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The thermal quality of construction joints with the balcony slab

Krzysztof Pawłowski (*orcid id*: *0000-0002-6738-5764*)
Bydgoszcz University of Science and Technology

Abstract: The article introduces selected aspects of creating material sets for an external wall connection with a balcony slab. The integral part of this work are calculations and analyses concerning the thermal quality of joints with balcony slabs produced using various construction and material solutions. Proper selections of the material layers of a building case in regards to thermal aspects and humidity essentially influence the building demand for energy (EU, EK i EP) and pollutant emissions into the natural environment.

Keywords: energy-saving construction, thermal quality of building elements, balcony slabs

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Introduction

A building consists of many partitions with each joint displaying individual physical characteristics that are influenced by changing external and internal environments. In numerous cases, the analysis of partitions and the building joints in regards of the material aspects and execution of construction technology does not raise objections during the design stage. However, knowledge of physical parameters, including heat and humidity exchange, ensures that many defects in the design and execution of the construction are avoided, and provide the proper parameters for the interior microclimate during the building usage (proper temperature, humidity and purity of internal air). Thus, the proper design of material layer sets for internal partitions and their joints should not be left to chance or intuition, but be based on the thorough analyses of the numerical calculations of stationary heat flow.

The thermal quality of building casing elements (planar building partitions (1D) and their construction joints (2D) and (3D)) are impacted by the following calculation parameters:

- heat transfer coefficient of a partition in a one-dimension field (1D) – U / U(1D), $W/(m^2 \cdot K)$,
- heat flux flowing through a building joint (thermal bridge in 2D or 3D fields) – Φ, W,
- linear coefficient of the heat transfer of a heat bridge in 2D field) – Ψ, $W/(m \cdot K)$, branch coefficient of heat transfer for a single part of a joint, e.g. for wall joint with a balcony slab ($\Psi_{g.}$ – in reference to the upper part of joint, $\Psi_{d.}$ – in reference to the lower part of joint),
- spot coefficient of heat transfer of a heat bridge in a 3D field – X, W/K,
- heat transfer coefficient of a partition with linear heat bridges (2D) – U(2D), $W/(m^2 \cdot K)$,
- minimum temperature on the internal surface of a partition in a heat bridge (2D) and (3D) – $t_{min.(2D)}$ / $t_{min.(3D)}$, °C,
- temperature factor $f_{Rsi(2D)}$ / $f_{Rsi(3D)}$ [–], defined on $t_{min.(2D)}/t_{min.(3D)}$.

The principal change in thermal protection of buildings (Regulation) and change in maximum values of heat transfer value $U_{c(max)}$ / $U_{(max)}$ for single external partitions for example external walls, windows, and roofs. In many cases the solution is limited to the definition of heat transfer through a flat construction partition in a 1D field, without concerning heat transfer in a 2D field. But the real field of heat transfer is usually an external partition that is part of a building as a whole, thus it is connected with a system of joints and binding partitions (ceiling, external or internal walls or floor on the ground).

Unfortunately, regulations do not specify limit requirements for heat loss through construction joints – 2D and 3D bridges, because the limit values were not set for the maximum value of linear heat transfer $\Psi_{max.}$ $[W/(m \cdot K)]$. According to definition values of Ψ, these are treated as correction coefficients for calculating 1D heat loss, with which the geometrical aspect (defined by assumption of measurements), should be taken into account similarly as an extension of heat flux. The example classification of heat bridge influence depending on the value of linear heat transfer Ψ is given in Table 1.

Table 1. Classification of a heat bridge impact on heat loss – own research based on (Wouters et al., 2004)

Influence of classes of heat bridge based on evaluation of Ψ coefficient			
C1 $\Psi_{i,e} < 0.1$	C2 $0.1 \le \Psi_{i,e} < 0.25$	C3 $0.25 \le \Psi_{i,e} < 0.5$	C4 $\Psi_{i,e} \ge 0.50$
negligible	little influence	big influence	very big influence

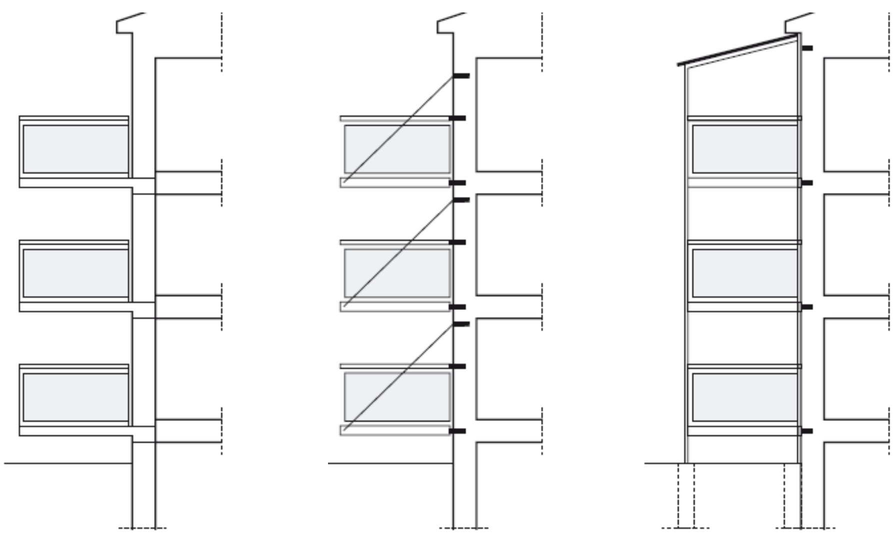
According to (Guidance by NFOSiGW) the limiting of heat loss through the building casing of a low energy building can be reached by verification of construction joints (heat bridges) in fulfilment of the criterion: $\Psi \le \Psi_{(max)}$, where: Ψ – value of linear coefficient of heat transfer for the selected heat bridge, W/(m · K), $\Psi_{(max)}$ – limit value of the linear coefficient of heat transfer for the selected heat bridge, W/(m · K) (for the NF40 standard – $\Psi_{(max)}$ = 0.10 W/(m · K), and for the joint of an external wall with a balcony slab $\Psi_{(max)}$ = 0.20 W/(m · K); for the NF15 – $\Psi_{(max)}$ = 0.01 W/(m · K)). However, the value of Ψ coefficient should not always be the only parameter which evaluates the quality of a heat bridge. A significant value of Ψ coefficient does not mean automatically that the heat bridge is essential.

The fulfilment of the criterion in order to avoid the risk of surface condensation (development of mould and mould fungi): $f_{Rsi.(2D)}/f_{Rsi.(3D)} \geq f_{Rsi.(kryt.)}$, requires a definition of the value $f_{Rsi.(2D)}/f_{Rsi.(3D)}$ based on the minimal temperature on the internal surface of the partition at the heat bridge (2D)/(3D) $t_{min.(2D)}/t_{min.(3D)}$, °C, and the value of $f_{Rsi.(kryt.)}$ concerning parameters of internal and external air (humidity and temperature). The maximum value from 12 months for Bydgoszcz was $f_{Rsi.(max)} = f_{Rsi.(kryt.)} =$ = 0.785 (February). This means that during the year, to avoid surface condensation, $f_{Rsi.(2D)}$ should stay above 0.785.

In this work there is an analysis of the physical parameters of an external wall joint with a balcony slab using different design solutions and materials.

1. Design of the physical parameters of construction joints with a balcony slab

A balcony is an open-air construction and architectural element that often protrudes from the façade of a building. The construction and material used for a balcony depends on many factors (for example load, user safety, architectural aspects). Figure 1 shows diagrams of balcony constructions: cantilevered, hanging and added).



a) cantilevered b) hanging c) added

Fig. 1. Diagrams of balcony construction (own study based on Grudzińska, 2011)

Cantilevered balconies are used when extension is about 1.5 m, or when load is significant. The slab thickness is from 8 to 12 cm (it can be constant or various).

Hanging balconies are fixed to construction walls by steel lines or support constructions with braces and beams from underneath. They do not need additional foundations, but they weigh down the building walls.

Balconies that are added later to the building and that located on their own foundations, which may be in the form of transverse solid walls or lighter steel or ferroconcrete poles, do not weigh down the building walls but are connected with anchors made of steel shapes. This maintains the stability of the structure and transfers horizontal load resulting from wind. It must be stressed that with such a solution, there does not occur a break in thermal insulation of the external wall (Grudzińska, 2011). The main problem in designing a balcony joint with an external wall is maintaining thermal insulation. Limitation of this heat bridge (2D) can be obtained by:

- supporting the balcony slab on ferroconcrete or steel cantilevers anchored in a ring beam,
- using added balconies,
- use of isothermal links.

Using bent steel sheets in balcony links as support (instead of rods as in most other solutions of this type) enables the increase of the thermal insulation thickness of the TIPOMEGA® system to 16 cm (Fig. 2). The balanced thermal conductivity of one running meter of an isothermal link depends on its thickness (8 cm, 12 cm, 16 cm), height (16-24 cm) and percentage of steel $\lambda = 0.055\text{-}0.258$ W/(m · K).

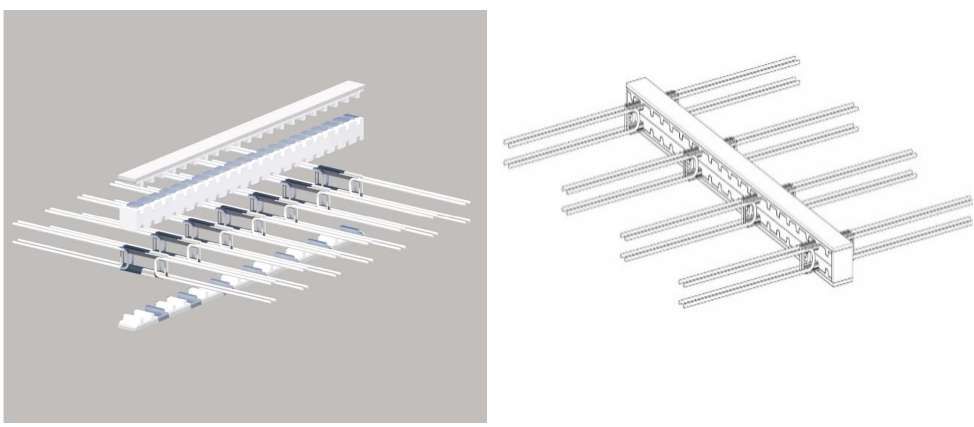
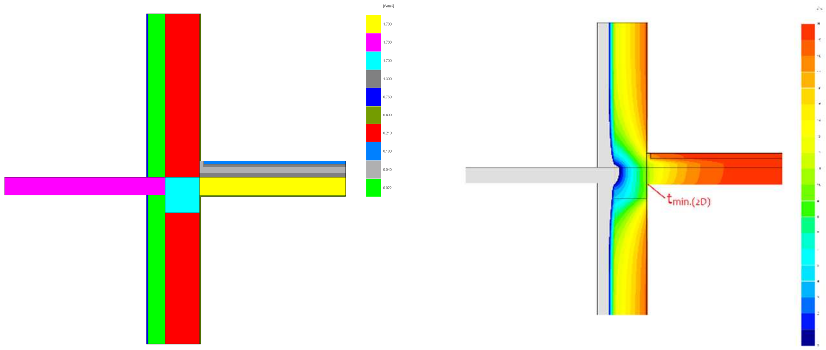


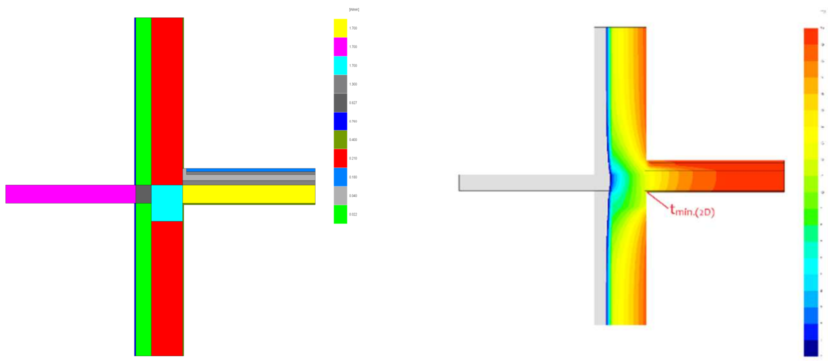
Fig. 2. Elements of an isothermal link system (source: www.tipomega.eu)

For the analyses, three basic calculation variants were selected: I – balcony slab cuts the thermal insulation layer, II – balcony slab supported by two ferroconcrete beams, III – connection of external wall with a balcony slab using an isothermal link (Figs. 3-5).



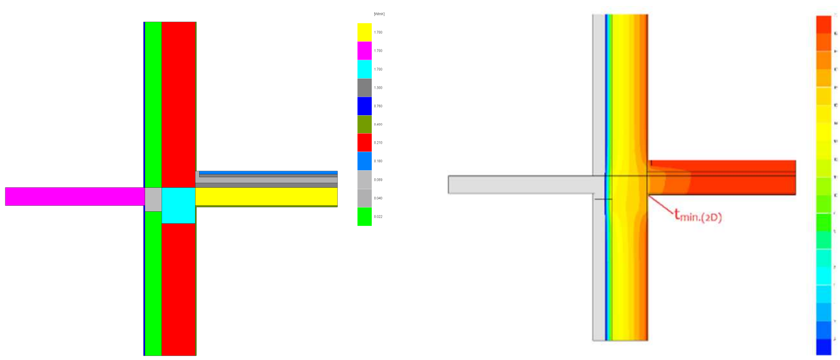
a) calculation model b) temperature distribution – isotherms

Fig. 3. Joint of external wall with a balcony slab (variant I) (*own study*)



a) calculation model b) temperature distribution – isotherms

Fig. 4. Joint of external wall with a balcony slab (variant II) (*own study*)



a) calculation model b) temperature distribution – isotherms

Fig. 5. Joint of external wall with a balcony slab (variant III) (*own study*)

When calculating heat loss through a part of a building casing, you need to use branch (partial) values of the heat transfer coefficient Ψ. Usually, values of the coefficient Ψ are given that concern the total additional heat loss through a bridge.

In order to resolve the thermal calculation concerning particular parts of a building correctly, for example in a particular external wall, the coefficient values of Ψ must be divided for appropriate joint branches participating in heat loss. The calculation procedure for the branch heat transfer coefficient Ψ consists of:

- separating the internal branches of a heat bridge, assigning initial and limit conditions,
- calculation (numerical), using computer software, of the heat flux flowing through separated branches (parts) of a bridge,
- calculation of related branch coefficient according to relevant relationships using data related to the branches.

Table 2. Calculation results of the physical parameters of a joint: external wall with balcony slab (*own study*)

Variant	U_1/U_2 W/(m² · K)	Φ W	$\Psi_{i.}$ W/(m · K)	$\Psi_{i1.}$ / $\Psi_{i2.}$ W/(m · K)	$t_{min.(2D)}$ °C	$f_{Rsi(2D)}$ –
variant I – balcony slab cutting the thermal insulation layer						
$B1_{(8)}$	0.20 / 0.25	37.29	0.526 (C4)	0.079 / 0.447	9.66	0.742
$B1_{(12)}$	0.15 / 0.17	31.25	0.485 (C3)	0.075 / 0.410	10.73	0.768
$B1_{(16)}$	0.12 / 0.13	27.22	0.447 (C3)	0.070 / 0.377	11.57	0.789
variant II – balcony slab supported by two ferroconcrete beams						
$B2_{(8)}$	0.20 / 0.25	33.40	0.429 (C3)	0.064 / 0.365	11.20	0.780
$B2_{(12)}$	0.15 / 0.17	26.69	0.371 (C3)	0.056 / 0.315	12.55	0.814
$B2_{(16)}$	0.12 / 0.13	22.36	0.325 (C3)	0.050 / 0.275	13.54	0.839
variant III – external wall joint with balcony slab using an isothermal link						
$B3_{(8)}$	0.20 / 0.25	21.50	0.131 (C2)	0.015 / 0.116	16.14	0.904
$B3_{(12)}$	0.15 / 0.17	16.27	0.110 (C2)	0.013 / 0.097	16.92	0.923
$B3_{(16)}$	0.12 / 0.13	13.15	0.095 (C1)	0.011 / 0.084	17.42	0.936
$B4_{(8)}$	0.20 / 0.58	21.75	0.101 (C2)	0.006 / 0.085	16.04	0.901
$B4_{(12)}$	0.15 / 0.47	16.38	0.080 (C1)	0.013 / 0.067	16.86	0.921
$B4_{(16)}$	0.12 / 0.41	13.29	0.068 (C1)	0.012 / 0.056	17.36	0.934
$B5_{(8)}$	0.20 / 0.25	24.56	0.207 (C2)	0.027 / 0.180	14.83	0.871
$B5_{(12)}$	0.15 / 0.17	19.87	0.200 (C2)	0.027 / 0.173	15.38	0.885
$B5_{(16)}$	0.12 / 0.13	17.08	0.193 (C2)	0.028 / 0.165	15.73	0.893
$B6_{(8)}$	0.20 / 0.87	24.63	0.141 (C2)	0.026 / 0.115	14.81	0.870
$B6_{(12)}$	0.15 / 0.83	19.92	0.130 (C2)	0.026 / 0.104	15.37	0.884
$B6_{(16)}$	0.12 / 0.82	17.18	0.123 (C2)	0.026 / 0.097	15.51	0.888

*) heat conduction coefficient of an isothermal link:
$B3_{(8)}$ – λ = 0.079 W/(m · K), $B3_{(12)}$ – λ = 0.089 W/(m · K), $B3_{(16)}$ – λ = 0.101 W/(m · K),
$B4_{(8)}$ – λ = 0.058 W/(m · K), $B4_{(12)}$ – λ = 0.068 W/(m · K), $B4_{(16)}$ – λ = 0.077 W/(m · K),
$B5_{(8)}$ – λ = 0.142 W/(m · K), $B5_{(12)}$ – λ = 0.203 W/(m · K), $B5_{(16)}$ – λ = 0.258 W/(m · K),
$B6_{(8)}$ – λ = 0.100 W/(m · K), $B6_{(12)}$ – λ = 0.139 W/(m · K), $B6_{(16)}$ – λ = 0.176 W/(m · K),
U_1 – heat transfer coefficient of an external wall
U_2 – heat transfer coefficient of external wall in a ring beam section
Φ – heat flux flowing through a joint
Ψ_i – linear heat transfer coefficient (defined on internal measurements)
(C1)-(C4) – thermal bridge classification according to Table 1
$\Psi_{i,1.}$ – branch coefficient of heat transfer (defined on internal measurements), relating to upper joint part
$\Psi_{i,2.}$ – branch coefficient of heat transfer (defined on internal measurements), relating to lower joint part
$t_{min.(2D)}$ – minimum temperature on internal joint part
$f_{Rsi(2D)}$ – temperature factor, defined on $t_{min.(2D)}$

Detailed analyses of procedures in this area are described in (Pawłowski, 2016). In the case of an external wall joint with a balcony slab there were defined values of the branch coefficient of heat transfer: $\Psi_{i,g.}$ – for upper joint part, $\Psi_{i,d.}$ – for lower joint part. For numerical calculations using TRISCO-KOBRU 86 software (*Program komputerowy …*), the following assumptions were made:

- joint modelling was performed according to principles introduced in PN-EN ISO 10211:2008,
- heat intercepting resistance (R_{si}, R_{se}) were assumed according to (PN-EN ISO 6946:2008) during calculation of heat fluxes, and according to (PN-EN ISO 13788:2003) during calculation of temperature distribution and temperature factor $f_{Rsi(2D)}$,
- temperature of internal air t_i = 20°C (living room), temperature of external air t_e = –20°C (III zone),
- values of heat conduction coefficients of construction materials λ, W/(m · K), were assumed on tables from (Pawłowski, 2016),
- external two-layer wall: cellular concrete block 24 cm thick – λ = 0.21 W/(m · K), polyurethan foam boards of thickness 8 cm / 12 cm / 16 cm – λ = 0.022 W/(m · K), ferroconcrete elements λ = 1.70 W/(m · K), gypsum parget 1 cm thick – λ = = 0.40 W/(m · K), thin layer parget 1 cm thick – λ = 0.76W/(m · K), isothermal links λ = 0.058-0.258 W/(m · K).

The calculation results for the analysed variants are presented in Table 2.

2. Summary and conclusion

Defining the physical parameters (heat and humidity) of an external wall and balcony slab using TRISCO-KOBRU 86 software for a two dimensional stationary heat flow allows the correct design of the material layers of building casing elements. Using approximate values for additional heat loss (for example (PN-EN ISO 14683:2008)) without taking into account the type and thickness of the material is unacceptable during the design process.

In variant I, where the balcony slab cuts the thermal insulation layer, the analyzed joint generates an additional heat loss of Ψ = 0.447-0.526 W/(m · K). According to the classification by (Wouters et. al., 2004) the influence of this type of joint (heat bridge) is big (C3) or very big (C4). Additionally, it must be noted that in this type of joint occurs a temperature decrease on the internal surface of a partition $t_{min.}$(2D) = 9.66-11.57°C. As a consequence, it can be said that in two cases of the calculation variants, there will be risk of surface condensation (development of mildew and mould mushrooms because of the condition: $f_{Rsi.(2D)} \geq f_{Rsi.(kryt.)} = 0.789$, was not fulfilled – Table 2).

Using a balcony slab supported by two ferroconcrete beams (variant II) results in the lowering of Ψ = 0.325-0.429 W/(m · K) and an increasing value of $t_{min.(2D)}$ = = 11.20-13.54°C in relation to variant I.

The joint of an external wall with a balcony slab using an isothermal link (variant III) caused a significant decrease in the value of Ψ = 0.068-207 W/(m · K) when compared to variant I and II. The influence of this joint (heat bridge) according to Table 1 is small (C2) and negligibly small (C1). Such a solution fulfills requirements formulated by NFOSiGW for the building standard of NF40 – $\Psi_{(max)}$ = = 0.10 W/(m · K), and for an external wall joint with a balcony slab $\Psi_{(max)}$ = = 0.20 W/(m · K). Moreover, the lowering of the temperature on the internal surface of a partition stays at level of $t_{min.}$(2D) = 14.81-17.42°C ($f_{Rsi.(2D)}$ = 0.870-0.936). Consequently, the criterion for avoiding surface condensation (mildew and mold mushroom development): $f_{Rsi.(2D)} \geq f_{Rsi.(kryt.)}$ = 0.789 (for a building located in Bydgoszcz) was fulfilled.

It is reasonable to set the limit for heat transfer Ψ_{max} in the regulations to a level of 0.05-0.10 depending on the type of analyzed joints (heat bridge). However, there is a need to run further numerical calculations (using professional software) on the physical parameters of building partitions for modern material and construction solutions in energy buildings in order to eliminate incorrect solutions in regards to the thermal aspects and humidity and also develop a catalogue of heat bridges.

The thermal quality of building casing elements (internal partitions and construction joints) should be decide on, based on optimized indicators for the energy demand of a building (EU), fina energy (EK), and non-renewable primary energy (EP).

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PN-EN ISO 6946:2008 Komponenty budowlane i elementy budynku. Opór cieplny i współczynnik przenikania ciepła. Metoda obliczania.

Program komputerowy TRISCO-KOBRU 86, PHYSIBEL c.V, Belgia. Licencja stanowiskowa na cele badawczo-dydaktyczne.

Rozporządzenie Ministra Infrastruktury i Budownictwa z dnia 14 listopada 2017 r. zmieniające rozporządzenie w sprawie warunków technicznych, jakim powinny odpowiadać budynki i ich usytuowanie (Dz.U. z 2017 r. poz. 2285).

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Wytyczne określające podstawowe wymogi niezbędne do osiągnięcia oczekiwanych standardów energetycznych dla budynków mieszkalnych oraz sposób weryfikacji projektów i sprawdzenia wykonanych domów energooszczędnych, www.nfosigw.gov.pl