BOOK OF PROCEEDINGS

1st International Conference on Built Environment

ICBE 2026

MAY 08th-09th, 2026
POLIS University, Tiranë

ISBN: 9789928347282

DOI: 10.37199/c4100031

CIP Katalogimi në botim BK Tiranë

Universiteti Polis

1st international conference on built environment (icbe) :

may 08th-09th, 2026 : book of proceedings / POLIS University,

Tirane. - Tiranë : Universiteti Polis, 2026. 1 burim në linjë (... f.)

ISBN 9789928347282

1.Arkitektura 2.Konferenca

72 (062)

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1st International Conference on Built Environment

ICBE 2026

Conference Theme and Rationale

The 1st International Conference on Built Environment (ICBE 2026) was conceived as an international and interdisciplinary forum for advancing knowledge, critical discussion, and innovation across architecture, urban planning, engineering, construction, materials, design, and the wider built environment. Organized by POLIS University in collaboration with the National Agency for Scientific Research and Innovation in Albania (AKKSHI), the Academy of Sciences of Albania and the University of Ferrara in Italy, the conference brought together academics, researchers, practitioners, students, and industry representatives to exchange research findings, professional experience, and emerging perspectives on the transformation of contemporary cities and territories.

The conference theme reflected the increasingly complex challenges shaping the built environment, with particular attention to sustainability, resilience, technological innovation, heritage preservation, and socially responsive design. Contributions addressed sustainable architecture and green building, innovative construction technologies and materials, climate-responsive and energy-efficient design, disaster risk reduction, circular approaches to construction, and the integration of renewable energy. Equal emphasis was placed on digital transformation through Building Information Modeling, Geographic Information Systems, artificial intelligence, data analytics, automated solutions, digital fabrication, and advanced manufacturing.

ICBE 2026 also recognized that the future of the built environment cannot be approached through technological innovation alone. Urban transformation, cultural heritage, adaptive reuse, inclusive design, ecological thinking, art, and interdisciplinary research were therefore integral to the conference rationale. The scientific sessions examined topics ranging from seismic resilience, geotechnical engineering, and structural safety to urban fragmentation, public space, heritage conservation, adaptive environments, and new relationships between human and non-human systems.

Through keynote lectures, scientific presentations, case studies, and interdisciplinary debate, the conference encouraged connections between research and practice while promoting approaches capable of responding to environmental, social, cultural, and technological change. The breadth of contributions demonstrated the value of bringing engineering, architecture, urbanism, design, heritage, and emerging technologies into a shared academic framework for more resilient, sustainable, adaptive, and human-centered environments.

Held on 8-9 May 2026 at POLIS University in Tirana, with in-person and online participation, ICBE 2026 welcomed guest speakers and participants from Albanian and international universities, research institutions, professional organizations, and industry. Its sessions established a platform for presenting current research, exchanging expertise, strengthening meaningful collaboration, and identifying future directions for the built environment.

The event

The **1st International Conference on Built Environment (ICBE 2026)** is an interdisciplinary academic and professional forum dedicated to exploring contemporary challenges, emerging research, and innovative approaches shaping the future of the built environment. Bringing together researchers, academics, architects, engineers, urban planners, designers, practitioners, and industry professionals, the conference promotes the exchange of knowledge and encourages collaboration across traditionally interconnected disciplines. Its thematic scope encompasses sustainable and resilient construction, technological innovation, advanced building materials, urban transformation, cultural heritage, and interdisciplinary design approaches. Particular attention is given to the growing role of digital technologies, data-driven methodologies, intelligent design processes, and advanced analytical tools in supporting more informed and responsive approaches to architecture, engineering, and urban development. At the same time, ICBE 2026 recognizes the importance of environmental responsibility, cultural identity, social needs, and human-centered design in shaping contemporary cities and territories. Through keynote lectures, scientific sessions, case studies, and interdisciplinary exchange, the conference provides a platform for presenting current research, discussing professional experiences, and developing new perspectives capable of contributing to **safer, more sustainable, adaptive, inclusive, and resilient built environments**.

Objectives

- Promote interdisciplinary collaboration among researchers, academics, practitioners, and professionals in architecture, engineering, urban planning, construction, design, heritage, and related fields of the built environment.
- Advance the use of digital technologies and innovative methodologies, including BIM, GIS, artificial intelligence, data analytics, digital fabrication, and parametric approaches, in research and professional practice.
- Encourage sustainable, resilient, and climate-responsive approaches to architecture, construction, and urban development through innovative materials, energy-efficient strategies, and environmentally responsible design.
- Address contemporary challenges affecting cities, buildings, and infrastructure through scientific research, applied case studies, evidence-based approaches, and innovative design solutions.
- Promote the conservation, transformation, and adaptive reuse of cultural heritage, balancing cultural identity, contemporary needs, structural safety, and responsible urban development.
- Support human-centered and socially responsive urban transformation, considering public space, mobility, ecological systems, community needs, and the wider social and economic impacts of the built environment.
- Provide a platform for knowledge exchange and emerging research, enabling scholars, young researchers, professionals, and students to present innovative ideas, strengthen international collaboration, and contribute to future directions in the built environment.

Main Conference Themes

- Sustainable architecture and green building practices.
- Innovations in construction technologies and materials.
- Heritage preservation and adaptive reuse in the built environment.
- Digital tools and smart technologies in architecture and construction (e.g., BIM, GIS).
- Climate-responsive and energy-efficient design.
- Disaster risk reduction and resilience in the built environment.
- Circular economy approaches in construction and material usage.
- Integration of AI and data analytics in building design.
- Acoustic and thermal performance in building design.
- Renewable energy integration in building systems.
- Advanced manufacturing techniques in construction, such as 3D printing.
- Innovations in construction technologies and materials.
- Heritage preservation and adaptive reuse in the built environment.
- Disaster risk reduction and resilience in the built environment.
- Digital tools and smart technologies in architecture and construction.
- Advanced manufacturing techniques in construction.
- Geotechnical Engineering for Sustainable Development.
- Cartography and Geographic Information System.
- Computer Automated Solutions for Built Environment.
- Reliability in Civil Engineering.
- Urban planning strategies for resilient cities.
- Climate-responsive and energy-efficient design.
- Regulatory frameworks and policies impacting construction and urban development.
- Design in the Era of Anthropocene (Rethinking the Relation between Human and Non-Human Species)
- Speculative Design (with Attention to “Discursive” and “Critical” Design)
- Design and Cross-Disciplinarity (with Emphasis on Processes rather than Design Outputs)
- Inclusive Design
- Art and Urban Regeneration (Focus on Participatory, Collaborative, and Research-Based Practice)
- Relational Art and Architecture
- Monuments and ‘Anti-Monuments’ (Particular Attention to the Process of Designing and Building the City)

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The conference is structured around six thematic sessions, each addressing a specific area of research and practice within the built environment.
Each session is coordinated by experts in the relevant disciplinary field and is open to professors, researchers, PhD candidates, and other scholars and professionals contributing to the conference themes.

SESSION I
Urban Planning and Societal Impact

Chair: Dr. Gent Avdija

This session examines the relationship between urban transformation, spatial development, and their social implications within contemporary cities. Contributions address rapid urbanization, urban fragmentation, the transformation and loss of public space, informal and spontaneous development, and the challenges associated with balancing growth and modernization with human-scale urban environments. Particular attention is given to the evolving conditions of Albanian cities and to planning approaches capable of supporting more inclusive, sustainable, socially responsive, and livable urban environments.

SESSION II
Sustainable Materials, Resilient Construction & Smart Design

Chair: Dr. Endri Duro

This session explores innovative approaches to sustainable construction, resilient structural systems, and environmentally responsive design. Particular attention is given to sustainable materials, energy-efficient and climate-responsive strategies, prefabricated and lightweight construction technologies, and human-centered approaches to structural and architectural design. The session investigates how material innovation, technological development, and responsible design practices can contribute to safer, more efficient, adaptable, and environmentally sustainable built environments.

SESSION III
Technological Advancements and Seismic Design for Resilient Places

Chairs: Dr. Seyyed Behrad Emadi & Dr. Ornela Şen

This session examines the role of technological innovation and advanced engineering methodologies in developing safer, more resilient, and adaptable built environments. Contributions address seismic hazard and risk assessment, digital fabrication, parametric and computational approaches, transformations of building envelopes and prefabricated housing systems, and emerging concepts for future urban mobility. The session highlights how the integration of engineering knowledge, digital technologies, and resilience-oriented design can strengthen the capacity of buildings, infrastructure, and urban environments to respond to contemporary and future challenges.

SESSION IV

Cultural Heritage

Chairs: Dr. Nikolla Vesho & Dr. Marsela Demaj

This session addresses the preservation, interpretation, and transformation of cultural heritage within contemporary architectural and urban contexts. Contributions explore conservation strategies for historic buildings and sacred architecture, seismic assessment and strengthening of heritage structures, adaptive reuse, and the social implications of urban regeneration and heritage loss. Particular emphasis is placed on achieving a responsible balance between conservation ethics, cultural identity, structural safety, and the evolving functional requirements of historic buildings and urban environments.

SESSION V

Spaces of Connection: Art and Design for an Interspecies and Interdisciplinary Environment

Chair: Dr. Francesco Scasciamacchia

This session explores the intersections of art, architecture, design, technology, and the built environment through interdisciplinary and experimental perspectives. It investigates changing relationships between human and non-human systems, spatial perception, adaptive reuse, post-industrial landscapes, urban representation, digital heritage, and environmentally and socially engaged design practices. Through critical, speculative, participatory, and research-based approaches, the session examines how art and design can generate new forms of connection, reinterpret existing environments, and contribute to emerging cultural and spatial narratives within contemporary cities.

SESSION VI

Next-Generation Pioneers of the Built Environment

Chair: Dr. Flogerta Krosi

This session provides a dedicated platform for emerging researchers and students to present innovative, experimental, and forward-looking approaches to the built environment. Contributions span architecture, engineering, urban planning, environmental resilience, design, and related creative disciplines, reflecting the interdisciplinary character of a new generation of researchers and practitioners. Through projects addressing topics such as bioclimatic design, flood-risk management, structural technologies, architecture-inspired design, and critical interpretations of objects and social space, the session encourages critical inquiry, experimentation, and new perspectives on the future of the built environment.

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Climate-responsive and energy-efficient design: Passive design strategies / Energy efficiency / Climate adaptation / Environmental performance.

Smart construction and material innovation: Lightweight construction / Prefabricated building systems / Advanced material applications / Resource-efficient technologies.

Human-centered design: Structural design for human needs / Performance-oriented architecture / Adaptable building systems / Integration of architecture and engineering.

Eco-Friendly Building Envelopes:
Thermal, Energy, Cost, and Time Performance of Prefabricated Lightweight MRC Panels in Residential Construction

DOI: 10.37199/c4100041

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Abstract

The construction sector remains one of the largest energy users worldwide, with a significant portion of its demand coming from space heating and cooling. Since the building envelope controls the transfer of heat between indoor and outdoor spaces, improvements in wall, roof and floor systems are key to increasing energy efficiency and reducing operational emissions. In this context, traditional reinforced concrete (RC) frame buildings with brick infill walls continue to dominate residential construction in many Mediterranean countries.

Although common and readily available, these systems often rely on multiple separate layers to provide structural stability and thermal insulation, which can increase construction complexity, thermal transition risks and variability during construction. At the same time, industrialized prefabricated systems, including lightweight micro-reinforced concrete (MRC) panels are emerging as promising alternatives for both structural and envelope functions.

This study evaluates the thermal, energy, cost, and construction-time performance of prefabricated lightweight micro-reinforced concrete (MRC) panels – a type of EPS-core

shotcrete sandwich system – as an alternative to traditional RC frame construction with brick infill walls. A comparative case study of a two-storey residential villa is conducted, combining energy analysis, cost assessment, and construction time evaluation.

Results show that the MRC system reduces wall U-values by nearly 50% and lowers annual primary energy demand by approximately 14.7%. Construction time is reduced by about 19%, while initial costs increased moderately (≈2.8%).

The findings highlight that while MRC panels improve envelope performance and construction efficiency, overall energy gains remain constrained by other envelope components, particularly the ground floor. The study supports a system-level approach to building design, where prefabricated solutions are integrated within a broader optimization framework.

***Keywords**: building envelope, prefabricated panels, energy performance, thermal transmittance, cost analysis, construction time*

1. INTRODUCTION

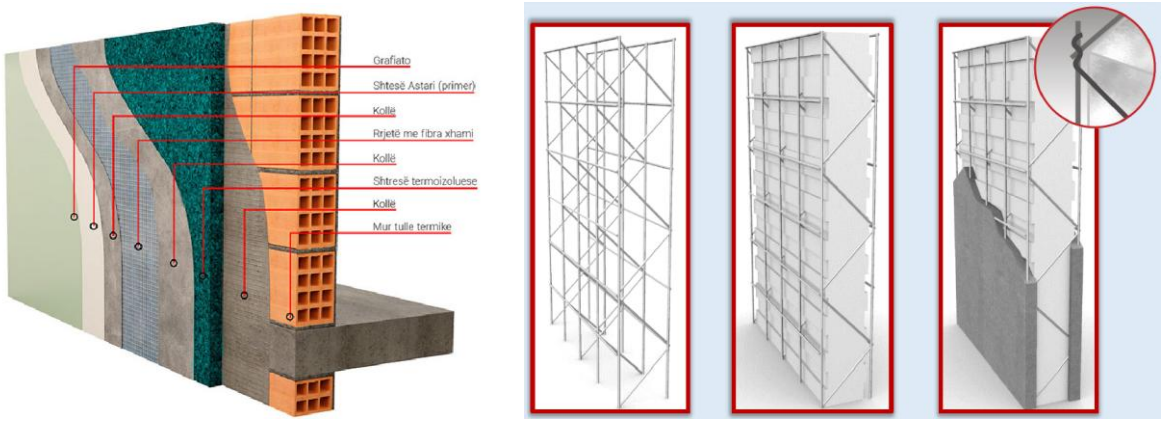
Buildings contribute significantly to energy consumption at global and European levels, mainly due to the need for comfortable thermal conditions. In the case of housing, heating and cooling directly depend on how well the envelope is constructed — walls, roof, floor, openings and connections between elements. Improving the building's envelope is one of the most effective ways to reduce energy consumption and negative environmental impact. European policies, such as the Energy Performance of Buildings Directive, as well as standards such as ISO 6946, ISO 10211 and ISO 13788, support this direction by providing clear calculation methods for heat transfer, thermal bridges and condensation risk. (*ISO 6946, 2017; ISO 10211, 2017; ISO 13788, 2012)*.

In traditional residential construction, especially in reinforced concrete frame structures, the building envelope is usually constructed in separate layers, with each layer having its own function — structural or thermal. Brick walls with external insulation are the most commonly used solution, because many builders know and master them well. However, this approach has its drawbacks. Coordination of different materials and workers often leads to errors, insulation breaks, and thermal bridges at critical points — slab edges, columns, window openings, and joints between the roof and the wall. Studies show that these thermal bridges can significantly impair the performance of the building: they increase heat loss, lower the temperature of internal surfaces, and, if not properly treated, can lead to condensation and mold formation. *(Alhawari & Mukhopadhyaya, 2017; Mayer et al., 2023).*

Prefabricated wall and panel systems have become prominent in industrialized construction strategies. Studies indicate that prefabricated envelopes can enhance dimensional accuracy, speed up assembly, improve quality control, and provide more consistent thermal

performance, especially when insulation is integrated into the panel rather than added afterward. Among these, precast concrete sandwich panels and lightweight systems stand out because they can serve structural, enclosure, and thermal functions within a single component. However, their real-world effectiveness relies on connector design, layer composition, insulation continuity, and junction treatment. In essence, simply including insulation inside a panel does not ensure optimal overall building performance. *(Yu et al., 2021; Sah et al., 2024; Tsoka et al., 2020; Kim & Allard, 2014; Ximei et al., 2018).*

This paper examines an integrated building system that uses lightweight MRC panels as a single element — both cladding and load-bearing structure. MRC panel refer to a category of lightweight prefabricated sandwich systems consisting of an expanded polystyrene (EPS) core (density about 16 kg/m³) combined with welded steel mesh reinforcement and shotcrete layers. These systems are also described in literature as 3D wire-mesh panels, shotcrete sandwich panels, or EPS-core structural panels. It has the potential to reduce the need for additional insulation, provide better thermal continuity, and at the same time simplify the structural and thermal design of the building.



a) b)

Figure 1. a) The conventional clay brick infill wall with façade cladding insulation system (left) and b) the lightweight prefabricated MRC panel infill wall system (right)

Despite the promise, a key gap exists in the appeal and practical performance of integrated prefabricated systems. Most studies focus on façade insulation or sandwich panel behavior, with fewer on the energy and implementation impacts of replacing traditional RC frames and brick infills with panel systems at the building level. This is especially true in markets where masonry construction dominates, and decision-makers need evidence on thermal performance, costs, and trade-offs. *(Yu et al., 2021; Ruoyu et al., 2020).*

This paper assesses whether prefabricated lightweight MRC panels can be a technically viable alternative to the traditional way of building's envelope. The study is based on a specific case – a two-story villa – relying on architectural drawings of the building and comparative energy and cost data for both methods. The paper answers three main questions:

(1) How does the MRC panel system affect the thermal performance of the wall and roof, compared to a traditional wall system?

(2) How does the improved envelope affect the reduction of the annual energy demand?
(3) What is the cost difference between the classic solution with RC frame and brick infill compared to the solution with MRC panel as a complete structural element?

2. LITERATURE REVIEW

The literature is clear: envelope performance is the key factor for building energy efficiency. The U-value, a widely used indicator, measures the amount of heat passing through walls and roofs. ISO 6946 standardizes the way it is calculated, and studies show it remains an important tool in design and verification. However, researchers point out that the U-value alone is not enough to fully understand the thermal behavior of a building, especially when factors such as thermal mass, air leakage, and insulation discontinuities directly affect energy consumption *(Song et al., 2024).*

Studies on prefabricated wall systems highlight their important role in sustainable construction. Yu et al. (2021) found that prefabrication offers energy savings, emission reductions, and higher manufacturing accuracy, but called for more evaluations across different wall types and climates. Sah et al. (2024) identified prefabricated external wall panels as key elements for energy-efficient and net-zero buildings, pointing in particular to precast concrete sandwich panels, which combine structural and thermal functions in a single component. Tsoka et al. (2020) showed, in a Mediterranean context, that prefabricated envelope systems can significantly improve energy performance when designed as multifunctional components, rather than simply as replacements for traditional wall layers.

Another important area of the literature deals with the thermal behavior of sandwich and precast concrete panels. Kim and Allard (2014) found that the shape and placement of connectors significantly influence heat transfer across these walls, as metal connectors can act as thermal bridges passing through the insulation layer. Earlier, Lee and Pessiki (2006) showed that panel configuration directly affects thermal resistance. Zhai et al. (2018) demonstrated that hybrid connectors can deliver higher thermal efficiency compared to more conductive alternatives. These findings are particularly relevant for MRC panels, showing that integrated systems can outperform traditional walls when the continuity of the thermal layer and the bridging effect of connectors are properly managed.

Thermal bridges are well-known problems that arise where insulation is interrupted by structural elements, irregularities, or high-conductivity materials. Alhawari and Mukhopadhyaya (2018) stress that they weaken envelope quality by increasing heat loss, lowering internal surface temperatures, and negatively affecting durability and indoor air quality. ISO 10211 provides detailed methods for their evaluation. In practice, integrated systems such as prefabricated panels can reduce these problems by lowering the number of junctions and interfaces that cause thermal bridging effects.

Envelope performance also depends on building airtightness, a factor that is often underestimated when only the U-values of opaque elements are considered. Studies show that quality control, testing, and assembly methods are critical for reliable performance. In

warm and mixed climates, air infiltration directly affects energy consumption. Field studies link higher airtightness to better overall building performance. Industrialized panel systems may offer advantages through controlled manufacturing and consistent assembly, but this depends on junction details and installation quality, not just on the panel material itself. *(Poza-Casado et al., 2020; Guillén-Lambea et al., 2019; Šadauskienė et al., 2016; Sinnott et al., 2012)*.

Thermal inertia refers to the ability of heavy envelopes to delay heat transfer — an effect that can be beneficial or modest, depending on the climate, building use, and ventilation system. The review by Verbeke and Audenaert shows that its impact is highly context-dependent: it can reduce peak loads and improve comfort, or it can be negligible and require careful balancing with insulation levels and operational needs. This is particularly relevant for lightweight prefabricated panels. While insulated integrated panels can reduce steady-state heat loss, their summer performance must be carefully evaluated, especially in climates where overheating and solar gains are real risks *(Verbeke & Audenaert, 2018; Aste et al., 2009; Di Perna et al., 2011)*.

The literature on off-site construction highlights its environmental and practical benefits beyond heat transfer — such as waste reduction and optimized assemblies — influenced by logistics, material choices, and system design. For practical decision-making, thermal, energy, cost, and constructability aspects should be assessed together, and it is precisely this integrated approach that forms the basis of this study. *(Yu et al., 2021)*.

3. METHODOLOGY

This study follows a comparative case-study approach, applied to a two-story residential villa. The reference building is a detached home, described through architectural drawings and analyzed using comparative data on energy performance, cost, and construction time. The core of the approach lies in evaluating two different construction options applied to the same building, under the same conditions.

The methodological framework is structured around three analytical directions:

- *Energy performance*, by examining the thermal behavior and annual energy demand of a traditional wall system against an MRC prefabricated panel solution.
- *Implementation cost*, by comparing the bill of quantities for the conventional RC frame with brick infill against the fully structural MRC panel solution.
- *Implementation time*, by comparing the total construction duration needed for each of the two scenarios.

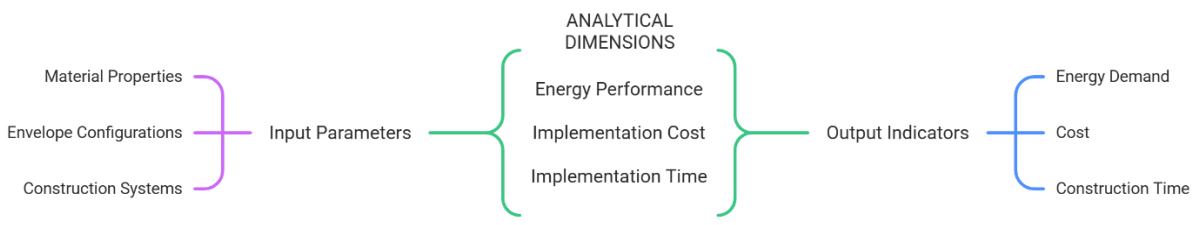


Figure 2. The comparative framework

The framework distinguishes clearly between input parameters (material properties, envelope configurations, and construction systems) and output indicators (energy demand, cost, and construction time), ensuring a structured comparison between the two scenarios.

3.1 The role of Building's Envelope in Energy Performance

The building envelope — which includes exterior walls, roof, ground floor, windows, and doors — has a direct impact on how much energy a building needs to maintain comfortable indoor conditions. These elements are the main pathway through which heat moves between the inside and the outside, driving both heat losses in winter and heat gains in summer.

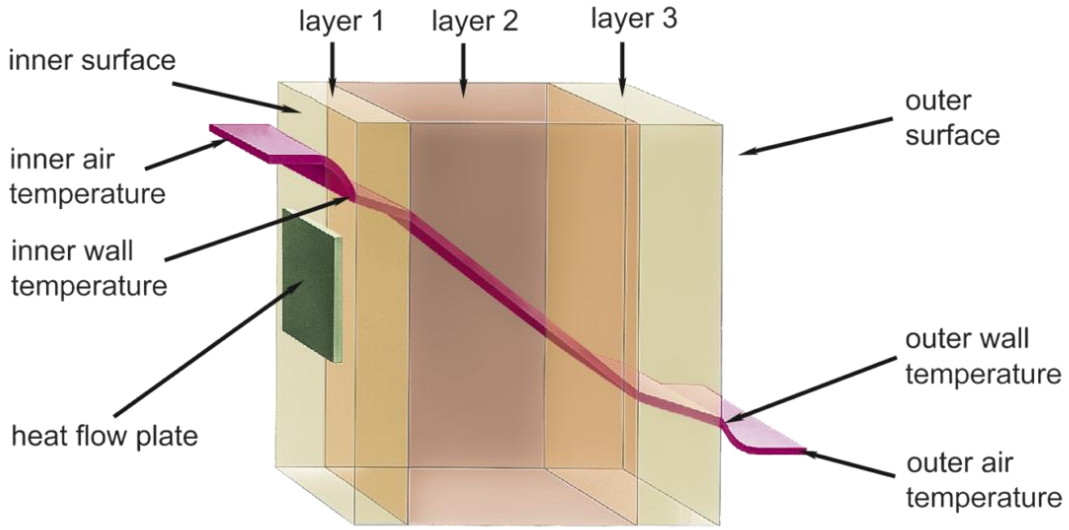


Figure 3. The heat flux measurement diagram (source: ahlborn.com)

The thermal performance of the envelope depends on the properties of the materials used, how the layers are arranged, and the quality of construction. The most important factors are the U-value, heat capacity, and airtightness, all of which directly influence how much energy the building consumes.

This study compares two energy scenarios under the same boundary conditions. Both variants use identical windows and ground-floor assemblies, but differ in their wall and roof construction. The traditional wall system has a wall U-value of 0.546 W/m²K and a roof U-value of 0.581 W/m²K. The MRC panel solution brings these down to 0.288 W/m²K and 0.33 W/m²K, respectively. The ground floor remains unchanged in both cases, with a U-value of 1.663 W/m²K — making it the thermally weakest part of the envelope in both scenarios.

The comparison is based on the following criteria: thermal transmittance of the main envelope components, annual total energy consumption, annual delivered energy, annual primary energy, and performance relative to the national building benchmark. The methodology follows the well-established principle that envelope heat transfer should be assessed through standardized thermal resistance and transmittance calculations, while also recognizing that whole-building performance is shaped by additional factors such as thermal bridges,

airtightness, and dynamic thermal behavior. For this reason, the results are not interpreted as simple U-value improvements in isolation, but rather as system-level outcomes of switching from one envelope technology to another. *(Poza-Casado et al., 2020; Verbeke, 2018)*.

3.2 Energy Simulation Framework

The energy performance assessment was conducted using the MEEC (Montenegrin Energy Efficiency Certification) software, a standardized calculation tool based on European energy performance methodologies for residential buildings. The analysis follows a quasi-steady-state approach consistent with regulatory energy certification procedures, allowing for comparative evaluation of building envelope performance.

The case study building is assumed to be located in Tirana, Albania, characterized by a Mediterranean climate. Due to the compatibility of climatic conditions, climate data for Podgorica, Montenegro were used within the MEEC software environment. Both cities exhibit similar temperature profiles, seasonal variations, and heating-cooling demand patterns, making this substitution methodologically acceptable for comparative analysis.

To ensure consistency, identical boundary conditions were applied to both construction scenarios. The main assumptions include:

- Indoor heating setpoint: 20-21 ºC
- Cooling setpoint: 25-26 ºC
- Occupancy profile: standard residential usage patterns
- Internal heat gains: based on typical household activity
- Ventilation rate: in accordance with standard residential air exchange assumptions
- Infiltration: assumed equal for both scenarios
- HVAC system: simplified system with standard efficiency parameters as defined in MEEC
- Primary energy factors: applied according to national energy certification convention.

The analysis isolates the influence of the building envelope by maintaining all other parameters constant across both scenarios. Consequently, the results should be interpreted as comparative evaluation of envelope performance, rather than an absolute prediction of real operational energy consumption.

It should be noted that the adopted methodology does not involve fully dynamic simulation, and therefore does not explicitly capture transient thermal effects, detailed occupant behavior, or advanced system interactions. However, it provides a robust and consistent basis for evaluating relative differences between construction systems within the same climatic and operational context.

3.3 U-value and thermal-envelope criteria

This study relies on the standard U-value approach, in line with ISO 6946, where thermal transmittance is defined as the inverse of the total thermal resistance of a building

component. Although the draft includes an incomplete mathematical explanation, the main goal is straightforward: to compare different envelope options based on how well they reduce heat flow through walls and roof assemblies. Since thermal bridges and local discontinuities can cause real-world performance to differ from standard U-value calculations, the study also briefly addresses these effects, drawing on ISO 10211 and related research.

The U-value, or thermal transmittance coefficient, tells us how much heat passes through a building element per unit area for every 1°C or 1K difference in temperature between inside and outside. It is calculated as the ratio between the heat flux density through the element and the indoor-outdoor temperature difference. Under controlled experimental conditions, this is expressed by the following formula:

$$U = \frac{q}{T_i - T_e}$$

where:
U= thermal transmittance coefficient (W/m^2K)
q= heat flux density (W/m^2)
T_i= indoor air temperature $(^\circ C)$
T_e= outdoor air temperature $(^\circ C)$

Theoretically, the U-value can also be calculated as the inverse of the total thermal resistance of the element:

$$U = \frac{1}{R_{tot}}$$

where R_{tot} includes the thermal resistances of all the component layers of the element, as well as the internal and external surface resistance. This method is widely used in design, while the direct measurement method serves for experimental verification of the real performance of building elements.

3.4 Condensation and surface-temperature considerations

The draft draws attention to temperature distribution and condensation risk, in line with ISO 13788 and research showing that cold spots can lead to condensation, moisture buildup, and material deterioration over time. Condensation is not directly simulated in this study, but is treated as a likely consequence of poor junctions and thermal bridging. Integrated panel systems may therefore be beneficial not only for achieving lower U-values, but also for improving thermal continuity and reducing the severity of cold bridges when properly detailed.

The way heat moves through a building element — and the temperature distribution that results — directly determines where condensation is most likely to form:

- Thermal bridges: These are localized areas, such as metal connectors or wall-to-floor joints, where heat flows much faster than through the surrounding construction. These spots tend to have the lowest surface temperatures and are therefore the first places where condensation develops.

- Insulation quality: Better insulation helps keep internal surface temperatures higher, which reduces the risk of the air near those surfaces cooling below its dew point.
- Heating consistency: Maintaining a steady, moderate level of heat across all rooms is more effective at preventing condensation than heating one room to a high temperature while leaving others cold.

3.5 Thermal bridge assessment

Thermal bridges are widely recognized in the literature as one of the main factors that weaken the thermal performance of building envelopes. They occur where insulation is interrupted by structural elements or changes in geometry, leading to increased heat flow and lower internal surface temperatures. Many studies show that thermal bridges can significantly raise heating and cooling energy needs, while also increasing the risk of condensation and indoor comfort problems. In practice, these effects are most visible at wall-to-floor junctions, column edges, window reveals, and roof-to-wall connections — precisely the areas where traditional layered construction tends to be most vulnerable.

Existing research on envelope design makes it clear that relying solely on the U-value of uniform elements can lead to underestimating real energy losses caused by thermal bridges. The difference between calculated and actual performance can be substantial, particularly in buildings where structural elements frequently interrupt the insulation layer. As a result, analyzing construction details and comparing different envelope systems has become an essential step in studies focused on building energy performance.

In recent years, there has been growing interest in integrated envelope systems, such as prefabricated panels with built-in insulation. These systems can reduce both the frequency and severity of thermal bridges compared to conventional masonry walls with separate insulation layers. By combining structural and thermal functions into a single continuous component, they limit the number of junctions and interfaces where bridging typically occurs. Such approaches are now seen as key to building more energy-efficient structures and improving the long-term durability of the envelope.

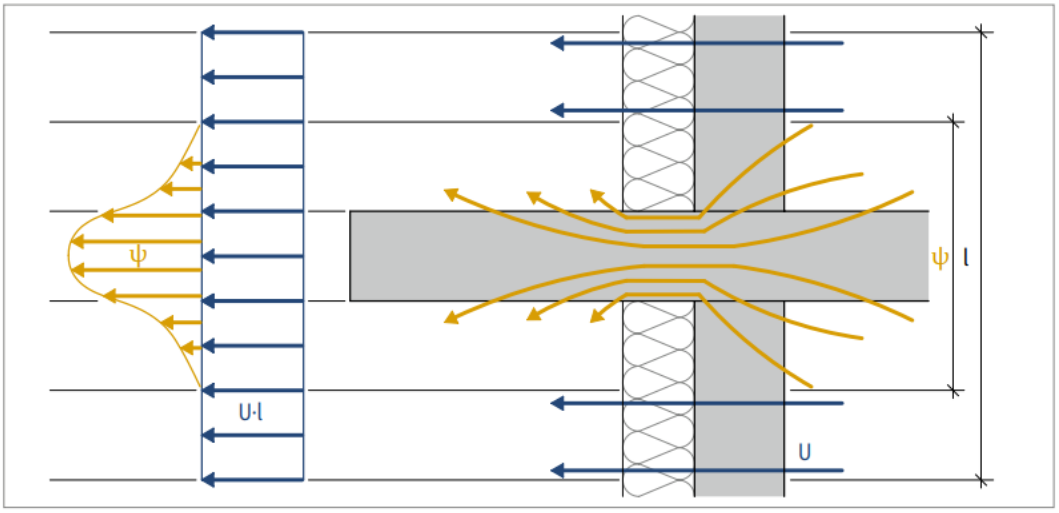


Figure 4. The illustrative diagram of a thermal bridge in building construction (source: schoeck.com)

It is important to clarify that thermal bridges, airtightness, and condensation effects are discussed qualitatively and are not explicitly included in the numerical energy calculations. Their role is considered interpretative, supporting the understanding of differences between construction systems. This represents a limitation of the study and may affect the accuracy of absolute performance values.

3.6 Cost and Time Comparison Method

For the cost and time comparison, the study relies on detailed Bills of Quantities for both scenarios. Both include the same work packages — earthworks, roof works, finishes, doors and windows, MEP, and external works. The key difference between the two lies in the structural and wall packages. In Scenario 1, the building follows a traditional approach, with RC foundations, columns, shear walls, beams, slabs, reinforcement bars, brick infill walls, and a separate façade insulation layer. In Scenario 2, the same RC foundations are kept, but the superstructure is built entirely with MRC panels, serving as both vertical and horizontal load-bearing elements. This results in significantly less reinforcement steel and eliminates the need for a separate brick infill package altogether.

The cost estimates were prepared in accordance with the Albanian Manual of Construction Works Prices and DCM No. 629, dated 15.07.2015, as referenced in both uploaded cost sheets. The time comparison is based on the total execution durations derived from the construction schedules developed for each scenario.

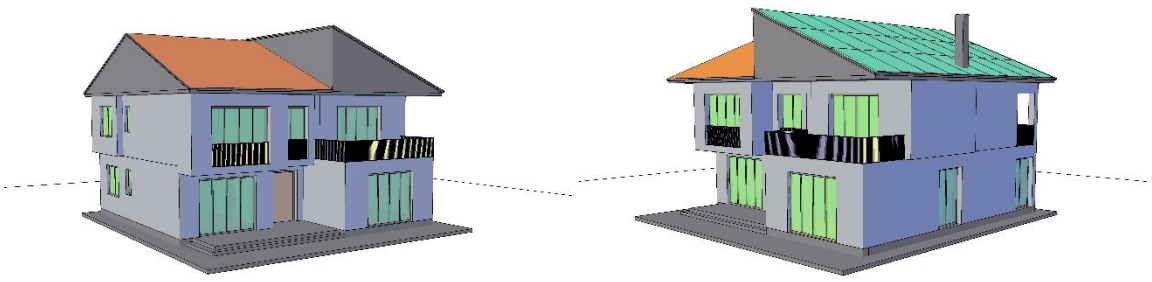


Figure 5. The 3D volumetry of the villa in the case study

This two-part structure allows the study to clearly separate the effects on operational energy performance from those related to construction cost and time. This distinction matters because the energy simulation focuses specifically on envelope differences, while the cost and time comparison reflects a broader, system-level substitution — one that goes beyond the envelope alone and covers the entire structural approach of the building.

4. RESULTS AND DISCUSSION

4.1 Energy performance of the envelope variants

The results clearly show that the prefabricated MRC panel system performs better in thermal and energy terms compared to the traditional wall solution. The wall U-value drops from 0.546 W/m²K to 0.288 W/m²K, reflecting a significant reduction in heat loss through the vertical envelope. The roof follows a similar trend, improving from 0.581 W/m²K to 0.33 W/m²K. Since

windows and ground floor remain the same in both scenarios, these gains are directly linked to the upgraded wall and roof assemblies.

At the whole-building level, the total annual energy requirement falls from 265.19 kWh/m²a in the traditional scenario to 225.65 kWh/m²a with the MRC panel system. Delivered energy drops from 298.46 kWh/m²a to 252.72 kWh/m²a, and total primary energy from 369.35 kWh/m²a to 315.07 kWh/m²a. This means the panel-based envelope cuts primary energy demand by roughly 14.7% — a meaningful improvement achieved through a single envelope technology change. Looking at monthly data, the reduction is most visible in the colder months, when heat losses through opaque elements are at their highest. January's demand falls from 35.61 to 28.39 kWh/m², February's from 27.92 to 22.15 kWh/m², and December's from 32.10 to 25.46 kWh/m².

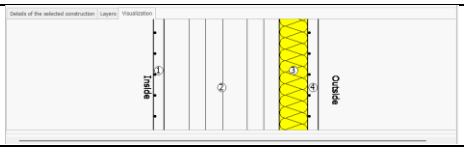
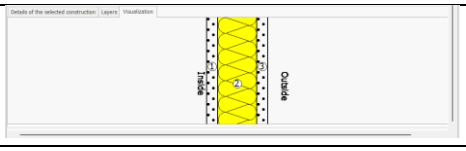
The reduction of approximately 14.7% in primary energy demand is primarily driven by improved envelope transmittance. However, the magnitude of improvement remains limited due to the unchanged ground floor performance, which acts as a dominant heat-loss pathway. This indicates that envelope optimization strategies must be holistic, as localized improvements cannot fully compensate for poorly performing elements.

These findings are consistent with the broader body of research on prefabricated and insulated panel systems. Several studies on precast sandwich walls show that integrated insulated assemblies tend to offer better thermal resistance than traditional masonry, provided that connector bridging and local construction details are properly handled. This case supports that conclusion: the prefabricated system delivers improved annual energy performance thanks to its lower transmittance and better thermal continuity compared to the conventional alternative.

That said, both variants still fall well above the national building benchmark of 148.5 kWh/m²a. The traditional scenario sits at 249.2% of the benchmark, while the MRC panel solution reaches 212.6%. Although the panel system clearly improves performance, it is not enough on its own to bring the building to a high-efficiency standard.

The main reason is straightforward: the ground floor U-value remains at 1.663 W/m²K in both cases — far worse than the wall and roof values — and likely accounts for a large share of the total heat loss. This highlights an important point: even a well-performing wall system cannot compensate for significant losses elsewhere in the envelope. Research consistently confirms that a building's energy performance depends on the combined behavior of all its components — walls, roof, floor, windows, airtightness, and junctions — not on any single element in isolation.

Table 1. The energy parameters input for both scenarios

	Traditional Wall	MRC Panel
Input wall		

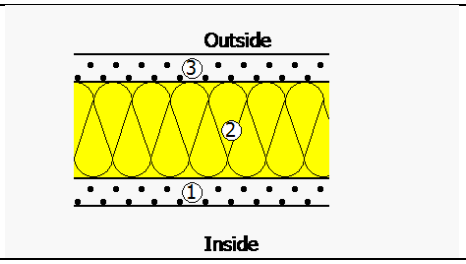
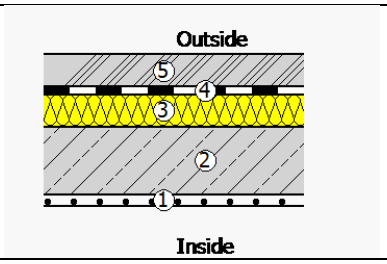
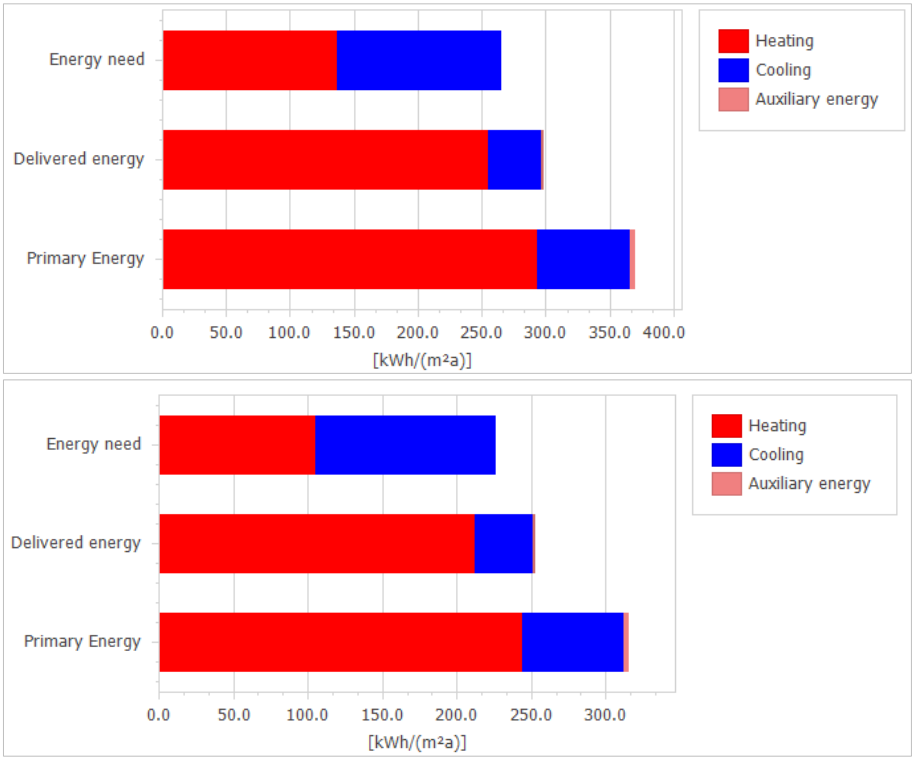
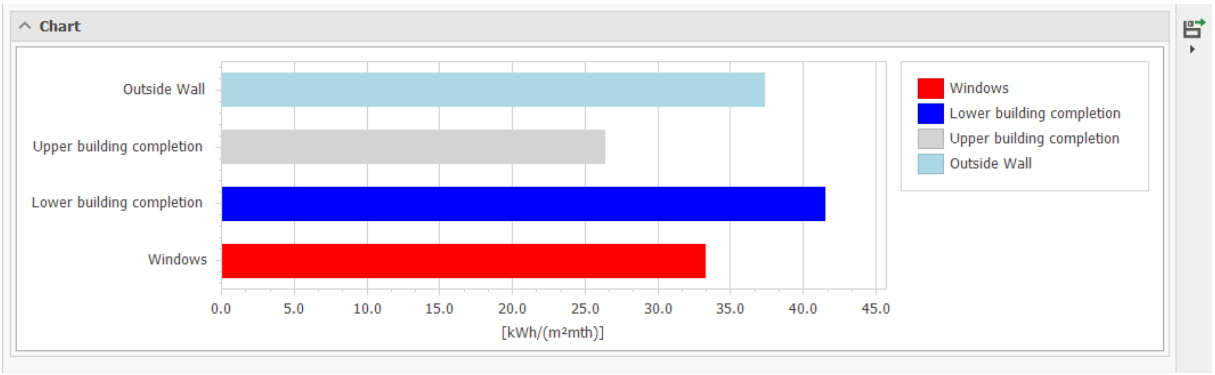
U-value W/(m²K)	0.546	0.288
Window	Same window for both variants	
U-value W/(m²K)	1.67	1.67
Roof		
U-value W/(m²K)	0.581	0.33
Ground floor	Same window for both variants	
U-value W/(m²K)	1.663	1.663

Table 2. The total energy performance results

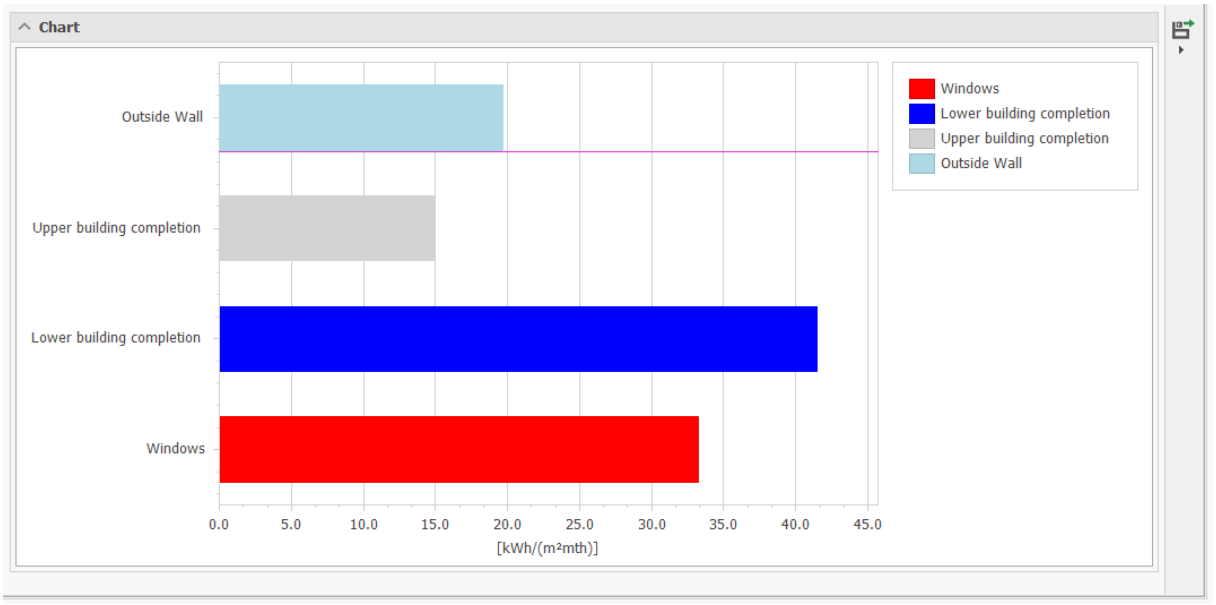
Results		
Total energy need (kWh/(m²a)	265.19	225.65
Total delivered energy (kWh/(m²a)	298.46	252.72
Total primary energy (kWh/(m²a)	369.35	315.07
National Building Benchmark	148.5	148.5
Differences between - Total primary energy and National Building	249.2%	212.6%



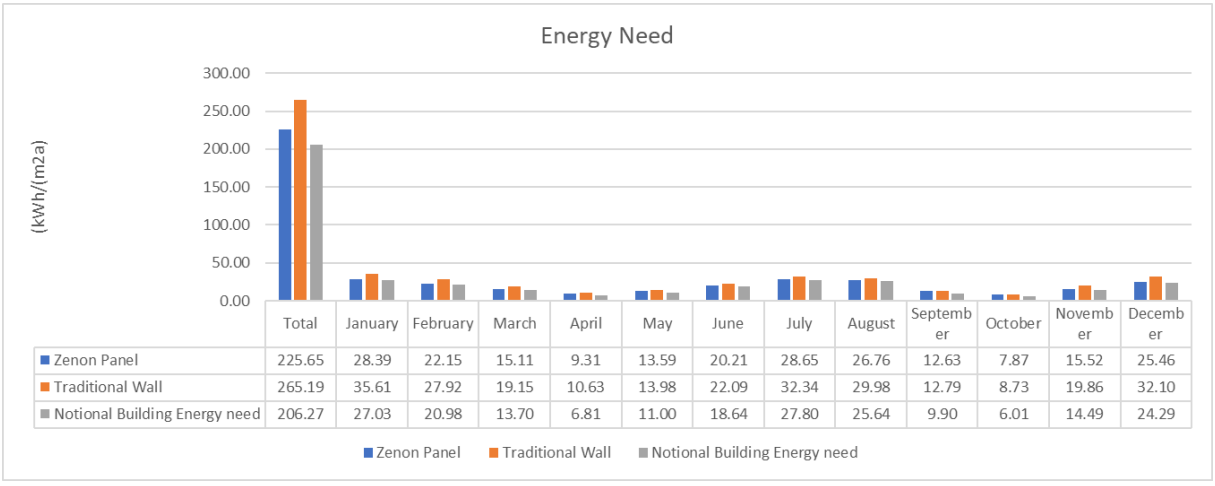
Graph 1. The performance graph of the Traditional Wall system (above) and MRC Panel (below)



Graph 2. The transmission heat losses chart of Traditional Wall system



Graph 3. The transmission heat losses chart of MRC Panel system



	Total	January	February	March	April	May	June	July	August	September	October	November	December
Zenon Panel	225.65	28.39	22.15	15.11	9.31	13.59	20.21	28.65	26.76	12.63	7.87	15.52	25.46
Traditional Wall	265.19	35.61	27.92	19.15	10.63	13.98	22.09	32.34	29.98	12.79	8.73	19.86	32.10
Notional Building Energy need	206.27	27.03	20.98	13.70	6.81	11.00	18.64	27.80	25.64	9.90	6.01	14.49	24.29

Graph 4. The monthly energy needs chart of MRC Panel, Traditional Wall and National Building

4.2 Thermal bridges, condensation risk, and construction quality

In traditional RC-frame construction with brick infill, thermal bridges typically form at slab edges, columns, beams, balconies, and wherever the structural frame meets the masonry or

external insulation layer. These are precisely the points where the insulation layer is most likely to be interrupted, compressed, or simply missing — and where heat finds the path of least resistance through the building envelope. In practice, such discontinuities are difficult to avoid entirely in layered construction, because each trade works on a separate system, and coordination gaps are common. An integrated panel system can help reduce these discontinuities by bringing structure, enclosure, and insulation closer together into a single coordinated assembly. The literature on thermal bridges and precast wall systems supports this view, but also warns that metal connectors and poorly designed junctions can themselves become significant heat transfer pathways if not carefully engineered (Alhawari et al., 2018; Kim et al., 2014).

The same logic applies to condensation risk. Lower surface temperatures caused by local thermal bridges increase the likelihood of condensation and mold growth, particularly in poorly ventilated areas such as corners, reveals, and junction zones. When surface temperatures drop below the dew point of the indoor air, moisture begins to accumulate — first invisibly, then visibly — leading over time to material deterioration, reduced air quality, and potential health issues for occupants. While integrated systems can improve thermal continuity and contribute to healthier interior surfaces, this is not an automatic outcome. The benefits depend heavily on precise connector design, accurate installation on site, and well-sealed junctions between panels and adjacent elements such as windows, floors, and roof edges.

For this reason, the MRC panel system should be seen not simply as a material swap, but as a broader detailing strategy — one that requires careful junction design and tight control over the quality of execution. The panel itself may perform well under laboratory or standard conditions, but its real-world effectiveness is ultimately determined by how well the critical details are resolved in practice. This means that the transition to an integrated panel system must be accompanied by a shift in design thinking: from component-by-component specification to a whole-envelope approach where every junction is considered, documented, and verified during construction.

4.3 Cost implementation results

The cost comparison offers a more nuanced picture than the energy analysis alone. The traditional construction method — an RC frame with perforated clay brick infill walls — carries an estimated total cost of €269,180 including VAT. The alternative approach, using lightweight MRC panels as the primary structural system, comes in at €276,618 including VAT. This represents a difference of €7,438, or approximately 2.76% more for the MRC panel solution. Before VAT, the gap narrows to €6,198, with figures of €224,317 and €230,515 respectively.

At first glance, the MRC panel solution appears more expensive. However, looking at the cost breakdown tells a more complete story. In the traditional scenario, the structural RC package costs €55,504, while the brick infill walls and façade insulation add another €17,088. In the

MRC scenario, the combined cost of RC foundations, MRC structural panels, and reinforcement steel totals €78,791 — but the separate infill wall package disappears entirely, because the panel system serves simultaneously as load-bearing structure and building enclosure. This means the higher upfront structural cost reflects a system-level substitution, not a straightforward like-for-like replacement of wall components.

From a practical standpoint, the cost increase can reasonably be considered moderate given what the system delivers. The MRC scenario reduces reinforcement steel from 18.35 tons to just 5.17 tons, eliminates the need for separate brick infill quantities, and merges structural and envelope functions into a single prefabricated component. These changes point to real potential benefits — a simpler and more streamlined workflow, better quality control, and possibly faster construction — even if these advantages are not directly captured in the static Bills of Quantities.

This is a well-known limitation in cost comparisons of this kind. Research on off-site and prefabricated construction consistently notes that standard initial-cost comparisons tend to undervalue industrialized systems, because the gains from factory-controlled production, reduced material waste, tighter tolerances, and shorter on-site construction time often do not show up in a conventional BOQ. The true economic picture only becomes clear when the full lifecycle of the building — including energy savings, maintenance, and construction efficiency — is taken into account. As a result, the comparative assessment may underestimate the full economic potential of the prefabricated system.

Table 3. Bill of Quantities and Cost for the RC frame structure and perforated clay brick infill walls

BILL OF QUANTITIES AND COST

Object: "Two-storey Residential Villa with RC frame structure and perforated clay brick infill walls"

No.	WORK DESCRIPTION	Unit	Quantity	Price (€/quantity)	Value €
	1. Earthworks				
1	Excavation	m^3	350	22	€ 7,700.0
2	Gravel fill	m^3	260	18	€ 4,680.0
3	Earth moving	m^3	400	4	€ 1,600.0
	Sum 1				€ 13,980.00
	2. Concrete and reinforced concrete works				
1	RC Foundations	m^3	52.6	150	€ 7,890.0
2	RC Columns and shear walls	m^3	11.1	220	€ 2,442.0
3	RC Beams	m^3	26.8	285	€ 7,638.0
4	RC Slab and stairs	m^3	42.3	280	€ 11,844.0
5	Rebar reinforcement	ton	18.35	1400	€ 25,690.0
	Sum 2				€ 55,504.00
	3. Infill Walls				
1	Infill wall with perforated clay bricks t=20cm	m^3	31.8	185	€ 5,883.0
2	Infill wall with perforated clay bricks t=12cm	m^3	8.0	181	€ 1,455.2
3	Facade cladding with thermo-insulation t=5cm + plaster.	m^2	195	50	€ 9,750.0
	Sum 3				€ 17,088.24
	4. Horizontal layers				
1	Styrobeton layer for filling and leveling	m^3	26.5	80	€ 2,120.0
2	Parquet flooring (rooms)	m^2	125	82	€ 10,250.0
3	Marble tile flooring (corridors and living room)	m^2	140	62	€ 8,680.0
4	Porcelain tile flooring (toilets)	m^2	73	30	€ 2,190.0
	Sum 4				€ 23,240.00
	5. Plastering and painting works				
1	Ordinary plaster for wall and ceiling	m^2	717	15	€ 10,755.0
2	Hydroplastic paint	m^2	717	6	€ 4,302.0
	Sum 5				€ 15,057.00
	6. Roof works				
1	Roof and insulation	m^2	195	65	€ 12,675.0
	Sum 6				€ 12,675.00
	7. Door and window works				
1	Doors	m^2	32.13	210	€ 6,747.3
2	Windows	m^2	65	185	€ 12,025.0
	Sum 7				€ 18,772.30
	8. Utilities Infrastructure - MEP				
1	Mechanical	lump sum			€ 10,000.0
2	Electrical	lump sum			€ 18,000.0
3	Plumbing	lump sum			€ 15,000.0
	Sum 8				€ 43,000.00
	9. Greening works and external arrangements				
1	All external works including greenery	lump sum			€ 25,000.0
	Sum 9				€ 25,000.00
	SUM 1 - 9				€ 224,316.54
	V.A.T. 20%				€ 44,863.31
	TOTAL				€ 269,179.85

**The cost estimate was drafted based on the manual of construction works prices and DCM No. 629 dated 15.07.2015.*

Table 4. Bill of Quantities and Cost with lightweight MRC panels as structural elements

BILL OF QUANTITIES AND COST

Object: "Two-storey Residential Villa with lightweight MRC panels as structural elements"

No.	WORK DESCRIPTION	Unit	Quantity	Price (€/quantity)	Value €
	1. Earthworks				
1	Excavation	m^3	350	22	€ 7,700.0
2	Gravel fill	m^3	260	18	€ 4,680.0
3	Earth moving	m^3	400	4	€ 1,600.0
	Sum 1				€ 13,980.00
	2. Reinforced concrete works and MRC structural panels				
1	RC Foundations	m^3	52.6	150	€ 7,890.0
2	MRC panels as vertical load-bearing elements	m^2	325	107	€ 34,775.0
3	MRC panels for horizontal load-bearing elements	m^2	270	107	€ 28,890.0
4	Rebar reinforcement	ton	5.17	1400	€ 7,235.8
	Sum 2				€ 78,790.76
	3. Horizontal layers				
1	Styrobeton layer for filling and leveling	m^3	26.5	80	€ 2,120.0
2	Parquet flooring (rooms)	m^2	125	82	€ 10,250.0
3	Marble tile flooring (corridors and living room)	m^2	140	62	€ 8,680.0
4	Porcelain tile flooring (toilets)	m^2	73	30	€ 2,190.0
	Sum 3				€ 23,240.00
	4. Plastering and painting works				
1	Ordinary plaster for wall and ceiling	m^2	717	15	€ 10,755.0
2	Hydroplastic paint	m^2	717	6	€ 4,302.0
	Sum 4				€ 15,057.00
	5. Roof works				
1	Roof and insulation	m^2	195	65	€ 12,675.0
	Sum 5				€ 12,675.00
	6. Door and window works				
1	Doors	m^2	32.13	210	€ 6,747.3
2	Windows	m^2	65	185	€ 12,025.0
	Sum 6				€ 18,772.30
	7. Utilities Infrastructure - MEP				
1	Mechanical	lump sum			€ 10,000.0
2	Electrical	lump sum			€ 18,000.0
3	Plumbing	lump sum			€ 15,000.0
	Sum 7				€ 43,000.00
	8. Greening works and external arrangements				
1	All external works including greenery	lump sum			€ 25,000.0
	Sum 8				€ 25,000.00
	SUM 1 - 8				€ 230,515.06
	V.A.T. 20%				€ 46,103.01
	TOTAL				€ 276,618.07

**The cost estimate was drafted based on the manual of construction works prices and DCM No. 629 dated 15.07.2015.*

4.4 Time implementation results

The construction timeline comparison further strengthens the case for the lightweight MRC panel system. According to the case study schedules, Scenario A — the traditional RC frame with brick infill walls — takes approximately 36 weeks, or around 9 months, to complete. Scenario B, using lightweight MRC panels, requires only 29 weeks. This is a reduction of 7 weeks, representing roughly 19.4% fewer total construction weeks.

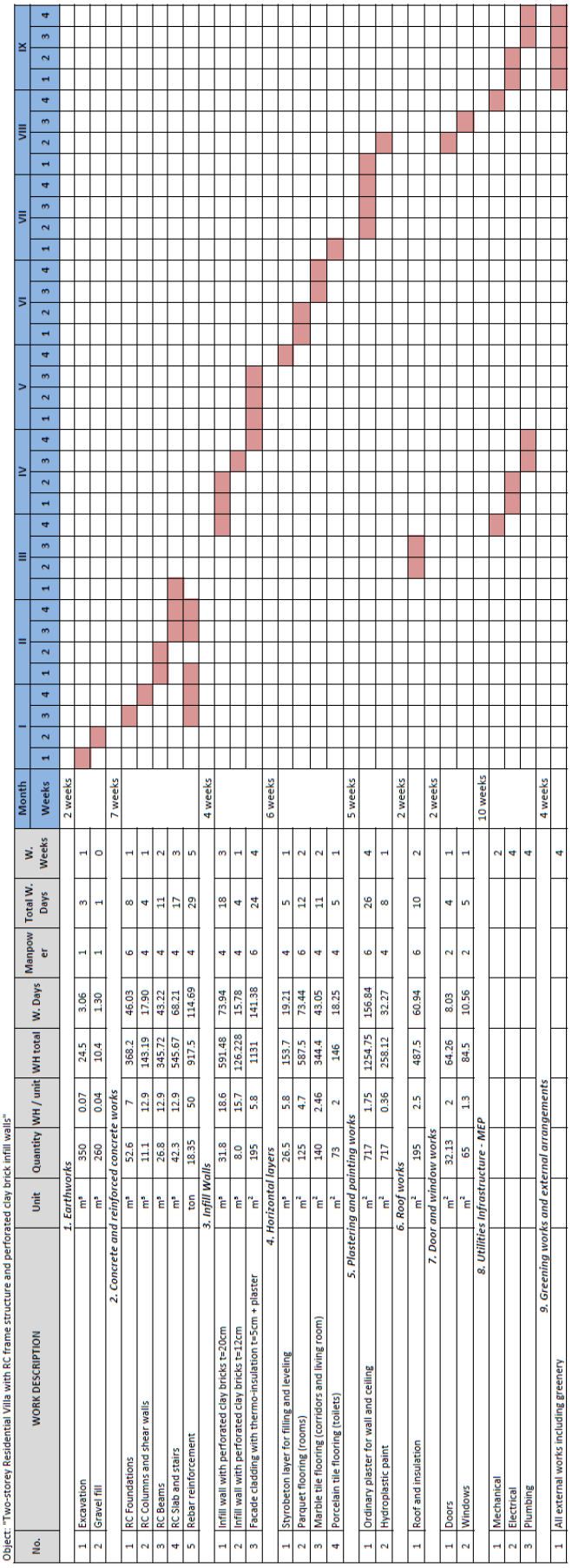
This difference has real and tangible implications on site. Traditional construction typically

follows a fragmented sequence: erecting the RC frame, waiting for curing, installing brick infill, adding façade insulation, and coordinating a series of finishing trades one after another. The MRC panel approach, by contrast, integrates structural and envelope functions into a single system, which simplifies the workflow and reduces the number of separate on-site operations needed to complete the building shell.

The shorter timeline of Scenario B highlights one of the most practical advantages of prefabricated construction. Industrialized panel systems generally allow faster site assembly, more predictable sequencing, and less dependence on wet trades compared to traditional RC frame methods. A time saving of nearly 20% of the total project duration is far from trivial — it can translate into lower site overhead costs, earlier building handover, reduced on-site labor exposure, and better cash flow management throughout the project.

When read alongside the energy and cost findings, the time results help build a more balanced and complete picture of what the MRC panel alternative actually offers. Although Scenario B carries a slightly higher initial cost, the shorter construction duration can partially offset this difference in real project conditions. This is an important point: the MRC system should not be judged on material and construction costs alone, but within a broader performance framework that also accounts for delivery speed, execution efficiency, and process simplification.

Taken as a whole, the time analysis confirms that the lightweight MRC panel solution brings not only thermal and structural benefits, but also a clear and measurable advantage in terms of implementation. For residential projects where timely delivery matters, cutting the construction period from 36 to 29 weeks is a compelling argument in favor of prefabricated integrated systems.

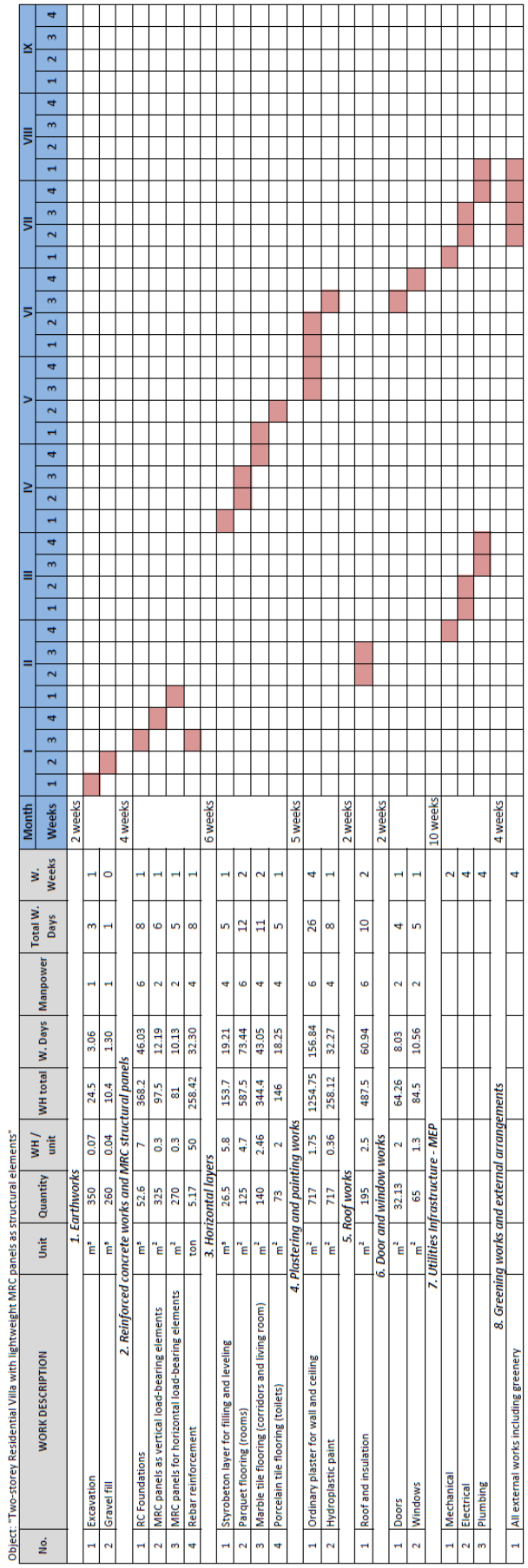


CONSTRUCTION TIME GANNT CHART

Object: "Two-storey Residential Villa with RC frame structure and perforated clay brick infill walls"

No.	WORK DESCRIPTION	Unit	Quantity	WH / unit	WH total	W. Days	Manpower	Total W. Days	W. Weeks	Month / Weeks	I 1	I 2	I 3	I 4	II 1	II 2	II 3	II 4	III 1	III 2	III 3	III 4	IV 1	IV 2	IV 3	IV 4	V 1	V 2	V 3	V 4	VI 1	VI 2	VI 3	VI 4	VII 1	VII 2	VII 3	VII 4	VIII 1	VIII 2	VIII 3	VIII 4	IX 1	IX 2	IX 3	IX 4
	1. Earthworks									2 weeks																																				
1	Excavation	m³	350	0.07	24.5	3.06	1	3	1																																					
2	Gravel fill	m³	260	0.04	10.4	1.30	1	1	0																																					
	2. Concrete and reinforced concrete works									7 weeks																																				
1	RC Foundations	m³	52.6	7	368.2	46.03	6	8	1																																					
2	RC Columns and shear walls	m³	11.1	12.9	143.19	17.90	4	4	1																																					
3	RC Beams	m³	26.8	12.9	345.72	43.22	4	11	2																																					
4	RC Slab and stairs	m³	42.3	12.9	545.67	68.21	4	17	3																																					
5	Rebar reinforcement	ton	18.35	50	917.5	114.69	4	29	5																																					
	3. Infill Walls									4 weeks																																				
1	Infill wall with perforated clay bricks t=20cm	m³	31.8	18.6	591.48	73.94	4	18	3																																					
2	Infill wall with perforated clay bricks t=12cm	m³	8.0	15.7	126.228	15.78	4	4	1																																					
3	Facade cladding with thermo-insulation t=5cm + plaster	m²	195	5.8	1131	141.38	6	24	4																																					
	4. Horizontal layers									6 weeks																																				
1	Styroboton layer for filling and leveling	m³	26.5	5.8	153.7	19.21	4	5	1																																					
2	Parquet flooring (rooms)	m²	125	4.7	587.5	73.44	6	12	2																																					
3	Marble tile flooring (corridors and living room)	m²	140	2.46	344.4	43.05	4	11	2																																					
4	Porcelain tile flooring (toilets)	m²	73	2	146	18.25	4	5	1																																					
	5. Plastering and painting works									5 weeks																																				
1	Ordinary plaster for wall and ceiling	m²	717	1.75	1254.75	156.84	6	26	4																																					
2	Hydroplastic paint	m²	717	0.36	258.12	32.27	4	8	1																																					
	6. Roof works									2 weeks																																				
1	Roof and insulation	m²	195	2.5	487.5	60.94	6	10	2																																					
	7. Door and window works									2 weeks																																				
1	Doors	m²	32.13	2	64.26	8.03	2	4	1																																					
2	Windows	m²	65	1.3	84.5	10.56	2	5	1																																					
	8. Utilities Infrastructure - MEP									10 weeks																																				
1	Mechanical								2																																					
2	Electrical								4																																					
3	Plumbing								4																																					
	9. Greening works and external arrangements									4 weeks																																				
1	All external works including greenery								4																																					

Figure 6. Construction time schedule of the RC frame structure and perforated clay brick infill walls



CONSTRUCTION TIME GANNT CHART

Object: "Two-storey Residential Villa with lightweight MRC panels as structural elements"

No.	WORK DESCRIPTION	Unit	Quantity	WH / unit	WH total	W. Days	Manpower	Total W. Days	W. Weeks	Month / Weeks	I 1	I 2	I 3	I 4	II 1	II 2	II 3	II 4	III 1	III 2	III 3	III 4	IV 1	IV 2	IV 3	IV 4	V 1	V 2	V 3	V 4	VI 1	VI 2	VI 3	VI 4	VII 1	VII 2	VII 3	VII 4	VIII 1	VIII 2	VIII 3	VIII 4	IX 1	IX 2	IX 3	IX 4
	1. Earthworks									2 weeks																																				
1	Excavation	m^3	350	0.07	24.5	3.06	1	3	1																																				
2	Gravel fill	m^3	260	0.04	10.4	1.30	1	1	0																																				
	2. Reinforced concrete works and MRC structural panels									4 weeks																																			
1	RC Foundations	m^3	52.6	7	368.2	46.03	6	8	1																																				
2	MRC panels as vertical load-bearing elements	m^2	325	0.3	97.5	12.19	2	6	1																																				
3	MRC panels for horizontal load-bearing elements	m^2	270	0.3	81	10.13	2	5	1																																				
4	Rebar reinforcement	ton	5.17	50	258.42	32.30	4	8	1																																				
	3. Horizontal layers									6 weeks																																			
1	Styrobeton layer for filling and leveling	m^3	26.5	5.8	153.7	19.21	4	5	1																																				
2	Parquet flooring (rooms)	m^2	125	4.7	587.5	73.44	6	12	2																																				
3	Marble tile flooring (corridors and living room)	m^2	140	2.46	344.4	43.05	4	11	2																																				
4	Porcelain tile flooring (toilets)	m^2	73	2	146	18.25	4	5	1																																				
	4. Plastering and painting works									5 weeks																																			
1	Ordinary plaster for wall and ceiling	m^2	717	1.75	1254.75	156.84	6	26	4																																				
2	Hydroplastic paint	m^2	717	0.36	258.12	32.27	4	8	1																																				
	5. Roof works									2 weeks																																			
1	Roof and insulation	m^2	195	2.5	487.5	60.94	6	10	2																																				
	6. Door and window works									2 weeks																																			
1	Doors	m^2	32.13	2	64.26	8.03	2	4	1																																				
2	Windows	m^2	65	1.3	84.5	10.56	2	5	1																																				
	7. Utilities infrastructure - MEP									10 weeks																																			
1	Mechanical								2																																				
2	Electrical								4																																				
3	Plumbing								4																																				
	8. Greening works and external arrangements									4 weeks																																			
1	All external works including greenery								4																																				

Figure 7. Construction time schedule of lightweight MRC panels as structural elements

4.5 Overall interpretation

Taken together, the results suggest that the MRC panel system delivers better thermal performance at a slightly higher initial cost compared to the traditional construction approach. This makes it a viable and environmentally friendly option, particularly for projects that prioritize envelope quality, industrialized construction methods, and integrated system design.

At the same time, the analysis reveals an important limitation: energy efficiency gains are ultimately constrained by the weakest part of the envelope. Even though wall and roof transmittance values were significantly improved, this did not lead to a proportional gain in overall energy compliance, because the ground floor remained highly conductive throughout both scenarios. The key lesson here is clear — MRC panels should not be treated as a standalone technological upgrade, but rather as one part of a broader, whole-envelope optimization strategy where all components are addressed together.

The cost comparison also points to a wider conclusion: judging the MRC panel system on initial cost alone gives an incomplete and potentially misleading picture. Its true value only becomes apparent when energy performance, construction time, and process efficiency are considered together as a package. Viewed through this lens, the MRC panel solution represents a more balanced and forward-looking approach to residential construction — one that is better aligned with the growing demand for sustainable, high-performance buildings.

5. CONCLUSIONS AND RECOMMENDATIONS

This study examined the thermal, energy, and cost-time implications of using prefabricated lightweight MRC panels as an alternative to traditional construction in a two-storey residential villa. The results clearly show that the panel-based envelope significantly improves the building's thermal performance. Compared to the conventional wall system, MRC panels reduced the wall U-value from 0.546 to 0.288 W/m²K, improved roof insulation, and brought annual primary energy consumption down from 369.35 to 315.07 kWh/m²a. These findings confirm that integrated prefabricated systems can deliver meaningful operational energy savings when they improve insulation continuity and reduce conductive heat losses through the opaque envelope.

At the same time, the study makes it clear that replacing the envelope alone is not sufficient to achieve high overall energy performance. Both scenarios continued to exceed the national benchmark by a wide margin, largely because the ground floor maintained a very poor U-value in both cases. This reinforces a well-established principle in building envelope research: real-world energy performance is shaped by the weakest components and by how all parts of the envelope — floors, junctions, windows, airtightness, and thermal bridges — work together as a system.

The cost analysis showed that the fully structural MRC panel solution is approximately 2.8% more expensive to implement than the traditional RC frame with brick infill. However, this

figure should not be read in isolation. The additional cost is relatively modest when weighed against the system's ability to combine load-bearing and enclosure functions in a single component, reduce the complexity of traditional wall construction, and offer the potential for higher quality and more consistent execution on site.

The time analysis adds another important dimension to this picture. The traditional scenario requires 36 weeks to complete, while the MRC panel scenario takes only 29 weeks — a saving of 7 weeks, or approximately 19.4% of the total construction period. This demonstrates that the prefabricated approach can significantly improve delivery speed and construction efficiency. In practical terms, this translates into better project planning, lower site overhead costs, and earlier building handover or occupancy.

Overall, the findings position lightweight MRC panels as a promising and environmentally responsible option for residential construction. Their main strengths lie in improved thermal performance, better energy efficiency, considerably faster construction, and only a moderate increase in upfront costs. This makes the system particularly well-suited for projects that place a high value on industrialized delivery, quality assurance, and execution speed.

Based on these findings, the following recommendations are put forward:

- Future design applications should optimize all envelope components — particularly the ground floor — in order to achieve stronger and more balanced overall energy performance.

- Future studies should incorporate detailed thermal bridge and airtightness analysis to further validate the operational benefits of integrated panel systems.

- Implementation assessments should go beyond first cost and also account for the indirect economic benefits associated with shorter construction durations.

- Broader life-cycle and environmental assessments should be carried out in future research to fully evaluate the sustainability potential of MRC panel systems.

In conclusion, the MRC panel system should be understood not as a simple material substitution, but as an integrated design and construction strategy — one that is capable of improving both building performance and project delivery outcomes in a meaningful and measurable way.

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