Green roof influence over the characteristics of the linear thermal bridges

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Abstract. Urban heat island (UHI) significantly affects the thermal-energy performance of the buildings. Moreover, urban materials absorb solar and infrared radiation, heat accumulation is dispersed in the atmosphere, a fact which increases air temperature. In this context, green roofs are the most suitable solution to resolve these vital issues. The expanding benefits of a green roof, such as energy saving, thermal insulation, and mitigating heat island effect emphasize the key role of this structure in overall thermal performance of buildings and microclimate conditions of indoor spaces. The main objective of the study is to analyse the influence of extensive green roof on the heat flow, in the thermal bridges developed structurally in buildings where they might replace the classical terrace roof. The influence is analysed through the comparison of the thermal impact of a classical terrace roof and that of an extensive green roof, through thermal characteristics of their components. The first part of the paper presents the structures of each type of roof and their thermic characteristics established and evaluated according to the normative regulation in force. In this context, the classical terrace roof and extensive green roof are examined from a thermic point of view, analysing the parameters of the types of thermal bridges usually met, in order to establish if the extensive green roof might have an influence on the overall heat flow. In conclusion, the unpredictable results obtained for the analysed thermal parameters let conclude that the extensive green roof solution presents a favourable environmental impact, promoting a "beautiful" added value to a building, in terms of both sustainability and aesthetics.

Keywords: thermal insulation; classical terrace roof; extensive green roof; heat flow; buildings.

1. Introduction
Nowadays, most of the world population lives in cities, and there is a rising tendency towards urban life year after year. A recent report of the United Nations shows that the population living in cities will have increased to 67% by 2050 [1]. This fact entails a significant growth of the environmental problems at a global scale and, also, affects the urbanization process. Issues such as urban heat island, greenhouse and a major reduction of energy sources can be assigned to urban agglomerations. In some researches of the urban heat island that analyse four areas in New York city, the reports showed that there is an average of 2°C temperature difference between the intensive vegetated areas and less vegetated areas, that can be explained by the substitution of the greening areas with built ones. This is the reason why efficacious control of urbanization and urban heat island with energy-efficient and ecological buildings has vital importance. In some reports of the International Energy Agency, on a worldwide scale, the built sector is responsible for 30-40% of energy consumption. The rise of urban temperatures increases the overheating risk and indoor thermal discomfort, which is mostly influenced by the heat flux and energy storage of the materials used in constructions [2,3,4].

The solutions for creating more environmentally friendly construction and improving the energy efficient technology and designs are continually searched. A green or vegetated roof represents a structural design that joins nature and engineering for building a sustainable alternative to the classical
roof [5]. Green roof systems can be taken into account as efficient and esthetical tools for energy saving in buildings. The high characteristics which must be implemented on the building's envelope, regarding these systems are the effect of evapotranspiration and the large thermal inertia [6].

The biggest influence on these properties is given by external factors like weather conditions, greenery dynamics, substrate composition and also drainage layers. All layers of the structure are considered as thermal insulation layers regarding their physical characteristics and their capacity to properly retain water. Through the multifunctional benefits of the green roof identified until now, the enhanced building envelope thermodynamics has been one of the most important characteristics for decreasing energy consumption in the built sector [7,8].

A large number of research studies have been conducted to evaluate the performance and benefits of green roofs through experiments and modelling analysis. In this context, it is very important to compare the thermal performance of a classical terrace roof and an extensive green roof, in different climatic parameters, in order to establish the behaviour mode, the influence over the indoor temperature and the thermal resistance of each structure over the building. The classical solutions of the envelope for thermal protection are usually insufficient; this is the reason why there are necessary new solutions for insulation or for improving the thermal conditions in buildings. The climate conditions and the degree of thermal protection are the facts taken into account when establishing the thickness of the insulation layer.

The purpose of this paper is to observe and to compare the heat fluxes and the thermal effect of the classical terrace roof and the extensive green roof through computer simulations only. Therefore, the case studies have been conducted to assess the degree of thermal protection of the building in the case of the classical terrace roof and in the case of the extensive green roof. The analyses of the structural components and the materials properties in both cases are carried out separately for a better understanding and easier tracking of the results. The structure of each roof and the four thermal bridges taken into study (the connection between exterior wall and the terrace roof slab, the connection between interior wall and the terrace roof slab - without reinforced concrete beam, the connection between interior wall and the terrace roof slab - with reinforced concrete beam, the connection between reinforced concrete beam and the terrace roof slab) have been modelled in AutoCAD software [9] and the numerical modelling has been realized using RDM 6 software [10], to determine the effect of thermal bridges.

Finally, the set of calculation of unidirectional thermal resistance and linear thermal transfer coefficients for the classical terrace roof and also for the extensive green roof is made according to Romanian regulations. The results have been compared to assess the impact of each roof over the thermal performance. The boundary conditions for the location of the building is the 3rd climate zone, characterized by outdoor design temperature Te = -18°C and indoor design temperature Ti = 20°C.

2. Case studies

2.1. Case study for thermal bridges in buildings with classical roof

In the simplest definition, the envelope of the building is the architectural element, acting as a physical separator between the conditioned and unconditioned environment of a building. The envelope of the building consists of the exterior walls and the terrace roof, (for the case studies presented in the paper), with all the components: ceiling, windows, doors, etc. The efficient use of the energy in a building is directly connected to the building envelope and can be presented as diminishing the energy demands for heating and cooling according to the structural characteristic of the envelope. The loss of energy is one of the important issues in energy performance and it is directly dependent on building type and age, climate and geographical conditions, the types of materials of the envelope and residents’ behaviour [11]. The building envelope thermal efficiency can be defined by the achievement of a considerable reduction in urban heat island (UHI) effects. In this context, energy-efficient, low-cost and eco-friendly retrofits are necessary, to decrease these effects. For the analysis and calculation, different numbers have been considered for the thermal bridges in the performed assessment, which
are presented in Table 1. At first, it is analysed the classical roof and its components. For a better understanding of the thermal performance of the classical roof, the structural components must be presented as they are indicated in Figure 1.

**Table 1.** The notations used for the thermal bridges in the performed assessment

| Analysed thermal bridges                                           | Notation of thermal bridge for the classical roof | Notation of thermal bridge for the extensive green roof |
|-------------------------------------------------------------------|--------------------------------------------------|---------------------------------------------------------|
| The connection between the exterior wall and the roof slab        | 1.1                                              | 2.1                                                      |
| The connection between the interior wall and the roof slab (without reinforced concrete beam) | 1.2                                              | 2.2                                                      |
| The connection between the interior wall and the roof slab (with reinforced concrete beam) | 1.3                                              | 2.3                                                      |
| The connection between the reinforced concrete beam and the roof slab | 1.4                                              | 2.4                                                      |

![Figure 1. The structural components of the classical terrace roof.](image)

In Table 2 the principal characteristics of the envelope elements are presented. These properties are the thickness of the materials, the bulk density, the coefficient of thermal conductivity and the heat mass capacity [12].

**Table 2.** Material properties (envelope with classical terrace roof)

| Envelope elements         | Layer thickness [m] | Bulk density [kg/m²] | The coefficient of thermal conductivity [W/m.K] | Heat mass capacity [J/kg.K] |
|---------------------------|---------------------|----------------------|-----------------------------------------------|-----------------------------|
| 1                         | Inner plaster       | 0.015                | 840                                           | 0.87                        | 1700                       |
| 2                         | Reinforced Concrete Slab | 0.15              | 2500                                          | 1.74                        | 840                        |
| 3                         | Masonry (brick without gaps) | 0.25             | 1800                                          | 0.80                        | 870                        |
| 4                         | Concrete slope      | 0.02                 | 1800                                          | 0.93                        | 840                        |
| 5                         | Vapour barrier      | 0.01                 | 1700                                          | 0.38                        | 1460                       |
| 6                         | Insulating coating  | 0.30                 | 20                                            | 0.044                       | 1460                       |
| 7                         | Waterproofing bracket | 0.01             | 1800                                          | 0.93                        | 840                        |
| 8                         | Diffusion layer     | 0.01                 | 600                                           | 0.17                        | 1460                       |
| 9                         | Waterproofing layer | 0.015                | 600                                           | 0.17                        | 1460                       |
| 10                        | Waterproofing protection | 0.10             | 1800                                          | 0.7                          | 840                        |
| 11                        | Mortar              | 0.01                 | 1800                                          | 0.93                        | 840                        |
| 12                        | Exterior plaster    | 0.025                | 840                                           | 0.87                        | 1700                       |
From the survey data, the most common types of thermal bridges found for the classical roof and taken for analysis, are those presented in Figure 2 ÷ 5.

**Figure 2.** The connection between the exterior wall and the roof slab - Thermal bridge 1.1.

**Figure 3.** The connection between the interior wall and the roof slab (without reinforced concrete beam) - Thermal bridge 1.2.

**Figure 4.** The connection between the interior wall and the roof slab (with reinforced concrete beam) - Thermal bridge 1.3.

**Figure 5.** The connection between the reinforced concrete beam and the roof slab - Thermal bridge 1.4.

### 2.2. Case study for thermal bridges in buildings with an extensive green roof

This section presents the structure of the extensive green roof taken into consideration, the representative thermal bridges for this roof and the material components of the roof.

A green roof is composed of the vegetation, the soil layer, the gravel layer (drainage layer), the geotextile, the anti-root layer and profile membrane over the classical roof. The proposed green roof scenarios were analysed in terms of thermal resistance based on the selection of the components.

For a better understanding of the thermal bridges of the extensive green roof, the structural components must be presented as they are indicated in Figure 6.

Table 3 presents the principal characteristics of the extensive green roof elements. These properties are the thickness of the materials, the bulk density, the coefficient of thermal conductivity and their heat mass capacity [12].

From survey data, the most common types of thermal bridges for the extensive green roof are the same chosen for the classical terrace roof, which are presented in Figure 7÷10.
Figure 6. The structural components of the extensive green roof

Table 3. Material properties (envelope with extensive green roof)

| Envelope elements             | Thickness of materials [m] | Bulk density [kg/m³] | The coefficient of thermal conductivity [W/m.K] | Heat mass capacity [J/kg.K] |
|------------------------------|----------------------------|----------------------|-----------------------------------------------|----------------------------|
| 1 Inner plaster              | 0.015                      | 840                  | 0.87                                          | 1700                       |
| 2 Reinforced Concrete Slab   | 0.15                       | 2500                 | 1.74                                          | 840                        |
| 3 Vapour barrier            | 0.01                       | 1700                 | 0.38                                          | 1460                       |
| 4 Insulating coating        | 0.30                       | 20                   | 0.044                                         | 1460                       |
| 5 Waterproofing bracket     | 0.01                       | 1800                 | 0.93                                          | 840                        |
| 6 Diffusion layer           | 0.01                       | 600                  | 0.17                                          | 1460                       |
| 7 Waterproofing layer       | 0.015                      | 600                  | 0.17                                          | 1460                       |
| 8 Profile membrane          | 0.01                       | 150                  | 0.7                                           | 1460                       |
| 9 Anti-root layer           | 0.01                       | 150                  | 0.70                                          | 1700                       |
| 10 Geotextile               | 0.2                        | 150                  | 0.10                                          | 1700                       |
| 11 Gravel layer             | 0.15                       | 1800                 | 0.7                                           | 840                        |
| 12 Soil layer               | 0.10                       | 1800                 | 1.16                                          | 840                        |
| 13 Masonry (brick without gaps) | 0.25                     | 1800                 | 0.80                                          | 870                        |
| 14 Mortar                   | 0.01                       | 1800                 | 0.93                                          | 840                        |
| 15 Exterior plaster         | 0.025                      | 840                  | 0.87                                          | 1700                       |
| 16 Cork layer               | 0.02                       | 120                  | 0.04                                          | 2500                       |

Figure 7. The connection between the exterior wall and the roof slab - Thermal bridge 2.1

Figure 8. The connection between the interior wall and the roof slab (without reinforced concrete beam) - Thermal bridge 2.2
3. Analyses and discussions

The linear thermal transfer coefficient, \( \psi \), is the surplus flow \( \Delta \phi \) transmitted by a linear bridge, relative to its length \( l \) and thermodynamic driving force for the flow of heat, \( \Delta T \) (temperature difference).

This is the defining relation for the linear thermal transfer coefficient, \( \psi \), but the practical calculation relationship is the mathematical formula given by Equation (1) [12]:

\[
\psi = \frac{\phi}{\Delta T} - \frac{B}{R}
\]

where \( \phi \) is the thermal flow associated with a bridge with a width \( B \) and a length of 1 m (W/m); and \( R \) represents the unidirectional thermal resistance (m²K/W).

The specific unidirectional thermal resistance is determined by the sum of the unidirectional resistances of the material layers, and the superficial resistance to the convective and radiative heat transfer of the interior and exterior surfaces, as shown in Equation (2) [12]

\[
R = \frac{1}{\alpha_i} + \sum \frac{d}{\lambda} + \frac{1}{\alpha_e}
\]

where \( \alpha_i \) and \( \alpha_e \) represent the convective and radiative heat transfer coefficients of the interior and exterior surfaces. In the calculus are used the following values for \( \alpha_i, \alpha_e \), and for corresponding thermal resistance:

\[
\alpha_i=8 \quad R_i=0,125
\]
\[
\alpha_e=24 \quad R_e=0,042
\]

Table 4 presents the thermal resistance value for the classical terrace roof \( (R_c) \), determined based on the dimension of each layer \( (d) \) and the coefficient of thermal conductivity \( (\lambda) \) [10].
Table 4. Determination of Unidirectional Thermal Resistance for the structure of the classical terrace roof

| Envelope elements       | $d$ [m] | The coefficient of thermal conductivity ($\lambda$) [W/m.K] | Thermal resistance ($R_c$) [m²K./W] |
|-------------------------|---------|-------------------------------------------------------------|-------------------------------------|
| Inner plaster           | 0.015   | 0.87                                                        |                                     |
| Reinforced Concrete Slab| 0.150   | 1.74                                                        |                                     |
| Concrete slope          | 0.040   | 0.93                                                        |                                     |
| Vapour barrier          | 0.010   | 0.38                                                        |                                     |
| Insulating coating      | 0.300   | 0.044                                                       |                                     |
| Waterproofing bracket   | 0.010   | 0.93                                                        | 7.455                               |
| Diffusion layer         | 0.010   | 0.17                                                        |                                     |
| Waterproofing layer     | 0.015   | 0.17                                                        |                                     |
| Waterproofing protection| 0.100   | 0.70                                                        |                                     |

The thermal resistance value for the structure of the extensive green roof ($R_g$) determined based on the dimension of each layer ($d$) and the coefficient of thermal conductivity ($\lambda$), is presented in Table 5 [10].

Table 5. Determination of Unidirectional Thermal Resistance for the structure of the extensive green roof

| Envelope elements       | $d$ [m] | The coefficient of thermal conductivity ($\lambda$) [W/m.K] | Thermal resistance ($R_g$) [m²K./W] |
|-------------------------|---------|-------------------------------------------------------------|-------------------------------------|
| Inner plaster           | 0.015   | 0.87                                                        |                                     |
| Reinforced Concrete Slab| 0.150   | 1.74                                                        |                                     |
| Vapour barrier          | 0.010   | 0.38                                                        |                                     |
| Insulating coating      | 0.300   | 0.044                                                       |                                     |
| Waterproofing bracket   | 0.010   | 0.93                                                        |                                     |
| Diffusion layer         | 0.010   | 0.17                                                        |                                     |
| Waterproofing layer     | 0.015   | 0.17                                                        |                                     |
| Profile membrane        | 0.002   | 0.38                                                        |                                     |
| Anti-root layer         | 0.010   | 0.70                                                        |                                     |
| Geotextile              | 0.020   | 0.10                                                        |                                     |
| Gravel layer            | 0.150   | 0.70                                                        |                                     |
| Soil layer              | 0.100   | 1.16                                                        |                                     |

Table 6 gives the thermal resistance value for the exterior wall ($R_w$), determined based on the dimension of each layer ($d$) and the coefficient of thermal conductivity for the material ($\lambda$) [10].

Table 6. Determination of Unidirectional Thermal Resistance for the exterior wall

| Envelope elements       | $d$ [m] | The coefficient of thermal conductivity ($\lambda$) [W/m.K] | Thermal resistance ($R_w$) [m²K./W] |
|-------------------------|---------|-------------------------------------------------------------|-------------------------------------|
| Inner plaster           | 0.015   | 0.87                                                        |                                     |
| Masonry                 | 0.250   | 0.80                                                        |                                     |
| Mortar layer            | 0.015   | 0.93                                                        | 5.23                                |
| Insulating coating      | 0.200   | 0.044                                                       |                                     |
| Exterior plaster        | 0.025   | 0.87                                                        |                                     |

In order to evaluate the thermodynamic performance for each type of roof taken into consideration in the study, the identification of the unidirectional thermal resistance and the linear thermal bridges coefficients have been established as parameters for comparison. All the thermal bridges have been analysed using the RDM 6 software as they are presented in Figure 11÷18. Table 7 presents the values
of linear thermal bridges coefficients, $\psi$, for both types of roof, and also, the thermal properties used in calculus, values being taken from the specialized literature and national design norms.

The results obtained for both roof cases analysed show that there is a positive influence in the case of the extensive green roof in comparison with terrace classical roof, Figures 11÷18 and Table 7. These positive influences are expressed as an increase of thermal resistance ($R_{element}$) exceeding 5%, for thermal bridge identified at the connection of roof with exterior wall, from 7.455 m²K/W to 7.789 m²K/W and a decreasing of linear thermal bridge coefficient ($\psi$) with almost 20%, from 0.1898 W/m²C to 0.1549 W/m²C, Figures 11÷12 and Table 7. In the cases of the other thermal bridges analysed, the variations of these parameters are in the same sense, but in the limits of 1-2%.
Figure 17. Isovalues of heat flow for the thermal bridge 1.4 of the classical terrace roof

Figure 18. Isovalues of heat flow for the thermal bridge 2.4 of the extensive green roof

Table 7. Linear thermal bridges coefficients, $\psi$

| No. | Thermal bridge type                  | Thermal flow ($\phi$) [W/m] | Temperature difference ($\Delta T$) [$^\circ$C] | The width of the thermal bridge ($B$) [m] | The unidirectional thermal resistance ($R_{element}$) [m²K/W] | Linear thermal bridge coefficient ($\psi$) [W/m²°C] |
|-----|-------------------------------------|-----------------------------|-----------------------------------------------|------------------------------------------|-------------------------------------------------------------|--------------------------------------------------|
| 1   | 1.1/figure 2 - classical terrace roof | 13,33                       | 38                                            | 1,20                                     | 7,455                                                        | 0,1898                                           |
| 2   | 2.1/figure 5 – extensive green roof  | 11,74                       | 38                                            | 1,20                                     | 7,789                                                        | 0,1549                                           |
| 3   | 1.1/figure 2 - classical terrace roof (wall) | 15,16                       | 38                                            | 1,20                                     | 5,23                                                         | 0,169                                             |
| 4   | 2.1/figure 5 – extensive green roof (wall) | 15,24                       | 38                                            | 1,20                                     | 5,23                                                         | 0,172                                             |
| 5   | 1.2/figure 3 - classical terrace roof | 6,78                        | 38                                            | 1,20                                     | 7,455                                                        | -0,1435                                          |
| 6   | 2.2/figure 6 – extensive green roof  | 6,72                        | 38                                            | 1,20                                     | 7,789                                                        | -0,1313                                          |
| 7   | 1.3/figure 4 - classical terrace roof | 6,78                        | 38                                            | 2,40                                     | 7,455                                                        | -0,1435                                          |
| 8   | 2.3/figure 7 – extensive green roof  | 6,70                        | 38                                            | 2,40                                     | 7,789                                                        | -0,1318                                          |
| 9   | 1.4/figure 5 - classical terrace roof | 13,57                       | 38                                            | 3,75                                     | 7,455                                                        | -0,1459                                          |
| 10  | 2.4/figure 8 – extensive green roof  | 13,39                       | 38                                            | 3,75                                     | 7,789                                                        | -0,1291                                          |

The results also emphasize the fact that the unidirectional thermal resistance in the case of the extensive green roof has an acceptable value, as it is presented in Table 5.

4. Conclusions
In the paper, the thermal resistance and the heat flow of the extensive green roof were analysed in order to establish the benefits of the green roof as a technique of insulating the buildings. Additionally, the components of these two roofs and the properties of the materials were selected and used to test their capacity to influence the heat flow intensity. Taking into account the complexity of this problem, the structural components and thermal analyses were conducted on the constructive details of thermal bridges by means of the RDM6 software.

Results from the thermal analyses show that there is an improvement for the extensive green roof in terms of thermal resistance and linear thermal bridge coefficient in the case of thermal bridge 1.1/2.1 and very low improvements for the other cases studied. This fact is confirmed by the numerical results and the modelling in the program.

In conclusion, the unpredictable results obtained for the analysed thermal parameters let conclude that,
although there is no well determined thermo-technical advantage for the extensive green roof solution, anyhow, this solution presents a favourable environmental impact, promoting a "beautiful" added value to a building, in terms of both sustainability and aesthetics, as long as the building's structure has been built to accommodate it.

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