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HEAT TRANSMISSION OF SLAB-ON-GROUND INDUSTRIAL FLOORS WITH VERTICAL PERIMETER INSULATION

BY

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Abstract. The surface heat loss of slab-on-ground industrial floors that are vertically insulated along the footing wall (with the insulation reaching under the ground level), is closely linked with the relatively large floor area of industrial halls. To give a comprehensive heat transmission analysis, the present paper first provides an overview of the *U*-value requirements for such floors in Hungary and Germany. For the determination of the heat transmission coefficient of slab-on-ground floors with vertical perimeter insulation, the study offers an algorithm as a thermal design calculation method to be used according to the ISO *13370*/2007 standard providing calculation methods for building elements in direct contact with the ground. Using practice oriented model parameters, the paper examines the *U*-values that can be attained by using thermally insulated reinforced concrete sandwich structure footing panels of a thickness of d_n = 10...20 cm depending on the floor size typically between B' = 10...100 m; based on this, the paper also analyses the specific features of thermal performances and it examines to what extent the heat transmission requirements can be met.

Key words: building structure; slab-on-ground floor; industrial floor; thermal protection; thermal insulation; heat transmission coefficient.

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1. Introduction

Because they are exposed to specific stresses, industrial floors are typically constructed of ground-bearing (occasionally placed on floor slabsin multi-storey car parks) thick concrete or reinforced concrete slab structures designed for heavy loads. They are mostly used in halls where it is not necessary to apply thermal insulation on the entire horizontal surface of the floor (*e.g.* because they are not fitted with floor heating or they function as a cold store or they are constructed with special regard to energy efficiency). Supermarkets, storage halls, logistics or production halls are good examples for such buildings. In these building types the winter heat loss of slab-on-ground industrial floors can be reduced by using reinforced concrete sandwich structure footing panels applied along their perimeter (Fig. 1) (Lohmeyer & Ebeling, 2008).

Fig. 1 – Slab-on-ground industrial floor and footing wall panel perimeter insulation.

The heat transmission coefficient (*U*-value) of the floor can be determined using the ISO standard *13370*/2007 providing calculation methods for the heat flow rates of building elements in thermal contact with the ground. The standard takes into consideration, among others, the three-dimensional nature of heat flow developing along the perimeter of the floor: in addition to the thermal characteristics of the ground and the floor with the elements connected to it along its outlines, it also considers the perimeter and the area of the floor, as well as the thickness of the external walls along its perimeter (Magyar Szabványügyi Testület, 2008).

2. Heat Transmission Requirements for Slab-on-Ground Industrialfloors in Hungary and Germany

In Hungary, the TNM (Ministry without Portfolio) Decree No. *7*/2006 (V.24.) on the determination of the energy characteristics of buildings stipulates as a general rule that the slab-on-ground floor of a building comprising rooms used for long-term dwelling and using energy to ensure the prescribed air conditions is to have a minimum heat transmission coefficient of 0.50 W/m^2.K in a 1.5 m strip along its perimeter. One of the possible methods to fulfil this requirement is to apply the necessary insulation on the footing walland not in the floor itself. However, the requirement does not apply, among others, to agricultural buildings which are used for non-residential purposes and to industrial buildings in which the internal heat gain deriving from the use of industrial technology is over 20 W/m^3 during the course of operation, or in which a ventilation rate of more than 20 is applied or is required in the heating period.

In Germany the 2009 energy efficiency regulation prescribes a heat transmission coefficient of $U \leq 0.50$ W/m^2.K for slab-on-ground floors of non-residential buildings in locations where the required room temperature is between 12° and 19°C in the heating period. Where this value is ≥ 19°C, the average, *U*, cannot exceed 0.35 W/m^2.K. When it is calculated, the parts of the floor which are located more than 5 m farther from the outer edge of the building can be disregarded. If the facility encompasses zones with different prescribed room heating temperatures, calculations have to be performed for each one of these zones individually. When calculating the heat loss of the slab-on-ground floor, the average heat transmission coefficient must be weighted by a factor of 0.5.

If a passive building is to be constructed using highly energy conscious methods, it is recommended to achieve a heat transmission coefficient of less than 0.15 W/m^2.K for slab-on-ground floors according to the general professional guidelines.

3. Calculation Method for the Heat Transmission Coefficient of Slab-on-Ground Industrial Floors with Vertical Perimeter Insulation

According to the ISO *13370*/2007 standard (in Hungary the MSZ EN ISO *13370*/2008 standard) the heat transmission coefficient (*U*-value) of a slab-on-ground industrial floor without insulation on its horizontal surface but with vertical insulation along the footing walls around its perimeter reaching under the ground surface, can be obtained in six major calculation steps.

As a first step, the total equivalent thickness (d_t) of the slab-on-ground industrial floor must be determined

$$d_t = w + \lambda\,(R_{si} + R_f + R_{se}), \qquad (1)$$

where: d_t is the total equivalent thickness of the slab-on-ground industrial floor, [m]; w – the total thickness of the external walls along the perimeter of the slab-on-ground industrial floor, [m]; λ – the thermal conductivity coefficient of the non-frozen ground, [W/m.K]; R_{si} – the internal thermal resistance of the slab-on-ground industrial floor, [m^2.K/W]; R_f – the thermal conductivity resistance of the slab-on-ground industrial floor, [m^2.K/W]; R_{se} – the external thermal resistance of the slab-on-ground industrial floor, [m^2.K/W].

The thermal conductivity coefficient of non-frozen ground (λ_t) is to be considered as one of the following options:

a) as a value relevant to the actual area (a value averaged to a depth equivalent to the width of the building) if it is known, or

b) as a value determined in the standard based on soil type: clay or mud: λ = 1.5 W/m.K; sand or gravel: λ = 2.0 W/m.K; homogenous rock: λ = 3.5 W/m.K, or

c) if the soil type is not known either: λ = 2.0 W/m.K.

The thermal resistances of slab-on-ground industrial floors – according to the ISO *6946*/2007 standard (in Hungary the MSZ EN ISO *6946*/2008 standard) on the calculation methods of the thermal resistance and the thermal transmittance of building components and building elements – are as follows:

a) the internal thermal resistance is R_{si} = 0.17 m^2.K/W;

b) the external thermal resistance is R_{se} = 0.04 m^2.K/W.

With such structural solutions, the thermal conductivity resistance (R_f) of slab-on-ground industrial floors comprises only the thermal conductivity resistance of floor coverings of any significant *R*-value and therefore the following need not be considered in the calculations:

a) thin floor coverings of an insignificant *R*-value,

b) solid concrete or reinforced concrete slabs and

c) different kinds of fillings (*e.g.* rubble, sandy gravel).

As a second step, the specific size of the slab-on-ground industrial floor (B') must be calculated

$$B' = \frac{A}{0.5P}, \tag{2}$$

where: B' is the specific size of the slab-on-ground industrial floor, [m]; A – the area of the slab-on-ground industrial floor, [m^2]; P – the perimeter of the slab-on-ground industrial floor in contact with the external environment, [m].

As a third step, the heat transmission coefficient of the slab-on-ground industrial floor without vertical insulation along the perimeter is to be determined, (U_0). Generally the total equivalent thickness (d_t) of the industrial floor without insulation on its entire surface is lower than the specific size of the floor (B') and therefore in such cases

$$U_0 = \frac{2\lambda}{\pi B' + d_t} \ln\left(\frac{\pi B'}{d_t} + 1\right), \tag{3}$$

where: U_0 is the heat transmission coefficient of the slab-on-ground industrial floor without vertical insulation along the perimeter, [W/m^2.K]; λ – the thermal conductivity coefficient of the non-frozen ground, [W/m.K]; B' – the specific size of the slab-on-ground industrial floor, [m]; d_t – the total equivalent thickness of the slab-on-ground industrial floor, [m].

As a fourth step, the excess equivalent thickness of the slab-on-ground industrial floor due to vertical insulation along its perimeter has to be determined

$$d' = \lambda R' = \lambda\left(R_n - \frac{d_n}{\lambda}\right), \tag{4}$$

where: d' is the excess equivalent thickness of the slab-on-ground industrial floordue to vertical insulation along its perimeter, [m]; λ – the thermal conductivity coefficient of the non-frozen ground, [W/m.K]; R' – the excess thermal resistance of the slab-on-ground industrial floordue to vertical insulation along its perimeter, [m^2.K/W]; R_n – the thermal resistance of the vertical insulation along the perimeter of the slab-on-ground industrial floor, [m^2.K/W]; d_n – the thickness of the vertical insulation along the perimeter of the slab-on-ground industrial floor, [m].

As a fifth step, the linear heat transmission coefficient for the vertical insulation along the perimeter of the slab-on-ground industrial floor under the ground level ($\Psi_{g,e}$) is to be determined

$$\Psi_{g,e} = -\frac{\lambda}{\pi}\left[\ln\left(\frac{2D}{d_t} + 1\right) - \ln\left(\frac{2D}{d_t + d'} + 1\right)\right], \tag{5}$$

where: $\Psi_{\mathrm{i},e}$ is the linear heat transmission coefficient for the vertical insulation along the perimeter of the slab-on-ground industrial floor under the ground level, [W/m.K]; λ – the thermal conductivity coefficient of the no-frozen ground, [W/m.K]; D – the height of the vertical insulation along the perimeter of the slab-on-ground industrial floor under the ground level (under the original external ground level), [m]; d_t – the total equivalent thickness of the slab-on-ground industrial floor, [m]; d' – the excess equivalent thickness of the slab-on-ground industrial floor deriving from the vertical insulation along its perimeter, [m].

As a sixth step we can obtain the heat transmission coefficient (U-value) of the slab-on-ground industrial floor

$$U = U_0 + \frac{2\Psi_{g,e}}{B'}, \qquad (6)$$

where: U is the heat transmission coefficient of the slab-on-ground industrial floor, [W/m^2.K]; U_0 – the heat transmission coefficient of the slab-on-ground industrial floor without vertical insulation along its perimeter, [W/m^2.K];

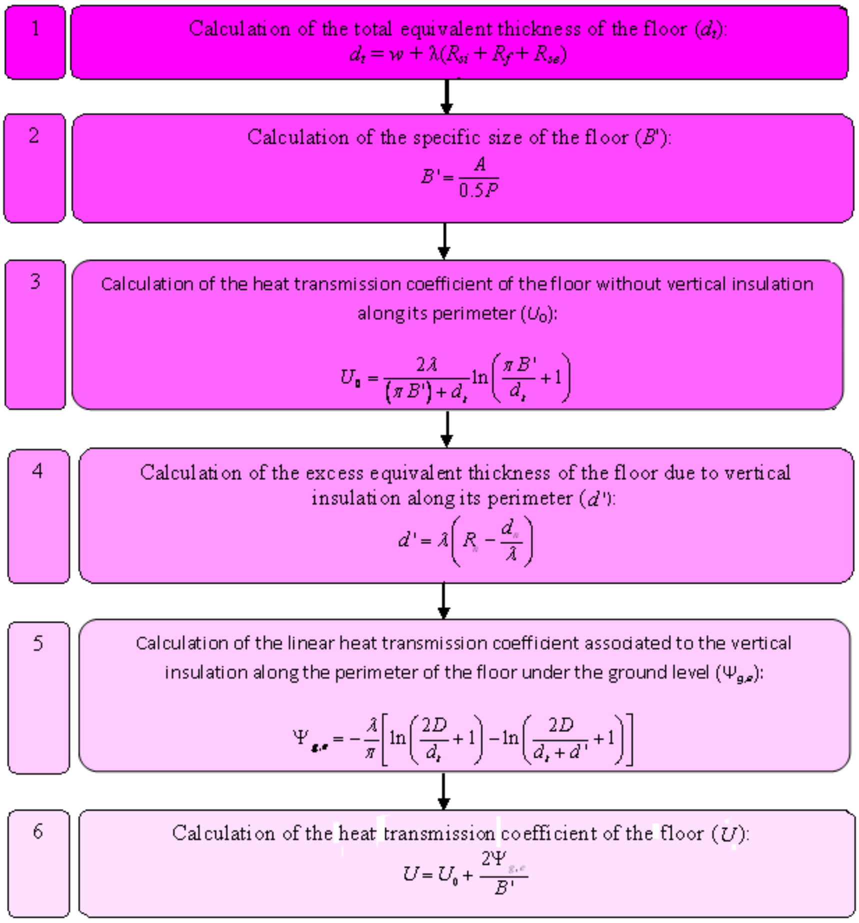

Fig. 2 – Algorithm for the calculation of the heat transmission coefficient of slab-on-ground industrial floor without horizontal insulation on its entire surface but with vertical insulation along its perimeter stretching under the ground level.

$\Psi_{g,e}$ – the linear heat transmission coefficient for the vertical insulation along the perimeter of the slab-on-ground industrial floor under the ground level, [W/m.K]; B' – the specific size of the slab-on-ground industrial floor, [m].

Fig. 2 gives a summary of the calculations to be performed in order to obtain the heat transmission coefficient of the slab-on-ground industrial floor if the entire horizontal surface is without insulation but there is vertical insulation along the perimeter of the floor stretching under the ground level at the footing wall (Kocsis, 2009; 2011).

4. Heat Transmission Coefficients of Slab-on-Ground Industrial Floor Models

Fig. 3 shows the heat transmission coefficients of slab-on-ground industrial floor models with vertical perimeter insulation as a function of the specific size of the floor, with footing insulations of different thickness, with the following practice-oriented parameters taken into account:

a) the specific size of the floor (B') is between 10...100 m (*e.g.* in the case of a hall of 16 × 25 m, $B' \approx 10$ m, in the case of a hall of 90 × 110 m, $B' \approx$ ≈ 50 m, in the case of a hall of 150 × 300 m, $B' = 100$ m if the outlines on the floor plan are all in direct contact with the outdoor environment);

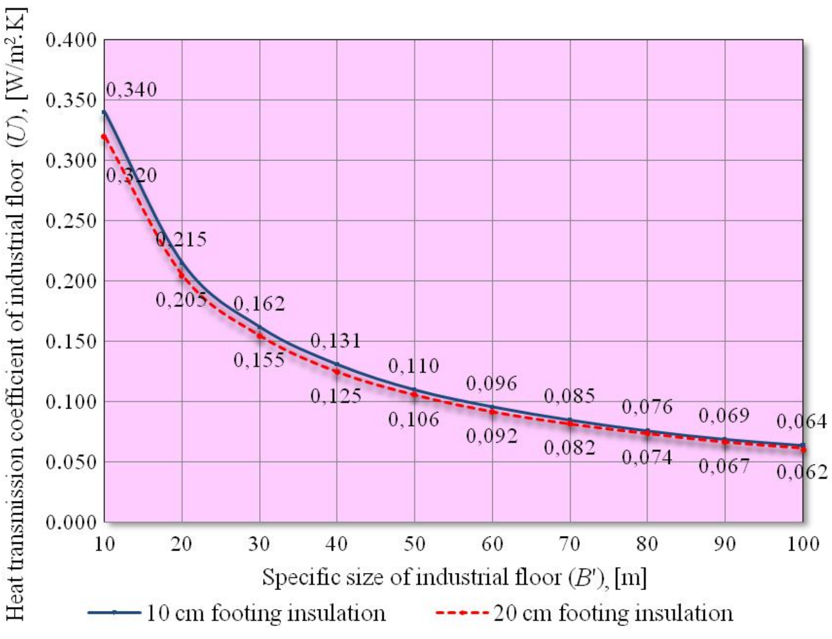

Fig. 3 – Heat transmission coefficients of slab-on-ground industrial floor models with vertical perimeter insulation as a function of the specific size of the floor being $B' = 10...100$ m, with footing insulations of a thickness of $d_n = 10...20$ cm.

b) there is an XPS (extruded polystyrene foam) insulation of a thickness of $d_n = 10...20$ cm within the footing walls between the 8...12 cm thick external and internal reinforced concrete layers; the vertical size of the XPS insulation under the ground level is D = 1 m and its design thermal resistance is λ_n = 0.036 and 0.038 W/m.K;

c) the thermal resistance of the floor is R_f = 0 m^2.K/W (disregarding the layers of insignificant R value);

d) the thermal conductivity coefficient of the non-frozen ground is λ = = 2 W/mK.

5. Conclusions

Based on the data shown in Fig. 3, it can be established that with the above parameters taken into account

a) if the specific size of the floor linearly increases, its heat transmission coefficient will – under invariable boundary conditions – show an exponential decrease: it will decrease to the largest extent, by approximately 0.12 W/m^2.K if B' = 10...20 m; then this thermal advantage decreases to half at every 10 m until, above B' = 60 m, the decrease of the U-value is only approximately 0.01 W/m^2.K linearly at every 10 m;

b) the use of footing insulation of a thickness of 20 cm instead of 10 cm does not have a significant effect on the surface heat loss of the floor: with B' = = 10 m the improvement is as much as ΔU = 0.020 W/m^2.K, but this difference becomes gradually smaller until, with B' > 80 m, the ΔU value will be as low as only one-tenth of the previous value (0.002 W/m^2.K);

c) with the use of a 10 cm footing insulation, a performance of U = = 0.34 W/m^2.K is enough for the slab-on-ground industrial floor of a relatively small hall of a size of B' = 10 m to comply with the requirement of $U \leq$ $\leq$ 0.35 W/m^2.K of the German energy savings regulation;

d) in buildings of a larger floor area, the longer path of heat flows from the floor through the ground to the external environment results in the radical decrease of heat loss: *e.g.* in the case of a floor of B' = 50 m the U-value will be U = 0.11 W/m^2.K, while with B' = 100 m it will be as low as U = 0.06 W/m^2.K;

e) if a value of $U \leq$ 0.15 W/m^2.K is required for passive house construction, this can only be achieved – with the structural properties considered in the calculations – if the specific size of the floor is $B' \geq$ approx. 33...34 m (if B' is less than approx. 33...34 m, solutions further reducing the heat transmission of the floor are required – *e.g.* the additional application of horizontal insulation, either along the perimeter or on the whole surface).

REFERENCES

Kocsis L., *Elavult családi házak talajon fekvő padlóinak hőátbocsátása. Utólagos lábazati hőszigetelés* – I. rész. Magyar Építéstechnika, **49**, *4*, 26-28 (2011).

Kocsis L., *Elavult családi házak talajon fekvő padlóinak hőátbocsátása. Utólagos lábazati hőszigetelés* – II. rész. Magyar Építéstechnika, **49**, *5*, 32-33 (2011).
Kocsis L., *Fűtött földszintek talajon fekvő padlóinak hőátbocsátása*. Építés Spektrum, **8**, *1*, 38-41 (2009).
Kocsis L., *Fűtött földszintek talajon fekvő padlóinak hőátbocsátása – 2. rész. Teljes felületén hőszigeteletlen vagy hőszigetelt, kerülete mentén függőlegesen hőszigetelt földszinti talajon fekvő padló hőátbocsátási tényezőjének számítási* módszere. Építés Spektrum, **8**, *4*, 30-34 (2009).
Kocsis L., *Talajon fekvő padlók*. In Osztroluczky M. (Ed.): *Épületszigetelési kézikönyv*. Verlag Dashöfer Kft., Budapest, 2009.
Lohmeyer G., Ebeling K., *Betonböden für Produktions und Lagerhallen*. Verlag Bau + Technik GmbH, Düsseldorf, 2008.
Lohmeyer G., Ebeling K., *Betonpadlók gyártó- és raktárcsarnokokban*. Publikál Kft., Budapest, 2008.
* * * *7*/2006 (V.24) *TNM rendelet az épületek energetikai jellemzőinek meghatározásáról*. https://magyarorszag.hu (2013).
* * * http://www.austrotherm.hu, 2013.
* * * http://www.betonboden.de, 2013.
* * * http://www.mabesz.hu, 2008.
* * * http://www.passipedia.de, 2013.
* * * *Industrieböden aus Beton für Frei- und Hallenflächen*. Deutscher Beton- und Bautechnik-Verein E. V., Berlin, 2005.
* * * *MSZ EN ISO 13370:2008. Épületek hőtechnikai viselkedése. Hőátvitel a talajban. Számítási módszerek* (*ISO 13370:2007*). Magyar Szabványügyi Testület, MSZT, Budapest (2008).
* * * *MSZ EN ISO 6946:2008. Épületszerkezetek és épületelemek. Hővezetési ellenállás és hőátbocsátás. Számítási módszer* (*ISO 6946:2007*). Magyar Szabványügyi Testület, MSZT, Budapest, 2008.
* * * *Verordnung zur Änderung der Energieeinsparverordnung*. Vom 29. April 2009, http://www.enev-online.org, 2013.

TRANSFERUL TERMIC LA PLĂCILE PE SOL ALE CONSTRUCȚIILOR INDUSTRIALE CU IZOLAȚIE PERIMETRALĂ VERTICALĂ

(Rezumat)

Pierderile de căldură ale plăcilor pe sol ale clădirilor industriale care sunt izolate pe verticală, de-a lungul elevației fundației (izolația ajungând sub nivelul solului), sunt în strânsă legătură cu suprafața relativ mare a halelor industriale. Pentru a oferi o analiză comprehensivă în ceea ce priveşte transferul termic, lucrarea de față oferă o imagine de ansamblu asupra cerințelor privind valoarea lui *U* pentru astfel de planşee din Ungaria şi Germania. Pentru determinarea coeficienților de transfer termic a plăcilor pe sol, izolate perimetral pe verticală, studiul oferă un algoritm ca metodă de calcul termic, care poate fi utilizat în conformitate cu standardul ISO *13370*/2007, oferind metode de calcul pentru elementele de construcții aflate în contact direct cu solul. Utilizând parametrii modelelor orientate spre practică, lucrarea examinează valorile lui U care pot fi obținute prin utilizarea la fundații a unor panouri sandviș din beton armat termoizolat, cu grosimi de d_n = 10...20 cm în funcție de dimensiunea planşeului, în general fiind între B' = 10...100 m; bazându-se pe aceste aspecte, în lucrare sunt studiate şi caracteristicile specifice ale performanței energetice, şi se analizează în ce măsură sunt îndeplinite condițiile de transfer termic.