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THERMICAL PHASE SHIFT DETERMINATION AROUND VERTICAL BRIDGES

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ABSTRACT

The way this concept is defined (in the prescription) is not the most proper for technical regulations where more clear and precise formulations are required especially when important concepts are defined.

The estimation of the corrected thermal resistance is based on the method of linear and punctual thermal transfer factors that are not defined in C107 – Prescriptions. Also the expression (equation) proposed for the estimation of the linear transfer factor y *, although practicable, is stated in an inhomogeneous and incomplete manner.*

For the assessment of these parameters are recommended the expressions that result from the analytical solving of the differential equation of heat lose, in unidirectional unsteady conditions, considering some simplified hypothesis.

KEYWORDS: the linear transfer factor, punctual thermal transfer factors, thermal bridges, thermal damping

1. INTRODUCTION

A large (perhaps a little too ample) collection of technical prescriptions was elaborated after 1993. The technical prescriptions regard the hygrothermal design of the buildings and consist in: standards and codes,reference books, methodologies, framework solutions. Among these, the C107 – Prescriptions collection brings numerous new elements aligned in a great degree to the similar regulations existing in European Community countries.

Essentielly, the new regulations include some articles and computation models that are closer to the effective behavior of the building elements and of the system reprezentend by the entire building.Therefore they provide a more rigorous theoretical framework for the hygrothermal design of the buildings.

The good and beneficial parts of these technical prescriptions are unquestionable; however some aspects less satisfactory will be analyzed in this paper. Thes aspects regard the theoretical aspects of the subject and also the practical possibilities of the computation models.

2. THE CORRECTED SPECIFIC THERMAL REZISTENCE CONCEPT

According to C107 – Prescriptions, the corrected specific thermal resistance is that resistance “allows for the influence of the thermal bridges on the magnitude of the specific thermal resistance estimated using a one directional calculation in the current field”. Regarding this definition some statements are necessary.

The thermal resistance in the current field, calculated for unidirectional thermal transmission and steady state conditions,depends on the structure of the building element in the sections that are not affected by the presence of the thermal bridges. In fact, the influence of the thermal bridges is exercised over the global thermal resistance of the building element and not over the unidirectional thermal resistance. For these reasons, it is right to consider that the corrected thermal resistance is an approximation of the actual thermal resistance, and the influence of the thermal resistance, that takes into account the unidirectional thermal resistance and the influence of the thermal bridges. The value of the corrected thermal resistance depends on the value of the actual global thermal resistance, and it is a good estimation when the computation is conducted correctly.

According to C107, the estimation of the corrected thermal resistance R’ is made with the equation:

$$U'=\frac{1}{R'}=\frac{1}{R}+\frac{\sum_{i}\psi_i.\ell_i}{A}+\frac{\sum_{j}\chi_j}{A} \qquad (1)$$

where the terms are the same as in C107 – Prescriptions.

The first term of the last expression from (1) represents the contribution of the unidirectional thermal resistance and the next two terms represent the influence of the linear and respectivly the punctual thermal bridges.

The factors y and χ are not defined precisely in C107 – Prescriptions. It is just a vague specification that “they give a correction for the unidirectional computation considering the presence of the thermal bridges …”. In C107 – Prescriptions the factors are estimated with:

$$\psi=\frac{\Phi}{\Delta T}-\frac{B}{R} \qquad (2)$$

$$\chi=\frac{\Phi}{\Delta T}-\frac{A}{R} \qquad (3)$$

where the terms are defined in C107.

Although expression (2) is correct for practical computation, the way it characterized raises some questions. Therefore the term Φ (thermal flux) is used inconsistently because it is stated in W/m instead of W. To be clear we must reexamine the provenance of the expression.

Let as consider a thermal brige with the length ℓ_i, situated inside an element with R, the unidirectional thermal resistance and U, the unidirectional heat transfer factor. In the absence of the thermal bridge, the thermal flux could be described with:

$$\Phi_c = U.A.\Delta T \qquad (4)$$

where:

Φc-unidirectional thermal resedance in current section (W);

A-the area of the thermal exchanges (m2);

ΔT-the total temperature drop (ºC).

The thermal bridge determines the increment (seldom the diminution) ΔΦ of the thermal flux related to the value Φc. The y factor will be defined analogously to the expression (4), using:

$$\Delta\Phi = \psi.\ell.\Delta T \qquad (5)$$

The total thermal flux that goes though the element results from the addition of the fluxes through Φc defined by eq.(4) and ΔΦ , defined with eq (5).

$$\Phi = \Phi_c + \Delta\Phi = U.A.\Delta T + \psi.\ell.\Delta T \qquad (6)$$

From (6) results:

$$\psi=\frac{\Phi}{\ell.\Delta T}-\frac{U.A.\Delta T}{\ell.\Delta T} \qquad (7)$$

or if : $A = B\cdot\ell_i$ and U = 1/R:

$$\psi=\frac{\Phi}{\ell.\Delta T}-\frac{B}{R} \qquad (8)$$

This is the correct and homogeneous expression (with the flux measured in W) for the estimation of the linear factors y. The expression (2) results from expression (8) if it is considered that ℓ_i=1m.

With expression (7) written as:

$$\psi=\frac{\Phi}{\ell.\Delta T}-\frac{\Phi_c}{\ell.\Delta T}=\frac{\Delta\Phi}{\ell.\Delta T} \qquad (9)$$

y can be defined as the supplementary thermal flux of a linear thermal bridge divided by its length and thermal drop. So, y represents the supplementary thermal flux that goes across a linear thermal bridge of 1 m, for a temperature drop of 1 ºC or 1K.

In the same manner for a punctual thermal bridge defined with equation (3) and defining $\Delta\Phi=\chi\cdot\Delta T$, the χ factor represents the supplementary thermal flux that goes across a punctual thermal bridge, for a temperature drop of 1 ºC or 1K.

3.VARIABLE THERMAL REGIM

The assessment of the building element thermal stability involves (among others) the estimation of the outdoor air temperature oscillations damping factor (ν) and also the factor that illustrates the alteration of phase of the outdoor air temperature oscillations (ε).

The computation of these factors is made according to the method given by the “Prescription for the thermal stability design of the building enclosing elements” (C107/7-02-Prescriptions).

Some researches and studies made by the authors of the paper relieved significant differences between the values of the factors mentioned above, estimated according to C107/7-02-Prescriptions, and the values of the factors estimated using numeric models of the thermal field in two-dimensional, non-stationary state. For example, see the case of the precast external wall panel from Fig.1, with the total tickness of 27 cm, made of three layers: the resistance one of 12,5 cm, reinforced concrete , a thermal insulation layer of 8 cm polystyrene, and a protection layer of 6,5 cm reinforced concrete. In the structure of the panel there are four types of linear thermal bridges, presented in section 1-1 to 4-4 (Fig.1).

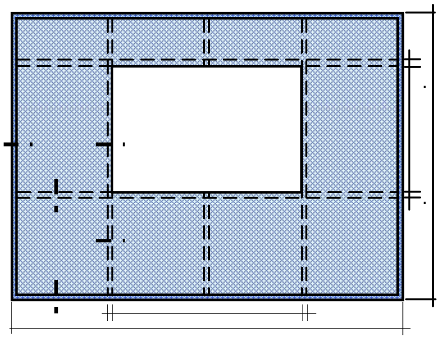

Fig. 1. The general composition of the wall panel

The following limit conditions are considered:

- cold season
- the convensional indoor air temperature is constant: T_i = 20 °C;
- the convensional outdoor air temperature has sinusoidal variation with a period of 24 h, around the value of -15 °C, with two variants of amplitude: ±5 °C and ±10 °C.
- warm season
- the conventional indoor air temperature is constant: T_i = 25 °C;
- the conventional outdoor air temperature has a sinusoidal variation with a period of 24 h, around the value of 24,6 °C, with the amplitude of ±7 °C.

a. The factor of thermal damping

According to C107/7-02 – Prescriptions, the outdoor, air temperature oscillations damping factormust be estimated both for the cold season and for the warm season of the year.

The model, using the finite element method, was made for an interval of 4 days and the results for the last day hold back.

For example, in the vertical joints of a thermal bridge (Fig.1, section 1-1), the temperature variations in the cold season (calculated by numeric modeling) in the indoor face and the outdoor face of the panel, inside and outside the bridge are presented in Fig.2. The time period is of 4 days and amplitude of outdoor air temperature is of ±10 °C.

For the vertical joints, the values of the thermal damping in the cold season are calculated as the ration between the external (outdoor) air amplitude and internal surface temperature amplitude:

- for the external (outdoor) air amplitude A = 5 °C:
- in the current field

$$\nu = \frac{A_{Te}}{A_{Tsi}} = \frac{5}{0.095} = 52.63$$

- in the thermal bridge

$$\nu = \frac{A_{Te}}{A_{Tsi}} = \frac{5}{0.320} = 15.63$$

- for the external (outdoor) air amplitude A = 10 °C:
- in the current field

$$\nu = \frac{A_{Te}}{A_{Tsi}} = \frac{10}{0.185} = 54.05$$

- in the thermal bridge

$$\nu = \frac{A_{Te}}{A_{Tsi}} = \frac{10}{0.640} = 15.63$$

Expectedly, the values resulted for the two variations of the amplitude are close. But large differences between the values obtainedin current field (section) and those obtained in the thermal bridge a (section) can be observed. However all the values are over the minimal standard value for the opaque sections of the external walls (ν_T = 15) recommended by the effectual prescriptions.

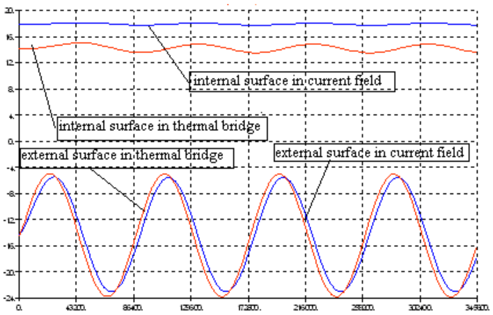

Fig. 2. Temperature variations on the panel surfaces in the cold season-vertical joint (P=4 days)

In Fig.3 are represented the diagrams of the temperature variation in the warm season on external (outdoor) and internal (indoor) faces of the panel in the vertical joint and also in another section out from the influence of the thermal bridge for amplitude of the outdoor air temperature variation of 7 °C and a period of 4 days.

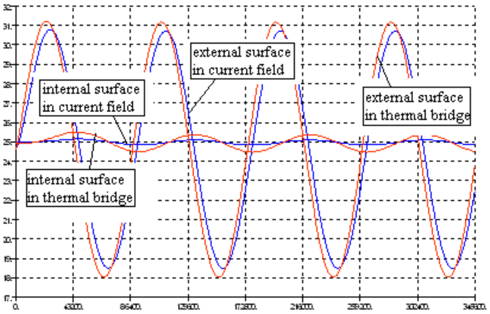

Fig. 3. Temperature variation on the panel surface in the warm season- vertical joint (P=4 days)

The values of thermal damping in the warm season, calculated as the ratio between the external (outdoor) air amplitude and internal (indoor) surface temperature amplitude, are:

- in the current field:

$$\nu = \frac{A_{Te}}{A_{Tsi}} = \frac{7}{0.13} = 53.85$$

- in the thermal bridge:

$$\nu = \frac{A_{Te}}{A_{Tsi}} = \frac{7}{0.45} = 15.56$$

The values damping in the warm season are over the minimal standard value for the opaque section of the external walls (ν_T = 15) recommended by the effectual prescriptions and they are close to the appropriate values from the cold season.

The values of the thermal damping factors for the other types of thermal bridges were calculated in the same way and the results are presented in Table 1.The thermal damping factor calculated according to the standard (for details see C107/7-02-Prescriptions) is the same for the warm season and for the cold season:

$$\nu_T = 0{,}9.e^{\frac{\Sigma D}{\sqrt{2}}} \frac{(s_1+\alpha_i)(s_2+B_1)(s_3+B_2)(\alpha_e+B_3)}{(s_1+B_1)(s_2+B_2)(s_3+B_3).\alpha_e}$$

$$= 0{,}9.2.718^{\frac{2.5}{\sqrt{2}}}$$

$$\frac{(17.9+8)(0.30+17.9)(17.9+0.538)(24+12.26)}{(17.9+17.9)(0.30+0.538)(17.9+12.26).24} =$$

$$= 76.46$$

The value that results for unidirectional conditions (consequently in current field) is with approximately 42% over the corresponding value computed by numeric models. The results centralized in Table 1 for all the types of thermal bridges (except for the vertical joints) are under the minimal standard value.

Table 1 - Thermal phase alteration (hours)

Crt.no.	Thermal bridge		Numerical model winter		Numerical model summer	C 107/7–02 Prescription
			A = 5 °C	A = 10 °C	A = 7 °C	
0	1		2	3	4	5
1.	Vertical joint		15.63	15.63	15.56	–
2.	Horizontal joint	superior	9.524	9.479	9.563	–
		inferior	10.20	10.10	11.20	–
3.	Window cill		10.53	10.53	10.53	–
4.	Concrete ribs		14.08	14.08	14.14	–
5.	Current field (mean values)		54.39	54.05	53.85	76.46

The thermal bridges adjacent fields, where the thermal damping is influenced by the presence of the bridges, are extending enough. For instance, in the horizontal joints and warm season (comparing with the values from the current field) the thermal damping is disturbed on horizontal strips of about 60 + 60 cm high over and under the joint. The same phenomenon appears in the case of the ribs and near the window opening perimeter. Because all these bridges are close (one or another) their influence surfaces overlap partially. In this situation the value of thermal damping determined according to C107/7-02 – Prescriptions in unidirectional conditions, widely lose its relevance (additionally, this value sums extra large compering to the value computed by numerical models for current field and unidirectional conditions).

b. Thermal phase alteration factors

According to C107/7-02 – Prescriptions, the phase alteration factor for the thermal oscillations of the outdoor air is calculated just for the warm season of the year.

The numeric model was made for an interval of 4 days and the results for the last day hold back.

The way the phase alternation factor is estimated (by numerical modeling) for the thermal bridge of the vertical joist will be described bellow.

In Fig. 4 are presented the diagrams of temperature variations on the panel faces (computed by numerical modeling) for the warm season over the last day. The time lags between the outdoor (external) face maximal temperature and the indoor (internal) face maximal temperature (consequently the alteration of phase) are also relieved.

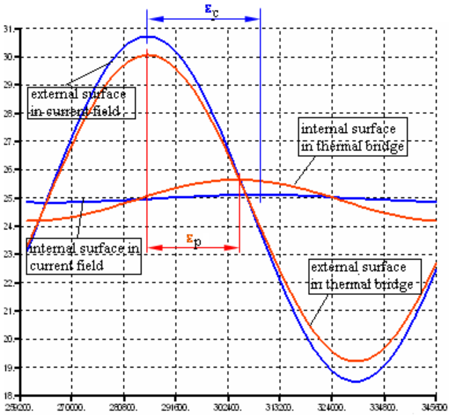

Fig. 4 - Temperatura variations on the panel surface in the earm season- vertical joint (P=4 days)

The phase alteration factor (measured in hours) results:

- in the current field: $\varepsilon_c = 6.4$ hours;
- in the thermal bridge: $\varepsilon_p = 5.1$ hours.

The phase alteration factor for multi-layered elements, determined according to C107/7-02 – Prescription results:

$$\varepsilon = \frac{1}{15}\left(40{,}5.\Sigma D - \mathrm{arctg}\frac{\alpha_i}{\alpha_i + B_i\sqrt{2}} + \mathrm{arctg}\frac{B_e}{B_e + \alpha_e\sqrt{2}}\right) =$$

$$= \frac{1}{15}\left(40{,}5.2{,}5 - \mathrm{arctg}\frac{8}{8+17{,}9\sqrt{2}} + \mathrm{arctg}\frac{12{,}13}{12{,}13+24\sqrt{2}}\right) =$$

$$= 6.8 \text{ ore}$$

The value determined with this method is close to the value estimated by numerical model in the current field (the gap is of 6%); but related to the values obtained in the vertical joint thermal bridge is a gap of 33%.

The values of the phase alteration factor for the other types of thermal bridges were calculated in the same way and the results are presented in Table 2.

Table 2

Crt. no.	Thermal bridge		Numerical model	C 107/7–02 Prescription
0	1		2	3
1	Rost vertical		5.1	–
2	Rost orizontal	superior	4.8	–
		inferior	4.8	–
3	Glaf fereastră		4.3	–
4	Nervuri de beton		5.4	–
5	Câmp curent		6.4	6.8

The values of the phase alteration factors are under the minimal standard value for the dwelling buildings external walls ($\varepsilon = 9$ hours).

3. CONCLUSIONS

In order to estimate the thermal insulating qualities of the building element, C107/7-02-Prescriptions introduce, using a too long denomination, the concept of “specific corrected thermal resistence”. The way this concept is defined (in the prescription) is not the most proper for technical regulation where more clear and precise formulation are required especially when important concepts are defined.

The estimation of the corrected thermal resistance is based on the method of linear and punctual thermal transfer factors that are not defined in C107 – Prescriptions. Also the expression (equation) proposed for the estimation of the linear transfer factor y, although practicable, is stated in a heterogeneous and incomplete manner.

As regards the “Prescription for the thermal stability design of the building enclosing elements” (C107/7-02 – Prescriptions) the subject of the prescriptions embraces not just the boundary building elements (as suggests the denomination of the prescription) but also the internal walls and the intermediate floor slabs that divide spaces with different temperatures. More severe are some aspects that concern computation methods recommended for the estimation of the outdoor air temperature oscillations damping factor and of the factor that illustrates the alteration of phase of the outdoor air temperature oscillations.

For the assessment of these parameters are recommended the expressions that result from the analytical solving of the differential equation of heat lose, in unidirectional unsteady conditions, considering some simplifid hypothesis. This method was elaborated and published more than 30 years ago in our technical literature, translated especially from Russian technical dissertation. The values estimated for temperature oscillations damping factor (Table 3) according to C107/7 - 02-Prescriptions are with 42% higher than the similar values calculated by numeric modeling (both in unidirectional conditions).

Farther the values estimated using bidirectional numerical models for the thermal bridges are about 4.5 times smaller that the values for the current section (field) estimated using unidirectional numerical models and 6.4 times smaller than the values calculated by C107/7-02.

Table3. Thermal damping and thermal phase alteration factors

Coefficient type	Numerical model (mean values)		02 Prescriptio	Difference (%)	
	Current field	therm. bridge	Current field	Current field	therm. bridge
0	1	2	3	4	5
Damping factors	54.0	12.0	76.5	42	538
Phase alteration factors	6.4	4.9	6.8	6.3	39

The phase alternation factor (Table 3) calculated according to C107/7-02-Prescriptions was with 6.3% over the value estimated by unidirectional numerical model, but with about 40% over the mean value from the thermal bridges calculated using bidirectional numerical models. For other cases of study the phase alternation factor calculated according to C107/7-02-Prescriptions was with 30% under the value estimated by unidirectional numerical model.

In these conditions it can be asserted that the methodology proposed by C107/7-02 Prescriptions for the estimation of the thermal damping and thermalphase alteration factors lead to results that are not very close to the correct ones.

Thus the values obtained according to C107/7-2 can be considered more as a rough guide.

Finally, it must be mentioned that C107/7-02 –Prescriptions do not give any indication regarding a possible estimation of the thermal damping and thermal phase alteration factors using numerical models, at least for unidirectional conditions

This situation is more difficult to understand because in the preliminary phase of elaboration (Phase III from 1999) the prescription has a detailed presentation of a numerical computation using the RENESTL numerical computer under unidirectional unsteady conditions.

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