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Research Article

Building Performance Simulation of Near Zero Energy Building Design in Indonesia

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Abstract: Indonesia aims to improve building performance by increasing energy efficiency to address energy issues and carbon emissions. One of the concepts for realizing building energy efficiency is a Near-Zero Energy Building (NZEB), defined as a building with significantly reduced energy demand, and renewable energy resources provide the remaining energy offset. The application of NZEB could be a feasible solution for energy savings strategies. However, the climate conditions in Indonesia, which are tropical, hot, and humid, might require a different design approach than in other regions. Therefore, this study determines whether the NZEB design suits Indonesia's conditions. A hypothetical office building in Jakarta, Indonesia, is modeled as a reference building. Then, this reference model is further evaluated by applying several Energy Efficiency Measures (EEM) to reduce energy use. The EEM selection is based on the NZEB design parameters: passive design, active design, and renewable power technologies. The evaluation uses a building performance simulation tool called DesignBuilder. The simulation results show a total percentage energy saving of 46.9% from the reference model or the Energy Use Intensity (EUI) of 120.18 kWh/m2/year. Although the energy reduction is significant, the current result still needs near-zero energy performance. Therefore, a further study investigating more EEMs is recommended, and the goal of the expected EUI is to be reconsidered for high-rise office buildings.

***Keywords*: near zero energy building, building performance simulation, designbuilder, energy efficiency measures, indonesia, high-rise office building

Nomenclature

NCM	Nitrocellulose Membrane
SHGC	Solar Heat Gain Coefficient
VT	Visible Transmittance

1. Introduction

Almost one-third of the total global energy is consumed by the building and construction sector, and the figure is expected to increase due to continuous development worldwide [1]. Improving building energy efficiency could be an

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effective way to address energy issues, specifically in Indonesia, where the International Energy Agency (IEA) reported that the energy savings opportunity to reduce the future energy demand in Indonesia would mainly be contributed by the building sector, with 38% of total energy efficiency opportunities, followed by the industrial sector and transport sector [1]. Furthermore, managing energy demand in the building sector by improving energy efficiency is critical to achieving the 1.5 °C target set by the Paris Climate Agreement [2].

Indonesia eagerly aims for more energy-efficient building construction and operation because it consumes 22% of national energy. Moreover, 45% of the carbon emission in Indonesia is from energy consumption, and buildings account for almost half of it, in addition to 4% of direct carbon emission. These figures are expected to rise as the building sector is the fastest-growing sector in the country, with commercial buildings having the highest annual growth rate. To address this issue, the Indonesian government has included the implementation of Zero Energy Building (ZEB) as one of the critical actions toward more energy-efficient and low-carbon development of the Indonesian building and construction industry. The goal is to implement the ZEB requirement in all new and most renovated buildings by 2050 [3].

The concept of ZEB has been widely studied, implemented, and regulated in developed countries like the European Union and the United States. Meanwhile, ZEB in Indonesia is planned as the long-term goal of 2050, and the related studies exploring the concepts and designs still need to be expanded today. It is necessary to provide more research and studies related to ZEB applications catered to Indonesia's specific needs, and the term Near-Zero Energy Building (NZEB) is considered the most appropriate for discussion, considering the ZEB in Indonesia is still in the early phase [4].

Considering the importance of energy-efficient buildings in Indonesia, applying NZEB could be a future solution for energy savings strategies. However, the climate conditions in Indonesia, which are tropical, hot, and humid, might need a different design approach than in other regions with different climate conditions. Currently, NZEB designs are being studied more in temperate and dry climate zones, with both heating and cooling energy needed, and design strategies are catered to those situations. Although few NZEB studies for topical zones are available, Indonesia, located on the equatorial, is exposed to intense sunlight all year round, and heating is nonessential.

Therefore, this study uses building performance simulation to determine whether the NZEB design framework suits Indonesia's conditions. According to Lu et al. [5], the NZEB design strategies include incorporating passive and active design strategies to achieve an energy-efficient building and installing renewable energy for the remaining energy demand.

The research objectives are as follows:

To develop a reference office building model for Jakarta, Indonesia, and obtain the energy consumption using a simulation tool;

To assess the energy performance of various Energy Efficiency Measures (EEMs) based on the NZEB design framework (passive design, active design, and renewable power generation) and evaluate the energy-saving achieved from the reference model;

To identify the most effective strategies to achieve energy efficiency in the building model and assess the potential of NZEB for high-rise office buildings in Indonesia.

Section 2 reviews the literature about NZEB, its definitions, and the current development of NZEB studies, especially in Indonesia. Section 2.2 also describes the NZEB design framework and details the design measures investigated in this study, such as passive design, active design, and renewable technology. Section 3 explains the methodology used to conduct this study, which consists of developing a reference-building model and evaluating EEMs by simulation. The design parameters of the reference model, including location and weather, construction material, internal gains, and activity parameters, are described in Section 3.1. Furthermore, Section 3.2 details the EEMs of NZEB that will be evaluated using building simulation according to the NZEB design framework. The simulation results are presented and analyzed in Section 4, which highlights the energy saving from each EEM, the energy generated from the renewable technology identifies the total energy reduction by combining those EEMs in a case study, and whether the near-zero energy target is fulfilled. Section 5 discusses further the simulation result, particularly in assessing the potential of the current building model to become NZEB by comparing it with existing literature and proposing recommendations for future improvement.

2. Literature review

2.1 *Definition of NZEB*

Since 1977, many articles have presented definitions of NZEB, but they vary depending on the boundaries and metrics. The available definitions lack consistency and are subject to international discussion [6].

European Union (EU), in the Energy Performance of Building Directive (EPBD) recast, defined NZEB as a building with very high energy performance. The nearly zero or very low amount of energy required should be covered to a very significant extent by energy from renewable sources produced on-site or nearby [7]. US Department of Energy (DOE) defined ZEB as an energy-efficient building where, on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy [8]. Meanwhile, Japan has divided ZEB definitions into 3 (three) categories based on the energy savings amount, with higher than 50% energy savings considered as ZEB ready, at least 75% energy savings as Nearly ZEB, and 100% energy saving as ZEB [9].

Despite the various NZEB definitions, Utami [4] has stated that two (2) essential points have been constantly mentioned for NZEB: a highly energy-efficient building design and the availability of onsite or nearby renewable power generation. This study will aim for near zero energy performance, meaning a building that consumes very little power from external sources (e.g., the power grid) and is self-sufficient following the abovementioned essential points.

2.2 *NZEB design framework*

The NZEB design framework generally consists of three main parameters [5]: passive design, active design, and renewable power generation.

2.2.1 *Passive designs*

Passive design refers to a design principle that uses the building's architecture and natural elements to regulate the indoor environment. Passive design is essential in the building's early design phase since most passive elements cannot be changed after construction. In addition, the passive components are the most significant determinant of the cooling load and have the most effective energy-saving potential [10]. Therefore, carefully considering the passive design during the design phase is essential. The passive designs are as follows but are not limited to building orientation and site planning, material selection, insulation, daylighting, solar gain, and roofs. The EEM in passive design evaluated in this study is related to glazing design.

2.2.1.1 *Building orientation*

This study explores several passive design strategies with predetermined building orientation. Considering Indonesia's location on the equator, an east-west-oriented design is avoided for building orientation. This results in excessive solar radiation received at the East-West side of the building envelope. Mulyani et al. [11] identified that East-oriented university buildings have the most extensive energy use, while South has the most optimized energy-saving orientation. Kamaruddin [12] studied the south-oriented office building as having the lowest cooling load, while the east-west-oriented one had the highest cooling load in Jakarta, Indonesia. Therefore, this study uses a North-South orientation for the building model.

2.2.1.2 *Glazing design*

The building envelope includes all the components separating the indoors from the outdoors. This includes exterior walls, foundations, roofs, windows, and doors. In this evaluation, various window materials are considered heat gain from solar radiation, which generally accounts for the most significant contributor to cooling load in Indonesia's buildings [10].

Window-to-Wall Ratio (WWR) indicates the fraction of the total window area to the gross wall area. WWR significantly influences the cooling load, as a higher WWR means a larger window area and more solar radiation entering the building's interior and vice versa. However, the window also allows daylight into the indoor space and provides a view to the occupant, which correlates to the occupant's comfort. Thus, WWR shall be considered carefully to balance the building's requirements.

The glazing material of the reference model is a single layer of reflective and tinted glass. The other alternative designs add the layer to double, with a lower Solar Heat Gain Coefficient (SHGC), Visible Transmittance (VT), and U-value. SHGC estimates the amount of solar radiation passing through the glass relative to the amount of solar radiation hitting the glass. VT addresses a fraction of the visible spectrum of sunlight (380 to 720 nanometers), weighted by the human eye's sensitivity, transmitted through the glazing. A product with a higher VT transmits more visible light. Meanwhile, the U-value, or thermal transmittance, is the heat transfer rate through the glazing divided by the difference in temperature across that structure.

2.2.1.3 *Local shading*

Local shadings, such as overhangs, louvres, and sidefins, are constructed on the external surface to reduce solar heat gains. Overhang refers to a protruding portion of a roof or wall that extends beyond the edge of the building. Louvre is an arrangement of parallel or horizontal blades, slates, or other materials designed to regulate airflow and light penetration. Meanwhile, the sidefin is similar to the overhang but is located on the side of the window. This study uses the overhang design, a protruding wall above each window, and the louver design, used only as a horizontal slate arrangement.

2.2.2 *Active designs*

Active design strategies involve using energy-efficient building services and systems that utilize mechanical and electrical power, such as lighting, mechanical ventilation, air conditioning, and building automation. In tropical climates, active design focuses mainly on air conditioning and lighting [13].

Lighting design is often considered with daylighting to maximize sunlight, especially in offices where activity mainly occurs during the day. Meanwhile, it is essential to maintain visual comfort, which is evaluated by the lighting level received in the working space. The lighting level required is referred to the National Standards, which is 350 lux for an office area [14].

Tropical climates like Indonesia rely heavily on air conditioning systems for indoor thermal comfort (GB Jakarta). In office buildings, more than half of the energy demand is for air conditioning, emphasizing the need for energy-efficient HVAC systems [13].

2.2.3 *Renewable power generation*

Renewable energy application is an essential strategy for NZEB since a renewable energy system enables the building to be self-sufficient and not depend on an external supplier. Besides, it contributes to reducing fossil fuel use and decreasing carbon emissions, essential in mitigating global warming. In installing a renewable system, it is required to consider the following factors [15]:

- Availability of renewable energy sources nearby or onsite;
- Availability of space for technology installation;
- Local regulation;
- Characteristics of the energy profiles to be offset by the renewable energy installation;
- Cost of energy purchased from the electrical or thermal energy provider for the building.

Solar panels are the most chosen renewable system for NZEB, especially in Indonesia, where sunlight is available throughout the year.

2.3 *NZEB study in Indonesia*

Literature related to NZEB study in Indonesia is still limited; most reviewed residential-type buildings. Latief et al. [16] studied the main components supporting NZEB achievement in a house: external walls, window area, glazing, and an efficient HVAC system. Those components are not fully aligned with the NZEB concept in other regions with different climates, such as subtropic climates. Koesalamwardi and Rostiyanti [17] investigated the cost-optimum design of residential NZEB using the genetic algorithm method, in which the selected configuration is considered a financially feasible option. Both studies use PV panels as renewable power technology to supply energy to the building.

Purbantoro and Siregar [18] studied the NZEB design for an existing office building in Jakarta. Retrofitting and employing renewable technology resulted in a 47% supply reduction from the utility grid. However, it is mentioned that NZEB is challenging to achieve by only retrofitting and recommends a passive design modification and occupant behavior change to result in more efficient performance.

The Indonesian government has recently launched a design catalog for NZEB, specifically for airport building design intended for future airport development in Indonesia [19]. This catalog adopts standard design principles of NZEB, which are:

- Reducing building energy needs with passive design;
- Increasing energy efficiency through active design;
- Implementation of renewable energy.

Another NZEB initiative the government took under the "Net Zero Healthy School" project is to revitalize some public school buildings in Jakarta and its satellite cities to achieve net zero performance. The project is conducted by optimizing passive strategies to maximize natural ventilation and daylighting while controlling the solar radiation entering the space to reduce the need for cooling. In addition, the design shall consider the occupant's health to the utmost by controlling indoor air quality, noise, glare, and thermal comfort [20].

Existing studies in Indonesia's NZEB focus on residential, school, and airport buildings, while few discuss office buildings emphasizing the implementation of renewable power generation. This study will try to fill the knowledge gap of NZEB design for high-rise office buildings by using building performance simulation and incorporating a comprehensive review of NZEB design aspects.

2.4 *Building performance modeling and simulation*

Modeling is creating a simplified representation of a real system using a computer-based tool that allows one to allow essential components out of the complex problem. Simulation is using a model to predict the behavior of a real system in the future [21]. Since the development of Building Performance Simulation (BPS) started in the 1960s, it has been involved in many applications, such as exploring ideas, product research development support, building design support, and building operation support.

In NZEB, designing a building that complies with the performance requirement has been challenging, and the support of the BPS tool in its early design phase has been indispensable [22]. Attia & De Herde [22] evaluated ten (10) BPS tools used in designing NZEB and compared their capabilities based on their usability, intelligence, interoperability, accuracy, and design process integration. DesignBuilder, the BPS tool utilized in this study, is one of the software discussed. The evaluation indicated that DesignBuilder has high accuracy due to using EnergyPlus as the analysis engine, while usability, intelligence, interoperability, and process adaptability are considered medium.

Building performance simulation is applied to designing or evaluating the energy performance of buildings in Indonesia. Some studies used simulation to calculate the cooling load of a university building [23] or dormitory [24] and evaluate the energy performance of an office building [25-26]. BPS is also used for design optimization for a building design in Indonesia to reduce its energy use by focusing on a specific design aspect such as building orientation [11-12], building shape [27], and building envelope [28]. Some studies simulated and evaluated several energy-saving measures to achieve a low-energy office building [29-30]. The study by Andarini [29] did not mention the energy performance target clearly, while Anisah et al. [30] aimed for green building targets in Indonesia.

Although many studies of building performance simulation applications are available for Indonesia, most use the existing building model, and no study targets near-zero energy performance. This study offers a new perspective on designing an office building in Indonesia, specifically a high-rise building, by considering design principles for NZEB.

3. Methodology

This study consists of 2 (two) main activities: developing a reference building that represents the typical high-rise office building in Indonesia and evaluating Energy Efficiency Measures (EEM) that consist of three aspects, which are passive design, active design, and renewable power generation, followed by a case study combining all design strategies. The workflow of the methodology is illustrated in Figure 1.

The study uses a building performance simulation software, DesignBuilder, combined with EnergyPlus for thermal simulation. A hypothetical building model is developed for this study, modeling a commercial office building in Indonesia. The office building type was chosen due to its enormous energy-saving potential and relatively straightforward layout compared to other building types, reducing the complexity of the simulation. The location and weather data used is Jakarta, which has many high-rise commercial buildings.

A widely used unit evaluates the energy performance, Energy Use Intensity (EUI), which is calculated as [31]:

$$EUI = \frac{Annual\ energy\ consumption\ (kWh/year)}{Conditioned\ area\ (m^2)} \quad (1)$$

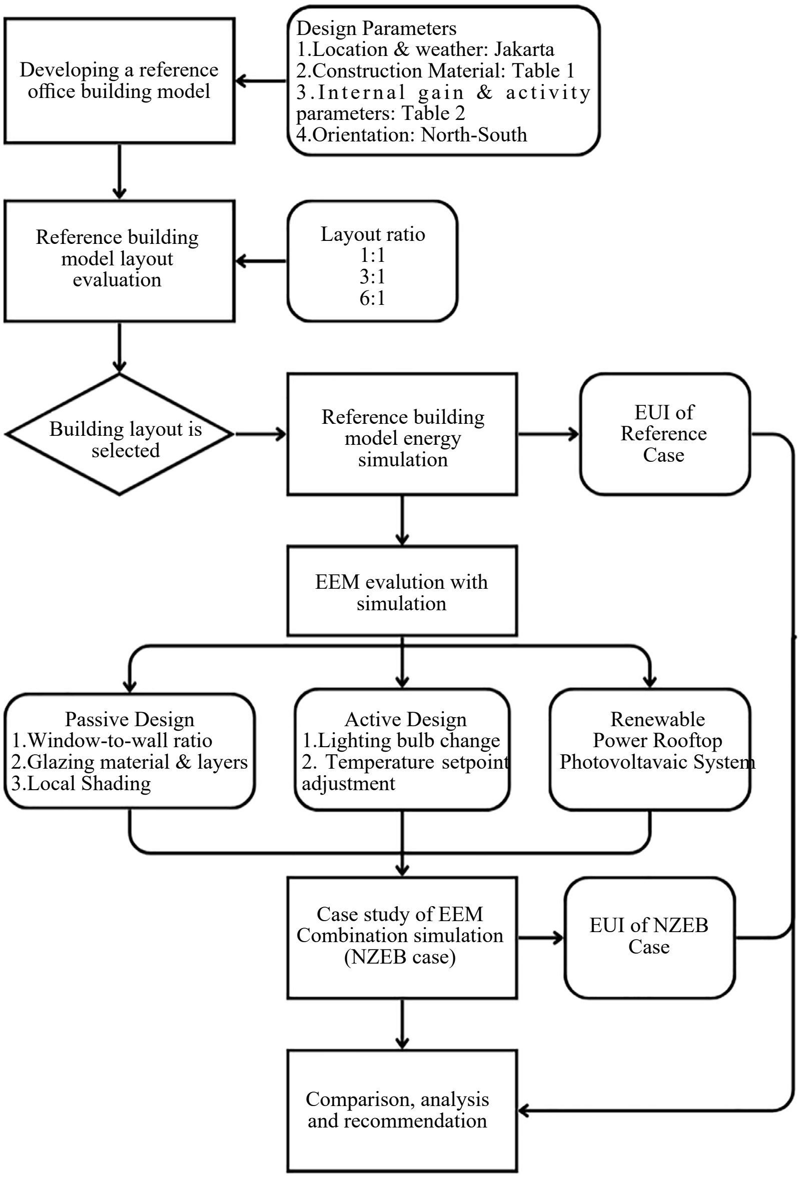

Figure 1. Workflow diagram of the study

3.1 *Developing a reference building*

This study utilizes a hypothetical building model to present a more general solution regarding NZEB design in Indonesia rather than to provide strategies for a specific building design. Therefore, a hypothetical building model is developed to represent a typical commercial office building in Jakarta. The design parameters selected for developing the model shall comply with Indonesia's National Standards published by Badan Standar Nasional (BSN), such as SNI 6389:2011, SNI 6390:2020, and SNI 6179:2020, comprising the energy conservation requirements for building envelope, air conditioning system, and lighting system in the building. Building materials, activity, internal gains, and other parameters referred to technical guidelines published by the Jakarta provincial government [10, 14, 32] and the Malaysian government [13, 33]. We referred to a study by Duarte et al. [34] on building geometry and layout, which developed a reference building model for offices in Singapore.

3.1.1 *Building models' design parameters*

The building model is square-shaped with dimensions 35 × 35 meters on each floor, consisting of office rooms in the perimeter zone and various areas (walkway, lift, restroom, mechanical room) located at the core zone (see Figure 2 and 3a). This arrangement is typical in office buildings, allowing the working area to receive more sunlight during the day. Meanwhile, the auxiliary rooms are gathered in the middle, where little sunlight is available because these rooms are not constantly occupied and are not used for work activities. The area of each floor is similar to the reference office model in Singapore [34], while the building shape will be evaluated further using simulation.

Table 1 listed design parameters for construction materials, and Table 2 recorded the internal gain and activity parameters selected for the reference model in this study.

3.1.2 *Building layout evaluation*

In this stage, a layout evaluation is conducted to determine the building layout that will be used for further EEM evaluation. There are three building layouts evaluated in the simulation, as shown in Figure 3. Those layouts are different in the room placement and shape ratio, and layouts A, B, and C account for proportions of 1:1, 3:1, and 6:1, respectively, adopted from a study by BSEEP [33]. The total floor area and each room area are the same, all oriented in a north-south direction. The layout with the most minor energy consumption based on the simulation result will be selected for this study. Lastly, the selected layout and its EUI will be considered the reference case and used as the baseline for further simulations.

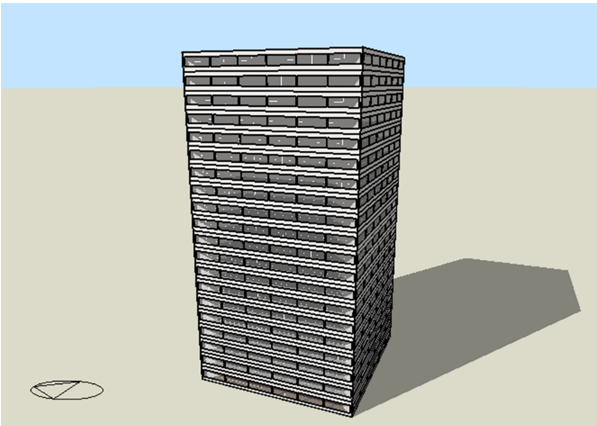

Figure 2. Reference high-rise office building in Jakarta, Indonesia

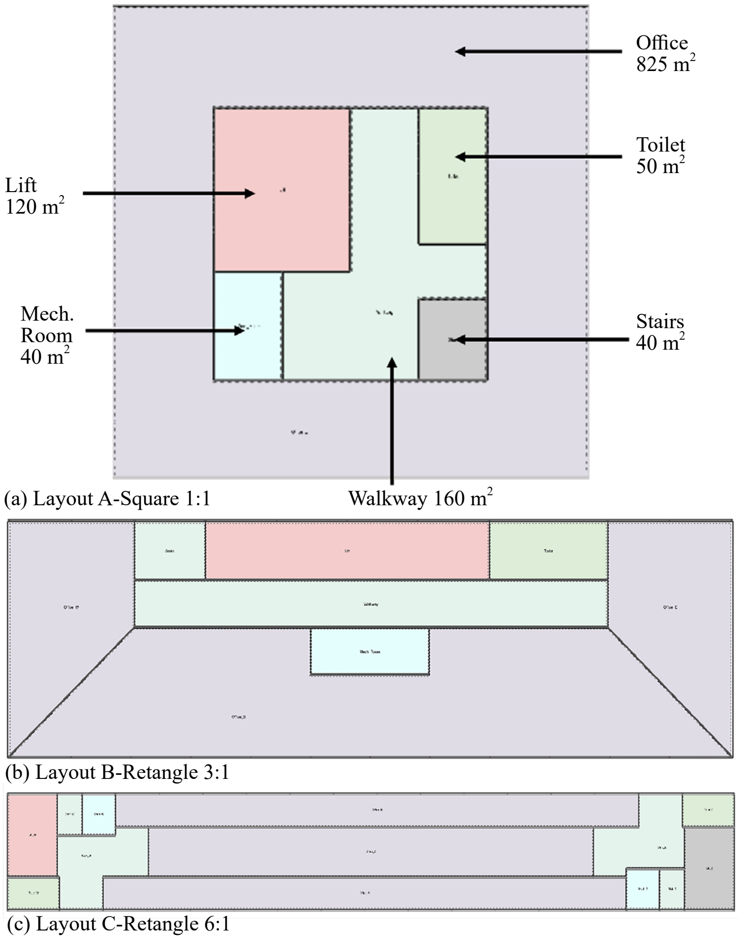

Figure 3. Layout variation for reference office building model

Table 1. Construction materials and thermal properties of building envelopes (outer surface to inner surface)

Description	Materials	Thickness (mm)	U-value (W/(m^{2}K))
External wall	Plaster	10	0.811
	Aerated Concrete Slab	150	
	Plaster	10	
Roof	Plaster	25	1.028
	2010 NCM membrane	12	
	Extended Polystyrene	25	
	Cast concrete	100	
Ground floor	Urea-formaldehyde foam	86.9	0.350
	Cast concrete	100	
	Floor/roof screed	70	
	Timber flooring	30	
Internal floor	Cast concrete (dense)	100	2.929
Glazing	Solar heat reflective glass (dark blue) SHGC: 0.387; VT: 0.34		5.7

Table 2. Internal gains and activity parameters for the reference building

Description	Gain parameters
Lighting system T5 light bulb, daylight control available	Office area: 10.8 W/m^2 Toilet: 3.4 W/m^2 Stairs: 3.2 W/m^2 Walkway: 3.3 W/m^2 Mechanical Room: 3.6 W/m^2
Occupancy	Office area: 10 m^2/person Weekday: 7 AM to 7 PM with occupancy schedule Weekend, Holiday: Empty (Based on ASHRAE 90.1)
Equipment	Office area: 10 W/m^2 (medium activity) Toilet: 5.48 W/m^2
Fresh air/ventilation requirement	Office area: 2.5 L/s.person & 0.3 L/s.m^2; Toilet: 12 L/s.person; Mechanical Room: 10 L/s.person
HVAC system	Variable Air Volume (VAV), Water-cooled chiller Setpoint: 24 °C

3.2 *Evaluation of energy efficiency measures (EEM)*

After the initial simulation, the reference model is further evaluated to achieve near-zero energy performance by applying several energy efficiency measures (EEM). The selection of EEMs is based on the three (3) main NZEB aspects [5]: passive design, active design, and renewable power generation.

3.2.1 *EEM in passive design strategy*

EEMs in passive design evaluated in this study are WWR, glazing material and layers, and local shading.

3.2.1.1 *Window-to-wall ratio (WWR)*

In addition to the default WWR of 50% used in the reference model, this study evaluates smaller and bigger WWRs of 30% and 70%. The glazing design stays the same as the reference, with no local shading installed. The simulation result is discussed in Section 4.3.1-point a.

3.2.1.2 *Glazing designs*

Table 3. Glazing design variations for EEM evaluation

Glazing Name	Glazing type	WWR	SHGC	Visible Transmittance	U-value (W/m^2·K)
Reference	Single, reflective, tinted	50%	0.38	0.34	5.700
Glazing A	Double, reflective, clear	50%	0.248	0.181	2.906
Glazing B	Double, reflective, clear	50%	0.154	0.07288	2.761
Glazing C	Double, reflective, clear	85% (curtain wall)	0.154	0.07288	2.761

Besides the reference case, three other alternatives for window materials are simulated, as shown in Table 3. Energyplus calculates the SHGC, VT, and U-value values indicated in Table 3 automatically using the ASHRAE method. Glazing A has the glazing type of double glazing with reflective panes, consisting of a stainless steel high-transmittance coating pane and a clear pane. Glazing B and C have the glazing type of double glazing with reflective panes, consisting of a stainless steel low-transmittance coating pane and a clear pane.

This simulation keeps the WWR constant at 50% as the reference case while changing the other properties. However, Glazing C is set to a different WWR as an 85% curtain wall to compare the effect of lower SHGC with higher WWR on the building's energy consumption. The result of the glazing design simulation is in Section 4.3.1-point b.

3.2.1.3 *Local shading*

Table 4 lists various dimensions of overhang and louvres applied to the simulation. At the same time, side fins are included in the combined shading design as they are usually combined with other shading types. The simulation result is discussed in Section 4.3.1-point c.

Table 4. Local shading variation for EEM evaluation

Local Shading	Overhang	Louvre	Sidefins
No shading-Reference	-	-	-
Overhang	0.5-meter	-	-
	1-meter	-	-
	2-meters	-	-
Louvre	-	0.5-meter	-
	-	1-meter	-
	-	1.5-meters	-
combined	-	1-meter	1-meter
	1-meter	1-meter	1-meter

3.2.2 *EEM in active designs/energy efficiency technology*

Active design strategy is related to applying energy-efficient technology in the building, such as HVAC, lighting, electronic appliances, and automation and control systems. HVAC and lighting systems will be discussed in this study.

As the technical guidelines recommend, the current reference model uses a Variable Air Volume (VAV) for the HVAC system. A preliminary simulation compares several cooling systems and their energy use. The simulation resulted in the VAV system as the most energy-efficient. Thus, for EEM selection, the VAV system is not changed, but the temperature setpoint is adjusted from 24 °C to 26 °C. The temperature increases within the comfort zone range for offices in Malaysia [35].

The current design using T5 bulbs for the lighting system is replaced with LED bulbs with similar performance and lower power requirements.

3.2.3 *EEM in energy production technologies*

Renewable power generation is an essential element in NZEB design. Indonesia is a tropical country with abundant solar radiation throughout the year, and photovoltaics (PV) is considered the most potential renewable technology. In this study, a rooftop PV system will be installed for onsite energy production. The PV modules cover around 70% of the rooftop area (total area 900 m^2), facing north with a 10-degree tilt angle [36-39]. The specifications of the PV system are shown in Table 5.

Table 5. Rooftop PV system specification

PV modules	Monocrystalline, 360 Wp, 72 cells (Risen)
No. of modules installed	450 modules
Module efficiency	15%
Total installed capacity	121.5 kWp

3.2.4 *A case study by combining several EEMs*

A case study will combine several EEMs and evaluate their energy performance. In this step, the building model is expected to achieve near-zero energy performance. The EEM combination is selected from those assessed in the previous section. Firstly, the EEM related to passive and active design is evaluated, and the energy savings are determined. Then, the EEM of renewable power generation is simulated to obtain overall energy savings and identify the potential to achieve NZEB.

4. Result

4.1 *Results of building's layout simulation*

This study simulates the different reference building layouts, evaluates energy use, and selects the most efficient design for the reference model. The simulation result is shown in Figure 4.

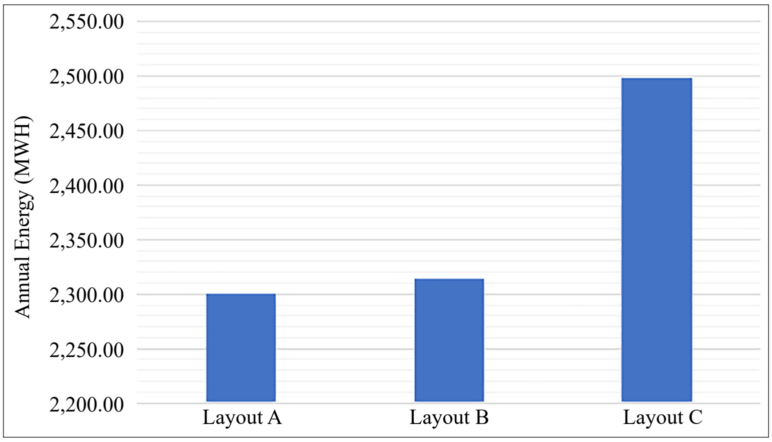

Figure 4. Simulation result of annual energy consumption in different building layouts

Layout C has the most significant energy consumption with an enormous ratio of 6:1 due to the higher cooling load caused by more surfaces directly exposed to solar radiation, which requires more cooling energy. Less difference in energy consumption occurred in layouts A and B. Thus, layout A is selected as the reference model for this study.

4.2 *Result of reference building model simulation*

The selected reference model is simulated, and the energy performance is evaluated. The result shows that the EUI is 215.02 kWh/m^2/year and 226.38 kWh/m^2/year for the 20- and 10-floor models, respectively. This result agrees with the average energy consumption in office buildings in Indonesia of 200-250 kWh/m^2/year [40].

Cooling systems consumed the most energy, at 86%, followed by office equipment and lighting, at 12% and 2%, respectively. This is expected in a tropical climate, as the hot and humid weather requires continuous air conditioning operation to achieve thermal comfort inside the building. It becomes a challenge for all engineers and designers to develop a building design that reduces cooling load without compromising the occupant's comfort.

Figure 5 shows the heat gain and internal gain into the building at 24-hour intervals based on the indoor setpoint at 24 °C.

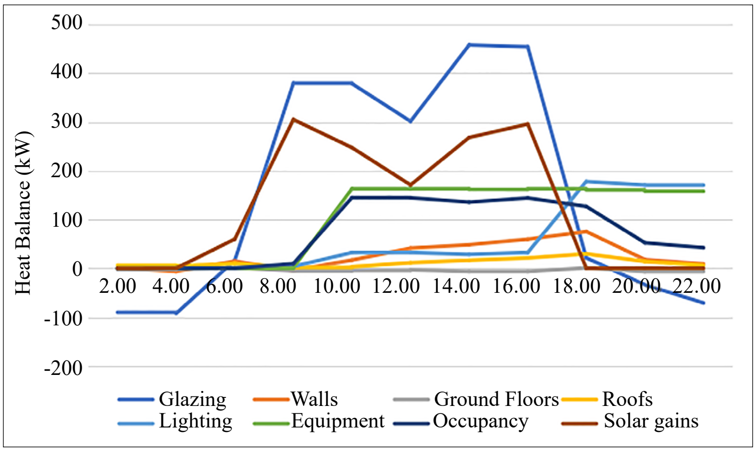

Figure 5. Heat gains and internal gains of the reference building

The highest gain comes from heat conduction through the glazing, followed by solar radiation through the glazing. Therefore, in EEM selection, it is crucial to address the glazing design to improve the energy performance significantly.

4.3 *Result of EEM evaluation*

4.3.1 *Simulation result of EEM in passive design*

4.3.1.1 *Window-to-wall ratio (WWR)*

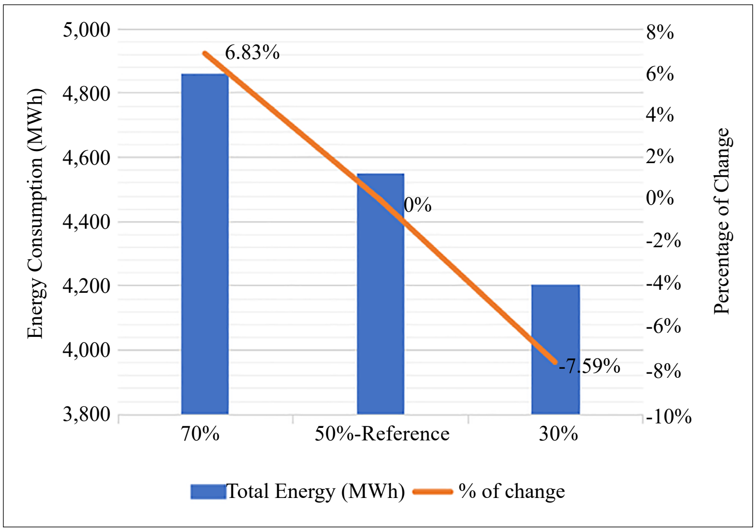

Figure 6. Simulation result of various WWR

The energy-saving comparison of various WWRs is shown in Figure 6. The WWR addition of 20% to the reference resulted in 7.59% energy saving, while a 20% reduction resulted in 6.83% higher consumption. In tropical climates like Indonesia, solar radiation contributes to the most heat gain in the building. Thus, the WWR value significantly impacts the heat gain and the building's energy consumption. Lower WWR is generally preferred for office buildings in Indonesia to reduce heat gain. However, this could reduce daylighting and visual aspects affecting the occupant's productivity, which is essential, especially in a working area. Considering these factors, a moderate WWR (e.g., 30-50%) is recommended for office buildings in Indonesia, adjusting the building's requirements.

4.3.1.2 *Glazing materials and layers*

Various designs consist of glazing materials and layers, WWR and local shading are simulated, and energy reduction is evaluated for each case (see Tables 3 and 4). The result for various glazing materials and layers is shown in Figure 7.

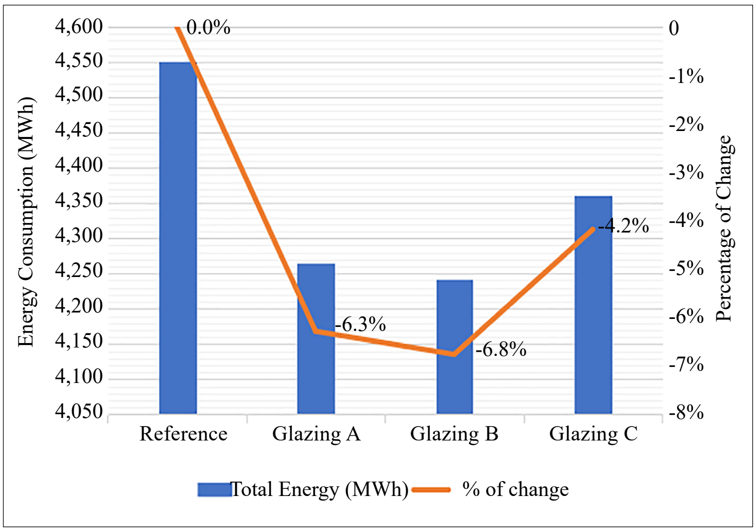

Figure 7. Simulation result of various glazing materials and layers

Glazing B (double glazing, reflective type, stainless steel high-transmittance coating pane + clear pane) resulted in the highest energy reduction of 6.8%. Glazing C is double glazing with a larger WWR of 85%, achieving a 4.2% energy reduction. This implied that the glazing material and layer effect were more significant than WWR. By comparing Glazing B and C results, it is shown that SHGC and WWR selection shall be considered simultaneously to maximize energy-saving.

4.3.1.3 *Local shading*

Lastly, the simulation result for local shading is shown in Figure 8. Combined shading and 2 m overhang resulted in the largest energy-saving at 11-12%. Although a 2-meter overhang has an enormous saving of 12%, this saving is insignificant compared to a 1-meter overhang with 10%, considering the increment of the overhang dimension. In addition, the combined shading design results in the same energy saving of 11%, indicating that combining all shading options (overhang, louvre, and sidefins) might be ineffective, and the 2-type combination (overhang and sidefins) is adequate. A 2-meter overhang results in higher energy savings, but the availability of construction space might be considered. Instead, a 1-meter overhang or a 1-meter overhang and 1-meter sidefins combination might be more feasible options.

Louvres are also considered effective as local shading, with an energy reduction of 6.6% and 9.3% for 0.5 meters and 1 meter, respectively. However, a 1.5-meter louvre becomes ineffective as energy consumption increases. As the louvre's dimension increases, it could block more incoming daylight and increase lighting energy consumption. Thus, in louvre installation, the slate dimension and arrangement shall be carefully considered to obtain the required daylight in the building.

In addition, the local shading function of blocking sunlight could overlap with some glazing designs, such as lower SHGC glass material and double glazing. The combination of glazing materials, layers, and local shading shall be balanced to acquire the desired performance requirement, considering the occupant's comfort, energy demand, and financial aspects.

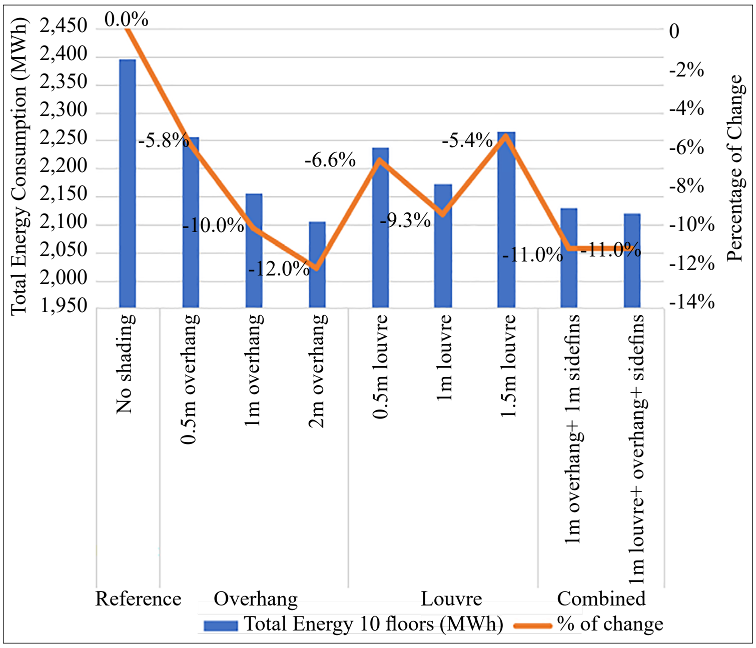

Figure 8. Simulation result of various local shading

Modifying the glazing design resulted in 5-12% energy savings. However, the glazing design would affect the cooling and lighting loads by affecting the amount of solar radiation and sunlight transmission into the building. Therefore, finding a balance between WWR, shading configuration, and glazing properties, such as SHGC, VT, and U-value, is essential.

4.3.2 *Result of EEM in active design*

In this study, setpoint change and lighting change are applied as the active design strategy. Changing the light bulb to an LED type results in a 50% reduction in lighting energy from the reference case for lighting design modification.

Setpoint adjustment in the HVAC system reduces the cooling load in the building and saves cooling energy consumption. In this study, the setpoint is increased by 2 degrees from 24 °C to 26 °C, which resulted in the cooling energy reduction of 24.5% annually from the reference case and contributed a 21.7% energy saving for the whole building's energy consumption. Figure 9 illustrates the comparison of cooling loads between different setpoints in one of the design days for cooling system sizing. Cooling load is shown as a negative value, which means the cooling will compensate for the heat gain inside the building (see Figure 5) to achieve the desired indoor setpoint. Adjusting the setpoint to 26 °C reduces the cooling load by around 60 kW since less energy is required to balance the heat gain.

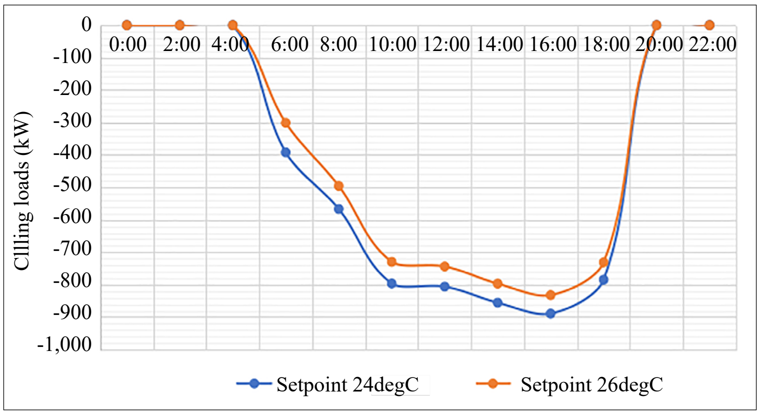

Figure 9. Comparison of Cooling Loads between Different AC Setpoints

4.3.3 *Result of renewable power generation simulation*

A rooftop PV system (see Table 5) is simulated in a 10-floor model, and the power generation is evaluated. Based on the simulation, the annual electricity generation from rooftop PV systems is 207,692 kWh, supplying around 15% of the energy demand in a 10-floor building. This proportion of energy covered by renewable resources with the same installation area (900 m^2) will be smaller as the number of floors increases.

4.3.4 Result of EEM combination: A case study

A case study for the NZEB model combines several EEMs from previous simulations. The 10-floor model is simulated for this case study. The selected EEMs are listed in Table 6. The selected EEMs for this case study are the best-performing and most feasible options from each EEM evaluated in the previous part. Glazing B is selected as it has the highest energy saving. For WWR, 40% is selected by considering the need for daylight and visuals from the window. The combined shading of the overhang and sidefins was selected considering the space's availability for construction. The AC setpoint is adjusted from 24 ℃ to 26 ℃, and the lighting bulbs are changed to LED type. The rooftop PV is installed as a renewable power source to provide additional power for the NZEB model.

Table 6. Selected EEM combination for case study

Design Aspect	EEM	Reference model	NZEB model
Passive Design	Glazing design	Reference (Single glazing, solar heat reflective glass, dark blue)	Glazing B (Double glazing, reflective type, stainless steel high-transmittance coating pane + clear pan)
	WWR	50%	40%
	Shading	No shading	1 m overhang + 1 m sidefins
Active Design	AC System	24 ℃ setpoint, VAV system	26 ℃ setpoint, VAV system
	Lighting	T 5 lighting	LED lighting
Renewable Energy	Photovoltaic (PV)	No PV	Rooftop PV (121.5 kW)

The total energy savings from the EEMs of passive and active design are 37.2%, and the EUI is reduced from 226.38 kWh/m^2/year to 142.18 kWh/m^2/year.

Adding up the energy production from renewable energy, the EUI of the NZEB model achieves 120.18 kWh/

m^2/year or a total energy saving of 46.9%. This means the current NZEB model consumes 46.9% less power from the utility grid than the reference model.

5. Discussion

Based on the result in section 4, the NZEB model in this study has achieved a 46.9% energy reduction from the reference model by applying several EEMs, such as modification of the glazing design, HVAC setpoint adjustment, and change of lighting bulb type. However, the current design with the EUI of 120.18 kWh/m^2/year does not achieve the expected outcome of near-zero energy performance, which means that the EUI value shall be as low as possible. Moreover, the height or number of floors also significantly affects the achievement of NZEB. Initially, 10-floor and 20-floor models are simulated as the reference case. However, the renewable power generation simulation shows that higher buildings have more challenges in adopting the NZEB concept because of the space limitation to install PV, resulting in less energy supplied to the building. The current study indicates that the 10-floor model is more feasible to become NZEB but still requires many improvements. A study in Canada indicated the challenge of achieving NZEB for high-rise buildings unless there are floor limitations of only 5-10 floors [41].

This indicates that it is challenging for a mid-rise to high-rise office building to achieve NZEB, and further EEMs are required. In future studies, more design aspects of NZEB shall be investigated to reduce energy and achieve near-zero energy performance. A significant parameter that needs evaluation is the proportion of area conditioned by mechanical cooling. The current model has approximately 77% of its gross floor area conditioned with the HVAC system, which has resulted in an enormous cooling demand. The recommended AC space in Singapore is 57% [42]. Other studies in NZEB for tropical climates suggested that wall insulation and natural ventilation design could significantly impact building performance [42-43]. Moreover, advanced renewable options are considerable, such as building-integrated PV (BIPV) [44] and shading devices integrated with PV, since office buildings in metropolitan areas like Jakarta usually have limited space for renewable technology installation.

Furthermore, the expectation of near-zero energy performance in a mid-rise to high-rise building shall be considered for future studies. In 2021, the Building and Construction Authority (BCA), Singapore, released a new roadmap to improve building performance, aiming to achieve Positive Energy for low-rise buildings, Zero Energy for mid-rise buildings, and Super Low Energy for high-rise buildings. These goals are achievable, but a paradigm shift, such as more excellent natural ventilation or hybrid AC system adoption, would be required. The feasibility study by BCA shows that by applying current cutting-edge technologies, the EUI of 45 kWh/m^2/year and 72 kWh/m^2/year are obtained for mid-rise buildings (7-story) and high-rise buildings (20-story), respectively [42].

6. Conclusion

This study modeled a hypothetical office building in Jakarta, Indonesia, and attempted to achieve NZEB using a building performance simulation tool. The model's initial energy performance is 215 kWh/m^2/year and 226.38 kWh/m^2/year for a 10-floor and 20-floor model, respectively. The simulation indicated that glazing (conduction and radiation) is the most significant contributor to heat gain.

Then, several EEMs are applied and simulated to reduce energy consumption, and the strategy is divided into three (3) main categories: passive design, active design, and renewable power generation. The passive design evaluated in this study mainly focuses on glazing designs, while lighting modification and setpoint adjustment are applied as active design strategies. For renewable generation, a rooftop PV system with a capacity of 121.5 kW is installed, occupying around 70% of its rooftop area. The EEMs evaluation resulted in a 46.9% energy supply reduction with the EUI of 120.18 kWh/m^2/year.

Based on the simulation result and benchmarking with the existing NZEB literature in more developed regions, near-zero energy performance is more achievable for the ten-floor model than the twenty-floor model. However, even in the ten-floor office model, considerable efforts are required to achieve the near-zero energy target, such as rearranging the building layout and the envelope designs to minimize air-conditioned areas and incorporating more advanced mechanical cooling systems and renewable power generation technologies. Moreover, a tall building with twenty floors or more is further challenging to achieve this goal as the energy demand multiplies and the space becomes limited.

To conclude, despite the significant energy savings, the current energy performance of the NZEB model in this study has yet to achieve the desired result of near-zero energy. This indicates the big challenge in designing a mid- to high-rise office building to be an NZEB in Indonesia. Future studies should explore more EEMs with advanced technologies and reconsider the feasibility of near-zero energy performance for high-rise office buildings in Indonesia.

Conflict of interest

The authors declare there is no conflict of interest at any point with reference to research findings.

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