Damage to Historical Balconies in View of Building Physics

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Abstract. The article presents the problem of damage to historical balconies, having other structural or material solutions than the modern ones. Their durability and maintenance aspects comprise a wide spectrum of issues, including repair and renovation methods, selection of new materials for the existing structures and their mutual interaction. The applied solutions must take into account the specificity of the components, their performance in the conditions of external environment, the impact of variable temperatures, both positive and negative ones (including, in particular, zero-crossings), atmospheric precipitation or solar radiation.

Particular attention was paid to balconies with steel and ceramic structure, whose technical diagnostics should include, apart from structural analysis, also detailed observations of heat and mass transfer phenomena. The paper presents the results of numerical analyses for two-dimensional models, similar to the actual structure of the historical envelope (both for the original state and after the performed thermo-modernization works) as well as the results of thermographic measurements of one of residential buildings with balconies with steel beams. In the adopted boundary conditions, the local climate was taken into account, based on the data from the nearest meteorological station. The present objective involved the acquisition of qualitative results. The obtained results comprised: the distributions of temperature fields in cross-sections, distribution of heat flux density changes, and temperature values in selected cross-section locations. The research confirmed the expected tendencies in temperature distributions in the envelope, the location of local thermal bridges and the zones of their impact. Further analyses should be continued on the obtained changes in heat flux density, both in the steel beam support node, as well as in the joints and bricks in the adjacent layers. These places overlap with the actual occurrence of loose and weakened mortars in the building walls and in ceramic tiles. In further analyses, simulation programs facilitating the determination of the amount and changes of moisture in time should be applied.

1. Introduction
The subject involving the condition of balconies to a large extent concerns historical buildings with structural and material solutions other than the contemporary ones. Other related issues involving their durability and maintenance comprise a wide spectrum of issues, including repair methods and renovations, selection of new materials for the existing structures and their interaction. The applied solutions must take into account the specificity of the performance of particular elements in the conditions of external environment, variable temperatures, both positive and negative ones (including, in particular, zero-crossings), atmospheric precipitation or solar radiation [1].

The applied building materials that dominate in the contemporary historical balconies include principally steel (structural beams) bricks and concrete (balcony slabs). In terms of damage to balconies with steel beams, numerous problems related to their repair have been reported, including the need to increase the load-bearing capacity of structural elements [2,3,4,5,6,7]. With these types of issues, when planning repair works, the knowledge on relevant historical material solutions is
essential, e.g. the type of applied structural steel [8]. The problems of sustainability and maintenance of balconies can be resolved by the application of processes offered by building physics. They are often addressed when we have to face problems of linear thermal bridges found in buildings erected in the 1990s, in places where balconies are located in external walls [9,10,11,12], or when we look for methods to increase temperatures in thermally weak places [13]. The problems of local temperature drops in the envelope may occur in the areas where steel balcony beams are seated in brick walls, (also when buildings are subjected to thermo-modernization works), which leads to the formation of local moisture zones. In historical brick walls we can observe the phenomenon of coupled heat and mass transfer [14,15,16,17,18,19].

The migration of moisture in mortars and bricks may take place in various ways [20]. The content of moisture in individual parts of the wall is conditioned by its material solutions, i.e. the impact of the external environment, depending on the location of the object (also with respect to the sides of the world) [20,21]. Nowadays, we can apply numerical analyses to verify and predict hygrothermal conditions of the envelope. The analyses may be helpful at the diagnostic, design and implementation stages.

2. Examples of historical balconies

For centuries balconies and terraces have been fulfilling useful functions in buildings: practical functions (enlarging the internal zone of the rooms) and architectural ones (elements of the architectural decoration of the façade). Their structure, shape and applied materials have been changing along with architectural trends, current trends and the development of building techniques. The oldest solutions include historic stone balconies, supported by stone supports, replaced in time with cast iron and steel cantilevers. The stone applied for balcony slabs was still found in Poland in the late nineteenth and early twentieth century [22]. At the beginning of the 20th century, the stone balcony slab was gradually being replaced by segmented arches see figure 1 (with the deflection arrow parallel or perpendicular to the wall), Klein slabs see figure 2 and then reinforced concrete slabs.

![Figure 1. Balconies with a slab in the form of segmented arch: (a) with the deflection arrow parallel to the wall [23], (b) perpendicular to the wall [23], (c) in an apartment house in Bytom, photo: J. Grabolus [24]](image)
At the end of the nineteenth and early twentieth century also iron alloys were widely applied to make cantilevers, balustrades and load bearing beams. In the 1970s and 1980s, the production of entirely cast iron balconies developed on a mass scale (cantilevers, slabs and balustrades) \[22\] in factories specializing in casting iron elements, including balconies, based on local designs \[22\] see figure 3 and figure 4.

**Figure 2.** Balconies with the Klein slab \[24\] (a) longitudinal section, (b) cross-section

**Figure 3.** A template of cast iron balcony elements manufactured by the factory "Neptun" J. Minz in Końskie (Poland), (a) balustrades, (b) cantilever, (c) balcony slab

**Figure 4.** Historic cast iron balconies on the facades of residential buildings, Radom (Poland), (a) and (b), photo: M. Trojanowska
In the twentieth century, balconies with reinforced concrete slabs began to be applied as a way to repair the damaged balconies on steel beams in the existing buildings whose wooden, stone or brick balcony slabs had been completely destroyed. When the technical condition of steel cantilevers was sufficiently good, they were used as structural elements, and the main structural reinforcement of the slabs was laid on beams (Figure 5). The whole structure, together with the cantilever beams, previously wrapped with steel mesh, was plastered.

Figure 5. Balconies with reinforced concrete slabs on steel beams in apartment houses in Zielona Street in Łódź (Poland) [24], (a) and (b)

3. Examples of balcony damage and their causes
The durability of balconies and terraces in historical buildings as well as their present-day repairs are conditioned to a large extent by the way they are used, the choice of appropriate repair solutions and the level of workmanship. As a result of design shortcomings, manufacturing errors, or the lack of proper maintenance of buildings, balcony elements are moistened, which ultimately brings about, among other things, the development of biological blooms (Figure 6a), damage to plaster coatings (Figure 6b,7ab,8a), cladding peeling (Figure 8b), formation of surface salt blooming, as well as the strain on the structure, requiring the implementation of temporary reinforcements (Figure 9a), or complete destruction of balcony slabs (Figure 9b).

Figure 6. Damage to balcony slabs of apartment houses: (a) Biological bloom developed on plaster surface, caused by damaged flashings, Gliwice (Poland), photo: A.Gwiżdż, (b) Damage to plaster on the palate of the balcony slab made as Klein floor, Gliwice (Poland) photo: J.Grabolus [24]
Figure 7. Damage to plasters on the palate of the balcony slab made as segmental floor, Gliwice (Poland), (a) and (b), photo: A. Gwiżdż

Figure 8. Damage to balcony elements, photo: A. Gwiżdż (a) Damage to the plaster coating in the masonry balustrade of the terrace, Wrocław (Poland), b) to ceramic cladding, Gliwice (Poland)

Figure 9. Damage to balcony structure: (a) requiring contemporary support, Wrocław (Poland), Photo: A. Gwiżdż, (b) complete destruction of the balcony slab, photo: J. Grabolus [24]
A significant part of the damage to balconies or historical terraces has been effected by technical solutions applied in the past (e.g. the lack of waterproofing insulation or flashings), with no repairs carried out when the first signs of damage were identified. In consequence, the penetration of rainwater into the balcony and terrace layers, their leaking on the underside of balcony slabs under external environment conditions, results in the corrosion of structural beams, steel beams or frost damage of ceramic tiles (e.g. Klein floors or segmental floors). Damage to plaster is described as the beginning of corrosion processes of steel balcony elements, due to the loss of protective properties of the plaster. The said consequences are becoming more significant in combination with ineffective waterproofing insulation (or the lack thereof) in sensitive areas, which are considered anchorage points for steel beams in the wall [4]. In the case of balconies with steel beams fixed in brick walls, in addition to corrosion of steel structural elements, also the loosening or weakening of mortars in walls or in ceramic tiles is observed. The authors presume that the responsibility for such damage can be attributed (along with other factors mentioned above) to local moisture condensation, due to reduced temperature found in the support zones of steel beams in brick walls.

4. Carried out research studies – assumptions and methods

In order to verify the problem, the authors carried out a numerical analysis for a two-dimensional model and thermographic measurements of an apartment building with balconies with steel beams. The assumption was to obtain qualitative results.

The analyses were carried out using the computer program THERM 7.4, based on the application of FEM for the calculation of an arbitrary two-dimensional model of a building element. It can be used, among others, to determine the distribution of temperature field in the envelope, to determine the impact zones of heat flux density changes and to determine temperatures in the selected cross-section within the scope offered by the 2D model. The calculations were carried out for two variants of the theoretical model approximated to real conditions. In the analysis, the impact of floor layers (usually wooden floors) and that of the finishing layers of the balcony were ignored, focusing on the section through the steel beam, in both cases. The model comprised a horizontal cross-section through the external ceramic wall at the place where the steel balcony beams were supported. The first case involved a non-insulated wall and the second one involved an anallogical system, after thermomodernization of the building with Styrofoam panels. The following was adopted for the models: a ceramic wall 510 mm wide on lime mortar, a steel I-beam 160 mm high, the depth of the support on the wall – 380 mm, on a cement cushion. The insulation of the external wall covered with 150 mm-thick Styrofoam boards was allowed for as well as the balcony insulation of the thickness of 50 mm. The models were built in line with the regulations, basing on the guidelines contained in PN-EN ISO 10211: 2008 [25] see table 1.

| Material                | Coefficient of thermal conductivity $\lambda$ [W/mK] | Emissivity |
|-------------------------|-----------------------------------------------------|------------|
| Historic ceramic brick  | 0.6                                                 | 0.85       |
| Limestone mortar        | 1.2                                                 | 0.80       |
| Cement mortar           | 1.7                                                 | 0.90       |
| Steel beam              | 50.00                                               | 0.68       |
| Styrofoam               | 0.045                                               | 0.80       |

The calculations were carried out with the preset calculation error lower than 5%, and with the coefficient $Q_{TM} = 6$ - a typical automatic FEM mesh division. The boundary conditions accepted for the calculations took into account local climate parameters, i.e. the parameters of the nearest meteorological station in Katowice.
• temperature of outdoor air: \( t_e = -2.4 \, ^\circ C \) (average annual temperature for the coldest month),
• temperature of indoor air: \( t_i = +20^\circ C \) (as for living quarters),
• heat transfer coefficients \( h_e = 25 \, \text{W} / (\text{m}^2\text{K}) \); \( h_i = 7.69 \, \text{W} / (\text{m}^2\text{K}) \);

The thermographic studies were carried out for a pre-war public utility building at Borowa Wieś. The applied thermographic method involved the use of the FLIR ThermaCAM - B-200 thermal imaging device consisting of a thermal camera and a monitor. The thermal imaging device enables the visualization of the temperature field on the examined surface in the form of thermal image - a thermogram. The measurements were made from the outside of the building. Test conditions - as recommended [26].

Rated data:
• Temperature measurement range from -20°C to 1200°C
• Angle of view of the camera (depending on the lens used) 250 x 190
• Thermal resolving power (at 30°C) 0.05 °K
• Spatial resolution 1.36 mrad
• Range of spectral sensitivity 7.5 - 13 μm.
• Number of points on the line - about 175

The thermograms show the values of temperature at a few selected points, marked on the respective thermograms with a cross and digits (e.g. SP01, SP02). Also the area AR01 was singled out, for which the minimum and maximum temperature values were determined. The changes in the surface temperature of the flat envelope were also read along the marked line li01, for which the minimum and maximum values of temperatures were also singled out.

5. Results and discussions
5.1. Numerical analysis
The obtained results included the distributions of temperature fields in cross-sections, the distribution of heat flux density changes and temperature values in given places of the cross-section. The temperatures were read at the selected points (1, 2 and 3, in line with Figures 10 and 11).

The analysis confirmed the occurrence of reduced temperatures at the contact place between the top of the steel beam and the brick wall (temperature in the joint), as compared to the wall joint temperature in the cross-section without the beam. The temperatures obtained with the present boundary conditions, for both accepted variants, are presented in Table 2.

| Variant of the accepted model | Temperature at the marked points [°C] |
|------------------------------|--------------------------------------|
| Variant 1                    | 1.1  11.4  12.1                        |
| Variant 2                    | 10.6 17.0 17.8                         |

The largest temperature difference at the preset points for both variants was found in the place where the beam was anchored in the wall, and it reached 9.5°K. The temperature in the joint, in the contact place with the steel beam was lower by 11°K as compared to the extreme joint in the preset model (in variant 1) and accordingly (in variant 2) by 7.2°K. There was a distinctive change in the heat flux density in the layer of bricks and joints from the room side, also in several layers of bricks above and below the beam’s location. Low temperatures at the interface between the beam and masonry (especially in variant 1) can be considered as zones subjected to condensation threat, and consequently bring about corrosion of the steel beam and weakening of joints in the masonry. In order to determine
the moisture content in a given cross-section and its increase in time, it would be advisable to apply simulation programs.

![Figure 10](image1.png)

**Figure 10.** Calculation results, variant 1: (a) distribution of temperature fields, (b) changes in heat flux density

![Figure 11](image2.png)

**Figure 11.** Calculation results, variant 2: (a) distribution of temperature fields, (b) changes in heat flux density

5.2. **Thermographic studies**

Analyzing the distributions of temperature on the surface of the external wall in the contact area with the cantilever balcony, thermal anomalies can be identified. In Figure 12, the maximum temperature at the assigned points on the outer surface of the wall is 3.9°C (temperature SP03). The minimum temperature on the surface of the external wall is 2.0°C (temperature SP02). The maximum temperature difference is 1.9 K. The difference is caused by point thermal bridges created by piercing
the external walls made of solid ceramic bricks with steel load bearing elements. The thermogram made it possible to determine the minimum and maximum temperatures in the AR01 field. The maximum temperature difference in the analyzed field is 3.1 K. It is higher as compared to the temperature difference at points SP02 and SP03 owing to the determined minimum temperature of the steel profile in the field AR01. The analysis of temperature distribution along the line LI01 passing through two adjacent steel load bearing profiles demonstrated the maximum temperature difference of 3.1 K. It should be noted that the said difference refers to the maximum temperature identified at the contact between the outer wall and steel cantilevers, the minimum temperature - steel profile in the immediate vicinity of the wall.

Figure 12. Results of thermographic studies

6. Conclusions
Steel and ceramic balconies constitute a large group of existing historical balconies. Due to their structural and material solutions, their diagnostics should include, apart from structural analyses, also detailed observation of the heat and mass flow phenomena. The results of the preliminary studies confirmed the expected tendencies in temperature distributions in the envelope, the places where local thermal bridges occurred and indicated the zones of their impact. Further analyses should be focused on the obtained changes in heat flux density, both in the steel beam support node as well as in the joints and bricks of in the adjacent layers. These places overlap with the real presence of loosened and weakened mortars in walls and in ceramic tiles of the buildings. In further analyses, we recommend the application of simulation programs that would allow us to determine the scope and changes of the moisture in time.

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