SOLAR PANEL SYSTEMS FOR ENHANCING ENERGY AUTONOMY AND THE AESTHETIC RENOVATION OF RESIDENTIAL BUILDINGS

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Abstract: *In the densely built urban and suburban environments of the 21st century, the availability of free space for solar energy utilization is severely limited. Consequently, rooftops are the primary sites for solar panel installation; however, they often provide insufficient surface area. For this purpose, it is proposed to design economical, resource-saving solar panels for mass multi-apartment residential buildings from the last century, combining facades with roofs to provide clean energy in cities and suburbs built up with residential construction, without disrupting but rather renovating the buildings' images. The methodology is based on the systematic design of solar panels on building facades and roofs, combining graphic development for roofs, walls, and facades with engineering. In the Republic of Armenia, typical multi-apartment residential buildings subject to modernization, or modern buildings that do not represent cultural or historical value and have a seismic conclusion, are selected. The analysis of the functions of solar panels enables the maximum capture of solar energy from photovoltaic systems installed on the building's facade and roof, making the solar panels part of a monumental wall panel. As a result of the study, an architectural conceptual proposal was presented, and solar panel combination modules were designed that, when combined with color graphics, give a new image to the above-mentioned buildings. Expert assessments confirm the project's applicability and the achievement of a renovated aesthetic design in line with the buildings.*

Keywords: *Solar Energy, Environmentally Friendly, Energy Saving, Solar Panels, Renovated Mass Residential Buildings*.

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Introduction

Many countries near the equator have favorable climatic conditions that allow them to use solar energy widely. They are among the most suitable and profitable regions for renewable energy; the potential for solar energy is greater than in other countries that already receive energy from the sun. Promoting the sector's development offers serious prospects for the country's economy and for improving the population's living standards.

The limited availability of energy sources necessitates alternatives; the best solution is inexhaustible solar energy. Generating solar energy through panels is beneficial, environmentally friendly, and economically efficient.

The relevance of the topic is driven by the need for radical changes in developing and implementing strategies to increase energy autonomy.

The significance of researching, developing, and applying solar energy sources stems from growing energy demand, the need to reduce emissions, and the need to ensure energy security. Solar cells and solar modules, as well as battery-based systems, have found wide applications in everyday life, across many areas of the economy, in space exploration, and in the military sector. They are indispensable in hard-to-reach places and far from electrical networks. Solar systems have several advantages: they are quiet, environmentally friendly, and require increasingly lower operating and maintenance costs, making them more flexible. Integrating solar panels into building facades and roofs to generate energy has become an innovative trend in architecture and

sustainability in recent years. This approach not only reduces energy costs but also helps create visually distinctive and ecologically sustainable environments. Educated and affluent households are more likely to have been early adopters of solar power, solar heating, and electric or hybrid transportation[1,2].

To equalize access to solar energy across all segments of society, it is possible to help residents of mass residential buildings in the suburbs adopt technologies that reduce household costs and promote solar energy use in the housing and automotive sectors [1,2]. The rate of solar panel installation should increase as much as possible from current levels, not only at the individual level but also at the community level. A shift to community installations is proposed to alleviate the cost burden and level the playing field for those without individual control over their property or transportation.

The buildings under study require renovation, which remains unresolved. The proposed approach addresses this gap by integrating photovoltaic panels into the façades and roofs of existing buildings, using color-graphic design solutions to create a modernized architectural image. At the same time, integrating photovoltaic systems helps reduce buildings' dependence on external energy sources. The objective of this research is to enhance the energy autonomy of existing buildings while improving their architectural appearance through the application of rational, context-appropriate renovation strategies.

In Armenia, the aesthetic aspect of solar panel installation is not yet coordinated by the state, and the panels are installed by the required number of owners in order to receive as much energy as possible; the process of transferring energy to other recipients and selling the surplus is carried out in parallel with the installation of the panels, as soon as they are connected to the electricity grid in order. Multi-apartment residential buildings built during the Soviet era that have currently received a seismic assessment will have the opportunity to combine the use of solar energy for residents with the acquisition of a renovated appearance for the buildings through the application of the proposed design concept.

The novelty of the current research lies in its interdisciplinary methodology, which bridges design, color graphics, and engineering. The research presents an architectural conceptual proposal for buildings equipped with solar panels to help reduce electricity costs and meet minimal electricity needs in unforeseen situations, while also providing residential neighborhoods with a refreshed aesthetic appearance.

Materials and Methods

We conducted comparative studies using international prototypes. To better understand existing challenges and opportunities, we conducted interviews and surveys with engineers from organizations involved in the production, import, and installation of solar panels, as well as with building residents. The theoretical basis of the research and the design of the proposed solutions were drawn from articles published in journals included in the international rating system for the latest technological capabilities and modern scientific achievements, as well as from modern scientific studies and research [3,4].

The results will be presented using computer software, employing advanced image processing techniques, detailed drawings, and a three-dimensional view to illustrate the project accurately. The project was developed using AutoCAD, 3ds Max, and Photoshop.

The research tasks are presented below:

- urgent need to obtain energy from solar panels to ensure increasing energy autonomy of buildings (social survey),
- factual clarification of the functional capabilities of solar panels,
- identification and justification of additional new opportunities for installing solar panels in typical residential buildings,

[1] Government urged to tackle inequality in 'low-carbon tech' like solar panels and electric cars. Available at: https://tinyurl.com/4ahume7t (accessed on November 26, 2026).

[2] In the US, saving money is the top reason to embrace solar power. Available at: https://tinyurl.com/3z745mxc (accessed on November 26, 2026).

- classification of solar panel types, according to the expediency of application on facades, and the combination of graphic approaches,
- study of existing and promising materials and technological capabilities used in the production sector,
- development of a methodology for collecting and coordinating research results,
- execution of functional volumetric sketch options, creation of forms for modules assembled from solar panels,
- development of original forms for installing solar panels on the roof and facades of buildings, modernization using new technologies,
- preparation of a conceptual proposal drawing package, including plans, sections, and three-dimensional views, generated using computer-aided design software.

During the execution of the project, the following tasks were undertaken:

- a comprehensive scientific study of the key issues was carried out,
- a methodological direction for conceptual design was developed based on scientific studies and justifications,
- conceptual design options for the installation of solar panels on the roofs and facades of four different types of buildings were developed and proposed,
- ergonomic solutions for implementation and maintenance were developed,
- possibilities for energy storage, consumption, and transmission were proposed,
- various constructive systems for the installation of solar panels were proposed, which will depend on the construction systems of buildings,
- modules carrying separate informational aesthetic messages of the conceptual proposal were presented.

The depletion of natural energy resources represents a serious global challenge, making the development of renewable energy an urgent priority – particularly as it offers safe energy and relies on inexhaustible resources. Currently, buildings are being designed in modern architectural styles, with decorative solar panels incorporated into the design.

Before the widespread implementation of solar panels, efforts in existing buildings focused on installing panels as unobtrusively as possible, preserving the building's visual appearance and color palette.

In modern designs and existing high-tech buildings, the challenges of integrating solar panels into facades and overall building volumes have been effectively resolved through innovative technologies and approaches. For example, Building Integrated Photovoltaics (BIPV). This technology involves integrating solar panels into the facades, roofs, or walls of the building as structural elements. This allows you to reduce the energy costs of the building and improve its appearance [5].

Energy-saving Buildings:

- In Switzerland and the Netherlands, residential buildings have been designed with facades integrated with solar panels, resulting in distinctive graphic compositions. In Switzerland, for example, engineers at the Technical University of Zurich (ETH Zürich) have developed “smart” solar panels that can move horizontally and vertically to optimize solar capture and the building's energy efficiency. These panels can also form graphic images, becoming part of the design.
- In Japan, numerous projects feature building facades covered with transparent or differently shaded solar panels, transforming the structures into works of art.
- The “Sara” cultural center in Sweden, a wooden building, includes high-efficiency solar panels to produce environmentally friendly energy.
- The Office for the Environment and Energy building in Basel (Switzerland). This 25-meter-high building is completely covered with solar panels. The panels are made of special 3D fused glass, creating a golden reflective effect. The design won a competition in 2013 and was completed in 2016, aiming to reduce the building’s energy consumption and promote sustainability.

- Sol Invictus Tower (Melbourne, Australia). This 60-story residential building is designed to have more than 32,000 square feet of solar panels installed on the facade and roof. The design also includes wind turbines, low-energy LED lighting, and energy storage systems, aiming to ensure the building's energy self-sufficiency.
- Solar Settlement (Freiburg, Germany). This residential complex consists of 59 houses, all of which produce more energy than they consume. The facades of the buildings are covered with solar panels that generate electricity and reduce carbon emissions.
- Paris Commercial Building (France). This newly constructed building features 18 hybrid solar panels on its facade, producing both electricity and hot water. The panels are oriented southwest for optimal energy production.

In the study, the above-mentioned approaches to installing solar panels are compared, and it is proposed to use the panels to renovate typical multi-apartment residential buildings as a monumental panel, while simultaneously developing a color scheme for the facades and roof.

General Classification of Mass Residential Buildings

The mass multi-apartment residential buildings of the last century are presented, with a proposal to achieve greater energy autonomy and a renewed image through the use of solar panels.

The mass residential buildings built in developing countries during the 1970s-2000s mainly reflect the socio-economic and architectural trends of that period [1,2,6]. These buildings mainly have the following characteristics:

Main description

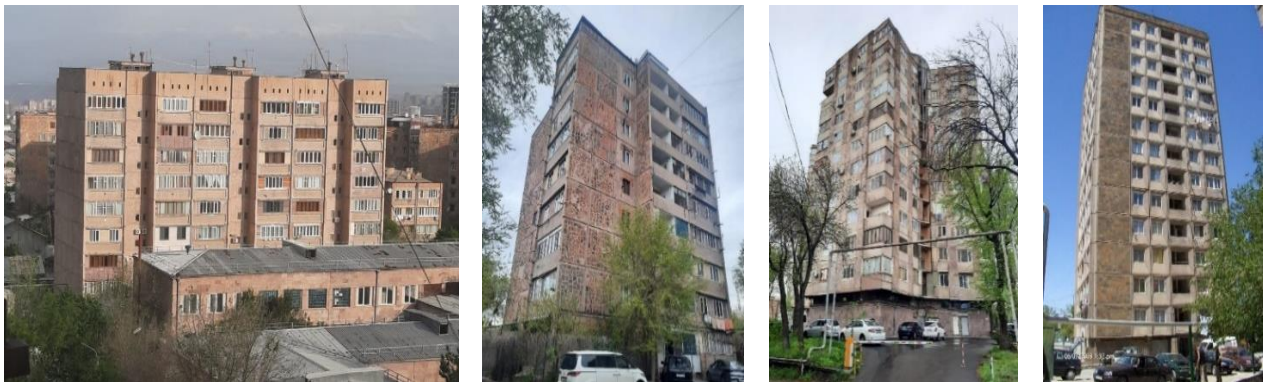
- Panel buildings: Widespread in Europe, Scandinavia, and the former Soviet Union (this study examines four typical multi-apartment residential buildings in the Republic of Armenia, formerly part of the Soviet Union). They were built from large factory-made reinforced concrete panels, using a modular principle. These models were used as a cheap housing solution, mainly 5-12 floors, sometimes up to 16-20 floors.
- Social Housing Estates: Large blocks of residential buildings built on the outskirts of cities. In Western Europe, they were often part of social housing projects (e.g., French banlieues, British council estates), mainly 3-10 floors.
- Residential Towers / High-rises: Most common in the UK, France, and Germany. Some buildings reached 20+ stories. The goal was to concentrate the population and use space efficiently in cities.

Architectural features included: Brutalist style, raw concrete, simple, strict geometric shapes, functional design, a modular principle without decoration, integration of road infrastructure and green zones, cheap building materials, and fast construction technologies.

The urban planning approach focused more on quantity than quality—problems included social isolation and often non-individualized housing. Many buildings have deteriorated over time. Since the 1990s, some countries have demolished or rebuilt such buildings.

In the Republic of Armenia during the Soviet period, typical panel residential districts were built, with buildings spaced and oriented according to urban planning, ensuring that sun-facing facades dominated. These buildings are typical panel residential buildings of no cultural value, a legacy from the Soviet Union [6-8]. The residential buildings of this period currently need renovation, which is proposed to be carried out by integrating solar panels with color graphic design on the facades and roofs.

The study presents four types of buildings measured by us: large-panel building, 9-story multi-entrance (Fig.1, type 1), building constructed by lift slab method, 12-story multi-entrance (Fig.1, type 2), large-panel building, 9-story single-entrance (Fig.1, type 3), and large-panel building, 14-story single-entrance residential buildings (Fig.1, type 4). Using the example of these four buildings listed above, constructed in the Republic of Armenia, we present the study's conceptual proposal, which applies to other similar buildings through the proposed modules or the main principles presented in the results.



Type 1 Type 2 Type 3 Type 4

Fig. 1. *Multi-apartment typical residential buildings*

Random surveys conducted among the owners of four selected apartment buildings, totaling 14 apartments, showed a positive response to the proposed concept. All surveyed residents responded positively and expressed interest in supplying their buildings with solar energy while improving their architectural appearance through renovation.

Construction and Types of Solar Panels

Modern methods for harnessing solar energy are rapidly advancing, aiming to provide renewable, environmentally friendly energy sources[3] [9]. Below are the main modern technologies used to harness solar energy:

1. Solar Panels (Photovoltaic Systems): Photovoltaic (PV) systems convert sunlight directly into electricity using semiconductors, such as silicon:
   - Monocrystalline (efficiency up to 23%) and Polycrystalline (efficiency around 18–20%) panels are widely used and highly efficient. These panels can be either monofacial or bifacial. Monofacial panels generate energy only from sunlight incident on the front side, while bifacial panels generate electricity from both the front and rear sides. Bifacial panels perform especially well on reflective surfaces and can increase energy production by 20–30%.
   - Thin-film flexible solar panels are less efficient than monocrystalline and polycrystalline panels, but perform better in low-light conditions and are more flexible in application.
   - Transparent solar panels are used on windows; however, they are less efficient than traditional solar panels.
   - Colored solar cells are integrated into building design.
2. Solar thermal energy uses the sun's heat to warm water or other liquids, which can then be used to produce electricity or provide heating.
3. Hybrid panels. These panels simultaneously produce electricity and hot water, using solar energy as efficiently as possible. They are especially effective in residential buildings where both electricity and hot water are required.
4. Concentrated Solar Power (CSP) uses mirrors or lenses to focus sunlight onto a small area to create heat, which is then converted into electricity.

Smart solar systems use AI (artificial intelligence) and IoT technologies to optimize performance, prevent shading losses, and improve maintenance.

[3] 90 + Solar Energy Statistics: The Green Gold Rush.
Available at: https://tinyurl.com/dnynjjuz (accessed on November 26, 2026).

Basic technologies

- PERC technology (Passivated Emitter and Rear Cell) increases efficiency
- IBC (Interdigitated Back Contact) cells, without front contacts, increase light reception
- TOPCon (Tunnel Oxide Passivated Contact)

Solar energy storage

Since the sun is not always available, it is necessary to store the energy received. Energy storage systems installed in buildings store excess energy for use during periods of high demand or limited sunlight. This increases energy autonomy and sustainability, reduces carbon emissions, and improves the city's ecological condition.

- Lithium batteries (Tesla Powerwall, BYD)
- Pumped Hydro Storage, large-scale/grid-level storage technology
- Thermal Storage, especially in CSP systems

Integration of solar energy into architecture

- BIPV (Building Integrated Photovoltaics): solar panels that become a structural part of the building (roofs, windows, walls).
- Solar facades, solar poles: integration of solar panels in an urban environment.

Based on the comparative study**,** monocrystalline bifacial solar panels were selected as the most effective solution. The amount of energy harvested from solar panels on the building and the economic efficiency can only be determined precisely during the actual design phase.

From the initial sketch-design stage, consultations were conducted with representatives of four organizations involved in the production and import of photovoltaic panels in the Republic of Armenia. Through parallel comparative discussions with these organizations, the technical applicability and feasibility of the proposed solutions were assessed and confirmed. The information and recommendations obtained during these consultations were subsequently systematized, comparatively analyzed, and incorporated into the development of the proposed solutions.

Depending on the building typology, the number of floors, entrances and elevators, as well as the number of apartments, residents, and patterns of occupancy and movement, may vary, resulting in different energy demand levels.

The number of installed solar panels will also depend on the building typology, the available unobstructed façade areas facing south and southeast (particularly around window openings), and the number of panels installed on the roof. Consequently, the volume of energy generated will vary accordingly.

The electricity consumption of common areas is relatively low, generally corresponding to the output of approximately 12–20 solar panels, depending on the building typology. Therefore, this aspect has not been emphasized as a central issue in the present study. Only at the detailed project design stage will it be possible to estimate the energy demand and potential solar energy generation with reasonable accuracy.

Results and Discussion

As a result of the study, a concept for installing solar panels in residential buildings has been proposed, enabling maximum use of solar energy, reducing residents' electricity consumption, and, depending on weather conditions, even making solar energy profitable. At the same time, residential buildings will receive a new, renovated image through the installation of solar panels and graphic design.

Solar panel design synthesis and integration on the facade and roof.

Combining solar panels and graphic design on the facades of residential buildings has both functional and aesthetic significance. This combination can create modern, energy-efficient, and environmentally friendly facades.

Several key principles to consider when combining graphic design with solar panels:

- The issue of aesthetic integration of solar panels in the facade composition, and their combination with graphics:
  - the dark tone and smooth, glossy surface typical of solar panels can stand out from the building's architectural design. Choose colors in the graphic design of the facades that are consistent with the shades of the panels,
  - use a minimalist linear design that does not interfere with the function of the panels, but emphasizes the modern appearance of the facade,
  - a modular approach: panels can be placed as part of the design as graphic elements, for example, to create symmetrical patterns or a rhythmic arrangement,
  - design the arrangement of panels so that they are combined with the facade graphic,
  - use color or pattern integration: for example, make the panels part of a "monumental" panel.
- Functional and informative design problem[4] [10]:
  - graphic solutions can also provide information: for example, using panels to create QR codes or infographics for residents of the area,
  - graphic design can be used to create visual “zones” where the panels are in harmony,
  - on the upper floors, as a “tilted” sun protection system on the roofs [11,12],
  - on the side facades or in areas free from windows, as decorative and functional frames,
  - integration of logos or images – color, other texture, or shading solutions (for example, a neutral texture on the walls that does not reduce the absorption of solar energy). Graphic images that express the idea of sustainability, environmental messages,
  - graphic design can emphasize “green” architecture: for example, using informative infographics in the inner courtyards of the building,
  - Solar energy can be used with LED lights for nighttime decorative lighting.

To achieve economic efficiency and resource conservation, monocrystalline bifacial photovoltaic panels were selected based on their high efficiency, long service life, high energy yield, low maintenance requirements, and dark-blue surface finish. In the proposed case study, two photovoltaic module sizes were used to accommodate the specific geometric and dimensional characteristics of the roof and façade surfaces of the apartment buildings. Selecting different module sizes also enabled greater flexibility in adapting the photovoltaic layout to the architectural scale and configuration of the existing buildings. The combination of the dark blue surface of the solar panels and the concrete/stone surfaces of the building facades has been integrated into the selected and presented options through appropriate color-matching solutions.

Options for combining solar panels on the facade and roof of a residential building, using graphic interventions, can be implemented with panels either imported into the country or produced domestically. The module options are presented (Fig.2). The solar panels are combined to form different compositions and designed accordingly, depending on the character of the building. On facades, panels are used with appropriate orientation on the walls (southern; in the northern hemisphere, the optimal orientation of the solar panels is towards the south), parallel or tilted to the horizon at an angle of 10°-15°. In the second option of type 4, the modules with solar panels are placed at an angle to the wall, maximizing the absorption of solar energy, as shown in Fig.6. In certain cases, bifacial panel installations parallel to the building facade can yield higher annual energy production, particularly when the facades are painted in light colors, and the panels are positioned 10–30 cm away from the wall to prevent overheating.

[4] How to clean solar panels without water.
Available at: https://tinyurl.com/ycxzta49 (accessed on November 26, 2026).

Moreover, panels installed parallel to the wall tend to generate more energy in winter than in summer because of the sun's seasonal position. On roofs, panel-based systems are also tilted toward an optimal orientation to capture as much energy as possible with as few resources as possible. In the conceptual proposal, the rooftop solar panels are installed at a fixed tilt angle, which may range between 20° and 40°. However, during the detailed design phase for a specific selected building, the engineer determines and specifies the optimal tilt angle based on the building's characteristics and site-specific conditions.

The integrated solar panels in this residential building and the graphic accent that completes it are shown in Figures 3-6, applied in 2 versions across 4 residential building types. The difference between the two options proposed in the example of one building lies in the design's stylistic peculiarity; the advantage is the ability to choose which option residents and/or the community will prefer. On the roofs, solar panels were installed mainly in the upper part of the elevator shaft and in areas free from ventilation ducts, with an aesthetic design. The limitations for the panels in the buildings were the ventilation system service area on the roofs, the exit area from the elevator shaft to the roof, window openings, and facades not facing south or southeast. As a result of implementing the conceptual proposal, building energy consumption will be reduced and energy autonomy will increase; the exact amount of electricity can be calculated during the actual design and implementation.

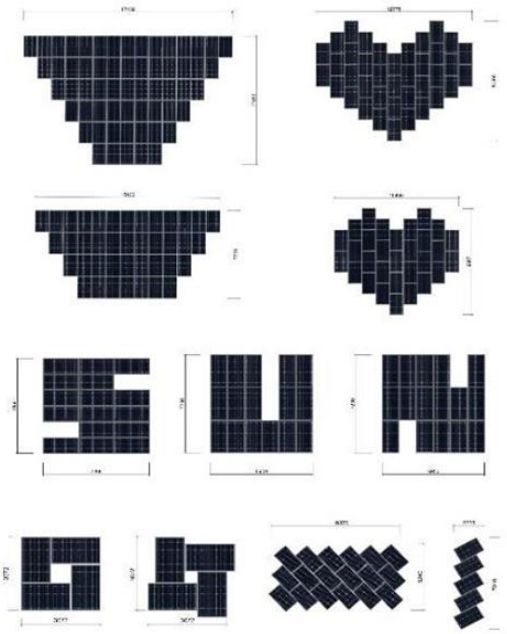


Fig. 2. *Solar panel combination models*

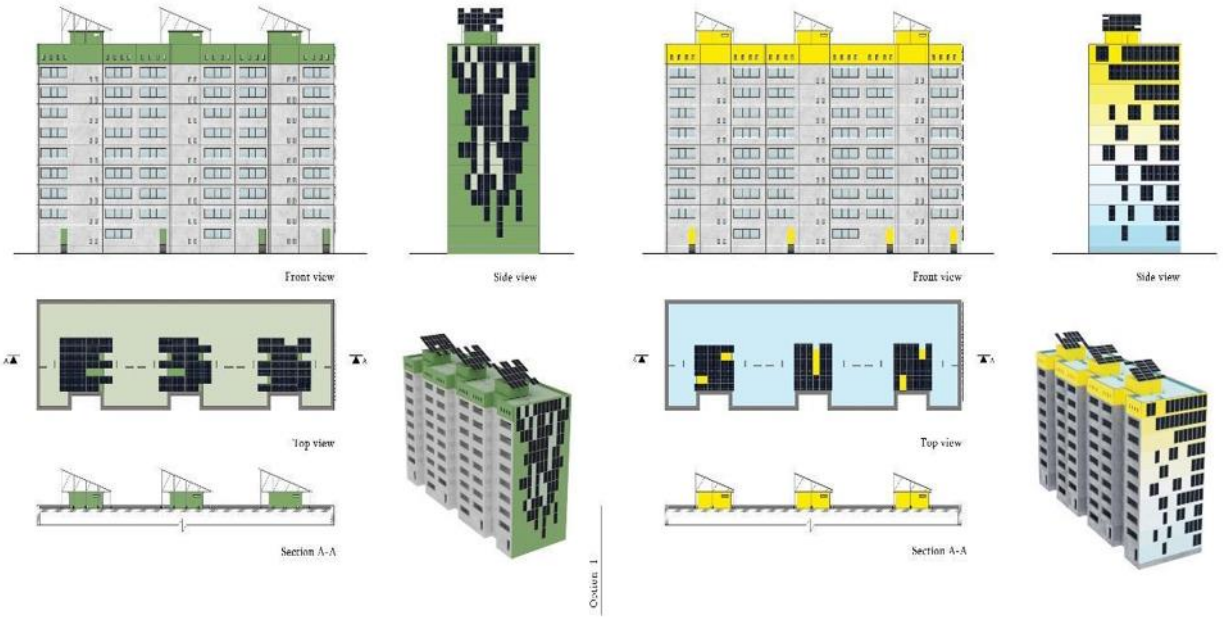


Fig. 3. *Two options for combining solar panels on the facade and the roof of a residential building, using graphic intervention (type 1)*

The proposal can be submitted to the Ministry of Energy, Infrastructure, and Natural Resources for further development and future investment. The work will enable the proposal to be applied in residential districts and improve energy independence.



Fig. 4. *Two options for combining solar panels on the facade and the roof of a residential building, using graphic intervention (type 2)*

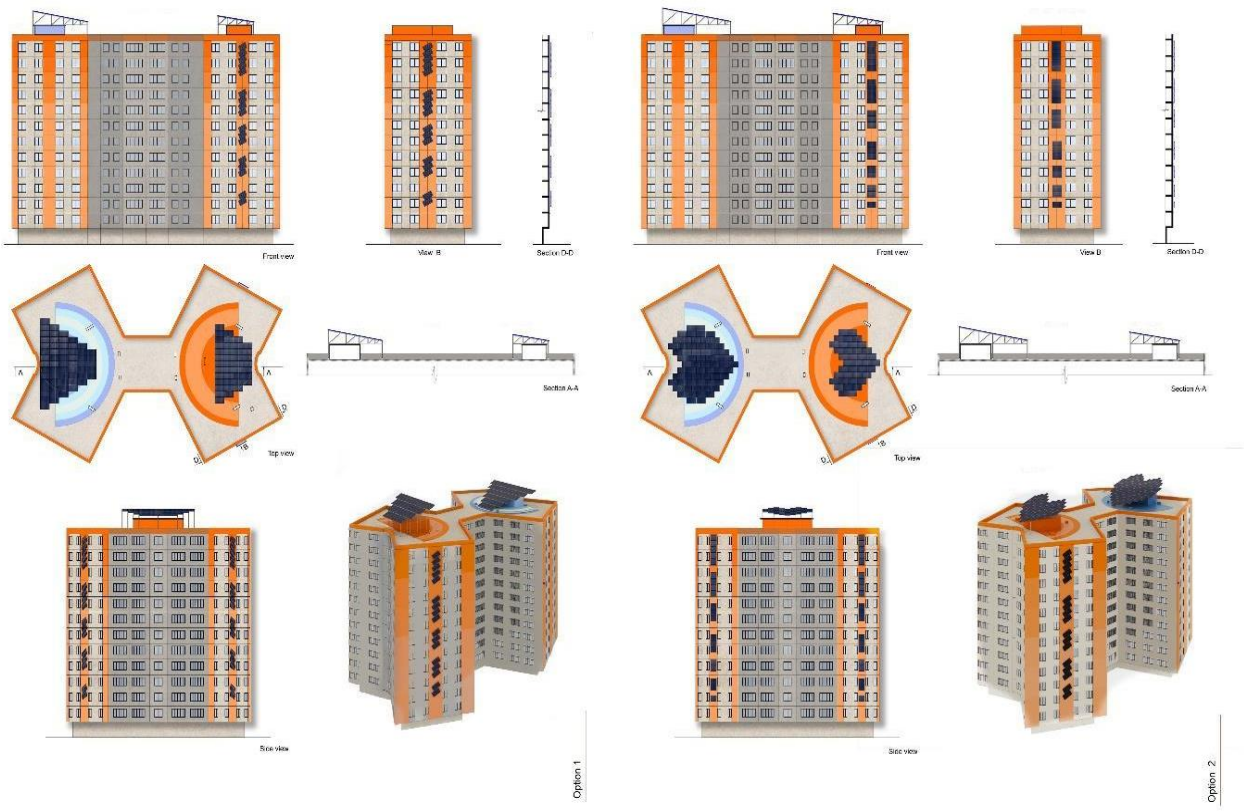


Fig. 5. *Two options for combining solar panels on the facade and the roof of a residential building, using graphic intervention (type 3)*

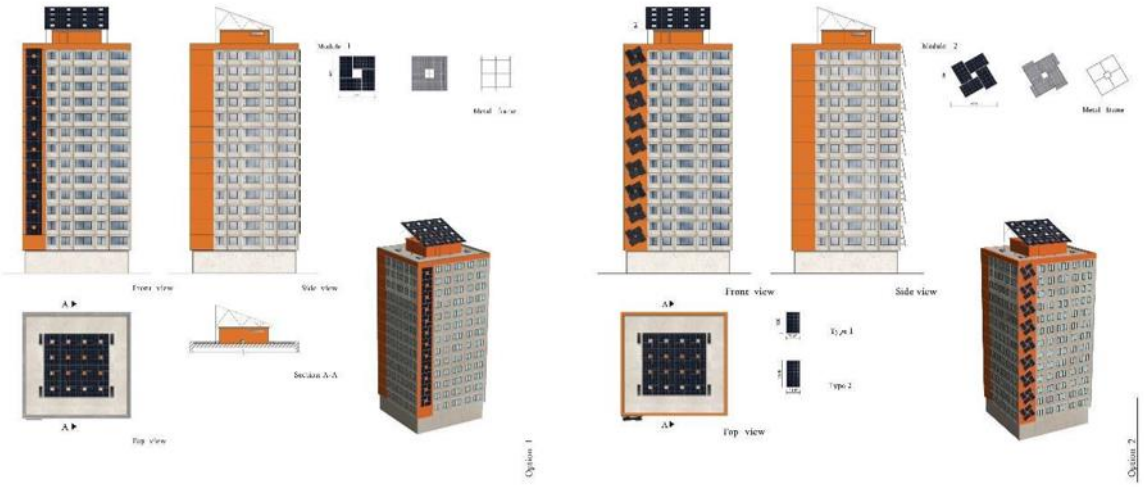


Fig. 6. *Two options for combining solar panels on the facade and the roof of a residential building, using graphic intervention (type 4)*

Conclusion

Integrating solar panels into residential buildings is a promising approach to reducing electricity costs, enhancing energy autonomy, and improving the resilience of residential communities. Beyond their economic and environmental benefits, these systems can help maintain access to essential services during power outages, including elevator operation, emergency lighting, mobile device charging, and other critical electrical functions. This is particularly important for vulnerable groups, including older residents and families with young children.

The study proposes an integrated approach to incorporating photovoltaic systems into the southern façades and rooftops of multi-apartment residential buildings, with particular consideration given to solar orientation, available installation surfaces, and shading conditions. The proposed configuration provides opportunities to increase on-site renewable energy generation and reduce dependence on conventional electricity supply. Furthermore, depending on seasonal variations in solar irradiation and the solar exposure of individual buildings, surplus electricity generated by buildings with more favorable orientations could potentially be shared with buildings experiencing lower solar energy yields through appropriate energy-sharing mechanisms. Where technically feasible and permitted by the relevant regulatory framework, excess electricity could also be exported to the public grid.

Given the extensive stock of mass-produced residential buildings constructed during the previous century, integrating photovoltaic technologies into renovation strategies presents an opportunity to address both energy-related and architectural challenges. Combining façade and rooftop PV installations with innovative architectural design solutions can improve the energy performance of existing residential buildings while enhancing their visual quality and the overall appearance of residential districts.

Overall, the proposed approach establishes a conceptual framework for integrating renewable energy technologies into the architectural modernization of existing multi-apartment housing. Its practical implementation could support the gradual transformation of conventional residential districts into more energy-efficient, energy-autonomous, and resilient urban environments. Further development of this approach should include building-specific energy assessments, technical feasibility studies, structural evaluations, and economic analyses to determine the optimal configuration and performance of solar panels under local climatic and urban conditions.

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Conflict of Interest

The authors declare no conflicts of interest.

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Ethics Statement

The authors confirm that this study was conducted in accordance with the Journal's Research Ethics and Integrity Statement and that all ethical requirements applicable to the study have been fulfilled.

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