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SIMPLIFIED CALCULATION OF THE GLOBAL THERMAL INSULATION COEFFICIENT

BY

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Abstract. According to Romanian Norm C107/1-2005, the heating energy consumption per volume is determined using the global coefficient of thermal insulation (*G*). The calculation requires the determination of the adjusted thermal resistance, *R′*, using the influence of thermal bridges on the 1D thermal resistance values. When computing *G*, the most time consuming stage is the determination of linear and punctual heat transfer coefficients, that requires either the use of thermal bridge catalogues (with errors of about 20...25%) or numerical modelling (with a maximum error of ±5%.). Both methods have the disadvantage of requiring more resources, without, however, being free of errors. This paper presents a simplified method for the calculation of the global coefficient of thermal insulation only with the 1D thermal resistances values, without using the linear heat transfer coefficients.

Key words: 1D thermal resistance; adjusted thermal resistance, thermal bridges, temperature distribution, energy efficiency.

1. Introduction

Global coefficient of thermal insulation is a performance criteria of the energy consumption required in the operation of buildings, used to calculate the amount of heat needed to heat a cubic meter of volume building during a year.

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Its value depends on the heat losses through conductive heat transfer, due to natural ventilation and additional heat losses due to the uncontrolled air infiltration.

Therefore it can be written:

$$G = G_1 + G_2, \tag{1}$$

where: G_1 (energy component of the global coefficient of thermal insulation) is the heat flow by direct transmission through the building envelope, related to the heated volume and temperature gradient between the inner and outer environment, [W/m^{3}K]; G_2 (air quality component of the global coefficient of thermal insulation) – the heat flux needed to heat outdoor air that infiltrates through leaks on windows and doors and by uncontrolled or controlled natural ventilation inside the building, related the heated volume of the building and the temperature gradient between the inner and outer environment, [W/m^{3}K].

G_2 is equal to 0.34n, [W/m^3.K], where n is the natural ventilation rate of the building, namely the number of air changes per hour (h^{-1}) and 0.34 is the product of the heat capacity and air mass density.

In order to compute the G_1 component of G, it is important to determine exactly the value of the adjusted thermal resistance, R', [m^2.K/W], that represents the corrected value of 1D thermal resistance by the influence of the thermal bridges. Its value, if correctly computed, tends to equal the value of the real thermal resistance of the constructive element.

This article presents three methods of computing the value of G coefficient, with and without considering linear heat transfer coefficients.

In the first method the calculation was made according to Norm C107/1-2005, using the heat transfer coefficients of linear thermal bridge values taken from catalogues.

Method II is based on some simplifications of the first method, as the adjusted thermal resistance is estimated as a geometric weighted average of 1D thermal resistances through typical cross-sections and thermal bridges. Heat transfer coefficients have been used where this approximation couldn’t be correctly be used.

2. Details of the Building

The calculation has been performed on a particular case of a single-family dwelling having the height: $G + 1F$, located in the Dumbrava Roşie village, Neamt county. According to Romanian norms the climate zone of the location is the III, having a design external temperature of –18°C. The main façade is oriented towards the South.

The structural members and the envelope consist of the following:

a) load-bearing masonry cross walls 30 cm thick strengthened by concrete columns and girdles;

b) interior load-bearing masonry cross walls 25 cm thick;

c) monolith reinforced concrete slabs;

d) continuous beams under columns and walls;

e) outer garret roof type;

Thermal insulation of the building consists of:

a) *slab on ground* – extruded polystyrene 15 cm thick;

b) *exterior walls* – fireproof expanded polystyrene 20 cm thick;

c) *upper floor* – mineral wool 20 cm thick;

d) *windows and doors* – insulated triple glazing.

Geometrical characteristics of the building are:

a) *Slab on the ground area* (A_1): 87.13 m²;

b) *Upper floor area* (A_2): 87.13 m²;

c) *Glazing area* (A_3): 35.58 m²;

d) *Outer walls area* (A_4): 201.14 m²;

e) *Ground floor height*: H = 3.20 m;

f) *First floor height*: H = 2.90 m;

g) *Envelope area*: A_0 = 410.98 m²;

h) *Building volume*: V = 531.52 m³.

Building cross-section is presented in Fig. 1.

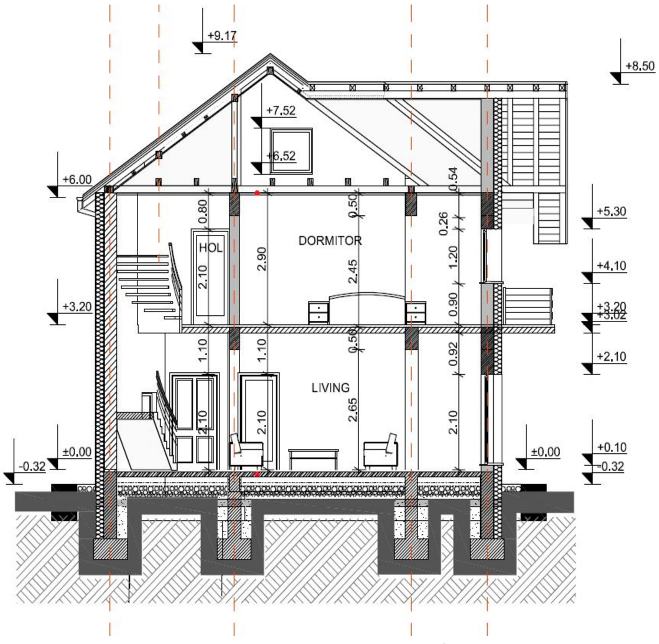


Fig. 1 – Vertical cross-section of the building.

3. Determination of the Global Thermal Insulation Coefficient

3.1 Method I – According to C107/2005

The value of G is computed according to the Romanian norm C107/2005 following the well known steps:

i) Computation of 1D thermal resistance for each element of the envelope.

1D thermal resistances are computed using eq.

$$R = R_{si} + \sum \frac{d}{\lambda} + R_{se}, \tag{2}$$

where: R_{si} is the interior superficial thermal resistance [m^{2}K/W]; R_{se} – exterior superficial thermal resistance [m^{2}K/W]; d_j – thickness of „ j” - layer [m]; λ_j – thermal conductivity of „ j”-layer [W/mK].

ii) Computation of the adjusted thermal resistances.

The adjusted thermal resistances is equal to:

$$R' = \frac{1}{\frac{1}{R} + \sum \frac{(\Psi l)}{A}}, \quad [\mathrm{m}^2.\mathrm{K/W}], \tag{3}$$

where: R' is the 1D thermal resistances, [m^{2}K/W]; Ψ – linear heat transfer coefficient, [W/m.K]; l – length of the thermal bridge, [m]; A – element envelope area, [m^2].

iii) Determination of the global thermal insulation coefficient (G).

Finally, the global thermal insulation coefficient has been computed using eq.:

$$G = \frac{\sum_j \left(\frac{A_j}{R_j^{'}} \tau_j \right)}{V} + 0.34n, \tag{4}$$

where: τ is the dimensionless temperature correction factor; n – ventilation rate [h^{-1}].

The results are presented in Table 1. The obtained G value has been compared with the value of the imposed normalized values G_N.

Table 1
Results from the Ist Method

Envelope area, A_0, [m^2]	410.98
Building heated volume, V, [m^3]	531.52
$\sum \frac{A \cdot \tau}{R'}$, [W/K]	134.007
n – ventilation rate, [h^{-1}]	0.5
G (according to C107/1- 2005), [W/m^{3}K]	0.422
G_N (for A_0/V = 0.773 and 2 floors), [W/m^{3}K]	0.54
G = 0.422 < G_N = 0.54	

3.2. Method II – Intermediary Method

The calculation implies that the design steps are similar to those from the Romanian norm C107/2005 with the addition of some simplifications

i) Computation of 1D thermal resistance for each element of the envelope.

The unidirectional thermal resistance for the constitutive layers of each envelope element is presented below for:

a) outer walls: brick wall and lintels, columns and girdles (Fig. 2).

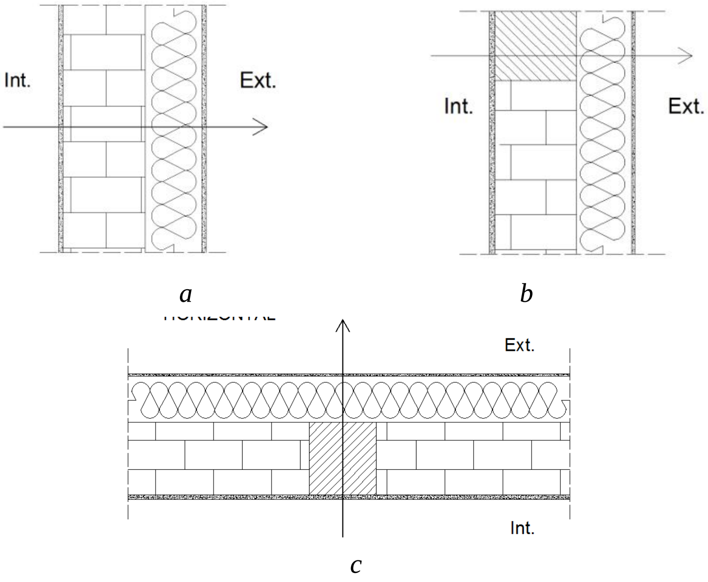


Fig. 2 – Heat flux direction through exterior walls:
a – typical cross section; *b* – girdles, lintels; *c* – columns.

b) slab on the ground: typical cross section inner foundations (Fig. 3).

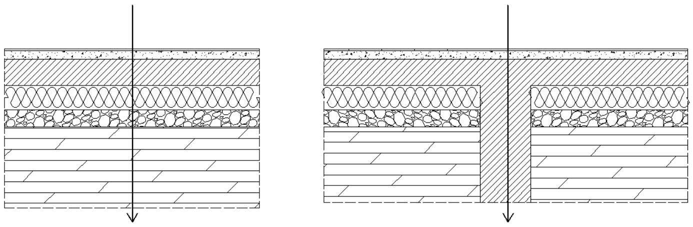


Fig. 3 – Heat flux direction through the slab on the ground:
a – typical cross section; *b* – inner foundation detail.

c) upper floor: typical cross section and structural walls (Fig. 4).

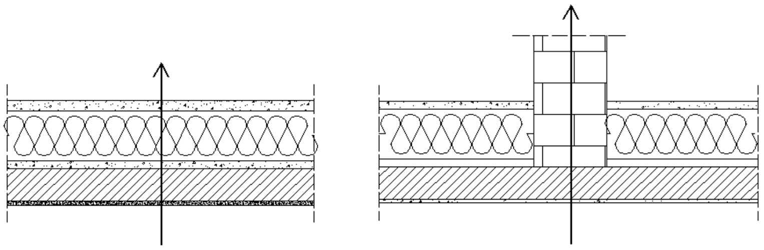


Fig. 4 – Heat flux direction through the upper floor:
a – typical cross section; *b* – under structural walls.

ii) Computation of the adjusted thermal resistances.

In this method both geometric weighted averages of thermal resistances and linear heat transfer coefficients are being used.

When computing R' for the outer walls, the slab on the ground and upper floor an weighted thermal resistance will be considered, that takes into consideration each 1D thermal resistance and its corresponding area. The adjusted thermal resistance is determined by the equation:

$$R' = R_1 \cdot \%A_1 + R_2 \cdot \%A_2, \tag{5}$$

where: R_1 is the 1D thermal resistance for the typical cross-section [m^{2}K/W]; $\%A_1$ – percentage from the total area of the typical cross-section; R_2 – 1D thermal resistance through the envelope's discontinuity, [m^2.K/W]; $\%A_2$ – percentage of the envelope discontinuity.

The geometry of the structure does not allow the use of this simplification for all thermal bridges, especially in corner areas. Some of these thermal bridges are presented in Fig. 5.

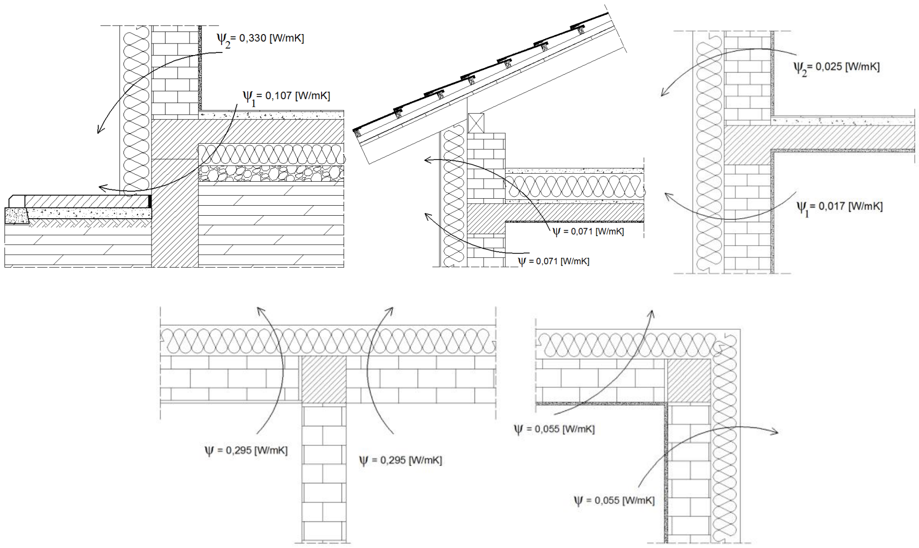


Fig. 5 – Horizontal and vertical thermal bridges.

The influence of the thermal bridges mentioned above has been quantified by the usual method, using the linear heat transfer coefficients already computed in the previous part.

iii) Computation of the adjusted thermal resistances of the glazing.

Thermal resistance for the windows is computed also as a weighted average, considering the thermal resistances of both the glazing and the frame and their corresponding areas:

$$R_{\text{win}} = R_{\text{glazing}} \cdot \%A_{\text{glazing}} + R_{\text{frame}} \cdot \%A_{\text{frame}}, \qquad (6)$$

where: R_{win} is the thermal resistance of window, [m^2.K/W]; R_{glazing} – thermal resistance of the glazing, [m^2.K/W]; $\%A_{\text{glazing}}$ - percentage of the glazing in total area of the window; R_{frame} – thermal resistance of the frame, [m^2.K/W]; $\%A_{\text{frame}}$ – percentage of the frame in total area of the window.

These values are provided by the glazing manufacturer.

iv) Determination of the global thermal insulation coefficient (G).

The results are presented in Table 2. The obtain G value has been compared with the value of the imposed normalized values G_N.

Table 2

Results from the IInd Method

Envelope area, A_0, [m^2]	410.978
Building heated volume, V, [m^3]	531.517
$\sum \frac{A\tau}{R'}$, [W/K]	138.328
n – ventilation rate, [h^{-1}]	0.5
G (according to C107/1- 2005), [W/m^3.K]	0.432
G_N (for $A_0/V = 0.773$ and 2 floors), [W/m^3.K]	0.54
$G = 0.432 < G_N = 0.54$	

3.3. Method III – Simplified Method

The design steps are similar to those of the previous method, however no linear heat transfer coefficient has been used.

i) Computation of 1D thermal resistances for each element of the envelope.

The unidirectional thermal resistances have been determined in the same manner as in the previous method, for each element of the building envelope.

ii) Computation of the adjusted thermal resistances.

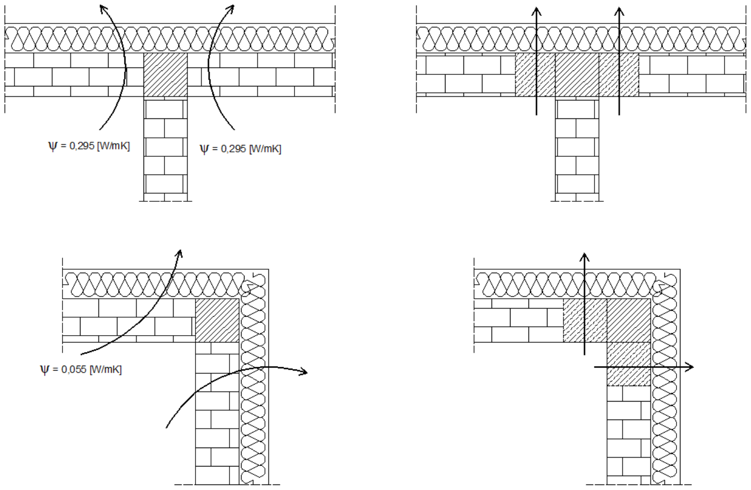
In order to eliminate the need of using linear heat transfer coefficients, the thermal bridges that don’t allow the use of the weighted average resistance will have their geometry modified to allow such a computation.

Therefore some modifications to the real geometry are proposed, that allow the use of the simplified method:

a) The area of the columns at the intersections of the exterior and interior walls will be translated on each side of the intersecting walls as shown in Fig. 6.

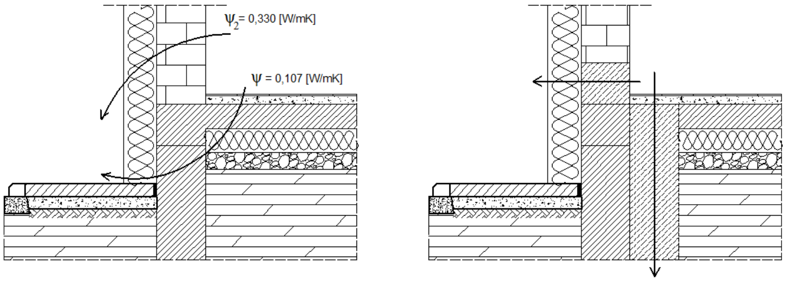
b) The area of the continuous foundation under the exterior wall will be taken as a geometric discontinuity of the slab on the ground and of the outer wall (Fig. 7);

c) The area of the outer girdles will be considered in the weighted average of the thermal resistance of the outer walls (Fig. 8).



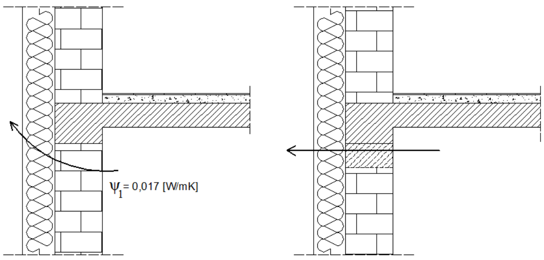
a *b*

Fig. 6 ─ *a* – Typical thermal bridge; *b* – Modified geometry of the thermal bridge.



a *b*

Fig. 7 ─ *a* – Typical thermal bridge; *b* – modified geometry of the thermal bridge.



a *b*

Fig. 8 ─ *a* – Typical thermal bridge; *b* – Modified geometry of the thermal bridge.

iii) Computation of the adjusted thermal resistances of the glazing.

The effect of the thermal bridges around the window will not be computed using linear heat transfer coefficients but using an adjusted thermal resistance between the glazing and frame, as shown in the previous method.

iv) Determination of the global thermal insulation coefficient (G).

The results are presented in Table 3. The obtain G value has been compared with the value of the imposed normalized values G_N.

Table 3

Results from the IIIrd Method

Envelope area, A_0, [m^2]	410.98
Building heated volume, V, [m^3]	531.52
$\sum \frac{A \cdot \tau}{R'}$, [W/K]	130.91
n – ventilation rate, [h^{-1}]	0.5
G (according to C107/1- 2005), [W/m^3.K]	0.416
G_N (for A_0/V = 0.773 and 2 floors), [W/m^3.K]	0.54
G = 0.416 < G_N = 0.54	

4. Conclusions

The main advantage of the proposed method (method III) is that it does not require numerical modelling, which involves a more laborious design and subjective assessments on the choice of the linear heat transfer coefficients. The accuracy of results is however smaller, due to the simplified geometric model, but provides a good degree of reliability.

For this particular case of the individual dwelling, the global heat insulation coefficients (G), calculated using the presented three methods, have smaller values than the normalised value of G_N, due to a favourable geometry of the building and high thickness of the insulation materials. The resulting values are shown in Table 4.

Table 4

Overall Results from all Three Methods

	Method I	Method II	Method III
$\sum \frac{A \cdot \tau}{R'}$	134.007	138.328	130.911
G (according to C107/1- 2005)	0.422	0.432	0.416
G_N (for A_0/V = 0.773 and 2 floors)	0.54	0.54	0.54
	G = 0.422<G_N	G =0.432<G_N	G =0.416<G_N

From Table 4, it can easily be observed that the third method (simplified method) provided similar results to method I, the error being less than 3%. The second method (intermediary method), although it has a good accuracy, has the disadvantage of introducing an increased heat loss in some thermal bridges.

The results show that the simplified method can be successfully applied to preliminary design stages for a fast predimensioning of envelope elements or when the numerical modelling of thermal bridges is time consuming or even impossible. Given the complexity of the problem, further studies are needed to validate this method and to improve this simplified method.

REFERENCES

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CALCULUL SIMPLIFICAT AL COEFICIENTULUI GLOBAL DE IZOLARE TERMICĂ

(Rezumat)

Conform Normativului C107/1-2005, cantitatea de căldură necesară încălzirii locuinței se determină cu ajutorul coeficientului global de izolare termică. Calculul presupune determinarea rezistenței termice corectate, *R*′, ținând seama de influența punților termice asupra valorii rezistenței termice specifice determinate pe baza unui calcul unidirecțional în câmp curent.

Etapa cea mai importantă este determinarea coeficienților de transfer termic liniari şi punctuali, care necesită fie utilizarea unor cataloage de punți termice (cu erori de circa 20...25%) sau modelarea numerică a acestora (cu erori maxime de ±5%.). Ambele metode au dezavantajul că necesită un timp de lucru suplimentar, fără a fi lipsite însă de erori.

Se prezintă calculul coeficientului global de izolare termică, calculat prin mai multe metode. Se propune un calcul simplificat al coeficientului global de izolare termică pentru clădiri de locuit, pe baza rezistențelor termice calculate atât în câmp curent cât şi în zona punților termice.