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Bioclimatic Retrofitting for Energy-Efficient Residential Buildings: A Case Study from Kruja, Albania

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Abstract

This study explores the energy-efficient and sustainable design techniques used in Kruja, Albania's mid-century buildings. The structures are examined in terms of environmental retrofitting; they were initially built with silicate brick retaining walls intended for standardization during the socialist period. Green roofs, shading devices, photovoltaic panel installation and computation, double-skin facades, passive heating and cooling, smart materials, and natural ventilation systems are some of the tactics implemented in the study. In order to improve building performance, reduce energy consumption, and diminish environmental effect, this paper elaborates a concrete example that highlights the necessity of utilizing sustainable materials, energy conservation methods, and new environmental design concepts. During the designing process, the integration of bioclimatic design principles and advanced material improves energy use efficiency, minimizes environmental impact, and assures occupant comfort. The study highlights significant potential in adopting a comprehensive approach to retrofitting that integrates traditional architectural knowledge with technological innovation.

Keywords: Sustainable architecture, bioclimatic design, energy efficiency in buildings, photovoltaic systems, passive heating and cooling, natural ventilation.

1. Introduction

Sustainable architecture incorporates environmental factors within design and construction patterns of buildings. Sustainable architecture tries to balance the needs of mankind with the preservation of ecology through efforts toward the reduction of energy consumption and environmental impact and through the incorporation of renewable energy sources. As climate change intensifies, sustainable practices are becoming a global imperative, particularly in urban areas where resource consumption is concentrated (United Nations Environment Programme UNEP, 2020).
By aligning national legislation to the European Union directives, such as the 2011 Law on Environmental Protection, Albania is demonstrating a clear commitment toward sustainability. Towns in Albania, such as Kruja, provide opportunities for implementing retrofitting tactics to improve energy efficiency in the existing structures. Buildings from the mid-20th century within the town of Kruja are, on one hand, made of retaining walls, made of silicate bricks in Soviet-type standardization, whose thermal performance is deteriorating and designs are archaic, whereas on the other hand, it is retrofitting them that will save energy with committed human comfort as an outcome (European Commission, 2011).
Recent studies are emphasizing the importance of implementing bioclimatic design principles in retrofitting processes to achieve energy efficiency and sustainability (Berardi, 2017). Bioclimatic design takes into consideration fueling factors, such as solar orientation, wind patterns, and local materials, to optimize energy use. In relation to further energy savings in the retrofit of these structures, innovations in materials science, such as PCM and advanced insulation technologies, provide further opportunities (Kalogirou, 2014). This article discusses the application of such strategies to the buildings in Kruja, focusing on their suitability to satisfy contemporary environmental goals.

The pursuit of sustainable architecture pointedly addresses broader and urgent issues such as energy consumption, environmental degradation, and climate change. This discipline emphasizes resource efficiency, ecological balance, and an enhancement in the quality of life of the occupants, through an integration of environmental issues into the design and retrofitting of buildings. With buildings accounting for nearly 40% of the total global greenhouse gas emissions as reported by the United Nations Environment Programme-UNEP, (2020), this necessitates immediate actions toward a less energy-consuming practice.

Albania, being an undeveloped country compared to others country in Europe, has been aligning its urban development programs with the directions of the European Union which expresses its commitment to sustainable development. The Law on Environmental Protection of 2011 and all the following policy frameworks further seek improvement in energy efficiency and enhancement of renewable energy uptake. Such a fact is very relevant in an urban setting like Kruja with most of the built environment in Kruja lying with mid-20th-century buildings of the socialist era. These buildings have retaining walls of silicate bricks and standardized design; when built, these were cheap but have become inefficient with the passage of time. The bad thermal insulation, high inside humidity, and heating with old systems turn these into problems of environmental and energy nature (European Commission, 2011).

Retrofitting buildings offers the chance to amend these inefficiencies whilst still keeping cultural essence and architectural identity. Recently and currently, bioclimatic design has been elaborating upon state-of-the-art proposals about retrofitting projects. In a nutshell, bioclimatic design is an integrative approach of taking into account the local climatic conditions-in the case of Kruja, a transitional Mediterranean-Continental climate-on recommendations towards an architectural solution. It balances passive systems and solar heating through renewable energy technologies while describing natural materials with minimum environmental impact (Berardi, 2017). Passive solar heating, natural ventilation, and green infrastructure would be effectively used to lessen energy use in similar climates by as much as 40% (Santamouris et al. 2018).

Some studies suggest, though not limited to, double-skin facades that enable a cooling cavity for passive temperature control and show very high potential of reducing heating and cooling loads (Saelens et al. 2011). Green roofs provide thermal insulation, stormwater management, and enhanced biodiversity in urban areas (Oberndorfer et al. 2007). In that context, integration of photovoltaic systems would lead to downsizing in fossil fuels use while aligning up with targets set by Albania on increasing renewable energy capacity (IRENA 2020).

This paper presents the incorporation of sustainable architectural strategies in the retrofitting of buildings in Kruja. The building study shows how traditional architectural elements can be interwoven with modern technological innovations via double-skin facades, thermal insulation, smart materials, green roofs, photovoltaic systems, and natural ventilation schemes. The findings will expand the increasingly burgeoning pool of studies on sustainable urban retrofitting while having significant ramifications for similar contexts around the world.

2. Geographical Position and Climate Analysis

Kruja is found at an altitude of 600 m (1,969 ft) on the foot of Mount Krujë (Albanian: Mali i Krujës) of the Kruja Gorge, while south and west of the town is found the plain of the Ishëm River. The town is located in the northern part of the outer Albania as a tectonic unit, which consists of anticlines of Mesozoic carbonate platforms. The administrative center of the municipality is the town of Kruja, but it also includes the villages of Barkanesh, Brre and Picerragë. The closest cities to Kruja are Tirana and Durrës at a distance of 20 and 37 km respectively.



Fig. 1. Geographical position of Kruja (Source: Google Earth)

Kruja's transitory climate, bridging continental and Mediterranean zones, necessitates adaptive design strategies. The city experiences average annual temperatures between 20–26°C, with winters dropping to −5°C and summer peaks reaching 35°C. Annual precipitation averages 1,700–2,000 mm, with snow occurring briefly in winter. Wind patterns predominantly from the northeast influence building design, requiring appropriate interventions such as windbreaks and controlled ventilation systems (Science Academy, 2012).

3. Location of the site, existing situation

The site is located in the inner part of the city. The groups of the buildings that are going to be analyzed do not are part of any historical value of the city. These kinds of buildings dating between 1960-1970 are relatively poor in terms of energy efficiency because of their structure, materials of construction (retaining walls with silicate bricks, and concrete slabs and staircases), no thermal insulation and dense thermal bridges. These buildings were built considering the socialist slogan standardization, and typification. The aim was to reduce the cost of the buildings, although the building analyzed has a special scheme.
The buildings are situated on a sloping terrain, within a well-defined urban setting. A street runs through the inner block, reaching the entrances of the buildings. The building orientation is strategically planned, reflecting the design principles of the socialist period. The east-west alignment maximizes exposure to sunlight, with the north side of the cube being minimized, ensuring optimal use of the southern part of the building. Energetic requalification is an effective approach to enhancing the quality of life for residents.



Fig. 2. Location of the group of buildings within the city of Kruja. A. Google map; B. Orthophoto, (Source: Gc Albania)

4. Existing Building Conditions

The analyzed buildings suffer from high moisture level (especially in the direct contact to the ground), inadequate thermal conditioning, and significant energy inefficiency. Originally constructed with a uniform design, these structures now feature diverse, owner-made modifications, such as glazing loggias and installing sun tents. The architectural form reflects northern Albanian tower influences, emphasizing the potential for culturally sensitive retrofitting. Additionally, the sloping terrain and orientation of these structures necessitate unique design interventions to enhance their energy efficiency.



Fig. 3. Photo of the buildings (2014); (Source: Authors).

Obtaining the plans proved to be challenging, so the buildings were measured on-site. The group of buildings is situated on a highly sloping terrain, which is one of the key reasons for the architectural decision to incorporate semi-levels. The elevation difference across the site is 20 meters. The buildings are constructed with silicate bricks retaining walls, concrete staircase structures, and concrete slabs. The total number of floors ranges from 5 to 6.

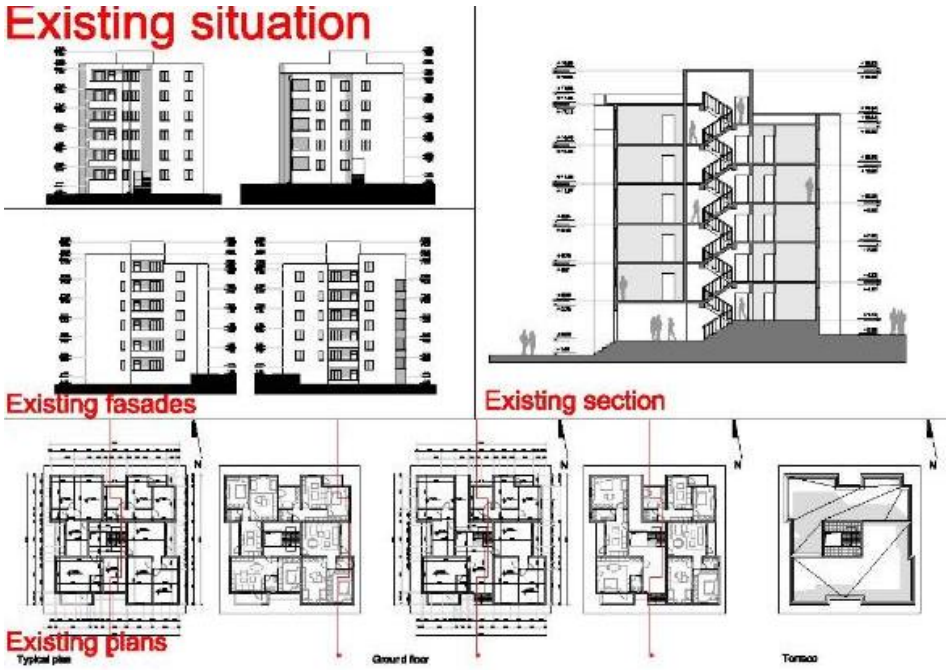




Fig. 4. A. Existing building situation, elevation, plans and sections; B. Existing buildings layout (Source: Authors)

The environmental strategies that are to be meant in this study consist in (i) inhabitance awareness for the implementation of new smart materials, such as: photovoltaics' panels, micronal materials, Neopor materials etc. (ii) The full benefits of the passive systems, collecting energy from it. (iii). Implementation of different environmental strategies such as passive systems, green roofs, shading systems, and ventilation systems.

5. Materials and Methods

5.1 Case Study Selection

The research focuses on a group of mid-20th-century residential buildings located in Kruja, Albania. These structures, built during the socialist period (1960–1970), are characterized by silicate brick retaining walls, reinforced concrete slabs, and staircases. Due to a lack of archival documentation, the architectural plans were reconstructed through on-site measurements, photographic documentation, and orthophoto analysis. The selected case study was chosen for its representativeness of widespread typologies in Albanian cities, making it an appropriate model for testing retrofitting strategies.

5.2 Climate and Environmental Data

Meteorological data for Kruja were collected from the Albanian Hydrometeorological Institute (Science Academy, 2012) to establish baseline climatic parameters, including average annual temperatures, seasonal extremes, precipitation levels, and dominant wind patterns. These inputs were essential for defining bioclimatic interventions such as orientation-based shading, ventilation strategies, and passive heating systems.

5.3 Assessment of Existing Conditions

The baseline energy and environmental performance of the buildings was evaluated through:

a) On-site inspection – documenting physical degradation, thermal bridges, moisture infiltration, and user-made modifications (e.g., enclosed balconies, shading devices).
b) Material analysis – identifying the thermal properties of existing wall assemblies composed of silicate bricks and uninsulated concrete slabs.

c) Energy demand estimation – using standardized consumption data for Albanian households (average 4,000 kWh/year per dwelling) to approximate heating and cooling loads.

5.4 Retrofitting Strategies Tested

A set of sustainable interventions was applied conceptually and evaluated for feasibility and potential energy impact. These included:

a) Double-skin façades – designed to create ventilated cavities for seasonal heat regulation.
b) Green roofs – evaluated for thermal insulation, stormwater retention, and biodiversity benefits.
c) Photovoltaic (PV) systems – calculated using the standard performance equation ($E = A \times r \times H \times PR$), with local solar irradiation data (1,600–1,800 kWh/m² annually).
d) Smart materials – including Neopor insulation and phase-change materials (PCM), tested for their thermal buffering capacity.
e) Passive design measures – natural ventilation through cross-flow and stack effect principles, shading devices, and buffer zones for seasonal adaptation.

5.5 Simulation and Calculation Methods

Energy demand reduction and PV yield were estimated through simplified performance calculations aligned with international standards (Duffie & Beckman, 2013). The photovoltaic system sizing followed the Global Solar Atlas database and NSRDB datasets. Insulation improvements were assessed using U-value reduction and literature-based energy saving benchmarks (BASF, n.d.; Cabeza et al., 2011). Natural ventilation and shading effectiveness were analyzed qualitatively, supported by references to computational fluid dynamics studies (Chen, 2009).

5.6 Evaluation Criteria

The retrofitting strategies were compared against the following performance indicators:

a) Annual reduction in heating and cooling demand.
b) Potential renewable energy generation (kWh/year).
c) Improvement in thermal comfort conditions (passive heating/cooling efficiency).
d) Contribution to sustainability goals, including reduced carbon emissions and alignment with EU energy directives.

6. Environmental Design Strategies applied on the buildings

Double-skin facades provide thermal insulation and climate control by creating a ventilated cavity between two glazing layers. This passive system harnesses solar gains during winter while dissipating heat in summer. Studies have shown that buildings with double-skin facades can reduce energy consumption by up to 25% in temperate climates (Saelens et al., 2011).

Green roofs mitigate urban heat islands, enhance stormwater management, and improve thermal insulation. They also contribute to biodiversity and create usable green spaces for urban residents. Research by Oberndorfer et al. (2007) indicates that green roofs can reduce building energy use by 5–10% annually (Oberndorfer et al. 2007).

Installing 442 m² of photovoltaic panels (according to the calculations; see section 10) on one building can meet annual energy demands. Using a performance ratio of 0.75, these panels significantly reduce dependency on conventional energy sources. Technological advancements have improved photovoltaic efficiency, adding to the already considerable power generation afforded by bifacial panels (IRENA 2020).

Natural ventilation, facilitated by atrium openings and strategically situated vents, ensures a consistent distribution of air. Vertical and horizontal ventilation systems have been introduced that provide improved indoor air quality and thermal comfort for the occupants. Computational fluid dynamics (CFD) modeling is increasingly being used to optimize this sort of system (Chen, 2009).

Shading devices such as light shelves and overhangs reduce solar heat gain in summer while also permitting adequate natural light penetration into the interiors. This dual function ultimately lowers energy when cooling and lighting are concerned. Intelligent shading initiatives, such as electrochromic glass and dynamic solar control systems, provide control on the basis of environmental conditions (Tavares et al., 2014).

7. Thermal insulation and smart materials implementation

The applicability of 5 cm of Neopor insulation allows reductions in heating and cooling energy consumption between 20 and 30%, lowering the overall demand from 5,280 kWh to approximately 4,227 kWh annually. The high R-value and low weight of the material render it suitable for retrofitting applications (BASF, n.d.).
The PCM embedded in building materials stabilizes indoor temperatures by absorbing excess heat during times of extreme temperature fluctuation and releasing it when the temperature drops. This technology reduces the reliance of the building on mechanical heating and cooling systems and has the potential to save as much as 15% on energy usage (Cabeza et al., 2011).
The inclusion of passive solar heating systems, and strategically placed thermal mass, mostly south-facing windows, maximizes heat retention during winter months. Solar heating is particularly effective in reducing energy costs in climates with high solar insolation (Duffie & Beckman, 2013).

8. Bioclimatic Design Interventions

Bioclimatic design principles integrate local climatic conditions into architectural solutions, optimizing building performance while minimizing environmental impact. The interventions for the Kruja buildings focus on the following strategies:
The buildings' east-west orientation maximizes solar gain in winter and reduces overheating in summer. Semi-level designs adapt to the sloping terrain, enhancing natural ventilation and daylight penetration.
Green roofs and urban landscaping create microclimates that improve thermal comfort. Trees and shrubs provide shading and act as windbreaks, reducing heat islands and energy consumption.
Dynamic shading systems, such as operable louvers and awnings, allow occupants to regulate solar heat gain and natural light. These elements are tailored to seasonal variations in sun angles.
Rainwater harvesting systems integrated with green roofs reduce water runoff and provide irrigation for vegetation.
Photovoltaic panels on rooftops or implemented on the new metallic structure generate clean energy, provide shadow reducing overheating during summer, furthermore, enhancing sustainability.
Salvaging and reusing building materials from site renovations minimizes construction waste and promotes circular economy principles.

9. Retrofitting Kruja's Buildings

A specific intervention was proposed for retrofitting of the existing Kruja's buildings. The below images reveal the aesthetic potential of the zone after bioclimatic implementation as seen in Figure 5.





Fig. 5. A. Existing buildings; B. Building after the implementation of the bioclimatic strategy (Source Authors).

The retrofitting of buildings in Kruja incorporates bioclimatic principles and sustainable technologies to address existing inefficiencies. Key interventions include:

9.1 Double-Skin Facades

The Double Skin Façade is a system that features two layers of skin arranged to create an intermediate cavity through which air can flow. The ventilation within this cavity can be natural, fan-assisted, or mechanical. The direction of airflow, as well as the ventilation type, varies depending on factors such as climate, building use, location, occupancy hours, and HVAC strategy.
The glass skins can either be single or double-glazed, with a gap ranging from 20 cm to 2 meters. To enhance protection and aid in heat extraction during the cooling season, solar shading devices are often installed inside the cavity or outside it. The shading device of the proposed solution is the metallic structure that provide shadow during summer.
The cavity can be ventilated either naturally or mechanically. In cooler climates, solar energy within the cavity can be circulated to the interior spaces to reduce heating needs, while in warmer climates, the cavity can be ventilated to the exterior to reduce solar heat gain and lower cooling demands. In both cases, this glazing configuration is expected to provide better insulation than traditional glazing. Recent studies have shown that the energy performance of buildings equipped with double-skin façades can be improved in both cold and warm climates by optimizing the façade's ventilation strategy.

9.2 Green Roof Installation

Extensive green roofs were introduced to reduce the urban heat island effect and improve stormwater management. The roofs also provide additional insulation, reducing energy demands for heating and cooling.

9.3 Photovoltaic Integration

Photovoltaic panels covering 442 m² (according to the calculations; see section 10) per building generate sufficient energy to meet annual demands. These systems include battery storage to enhance energy resilience.

9.4 Natural Ventilation Enhancements

Natural ventilation systems were improved by integrating cross-ventilation schemes within apartments and enhancing atrium airflow through operable skylights.

9.5 Adaptive Insulation and Materials

Neopor insulation and phase change materials were applied to walls and ceilings, significantly enhancing thermal performance. Local materials, such as stone and clay, were reused to preserve cultural heritage while reducing environmental impact.

10. Bioclimatic strategy

The strategy of using the greenhouse effect to enhance energy efficiency in winter capitalizes on solar energy to warm interior spaces. This approach involves integrating greenhouse-like structures along balconies, strategically positioned on the southern, eastern, and western sides of the building to maximize heat gain and solar exposure. Here's an elaboration on how this system functions effectively:

10.1 Greenhouse Effect and Solar Optimization

Typically, between the months of November and February, especially at winter solstice around December 21, the solar altitude at noon is slightly more than 25 degrees. At these low angles of the sun, sunlight penetrates deep into the structures of the greenhouses designed to trap and retain heat. These greenhouses, thanks to their transparent glazing, cause virtually no obstruction. Besides, the greenhouses are strategically placed to optimize sunlight penetration through the day.

The supportive metal frame for the glazing is careful designed not to shade the structures from sunlight during the designated winter period. The result is maximum utilization of solar energy; thus, there is no loss due to shading. This same structure can just as easily also be adapted for heat management in summer and to diminish excessive solar gain as required, providing a solution with flexible shading options.

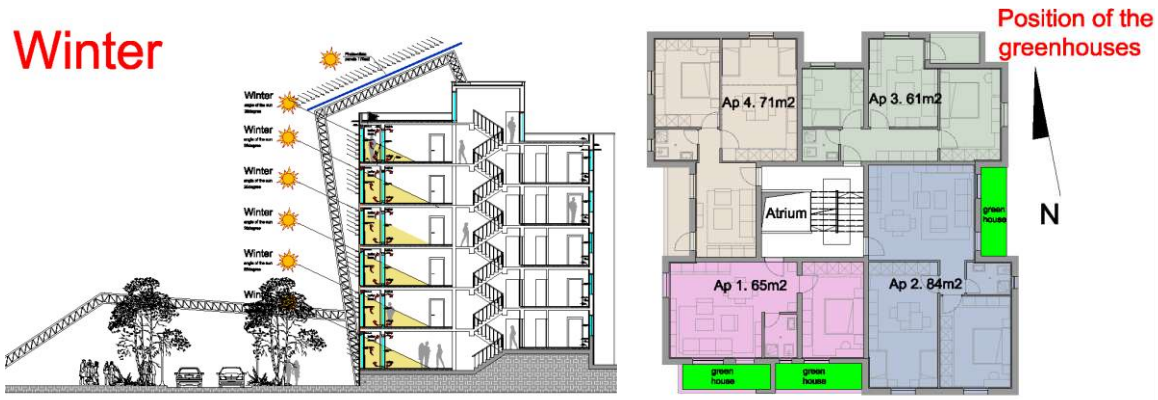


Fig. 6. A. Winter scenario; B. Position of the greenhouses (Source: Authors)

10.2 Buffer Zone Dynamics

The buffer zone, created between two glazing layers, plays a critical role in thermal regulation. As sunlight enters, it warms the air trapped in this space. This warmer air naturally rises due to convection, while cooler air settles at the bottom. The system leverages this natural air movement by incorporating strategically placed valves:

1. Upper Valve: Positioned at the top of the glazing, this valve allows warm air to flow into the building interior.
2. Lower Valve: Located at the bottom, this valve permits cooler interior air to enter the buffer zone for warming.
This setup facilitates continuous air circulation, with warm air entering the living spaces and cooler air being reheated within the buffer zone. The system functions passively, relying on temperature differences and convection to maintain a steady airflow.
Thermal mass can also be incorporated into the buffer zone, specifically in the upper part of the floor slab. This allows it to absorb heat during the day and release it through radiation over an extended period, even after the sun sets.
It must be underlined that the efficiency of the buffer zone is higher in the southern part of the building, because of the longer time lag of solar radiation and bigger sun angle compared to the other orientations.

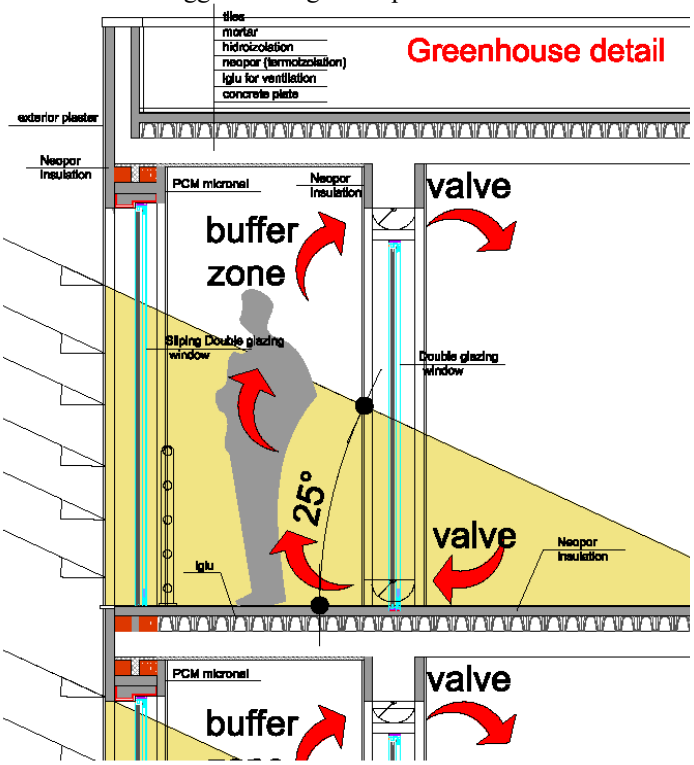


Fig. 7. Buffer zone (Source: Authors)

10.3 Nighttime Insulation

During the night, when solar energy is unavailable, the valves are closed to prevent heat loss. The warm air retained within the buffer zone acts as an insulating layer, helping to maintain a comfortable indoor temperature for several hours. This reduces reliance on active heating systems, lowering energy consumption.

10.4 Benefits and Efficiency

-Energy Savings: By using the greenhouse effect and passive air circulation, the system minimizes the need for conventional heating during daylight hours.
-Thermal Comfort: The continuous flow of warm air ensures a consistent indoor temperature, enhancing occupant comfort.
-Sustainability: This approach reduces energy dependency and aligns with sustainable building practices.
-Adaptability: In summer, the same system can be adjusted to expel hot air and introduce cooler air, demonstrating its dual-season functionality.

10.5 Design Considerations

- Glazing Selection: High-performance glazing is essential to maximize solar gain while minimizing heat loss.
- Valve Placement: Valves must be optimally located for effective air circulation and ease of use.

- Material Choice: The metallic frame should be thermally efficient to prevent heat conduction losses and ensure durability.
- Insulation: Proper insulation around the greenhouse structures and buffer zone further enhances the system's performance.

By leveraging this passive solar heating strategy, the building achieves enhanced energy efficiency, reduced heating costs, and improved occupant comfort during winter, while maintaining adaptability for summer cooling needs.

10.6 Summer strategy

During the summer, the primary element providing shade for the building and creating a microclimate for the surrounding area is the metallic structure. Additionally, photovoltaic platforms, designed to function as an effective shading system, offer significant protection from direct sunlight. On June 21 (summer solstice), at 12:00 PM, the sun's angle is approximately 73 degrees, ensuring that the shading systems cast sufficient shadow to keep the building relatively cool.

The metallic structure is equipped with additional shading systems to shield the building and its surroundings from overheating. During this season, the greenhouse transforms into an open loggia, allowing for rapid and efficient ventilation of the building.

The greenhouses during the summer time will stay open in order ovoid the overheating of the buildings.

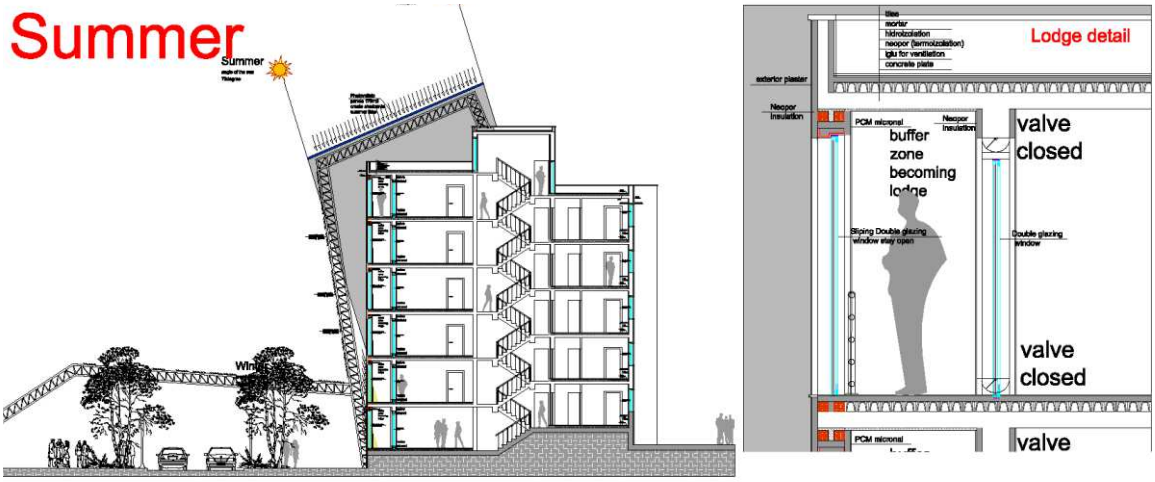


Fig. 8. Summer scenario (Source: Authors)

10.7 Natural ventilation

Significant attention is given to the natural ventilation system of the building, with particular interest in the inner atrium. A close examination reveals that the atrium plays a crucial role in the building's ventilation. The system functions effectively due to the openings at the upper part of the atrium, which facilitate airflow. The pressure difference between the bottom and the top of the building ensures consistent air movement (stack ventilation).

However, ventilation within the apartments presents a more complex challenge. The ventilation system performs optimally when the apartment doors are open, allowing direct connection to the atrium. Otherwise, the apartments face difficulties, as the system lacks true cross-ventilation that spans the entire building. Instead, ventilation is limited to specific corners, reducing its overall efficiency.

To enhance the system's performance, an iglu system has been incorporated into the flooring. This addition helps improve airflow and supports the natural ventilation strategy, ensuring better air circulation throughout the building.

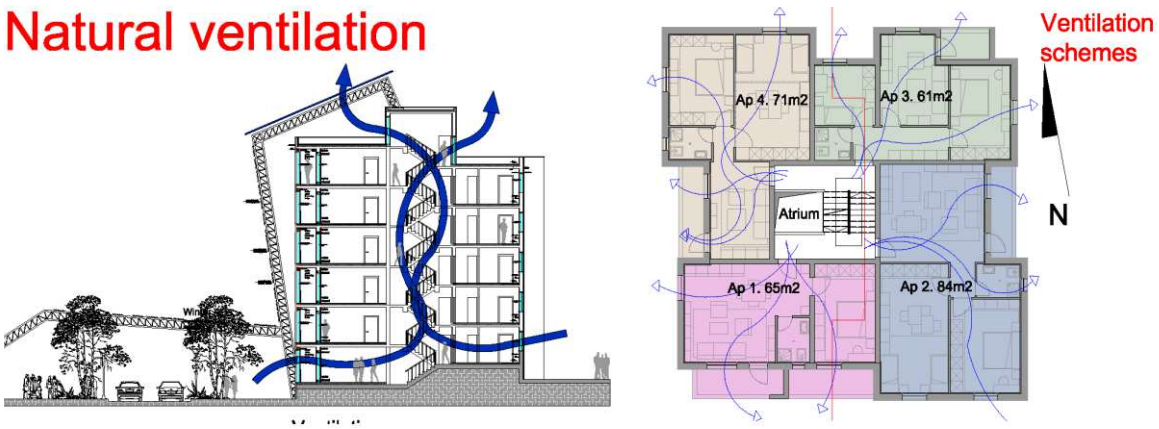


Fig. 9. Cross and stack ventilation in the building (Source: Authors)

11. Photovoltaic Panels Calculation

11.1 PV calculation

To calculate the energy output of a photovoltaic (PV) system in the Kruja's neighborhood, can be used the following formula:

$$E = A \times r \times H \times PR \quad (1)$$

Here are the variables with values relevant to Kruja:

1. A (Total solar panel area): Determined by the system design.
2. r (Solar panel yield): Typically, around 15.6% for standard panels.
3. H (Annual average solar radiation): In Kruja, the annual global horizontal irradiance (GHI) is approximately 1,600–1,800 kWh/m² depending on tilt and orientation (sourced from the Global Solar Atlas and NSRDB).
4. PR (Performance Ratio): Typically ranges from 0.75 to 0.85, accounting for system losses (Photovoltaic software 2025).

11.2 Example Calculation for a building (22 apartments)

Estimate Energy Demand Per Apartment:

- Average energy consumption per apartment: 4,000 kWh/year (a standard value for residential use in similar climates).
- Total energy demand for 22 apartments: Total Energy Demand=22×4,000=88,000kWh/year
- Solar Panel Output in Kruja: Using the formula E=A×r×H×PR, we previously calculated:
  r=0.156r = 0.156 (15.6% panel efficiency)
  H=1,700 kWh/m2H (solar radiation for Kruja).
  PR=0.75 (performance ratio)
  The energy output per square meter of panel is:
  E/m2=1×0.156×1,700×0.75=199kWh/year per m2

  Determine Total Panel Area: To meet the energy demand of 88,000 kWh/year:

  Required Area=E/m2Total Energy Demand=19988,000≈442m2

The solar panel area needed to supply energy for 22 apartments in Kruja is approximately 442 square meters for just one building. This estimate assumes optimal panel placement, no significant shading, and average energy consumption. Adjustments may be needed for specific site conditions or energy efficiency measures within the apartments.

The PV panels that are used for calculation are standard monocrystalline photovoltaic (PV) panels with the following characteristics:
Panel Efficiency (r): 15.6%, typical for standard monocrystalline PV panels.
Performance Ratio (PR): 0.75 (considering system losses like inverter efficiency, cable losses, shading, and temperature effects).
Global Horizontal Irradiance (H): Estimated at 1,700 kWh/m2, annually for Kruja, derived from solar radiation data in the region.
These panels are widely used in residential and commercial installations due to their high efficiency, durability, and cost-effectiveness. If it is planned to use higher-efficiency panels (e.g., 20% efficiency) or bifacial panels, the required area would decrease proportionally. Similarly, for polycrystalline or thin-film panels with lower efficiencies, the area would increase.
The metallic structure implemented in the project will serve not only as a shading device during summer but also for fixing the PV panels.

12. Results and Discussions

The interventions described in this study demonstrate the potential of combining traditional architectural principles with modern sustainable technologies. These retrofitting efforts in Kruja reflect a broader global trend of addressing climate change by adapting existing infrastructure rather than solely relying on new construction. By integrating bioclimatic design principles, the retrofits not only improve energy efficiency but also enhance occupant comfort and environmental resilience.
Both winter and summer performance was clearly improved by passive interventions such buffer zones, double-skin façades, and optimal shading. Through greenhouse-like enclosures, the buffer zone concept made passive solar heating possible in the winter, lowering heating demands and extending indoor comfort past the hours of daylight. While preserving daylight penetration, dynamic shading devices and PV-mounted metallic structures decreased the risk of overheating throughout the summer. These results are consistent with research by Saelens et al. (2011) showing that double-skin façades can reduce seasonal energy use by as much as 25% (Saelens et al., 2011).
Integration of photovoltaics worked especially well. With 442 m² of usable rooftop space per building, the estimated yearly PV output was approximately 88,000 kWh, which was enough to provide 22 units' whole energy needs. This indicates that solar-based retrofits are feasible in Mediterranean-Continental climates, with a self-sufficiency ratio of almost 100%. Similar findings were published in IRENA (2020), highlighting the importance of PV in southern European home retrofits (IRENA 2020).
Improved biodiversity, less urban heat island effects, and better thermal insulation are just a few of the direct and indirect advantages that come with green roofs and vegetation-based solutions. The results are consistent with Oberndorfer et al. (2007)'s research, which emphasizes how green roofs may manage stormwater runoff and lower building energy demands (Oberndorfer et al., 2007). However, green roof maintenance necessitates ongoing irrigation system investment and recurring inspections, which can be difficult without sufficient financing.
A common focus on striking a balance between cost-effectiveness and energy efficiency may be seen when comparing these results to comparable retrofitting projects in Europe and Asia. For example, Santamouris et al. (2018) point out that, depending on the degree of intervention, retrofitting projects in Southern Europe frequently result in energy savings of 30–50% (Santamouris et al., 2018). These savings align with estimates for the Kruja buildings, suggesting that these tactics could be replicated in other Mediterranean locales.
According to Xhexhi, K (2023) a bioclimatic application must take into consideration the orientation of the building, climate parameters of the location, existing situation of the building, existing materials of the construction, applied materials of construction after bioclimatic application, glazed façade surface, the role of smart materials in terms of energy harvesting such as PCM, ventilation systems, inhabitance behavior, the role of vegetations and green roofs, passive solar systems, HVAC systems, shading devices, U-value parameters, building thermal performance, building thermography, PV panels calculation, etc. All of these parameters are taken into consideration also in this current study (Xhexhi, 2023).
The proposed retrofitting measures demonstrated significant potential in enhancing the thermal and energy performance of the case study buildings. Application of 5 cm Neopor insulation reduced annual heating and cooling energy demand by approximately 20–30%, lowering total demand from 5,280 kWh to 4,227 kWh per dwelling. Incorporation of PCM-based materials further stabilized indoor temperatures, with an estimated 15% reduction in peak load reliance, consistent with findings by Cabeza et al. (2011).

The Kruja case study demonstrates how sustainable retrofitting may convert traditional building forms which were initially created under socialist-era standardization into energy-efficient typologies. In addition to its local advantages, this strategy helps Albania comply with EU energy regulations and provides a replicable model for other Mediterranean-Continental situations. An all-encompassing approach to lowering carbon emissions and enhancing occupant well-being in the stock of aging urban housing is the integration of renewable energy sources, bioclimatic techniques, and smart materials.

There are still a number of obstacles in spite of the encouraging outcomes. Implementing retrofitting initiatives might be hampered by a lack of funding and technical know-how, especially in rural or poor areas. Furthermore, Albania lacks strong policy frameworks and incentives for energy-efficient retrofitting, which emphasizes the necessity of international cooperation and government support.

The lack of sophisticated building performance simulations (such as Energy Plus, TRNSYS, or CFD modeling), which may offer a more accurate measurement of energy savings and comfort levels, is a limitation of this study. In order to validate and improve the suggested retrofitting techniques, future research should include occupant behavior analysis, long-term monitoring, and dynamic simulation tools.

Conclusion

In renovating buildings from the mid-20th century in Kruja, Albania, this project demonstrates the transformative power of sustainable design techniques. Through the use of bioclimatic design principles and cutting-edge materials, these interventions considerably improve occupant well-being, lower environmental impact, and increase energy efficiency. The results highlight how crucial it is to approach retrofitting holistically, integrating cutting-edge technical advancements with conventional architectural expertise.

Future studies should concentrate on evaluating the renovated buildings' long-term performance, especially with regard to energy savings, HVAC systems, maintenance needs, software simulations, and occupant satisfaction. Furthermore, expanding these tactics to other areas with comparable socioeconomic and climatic circumstances may confirm their efficacy and support international sustainability initiatives.

References:

[1]. United Nations Environment Programme (UNEP). (2020). Cities and climate change. Retrieved from https://www.unep.org

[2]. European Commission. (2011). Albania 2011 Progress Report.

[3]. Berardi, U. (2017). A cross-country comparison of the building energy consumptions and their trends. Journal of Cleaner Production, 142, 4041–4056. https://doi.org/10.1016/j.jclepro.2016.10.045

[4]. Kalogirou, S. A. (2014). Solar energy engineering: Processes and systems. Academic Press.

[5]. Santamouris, M., Kolokotsa, D., & Vasilakopoulou, K. (2018). The contribution of smart cities to the goal of zero energy buildings. Energy and Buildings, 165, 132–144. https://doi.org/10.1016/j.enbuild.2017.12.013

[6] Saelens, D., Roels, S., & Hens, H. (2011). Strategies to improve the energy performance of multiple-skin facades. Building and Environment, 46(2), 311–318. https://doi.org/10.1016/j.buildenv.2010.07.022

[7] Oberndorfer, E., Lundholm, J., Bass, B., Coffman, R. R., Doshi, H., Dunnett, N., & Rowe, B. (2007). Green roofs as urban ecosystems: Ecological structures, functions, and services. BioScience, 57(10), 823–833. https://doi.org/10.1641/B571005

[8] International Renewable Energy Agency (IRENA). (2020). Renewable energy statistics 2020. Retrieved from https://www.irena.org

[9] Science Academy. (2012). Kruja meteorological data. Institution of Hydrometeorological Studies.

[10] Duffie, J. A., & Beckman, W. A. (2013). Solar engineering of thermal processes. John Wiley & Sons.

[11] BASF. (n.d.). Neopor insulation. Retrieved from https://www.basf.com

[12] BASF. (n.d.). Micronal PCM. Retrieved from https://www.basf.com

[13] Cabeza, L. F., Castell, A., Barreneche, C., De Gracia, A., & Fernandez, A. I. (2011). Materials used as PCM in thermal energy storage in buildings: A review. Renewable and Sustainable Energy Reviews, 15(3), 1675–1695. https://doi.org/10.1016/j.rser.2010.11.018

[14] Chen, Q. (2009). Ventilation performance prediction for buildings: A method overview and recent applications. Building and Environment, 44(4), 848–858. https://doi.org/10.1016/j.buildenv.2008.05.025

[15] Tavares, P., Gaspar, A. R., & Martins, A. G. (2014). Influence of lighting and shading control on visual comfort and energy savings in residential buildings: A case study. Energy and Buildings, 80, 637–647. https://doi.org/10.1016/j.enbuild.2014.05.040

[16] Photovoltaic software. http://photovoltaic-software.com/PV-solar-energy-calculation.php (accessed on 20.03.2025)

[17] Xhexhi, K. (2023). Tirana, the Capital of Albania. A Brief History of Regulatory Plans, Anti-Bombing Hideouts, and Its Climate Conditions. In: Ecovillages and Ecocities. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-20959-8_2

[18] Xhexhi, K. (2023). LEED and BREEAM Building Standards and Albanian Law Related to Building Thermal Performance. In: Ecovillages and Ecocities. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-20959-8_3

[19] Xhexhi, K. (2023). Social Impact in a Specific Neighborhood in Tirana, Albania. In: Ecovillages and Ecocities. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-20959-8_4

[20] Xhexhi, K. (2023). Climate Parameters, Heat Islands, and the Role of Vegetation in the City. In: Ecovillages and Ecocities. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-20959-8_6

[21] Xhexhi, K. (2023). Existing Site Conditions. Building Thermography and U-value Measurements. Case Study Tirana, Albania. In: Ecovillages and Ecocities. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-20959-8_7

[22] Xhexhi, K. (2023). Bioclimatic Eco-Renovation Concept Design and Strategies. The Use of Different Materials. In: Ecovillages and Ecocities. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-20959-8_8

[23] Xhexhi, K. (2023). Bioclimatic Eco-Renovation. Case Study Tirana, Albania. In: Ecovillages and Ecocities. The Urban Book Series. Springer, Cham. https://doi.org/10.1007/978-3-031-20959-8_9