Building operation of buildings and constructions

NEARLY ZERO-ENERGY MULTIPURPOSE BUILDING FOR DESA HARAPAN BARU IN EAST KALIMANTAN

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Abstract

Introduction. Desa Harapan Baru, one of the traditional villages in East Kalimantan, is located in a remote coastal area. Limited transportation access, lack of clean water, and poor environmental hygiene are among the major issues faced by the community. As a result, villagers rely on natural resources available around them — such as ulin timber for construction and generators for electricity supply. However, insufficient knowledge of construction practices and reforestation has negatively affected the environment, contributing to flooding in the area. Furthermore, since the generators are situated in a remote location, fuel prices have doubled. **Purpose of the study**. This study aims to design a nearly zero-energy multipurpose building (nZEMB) that aligns with local traditions and community needs. Besides improving the local economy, the project intends to raise awareness about sustainability. **Methods**. Several methods were employed during the design process. First, an assessment of local behavior and cultural practices was conducted to ensure easier community adaptation to new technologies. Solar PV was then selected and installed on the nZEMB roof. PV performance was simulated using PVsyst, computational fluid dynamics (CFD) analysis was carried out with Ansys Fluent, and energy efficiency was evaluated using DesignBuilder. **Results**. The renewable energy system — consisting of 17 solar panels — can fully meet the energy demand of the nZEMB in Desa Harapan Baru. Total daily energy consumption is 59.19 kWh, while the solar panels can generate up to 120 kWh. Additionally, incorporating traditional roof openings and a raised-floor design enhances natural airflow and reduces overall energy use.

Keywords: nearly zero-energy building; remote village; energy efficiency; tropical climate; Indonesian traditional architecture; East Kalimantan.

Introduction

Desa Harapan Baru is a traditional village located in East Kalimantan, Indonesia (Fig. 1), at approximately 1.78° S latitude and 116.42° E longitude. Situated along the seashore, the village is geographically remote and has limited transportation access. Motorboats are required to reach Desa Harapan Baru from the nearest city. Historically, settlement near water bodies has been an integral aspect of human culture (Arifin et al., 2024; Lubis et al., 2018; Putro and Zain, 2021). Rivers and coastal zones have often functioned as determining factors for human settlement patterns, while at the same time being dynamically influenced by human activity. In Desa Harapan Baru, most residents earn their livelihoods from marine fishing and from cultivating milkfish and shrimp ponds.

It is common for residents to live in houses that are regularly inundated during high tides. Even during low tides, the community continues to face health-related problems. The village experiences severe challenges, including limited access to clean water, poor sanitation conditions, and insufficient electricity supply from the national utility company (PLN) (Fig. 2). As a result, residents rely on boat engines and diesel generators to produce electricity (Fig. 2). There is also a substantial demand for ice as a means of preserving fish; approximately 400–800 bags of ice, each costing 3,000 IDR, are sold daily. Since ice production facilities are not available in Desa Harapan Baru, residents must purchase ice from a neighboring village located about 20 kilometers away, requiring approximately
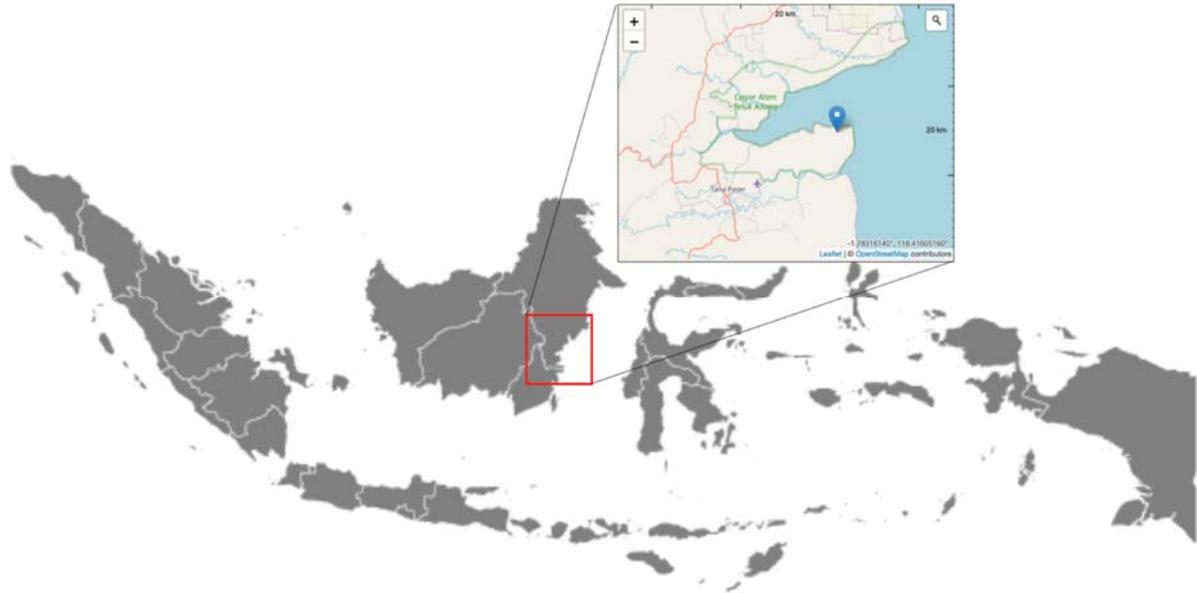
Fig. 1. Location of Desa Harapan Baru on Kalimantan Island, Indonesia (1.78° S, 116.42° E)

Fig. 2. Limited access to clean drinking water, unhygienic environmental conditions, and the absence of electricity supplied by the local government (PLN) in Desa Harapan Baru (a); the use of diesel generators as the village power source (b); nighttime conditions inside residential houses (c)

1.5 hours of travel by boat. Despite these difficulties, the local population continues to reside over the water and construct their homes above it, as they do not own land and depend on fishing activities conducted along the seashore.

As the villagers live in a remote area, they rely heavily on locally available resources. Men primarily work as fishermen, while women support household livelihoods by making fishing nets, drying fish, or selling the catch. Due to the difficulty and high cost of obtaining construction materials from outside the village, houses and other structures are generally built using local materials. This situation becomes more critical during major social events, such as weddings, when temporary structures are often constructed using ulin timber. After the events, these temporary buildings are typically abandoned. Such practices negatively affect the local environment,

particularly through deforestation, which increases the risk of flooding. To move between houses, residents have constructed timber bridges made from ulin wood (Fig. 2). As a result, most daily activities depend on housing structures and these timber bridges.

In response to these conditions, this research aims to develop a nearly zero-energy multipurpose building (nZEMB) that can accommodate various community activities. The study begins with a review of the existing literature on nearly zero-energy buildings (nZEBs) worldwide, as limited information is available regarding their application in tropical climates. Fundamental nZEB design principles involve the integration of multiple energy-efficient technologies (Feng et al., 2019). Passive strategies, such as daylighting systems and natural ventilation, can significantly reduce cooling energy demand (Alwetaishi, 2022; Shi et al., 2020). Photovoltaic (PV) systems represent the most widely adopted renewable energy technology in nZEB design (Ohene et al., 2022), while effective operational management and occupant engagement are also essential for achieving high energy performance during building operation (Kim et al., 2015; Wilberforce et al., 2023).

Designing an nZEMB alone may not fully address the challenges faced by Desa Harapan Baru, as an understanding of local culture is equally important. Previous initiatives introduced simple rooftop solar panel systems; however, not all community members were able to adapt to these technologies. Behavioral transitions from diesel-based energy systems to solar energy proved challenging, largely due to limited knowledge and education related to renewable energy technologies. Consequently, this research integrates local cultural practices and occupant behavior into the building design process. Blending local traditions with new technologies helps reduce resistance to technological adoption and facilitates knowledge transfer within the community.

To develop an nZEMB suitable for Desa Harapan Baru, this study examines technical feasibility and proposes appropriate design guidelines. The specific objectives of the research are as follows:

i. To investigate feasible and effective energy-efficiency design strategies for tropical climates. Based on the literature review, a solar panel system is proposed as the primary energy source for the nZEMB in Desa Harapan Baru.

ii. To evaluate the feasibility and potential of integrating solar panel systems into nZEMB buildings.

iii. To enhance understanding of local culture and occupant behavior in order to improve operational management and occupant engagement.

Methodology and Input Data

The methodology adopted in this study consists of two main components, as illustrated in Fig. 3. The first component focuses on examining the behavior and cultural practices of the residents of Desa Harapan Baru. This approach aims to identify the actual needs of the local community. To achieve this, a combination of 24-hour interviews, site visits, and a literature review was employed. Human activity patterns were identified through 24-hour interviews (Sari and Chiou, 2019; Sari et al., 2024). During
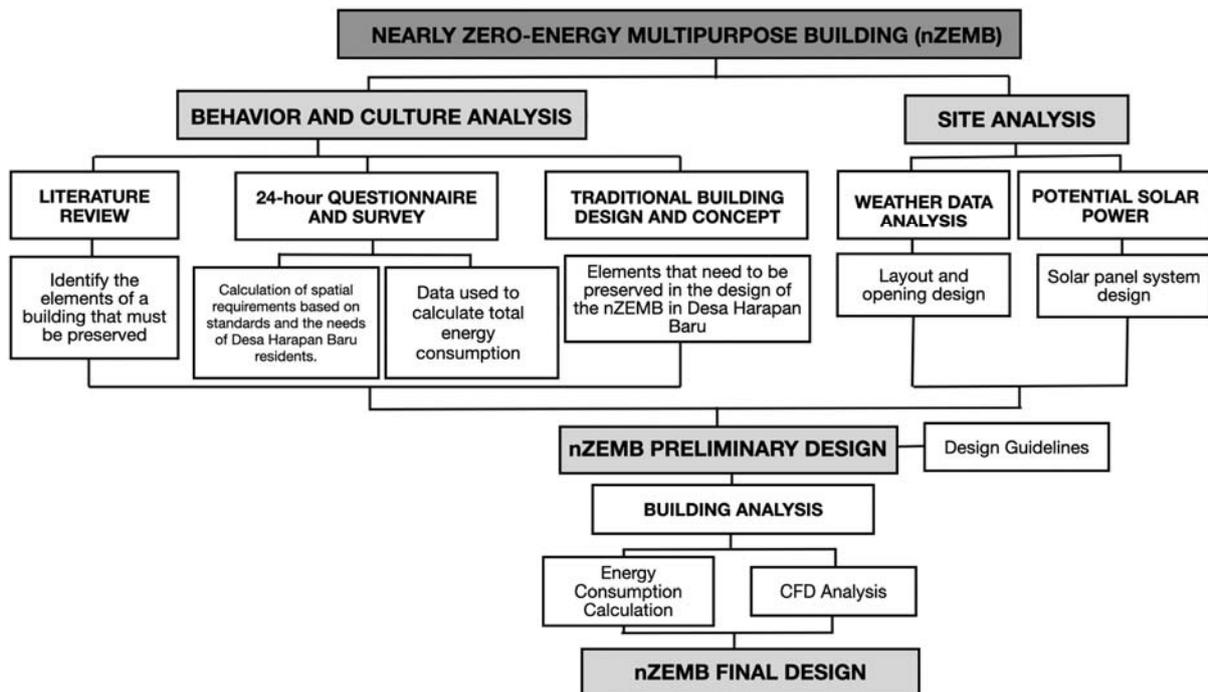

Fig. 3. Stepwise methodology for designing an nZEMB in Desa Harapan Baru, East Kalimantan

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these interviews, residents were asked to describe their daily activities over a full 24-hour period, from waking up to going to sleep. By obtaining detailed information on user behavior, the building design can be better tailored to actual needs. Based on this information, the required spaces and the total daily electricity consumption were subsequently calculated.

While the first methodological component focuses on human behavior, the second emphasizes building physics. The second component of the methodology is based on site analysis (Fig. 3). Adapting zero-energy building strategies to the local climatic context is a fundamental aspect of zero-energy building design. In Desa Harapan Baru, access to government-supplied electricity is unavailable, and residents rely on petroleum-based fuels to meet their daily energy needs; therefore, reducing electricity consumption is essential. The most effective approach to minimizing energy demand is the integration of passive design strategies and renewable energy systems. Given the hot and humid tropical climate of the site, the design of building openings plays a critical role in reducing reliance on

mechanical cooling, such as fans. Well-considered opening configurations can minimize solar heat gain while maximizing natural airflow. Accordingly, several analyses were conducted, including daylighting analysis, computational fluid dynamics (CFD) simulations, and energy consumption calculations. In addition, assessing solar energy potential and performing related calculations were required for Desa Harapan Baru.

Desa Harapan Baru

1. Analysis of Human Behavior and Culture

The community of Desa Harapan Baru consists of 412 households (Fig. 4). In addition to residential buildings, the village includes a mosque, an elementary school, a junior high school, a kindergarten, a health center, a government office, a warehouse, and a small local shop (*warung*). The results of a survey conducted with 92 household heads indicate that each household consumes approximately 612 kWh for lighting, 39 kWh for street lighting, and 17 kWh for other electrical equipment. At present, these energy demands are met primarily through diesel-based electricity generation. Diesel fuel is purchased at prices ranging from 5,000
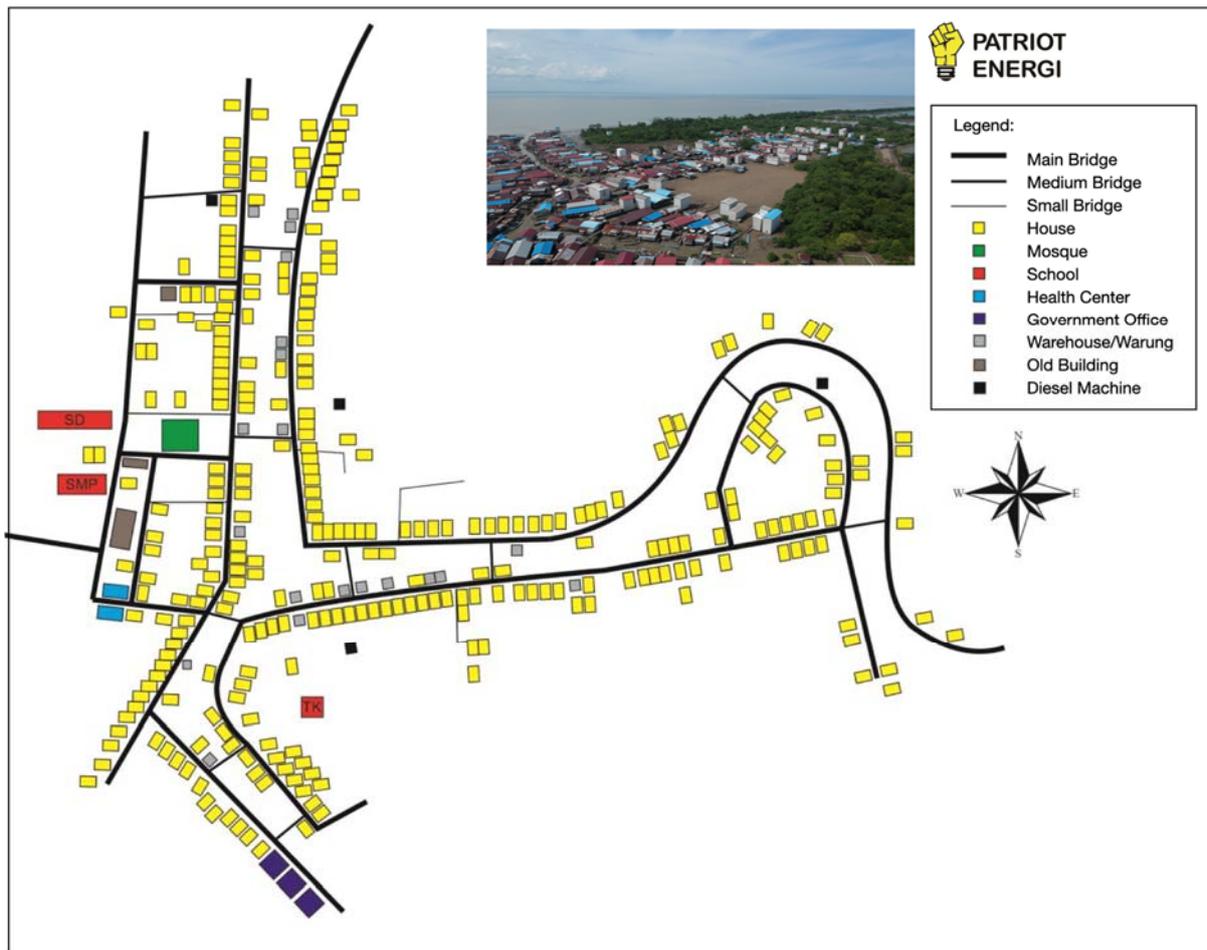

Fig. 4. Building composition of Desa Harapan Baru, East Kalimantan, Indonesia,
showing the dominance of residential buildings (highlighted in yellow)

to 15,000 IDR (approximately 0.3–0.9 USD per liter) and is typically used for about 12 hours per day, from 18:00 to 06:00. Peak electricity consumption is estimated to occur between 18:00 and 19:00 (Fig. 5). When compared with the average daily household income — approximately 50,000 to 150,000 IDR (3–9 USD) — the cost of electricity represents a substantial financial burden for local residents.

The results of the preliminary interviews indicate that women spend significantly more time at home than other household members (Fig. 6). In contrast, men typically remain at home only in the early morning hours (00:00–08:00) and in the evening (18:00–23:00), as their primary activities take place outside the household. Women, on the other hand, spend most of their time at home, where their daily
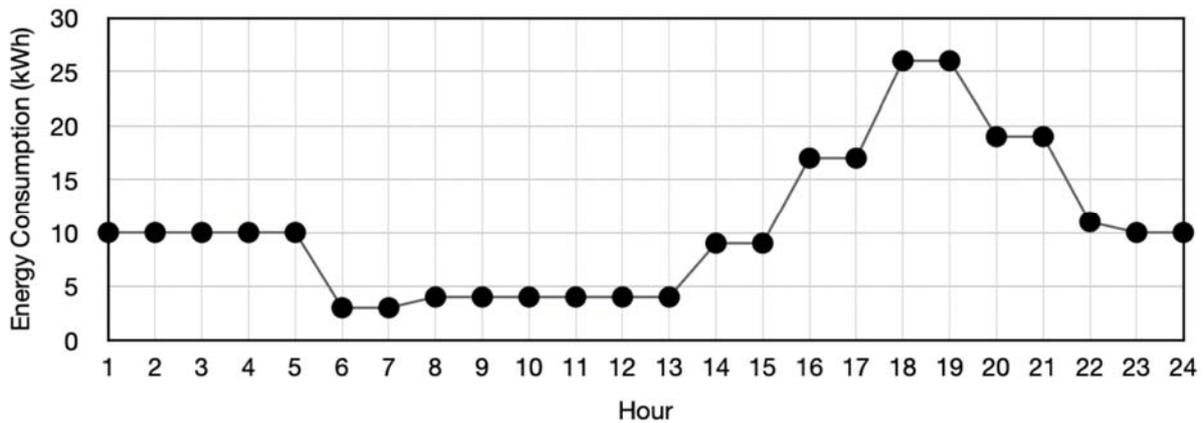

Fig. 5. Electricity load profile of a residential building in Desa Harapan Baru, showing peak demand between 18:00 and 19:00
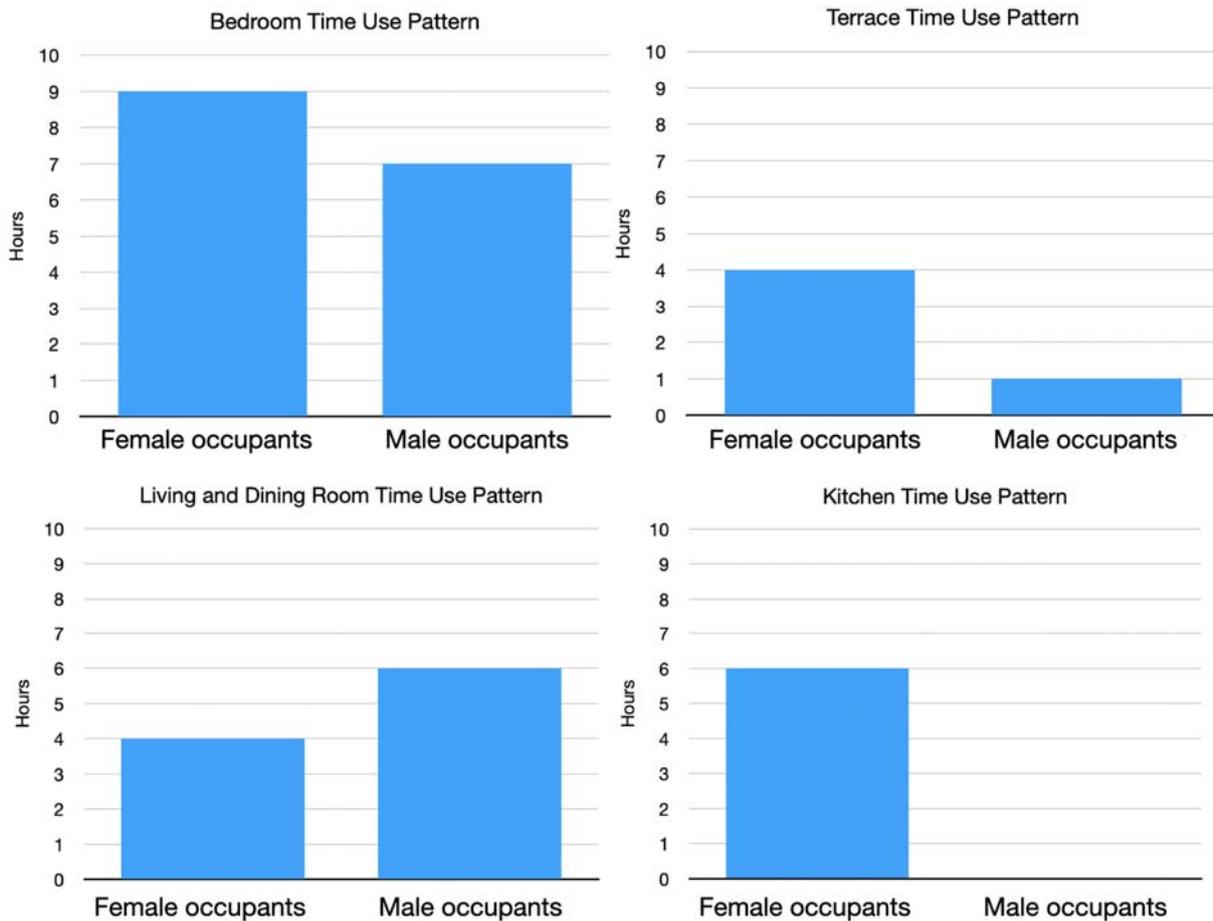

Fig. 6. 24-hour occupancy behavior in Desa Harapan Baru, indicating that women spend more time indoors than men and children

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activities include cooking, cleaning, sewing, and operating small local shops (warungs) that sell basic goods. Despite women's dominant presence in the domestic environment, decision-making related to the household — particularly concerning electricity use — is largely undertaken by men. This imbalance has led to mismatches between household needs and energy-related decisions. When new technologies are introduced, training is typically provided only to men. However, because men are often away from home, women are unable to operate, troubleshoot, or repair these technologies when problems arise. As a result, some equipment becomes unusable once it breaks down. For these reasons, this study places particular emphasis on the behavior and daily activities of women and children in the design of new buildings and in the calculation of energy consumption. Women's involvement in energy use and design-related decisions is expected to have a direct influence on environmental outcomes. Interview findings further reveal that local residents — especially women — require dedicated spaces for everyday activities such as selling fish, drying fish, operating *warungs*, and sewing fishing nets. Given the limited size of their houses, these activities are often carried out on terraces or timber bridges. In addition, rising sea levels frequently cause flooding in the village, limiting safe outdoor spaces for children to play. The community also lacks adequate spaces for collective activities, including social gatherings, wedding celebrations, and local meetings. Accordingly, the design of the multipurpose building proposed in this research is directly informed by the needs of local residents. With local residents managing and maintaining the building, it is expected to become more functional and useful. Finally, the findings from this study were compared with insights from international literature. These comparisons include approaches to preserving traditional buildings while incorporating new materials in ways that remain culturally acceptable to local communities. The literature review also helped identify key architectural elements that should be retained in order to maintain cultural continuity.

2. Traditional Houses in Desa Harapan Baru

As illustrated in Fig. 7, houses in Desa Harapan Baru are typically constructed as *rumah panggung* (raised-floor houses). Owing to frequent flooding in the area, this elevated housing typology has been widely adopted. Semi-permanent timber bridges connect individual houses to facilitate access. During periods of flooding, residents often rely on boats for access. The houses are primarily built using ulin wood. These houses accommodate a wide range of daily activities, including fish sorting, discussions of daily needs, small-scale trading (*warung*), fish drying, and monthly community meetings. Overall, the architectural form of the buildings is strongly

Fig. 7. Facade, interior spaces, and floor plan of a traditional house in Desa Harapan Baru (Sanusi, 2022)

influenced by climatic conditions, flooding patterns, and local cultural practices.

The roofs of the houses are constructed from zinc sheets and typically follow a gable configuration. The floor plan is rectangular, with dimensions ranging approximately from 6 to 10 meters in length, depending on the needs of the household (Fig. 7). Various openings, including covered windows, are incorporated to reduce direct solar exposure while allowing daylight and ventilation. The raised floor functions as a protective measure against flooding (Fig. 7). Access to the main living space is provided by a removable ladder made from scraped or chipped logs, which can be easily pulled up and stored. The supporting columns of the house are left unenclosed, allowing air to circulate freely beneath the structure. The internal layout generally consists of four main spaces: a terrace, a combined living and dining area, a bedroom, and a kitchen (Fig. 7). This spatial organization is comparable to that of traditional Kalimantan houses known as Lamin houses (Sari et al., 2023). The functions of these spaces are as follows:

1. Terrace: Commonly used for sorting fish, selling daily products, and sewing fishing nets. It also serves as a play area for children.

2. Living and dining area: A centrally located enclosed space used for family gatherings.

Neighbors may also gather here to socialize and discuss community matters, with decision-making typically involving adult male members.

3. Bedroom: Used as the primary sleeping space for the family.

4. Kitchen: Located at the rear of the house and used for cooking and water storage, with a bathroom situated nearby.

As part of the nZEMB design process, a local traditional house was analyzed and redrawn, as shown in Fig. 8. This approach supports the preservation of village identity and cultural continuity while enabling residents to adapt to modern technologies. Another objective is to retain cultural expressions embodied in traditional architecture. Based on literature sources (Brisbane City Council, 2018, 2023), several facade and architectural elements were identified as essential to preserve:

1. Roof and eaves: In traditional architecture, the roof functions as the "hat" of the house. Extended eaves and overhangs help cool interior spaces and protect openings from environmental exposure.

2. Terrace: Provides a welcoming ornate interface with the surrounding environment and traditionally serves as an inviting entrance for visitors.

3. Windows: Serve as a connection between indoor and outdoor spaces, allowing daylight and ventilation while framing views to the outside. In many traditional house types, windows are positioned along the external walls.

4. Ornamental elements: Features such as railings contribute to the visual identity of the house. Preserving or matching traditional details and materials helps maintain local cultural character.

The proposed nZEMB preserves and adapts several of these elements, including the roof shape, spatial layout, raised floor, veranda, terrace, and decorative entrance features.

nZEMB Design

1. Passive Design

Land within Desa Harapan Baru was allocated for community use, and a centrally located site within the settlement was selected for the construction of the nZEMB. Its position at the heart of the village makes it suitable for an nZEMB. The available site area measures approximately 40 m × 80 m (Fig. 9), with geographic coordinates of 1°46′18.37″ S and 116°25′08.59″ E, at an elevation of −1 m above sea level. At present, the site is used as a football field. However, since Desa Harapan Baru is located within a tidal zone, additional elevated walkways and raised floor systems are required to mitigate the effects of flooding. According to Decree No. SK.7781/MENLHK-PKTL/KUH/PLA.2/12/2021, the village and settlement area of Desa Harapan Baru has been excluded from the Adang Nature Reserve. This designation eliminates regulatory overlap between relevant governmental agencies in development planning and permits the construction of new buildings within the area.

An understanding of local climatic conditions is essential for effective passive design and for adapting design strategies to the proposed building. Weather data were analyzed using Climate Consultant software (Society of Building Science Educators, 2021), a graphic-based tool that assists architects, builders, contractors, homeowners, and students in interpreting local climate characteristics (Pinassang

1. Side to side gable roof
2. Separate veranda roof
3. Lowset on stumps
4. Chamfer board cladding
5. Simple timber dowel gate
6. Symmetrical simple wooden stairs
7. Front terrace
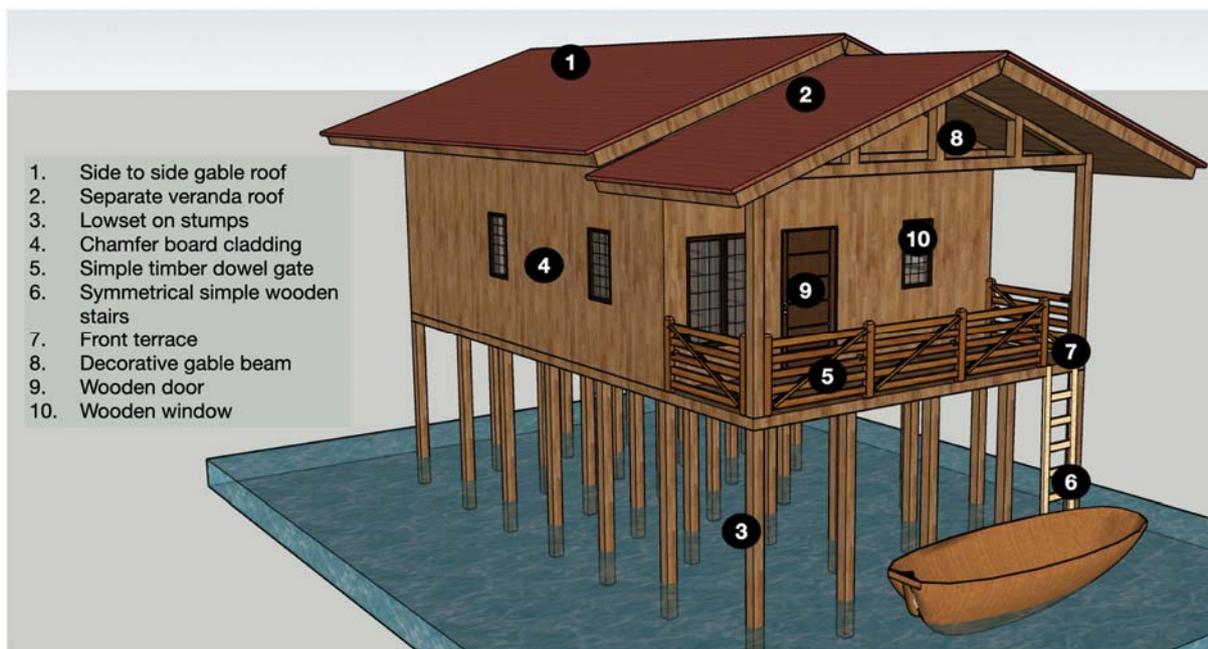8. Decorative gable beam
9. Wooden door
10. Wooden window

Fig. 8. Traditional house elements from Desa Harapan Baru adapted for the design of the modern nZEMB

Fig. 9. Location of the nZEMB site (a) and current conditions of the surrounding plots, classified as wetland areas (b)

et al., 2021). Fig. 10 presents the results of the climate analysis. The local climate is tropical and is characterized by two main seasons: a dry season, typically occurring between May and October, and a rainy season, generally between November and April. Maximum temperatures of up to 35.8°C were recorded in March and December, while the lowest temperature, approximately 23.2°C, was observed in January. The highest relative humidity occurs in May, reaching 84 %, whereas the lowest values around 39 % were recorded in June, September, and March. Wind speeds peak in April, with a maximum recorded value of 12.86 m/s.

Considering that Desa Harapan Baru is located in a remote area, building materials must be locally available, as transportation costs significantly affect construction feasibility. The building is therefore constructed entirely using local materials, which also helps address challenges related to water exposure and flooding. Ulin wood was selected for the walls and floors, as Kalimantan is rich in this timber species. Zinc was chosen as the roofing material because it is one of the most accessible and affordable

roofing materials in the region (Anggraeni, 2020). In addition, the thermo-hygrometric properties of ulin wood and zinc were examined. Thermo-hygrometric characteristics refer to the combined behavior of materials under varying temperature and humidity conditions (Merello et al., 2014). These properties are particularly important in passive building design, as they directly influence human thermal comfort (Falasca et al., 2023; Palapessy, 2018). Considering thermo-hygrometric behavior supports the development of energy-efficient buildings, assists in moisture control, and helps prevent mold growth — factors that are especially critical in tropical climates such as that of Kalimantan.

Kalimantan faces distinct environmental challenges related to settlement development along rivers and wetlands. Ulin wood (*Eusideroxylon zwageri*) is known for its exceptional durability and resistance to a wide range of temperature and humidity conditions. The use of ulin wood in house construction has become a cultural tradition among communities in Kalimantan, particularly those living in wetland areas (Arifin and Itta, 2013). Previous
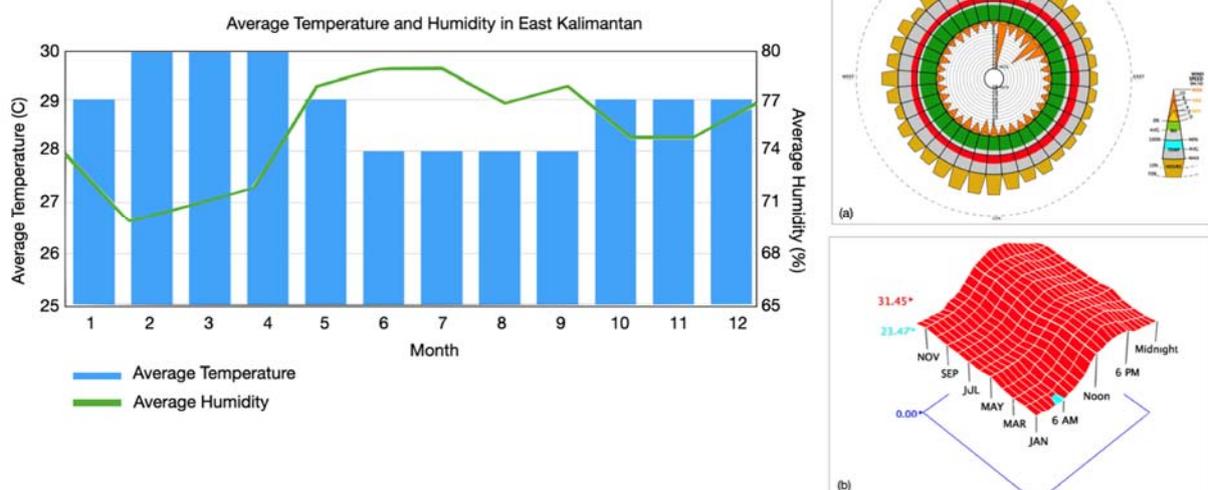

Fig. 10. Climate analysis for East Kalimantan conducted using Climate Consultant software

studies confirm that this material is suitable for a wide range of building applications (Palapessy, 2018). Its natural properties allow it to withstand changes in temperature and humidity, as well as exposure to seawater.

The climate of Desa Harapan Baru is representative of much of Indonesia, characterized by a humid tropical climate with consistently high temperatures and humidity throughout the year. Zinc roofing is an affordable and widely used material in Kalimantan; however, its thermal properties can lead to increased indoor temperatures and perceived humidity levels (Alkausar and Riyani, 2023). Due to its lightweight nature and thermal properties, zinc roofing readily absorbs solar heat, contributing to elevated indoor temperatures (Paramita, 2025). While zinc roofs do not directly increase indoor humidity, higher temperatures can intensify the perception of humidity and reduce thermal comfort (Alkausar and Riyani, 2023). In the hot and humid conditions of Desa Harapan Baru, even slight temperature increases can significantly affect occupant comfort. Consequently, zinc roofing in such climates requires mitigation strategies, including the use of light-colored or coated zinc materials, improved natural ventilation, and additional thermal insulation.

Based on these considerations, several passive design strategies are proposed for the nZEMB:

1. In response to local climatic conditions, available resources, and site characteristics, zinc roofing is adopted, while raised floors and columns are constructed from ulin wood. The timber walkway is designed with a minimum width of one meter.

2. The building is designed to promote natural ventilation through shaded openings and appropriately oriented windows that face prevailing wind directions, thereby reducing heat gain from the zinc roof.

3. Passive cooling is enhanced through a patio-based ventilation strategy, particularly during hot periods.

4. Natural cross-ventilation is supported through an open-plan layout and the use of ceiling fans.

5. Thermal heat gain is further reduced by controlling solar radiation.

To reduce reliance on petroleum-based energy sources, the building is designed to produce its own electricity. Solar panels are therefore incorporated as the primary energy generation system. As shown in Table 1, measurements of received solar energy were used to obtain solar irradiation data. Table 1 presents global horizontal solar irradiation data obtained from Meteonorm 8.0 (1991–2009) for the proposed off-grid solar (OGS) site. A Meteonorm report was automatically generated when PVsyst was accessed (PVsyst documentation, 2023).

The solar resource in Desa Harapan Baru varies throughout the year, with the lowest global horizontal

Table 1. **Monthly global horizontal solar irradiation at the proposed site in Desa Harapan Baru**

Month	Global horizontal solar irradiation (kWh/m²/month)
January	145.7
February	140.2
March	158.6
April	142.8
May	135.3
June	110.1
July	146.6
August	154.0
September	152.2
October	146.6
November	147.2
December	140.5
Year	1,719.7

irradiation recorded in June at 110 kWh/m²/month and the highest in March at 158 kWh/m²/month. The total annual global horizontal irradiation at the site is 1,719.7 kWh/m². These values indicate that Desa Harapan Baru has a high potential for harvesting solar energy to meet local energy demands. Further analysis was carried out using PVsyst software to evaluate the solar energy potential and to design the solar panel system. Table 2 presents the DC output voltage and current of the solar array, denoted as U_{mpp} (1) and I_{mpp} (2), respectively.

$$U_{mpp} = voltage\ of\ a\ solar\ module \times$$

$$\times number\ of\ modules\ in\ series; \qquad (1)$$

$$I_{mpp} = current\ of\ a\ solar\ module \times$$

$$\times number\ of\ modules\ in\ parallel. \qquad (2)$$

EArrNom represents the amount of energy produced by the solar array as a result of converting incident solar irradiation. It is calculated using the following equation:

$$EArrNom = Globeff \times Pnom, \qquad (3)$$

where global effective irradiance (Globeff) represents the global solar irradiation after accounting for optical losses such as shading, incidence angle modifier (IAM), and soiling, while Pnom denotes the nominal power of the PV array at standard test conditions (STC), equal to 30 kWp. When the available solar energy is insufficient to satisfy the load demand, the resulting energy shortfall is referred to as E_Miss. This condition occurs when the combined output of the PV system and the battery energy storage system is unable to fully meet the required energy demand. The solar fraction can be calculated based on the ratio between the energy supplied to the user (E_User) and the energy needs (E_Load), as expressed in Eq. (4):

$$solar\ fraction = E\_User / E\_Load. \qquad (4)$$

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Table 2. **Solar panel characteristics based on U$_{mpp}$ and I$_{mpp}$ calculations**

PV system		Battery	
Manufacturer	Trina Solar	Manufacturer	Narada
Model	TSM-DE 18M-(II)-500	Model	EosG 1000
Nominal power per module	500 Wp	Technology	Sealed lead-acid (gel)
Number of PV modules	60 modules	Configuration	6 parallel × 24 series
Total nominal power (STC)	30 kWp	Minimum discharge SOC	20.0 %
Power at operating conditions (50°C)		Stored energy	231.0 kWh
P$_{mpp}$	27.31 kWp	**Battery pack characteristics**	
U$_{mpp}$	156 V	Voltage	48 V
I$_{mpp}$	175 A	Nominal capacity	6,000 Ah (C10)
Controller (universal controller)		Temperature	Fixed at 35°C
Technology	MPPT converter	**Battery management control**	
Temperature coefficient	−5.0 mV/°C per cell	Control thresholds	SOC-based
Converter		Charging (approx.)	SOC = 0.90 / 0.75 53.9 / 50.7 V
Maximum / European efficiency	97.0 / 95.0 %	Discharging (approx.)	SOC = 0.20 / 0.45 47.7 / 49.5 V
Total PV power			
Total nominal power (STC)	30 kWp		
Total modules	60 modules		
Module area	143 m²		

Several photovoltaic installations have been evaluated using the Performance Index developed by the European Joint Research Center (JRC), which is incorporated into the IEC EN 61724 standard (PVsyst, 2023). These indicators are based on the incident global irradiation received by the solar array and are normalized by the nominal installed power, Pnom, expressed in kilowatt-peak (kWp) under standard test conditions (STC). According to STC, global irradiation under outdoor conditions is defined as 1,000 W/m², the module temperature is set at 25°C, and the solar spectrum corresponds to AM 1.5, which represents a normalized solar spectrum equivalent to 1.5 times the atmospheric air mass at sea level. Under these reference conditions, performance indicators are independent of the array size, geographic location, and field orientation (Kim et al., 2015). Yield values are therefore expressed in units of kWh/kWp/day, which are numerically equivalent to the equivalent operating time at a constant irradiation of 1 kW/m². These values may also be interpreted as hours per day at 1 kW/m² or as kWh/m²/day (Kim et al., 2015).

The integration of passive design strategies with photovoltaic systems provides an effective approach for achieving an optimal nZEMB design for Desa Harapan Baru. Based on the established design guidelines, a preliminary nZEMB configuration was developed. Subsequently, two analytical methods were applied to evaluate the proposed design. First, indoor thermal comfort was assessed using computational fluid dynamics (CFD) analysis conducted with ANSYS Fluent

software. Finally, building energy consumption was evaluated using DesignBuilder software through energy simulation.

2. nZEMB Architecture Design

The final design of the nZEMB is presented in Fig. 11. The proposed nZEMB incorporates a landing dock, a cold storage facility, a market hall, warung stalls, a multipurpose room, a kitchen, lavatory facilities, a *mushola* (prayer room), and a plaza. In Desa Harapan Baru, landing docks are commonly found at individual houses, as most residents work as fishermen. After fishing is completed, the catch is typically sorted immediately. The nZEMB consolidates these dispersed activities into a single centralized facility. Providing a large landing dock allows post-fishing activities, such as unloading and sorting the catch, to be carried out more efficiently than selling fish directly to customers upon arrival. According to an earlier interview, local residents expressed the need for cold storage facilities so that fish do not have to be sold immediately after fishing trips. The availability of cold storage would enable fishermen to preserve their catch and avoid selling it at low prices under time pressure.

Near the landing dock, fish can be sold directly at the market hall. The warung, which serves as a retail space for everyday goods, is located adjacent to the market hall. Traditionally, such activities as fish sorting and the sale of daily necessities are carried out by women either within their houses — on terraces or timber bridges — or directly on the bridges themselves. By relocating the warung and these activities to the nZEB, the building becomes
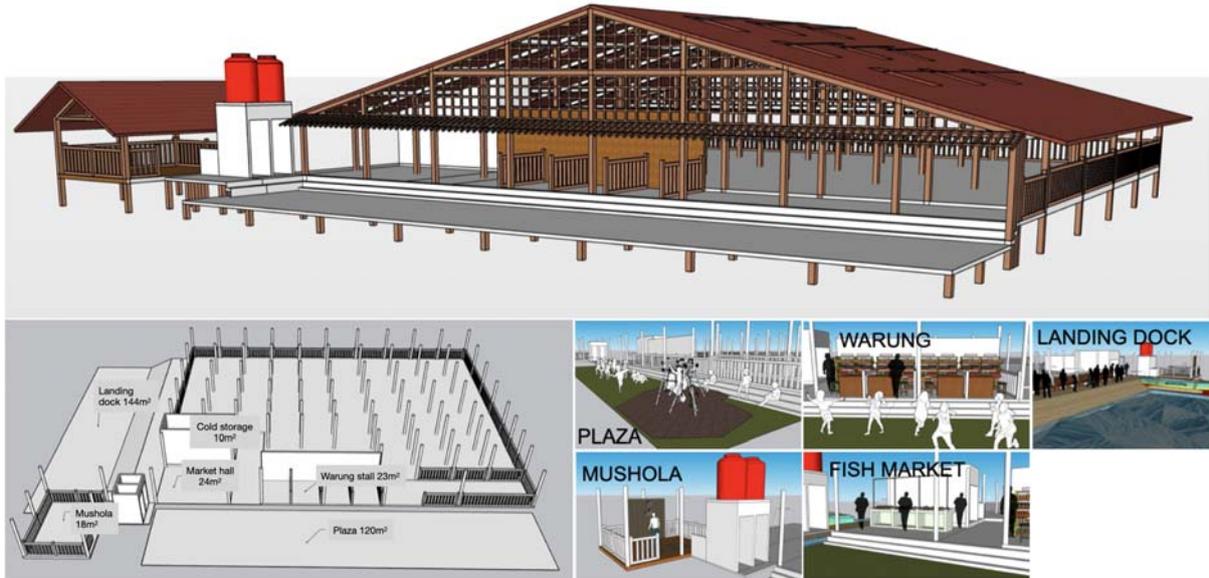
Fig. 11. Final design of the nZEMB in Desa Harapan Baru, East Kalimantan, incorporating a landing dock, a market hall, warung stalls, a plaza, and a mushola (prayer room)

more functional and better supports daily community practices. Within the complex, the multipurpose room represents the most significant shared space, as it is intended for wedding celebrations and other communal events.

A simple kitchen is provided for food preparation during community events and social gatherings. The nZEMB also incorporates a mushola, serving as a prayer space for residents engaged in fishing, trading, and other communal activities. The interviews revealed that Desa Harapan Baru lacks a designated playground for children. In response, the building design includes a plaza that functions as a play area for children and can also serve as a communal gathering and meeting space for village residents. Lavatory facilities are provided to support users of the plaza, including children, women engaged in fish and goods trading, and men returning from

work. A detailed description of the required spaces is presented in Table 3, while Table 4 summarizes the calculated areas for each functional space.

3. Solar Panel Design

A total of 17 solar panels were incorporated into the design (Fig. 12). The required number of panels was determined based on the solar potential analysis presented in the previous section and was further refined according to the roof geometry. The placement of the solar panels was carefully designed to respond to local needs while avoiding alterations to the traditional roof shape. Fig. 12 illustrates the proposed location of the off-grid solar (OGS) system on the roof of the multipurpose building. The estimated rooftop area allocated for the OGS system installation is 143 m^2.

The Desa Harapan Baru OGS system has a solar system capacity of 25 kW (30 kWp installed)

Table 3. **Space organization and qualitative characteristics of the proposed nZEMB**

Activity	Space	Zone	Quality				
			Access	View	Sunlight	Ambience	Natural ventilation
Fish market	Landing dock	Semi-private	o		o		
	Cold storage	Private	o				
	Market hall	Public	o		o		o
Warung	Warung stall	Public	o		o	o	o
Communal space	Multipurpose room	Public	o	o	o	o	o
	Kitchen	Semi-private	o		o		o
	Lavatory	Private	o		o		o
	Mushola	Semi-private	o	o	o	o	o
	Plaza	Public	o	o	o	o	o

Table 4. **Area calculation for each functional space based on standards and local community needs in Desa Harapan Baru**

| Activity	Space	Standard requirement (m²)	Unit	Capacity	Required area (m²)	Total area (m²)
Fish market	Landing dock	40 m² per 10-GT boat	Boat	3	120	144
	Cold storage	0.96	Rack	10	9.6	10
	Market hall	2	Person	10	20	24
Warung	Warung stall	3	Person	6	18	23
Communal space	Multipurpose room	4	Person	100	400	400
	Kitchen	1	Room	10	10	10
	Lavatory	2	Room	2	4	4
	Mushola	2	Person	10	18	18
	Plaza	6	Person	20	120	120
	Circulation space	1	Person	2	18	18
	Net sewing area	1	Person	10	29	29
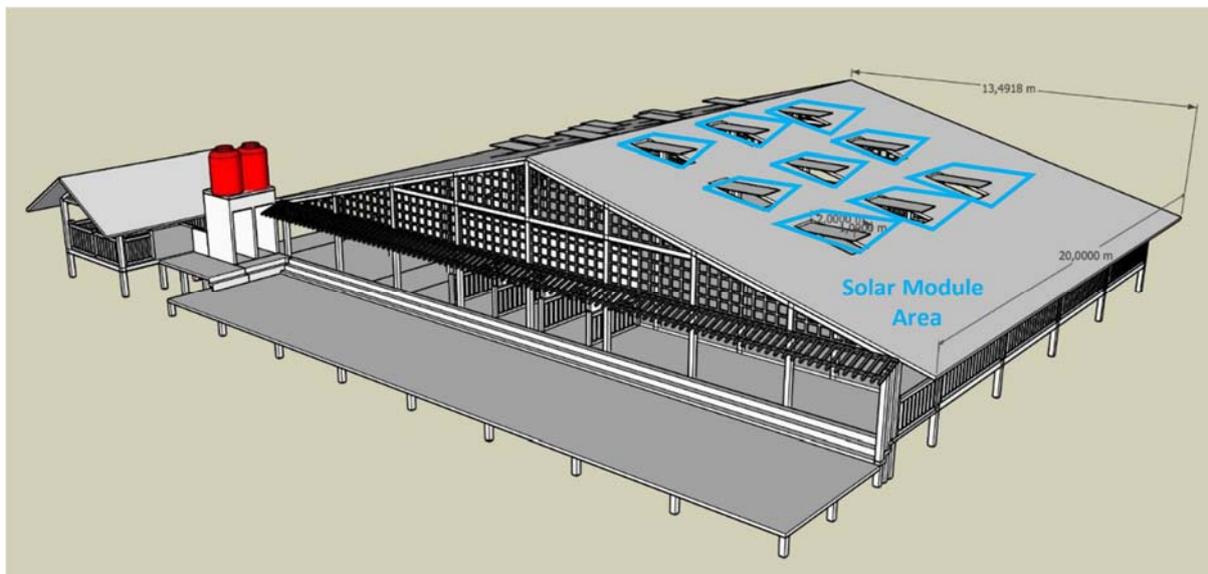
Fig. 12. Overview of the multipurpose building with an off-grid solar system (17 solar panels) installed on the roof

and a battery energy storage capacity of 231 kWh. A total of 60 photovoltaic modules, each rated at 500 Wp, are arranged in 15 parallel strings, with four modules connected in series within each string. The solar modules are installed at a tilt angle of 15° and an azimuth angle of 90°. The battery storage system consists of sealed gel lead-acid batteries, with 6 batteries connected in parallel and 24 connected in series. As summarized in Table 5, the main technical characteristics of the Desa Harapan Baru OGS system were derived using Eqs. (1) and (2). The PVsyst software was employed to estimate the energy yield of the system. Various system losses were incorporated into the simulation, and the assumed loss parameters are presented in Table 6.

A total of 17 solar panels installed on the building are capable of producing 120 kWh/day.

Fig. 13 presents the detailed results of the PVsyst simulation. In the first year of operation, the simulated 30 kWp OGS system in Desa Harapan Baru generated 39.17 MWh of electricity. Based on the first-year output, the system achieved a solar fraction of 89.42 % and a specific yield of 1,370 kWh/kWp/year. As illustrated in Fig.13a, the energy supplied by the OGS system to end users is denoted as E_User, while the energy demand from the user or load is denoted as E_Load. The monthly average values of unused energy (Lu), collection losses (Lc), system losses (Ls), and final energy yield (Yf) are approximately 0.07 kWh/kWp/day, 0.70 kWh/kWp/day, 0.28 kWh/kWp/day, and 3.58 kWh/kWp/day, respectively. The E_User value was obtained by subtracting all system losses from the nominal array energy at standard test conditions

Table 5. **Characteristics of the nZEMB solar system in Desa Harapan Baru**

PV system	
Manufacturer	Trina Solar
Model	TSM-DE-18M-(II)-500
Nominal power per module	500 Wp
Umpp	156 V
Impp	175 A
Total PV power	
Total nominal power (STC)	30 kWp
Total number of modules	60 modules
Battery	
Manufacturer	Narada
Model	EosG 1000
Configuration	6 parallel × 24 series
Minimum discharge SOC	20 %
Stored energy	231 kWh
Battery management control	
Charging	SOC = 0.90 / 0.75
Voltage (approx.)	53.9 / 50.7 V
Discharging	SOC = 0.20 / 0.45
Voltage (approx.)	47.7 / 49.5 V

Table 6. **Loss assumptions applied in the PVsyst simulation**

| Thermal loss factor	Module temperature as a function of irradiation
Uc (const.)	20 W/m²K
Uv (wind)	0 W/m²K/(m/s)
Module quality loss	
Loss fraction	–0.8 %
IAM loss factor	
Incidence effect (IAM): Fresnel AR coating, n(glass) = 1.526, n(AR) = 1.290	
DC wiring losses	
Global array resistance	15 mΩ
Loss fraction	1.5 % at STC
Module mismatch losses	
Loss fraction	2.0 % at MPP
Series diode losses	
Voltage drop	0.7 V
Loss fraction	0.4 % at STC
Strings mismatch losses	
Loss fraction	0.1 %
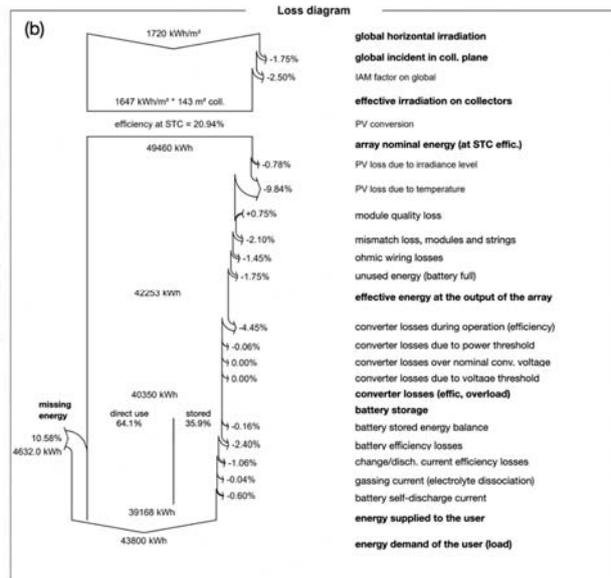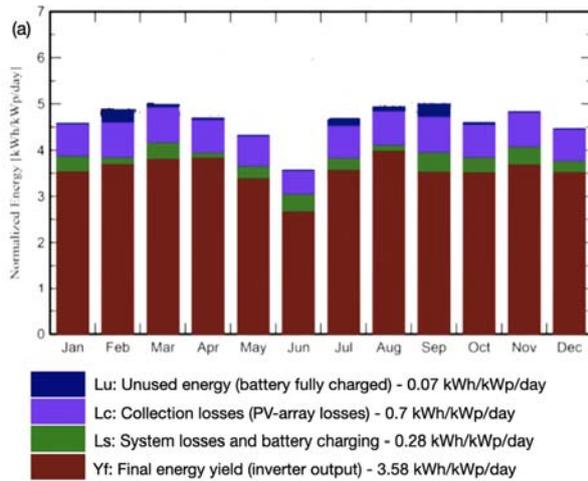
Fig.13. PVsyst simulation results showing (a) annual specific energy yield (kWh/kWp/day) and (b) a detailed loss diagram for the proposed OGS system

(EArrNom), as illustrated in the loss diagram shown in Fig. 13b.

nZEMB Performance Analysis

A key consideration in passive building design for tropical climates is the ability to regulate indoor temperatures in a way that minimizes or eliminates the need for mechanical cooling. However, in recent years, rising ambient temperatures have reduced the effectiveness of purely passive strategies. In Desa Harapan Baru, the existing diesel generator system represents a major challenge, as it relies on petroleum-based energy and results in high electricity costs and consumption. Replacing this system with renewable energy sources is therefore essential. To design a nearly zero-energy building, a balance between energy demand and energy generation must be established. Given Indonesia's proximity to the equator, solar energy represents a highly viable and abundant renewable resource. It was therefore proposed that the building

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incorporate not only passive design strategies but also active technologies, such as solar panels, to achieve substantial energy savings. As discussed in the previous section, daylighting control and cross-ventilation were identified as critical design parameters for the nZEMB in Desa Harapan Baru. The effectiveness of the proposed design was then evaluated, followed by calculations of the solar energy output.

1. Daylighting Control

The use of daylight in tropical climates plays an important role in reducing energy consumption. However, improper placement may lead to increased heat gains, which can result in higher electricity demand. In Indonesia, lighting standards are regulated by the Indonesian National Standard (SNI), specifically SNI 6197:2020 on Energy Conservation in Lighting Systems, which is a revision of standard SNI 6197:2011. This standard specifies recommended illumination levels and maximum lighting power densities. For multipurpose buildings, SNI recommends an illumination level of 250 lux (National Standardization Agency of Indonesia, 2020). Accordingly, a daylighting control analysis was conducted for the nZEMB design using the DesignBuilder simulation tool in compliance with this standard.

Simulations of the daylighting performance of the nZEMB in Desa Harapan Baru, Kalimantan, were conducted using DesignBuilder software. Developed based on the U.S. Department of Energy's EnergyPlus engine, DesignBuilder is widely used to evaluate the environmental performance of both new and existing buildings. It enables detailed analysis of indoor energy consumption and thermal comfort (DesignBuilder Software Ltd., 2023). In addition to daylighting analysis, the software was also used to assess overall energy consumption. The schematic design of the building is shown in Fig. 14. The building geometry is approximately square, with a predominantly south-facing orientation. Various functional areas within the building were included in the simulation, namely the multipurpose room,
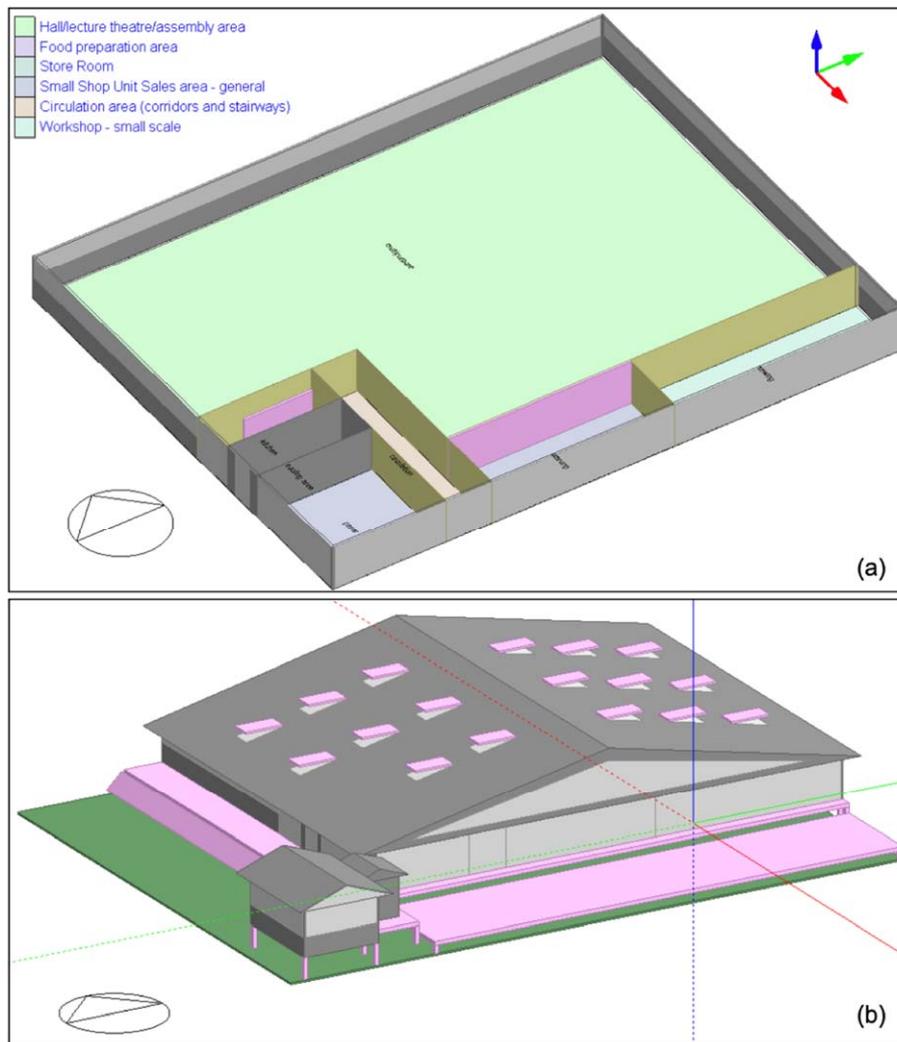

Fig. 14. DesignBuilder schematics of the nZEMB showing (a) the main building layout and (b) the 3D building model

kitchen, cold storage, market hall, circulation spaces, warung stalls, sewing areas, lavatories, and communal dining area, resulting in a total simulated floor area of 513 m^2. The building site is located at an elevation of 1 m below sea level. Desa Harapan Baru lies within a tropical climate zone, classified as ASHRAE climate zone 3C.

After modeling the building geometry in DesignBuilder, the next step was to define the building activity templates. DesignBuilder provides a range of predefined activity templates that include parameters such as metabolic rates, occupancy densities, and clothing levels. In this study, the default parameters for a multipurpose building with a kitchen were applied, and no mechanical heating or cooling systems were included in the simulation.

This research utilizes Time Use Survey (TUS) data collected from occupants of Desa Harapan Baru to model occupant behavior, as shown in Fig. 6. The TUS records information on individual activities over a 24-hour period and includes data on occupations and demographic characteristics. A detailed understanding of user behavior contributes to improved building design (Sari and Chiou, 2019).

The results generated by the DesignBuilder simulation tool can be presented in terms of illuminance and daylight factor (DF). Illuminance refers to the amount of light incident on a surface before reflection and is measured in lux (Müeller, 2013). The daylight factor is defined as the ratio of indoor to outdoor illuminance under overcast sky conditions (Sari and Chiou, 2016). Since overcast conditions are relatively uncommon in tropical climates, this study focuses primarily on illuminance rather than DF. Fig. 15 illustrates illuminance values at selected measurement points and the spatial distribution of lux levels within the building. Openings were introduced in both the roof and walls, with the highest levels of illuminance observed on the north and south sides of the building to enhance daylight penetration. These facades are not shaded by roof overhangs, which contributes to higher illuminance levels. In contrast, the east and west facades are shaded by overhangs measuring 1 m in length. It is estimated that daylight penetration reaches a depth of approximately 1 m, as shown in Fig. 15.

Fig. 16 illustrates the distribution of daylight levels across the different zones of the building. The mushola exhibited the highest illuminance values, primarily due to its relatively small floor area (18 m^2). As musholas are typically used exclusively for prayer, the elevated illuminance levels can be moderated, if necessary, through the use of additional facade shading elements, such as curtains. As indicated by the simulation results, illuminance levels decrease with increasing room depth. The daylight levels in the other areas of the main building were estimated to be approximately 250 lux, which corresponds to the average illuminance recommended by the Indonesian SNI standard. Overall, the daylighting simulation indicates that the building complies with national lighting requirements for daylight performance.

2. Airflow, Cross-Ventilation, and CFD Simulation

To simulate airflow around the nZEMB, computational fluid dynamics (CFD) analysis was conducted using ANSYS Fluent 19.1 (ANSYS Inc., 2021). CFD simulations provide detailed insights into both internal and external airflow patterns and are widely used in studies of natural cross-ventilation.
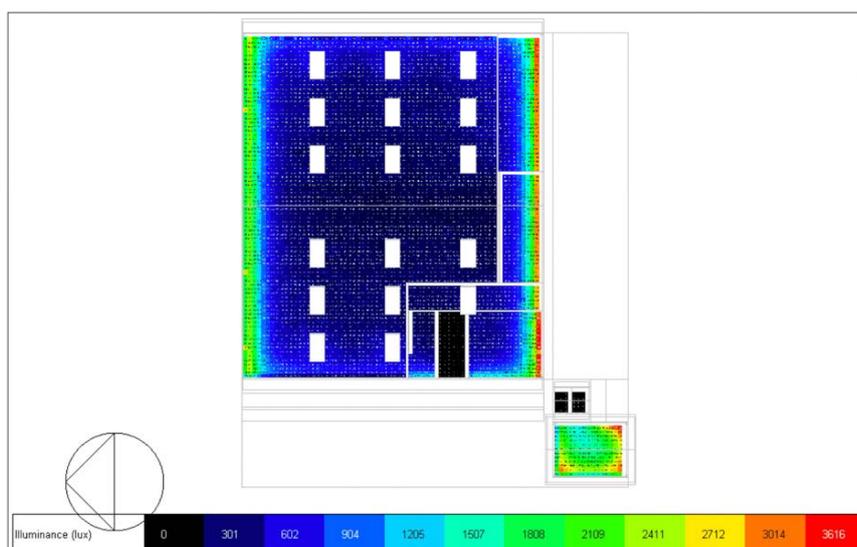

Fig. 15. Daylighting simulation results obtained using DesignBuilder software. Higher illumination levels were observed on the north and south facades due to the absence of shading overhangs, while the east and west facades exhibited lower illumination levels as a result of 1 m overhangs
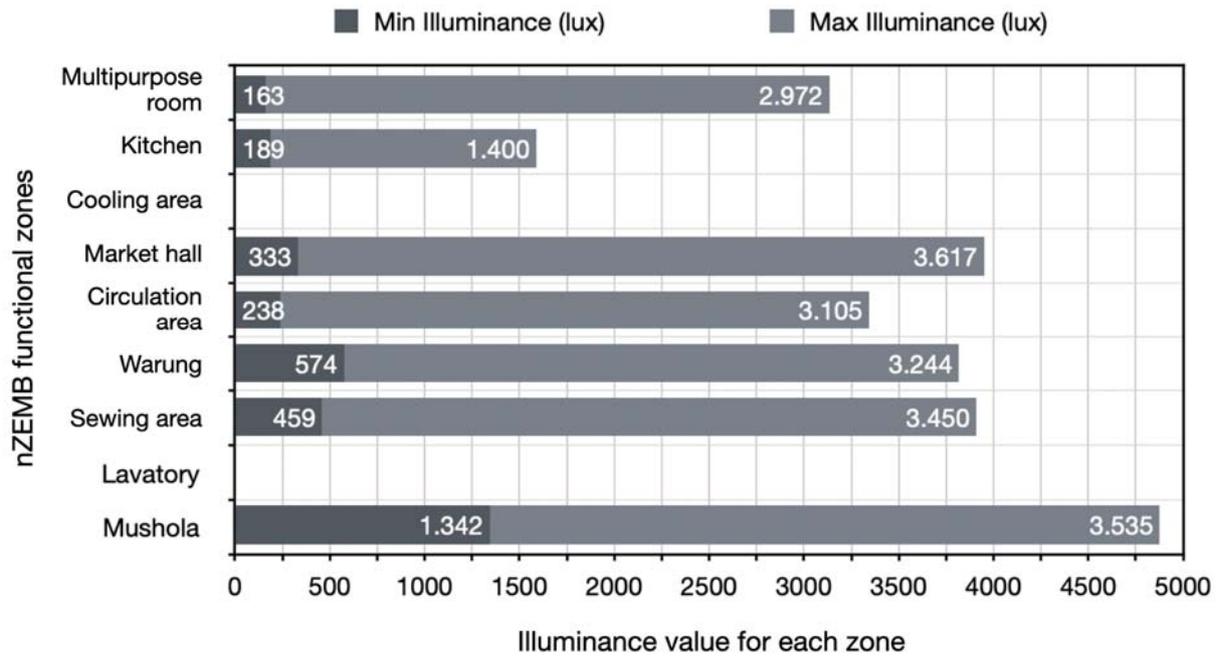
Fig. 16. Summary of illuminance distribution across different zones; the mushola exhibits the highest illuminance due to its relatively small floor area

However, the accuracy of CFD results requires careful validation. The CFD simulation approach was adopted from previous studies by Sudirman et al. (2023, 2025) and validated against wind tunnel experiments reported by Sudirman et al. (2024) to assess natural ventilation performance.

The governing equations were solved using ANSYS Fluent 19.1, including the 3D steady Reynolds-averaged Navier–Stokes (RANS) approach with the shear stress transport (SST) k–ω model (Menter, 2012), the realizable k–ε (RLZ) model (Shih et al., 1995), and the renormalization group k–ε (RNG) model (Choudhury, 1973; Yakhot et al., 1992). In addition, scale-adaptive simulation (SAS) using the SST k–ω model (Egorov et al., 2010) and large eddy simulation (LES) approaches (Lilly, 1992; Smagorinsky, 1963) were also considered. Pressure–velocity coupling was handled using the SIMPLE algorithm. Second-order discretization schemes were applied for pressure interpolation, as well as for the momentum and turbulence equations. The results showed that LES and SAS exhibited good agreement with wind tunnel measurements and outperformed RANS models. Specifically, the agreement in predicted indoor air velocities for buildings without partitions was approximately 56 %, 73 %, and 97 % for RANS, SAS, and LES, respectively. Although both LES and SAS demonstrated high accuracy, they required significantly greater computational resources. Therefore, in the present study, steady-state RANS equations with the RNG k–ε turbulence model were adopted, as this model outperformed the SST k–ω

and RLZ k–ε models in the validation studies. The same solver settings used in the validation cases were applied in this analysis.

An initial assessment of the building's physical performance was conducted using CFD simulations. The objective of this analysis was to investigate airflow patterns within the multipurpose building and to evaluate strategies for maximizing natural cross-ventilation. The full-scale building has dimensions of 24 m × 19.5 m × 6.5 m (D × W × H) and a roof slope of 16°. The building geometry includes walls, ceilings, and roof elements with a uniform thickness of 15 cm. The dimensions of the computational domain were determined in accordance with best-practice guidelines proposed by Franke et al. (2007) and Tominaga et al. (2008). As illustrated in Fig. 17a, the distance between the inlet plane and the windward facade is set to 5H, while the distance between the leeward facade and the outlet plane is 15H. The lateral boundaries are located at a distance of 5H from the building, and the vertical distance from the ground to the top boundary is 6H, where H represents the building height (6.5 m). The computational mesh consists of 2,733,130 hexahedral cells (Fig. 17b), with a maximum stretching ratio of 0.89. Mesh resolution was established based on a mesh sensitivity analysis, in which the mesh was systematically refined and coarsened using a linear scaling factor of √2 (not shown in this paper).

CFD simulations were conducted using boundary conditions that closely represent real-life conditions. In this study, the air velocity was determined based on measurements provided by the Indonesian
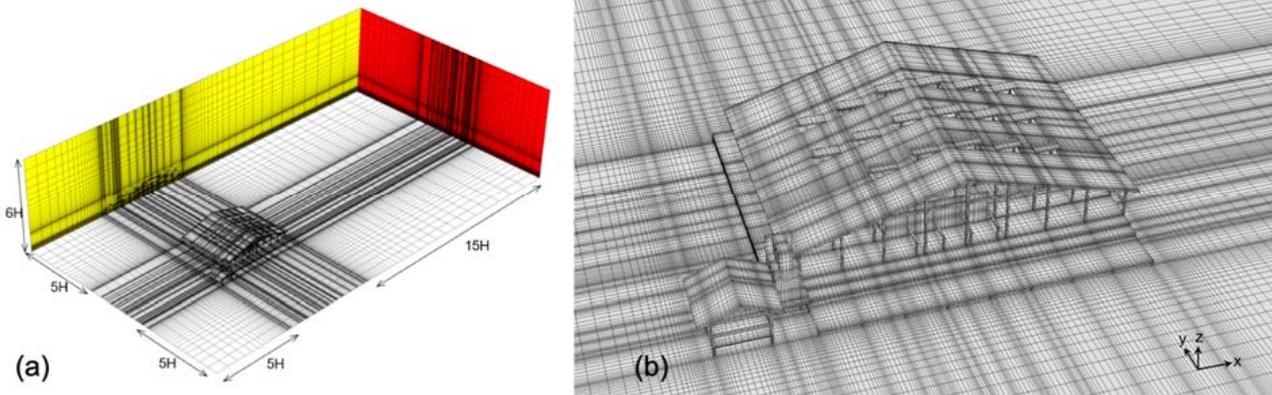
Fig. 17. CFD simulation setup for the nZEMB: (a) computational domain configuration, including the distances between the inlet plane, lateral boundaries, and the top boundary; (b) computational mesh consisting of 2,733,130 hexahedral cells

Agency for Meteorological, Climatological, and Geophysical Studies (BMKG, 2024). A logarithmic inlet velocity profile was applied at a reference height of 10 m above ground, with a reference wind speed of 12.86 m/s (U_{ref}). The building was assumed to be located in an open coastal area with short grass, characterized by an aerodynamic roughness length of z_0 = 0.005 m (Wieringa, 1992). The atmospheric boundary layer (*ABL*) friction velocity (u^*_{ABL} = 0.711 m/s) was calculated based on the reference wind speed (U_{ref}) at the reference height. Turbulence kinetic energy (k) and turbulence dissipation rate (ε) were specified using user-defined functions (*UDF*). Fig. 18 illustrates the railing system surrounding the building. The railings, with a height of 1 m, replace the external walls to enhance airflow. In the CFD simulations, the railings were modeled as porous media using a porous-jump boundary condition, with a porosity of 74 % and a thickness of 0.012 m. The porous parameters were adopted from wind tunnel experiments on perforated materials (case N1) reported by Tominaga et al. (2008).

Fig. 19 presents contours and vectors of the dimensionless mean streamwise velocity (U/U_{ref}) in three horizontal planes at heights of (a) z/H = 0.23, (b) z/H = 0.38, and (c) z/H = 0.46, where H denotes the building height (6.5 m). Wind velocity increases slightly with height due to the jet effect induced by airflow through the ceiling openings, as observed in Fig. 19b. A recirculation region develops within the ranges y/W = 0.13–0.35 and x/D = 0.13–0.40, primarily due to the presence of the cold storage room, which acts as an obstruction to airflow. As previously noted, the building's coastal location results in relatively high wind velocities. The inclusion of railings reduces airflow within the occupied zone by approximately 0.05 U_{ref}, while remaining within acceptable thermal comfort limits (Fig. 19a). Given that most activities within the building involve floor seating and no chairs are provided, the occupied zone is defined as the space below 1 m in height. A more detailed velocity contour is shown in Fig. 20. Adjusting the porosity of the railings and introducing additional openings at the roof and raised floor levels could further enhance airflow within the occupied zone of the nZEMB.

3. Energy Simulation and Design Optimization

Subsequently, the building was analyzed using DesignBuilder software. This tool enables users

Fig. 18. Isometric view of the building showing the locations of railings and perforated walls. The prevailing wind direction is from the west, toward the landing dock
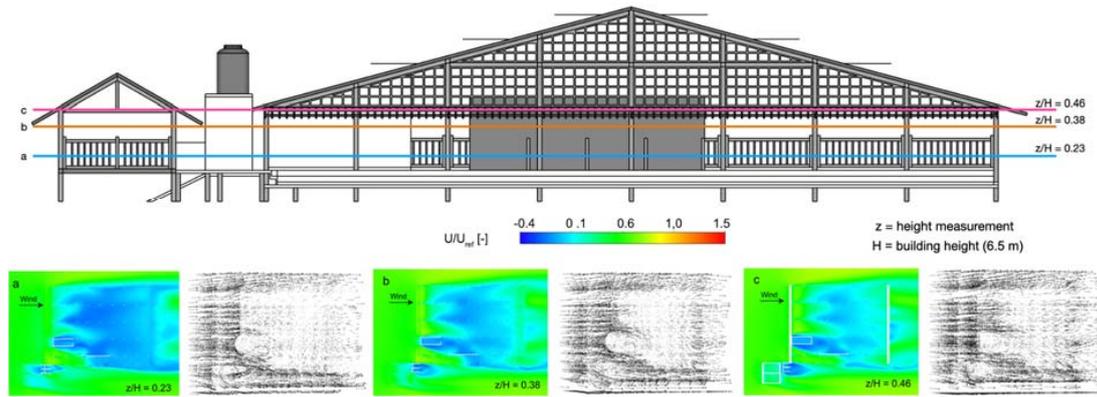
Fig. 19. Contours of dimensionless mean streamwise velocity (U/U_{ref}) in horizontal planes at (a) z/H = 0.23,
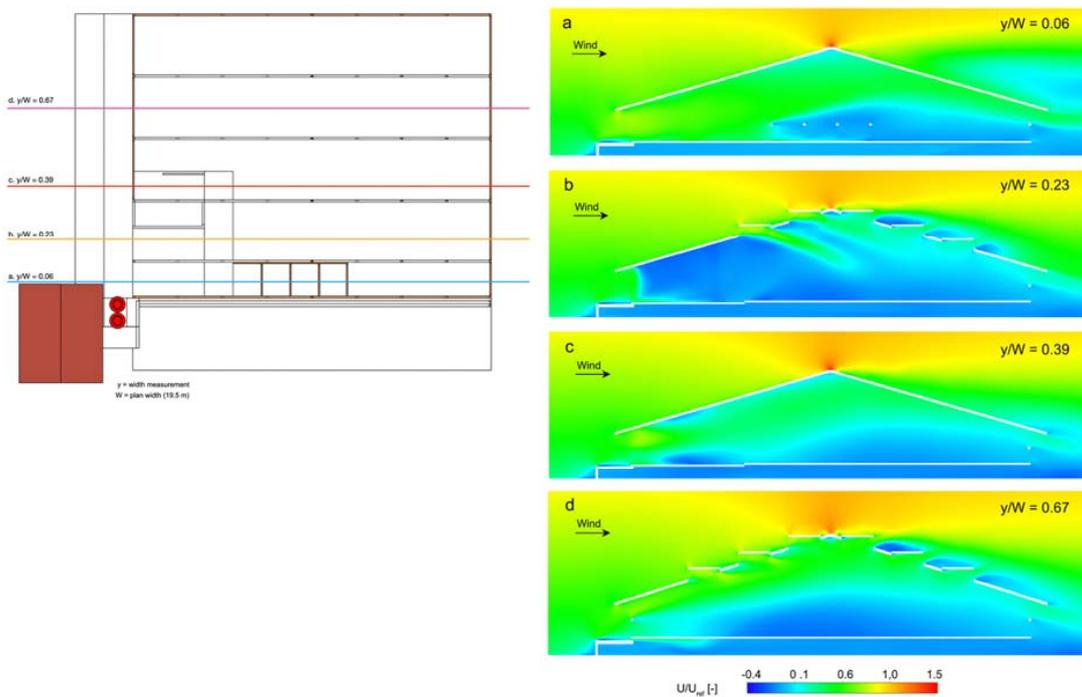(b) z/H = 0.38, and (c) z/H = 0.46

Fig. 20. Contours of dimensionless mean streamwise velocity (U/U_{ref}) in vertical planes at (a) y/W = 0.06;
(b) y/W = 0.23; (c) y/W = 0.39; and (d) y/W = 0.67

to make informed design decisions based on a single model (DesignBuilder Software Ltd., 2023). It allows for the analysis of building energy consumption by accounting for a range of complex variables, including climatic conditions, occupant behavior, and building characteristics. In general, three main factors influence energy consumption in buildings. The first is the occupant system, which includes occupant comfort requirements and behavioral patterns; in this study, these aspects were represented through the Time Use Survey (TUS). The TUS data served as the primary input for defining occupant schedules and behavior, consistent with the approach used in the daylighting analysis. The second factor is the building system, which includes lighting. In this study,

no mechanical cooling system was implemented due to the remoteness of the site. Similarly, heating systems were excluded, as Desa Harapan Baru is located in a tropical climate where heating demand is negligible throughout the year. The third factor is the external environment system.

Electrical consumption in the nZEMB was determined by analyzing the average number of users per day during weekdays, weekends, and special occasions such as weddings and local community meetings. Electrical appliances used in the nZEMB were categorized by functional space, as summarized in Table 7. Table 8 presents the general parameters required for the simulation of internal gains, including target illuminance levels, fresh air requirements,

Table 7. **Electrical appliances and lighting loads categorized based on the nZEMB interview survey**

Space	Area (m²)	Lighting / Equipment	Quantity	Unit power (W)	Total power (W)	Duration (h/day)
Landing dock	144	General lighting	4	25	100	12
Cold storage	10	General lighting	2	20	40	12
		Freezer	3	100	300	24
Market hall	25	General lighting	3	20	60	2
		Fan	1	50	50	12
Warung stall	20	General lighting	4	20	80	6
		Fan	2	50	100	12
Multipurpose room	440	General lighting	30	20	600	3
		Fan	5	50	250	12
Kitchen	12	General lighting	2	20	40	3
		Electric stove	2	600	1,200	12
		Fan	2	50	100	12
Lavatory	5	General lighting	1	20	20	6
Mushola	28	General lighting	1	20	20	3
Plaza	150	General lighting	4	25	100	12

Table 8. **Input parameters used for the nZEMB simulation in DesignBuilder**

Variable	Space	Value
Target illuminance	-	250 lux
Minimum fresh air	Multipurpose room	7.5 L/s·person
	Bathroom	10 L/s·person
	Kitchen	12 L/s·person
	Cold storage	10 L/s·person
Natural ventilation setpoint	-	27°C
Weather data	-	Samarinda City, East Kalimantan

natural ventilation conditions, and climatic data. As a result of the energy simulation, Table 9 outlines the internal input parameters and material properties applied in the model. A five-year analysis covering the period from 2019 to 2023 was conducted. On average, the total daily electricity consumption of the nZEMB is approximately 59.19 kWh. The simulation results indicate that the installed solar PV system is capable of supplying the full electricity demand required for daily activities (Fig. 21). Overall,

Table 9. **Description of materials used for nZEMB building elements**

Building element	Construction type
Construction template	Timber frame
External wall	Lightweight timber frame
Pitched roof (unoccupied space)	Lightweight uninsulated pitched roof
Internal partitions	Lightweight gypsum plasterboard (2 × 25 mm)
External and internal floors	Timber

the findings demonstrate that an nZEB performance can be achieved with the proposed design.

Conclusion

Desa Harapan Baru experiences a severe shortage of electricity, making the introduction of renewable energy sources, such as solar power, particularly important. This study presents the design of a nearly zero-energy multipurpose building (nZEMB) developed for Desa Harapan Baru. The building design was informed by an analysis of local culture and occupant behavior. By integrating these aspects into the architectural process, the proposed building is expected to be more readily accepted by the community and to facilitate adaptation to new technologies. The introduction of renewable energy through architectural design also serves an educational purpose, as local residents can directly experience the benefits of solar energy in their daily activities. In this way, local needs can be addressed while simultaneously reducing environmental impacts. The main findings of this research can be summarized as follows:

1. Passive design strategies adapted from local housing typologies demonstrate that nearly zero-energy performance can be achieved by reducing reliance on mechanical ventilation and artificial lighting.

2. Properly designed openings and shading systems effectively regulate daylight distribution; as room depth increases, illuminance levels decrease accordingly. The combined use of openings and shading allows daylight penetration to be maximized while limiting heat gain.

3. Cross-ventilation and heat reduction are enhanced through large window openings and grid-based ventilation integrated into the roof design.

4. Overall building energy consumption can be reduced by improving the building envelope using passive strategies, such as solar shading.
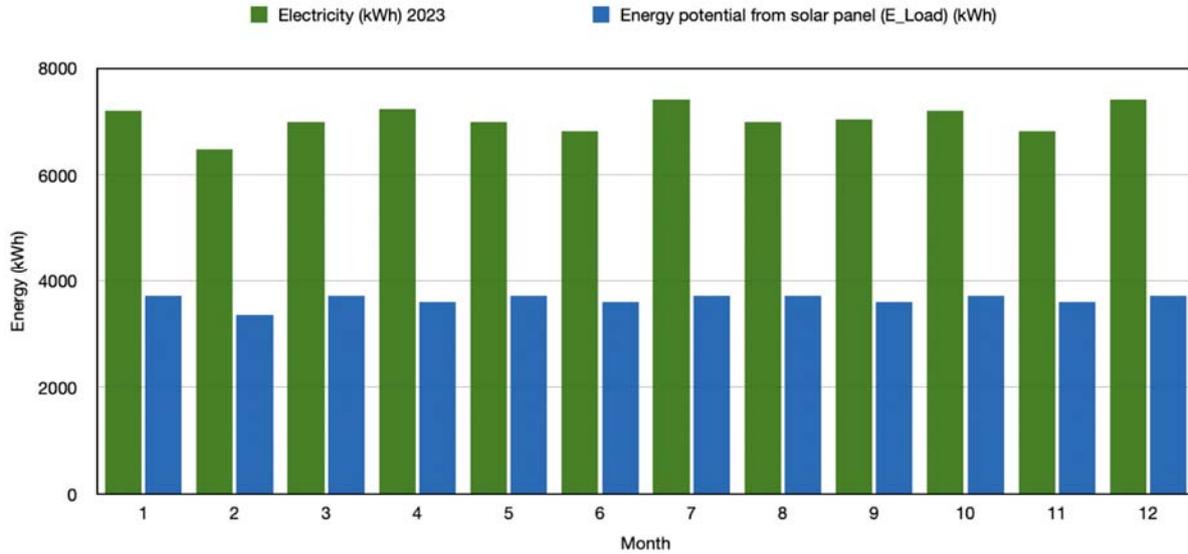
Fig. 21. Comparison between the energy consumption of the nZEMB and the energy generated by the solar panel system.
The total daily energy demand is approximately 59.19 kWh, while the solar panels generate about 120 kWh per day

5. Solar energy was shown to be an effective renewable energy alternative for meeting the electricity needs of Desa Harapan Baru.

6. The installation of 17 solar panels on the roof is sufficient to supply energy for all building activities, including cold storage equipped with large freezers.

Despite the high potential for solar energy utilization in Desa Harapan Baru, this renewable resource remains underutilized in the residential sector. One of the main challenges is the lack of local capacity to operate and maintain solar technologies, which often results in system failure. In many cases, women — who spend more time at home and manage household activities — are not trained in maintaining these technologies. This limits the long-term functionality of installed systems and reflects a broader lack of awareness regarding the potential of buildings to generate their own energy. The proposed nZEMB consolidates multiple household and community activities into a single facility, enabling more efficient energy use. The results demonstrate that solar energy can fully meet the electricity demand of the proposed design. This study offers an effective strategy for tropical climates and provides guidance for architects and designers involved in the design and retrofitting of energy-efficient buildings. Further development and analysis are recommended to refine and enhance the proposed design.

References

Alkausar and Riyani, R. A. E. (2023). Vernacular passive design with natural ventilation of Banjar housing for thermal comfort. *Paragraphs Environmental Design*, Vol. 1, No. 1, pp. 83–92. DOI: 10.59260/penvid.2023.83921212.

Alwetaishi, M. (2022). Can we learn from heritage buildings to achieve nearly zero energy building and thermal comfort? A case study in a hot climate. *Advances in Building Energy Research*, Vol. 16, Issue 2, pp. 214–230. DOI: 10.1080/17512549.2020.1844047.

Anggraeni, D. S. N. (2020). *Karakteristik Perumahan di Kalimantan Barat*. [online] Available at: https://www.suarapemredkalbar.com/read/opini/25082020/karakteristik-perumahan-di-kalimantan-barat#:~:text=seng/asbes%20 masih%20menjadi%20pilihan%20utama%20masyarakat%20Kalimantan,persen%20menggunakan%20asbes%2C%20 sisanya%20menggunakan%20jenis%20atap [Date accessed April 18, 2025].

Ansys Inc. (2021). *ANSYS Fluent Theory Guide*. [online] Available at: https://dl.cfdexperts.net/cfd_resources/Ansys_ Documentation/Fluent/Ansys_Fluent_Theory_Guide.pdf [Date accessed October 9, 2024].

Arifin, Y. F. and Itta, D. (2013). The potency of ulin (*Eusideroxylon zwageri* T. et. B) for supporting Banjarese building construction in "wetland architecture". *Journal of Wetlands Environmental Management*, Vol. 1, No. 1, pp. 61–64. DOI: 10.20527/jwem.01.01.03.

Arifin, M., Wunas, S., Mushar, P., Arifin, M. A., Pananrangi, A. I. A., Lakatupa, G., and Abdu, J. M. A. M. (2024). Typology and configuration of Lake Tempe floating house in South Sulawesi, Indonesia. *Journal of Asian Architecture and Building Engineering*, Vol. 23, Issue 5, pp. 1489–1499. DOI: 10.1080/13467581.2023.2270022.

Brisbane City Council (2018). *Traditional Housing: Alterations and Extensions Design Guide*. [online] Available at: https://www.arkhefield.com.au/assets/Projects/Traditional-Housing-Guide/Traditional-Housing-alterations-and-Extensions-Design-Guide.pdf [Date accessed March 14, 2023].

Brisbane City Council (2023). *Traditional Housing: Alterations and Extensions Design Guide*. [online] Available at: https://www.brisbane.qld.gov.au/content/dam/brisbanecitycouncil/corpwebsite/building-and-planning/documents/traditional-housing-alterations-and-extensions-design-guide.pdf.coredownload.pdf [Date accessed March 14, 2023].

Choudhury, D. (1973). *Introduction to the renormalization group method and turbulence modeling*. Fluent Incorporated. 70 pages. https://books.google.co.in/books?id=mKWEQwAACAAJ

DesignBuilder Software Ltd. (2023). *DesignBuilder*. [online] Available at: https://designbuilder.co.uk/ [Date accessed August 5, 2023].

Egorov, Y., Menter, F. R., Lechner, R., and Cokljat, D. (2010). The scale-adaptive simulation method for unsteady turbulent flow predictions. Part 2: application to complex flows. *Flow, Turbulence and Combustion*, Vol. 85, Issue 1, pp. 139–165. DOI: 10.1007/s10494-010-9265-4.

Falasca, S., Di Bernardino, A., and Salata, F. (2023). On the identification and characterization of outdoor thermo-hygrometric stress events. *Urban Climate*, Vol. 52, 101728. DOI: 10.1016/j.uclim.2023.101728.

Feng, W., Zhang, Q., Ji, H., Wang, R., Zhou, N., Ye, Q., Hao, B., Li, Y., Luo, D., and Lau, S. S. Y. (2019). A review of net zero energy buildings in hot and humid climates: experience learned from 34 case study buildings. *Renewable and Sustainable Energy Reviews*, Vol. 114, 109303. DOI: 10.1016/j.rser.2019.109303.

Franke, J., Hellsten, A., Schlünzen, H., and Carissimo, B. (2007). *Best Practice Guideline for the CFD simulation of flows in the urban environment*. [online] Available at: https://sciencespo.hal.science/ENPC-CEREA/hal-04181390v1 [Date accessed August 10, 2024].

National Standardization Agency of Indonesia (2020). *Konservasi energi pada sistem pencahayaan. Indonesian National Standard SNI 6197:2020*. [online] Available at: https://akses-sni.bsn.go.id/dokumen/2020/SNI%206197-2020/#p=1 [Date accessed March 14, 2023]

Kim, S.-K., Lee, S.-J., Kwon, H. J., and Ahn, M. (2015). Zero-energy home development in Korea: energy-efficient and environmentally friendly design features and future directions. *Housing and Society*, Vol. 42, Issue 3, pp. 222–238. DOI: 10.1080/08882746.2015.1121682.

Lilly, D. K. (1992). A proposed modification of the Germano subgrid-scale closure method. *Physics of Fluids*, Vol. 4, Issue 3, pp. 633–635. DOI: 10.1063/1.858280.

Lubis, M. S., Harjoko, T. Y., and Susanto, D. (2018). The floating houses of Sintang City: space, resources and political nexus. *IOP Conference Series: Materials Science and Engineering*, Vol. 316, 012003. DOI: 10.1088/1757-899X/316/1/012003.

Menter, F. R. (2012). Two-equation eddy-viscosity turbulence models for engineering applications. *AIAA Journal*, Vol. 32, No. 8, pp. 1598–1605. DOI: 10.2514/3.12149.

Merello, P., Fernández-Navajas, Á., Curiel-Esparza, J., Zarzo, M.,and García-Diego, F. J. (2014). Characterisation of thermo-hygrometric conditions of an archaeological site affected by unlike boundary weather conditions. *Building and Environment*, Vol. 76, pp. 125–133. DOI: 10.1016/j.buildenv.2014.03.009.

Meteorological, Climatological, and Geophysical Agency (BMKG) (2024). *Weather Forecast, Penajam District Penajam Paser Utara Regency - East Kalimantan Province*. [online] Available at: https://www.bmkg.go.id/cuaca/prakiraan-cuaca/64.09.01.1011 [Date accessed June 6, 2024].

Müeller, H. F. O. (2013). Chapter 9 - Daylighting: In: Sayigh, A. (ed.). *Sustainability, Energy and Architecture. Case Studies in Realizing Green Buildings*. Oxford: Academic Press, pp. 227–255. DOI: 10.1016/B978-0-12-397269-9.00009-8.

Ohene, E., Hsu, S.-C., and Chan, A. P. C. (2022). Feasibility and retrofit guidelines towards net-zero energy buildings in tropical climates: a case of Ghana. *Energy and Buildings*, Vol. 269, 112252. DOI: 10.1016/j.enbuild.2022.112252.

Palapessy, J. G. (2018). *Experimental research on the flexural strength of ironwood (ulin) (Eusideroxylon zwageri)*. Undergraduate Thesis in Civil Engineering. [online] Available at: https://repository.maranatha.edu/9757/ [Date accessed April 18, 2025].

Paramita, B. (2025). *Building climate resilience in Indonesia: the role of cool roofs*. [online] Available at: http://journals.openedition.org/factsreports/7823 [Date accessed April 18, 2025]

Pinassang, J. L., Harsritanto, B. I. R., and Sari, D. P. (2021). What we can learn from vernacular house and COVID-19 infection? A review of Mbaru Niang, Flores, Indonesia. *E3S Web of Conferences*, Vol. 37, 04017. DOI: 10.1051/e3sconf/202131704017.

Putro, J. D. and Zain, Z. (2021). Active and passive adaptation of floating houses (Rumah Lanting) to the tides of the Melawi River in West Kalimantan, Indonesia. *Geographica Pannonica*, Vol. 25, Issue 2, pp. 72–84. DOI: 10.5937/gp25-30422.

PVSyst (2023). *Normalized performance index*. [online] Available at: https://www.pvsyst.com/help/project-design/results/normalised-performance-index.html [Date accessed August 10, 2024].

PVsyst documentation (2023). *Geographical Sites*. [online] Available at: https://www.pvsyst.com/help/meteo-database/geographical-sites/index.html [Date accessed August 10, 2024].

Sari, D. P. and Chiou, Y.-S. (2016). The lighting design control strategy: a method for optimum daylighting performance in subtropical climate. In: *4th Annual International Conference on Architecture and Civil Engineering (ACE 2016), Shanghai, China, December 9–11, 2016*. DOI: 10.5176/2301-394X_ACE16.119.

Sari, D. P. and Chiou, Y.-S. (2019). Do energy conservation strategies limit the freedom of architecture design? A case study of Minsheng Community, Taipei, Taiwan. *Sustainability*, Vol. 11, Issue 7, 2003; DOI: 10.3390/su11072003.

Sari, D. P., Sudirman, M., and Chiou, Y. S. (2024). Modernity in Javanese tradition: adapting vernacular design and local culture to Indonesian urban living. *Architectural Science Review*, Vol. 67, Issue 2, pp. 105–119. DOI: 10.1080/00038628.2022.2136131.

Sari, D. P., Sumarno, A., Prasetyo, A. M., Maidina, and Ngeljaratan, L. N. (2023). Energy conservation techniques in tropical climate - a comprehensive review and adaptation of the Lamin House for Nusantara. *EVERGREEN Joint Journal of Novel Carbon Resource Sciences & Green Asia Strategy*, Vol. 10, Issue 3, pp. 2021–2028. DOI: 10.5109/7151769.

Shi, F., Wang, S., Huang, J., and Hong, X. (2020). Design strategies and energy performance of a net-zero energy house based on natural philosophy. *Journal of Asian Architecture and Building Engineering*, Vol. 19, Issue 1, pp. 1–15. DOI: 10.1080/13467581.2019.1696206.

Shih, T.-H., Liou, W. W., Shabbir, A., Yang, Z., and Zhu, J., (1995). A new k-ϵ eddy viscosity model for high Reynolds number turbulent flows. *Computers & Fluids*, Vol. 24, Issue 3, pp. 227–238. DOI: 10.1016/0045-7930(94)00032-T.

Smagorinsky, J. (1963). General circulation experiments with the primitive equations. *Monthly Weather Review*, Vol. 91, No. 3, pp. 99–164. DOI: 10.1175/1520-0493(1963)091<0099:GCEWTP>2.3.CO;2.

Society of Building Science Educators (2021). *Climate consultant*. [online] Available at: https://www.sbse.org/resources/climate-consultant [Date accessed August 5, 2023].

Sudirman, M., Gillmeier, S., Van Hooff, T., and Blocken, B. (2024). Wind tunnel measurements of cross-ventilation flow in a realistic building geometry: influence of building partitions and wind direction. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 254, 105907. DOI: 10.1016/j.jweia.2024.105907.

Sudirman, M., Van Hooff, T., Gillmeier, S., and Blocken, B. (2023). Validation of cross-ventilation flow in a realistic building geometry. In: Wang, L. L., Ge, H., Zhai, Z. J., Qi, D., Ouf, M., Sun, C., and Wang, D. (eds.). *Proceedings of the 5th International Conference on Building Energy and Environment*. Singapore: Springer, pp. 305–308. DOI: 10.1007/978-981-19-9822-5_33.

Sudirman, M., Van Hooff, T., Gillmeier, S., and Blocken, B. (2025). Validation study of cross-ventilation in a realistic building geometry: RANS, SAS and LES. *Building and Environment*, Vol. 269, 112354. DOI: 10.1016/j.buildenv.2024.112354.

Tominaga, Y., Mochida, A., Yoshie, R., Kataoka, H., Nozu, T., Yoshikawa, M., and Shirasawa, T. (2008). AIJ guidelines for practical applications of CFD to pedestrian wind environment around buildings. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 96, Issues 10–11, pp. 1749–1761. DOI: 10.1016/j.jweia.2008.02.058.

Wieringa, J. (1992). Updating the Davenport roughness classification. *Journal of Wind Engineering and Industrial Aerodynamics*, Vol. 44, Issues 1–3, pp. 357–368. DOI: 10.1016/0167-6105(92)90434-C.

Wilberforce, T., Olabi, A. G., Sayed, E. T., Elsaid, K., Maghrabie, H. M., and Abdelkareem, M. A. (2023). A review on zero energy buildings – pros and cons. *Energy and Built Environment,* Vol. 4, Issue 1, pp. 25–38. DOI: 10.1016/j.enbenv.2021.06.002.

Yakhot, V., Orszag, S. A., Thangam, S., Gatski, T. B., and Speziale, C. G. (1992). Development of turbulence models for shear flows by a double expansion technique. *Physics of Fluids*, Vol. 4, Issue 7, pp. 1510–1520. DOI: 10.1063/1.858424.

МНОГОФУНКЦИОНАЛЬНОЕ ЗДАНИЕ С МИНИМАЛЬНЫМ ЭНЕРГОПОТРЕБЛЕНИЕМ ДЛЯ ДЕСА ХАРАПАН БАРУ В ВОСТОЧНОМ КАЛИМАНТАНЕ

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Аннотация
Введение. Деса Харапан Бару — одна из традиционных деревень Восточного Калимантана, расположенная в удаленной прибрежной зоне. Местное сообщество сталкивается с рядом серьезных проблем, включая ограниченную транспортную доступность, нехватку чистой воды и неудовлетворительные санитарно-гигиенические условия. В результате жители вынуждены использовать природные ресурсы, доступные в непосредственной близости, в частности, древесину улин для строительства и дизельные генераторы для производства электроэнергии. Однако недостаточный уровень знаний в области строительства и лесовосстановления негативно сказался на окружающей среде, способствуя возникновению наводнений. Кроме того, из-за удаленного расположения генераторов стоимость топлива в деревне фактически удвоилась. **Целью данного исследования** является проектирование многофункционального здания с почти нулевым энергопотреблением (МЗПНЭ), отвечающего местным культурным традициям и потребностям сообщества. Помимо улучшения экономических условий, проект направлен на повышение осведомленности населения в вопросах устойчивого развития. **Методы**. В процессе проектирования применялся комплексный методологический подход. На первом этапе был проведен анализ поведенческих и культурных особенностей местного населения с целью облегчения адаптации сообщества к новым технологиям. Затем на кровле здания МЗПНЭ была выбрана и установлена фотоэлектрическая солнечная система. Моделирование работы фотоэлектрических панелей выполнялось с использованием программного обеспечения PVsyst; анализ воздушных потоков осуществлялся методом вычислительной гидродинамики (CFD) в среде Ansys Fluent; оценка энергоэффективности здания проводилась с помощью программного комплекса DesignBuilder. **Результаты** исследования показывают, что система возобновляемой энергии, состоящая из 17 солнечных панелей, способна полностью покрыть энергетические потребности МЗПНЭ в Деса Харапан Бару. Суммарное суточное энергопотребление составляет 59,19 кВт·ч, тогда как установленная солнечная система способна вырабатывать до 120 кВт·ч в сутки. Кроме того, использование традиционных архитектурных решений — таких как проемы в кровле и конструкция с приподнятым полом — способствует улучшению естественной вентиляции и снижению общего энергопотребления.

Ключевые слова: здание с почти нулевым энергопотреблением; удаленная деревня; энергоэффективность; тропический климат; традиционная архитектура Индонезии; Восточный Калимантан.