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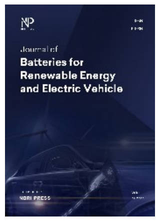


# Renewable Energy Solutions for Achieving Net Zero Building

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**ABSTRACT**

This paper presents an in-depth analysis of the Jowata architectural concept, designed as a net zero building through the integration of multiple renewable energy systems. Located in Kota Baru Parahyangan, Bandung, the design incorporates passive, active, and renewable energy strategies, focusing on solar photovoltaic (PV) panels, wind turbines, and pico hydro systems to meet the building's energy needs. Comprehensive simulations, including Global Horizontal Irradiation (GHI) and wind speed analyses, were conducted to optimize the placement and efficiency of these technologies. The Jowata Grid System, supported by the local energy grid, achieves a 71.5% renewable energy offset, resulting in annual $CO_2$ emissions savings of approximately 23,987 tons. The building's Energy Use Intensity (EUI) is significantly below regional benchmarks, demonstrating the efficiency of the design. This study highlights the effectiveness of combining various renewable energy sources in achieving net zero emissions and offers a blueprint for sustainable building practices in similar climatic regions.

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## INTRODUCTION

The escalating concerns over climate change and environmental degradation have placed an urgent spotlight on the need for sustainable practices across various sectors. Among these, the building sector stands out as a major contributor to global energy consumption and carbon emissions, accounting for approximately 40% of total energy use and 30% of energy-related CO2 emissions worldwide [1]. As urbanization continues to accelerate, the demand for energy-efficient buildings has become increasingly critical. In response, the concept of Net Zero Buildings (NZBs) has emerged as a pivotal solution to curbing energy use and reducing the carbon footprint of the built environment. NZBs are designed to balance energy consumption with renewable energy generation, thereby achieving a net-zero energy balance over the course of a year [1], [2].

The urgency of transitioning to NZBs cannot be overstated. With the world facing intensifying climate impacts, including extreme weather events, rising sea levels, and diminishing biodiversity, there is a pressing need to decarbonize all aspects of human activity, including the construction and operation of buildings. NZBs represent a viable pathway to achieving these goals by significantly lowering the energy demand of buildings while simultaneously promoting the use of clean, renewable energy sources. The adoption of NZBs is not only a critical step in mitigating climate change but also in enhancing energy security, reducing operational costs, and improving the overall quality of the built environment [3].

The design and implementation of NZBs involve several key aspects, each contributing to the overall energy efficiency and sustainability of the building. These aspects include passive design, active design, net zero design, and healthy design, all of which must be carefully integrated to achieve the desired outcomes [3], [4].

Passive Design is the foundation of NZBs, focusing on maximizing the building's natural energy efficiency by optimizing its orientation,

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insulation, window placement, and thermal mass. These elements are designed to reduce the need for artificial heating, cooling, and lighting, thereby minimizing the building's energy demand. For instance, strategic placement of windows can enhance natural daylighting, while high-performance insulation can maintain indoor temperatures with minimal energy input.

Active Design complements passive strategies by incorporating energy-efficient systems and technologies to manage the building's energy use. This includes high-efficiency HVAC (heating, ventilation, and air conditioning) systems, energy-efficient lighting, and advanced control systems that optimize energy performance [5]. Active design also integrates renewable energy technologies, such as solar panels, wind turbines, and geothermal systems, to generate clean energy on-site, reducing the building's reliance on external energy sources [1], [6].

Net Zero Design is the culmination of passive and active design strategies, where the goal is to achieve a net-zero energy balance. This means that the building generates as much energy as it consumes on an annual basis, typically through the integration of renewable energy systems [7]. Net zero design requires a holistic approach, considering not only energy efficiency and renewable energy generation but also energy storage solutions, grid interaction, and demand-side management to ensure a consistent and reliable energy supply [5], [8].

Healthy Design is an often-overlooked aspect of NZBs, but it plays a crucial role in ensuring the well-being of occupants. This design approach emphasizes indoor environmental quality, including air quality, thermal comfort, natural lighting, and acoustics, all of which contribute to the overall health and productivity of building users [9]. Healthy design is particularly important in the context of NZBs, where the focus on energy efficiency must be balanced with the need to create comfortable and livable spaces [10], [11].

In this paper, the various renewable energy solutions will be explored that contribute to the realization of NZBs, focusing on their integration within passive, active, and net zero design frameworks. this research aims to provide a comprehensive understanding of how renewable energy can be leveraged to achieve Net Zero Buildings, contributing to the global effort to combat climate change and promote sustainability in the built environment.

## METHODOLOGY

### Research Design and Location

This study is centered on the architectural concept "Jowata," an innovative design framework developed for a building project in Kota Baru Parahyangan, Bandung. The name "Jowata" is derived from the Sundanese words "Hejo" (meaning green) and "Perwata" (meaning mountain range), reflecting the project's commitment to sustainability and its integration with the natural landscape. The design aims to create a Net Zero Building (NZB) that harmonizes with the local microclimate while prioritizing energy efficiency and occupant well-being.

The first phase of the study focuses on passive design strategies, with a detailed analysis of the microclimate and site-specific conditions. This involves evaluating the building orientation, natural ventilation, solar shading, and material selection to optimize energy efficiency. The microclimate analysis includes temperature, humidity, wind patterns, and solar radiation data, which are critical for designing an effective passive system. The site analysis also considers the surrounding topography, vegetation, and urban context to minimize heat gain and enhance natural cooling. Simulation tools such as Revit are employed to model these factors and predict their impact on the building's energy performance.

In parallel with the passive design, the study conducts an in-depth analysis of healthy design principles, focusing on thermal comfort as a key parameter. The Overall Thermal Transfer Value (OTTV) is calculated to assess the building envelope's effectiveness in controlling heat transfer. This analysis is coupled with an evaluation of Energy Use Intensity (EUI) to quantify the energy required to maintain indoor thermal comfort. The goal is to achieve a balance between energy efficiency and occupant comfort, ensuring that the building not only meets NZB standards but also provides a healthy indoor environment. Autodesk Insight is utilized to simulate and optimize the thermal performance and energy consumption of the building.

The core of the study lies in the net zero design, which integrates renewable energy solutions to offset the building's energy consumption. The project explores the potential of solar panels, wind energy, and pico hydro systems as primary energy sources. Solar panels are strategically placed to maximize solar gain, while small-scale wind turbines are considered for harnessing wind energy. Pico hydro, a micro-hydropower system, is examined as an additional renewable energy source, particularly suited for areas with water flow. The energy generation capacity of these systems is simulated using HOMER software, which allows for detailed modeling of hybrid renewable energy systems and their interaction with the building's energy demands.

### Data Collection and Modeling Tools

To accurately assess and optimize the building's performance, a combination of simulation and modeling tools is employed. Revit is used for the initial design and passive design analysis, providing detailed architectural and structural models. Autodesk Insight facilitates the evaluation of thermal comfort and energy use intensity, offering insights into how design choices affect energy consumption and occupant well-being. HOMER software is utilized to simulate the integration of renewable energy systems, enabling the calculation of potential energy outputs and the overall feasibility of achieving net zero status [12], [13].

Data for the simulations are collected from a variety of sources, including local climate data, building material specifications, and renewable energy resource assessments. The analysis involves comparing the energy performance of different design options, with a focus on minimizing energy consumption and maximizing renewable energy generation. The results of the simulations are analyzed to determine the most effective design strategies for achieving a Net Zero Building in the context of Kota Baru Parahyangan.

While this study provides a comprehensive analysis of the Jowata design concept, certain limitations must be acknowledged. These include the accuracy of simulation tools, potential variability in local climate conditions, and the assumptions made regarding renewable energy resource availability. Future research could explore the long-term performance of NZBs in different climatic regions and the impact of technological advancements on their feasibility.

## RESULTS AND DISCUSSION

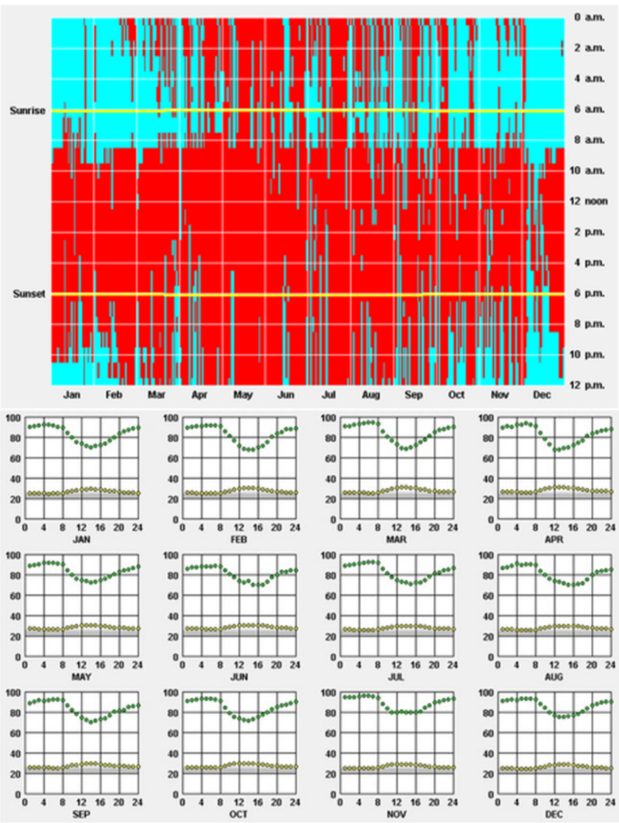
The architectural concept of "Jowata," a name derived from the Sundanese words "Hejo" (green) and "Perwata" (mountain range), embodies a visionary approach to sustainable building design tailored to the unique environmental context of Kota Baru Parahyangan, Bandung. This concept integrates seamlessly with the natural landscape, leveraging the region's topography and climate to optimize energy efficiency and occupant comfort. Central to Jowata is the principle of harmony with nature, where the building's orientation and form are meticulously designed to enhance natural ventilation, daylighting, and thermal mass, thus minimizing reliance on mechanical systems.

The design incorporates passive strategies such as strategic shading, high-performance insulation, and reflective materials to regulate indoor temperatures and reduce heat gain. Complementing these passive features are active design elements that harness renewable energy sources, including solar panels, wind turbines, and pico hydro systems, to achieve a net-zero energy balance [14], [15]. The Jowata concept not only addresses energy efficiency but also prioritizes the health and well-being of its occupants through thoughtful integration of natural light, air quality, and thermal comfort. By marrying advanced technology with traditional wisdom, Jowata represents a holistic approach to sustainable architecture, setting a benchmark for future Net Zero Building designs in similar climatic and cultural contexts [16]. Fig. 1 shows the concept of Jowata's architectural design.

**Fig. 1.** Jowata's architectural design.

The passive design of the Jowata concept begins with a thorough microclimate and site analysis, which is essential for optimizing the building's energy performance and environmental integration. The microclimate analysis involves evaluating local climatic conditions such as temperature variations, humidity levels, solar radiation, and prevailing wind patterns. This data is crucial for designing building features that leverage natural elements to reduce energy consumption. For instance, the orientation and placement of windows are strategically determined to maximize solar gain during the winter months while minimizing heat buildup in the summer. By understanding and incorporating these microclimate factors, the Jowata design ensures that the building's passive systems are aligned with its environmental context, thus improving overall energy efficiency.

Site analysis complements the microclimate study by examining the physical and topographical characteristics of the location. This includes assessing the surrounding landscape, including vegetation, topography, and nearby structures, to inform decisions about shading, heat reflection, and wind protection [17], [18]. This comprehensive approach to site and microclimate analysis forms the foundation of the Jowata design, ensuring that the building operates sustainably within its unique setting. Fig. 2 depicts the micro climate and site analysis of Jowata.



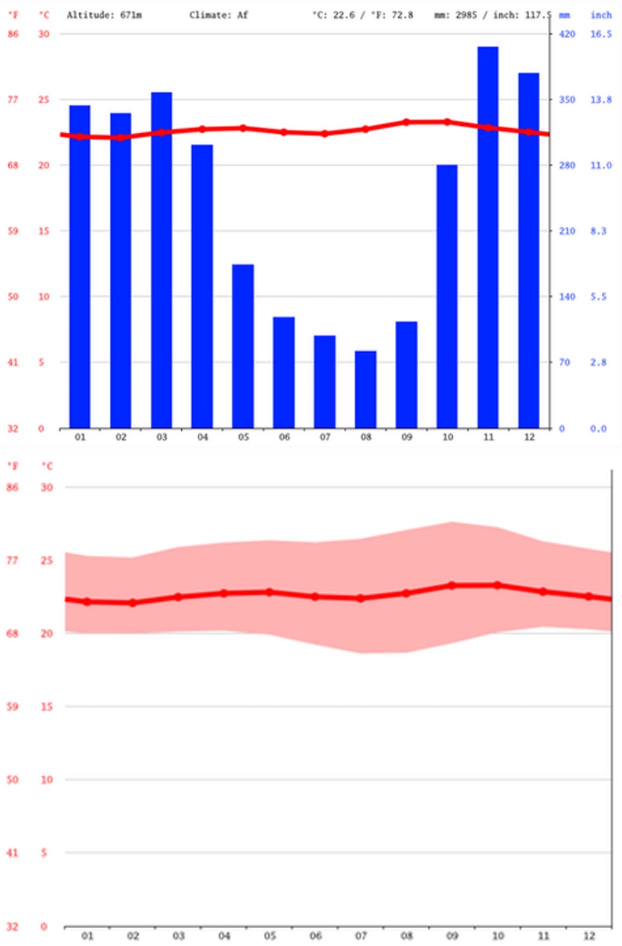




**Fig. 2.** Micro climate analysis.

The site precipitation analysis reveals an annual average of approximately 2,985 mm, indicating a high level of rainfall that significantly influences the building's design considerations. This substantial precipitation, coupled with the wide range of humidity and dry bulb temperature simulation graphs, underscores the site's overall comfort and informs strategies for managing moisture and preventing issues such as mold growth. Temperature analysis further refines the understanding of the site's climatic conditions, identifying May through October as the months of greatest thermal comfort, based on dry bulb temperature simulations. During these months, the temperature range supports a favorable indoor climate without extensive mechanical cooling.

The microclimate analysis shows that the highest recorded temperature on-site is 27.6°C in September, while the lowest is 18.6°C in July. This variation in temperature informs the passive design strategies, emphasizing the need for thermal insulation and ventilation systems that accommodate these seasonal extremes while maximizing energy efficiency throughout the year.

In evaluating the Jowata concept's thermal performance, the Overall Thermal Transfer Value (OTTV) and Energy Use Intensity (EUI) serve as critical metrics for assessing energy efficiency and occupant comfort. The OTTV analysis measures the building envelope's effectiveness in minimizing heat transfer between the interior and exterior environments, ensuring that the design achieves optimal thermal insulation and reduces the reliance on active heating and cooling systems. By analyzing OTTV, the Jowata design can be fine-tuned to enhance its ability to maintain stable indoor temperatures and improve overall energy efficiency.

Concurrently, Energy Use Intensity (EUI) quantifies the building's energy consumption per unit area, providing a comprehensive view of its energy performance relative to similar buildings. Lower EUI values indicate more efficient energy use, which aligns with the goal of achieving Net Zero status. Through these analyses, the Jowata design can effectively balance energy needs with thermal comfort, ensuring that the building not only meets stringent energy performance criteria but also provides a healthy and comfortable environment for its occupants.

Table 1 shows the calculation of OTTV in the Jowata's design, according to SNI 03-6389. The OTTV total is 25.88 W/m2 and less than 45 W/m$^2$, means good.

**Table 1.** Summary of Jowata's OTTV.

| Elevation | Wall Con (W) | Win Con (W) | Win Sol (W) | Total | Area | OTTV (W/m$^2$) |
|---|---|---|---|---|---|---|
| North Wall | 576.69 | 5,399.97 | 29,492.2 | 35,459.86 | 1,384.61 | 14.38 |
| South Wall | 535.04 | 6336 | 33,510.4 | 40,381.44 | 1,408 | 29.16 |
| West Wall | 986.31 | 10,356.2 | 54,493.7 | 65,836.33 | 2,454.1 | 26.83 |
| East Wall | 785.31 | 7,607.71 | 49,523.7 | 57,916.76 | 2,465.78 | 41.13 |
| | | **Total Area** | | | 7,712.49 | **25.88** |

The energy use intensity (EUI) analysis of the Jowata design demonstrates exceptional efficiency in its energy performance. The monthly EUI is calculated at 4.49 kWh/m², significantly below the 8.5 kWh/m² threshold established by Permen ESDM No. 13/2012, and the yearly EUI stands at 53.94 kWh/m², well under the 300 kWh/m² limit set by ASEAN-USAID.

This results in a remarkable 46% reduction in energy intensity compared to the benchmark model, highlighting the building's superior energy efficiency. Additionally, the operational cost has decreased from 4.74 USD/m²/year to 3.49 USD/m²/year, translating into an annual savings of IDR 485,962,000. These findings not only underscore the effectiveness of the Jowata design in reducing energy consumption but also illustrate significant cost savings, reinforcing its economic and environmental benefits.

**Renewable Energy Solutions**

The Jowata Grid System is meticulously designed to achieve net zero energy consumption by leveraging a hybrid renewable energy scheme. The building's daily energy load is calculated at 5,703.34 kWh, with a peak daily demand of 1,070.58 kWh, necessitating a robust and flexible energy solution. To meet these demands, the Jowata design incorporates a combination of solar photovoltaic (PV) panels, wind turbines, pico hydro systems, and a battery storage system paired with an inverter.

The solar PV panels are strategically positioned to maximize energy capture during daylight hours, while wind turbines provide a supplementary energy source, particularly during periods of low sunlight. The pico hydro system, tailored for the site's specific water flow characteristics, offers a reliable and continuous energy supply [7], [11], [19].

The integration of battery storage ensures that excess energy generated during peak production times is stored for use during periods of high demand or low renewable energy generation, thus maintaining a consistent and stable energy supply. This hybrid system not only supports the building's net zero energy goals but also enhances its resilience and sustainability, ensuring reliable energy performance throughout the year. Fig. 3 shows the jowata grid system.

*Solar PV*

The potential for solar energy at the Jowata site has been thoroughly analyzed using Global Horizontal Irradiation (GHI) simulations, focusing on both site-specific monthly radiation levels and temperature conditions. The results indicate an annual average GHI of 4.81 kWh/m²/day, with an average annual temperature of 24.93°C and a peak solar potency of 5 hours per day.

These favorable conditions make solar energy a viable and significant contributor to the building's energy needs. The solar panels are strategically oriented to the north to optimize energy capture throughout the year. A detailed simulation conducted using Homer software confirms that solar panels will provide 61.6% of the total energy requirements for the Jowata Grid System. This substantial contribution underscores the effectiveness of the solar panel installation in supporting the net zero energy goals of the building, making it a cornerstone of the Jowata's renewable energy strategy.

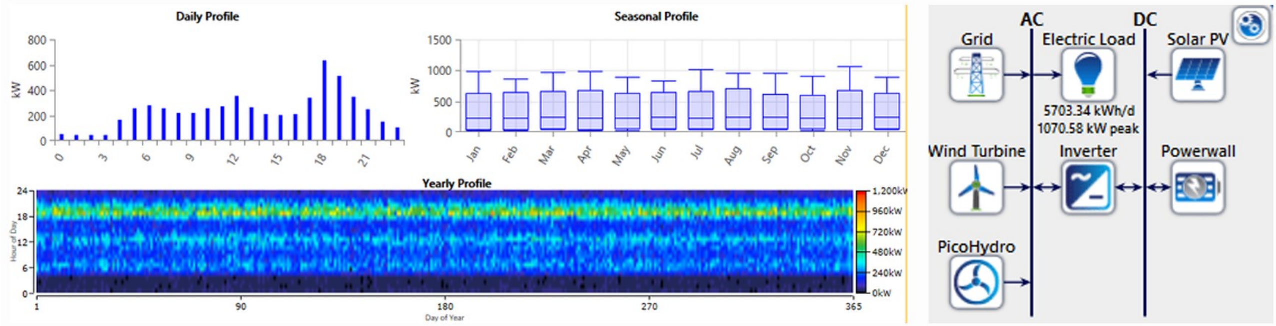



**Figure 3.** Jowata grid system.

Fig. 4 and 5 shows site monthly radiation and site temperature, respectively. Meanwhile figure 6 illustrate building integration for Solar PV system and fig. 7 depicts the result of solar panel simulation.

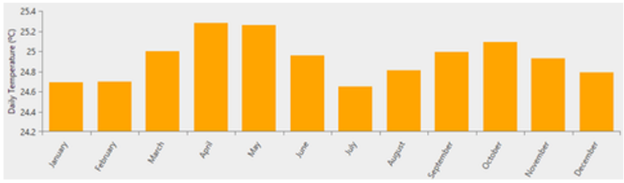


**Figure 5.** Site temperature.

**Fig. 4.** Site monthly radiation.

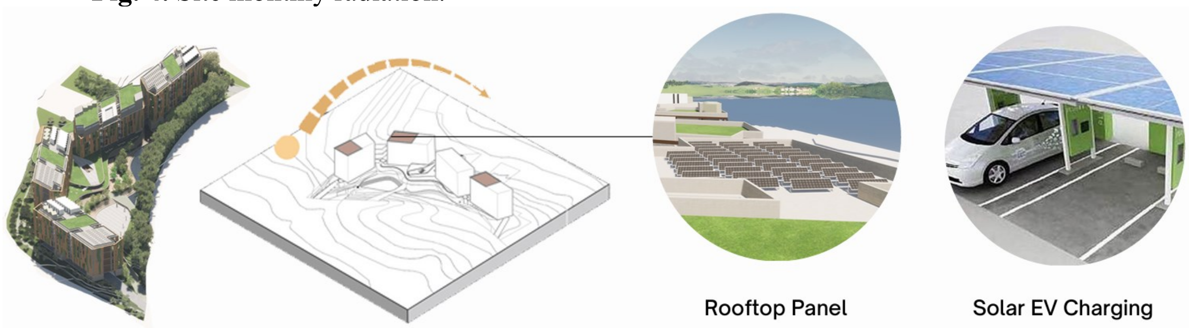
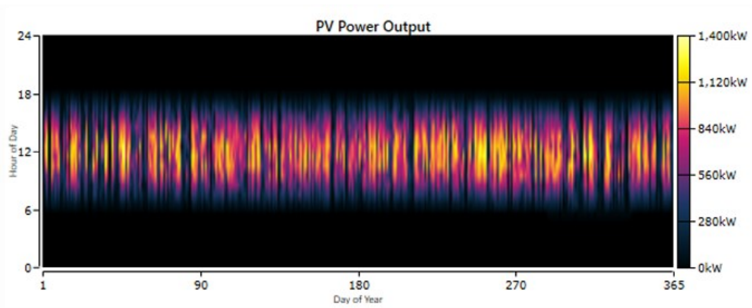



**Fig. 6.** Building integration of solar PV system in the Jowata.




| Quantity | Value | Units |
|---|---|---|
| Minimum Output | 0 | kW |
| Maximum Output | 1,295 | kW |
| PV Penetration | 99.3 | % |
| Hours of Operation | 4,429 | hrs/yr |
| Levelized Cost | 56.4 | $/kWh |

| Quantity | Value | Units |
|---|---|---|
| Rated Capacity | 1,560 | kW |
| Mean Output | 236 | kW |
| Mean Output | 5,662 | kWh/d |
| Capacity Factor | 15.1 | % |
| Total Production | 2,066,728 | kWh/yr |

**Fig. 7** The simulation of Solar PV system in Jowata grid.

*Wind Energy*

The wind energy potential at the Jowata site has been meticulously analyzed through wind speed simulations, considering site-specific monthly wind speeds (fig. 8), wind speed profiles (fig. 9), and wind turbine power curve simulations (fig. 10). The annual average wind speed at the site is recorded at 3.81 m/s, which supports the selection of a vertical axis Savonius wind turbine model, known for its efficiency in low-wind conditions.

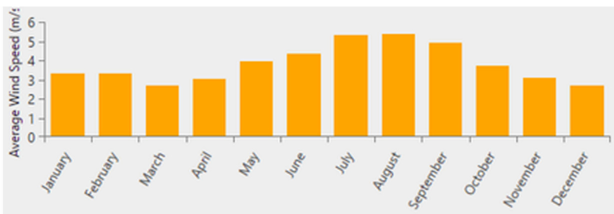


**Figure 8.** Site monthly wind speed.

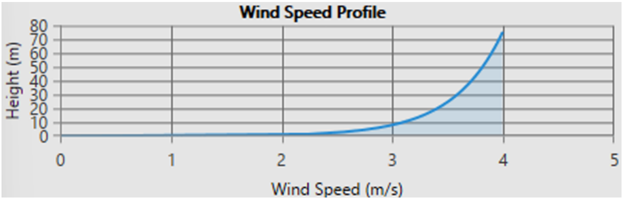



**Fig. 9.** Site wind speed profile.

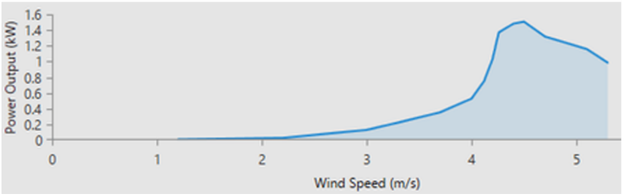



**Fig. 10.** Site wind turbine power curve simulation.

A comprehensive simulation using Homer software reveals that the wind turbine system will contribute 6.41% of the total energy needs for the Jowata Grid System. Additionally, Computational Fluid Dynamics (CFD) simulations were conducted to optimize the turbine model, ensuring its performance aligns with the specific wind conditions of the site. While the wind energy contribution is smaller compared to solar energy, it plays a crucial role in diversifying the renewable energy mix and enhancing the overall stability and resilience of the Jowata's energy system.

Fig. 11 depicts the building integration on wind turbine system and fig. 12 shows the wind turbine and CFD simulation.

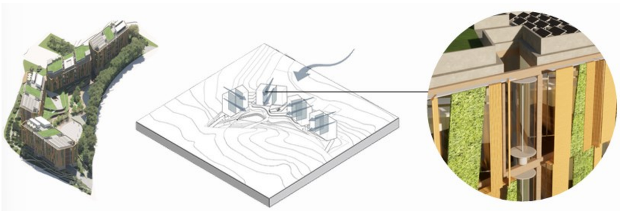
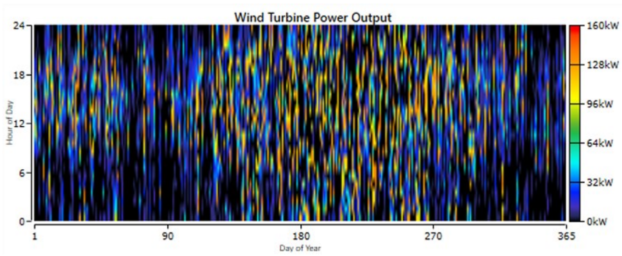
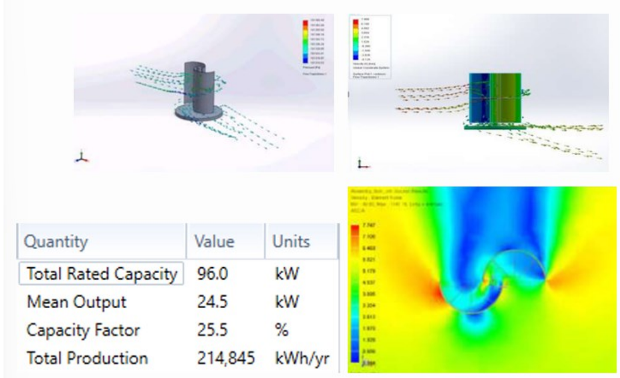


**Figure 11.** Integrated wind turbine system on Jowata.



| Quantity | Value | Units |
|---|---|---|
| Total Rated Capacity | 96.0 | kW |
| Mean Output | 24.5 | kW |
| Capacity Factor | 25.5 | % |
| Total Production | 214,845 | kWh/yr |

**Figure 12.** Wind turbine and CFD simulation.

*Pico Hydro*

The site potential for pico hydro energy has been thoroughly evaluated through detailed simulations, focusing on aspects such as water stream flow (fig. 13), monthly water speed (fig. 14), and the hydrokinetic turbine power curve (fig. 15). The analysis reveals an annual average water speed of 3.89 m/s and an annual average water stream flow of 0.29 L/s, making the site suitable for pico hydro energy generation. The system utilizes a cross-flow pico hydro turbine, strategically placed at the bottom of the greywater pipe system.


**Fig. 13.** Site monthly water stream flow.

**Fig. 14.** Site monthly water speed.

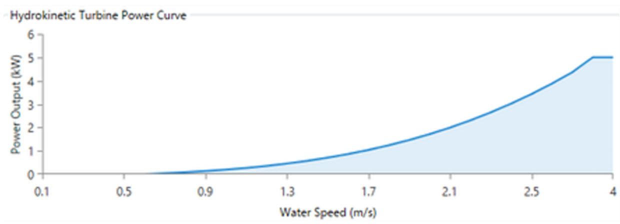



**Fig. 15.** Site Hydrokinetics Turbine Power Curve Simulation.

The water sources for this setup include fog atmospheric water, rainwater, and greywater, which are effectively harnessed to power the turbine. Fog atmospheric water refers to the collection of water droplets from the air, typically harvested through the use of fog nets or other condensation systems. These systems capture moisture from fog, converting it into usable water. In locations where fog is frequent, this method can be a sustainable way to gather water without relying on traditional water sources [13], [18], [20].

Rainwater is the water collected directly from rainfall. In building systems, rainwater is often harvested from rooftops and other surfaces, then stored in tanks or reservoirs for later use. Rainwater harvesting is a common and effective way to supplement water supply, particularly in areas with sufficient rainfall. It can be used for various purposes, including irrigation, flushing toilets, and in some cases, treated for potable use.

Meanwhile greywater refers to the relatively clean wastewater generated from domestic activities such as laundry, dishwashing, and bathing. Unlike blackwater, which contains human waste, greywater can be recycled and reused for non-potable purposes, such as landscape irrigation or toilet flushing. In some systems, greywater can be treated and filtered to further reduce environmental impact and decrease the demand on fresh water sources.

Fig. 16 depicts the building integration on the Jowata system, while fig. 17 shows the simulation of the system.

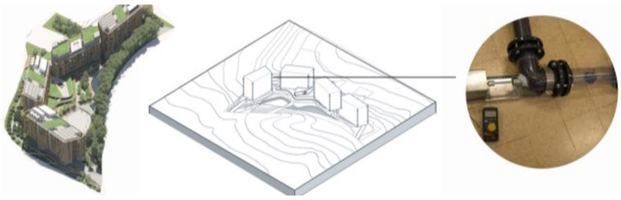
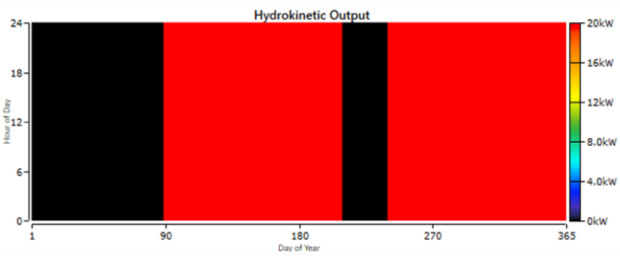
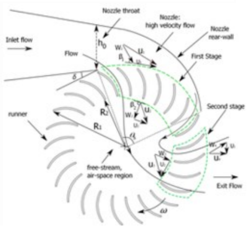


**Fig. 16.** Integrated pico hydro system in the Jowata.




| Quantity | Value | Units |
|---|---|---|
| Total Rated Capacity | 20.0 | kW |
| Mean output | 13.4 | kW |
| Capacity factor | 66.8 | % |
| Total Production | 117,120 | kWh/yr |



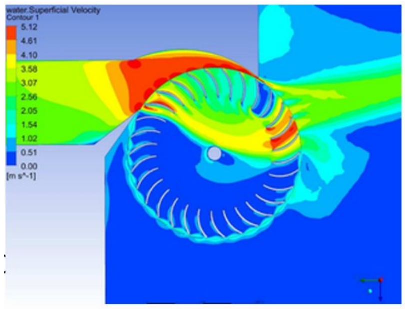



**Fig. 17.** Simulation on pico hydro system

The Jowata Grid System effectively integrates various renewable energy sources, including wind turbines, solar PV, and pico hydro, along with support from the local grid, to achieve significant energy efficiency and carbon reduction. Through the combined efforts of these renewable technologies, the Jowata design achieves a renewable energy offset of 71.5%.

This means that over 70% of the building's energy needs are met through sustainable sources, reducing its reliance on non-renewable energy and significantly lowering its carbon footprint. Each of these renewable energy components plays a vital role in supporting the building's net zero goals, with solar PV contributing the largest share, supplemented by wind energy and pico hydro, while the grid provides additional support during peak demand periods or when renewable output is low. Figure 18 depicts the total input and output of the Jowata grid system. Meanwhile figure 19 shows the monthly average electricity production in the Jowata grid system.

| Production | kWh/yr | % |
|---|---|---|
| LONGi Solar LR6-72PE | 2,066,728 | 61.6 |
| Aeolos-V1kW | 214,845 | 6.41 |
| Pico Hydro Turbine | 117,120 | 3.49 |
| Grid Purchases | 955,365 | 28.5 |
| Total | 3,354,058 | 100 |

| Consumption | kWh/yr | % |
|---|---|---|
| AC Primary Load | 2,081,432 | 65.5 |
| DC Primary Load | 0 | 0 |
| Grid Sales | 1,095,936 | 34.5 |
| Total | 3,177,369 | 100 |

| Quantity | kWh/yr | % |
|---|---|---|
| Excess Electricity | 35,698 | 1.06 |

**Fig. 18.** Overall production and consumption of the Jowata grid system.

The environmental impact of these efforts is substantial. By offsetting 71.5% of its energy needs with renewable sources, the Jowata Grid System saves an estimated 23,987 tons of $CO_2$ equivalent emissions annually. This calculation is based on the assumption that every 10 kWh of energy produced by non-renewable sources typically results in the emission of approximately 10 kg of $CO_2$ equivalent. The significant reduction in carbon emissions highlights the effectiveness of the Jowata design in contributing to global sustainability efforts and demonstrates the potential of integrating multiple renewable energy technologies to achieve a net zero building.

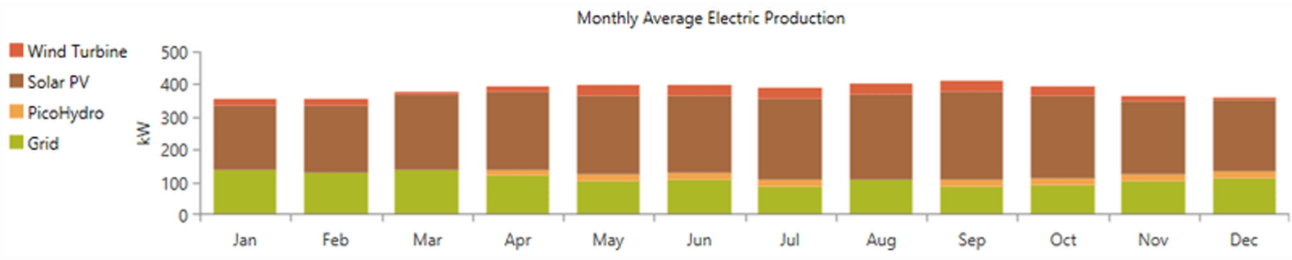



**Fig. 19.** The monthly average electricity production in the Jowata grid system.

## CONCLUSION

The Jowata architectural concept demonstrates a comprehensive approach to achieving a net zero building through the strategic integration of renewable energy technologies, including solar PV, wind turbines, and pico hydro systems. By harnessing these sustainable energy sources, the building not only meets a significant portion of its energy demands but also substantially reduces its carbon footprint, offsetting 71.5% of its total energy needs and saving nearly 23,987 tons of $CO_2$ equivalent annually. The design's efficiency is further evidenced by its low Energy Use Intensity (EUI), which significantly surpasses regional benchmarks, alongside substantial operational cost savings. These results underscore the viability of net zero buildings in contributing to global sustainability goals and highlight the importance of adopting a holistic approach that combines passive, active, and renewable energy strategies. The Jowata model serves as a valuable blueprint for future developments aiming to achieve net zero emissions in the built environment.

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## AUTHOR CONTRIBUTION

M. W. S. Mubarok contributed as the main contributors of this paper on renewable energy analysis, meanwhile S. Ramadhani and M. I. Tsaqif contributed on the architectural design and support the paper writing. All authors read and approved the final version of the paper.

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