0$ *°C*, and the heat transfer resistances of the surfaces $R_{si} = 0{,}13$ $m^2 \cdot K/W$, and $R_{se} = 0{,}04$ $m^2 \cdot K/W$ were selected.

2.3 Determining the thermal transmittance

According to the standard EN ISO 10211:2017 [15] the linear thermal transmittance considered of the linear thermal bridge separating two environments being, Ψ, is given by:

$$\Psi = L_{2D} - \sum_{j=1}^{N_j} U_j \cdot l_j \qquad (1)$$

where: L_{2D} – the thermal coupling coefficient obtained from a 2-D calculation of the component separating the two environments being considered; U_j – the thermal transmittance of the 1-D component *j* separating the two environments being considered; l_j – the length within the 2-D geometrical model over which the value U_j applies; N_j – is the number of 1-D components.

The Ψ-value represents the difference between the thermally interrupted component and the uninterrupted component that is assumed for the balance. First the heat flow or the conductance L_{2D} is determined by means of the heat flow simulation.

3 Results

Fig. 3 shows the intensity of heat flow through the corners insulated with PIR faced with different facings.

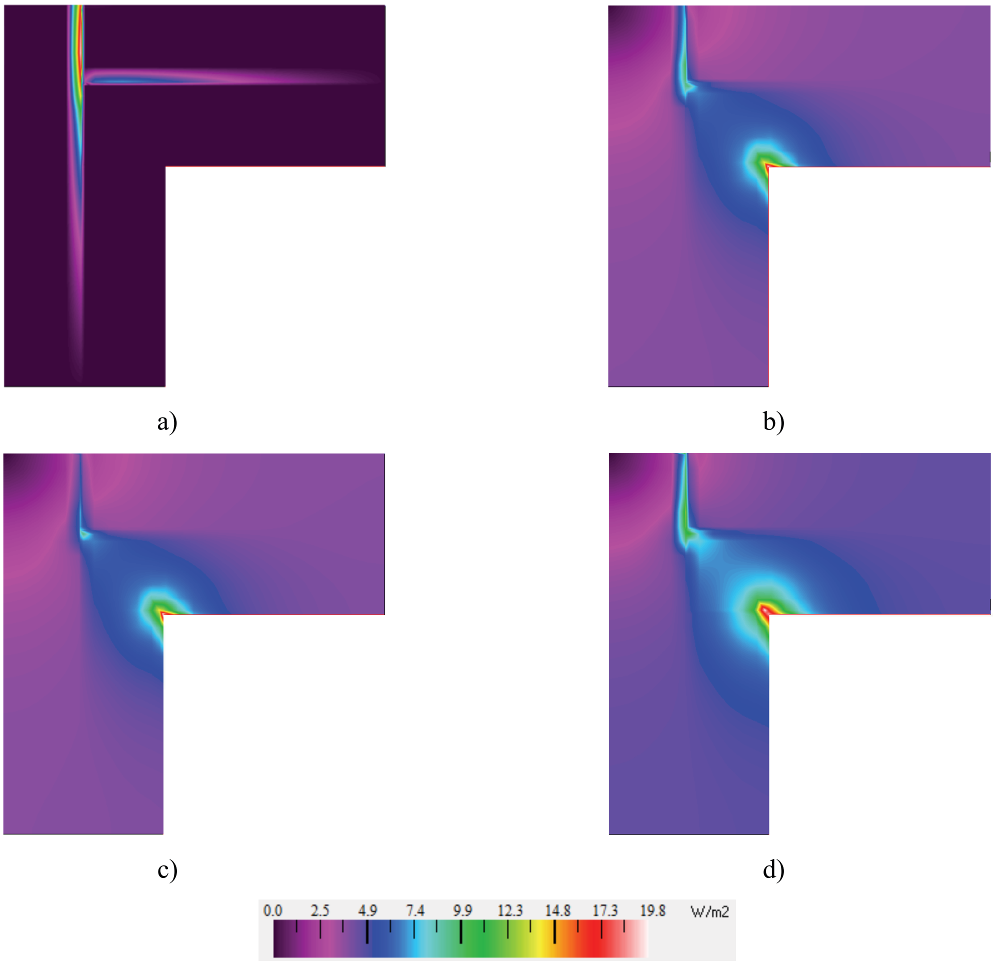
a)
b)
c)
d)

Fig. 3. The intensity of heat flow through the corners of the wall insulated with PIR, faced with different facings: a) aluminium foil, b) multilayer aluminized facing, c) composite paper facing, d) plastic facing

Fig. 3a differs from the rest of Fig. 3, and this is because of the thermal conductivity of aluminium foil, which conductivity (211 *W/m·K*) is much higher compared to the surrounding materials (thermal conductivity of PIR is 0,022 *W/m·K*), therefore heat flow is gathered around the aluminium facing. The heat flow rate per metre can be calculated using equation from [15]:

$$\Phi_l = L_{2D}\cdot(\theta_{int} - \theta_e),\ W \qquad (2)$$

Using Eq. 2, it can be calculated that the heat flow through the specimen with aluminium foil facing is Φ =3,47 *W*, and for specimen with other facings Φ = 2,85 *W*, i.e. 1,2 times lower.

Table 2. Calculation results

Facing type	L_{2D}	**Thermal bridge value, Ψ, $W/(m\cdot K)$**
a) aluminium foil	0,1735	-0,006
b) multilayer aluminized facing	0,1425	-0,037
c) composite paper facing		-0,037
d) plastic facing		-0,037
e) without facing	0,142	-0,039

The results obtained (Table 2) show that the value of the thermal bridge when multilayer aluminized facing, composite paper facing, or plastic facing are used is equal. This is because these facings have a very similar thermal conductivity coefficient, which is close to the thermal conductivity coefficient of the PIR thermal insulating material, and therefore their influence on the size of the thermal bridge is very small. As in the case with aluminium foil, even a very thin facing can make the situation worse.

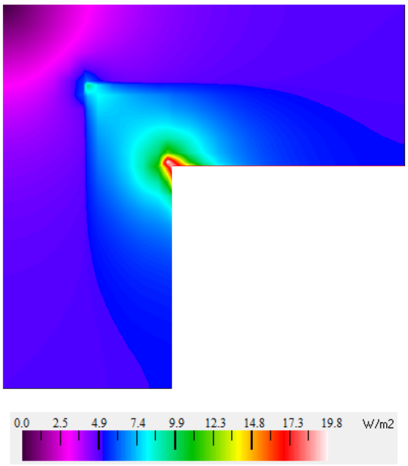

Fig 4. The intensity of heat flow through the wall corner insulated with PIR, without facing

When using PIR insulation without facings, the calculated *U* value is close to the case when PIR is used with facings which have similar thermal conductivity as PIR itself.

Fig. 4 shows the intensity of heat flow through the corner insulated with PIR without any facings. In the modelled corners, a 10 *mm* PU glue layer is used in the PIR insulation joint so that the aluminium foil facing on the joint does not come in to contact to the aluminium foil facing on the outside. Since PU glue is not commonly used in the joint, we consider the situation where the aluminium foil facing in the joint is in contact with both the PIR aluminium foil on the outside and at the masonry. The simulation result is presented in Fig. 5.

The linear thermal transmittance is calculated, and its value is Ψ = -0,0006 $W/(m\cdot K)$, i.e. 10 times lower than given in the Table 2. Then the heat flow rate per metre is calculated using Eq. 2, which is Φ = 3,59 *W*, or 3 *%* higher than in the first case. If compared to the heat flow through the wall corner insulated with PIR without facing, the difference is up to 26 *%*.

In order to reduce the heat flow to the outside, which is formed around the aluminium foil facing at the joint of the PIR insulation boards, it is necessary to remove the facing at this joint (Fig. 6).

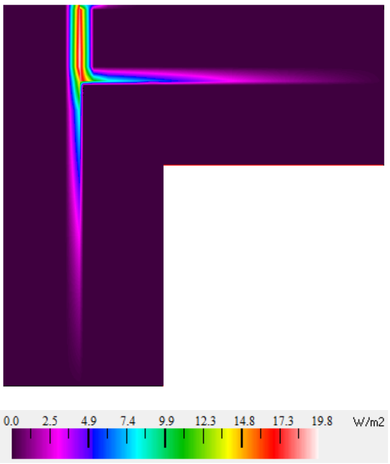

Fig 5. The intensity of heat flow through the wall corner insulated with aluminium foil faced PIR, without PU glue

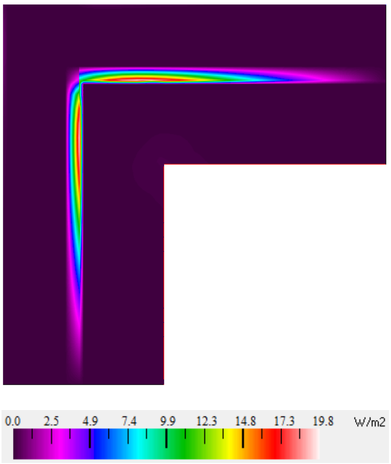

Fig. 6. The intensity of heat flow through the wall corner insulated with aluminium foil faced PIR, without aluminium foil in the joint

In this case, the linear thermal transmittance value is Ψ = -0,037 $W/(m\cdot K)$, and the heat flow rate per metre is Φ = 2,89 *W*, i.e. the same as with other facings.

However, all these cases are useful when designing a new energy efficient building. The following are the modelling results when a building is being renovated using 70 *mm* PIR insulation, and other materials as given in Table 1. The heat transfer coefficient of such wall is U = 0,20 $W/(m^2\cdot K)$.

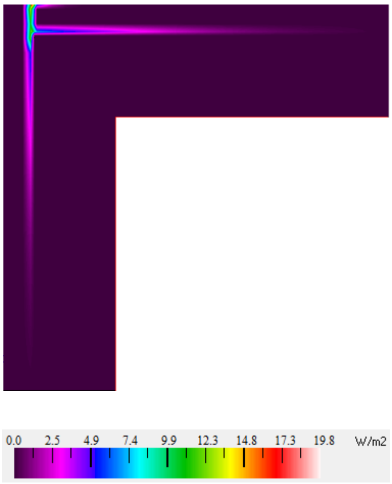

Fig. 7. The intensity of heat flow through the wall corner insulated with aluminium foil faced PIR (70 *mm*)

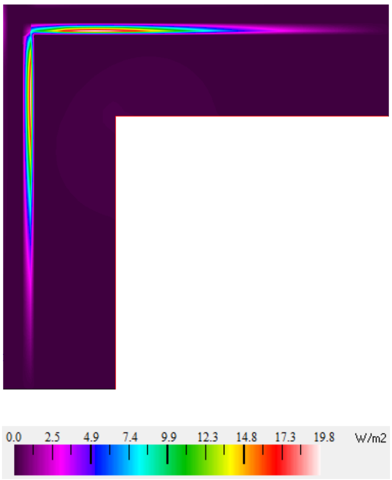

Fig. 8. The intensity of heat flow through the wall corner insulated with aluminium foil faced PIR (70 *mm)*, without aluminium foil in the joint

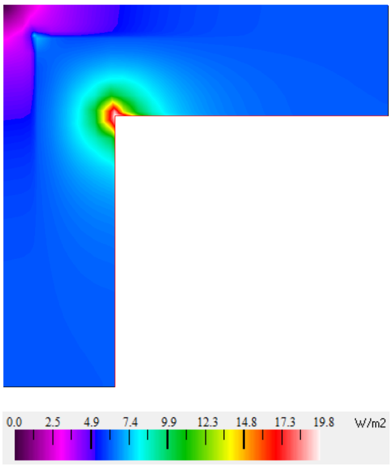

Fig. 9. The intensity of heat flow through the wall corner insulated with PIR (70 mm), without facing and PU glue

Fig. 7 illustrates the heat flux intensity when the PIR faced with aluminium foil in the joint. In this case, the linear thermal transmittance value is Ψ = -0,036 *W/(m·K),* and the heat flow rate per metre is Φ = 7,28 *W*, e.g. the same thickness with multilayer aluminized facing linear thermal transmittance value is Ψ = -0,067 *W/(m·K),* and the heat flow rate per metre is Φ = 6,65 *W.*

Figure 8 illustrates the heat flux intensity when the PIR is without aluminium foil facing in the joint. In this case, the linear thermal transmittance value is Ψ = -0,063 *W/(m·K),* and the heat flow rate per metre is Φ = 6,74 *W*, so it is almost the same as with PIR faced with more efficient facings.

For comparison, the heat flux intensity when PIR insulation is uniform, i.e. without PU glue in the joint and without facings is given in Fig. 9.

Results of numerical calculation are given in Table 3.

Table 3. Calculation results

Type	**Thermal bridge, Ψ, *W/(m·K)***	**The heat flow rate per metre Φ, *W***	**Difference compared to unfaced PIR, %**
200 *mm* PIR without facing and without PU glue in the joint	-0,039	2,84	-
200 *mm* PIR with facings listed in Table 2 (b, c and d) and with PU glue in the joint	-0,037	2,85	0,3
200 *mm* PIR with aluminium facing and with PU glue in the joint	-0,006	3,47	22
200 *mm* PIR with aluminium facing and without PU glue in the joint	-0,0006	3,59	26
200 *mm* PIR without aluminium facing and PU glue in the joint	-0,037	2,89	1,7
70 *mm* PIR without facing and without PU glue in the joint	-0,056	6,59	-
70 *mm* PIR with facings listed in Table 2 (b, c and d) and with PU glue in the joint	-0,067	6,65	0,9
70 *mm* PIR with aluminium facing and without PU glue in the joint	-0,036	7,28	10,5
70 *mm* PIR without aluminium facing and PU glue in the joint	-0,063	6,74	2,3

4 Conclusions

1. When PIR thermal insulation with facings is used to insulate buildings, the increase in longitudinal thermal bridge at the thermal insulation corner joint because of the facing, shall only be considered when the PIR products are faced with aluminium foil. The presence of an aluminium foil facing at the corner joint of the thermal insulation has been found to increase heat flow up to 26 *%*, while other facings: plastic, paper or multilayer aluminized facing, increase it up to 2 *%*.
2. When two PIR boards are joined at the corner, the aluminium foil facing on these connecting boards will not come into contact. The aluminium foil entering the corner joint must be removed or separated from the inner and outer facing of the PIR products.
3. The use of PU glue for bonding PIR boards in corners where the aluminium foil facing is not removed only slightly reduces the influence of the aluminium facing on the heat transfer through the joint: in this case, the heat flow through the joint is increased up to 22 *%*, if compared with PIR insulation without facing or with other facings.
4. The increase in heat flux due to the influence of the aluminium foil facing on the corner joint is not significantly dependent on the thickness of the thermal insulation layer. However, when thicker PIR products are used, the heat loss through the wall corner is smaller, resulting in a higher percentage value. In both cases, the influence of the facing contributes to an increase in the heat flux of about 0,7 *W*, in case of a 200 *mm* thick insulation it accounts for about 26 *%*, and for a 70 *mm* thickness only for 10 *%*.
5. There is no mandatory requirement in the standards and calculation methodologies to assess the impact of PIR insulation facings. However, the results of this study show there could be some serious influence of certain facings to the energy performance of buildings. Therefore, wider experimental studies are preferred and the next step to support this numerical data will be investigation of the results of numerical calculation in laboratory measurements. This is intended to be done with the hot box equipment or guarded hot plate apparatus.

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