PRESERVING HERITAGE, ENHANCING EFFICIENCY: PASSIVE TECHNOLOGIES FOR ACHIEVING ZERO ENERGY IN HISTORIC BUILDINGS

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ABSTRACT:

The European Union has long prioritized the enhancement of energy efficiency in buildings, aligning with the nZEB (nearly Zero Energy Building) standard, with the ambitious target of achieving Zero Energy Buildings (ZEB) by 2030. This article aims to showcase the use of passive technologies for achieving a Zero Energy Building on a historic building located in Bucharest, with a volumetric design worth emphasizing dating back to the post-war period. This study underscores the challenges architects and engineers encounter in upgrading the energy efficiency of such structures while preserving both their aesthetic coherence and the architectural integrity of the period. Various passive technologies are employed to boost the energy efficiency of the selected building. These include measures such as: thermal bridge reduction, thermal envelope and window details for capturing solar energy and reducing the overheating. The active technologies that remain include ventilation and heating in a small percentage. To assess and quantify the energy efficiency achieved through these interventions, the Passive House Institute's methodology is adopted. Also, for calculating the solar gain, custom more detailed methods are applied. By showcasing the successful integration of passive technologies in a historic building, this paper contributes to a sustainable architecture and offers practical insights for architects, engineers and stakeholders for achieving ZEB status while respecting the unique characteristics and the heritage of historic structures.

1. INTRODUCTION

Retrofitting historic buildings to achieve Passive House standards presents both an opportunity and a debated issue among architects, conservation specialists and engineers. On the one hand, strict preservationists argue against interventions that might alter a building's original form (Sustainable Building Conservation: Theory and Practice of Responsive Design in the Heritage Environment), materials, or aesthetic features, deeming such measures intrusive. On the other hand, proponents of adaptive conservation emphasize the need for modern energy-efficiency improvements to ensure a building's continued viability and reduce carbon emissions (Sven et. al., 2019). Diverging hypotheses arise particularly when deciding how to minimize thermal bridges, upgrade windows' characteristics, or incorporate solar gains in heritage structures - questions that remain central to achieving deep energy retrofits in older buildings (Gligor et. al., 2025).

Globally, the building sector accounts for a considerable share of energy consumption. Historic buildings often amplify this issue due to their aging building envelopes, inefficient glazing, and inadequate insulation. Although numerous studies have examined strategies for increasing their energy performance, controversies persist regarding the most effective combination of methods. Whether accomplished by combining interior and exterior insulation, employing specialized glazing like Vacuum Insulating Glass (VIG), or optimizing ventilation schemes to redistribute surplus heat. By focusing on the case study of a building located in Bucharest's protected heritage area, this article illustrates how the strategies aimed at increasing their energy performance can be holistically integrated.

Contemporary research offers five key insights that inform our approach. First, various teams have illustrated the importance of thermal bridging mitigation in historic masonry, underscoring the balance between structural integrity and condensation risks. Second, VIG solutions appear promising for improving window performance without drastically altering frame profiles, yet questions remain about cost, durability, and visual authenticity. Third, managing shading and overheating is vital, as retrofitted envelopes often experience heightened summer heat loads. Fourth, ventilation and heat redistribution techniques can transform zones of excessive solar gain into auxiliary heat sources, reducing dependence on conventional systems. Finally, an adaptive conservation framework permits alterations that respect cultural value, ensuring that sustainability improvements do not undermine heritage significance (Bungău et. al., 2024).

The primary aim of this study is to demonstrate that an underutilized historic building as in Figure 1 can be effectively upgraded to meet Passive House criteria through an integrated retrofit strategy despite its protected status. The main components of the proposed framework are: mitigating thermal bridges with dual-layer insulation, replacing heritage windows with VIG technologies, recalibrating glazed balconies to prevent both heat loss and overheating, optimizing the thermal balance with zenithal glazing, and redesigning the ventilation system to recirculate excess solar heat.

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Figure 1. Photograph of the studied building

The following chapters elaborate these themes in depth. Chapter 2 details a dual-insulation approach that significantly diminishes thermal bridges. Chapter 3 explores the rationale behind VIG window replacements, while Chapter 4 discusses how to manage a retrofitted glazed balcony prone to both heat loss and overheating. Chapter 5 examines the nuanced thermal energy balance in such spaces, and Chapter 6 highlights how adaptive ventilation schemes can redistribute surplus solar heat to underheated areas. Finally, Chapter 7 situates these technical solutions within a broader conservation discourse, illustrating how adaptive measures can safeguard both cultural heritage and environmental sustainability (Magrini et. al., 2015).

Ultimately, this research highlights the opportunity to retrofit historic buildings in a way that enhances their sustainability and preserves their cultural value. The integration of innovative solutions with respect for heritage can pave the way for a broader approach to adaptive conservation, one that allows historic buildings to meet the energy demands of the future while maintaining their historical essence. The findings of this paper are intended not only to offer practical solutions for the specific case of the studied Bucharest building but also to contribute to the broader field of sustainable preservation practices, with implications for architects, engineers, policymakers, and conservationists around the world.

2. CASE STUDY

This article investigates a building situated in a protected area that, while not a listed monument itself, is subject to strict preservation guidelines to maintain its architectural, urban, and historical significance (Fawcett et. al., 2019). Any interventions on such buildings must not only preserve but also can enhance the existing values associated with their heritage.

The studied building was constructed in the "Domenii" development in Bucharest, a site originally used for experimental garden for plants before its subdivision in 1933 for residential development illustrated in Figure 2. The specific plot for this building was approved by the city hall in 1936, with the design attributed to architect C. Duțulescu. Although not directly impacted by major historical events, the building's history is intertwined with significant moments in Romania's past. For instance, in 1944, during a two-hour American bombing raid targeting Bucharest's infrastructure to disrupt oil exports to Germany and military logistics to the Eastern Front, parts of the subdivision were heavily damaged. While this building survived, the broader context of wartime destruction influenced its subsequent modifications.

Figure 2. Territorial urban planning

In 1974, the building underwent a significant alteration when the terrace was enclosed with glazed panes, marking a departure from its original design. Over the years, the interior floor plans have also been altered, with one of the most notable changes being the removal of ceramic heating stoves and the corresponding chimneys, which were once integral features of the structure.

The chosen building features a gentle roof slope characteristic of buildings aiming to preserve an early 1920s flat roof style as in Figure 3. Across Europe in that period, and particularly in Cubist-inspired architecture, flat or terrace roofs were generally preferred. However, in Romania's moderate-precipitation climate, combined with economic reasons and mistrust in flat roofs, many buildings that aspired to this "roofless" aesthetic introduced small slopes and discreetly concealed gutters. From an energy standpoint, this design choice also facilitates today the integration of photovoltaic panels or other equipment, keeping them mostly hidden from view.

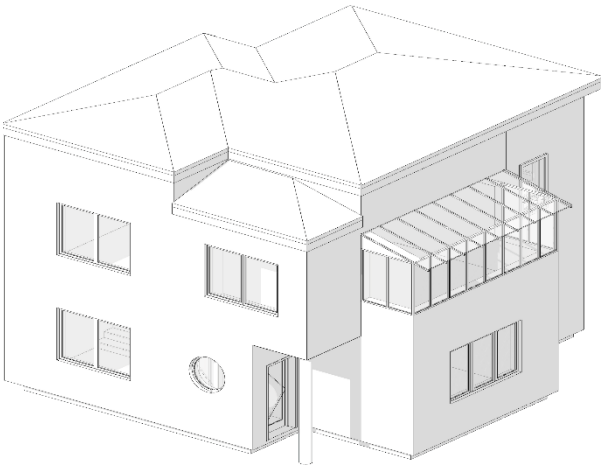

Figure 3. 3D model of the studied building. Roofing and glazing proportions can be observed

The building has a simple composition for the facades, inspired by modern Cubist architecture, completely devoid of ornaments. The external finishing of the facades was performed differently in the area of the window openings by treating the borders with smooth surfaces. From an architectural perspective, the

building's design, intended primarily for residential use, is lacking of any elaborate mural decorations. Its finishing materials reflect commonly available industrial and artisanal products of the era, such as Calcio Vecchio cement plaster. Ornamentation can be found solely in the ironwork of the stairwell window and the entrance door, where a geometrically stylized sun motif is employed. The west-facing windows and entrance door that illuminate the staircase to the upper floor are safeguarded by a metal grille, also featuring a repetitive, stylized sun motif.

The building's structural system is based on solid brick masonry walls without concrete columns or beams, providing a load-bearing framework typical of early 20th-century designs. Reinforced concrete floors rest directly on the masonry for stability. The access stairs between levels are also constructed of reinforced concrete.

Given the building's extensive history, transitioning it from its original 1930s construction methods to meet Europe's 2030 energy efficiency goals, a leap spanning nearly a century, presents significant challenges (3ENCULT, 2015). The upgrading to Passive House Standard follows the classic principles: Thermal envelope, Thermal bridges, Airtightness, Windows and solar gain, Shading and avoiding overheating, Fresh air with heat recovery, shown in Figure 4.

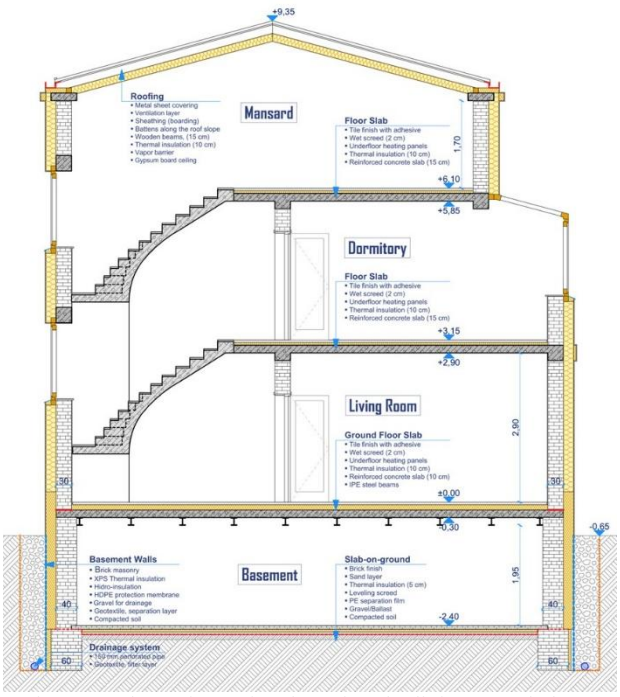

Figure 4. The main section featuring the living area, balcony room, and staircase, after the retrofit has been made

The stratifications of all building elements and bay details are visible, including the foundation details in the basement, window installation in the insulation layer using pre-frames, roofing details, and the connection between the roof and vertical walls at the eaves. The ventilation systems have been integrated at the upper floor within the ceiling level with distribution through the attic, and at the ground floor through the insulation layer of the slab above the basement.

3. THERMAL BRIDGES AND ENERGY LOSS: STRATEGIES FOR MITIGATION

Enhancing the thermal comfort of existing buildings presents significant challenges, particularly when dealing with historic structures. This difficulty arises primarily from two major factors: financial constraints and technological limitations.

Financially, the costs associated with upgrading and retrofitting these buildings to improve thermal efficiency can be prohibitively high. Historic buildings often require specialized materials and techniques to preserve their architectural integrity, which can further inflate costs. The methods and technologies available for improving thermal comfort in newer constructions may not be compatible with the materials and construction techniques used in historic buildings. This necessitates innovative approaches that can address the unique characteristics of these older structures while maintaining their historical value. Thus, balancing the need for improved thermal comfort with the financial and technological constraints is a complex task.

It is demonstrated that insulating the exterior of foundations can remove heat losses. However, this approach does not resolve the issue of thermal bridges; in fact, it exacerbates the problem. After insulating the entire building, thermal bridges become more pronounced and problematic, highlighting a significant drawback of this method. Thus, while exterior insulation can reduce heat loss, it inadvertently increases the severity of thermal bridging (Moga et. al., 2015).

To address the issue of thermal bridges, this study highlights the importance of applying insulation both on the exterior and interior of walls. Implementing this dual-layer insulation strategy significantly reduces thermal bridges by 80 to 90 percent. The effectiveness of this approach lies in the interruption of heat transmission through the materials: the exterior insulation blocks the majority of heat energy from penetrating the outer wall, while the interior insulation prevents the thermal bridges to connect the outside ambient directly to the interior. By combining both methods, the thermal bridge problem is substantially mitigated, resulting in enhanced overall thermal efficiency.

Interior insulation often poses challenges related to condensation and hygro-dynamics. However, the examples in Figures 5 and 6 shows that the thickness ratio between interior and exterior insulation is crucial. To prevent condensation issues, the interior insulation should be approximately one-third the thickness of the exterior insulation. This ratio ensures that the interior environment remains stable, minimizing moisture-related problems and maintaining effective thermal performance (Douglas et. al., 2016). The following images show three versions of a foundation detail from a historic building: first without insulation, second with standard insulation, and third using a new proposed interior-exterior insulation method to reduce thermal bridges.

In the right-hand drawings, thermal flux is depicted using colors (blue to yellow/red) and isotherms with black lines. The Ψ value quantifies the thermal bridge. At the top, the "Detail Scheme" represents the materials: yellow for thermal insulation, dull dark red for brick, blue and red for interior and exterior spaces, and brown for the ground.

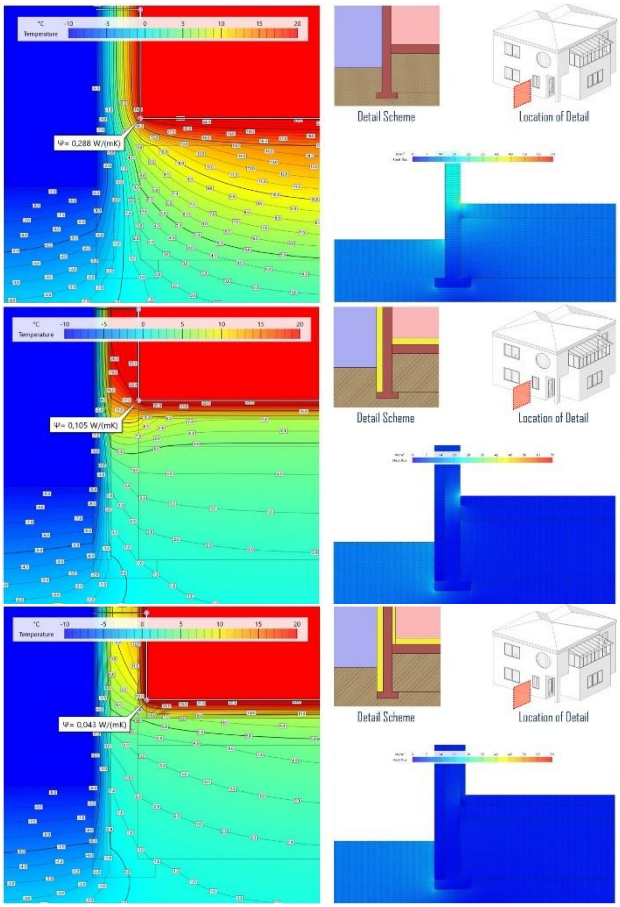

Figure 5. Thermal analysis in the left, thermal bridge value indicated by Ψ. Material indications in the middle. Analysis of vapor transfer in the lower right

The lower right image illustrates a graphical representation of heat flux. In the first scenario, where the foundation lacks insulation, thermal energy is primarily lost through the walls, with some heat loss occurring through the floors. This is depicted in cyan, indicating heat transfers exceeding 20 W/m². Such significant heat loss leads to general temperature discomfort (Kalamees et.al., 2021), as the surfaces of interior elements should not be more than 4°C cooler than the indoor air temperature as stated by EN ISO 13788:2012. An important issue to assess is the intersection between the floor and walls (Sedlbauer et. al., 2003), where heat transfer exceeds 40 W/m², creating a risk of condensation and fostering the development of microorganisms.

In the second scenario, where thermal insulation has been applied to both the façade and ground slab, the general heat flux through the walls is significantly reduced from 1.91 to 0.21 W/m²K, by adding 15 cm of mineral wool. However, a thermal bridge with a Ψ value of 0.105 W/mK persists around the building's perimeter. To address this, the addition of interior wall insulation was proposed. This effectively eliminated the thermal bridge and further reduced heat loss throughout the building. As a result, the wall's thermal transmittance improved, dropping from 0.21 to 0.16 W/m²K.

The key finding from this example is the importance of combining both interior and exterior insulation. By following the guideline of applying two-thirds of the insulation on the exterior and less than one-third on the interior, the risk of condensation can be minimized. This principle was further tested with an additional detail in a secondary example, which proved even more relevant, reinforcing the effectiveness of this insulation approach in reducing heat loss and improving overall building thermal performance.
The second example focuses on the entrance of the building, where the upper floor extends outward, creating a covered entryway. This floor is supported by a concrete column, which forms a significant thermal bridge, making it an ideal case for this study.

Analyzing the detail as it is, without adding any insulation, the thermal bridge has a Ψ value of 0.365 W/mK. The graphic on the lower right highlights one of the most overlooked factors in building retrofits: condensation and vapor transmission through the building elements. In this image, light yellow shades represent low relative humidity, while darker blue signifies high humidity levels, and grey areas indicate a 100% chance of condensation. In this scenario, the risk of condensation is at its maximum in this building and one of the worst cases in any other retrofits. Despite concrete's reputation as a vapor barrier, the concrete slab shows significant condensation due to micro-cracks from its century-old age, making the material permeable. Additionally, condensation is present in the brick masonry vertical wall, which, over time, weakens the brick from within, leading to spalling on the exterior surface.

By thermal insulating the exterior side of the wall as is standard in modern construction practices, the condensation issue is significantly reduced, with condensation remaining only at the intersection of the brick masonry and concrete slab. However, the insulation leads to a surprising and concerning new effect (Baba et. al., 2015): the thermal bridge actually worsens, with the Ψ value increasing from 0.365 W/mK to 0.848 W/mK (Fabrizio et. al., 2014). This significant increase presents a serious issue, as it creates a favorable environment for mold growth.

As in the previous example, the solution lies in using a combination of exterior and interior insulation. By applying 1/3 of the thickness of the exterior insulation on the interior of the wall, both problems are effectively addressed. The condensation is completely eliminated, and the thermal bridge is significantly reduced, with the Ψ value dropping by 3 times compared to the initial state of the building. This demonstrates that strategic insulation placement can both prevent condensation and minimize thermal bridging in complex architectural details.

The thermal envelope analysis was conducted in two phases:
First, volumetric insulation and heat losses were calculated using the thermal transmittance formula for the exterior walls, following SR EN 12524 standards:

$$\boldsymbol{U} = \frac{1}{R_{si}+\frac{d_1}{\lambda_1}+\frac{d_2}{\lambda_2}+\frac{d_3}{\lambda_3}+R_{se}} \quad (1)$$

Where: U= Thermal transmittance of one element [kWh/ m^2/ y].

Secondly, all potential thermal bridges in the envelope were verified (foundations, walls intersections, window and shading fittings, ceiling intersections, etc.) using a simplified formula to calculate them:

$$\Psi = (U_w - U_{TB}) * L \quad (2)$$

Where: Ψ = Linear Thermal Bridge [W/mK],

Uw = Thermal transmission through wall (or another envelope component),

UTB = Thermal transmission through a linear thermal bridge,

L = Length of the thermal bridge.

If the results exceeded Ψ values of 0.050 W/mK, further analysis was conducted using two-dimensional computation software for higher precision. Two specific details were chosen for illustration, as shown in Figure 5 and 6.

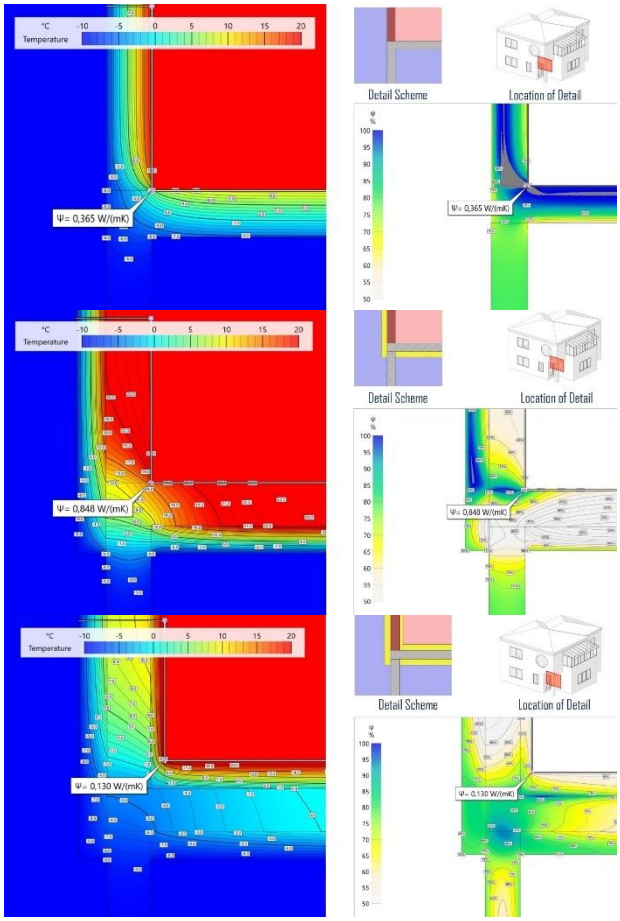

Figure 6. Thermal analysis in the left, thermal bridge value indicated by Ψ (Material indications in the middle; Analysis of vapor transfer in the right)

4. BALANCING CONSERVATION AND INNOVATION: UPGRADING HISTORIC WINDOWS FOR ENERGY EFFICIENCY

The replacement of original wooden windows in historic buildings with modern energy-efficient options (English Heritage, 2017) is a controversial issue. Conservationists argue that these windows should be repaired and upgraded to enhance thermal performance without compromising their historic character. On the other hand, proponents of adaptive conservation emphasize that upgrading to modern (Pavlou, 2016), high-performance windows (Hastings, 2016) can significantly reduce energy consumption, improve comfort, and raise health & well-being index in historic buildings.

This paper proposes the use of Vacuum Insulating Glass (VIG) as a solution, which has the advantage of being 35% lighter than traditional triple glazing. Traditional triple-glazed panels typically have a thickness of around 90 mm, while the original frames in historic buildings are often much thinner, around 45 mm. The adoption of VIG technology offers the placement of window panes into existing frames.

It is also important to note that while the material of the window frame itself remains unchanged in appearance, there is a structural enhancement that takes place as in Figure 7. The original softwood is replaced with hardwood, which offers superior structural properties and better durability.

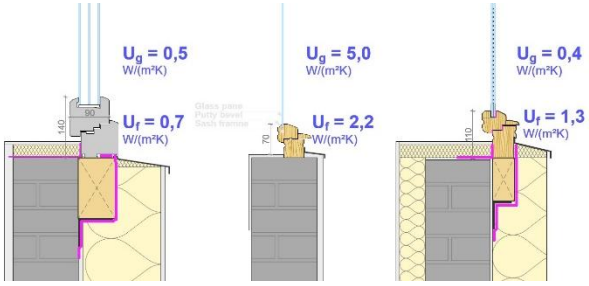

Figure 7. The left example is a modern window made of PVC profile; in the middle the original historic windows are shown. The example in the right is the custom drawn profile made of hardwood, and with dimensions only 10% bigger than the original example

While increasing window size or altering their orientation is generally not feasible due to preservation concerns, adjusting the depth at which the windows are fitted can make a significant impact (Van Balen et. al., 2015). By positioning the windows closer to the exterior, it is possible to increase solar gain, which helps to naturally warm the interior and reduce reliance on heating systems. Even if airtightness may require more effort by exterior positioning of windows it is worth modifying since a diligent installation on-site can solve it (Fedorik, 2020) (Rhee-Duverne et. al., 2013).

The method of assessing the windows thermal efficiency is by using both glass and frame coefficients as prescribed by SR EN ISO 10077-1, shown in Table 8, but slightly modified to better reflect reality. The added expression ($\Psi_m * l_m$) introduces the type of fitting on-site wich represents thermal bridges due to potential improper installation of windows.

	Single pane window	Triple Glazing window	Vacuum window
Ug	2,20	0,50	0,40
Uf	1,70	0,85	0,85
g	0,80	0,50	0,57
Ψ	0,70	0,05	0,08

Table 8. Window panes comparison

$$U_w = \frac{(U_g * A_g) + (U_f * A_f) + (\Psi_g * l_g) + (\Psi_m * l_m)}{A_g + A_f} \quad (3)$$

Where U_w= Thermal transmittance of one window [W/m$_2$ K]

5. SHADING SOLUTIONS FOR ENERGY EFFICIENCY: RETROFITTING THE GLAZED BALCONY

From the beginning the building was constructed with wooden window roller shutter integrated in the layering of the walls, which is verry good for retrofitting to today's standard of energy

efficiency. The existing glazed balcony was a huge reason for heat losses during winter time and medium reason contributing to overheating. After the improvement done by replacing the glazed surface of the balcony, the heat loss in winter is mitigated and reduced by 94% but in summer the percentage is the other way around, the overheating has increased by 755 %. This side effect is very common in retrofitted buildings, where overheating is more prominent after the retrofit compared to before the retrofit (Mitchell et.al., 2018).

The solution is to protect the entire balcony with an overhang, wich reduces the solar gain in summer, and by what percentage it depends on the dimensions of the overhang:

- 65% if the shading is the same dimensions as the balcony. This solution covers only the roofing part of the glazed balcony.
- 85% if the shading is 50 cm larger in all directions. This solution covers the roofing, and the vertical side of the glazing but only at noon, evenings and mornings are not.
- 95% if the shading is 90 cm larger in all direction. This solution covers the vertical side of the balcony except the sun-set and the sun-rise. Luckily, at the first hour of the day, the neighbor buildings act as shading, and in the evening its own building roofing acts as shading for the last sun-rays.

Surprisingly, following the retrofit, the glazed balcony performs so efficiently that it overheats in winter because of the greenhouse effect. At this point there are two options: adopt a partial shading system for the balcony roof during winter, or use the extra solar gain to heat other parts of the building. To maximize energy efficiency, the second option is chosen and will be detailed further in the following chapters.

6. HARNESSING SOLAR ENERGY: BALANCING SEASONAL VARIABILITY IN GLAZED BALCONY RETROFITS

This chapter focuses more on the room with glazed balcony, with the floor plan area of 22 square meters. While excessive heating in winter is typically unlikely (U.S. Department of Energy, 2010), the unique conditions of this space warrant investigation (Meijer, et. al., 2009). The glazed balcony, which includes a large window area with a horizontal inclination (zenithal window), makes it susceptible to significant solar gains even in winter (Maouela et. al., 2023). Given this setup, it is essential to study the thermal energy balance in December, the coldest month, to assess the risk of overheating and evaluate energy efficiency (ASHRAE, 2017). The thermal energy balance for the space is calculated using the formula:

$$Q = (Q_s + IHG) - (Q_T + Q_V) \quad (4)$$

where: Q = Total Heat Exchange
QS = Solar Gains
IHG = Internal Heat Gain
QT = Heat losses by Transmission (exterior envelope)
QV = Heat losses by Ventilation

The Solar Gains [QS] depend on factors such as solar radiation, window orientation, and window characteristics (Palmero et. al., 2010). In December, the average daily solar radiation in Bucharest is approximately 1.1 kWh/m²/day, this results in:

- Total Solar Radiation in December = 1.1 kWh/m2 /day × 31 days = 34.1 kWh/m2.
- For the horizontally inclined window (zenithal window), which receives full solar radiation, an adjustment factor of 1 is used. Assuming a medium solar heat gain coefficient (SHGC) of 0.5 for the window, the solar gain is calculated as:
- Solar Gain (Horizontal) = 34.1 kWh/m2 * 1m2 * 0.5 = 17.05 kWh
- For the south-facing portion of the glazed balcony, an additional coefficient of 0.75 is applied, resulting in a solar gain of 12.80 kWh. Similarly, for the east-facing side, a coefficient of 0.5 is used, giving a solar gain of 8.50 kWh.
- Solar Gain (South) = 34.1 kWh/m2 * 1m2 * 0.5 * 0,75 = 12.80 kWh
- Solar Gain (East) = 34.1 kWh/m2 * 1m2 * 0.5 * 0,50 = 8.50 kWh

However, the presence of neighboring buildings and other potential shading elements necessitates further adjustments. A 40% reduction in solar gains is applied to both the southern and eastern sides, while the horizontal window experiences a 20% reduction to account for partial shading.

Solar Gain (Horizontal) = 17.05 kWh – 20% = 13,65 kWh
Solar Gain (South) = 12.80 kWh – 40% = 7,7 kWh
Solar Gain (East) = 8.50 kWh – 40% = 5,1 kWh

The significant zenithal solar gain captured by the horizontal window could reduce the specific heating demand on the upper floor from 15 kWh/m²/year to as low as 0 kWh/m²/year under ideal conditions (Chiras, 2012; McManamon et al., 2018). This assumes approximately 60 hours of evenly distributed sunny weather throughout December. However, if overcast conditions persist for more than 7 days without sunny periods, solar gains could decrease by a factor of 4. To account for such weather deviations, a safety margin was incorporated, and a specific heating demand of 3 kWh/m²/year was maintained for the upper floor as a precautionary measure.

Detailed calculation can be seen in Figure 9, including the dimensions of the glazed balcony and the heat losses through walls and windows. As shown, the energy balance of the glazed balcony is lower than expected, with a net gain of only +2 kWh, insufficient to sustain heating for other rooms.

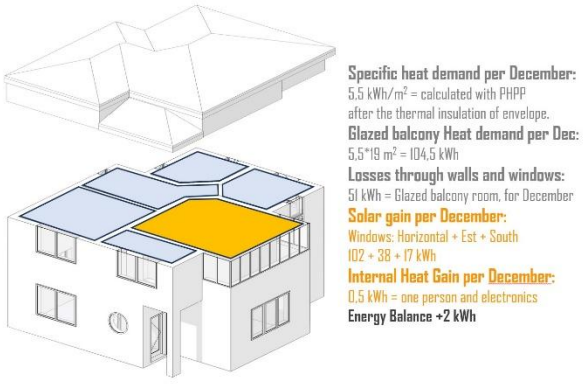

Figure 9. Calculation of the energy balance for balcony room. Solar gains and Internal Heat Gains are indicated in orange

To improve solar gain and increase the difference between heat gained and lost, zenithal windows were added to the roof (Klingenberg, 2019). The results are displayed in Figure 10, where the energy balance for each room is highlighted in orange. With the addition of these windows, the analysis demonstrates that it is feasible to reduce the heating demand on the upper floor to nearly 0 kWh, significantly enhancing the building's energy efficiency (Kristian et. al., 2008).

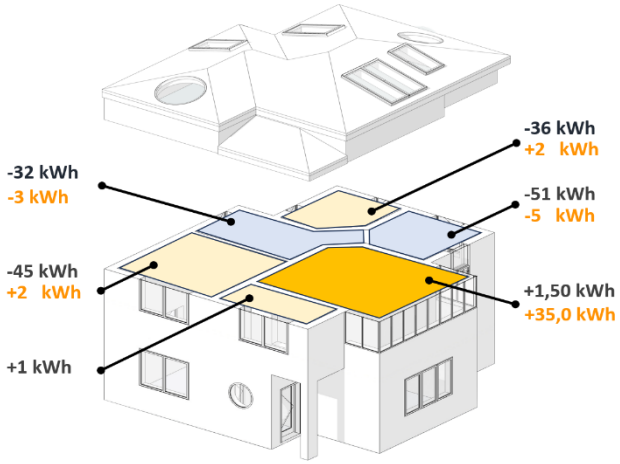

Figure 10. Solar gains calculated for each room with orange color, and energy balance of each room considering area of the thermal envelope with black (contact with exterior temperature)

While a monthly based calculation is widely used and very pertinent, a daily or even hourly based calculation is more accurate wich provides detailed insights into fluctuations in energy demand and supply, and allows for pre-visualization plus optimization of peak loads.

Since the solar gains is a renewable source of energy, and it fluctuates throughout the year, and especially in winter, a detailed calculation was made considering 62-93 hours of direct sunlight over December, revealed in Figure 11, compared to 120 to 150 in October (Autum) or 280-320 in July (Summer).

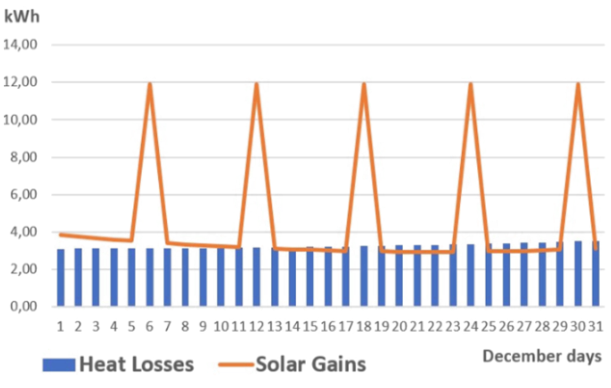

Figure 11. Distribution of Heat loses and Solar gains at winter solstice (December)

For example, the balcony room which already had 7,5 square meters of zenithal window and was added 4,0 square meters has an energy balance close to net zero, with the exceptions of the 62 hours of direct sunlight which looks like the below graphic. To be noticed the mean solar gain is lowest on 22 December at winter solstice and highest on 1 December.

But the most important aspect are the spikes in the solar gains which represent those 62 hours of sunlight which were distributed evenly in this case, although those can be randomly placed, without changing the overall result.

The excess thermal energy resulted from the spikes can be used to heat up other rooms, but in order to do that the energy needs to be transferred by air with the help of the ventilation.

7. VENTILATION INNOVATIONS: MANAGING SOLAR GAINS FOR OPTIMAL EFFICIENCY

The ventilation scheme employed in this project deviates from the typical layout, incorporating innovative adjustments aimed at optimizing energy efficiency by better management of solar gain through airflow (McGill, et. al., 2015).

Without precise solar gain calculations, these changes could not have been effectively implemented, as the ability to handle temporary heat surpluses is key to balancing overall energy consumption. All three proposed measures for addressing the heat surplus, are tailored to the specific dynamics of the building.

The first measure was rethinking the role of storage spaces in the ventilation design (Heiselberg, 2002). Typically, storage areas act as suction zones, as air extraction, but in this case, exceptions were made to optimize energy use. For future reference, other rooms that could have the air flow inverted, from extraction to supply are all auxiliary room functions (Rojas, 2014).

The second adjustment took place in the glazed balcony room. Usually, such spaces tend to experience intense solar gain, turning them into heat traps (Del Ferraro et. al, 2020). Rather than letting this heat go to waste or overburdening the HVAC system, the supply air to the glazed balcony was increased from 30 to 50, essentially turning the space into a small furnace for the entire home.

This decision helps balance the solar gain, redistributing excess heat to other parts of the house, reducing the need for additional heating sources (Pellegrini et. al., 2018). The main idea is to turn this room into a sun-room, results that are similar to other historic building retrofits with large window areas just by increasing the window efficiency.

The third measure is air extraction, another crucial element of ventilation, which was also reconfigured (Grimsrud et. al., 2000). Traditionally air is supplied through ceilings from one room, and extracted from the ceilings of another room. This is usually done because of a practical reason, to have all HVAC ducting in the ceiling, but in this case, it was predominantly moved downstairs and towards the base of the walls.

This strategic adjustment allows for better heat distribution, particularly from the upper to the ground floor. By pulling air from lower zones, the ventilation system effectively circulates warmer air, bringing it downward to regulate the ground floor's temperature, as shown in Figure 12. This design reflects principles used in solar gain management, where the goal is to harness heat rather than eliminate it (Prasad et. al., 2015). Here, the system actively moves warmth from one area of the home to another, optimizing natural heat flow.

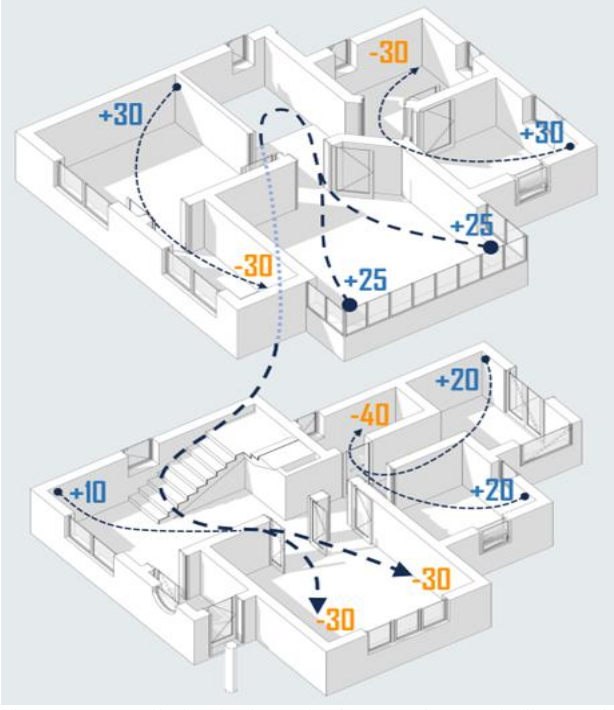

Figure 12. Ventilation in the entire house. Blue text indicates air supply and orange text represents air extraction. The dotted lines represent air flow from one room to another

In conclusion, the upper floor serves as a solar heat bank, generating and storing warmth from the sun, which is then distributed to the ground floor. The increased air supply on the upper floor ensures that warmer air is funneled downward, creating a passive heating system that reduces the reliance on conventional heating. This concept of personalized ventilation supplements goals found in Passive House design like airtight construction and solar gain, increasing the energy efficiency even higher (Feist et. al., 2001).

8. BLENDING HERITAGE AND SUSTAINABILITY: ADAPTING HISTORIC ARCHITECTURE TO MODERN STANDARDS

According to the List of historical monuments published in the Official Gazette of Romania, Part I, no. 113bis/15.II.2016, based on the Order of the Minister of Culture no. 2828 of December 24, 2015, the building is not classified in any of the value groups A/B or categories, monument/ensemble/site, established by Law 422/2001 on the protection of historical monuments. However, according to Decision no. 279/2000 of the General Council of the Municipality of Bucharest approving Zonal Urban Plans for protected built-up areas, the area where the building is located is a protected built-up area named “Protected area no. 73 - Domenii subdivisions, sub-zone L2b” in the related regulations of the area.

To fully adopt the features outlined in the previous chapters and upgrade the building to Passive House standards, it was essential to develop architectural solutions that preserved the building’s historic heritage. This required careful consideration of the following three key topics:

The building's façades exhibit a simple composition inspired by modern Cubist architecture, entirely devoid of ornaments. The external finish varies around the window openings, where smooth surfaces define the borders, contrasting with the main field areas treated with a cement-based plaster applied using the calcio-Vecchio technique. This differentiation helps maintain the historic visual appeal while accommodating the insulation, blending energy efficiency with heritage conservation (Böhm et.al., 2014), and preserving the building’s original architectural character.

Secondly, altering rooftops in most cases or adding elements such as windows or dormers is prohibited, but the 17° slope angle of this building allows constructive elements to be hidden from pedestrian view (Charter, 1964). The only modification is at the junction between the vertical walls and the roof at the eaves, where, after applying thermal insulation without thermal bridges, the hidden gutter detail was reconstructed.

Thirdly, even the improvement of windows is a critical necessity. Measures were taken to preserve as much of the original aesthetic as possible. For instance, the window frames used in this project are custom-made and only 10% wider than standard commercial profiles. Moreover, the installation was carried out within the insulation layer, positioning the windows outside the masonry plane, thereby maintaining the original visual appearance.

In conclusion the shift from strict preservation to adaptive conservation (Jokilehto, 1999) aligns with broader sustainability principles (Cristeaa, et al., 2025), as maintaining functionality is critical for a building's ongoing use and care (Herr & et. al., 2013). This idea resonates with The Burra Charter (Australia ICOMOS, 2013), which advocates for conservation that allows change, provided it respects and retains a building's cultural significance.

It’s often more sustainable to allow a historic building to adapt to contemporary needs than to enforce strict preservation rules (Plevoets et. al., 2011) that might leave it inadequately used. By balancing modern needs with historic integrity (Rodwell, 2007), this method offers a way to negotiate with commissions of monuments, ensuring that the building can continue to serve a functional purpose in the present while preserving its cultural and aesthetic heritage. This approach underscores the notion that preserving a building's spirit and utility is sometimes more important than an unyielding adherence to original forms, materials, or construction techniques (Latham, 2000).

9. CONCLUSIONS

The heating demand without thermal rehabilitation, shows that heating is required even on certain days in April and October. The results show a decrease of heating needs, by 7 times, from 20 to only 5 kWh/ m2/ month. Specific energy demand before retrofit is indicated with red and after the retrofit with blue, also solar gains appear in yellow.

The second graph from Figure 13 demonstrates a significant reduction in heating demand, approximately 80%, following thermal rehabilitation. Post-intervention, heating is needed only on a few days in March and November. Additionally, the peak heating demand drops dramatically, from 25 kWh/m² per year to just 4 kWh/m² per year. This substantial decrease highlights the effectiveness of thermal rehabilitation in reducing energy consumption and improving the building's overall energy efficiency (Zsak et. al., 2025).

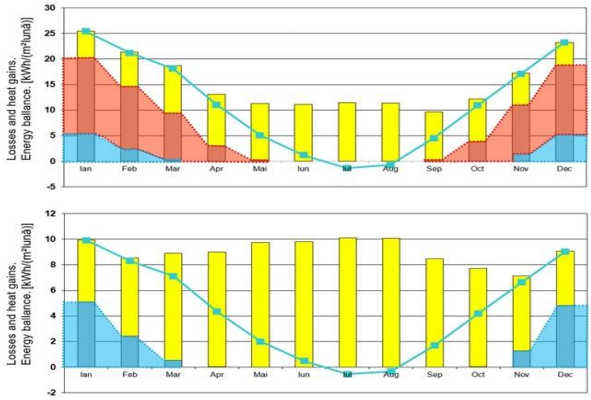

Figure 13. Energy balance before and after the energy retrofit

The following can be listed as the main conclusions of this research:

- Thermal bridges of historic buildings can be removed with interior insulation but with the rule of being not more than 1/3 of the exterior thickness to remove the dew point without adding any vapor barriers.
- Preserving historic shape and material of windows is possible with new technologies of VIG glazing while increasing comfort and wellbeing of interior spaces. The key advantage being that East and Vest oriented windows have a positive effect on the energy balance unlike traditional windows wich have a neutral energy balance.
- It is possible to reach an energy balance of zero kWh with passive methods with the help of south and zenithal windows for the best solar gains.
- Excess thermal energy can be partially transferred from the upper floor to the lower floor through ventilation systems.

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