POLITECNICO DI TORINO

Master's Degree in **BUILDING ENGINEERING**

A Tiny House District in Milan: A Sustainable Proposal for Affordable Housing

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Abstract

This thesis presents a sustainable design proposal for a tiny house district in Milan, aiming to tackle the increasing challenge of affordable housing in rapidly growing megacities. In cities like Milan, high amounts of real estate prices have made it difficult to access quality housing, often forcing people to choose between affordability and livability. This project focuses on a compact housing unit thoughtfully designed for two persons, occupying only 28 square meters while efficiently integrating essential spaces such as a living room, kitchen, bathroom, and bedroom. Guided by the principle of “less house, more home,” as emphasized in ArchDaily's Tiny House 2024 Architecture Competition (1), the design carefully balances the need for functional, comfortable living with the constraints of limited space, showing that smaller dwellings can still provide a meaningful, high-quality living experience.

Sustainability is at the heart of this proposal, with a strong focus on passive design strategies and energy efficiency to reduce environmental impact. The building’s thermal performance is enhanced to lower energy consumption by making the most of natural ventilation, capturing valuable winter sunlight to support heating needs, and incorporating building-integrated photovoltaic (BIPV) panels that not only generate renewable energy but also serve as shading devices during the hotter summer months. By thoughtfully integrating natural site conditions and sustainable technologies, this approach offers an innovative solution that reconciles affordability, comfort, and environmental responsibility. In conclusion, this thesis illustrates how tiny houses can become a viable option for sustainable urban living in Milan’s challenging housing landscape.

1. Introduction

Rapid urban growth in megacities like Milan has significantly increased the demand for affordable housing, presenting a major challenge for both residents and urban planners (2). In such environments, high property prices frequently compel individuals and families to make difficult trade-offs between affordability and quality of living. This project tackles this issue by proposing a sustainable, compact housing concept tailored for a tiny house district near Milan. The main goal is to design a 28-square-meter dwelling optimized for two people, efficiently incorporating essential spaces such as a living room, kitchen, bathroom, and bedroom, within a limited footprint. Guided by the philosophy of "less house, more home", the design aims to prove that smaller dwellings can still offer meaningful, high-quality living experiences by thoughtfully balancing space efficiency, occupant comfort, and environmental sustainability (3).

An essential part of achieving this balance was performing a detailed climatic and environmental analysis of the site, which is located in via Racconigi, Milan. To gain a thorough understanding of the local microclimate and its influence on the building's performance, the Climate Consultant software (4) was utilized. This advanced tool compiles comprehensive meteorological data and generates detailed insights into critical parameters such as wind direction and speed, solar path and intensity, and shading requirements. These insights were instrumental in informing the building's shape, orientation, and envelope design, ultimately enhancing both energy efficiency and occupant comfort throughout the year.

For instance, the climatic data revealed that the southern exposure receives significant solar radiation, particularly beneficial during Milan's cold seasons. In response, the building was deliberately designed with a wider façade facing south in order to maximize solar gain, thereby naturally heating the interior spaces and reducing dependence on mechanical heating systems. The design also incorporates fixed Building-Integrated Photovoltaic (BIPV) panels on the southern roof and walls. This inclination is optimized to capture sufficient summer sunlight for renewable energy generation, while also serving as shading elements that help prevent overheating in the warmer seasons. Moreover, the fixed installation of these panels significantly reduces maintenance costs compared to an adjustable solar system, which aligns well with the affordability goals of this project (5).

Beyond solar considerations, passive design strategies are integrated throughout the project to further improve thermal performance and create a comfortable indoor environment. Green walls are installed on the east and west building envelopes, complemented by a green roof. These vegetated elements act as natural insulators, reducing heat gain during summer and heat loss in winter, while also contributing to the building's microclimate by enhancing air quality and providing a calming visual connection to nature (6). The north façade incorporates a secondary "skin" made of expanded metal supported by an aluminum substructure. This assembly not only provides structural support for the green walls, roof, and photovoltaic equipment, such as tanks and electrical switchboards, but also functions as a windbreak, reducing the impact of cold winter winds and protecting the main building envelope.

Internally, the two-story layout supports a clear functional division: the ground floor accommodates shared living spaces, including the living room, kitchen, and bathroom, while the upper floor provides private bedrooms for rest and relaxation. To maintain a sense of openness and spatial continuity within the compact footprint, a void is strategically placed on the west side of the first floor. This architectural feature facilitates visual and physical connectivity between the floors and plays a vital role in natural ventilation. Cool air enters through operable windows on the south-facing ground floor and rises through the void, exiting via openings on the northern side of the upper floor. This passive ventilation strategy utilizes the stack effect to promote continuous airflow without the need for mechanical ventilation, improving indoor air quality and thermal comfort while reducing energy consumption.

In summary, this project demonstrates a comprehensive approach to sustainable urban housing that integrates detailed climatic analysis, passive environmental design strategies, and cost-effective renewable energy technologies. By utilizing the site's natural conditions and carefully calibrated architectural solutions, the tiny house design not only achieves energy efficiency and occupant comfort but also supports economic feasibility and affordability. This design proposal provides a compelling example of how compact dwellings can be transformed into vibrant, comfortable, and sustainable homes, offering a promising path forward for addressing the housing challenges faced by Milan and other rapidly urbanizing cities worldwide.

2. Site Characterization

2.1 Geo-Location:

The site is located in via Racconigi, the northwestern area of Milan, Lombardy. It is situated in a mainly residential neighborhood, close to Parco Nord and well connected to the city center. The geo-location coordinates of the site are:

Latitude: 45.52

Longitude: 9.20

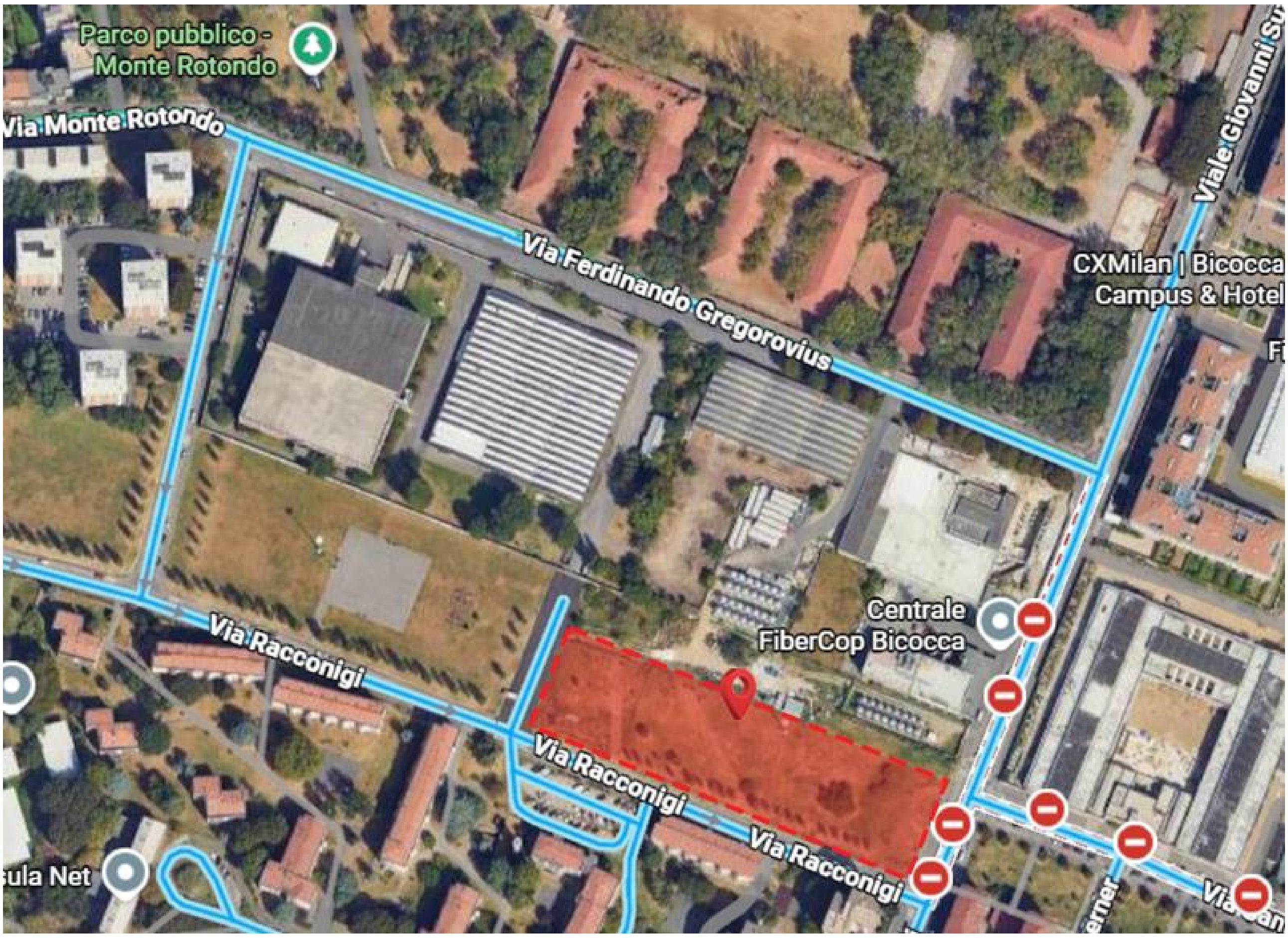

Figure 1. Google Earth picture of the location

2.2 Morphology of The Area

The location is characterized by a mix of housing units surrounded by green spaces and tree-lined areas. It benefits from excellent connectivity through a network of primary and secondary roads, alongside clearly defined sidewalks and vehicle routes, ensuring convenient accessibility. Essential amenities are within close proximity, including several supermarkets located between 400 and 900 meters away, a hospital approximately 2.3 kilometers from the site, and a gym within 900 meters, providing residents with easy access to daily necessities and healthcare services. Public transportation is also readily available, with the M5 Metro station situated just 750 meters from the area. The site receives sunlight predominantly from the south and southeast throughout the day (7). Seasonal wind patterns contribute to the local climate: during warmer months, prevailing winds from the southwest promote natural ventilation and cooling, while in colder seasons, winds from the north and northeast necessitate thoughtful architectural design to ensure thermal comfort and reduce heat loss (8).

Figure 2. Masterplan of the Tiny House (Scale: 1:500)

2.3 Climate Analysis

Based on the temperature range chart illustrated in **Figure 3**, the climate of Milan exhibits moderate seasonal variation. Winter months (December to February) experience average low temperatures slightly below 0°C, while summer months (June to August) see average highs reaching around 30°C. The comfort zone, which is shaded in gray, spans roughly between 20°C and 26°C, indicating that temperatures from late spring to early autumn generally fall within or near this comfortable range. The temperature data shows that the warmest months of July and August have occasional peaks above the comfort zone, suggesting potential cooling needs during these periods. Conversely, the colder winter months may require heating to maintain indoor comfort. Overall, the climate presents a balanced profile suitable for passive design strategies focused on both heating and cooling efficiency.

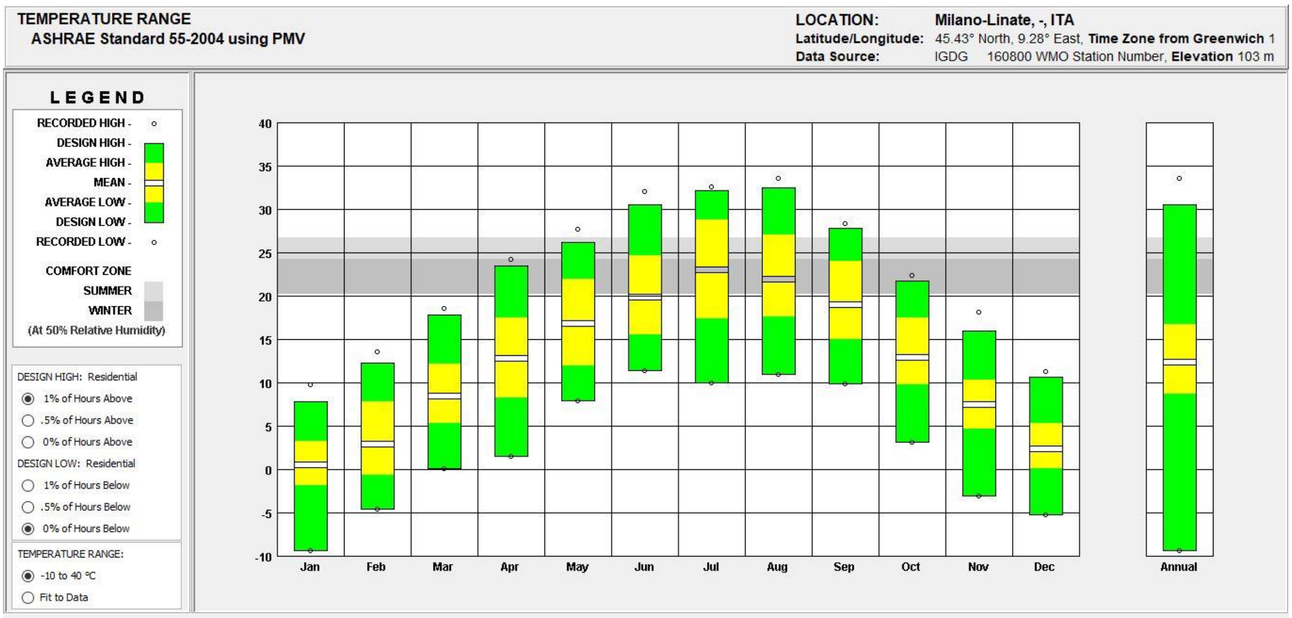

Figure 3. Temperature Ranges

Figure 4 demonstrates the annual wind diagram for Milan. During the months from May to September, the prevailing winds predominantly come from the south and southeast directions. Wind speeds frequently reach averages around 4 to 6 meters per second, with peak gusts occasionally approaching 10 meters per second. Relative humidity tends to be moderate to high, especially when wind speeds are lower. The temperature range during these months typically varies between 21°C and 27°C, indicating warm conditions coinciding with prevailing winds. This wind pattern suggests opportunities for natural ventilation by orienting openings to capture the southern airflow, which can aid in cooling during the warmer months and improve indoor air quality. Additionally, the moderate wind speeds support the feasibility of passive cooling strategies without excessive discomfort due to drafts.

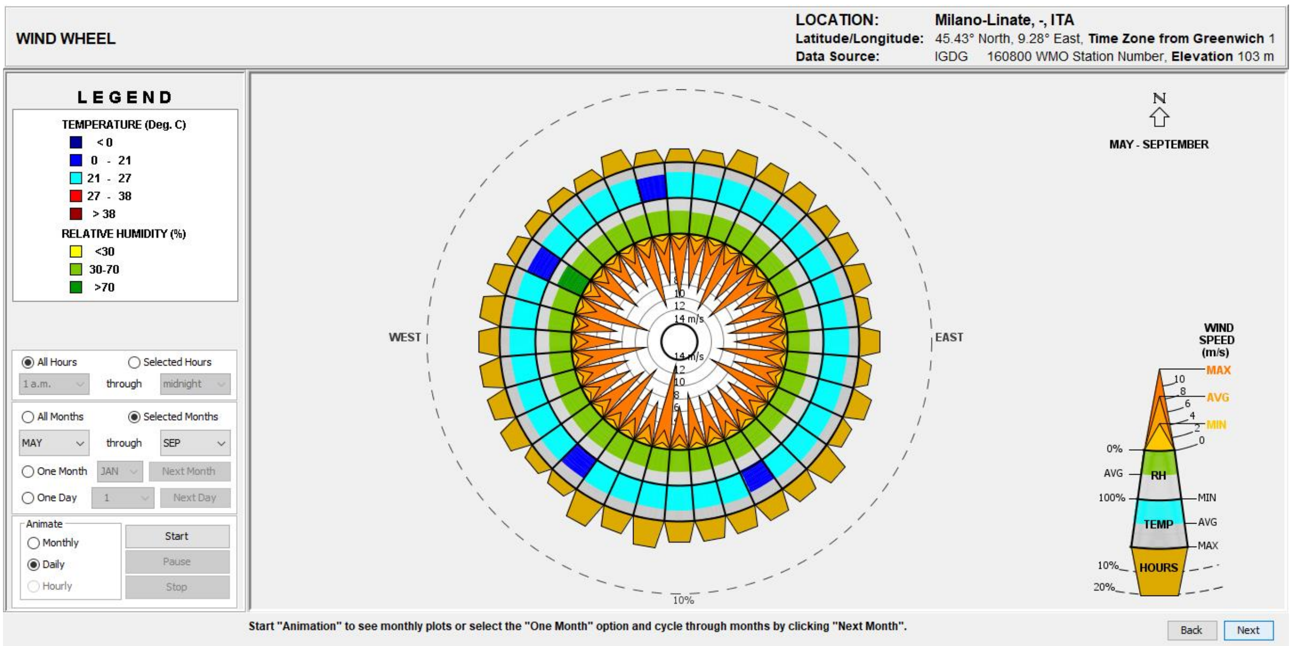

Figure 4. Annual Wind Path

Based on the sun chart (**Figure 5**), the sun's path varies significantly throughout the year, influencing solar exposure and shading needs (9). During the summer months (approximately June 21 to December 21), solar altitude angles are high, leading to strong sunlight exposure primarily in the mid-morning to mid-afternoon hours. In this period, temperatures often exceed 27°C (marked in red), indicating that shading is crucial to prevent overheating and reduce cooling loads. Conversely, in the cooler months from December 21 to June 21, the sun remains lower in the sky, with solar angles that promote sunlight penetration into the building, aiding passive heating and natural lighting. The chart highlights the importance of designing building elements, such as overhangs or fixed shading devices, that can effectively block excessive summer sun while allowing beneficial winter solar gain, optimizing thermal comfort and energy efficiency year-round.

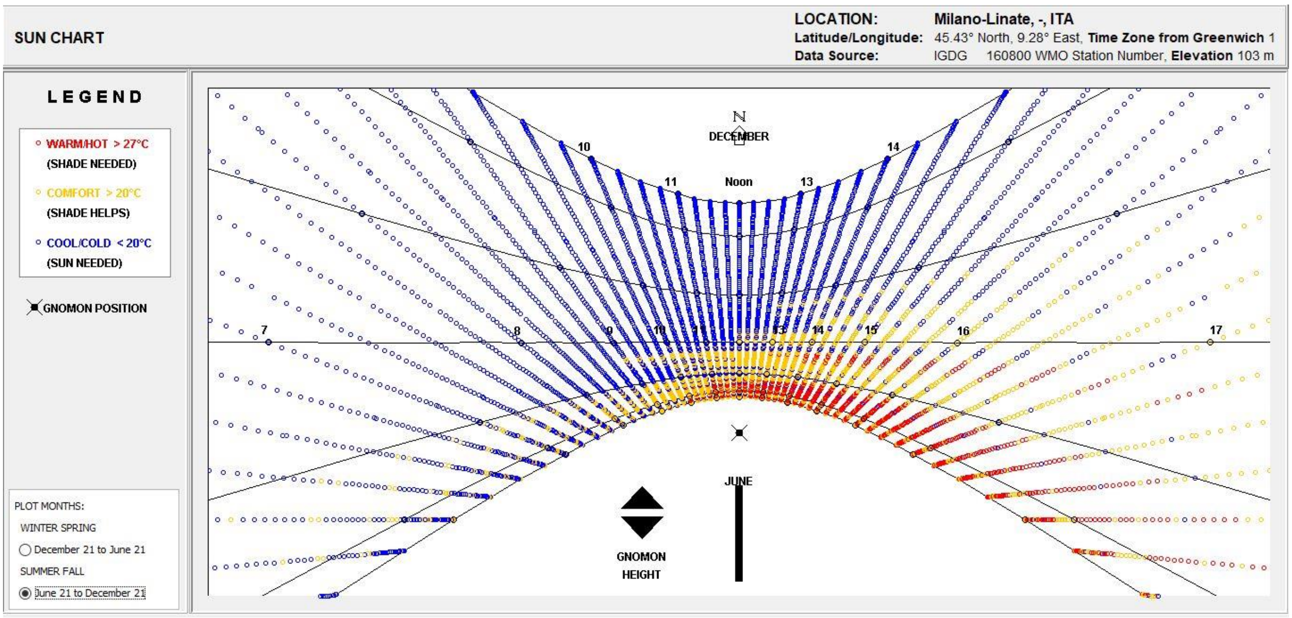

Figure 5. Sun Chart

Figure 6 shows the radiation range chart for Milan. It has been illustrated that the site experiences significant seasonal variation in solar radiation throughout the year. The highest solar radiation levels occur between April and August, peaking in June with daily totals exceeding 7,000 Wh/m². During these months, the sun's intensity provides ample potential for solar energy harvesting, making it an ideal period for photovoltaic energy generation. In contrast, the winter months (December to February) receive much lower radiation, with daily totals often below 1,000 Wh/m², reflecting reduced solar availability and necessitating greater reliance on passive solar design strategies to maximize heat gain. The annual solar radiation profile highlights the importance of incorporating both shading devices to prevent overheating in summer and design features that optimize solar gain during colder months, supporting energy efficiency and occupant comfort year-round.

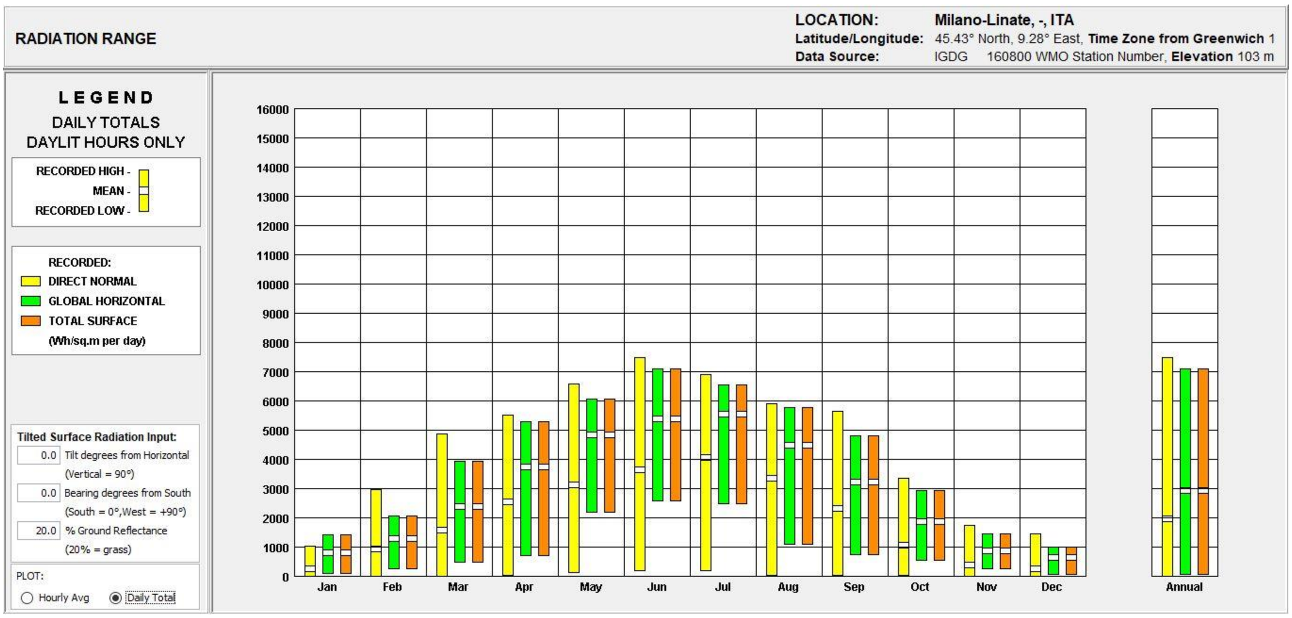

Figure 6. Radiation Ranges

The psychrometric chart for Milan (**Figure 7**) illustrates the relationships between air temperature, humidity, and other atmospheric properties. The indoor comfort conditions can be effectively maintained for the vast majority of the year using passive and low-energy design strategies. The chart indicates that about 100% of the hours annually fall within or near the comfort zone when appropriate strategies are applied. Key strategies contributing to this include internal heat gains, passive solar heating, and sun shading of windows, which together provide significant thermal regulation. Cooling and dehumidification needs are minimal, required for less than 10% of the year, reflecting the generally temperate climate. These conditions suggest that with careful design, such as optimized natural ventilation, shading, and passive solar gain, the building can maintain comfortable indoor environments efficiently, reducing reliance on active mechanical systems and supporting sustainability goals.

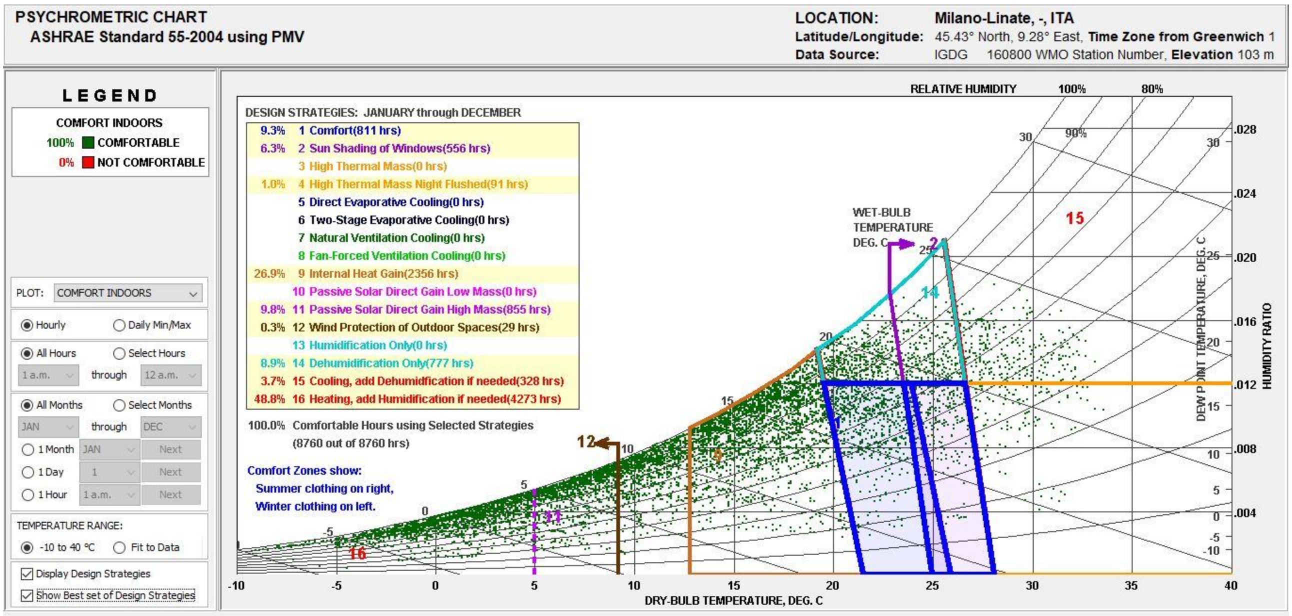

Figure 7. Psychrometric chart

2.4 Air Quality

Milan struggles with air pollution, particularly in winter months, due to the dense concentration of buildings and heavy vehicular traffic (10). **Figure 8** shows that annual average PM2.5 concentrations hover around 20-25 µg/m³, often exceeding EU limits. Traditional building designs often exacerbate this issue by creating urban canyons that restrict air flow, trapping pollutants at street level, and reducing natural ventilation. The adoption of green building strategies offers a promising solution to mitigate these effects. Incorporating features such as green roofs, vertical gardens, and increased vegetation around buildings can improve air quality by filtering airborne pollutants and producing oxygen. Additionally, green buildings promote better indoor air quality through the use of non-toxic materials and efficient ventilation systems. By enhancing urban biodiversity and facilitating natural air circulation, green buildings help reduce the heat island effect and lower energy consumption, contributing to a healthier, more sustainable urban environment in Milan.

2.5 Area Facilities

The area features a variety of building types. Predominantly, the neighborhood consists of residential buildings, including detached houses, townhouses, and small apartment complexes. These structures are often complemented by green courtyards and shared outdoor spaces. Additionally, the presence of a nearby park provides residents with accessible recreational space, enhancing the neighborhood's livability and connection to nature. Scattered throughout the area are also larger apartment blocks and institutional buildings, which serve both residential and commercial purposes. In addition, residents have convenient access to several supermarkets, a hospital, and a gym, ensuring their daily needs and healthcare requirements. This diverse architectural fabric supports a vibrant, livable neighborhood that meets the needs of a broad range of residents while maintaining a cohesive urban character.

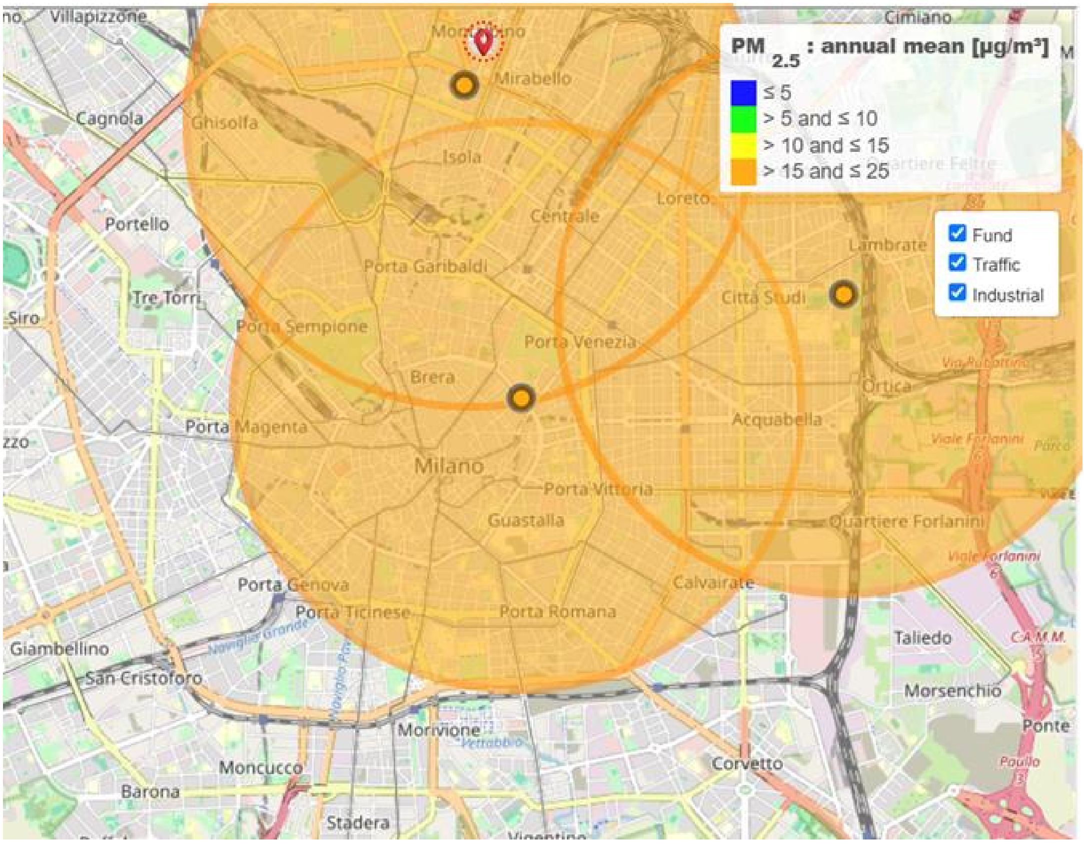

Figure 8. Annual Average of PM2.5 Index in Milano, 2024. The three orange circles on the map indicate the locations of traffic monitoring stations. Source: ISPRA (10)

2.6 Green Areas

As of 2024, Milan's urban green space coverage is approximately 11% of the municipal area, illustrated in **Figure 9**. On average, Milan offers approximately 19 square meters of public green space per resident. This includes parks, gardens, tree-lined avenues, and other accessible green areas that contribute to the city's overall livability and environmental quality (11). This project aims to develop this site into a sustainable, high-performance, and environmentally friendly building; therefore, it would be beneficial to acknowledge the existing green areas within the project and consider expanding them.

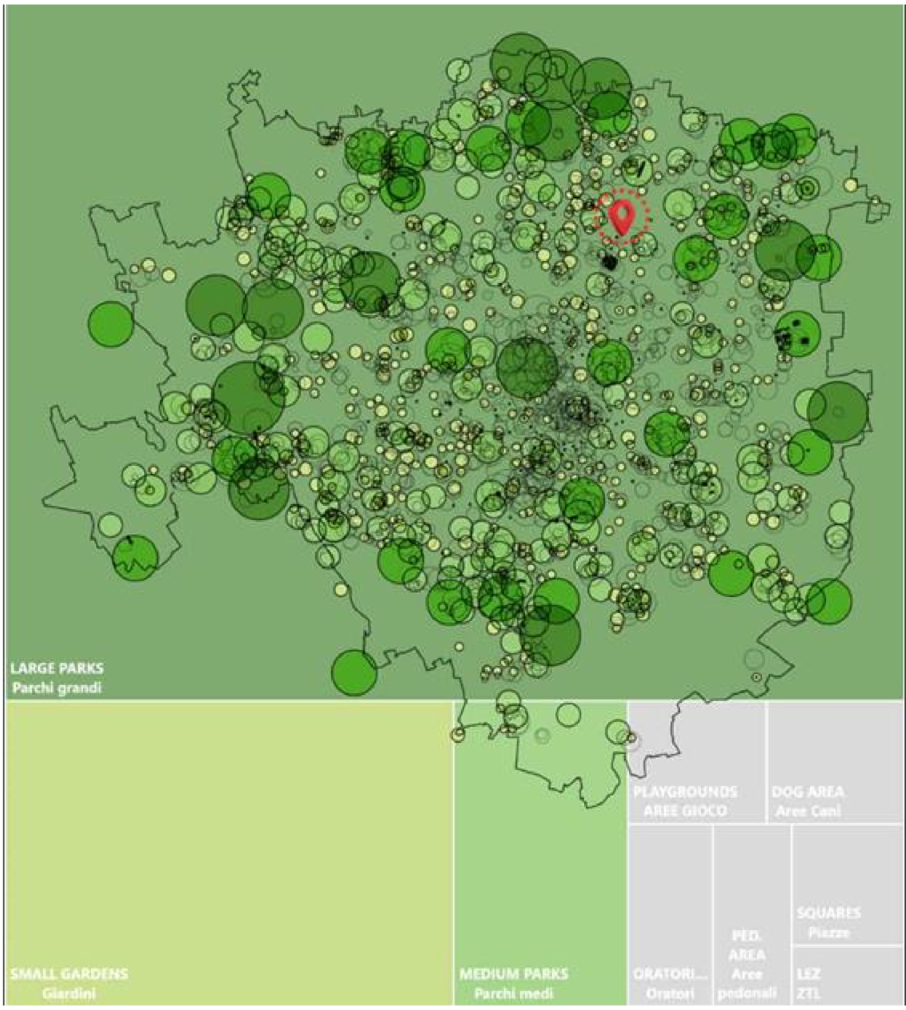

Figure 9. Public parks and gardens. Source: Transform Transport (11)

2.7 Accessibility

The transportation network in the area is highly efficient and well-integrated, characterized by numerous bus and tram stops situated within close proximity, as well as convenient access to nearby metro stations (12). This variety of public transit options ensures residents and visitors have a wide range of reliable options to choose from. In addition, the road infrastructure in the surrounding area is well-maintained and facilitates smooth movement for vehicles. Traffic volumes in the vicinity are generally low, which contributes to a stress-free commuting experience with minimal delays. Additionally, the area is linked to the city center by wide avenues that circle around it, providing straightforward and convenient routes for both private vehicles and public transportation. These features make the area exceptionally well-connected and accessible, enhancing its appeal as a convenient and practical location for residents and commuters alike.

3. Design Concept and Principles

The primary goal of this project is to design an energy-efficient and affordable residential building that responds thoughtfully to its local climate conditions. By optimizing solar gain through strategic orientation and integrating fixed BIPV panels for sustainable energy generation, the proposed design focuses on reducing reliance on external power sources while minimizing maintenance costs. Additionally, creating a comfortable indoor environment through natural ventilation and improved thermal performance with green walls and roofs supports occupant well-being. Overall, the project aims to balance sustainability, cost-effectiveness, and comfort to contribute to affordable, eco-friendly housing solutions in the Milan area.

Figure 10. South and North View of the Building

3.1 Space and Function

3.1.1 Site Plan

The site comprises 11 buildings, and each building height is 6.60 meters measured with respect to the ground level. The design goal is to arrange the buildings in order to maximize sunlight exposure during winter while minimizing wind impact. To support this goal, two large green spaces are situated on the north side of the buildings. These green areas serve dual purposes: providing residents with inviting spaces for evening relaxation and offering playgrounds for children. Covering a total of 1,145 square meters for 22 occupants, the green space allocation amounts to approximately 50 square meters per person, aligning with the recommended standards set by the World Health Organization (WHO) (13). Each of the 11 housing units is allocated its own dedicated parking space, with an additional four parking spots available for guests. Moreover, native species are considered wherever possible in private green spaces and never be included on the Blacklist referenced in DGR46-5100 / 2012.

Figure 11. Site plan of the Tiny House (Scale: 1:200)

3.1.2 Ground Floor

The ground floor is designed with an internal height of 2.9 meters to ensure ample spatial comfort and optimal air quality, in compliance with current state laws and relevant regulations. It includes communal spaces such as the living room, kitchen, and bathroom, and has a minimum floor area of 16 square meters. These dimensions support a functional and comfortable living environment, promoting hygiene, accessibility, and ease of movement within the main activity zones of the home.

3.1.3 First Floor

On the first floor, the internal height is set slightly lower at 2.7 meters, still meeting all regulatory standards for comfort and air quality. This floor primarily contains private spaces such as bedrooms, with minimum room sizes of 12 square meters. These spatial requirements help maintain privacy, comfort, and usability, ensuring the sleeping areas are appropriately sized for restful living while adhering to safety and accessibility standards.

3.2 Functional Distribution

3.2.1 Ground Floor

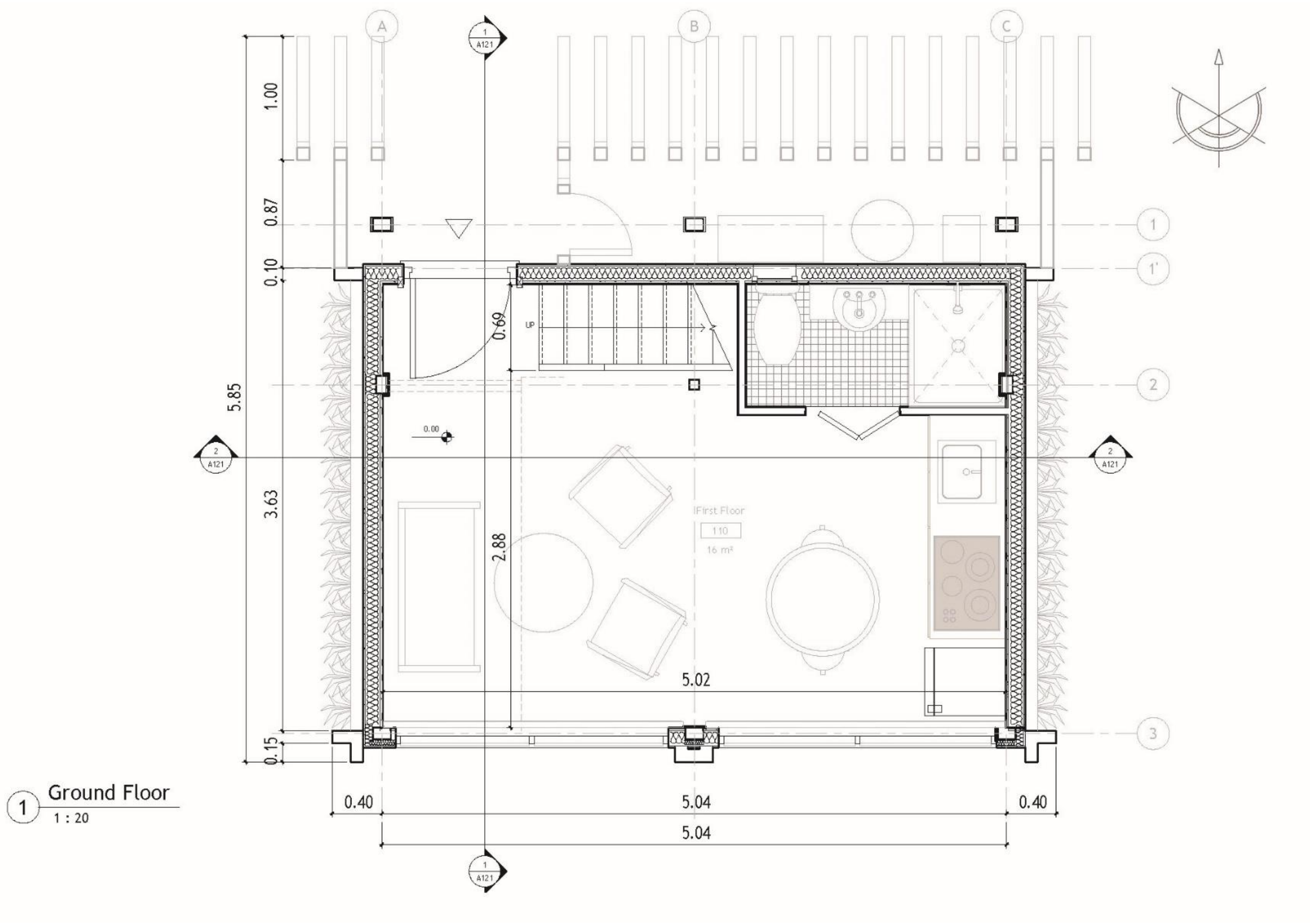

Figure 12. Ground Floor Plan

3.2.2 *First Floor*

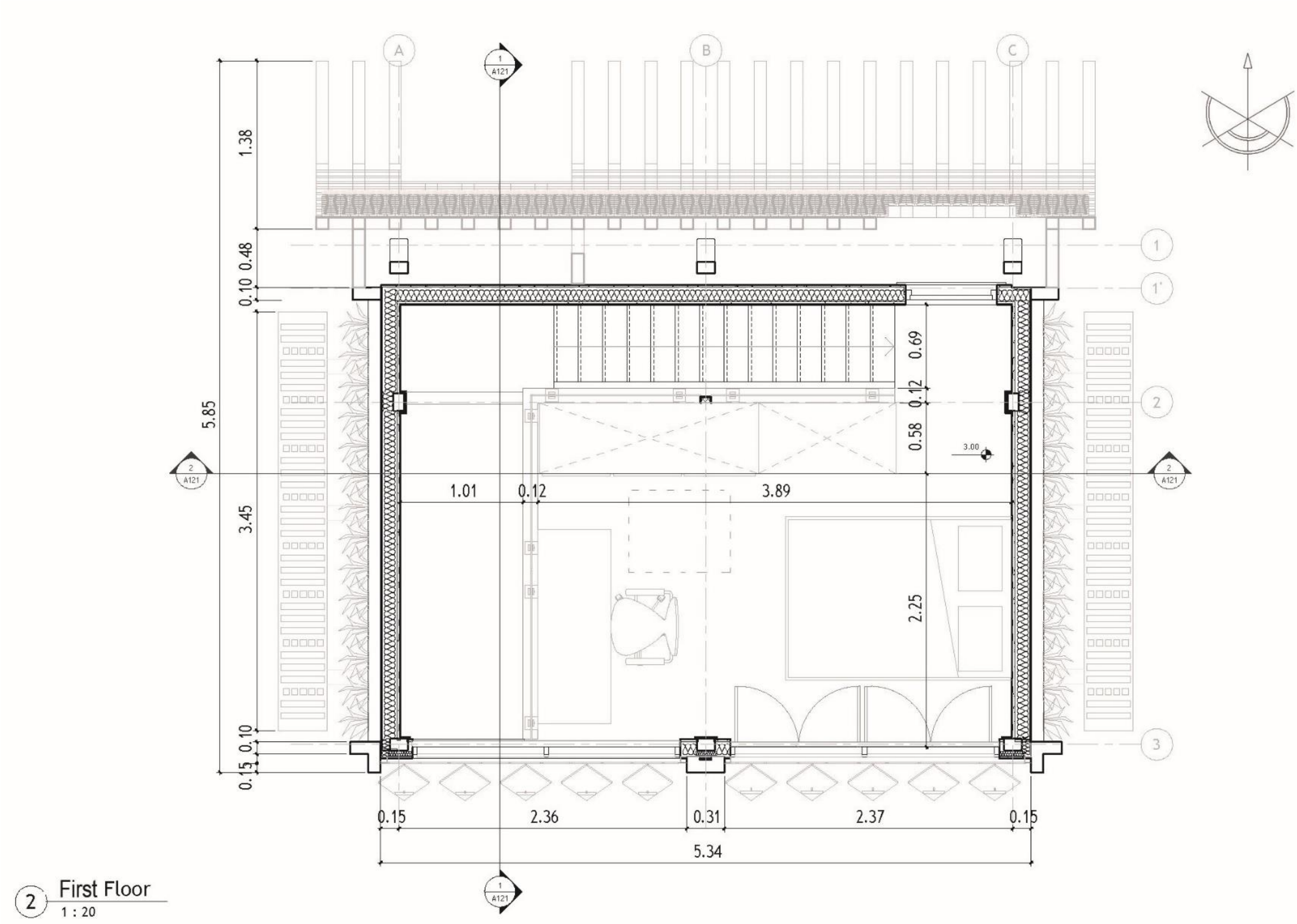

Figure 13. First Floor Plan

3.2.3 Sections

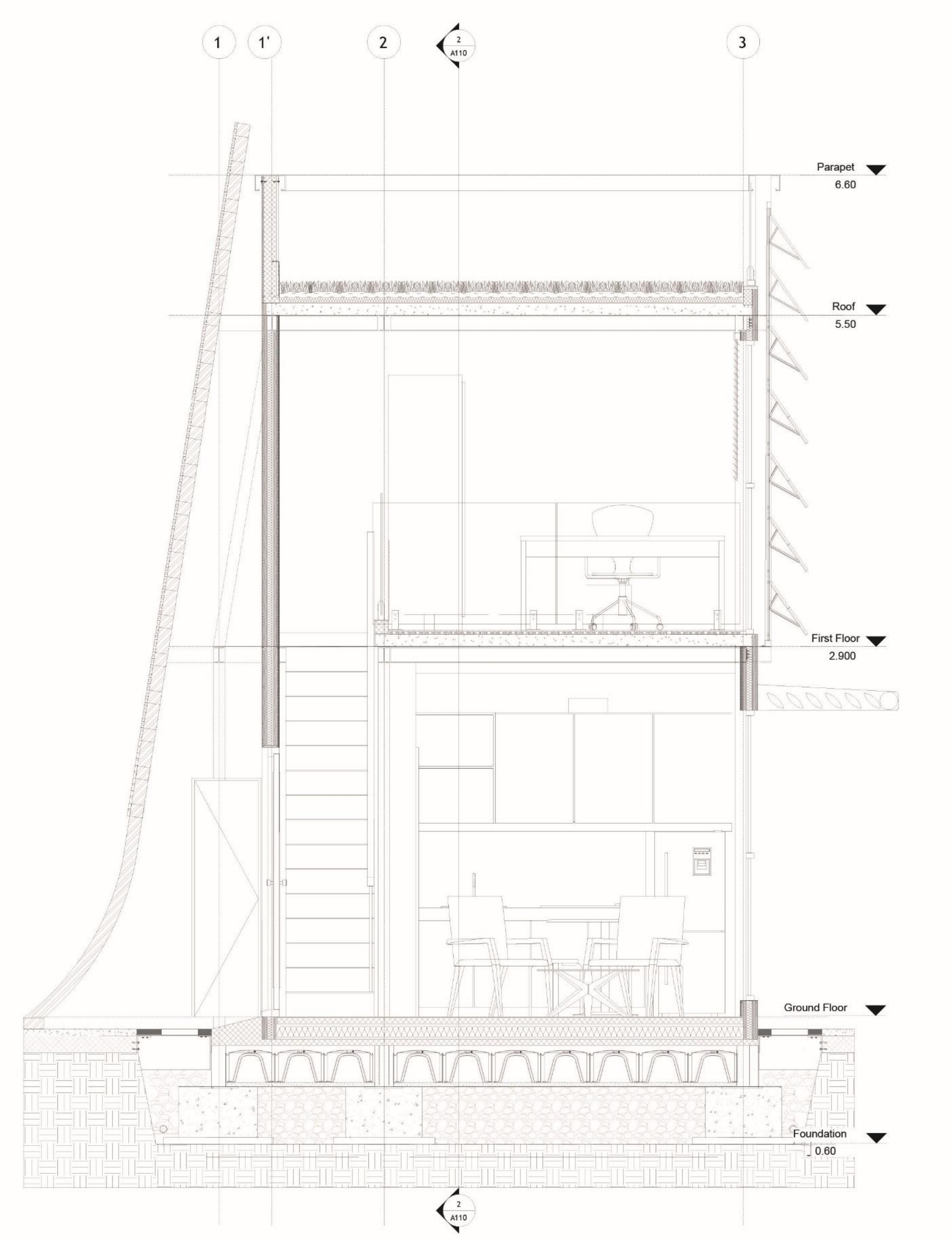

Figure 14. Section 1 of the Building

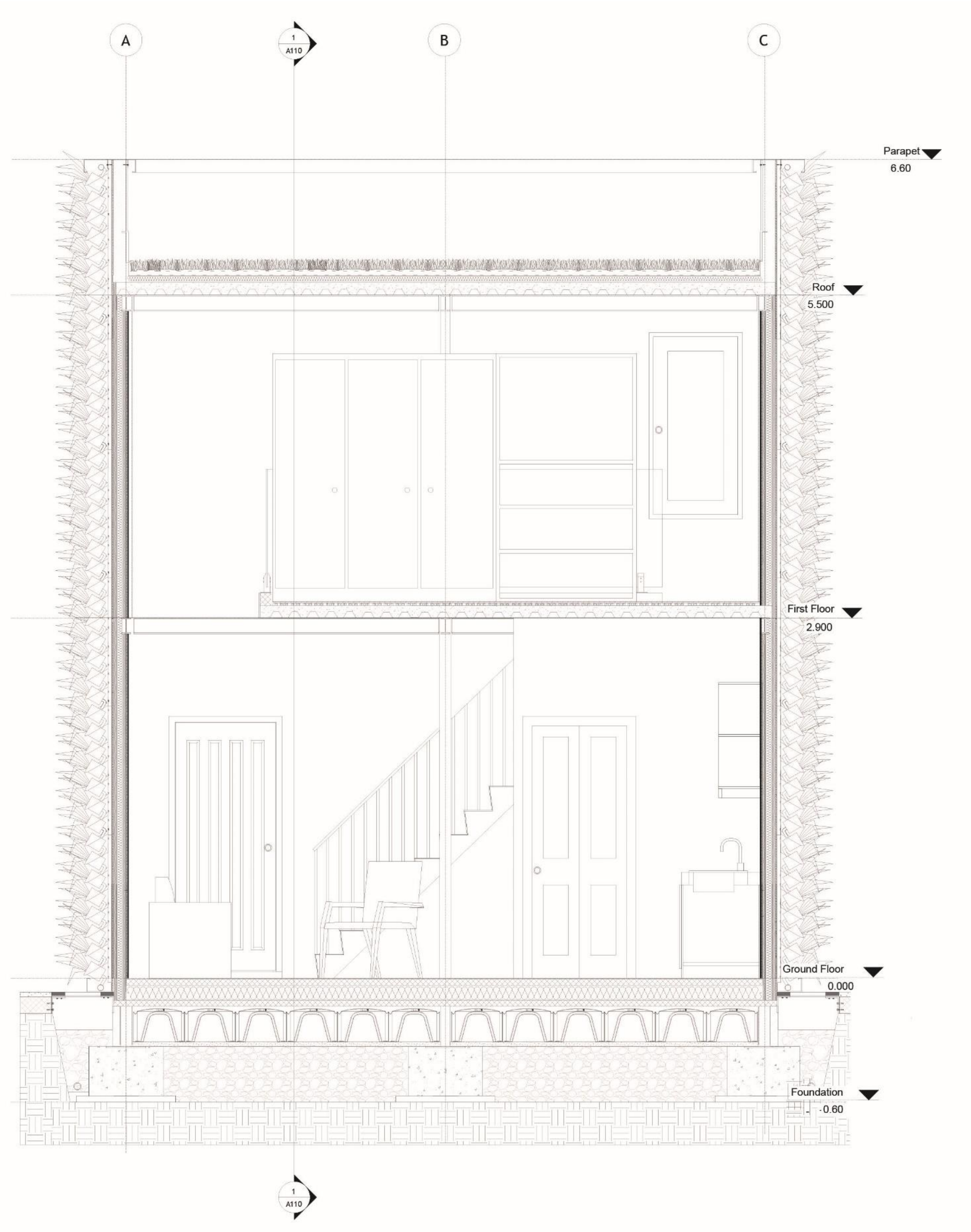

Figure 15. Section 2 of the building

4. Main Building Subsystems: Technological Choices

4.1 Structural Scheme

The typology adopted for this project is a steel structure, primarily composed of prefabricated steel columns and beams. Steel offers significant advantages, including a high strength-to-weight ratio, flexibility in design, and accelerated construction timelines.

The design process followed several key criteria aimed at achieving a durable, efficient, and sustainable structure. First, high-performance steel materials were selected for their strength, durability, and compatibility with the surrounding environment, while also considering their recyclability and lower environmental impact compared to traditional materials. Second, the design focused on simplicity and structural efficiency, prioritizing solutions that support sustainability throughout the building’s entire lifecycle, from design and construction to eventual disassembly and reuse. The modular nature of the steel components, connected predominantly through bolted joints, facilitates easy assembly, disassembly, and future reuse, aligning with circular economy principles. From a regulatory standpoint, the number, size, and weight of structural elements such as steel columns and beams were carefully determined in compliance with Italian building codes to meet stringent safety and performance standards.

4.1.1 Columns

For the structural system, prefabricated steel columns of various dimensions have been selected. These columns are arranged on a regular grid and anchored to precast concrete foundations using base plates that are welded to the columns and secured with bolted connections, complemented by grout pouring to ensure stability and load transfer. Among these, rectangular hollow section (RHS) columns measuring 150 mm by 100 mm are used, providing a strong, efficient, and versatile profile well-suited for load-bearing purposes. The columns are delivered to the site pre-equipped with bolted joints for connecting the primary beams, facilitating efficient and precise assembly during construction.

4.1.2 Primary Beams

The primary beams used in the structure are prefabricated universal beams (UB) with dimensions of 12 inches by 76 pounds per foot and a thickness of 13 millimeters. These beams serve to connect adjacent columns and are secured to the columns through bolted connections. Upon delivery to the site, the primary beams are already equipped with bolted joints for the attachment of secondary beams, facilitating streamlined assembly.

4.1.3 Secondary Beams

Secondary beams are also prefabricated and span between two primary beams positioned opposite each other. Each primary beam supports four secondary beams, spaced at 2-meter intervals. The connections between secondary and primary beams are established using bolted connections, ensuring structural stability and ease of construction.

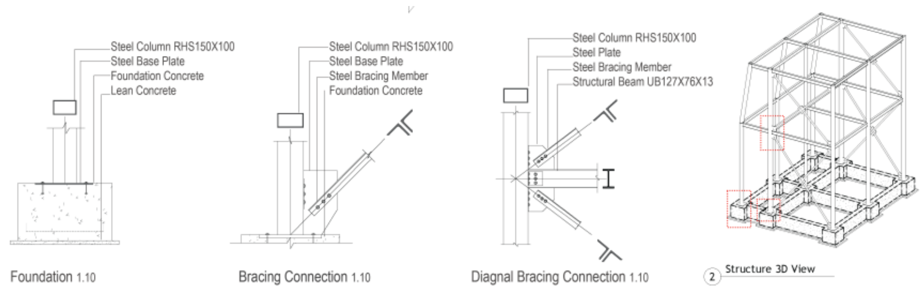

Figure 16. Structural Scheme of the project

4.2 Horizontal and Vertical Partitions

4.2.1 Slabs

The flooring system in this building employs metal deck slabs. Metal decking consists of corrugated steel sheets that act as permanent formwork and reinforcement for the concrete slab poured on top. This system is favored for its lightweight properties, structural efficiency, and ease of installation. Metal deck slabs provide excellent strength and durability, support long spans, and contribute to faster construction times while maintaining high performance in load-bearing and fire resistance.

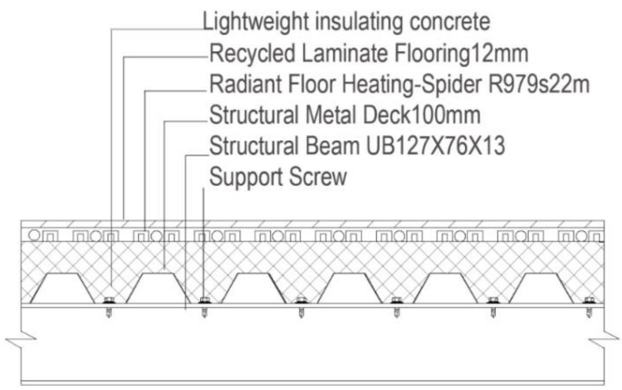

Figure 17. Metal Deck Slab

4.2.2 External Partition

On the north side of the building, a ventilated skin made of expanded metal is installed, supported by a robust aluminum substructure connected to the main building framework. This partition serves two primary purposes. Firstly, it creates an external buffer zone that accommodates green walls and rooftop vegetation, as well as housing essential BIPV system components such as tanks and switchboards, without intruding into the internal living spaces. Secondly, the expanded metal skin acts as a protective barrier against harsh winter winds, reducing their direct impact on the building envelope and improving thermal comfort inside. This layered partition system also facilitates natural ventilation by allowing air to circulate between the skin and the main wall, thereby enhancing the building's overall energy efficiency and contributing to a healthier indoor environment.

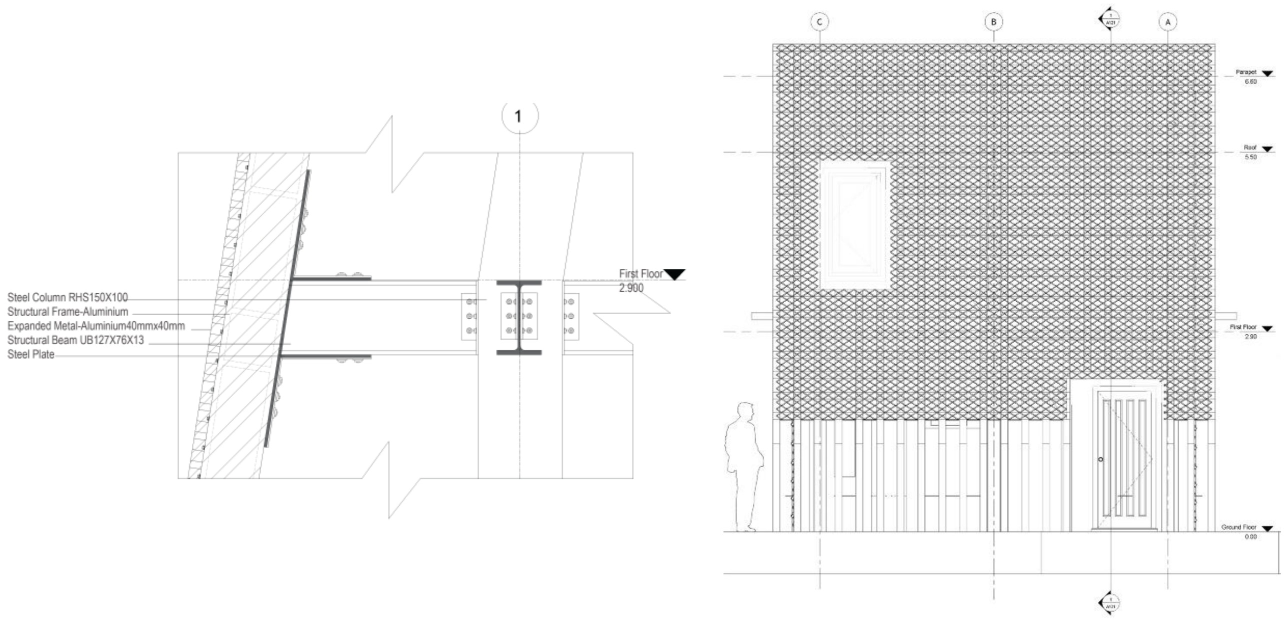

Figure 18. Expanded Metal Envelope and Aluminum Substructure

4.3 Building Envelope

Façade requirements refer to the essential guidelines and considerations involved in designing and constructing the exterior structure of a building. These requirements cover both functional and aesthetic aspects and play a vital role in ensuring the building's performance, durability, and overall appearance. Key aspects of façade design typically include:

- **Weatherproofing:** The façade protects the building from environmental factors like rain, wind, snow, and harmful UV radiation. It is carefully designed to prevent water infiltration, air leakage, and heat loss through thermal bridges.
- **Insulation:** Providing effective thermal insulation is crucial for energy efficiency and maintaining comfortable indoor temperatures. The façade reduces heat exchange between inside and outside, helping to lower heating and cooling demands.
- **Structural Integrity:** The façade is strong and stable enough to handle various forces such as wind pressure, seismic activity, and its own weight, ensuring long-term durability and safety.
- **Fire Resistance:** Compliance with fire safety standards is an essential aspect. The façade prevents fire spread by using fire-resistant materials, fire-rated windows, and other protective measures.
- **Sustainability and Energy Efficiency:** The design of the façade prioritizes eco-friendly principles by using sustainable materials, integrating renewable energy technologies, and optimizing natural light and ventilation to reduce energy consumption.
- **Aesthetics and Visual Appeal:** Beyond functionality, the façade plays a major role in defining the building's character. It is visually attractive, complements its surroundings, and clearly expresses the architectural vision.
- **Maintenance and Durability:** Façades are built to last with materials and finishes that can withstand the test of time, while also being easy to clean and maintain, minimizing the effort and cost over the building's life.

4.3.1 External Envelope

The external envelope of the building consists of five distinct layers, each carefully selected to contribute to the overall performance of the wall system. The primary objective of this multi-layered envelope is to minimize thermal transfer between the interior and exterior environments, thereby improving energy efficiency, while also controlling moisture ingress to maintain structural integrity and indoor comfort.

Among these layers, the insulation layer, made of wood fiber and measuring 120 mm in thickness, plays the most critical role in achieving the desired thermal resistance and reaching the target U-value. The substantial thickness of this insulation layer significantly reduces heat flow, helping to maintain a stable indoor temperature regardless of external weather conditions.

Given the site's exposure to rain and moisture, a waterproof cement board layer, 10 mm thick, is incorporated into the envelope design. This layer acts as a protective barrier, preventing water penetration and protecting the insulation and internal wall components from moisture-related damage.

The external layers begin with a 4 mm cement-based plaster, which provides a durable and weather-resistant outer surface. Behind the insulation, steel studs are placed at intervals of 150 mm, offering structural support and maintaining the integrity of the wall assembly. Finally, the interior face is finished with a single layer of drywall, covered with paint, providing an aesthetically pleasing and functional surface inside the building.

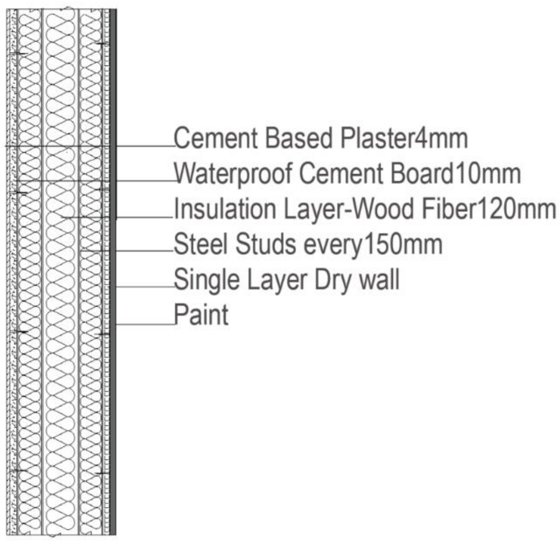

Figure 19. External Envelope Stratigraphy

4.3.2 Building-integrated Photovoltaic (BIPV) Panels

The building façade integrates fixed BIPV panels installed at an optimal angle of approximately 40 degrees, serving as a multifunctional component of the envelope system. This fixed tilt allows the panels to efficiently generate solar energy during the summer while acting as a shading device that reduces solar heat gain, thereby lowering cooling demands and enhancing indoor thermal comfort. During winter, the lower solar incidence angle enables increased sunlight penetration through the façade, supporting passive solar heating and improving natural daylighting inside the building. This seasonal balance improves the building's overall energy performance by reducing reliance on mechanical heating, cooling, and artificial lighting systems while contributing to occupant well-being throughout the year.

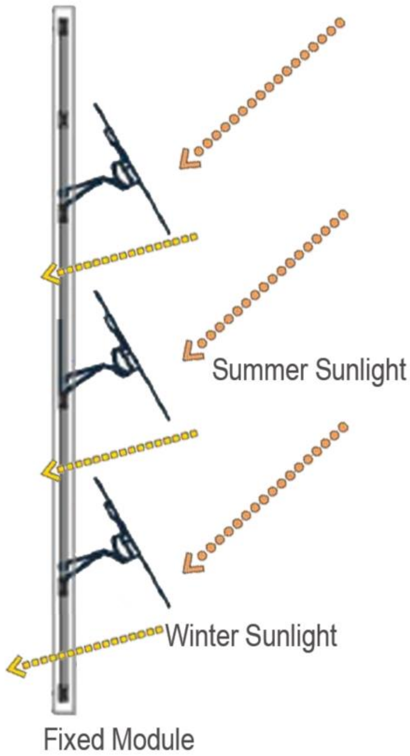

Figure 20. Displacement of BIPV Panels

From both a sustainability and affordability perspective, the fixed BIPV panels offer significant advantages. Their stationary design minimizes maintenance requirements compared to adjustable systems, reducing long-term operational costs and enhancing reliability. This aligns closely with the project's goal to provide sustainable, energy-efficient housing that remains economically accessible.

The integration of energy generation, solar shading, and daylight optimization within the façade transforms the building envelope into an active, high-performance element that supports environmental responsibility and occupant comfort. Moreover, the prefabricated nature and straightforward installation of fixed BIPV panels contribute to lowering initial construction costs, making them a practical and effective solution for affordable housing developments focused on long-term resilience and sustainability.

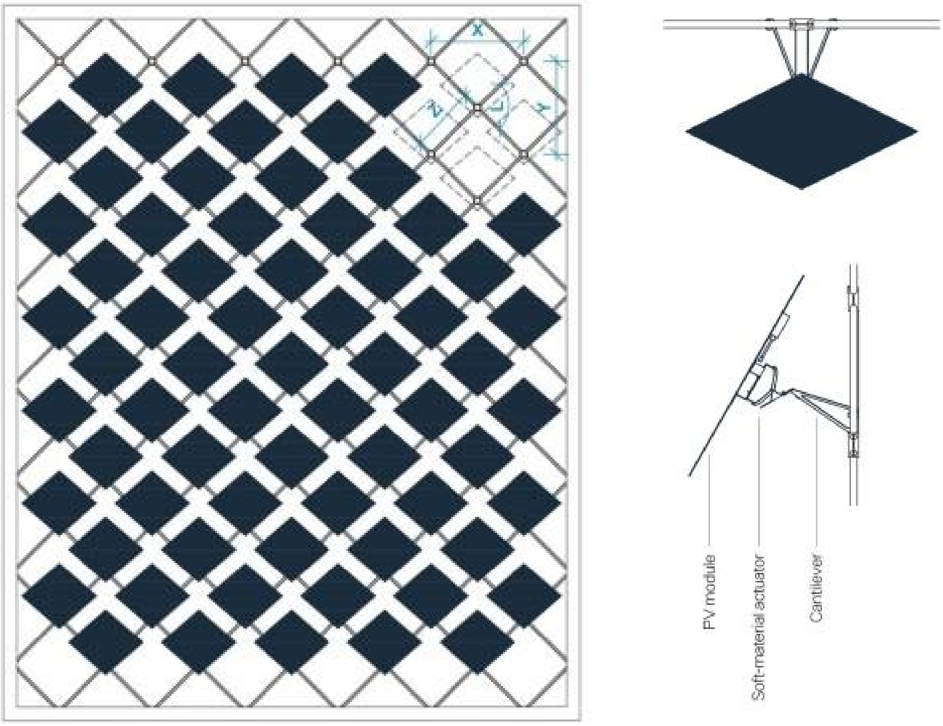

Figure 21. BIPV Panel Layout and Details

4.3.3 Green Wall

To enhance the building's energy efficiency and contribute to creating a comfortable microclimate around the structure, two extensive green walls were incorporated on the east and west façades of the building.

These living walls provide multiple benefits beyond their aesthetic appeal. By covering large portions of the exterior with vegetation, the green walls act as natural insulation layers, reducing heat gain during hot summer days and heat loss in the winter. This helps to significantly decrease the building's overall energy consumption for heating and cooling.

Additionally, the green walls contribute to the creation of a localized microclimate around the building by improving air quality and increasing humidity. They also offer ecological advantages, such as supporting urban biodiversity by providing habitat for insects and birds, and contributing to noise reduction in the surrounding area.

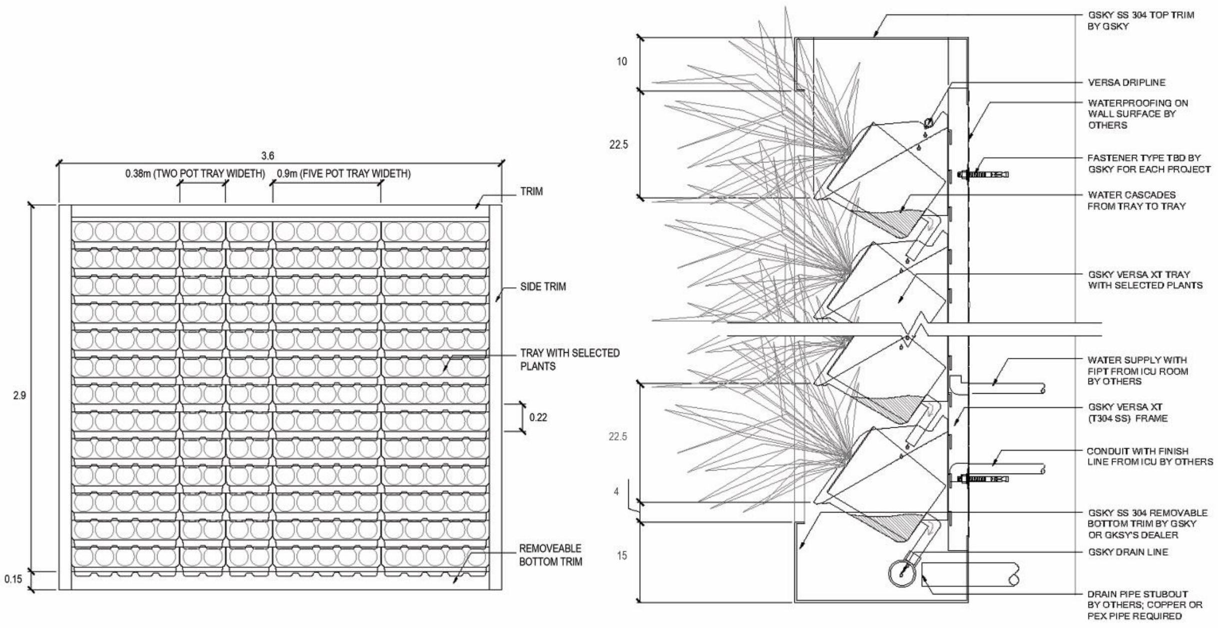

Figure 22. Front and Section Views of Green Wall

5. Energy Performance Analysis

5.1 U-values

Figure 23 presents detailed thermal characteristics of a building element's surfaces, highlighting both inner and outer conditions. The inner surface shows moderate convective (2.15 W/m^2·K) and radiative (5.54 W/m^2·K) heat transfer coefficients, along with a surface resistance of 0.13 m^2·K/W, reflecting its role in retaining indoor heat. The outer surface, exposed to external conditions, exhibits a much higher convective heat transfer coefficient (19.87 W/m^2·K), indicating greater heat loss potential due to environmental factors, with a slightly lower radiative coefficient and surface resistance.

The overall thermal performance is expressed through U-values and R-values, which quantify heat transfer and insulation effectiveness, respectively. Without thermal bridging, the U-value is 0.202 W/m^2·K, indicating good insulation based on the ASHRAE standards 90.2 (14). When accounting for thermal bridging according to BS EN ISO 6946 standards, the values remain consistent, suggesting minimal impact from thermal bridges. The element's thickness (0.159 m) and high internal heat capacity (27.73 KJ/m^2·K) contribute to its ability to store heat, enhancing thermal comfort and energy efficiency. This analysis confirms the component's strong thermal resistance, supporting sustainable building design goals.

Inner surface	
Convective heat transfer coefficient (W/m2-K)	2.152
Radiative heat transfer coefficient (W/m2-K)	5.540
Surface resistance (m2-K/W)	0.130
Outer surface	
Convective heat transfer coefficient (W/m2-K)	19.870
Radiative heat transfer coefficient (W/m2-K)	5.130
Surface resistance (m2-K/W)	0.040
No Bridging	
U-Value surface to surface (W/m2-K)	0.263
R-Value (m2-K/W)	3.969
U-Value (W/m2-K)	**0.202**
With Bridging (BS EN ISO 6946)	
Thickness (m)	0.1590
Km - Internal heat capacity (KJ/m2-K)	27.7340
Upper resistance limit (m2-K/W)	3.969
Lower resistance limit (m2-K/W)	3.969
U-Value surface to surface (W/m2-K)	0.263
R-Value (m2-K/W)	3.969
U-Value (W/m2-K)	**0.202**

Figure 23. Thermal Properties and U-values of the Building Envelope

The condensation report indicates that the building structure is free from interstitial condensation, with zero condensation interfaces identified, confirming no internal moisture buildup within the wall assembly. Surface condensation risk is also low, with good thermal quality noted and mold growth considered unlikely under the current conditions.

The accompanying Glaser diagram visualizes the temperature (green line), partial vapor pressure (red line), and saturated vapor pressure (blue line) across the wall's cumulative equivalent air thickness in January. The red line remains below the blue line throughout, indicating that the partial vapor pressure does not exceed the saturation point, thus preventing condensation within the structure.

The presented analysis refers to the simple building envelope stratigraphy without added BIPV or green wall systems. The U-value and R-value results, alongside the condensation report, reflect the performance of this simple building envelope, demonstrating strong thermal resistance (U-value of 0.202 W/m²·K) and an effective moisture control strategy with no risk of interstitial or surface condensation.

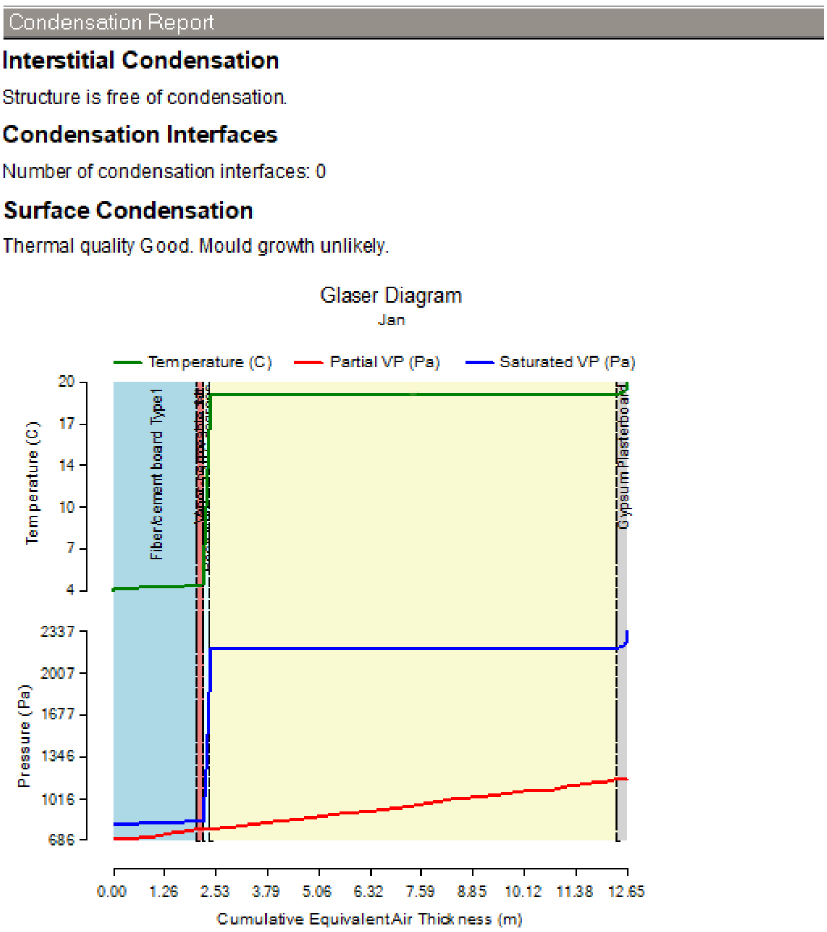

Figure 24. Condensation Report Summary related to the Building Envelope

5.2 Ventilation

To ensure a comfortable and well-ventilated indoor environment, the two levels of the building are intentionally connected through a void located on the west side of the first floor. This open space facilitates natural air circulation by allowing fresh air to enter through the south-facing windows on the ground floor and flow upward, exiting through a window on the north side of the first floor. This natural ventilation path enhances airflow throughout the interior, improving air quality and thermal comfort without relying on mechanical systems. The design not only supports energy efficiency but also creates a pleasant and healthy living space for the occupants.

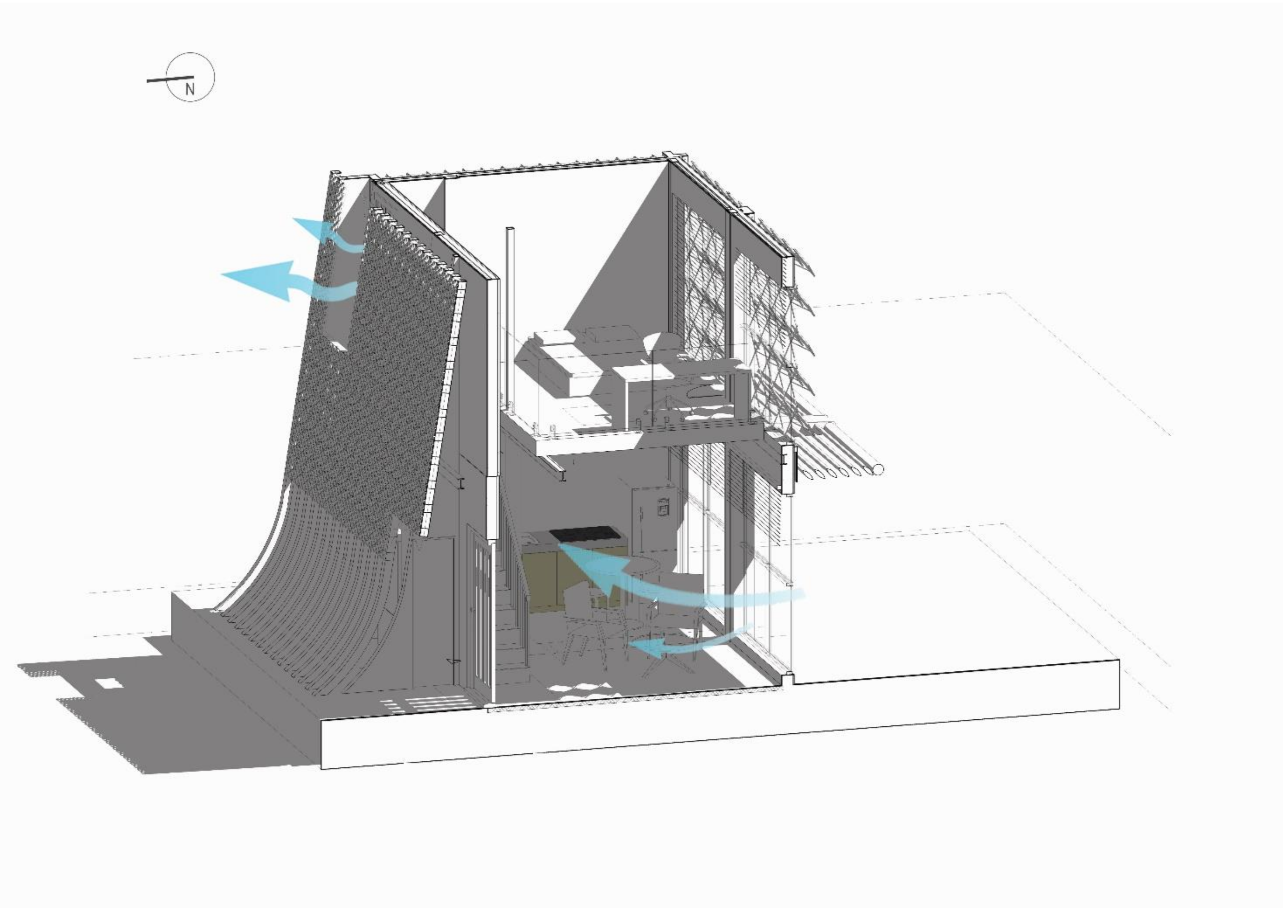

Figure 25. Ventilation and Airflow Through the Building

6. Conclusion

This project successfully addresses the critical challenge of providing affordable and sustainable housing in the rapidly urbanizing context of Milan through the design of a compact, energy-efficient tiny house optimized for two occupants. By utilizing comprehensive site-specific climatic analysis using Climate Consultant software, the design thoughtfully integrates passive strategies that respond directly to local environmental conditions. The south-facing orientation and fixed BIPV panels maximize solar gain during winter for natural heating and energy generation, while simultaneously providing shading in summer to prevent overheating. This dual function of the façade components, coupled with green walls and a green roof, not only enhances the building's thermal performance but also contributes to improved air quality and the creation of a comfortable microclimate.

The building's structural system and partitioning further support sustainability and occupant comfort. The use of prefabricated steel components ensures efficient, durable construction aligned with circular economy principles, while the ventilated north façade with expanded metal skin acts as both a wind barrier and a support for green infrastructure and photovoltaic equipment. Inside, spatial planning balances privacy and openness, with floor areas and ceiling heights complying with regulations to optimize comfort. The void connecting the two floors enhances natural ventilation by facilitating airflow driven by temperature differentials and prevailing winds, reducing energy consumption and promoting indoor air quality. Thermal analysis confirms the building's strong insulation performance, with U-values indicating effective heat retention and minimal impact from thermal bridging. Additionally, condensation risk assessments validate the structure's moisture resilience, ensuring durability and occupant health. In conclusion, the project exemplifies how compact housing, when carefully designed and integrated with renewable technologies and passive climate-responsive features, can offer an affordable, sustainable, and comfortable living solution that meets the needs of modern urban residents while addressing environmental challenges.

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