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The application potential of net zero energy building using rooftop photovoltaics case study of apartments in Gorontalo Province

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ABSTRACT

Gorontalo Province is one of the developing regions in Indonesia. The province has been actively building apartments since 2009. The construction increases population density and energy use intensity. Consequently, demand for electricity power rises. Renewable energy such as rooftop photovoltaics has the potential as a power source for the apartments, considering the abundant solar radiation in Gorontalo which is located near the equator line. Three apartments representing three levels of the inhabitant's income are selected as study case for the application of photovoltaic (PV) on roof to achive net zero energy building. Simulation of PV energy to power the buildings is conducted using photovoltaic geographical information system (PVGIS). By utilizing monthly electrical bill data, it is found that PV on roof is sufficient to cover the building energy demand and achieve net zero energy building (NZEB). However, there is uncertainty of the fluctuation of energy demand due to the tenant's energy consumption behaviour. The consumption intensity is limited only by the installed power on each apartment unit. PV on roof alone is unable to provide the need if it is employed to power the unit to the maximum extent.

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1. INTRODUCTION

Gorontalo Province is one of the developing regions in Indonesia. The province has been actively building flats/apartments since 2009. The apartments are built to accommodate low income people who cannot afford of houses (especially landed houses), people who moved from another city to work by the duty of their corporation and do not have any place to live, and for students who in need of low cost housing. To facilitate the demand of housing, since 2007 the government of Indonesia has commenced a national plan called "One Thousand Towers" to promote the construction of apartments, continued by the "One Million Housing Program" to stimulate the housing supply process in 2015 [1], [2].

The apartments were built all over Indonesia by the Ministry of Public Works and Housing. The designs adhere to regulations for the construction of public apartments [3]. Therefore, there is a resemblance between the built structures. In 2022, there were already 896 public apartments throughout Indonesia constructed by the Ministry of Public Works and Housing [4]. In the metropolitan and megapolitan cities of Indonesia, there has been a shift from traditional housing to more modern landed houses and low-cost apartments [5]. Social, cultural, and economic factors have driven this transformation. However, in Gorontalo, a small city in Gorontalo province, most apartments are erected as a living place for civil servants, who originally resided in another city.

An apartment holds many houses and people in a building, thus has a larger energy use intensity (EUI) compared to simple landed housing. Electricity energy consumption in Indonesia is largely contributed by the residential sector [6]. Although households in Indonesia mostly use energy from electricity rather than gas [7], it is challenging to provide more electricity to apartments. Renewable energy, such as photovoltaic (PV) energy, should be introduced as a reliable alternative for energy provision. The use of renewable energy in buildings will benefit the achievement of sustainable development, as the application is an indicator of the performance of green buildings in Indonesia [8].

The incorporation of renewable energy in buildings will encourage the fulfilment of net zero energy (NZE), where buildings rely only on solar energy and other renewable sources to meet their energy needs [9]. Accordingly, there are two factors regarding the NZE: the energy produced by renewable technologies and the energy consumed by the building. The balance between energy production and consumption comprises the NZE. The roadmap of buildings and construction in Indonesia has targeted that in 2050, every new and old building will have a net zero energy building (NZEB) [10]. Indonesia, located on the equator line, has abundant solar radiation year-round as the source of energy for PV. Gorontalo lies in Eastern Indonesia and receives approximately 5.1 kWh/m^2/day with a monthly variation of approximately 9% [11]. Building energy consumption corresponds to factors such as the type of activity in the building, the number of people, and the electrical appliances used in the building. While apartments are residential buildings with an energy use intensity lower than that of commercial and office buildings, accomplishing the NZEB for apartments considering the solar potential of Gorontalo should be feasible.

The use of renewable energy, particularly PV on roofs has many advantages for the country. Some studies found that it could meet 14% of the country's energy demand [12], and even 28% [13]. However, there is a need to take a greater emphasis on the economic potential of the energy produced rather than the cumulative amount of energy produced annually [14]. This paper discusses the advantages of PV on apartment roofs and their impact on the economic savings of apartment tenants. However, some techniques to achieve zero-energy building solutions involve passive and active solar solutions and efficient energy systems [15].

There are some researches regarding NZEB utilizing rooftop PV in Indonesia. Gunawan *et al.* [16] stated that an apartment unit in Jakarta requires 3.7 kWp of PV power. Yet, it is lacking of explanation on the demanded energy. Sakti *et al.* [17] calculated the energy demand using consumption energy per capita. Megantoro *et al.* [18] estimated the apartment energy demand based on the usage of electrical device and the duration it turned on. Meanwhile, Harani [19] designed the PV to supply energy for shared facilities in an apartment. The mentioned studies are not considering the tenant's electricity consumption. Therefore, this research focuses on providing energy to the building considering the building energy demand with regard to the tenant's monthly electricity expenditure, roof area for PV installation, and roof orientation.

2. METHOD

The research was conducted through the following steps: data collection involves gathering information regarding the development of apartments in Gorontalo Province, tenant electricity bills, and apartment roof data. The data are analyzed and become the input and target to be achieved through simulation using the photovoltaic geographical information system (PVGIS). The results were then analyzed to determine the applicability of NZEB in the apartments of Gorontalo and its economic saving potential.

Two schemes were proposed to achieve NZEB. Scheme 1: Energy-independent building, providing renewable energy through PV to cover 24 hours electricity energy usage for all the apartment units with the extent of installed power. Scheme 2 providing renewable energy through PV to cover monthly energy usage. Scheme 1 requires the data of installed electric power on each apartment unit and the number of apartment units in a building. Scheme 2 requires the electricity bills of the tenants.

The apartments will be provided with PV energy. The estimation of the PV power simulated using PVGIS. The tool is selected because it is easy to use the user interface and its simulation result is lower than HOMER and PVSYST [20], and higher than PVWatts [21]. Therefore, the expected result is neither too high nor too low. PVGIS also demonstrated assuring performance, as its simulation result had the lowest deviation compared to the experimental measurements [22]. PVGIS is free and easier to use than HOMER and PVSYST for PV energy production simulations and simple analysis.

2.1. Data collection

The research is initiated by collecting apartment data in Gorontalo Province from the office of a housing provider in the region of Sulawesi Island, Indonesia. Purposive sampling is conducted as the data are sorted through some qualifications, such as building orientation and users' income profile. Three apartments are selected from this list. These are apartments for low-income people, an apartment for the Marine Base in Gorontalo, and an apartment for the officer of the Financial and Development Supervisory Agency in Gorontalo. The questionnaire form is given where the tenant fills in information, such as monthly electricity bills. Buildings are also visited and measured to calculate the roof area and slope degree.

2.2. Data analysis

Monthly electricity bills from the tenants are converted into monthly electricity consumption (kWh). The data is sorted and the minimum, maximum, and average values are calculated. The roof slope will be used as an input for the simulation, and the roof area as an evaluation tool for the PV modules to fit the structure.

This is a preliminary study of the application of NZEB using rooftop photovoltaics on building apartments, employing monthly energy demand as a basis for renewable energy fulfillment in the building. The data may not cover the tenant peak hourly energy demand, which will provide a more precise estimation of the required PV power. However, the analysis conducted in this study will provide insight into the variation in renewable energy to be supplied owing to a difference in the energy consumption profile.

2.3. PVGIS simulation

The location of the building (latitude and longitude) is input into PVGIS, and the system will choose a solar radiation database related to the position. In PVGIS, we defined variables such as the PV technology, mounting position, slope, and azimuth. For this technology, crystalline silicon is selected. The roof added/building integrated is selected as the mounting position. The input for the slope and azimuth is taken from the measurement of the roof slope and building orientation obtained from Google Earth.

The simulation output provides data such as the monthly energy output (kWh). The energy production result may differ in each month; however, the expected minimum value from each month of the simulation result should be equal to or greater than the building energy demand. However, the minimum values for the two schemes are different because they have different objectives.

2.4. Achieving net zero energy building

To achieve NZEB, the balance between energy generation from renewable sources and building demands should be met. Nevertheless, the building energy demand might depend on the installed power and behavior of the occupant. For an independent energy building (Scheme 1), the monthly minimum energy produced by PV is the total energy to be supplied to all the apartment tenants for 24 hours monthly, while for Scheme 2, the minimum value should meet the total building energy consumption.

3. RESULTS AND DISCUSSION

All the buildings selected as study cases are located in Gorontalo City. The building designs are typical, with some differences in the unit layout. According to Indonesian government regulations, apartments are categorized as low-rise buildings (≤ four floors). Apartment for the low income people will be labeled as Apartment A, apartment for the Marine Base in Gorontalo is labeled as Apartment B, and apartment for the officer of Financial and Development Supervisory Agency is labeled as Apartment C. To provide renewable energy, residential PV modules 400 Wp [23] (1.725 m × 1.134 m) is selected. The PV modules will be put on two sides of the roof. All the roofs have a slope of 32°. The broader roof of Apartment A faces east and west (azimuth 113° and -67°), Apartment B faces north and south (5° and -175°), and Apartment C faces east and west (92° and -88°).

3.1. User energy consumption profile

There are three surveyed apartments, each of which has different income level. Income influences tenants' buying power and monthly expenditures. Therefore, there is a variety of energy demands for every apartment. Indonesia employs prepayment electricity, in which people need to top up their credit to use electricity in their homes. This was intended to encourage savings in the household energy consumption [24]. The available top-up credit varied from Rp 20,000 ($1.22), Rp 50,000 ($3.05), Rp 100,000 ($6.10), to a maximum of Rp 50,000,000 ($3054). For example, if they paid Rp 50,000, a house with an installed electricity power of 0.9 kVA will get a 37.0 kWh credit, while a 1.3 kVA powered house will get a 34.6 kWh. The electricity usage range for each apartment is presented in Table 1.

As shown in Table 1, Apartment C has the highest electricity usage. Even though Apartment A is for low-income people, the household activity is more intense than that of the tenant in Apartment B; thus, electricity usage is higher. Figure 1 shows how Apartment C is superior in each category: minimum, average, and maximum. Instead of using an AC, people living in apartments A and B use fans to cool their rooms. Meanwhile, 84% of people living in Apartment C enjoyed air conditioning to fight the heat of their unit environment.

Table 1. Range of monthly electricity usage in studied objects

Apartment A (kWh)	Apartment B (kWh)	Apartment C (kWh)
147.9	138.4	484.5
110.9	103.8	346.1
74.0	69.2	276.9
51.8	41.5	207.7
37.0	34.6	138.4
	13.8	69.2

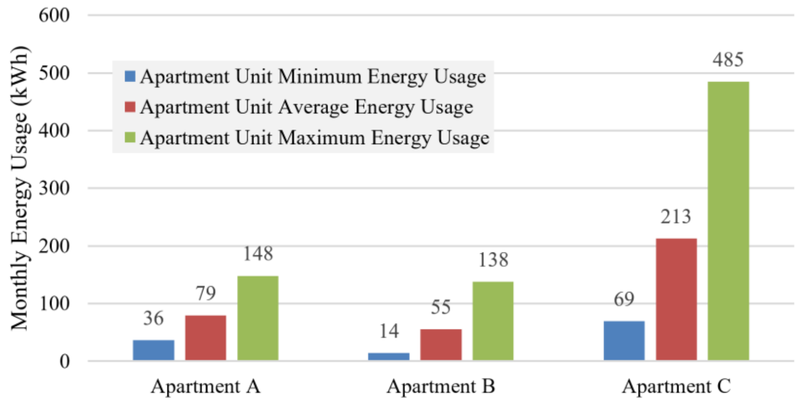

Figure 1. Energy consumption gap between apartments of different income level in Gorontalo

3.2. Feasibility of NZEB Scheme 1 (energy independent building)

To achieve energy-independent buildings, an initial estimation of the energy demand is required. Table 2 shows the calculation of the energy demand in each apartment. Apartment A has 80 apartment units, and each of them has an installed electricity power of 0.9 kVA. Apartment B has 35 units, while Apartment C has 48 units. The units in both apartments B and C have an installed electric power of 1.3 kVA. Because the PVGIS output is monthly, the duration of provision is 720 hours (24 hours x 30 days). To cover building needs, PV power should produce a minimum monthly energy equal to or greater than the building need.

The simulation of PVGIS is conducted with the input of the installed PV peak power taken from the number that may give the result of its minimum value meeting the energy demand. Table 3 presents an analysis of the feasibility of Scheme 1. It is found that the area of the PV module exceeds the available roof area, which renders Scheme 1 unfeasible. The minimum PV production rate of Apartment B is lower than that of the other apartments due to the roof orientation. The roof planes of Apartment B face both north and south, while the other apartments face west and east. The roof facing east and west in Gorontalo has better in-plane irradiation than the north and south [25].

Figure 2 shows the relationship between the monthly PV energy production and building energy demand. It can be seen in the graph in Figure 2 that the difference between the energy produced and consumed for Apartment A ranges from 1801 to 17035 kWh, 569 to 11881 kWh for Apartment B, and 1570 to 14733 kWh for Apartment C. With this result, the buildings not only act as NZEB but also as positive energy buildings, which produce more energy than they use. In this scheme, the Load Match Index is always greater than 100%.

Table 2. Estimation of building energy demand for Scheme 1

Category	Apartment units	Unit power (kVA)	Monthly provision duration (hours)	Energy demand (kWh)
Apartment A	80	0.9	720	51840
Apartment B	35	1.3	720	32760
Apartment C	48	1.3	720	44928

Table 3. NZEB feasibility for Scheme 1

Category	Roof area (m^2)	PV power (kWp)	Minimum PV monthly production (kWh)	Minimum PV production rate (kWh/kWp)	Area for PV module (m^2)	PV area occupation (%)
Apartment A	1331	580	53641	92.5	2836.2	213%
Apartment B	1010	380	33329	87.1	1858.3	184%
Apartment C	1226	500	46498	93	2445.2	199%

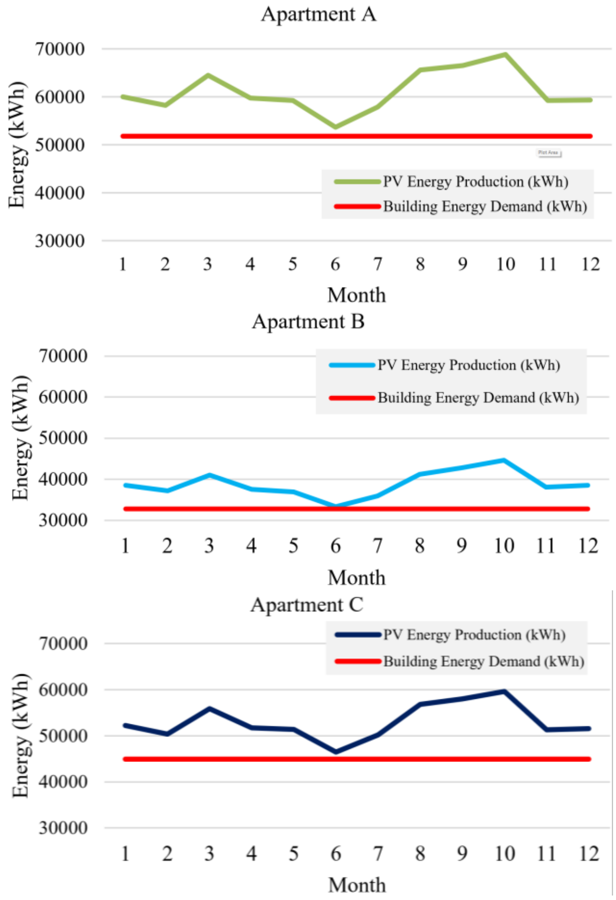

Figure 2. PV monthly production on 3 apartments consistently larger than building energy demand

3.3. Feasibility of NZEB Scheme 2 (fulfillment of building energy consumption)

The objective of Scheme 2 is to reduce the dependency on non-renewable energy by using renewable energy. As learned from the above scheme, achieving an NZEB that covers the consumption of maximum installed electricity for 24 hours by relying on the production of PV on the roof is not feasible. There should be another source of renewable energy to accomplish NZEB in this scheme. Scheme 2 shows the PV power using the tenant's total energy consumption as the base value.

Table 4 shows the monthly energy demand based on the survey data. Although Apartment C has only 48 units, the average monthly energy consumption is so high that the monthly energy demand has skyrocketed. To meet the energy demand, the PV power should produce a minimum energy equal to or more. The results of the PVGIS simulation determined the PV power required to supply the apartments. The values are 70 kWp for Apartment A, 24 kWp for Apartment B, and 120 kWp for Apartment C. All the PV modules may fit on the roof since the required area is smaller than the available roof space.

While Scheme 2 is more feasible than Scheme 1, there is uncertainty in the fluctuation of building energy consumption due to tenant behavior. Building energy utilization may escalate; therefore, there will be more demand for PV power to achieve NZEB. It is a concern that PV modules will use more than the available roof space to satisfy this need.

3.4. Data validation

A comparison between the PVGIS simulation results and field measurements is conducted for data validation. Although there is a lack of publications regarding the daily or annual production rate of residential PV in Gorontalo, there is an article on the economic savings of PV. The PV production rate of PV is taken from the annual electricity bill savings [25]. The comparison given in Table 5 shows 15.8-18.3% of difference in the PV production rate between the simulation and on-field results. However, the contrasting result is mainly due to the difference in roof slope, not by the PV power or roof orientation. A lower inclination plane results in a higher irradiation gain. The roof pitch significantly influences the annual energy yield compared with the roof orientation [26].

Table 4. NZEB feasibility for Scheme 2

Category	Monthly energy demand (kWh)	Roof area (m^2)	PV power (kWp)	Minimum PV monthly production (kWh)	Area for PV module (m^2)	PV area occupation (%)
Apartment A	6320	1331	70	6474	342.2	25.7%
Apartment B	1925	1010	24	2105	117.3	6%
Apartment C	10224	1226	120	10791	586.8	47.9%

Table 5. Comparison of simulation result with PV

Category	Roof slope	Roof orientation	PV power (kWp)	Annual PV energy production (kWh)	PV production rate (kWh/kWp)
Field measurement	6°	North and south	1.8	2702	1501.1
Simulation - Apartment A	32°	East and west	70	88474	1263.9
Simulation - Apartment B	32°	North and south	24	29413	1225.5
Simulation - Apartment C	32°	East and west	120	150757	1256.3

3.5. Comparison between the schemes

The provision of renewable energy to achieve NZEB in Scheme 1 is restricted by the available roof space in the building. It is difficult for the PV system on the roof to supply energy to the entire building. Architecturally, adding more roof space to a building is impossible because the required roof space is almost twice or more than twice the existing area. Creating roof space near the ground, for example, the roof space for parking areas, might be reasonable, although the design should consider the factor of shading from the midrise building.

To ensure the availability of energy for 24 hours, the building should be connected to a power grid. Independent-energy apartment buildings are unachievable due to the enormous objective. Powering entire apartment units with the limit of installed power for 24 hours will only spoil tenants and does not represent the action of energy conservation.

The calculation of the energy demand for Scheme 2 is based on the energy consumption data. The data for each building may vary and fluctuate over time. Providing renewable energy by employing PV on roofs to meet the current energy demand is achievable. Given that demand gradually increases over time, the roof might not be adequate for the installation of other PV modules. This problem requires a solution for another source of energy from a power grid. However, to prevent the escalation of electricity consumption, an energy-efficiency measure should be taken.

3.6. Thermal comfort and building energy efficiency

This research provides insights from different apartments with 3 income profile users. Apartment A is populated with low income community, and the available units are about twice of the other apartment units. Despite its building density, people use less electricity because of financial constraints. Apartment B is occupied by marine who are always on duty and infrequently using electricity at home. The apartment units are also fewer than apartments A and C. In contrast to Apartment A, Apartment C, which was occupied by an officer of the Financial and Development Supervisory Agency and their family, has the highest energy expenditure because of its high purchasing power. They could afford more electrical appliances than people in other apartments. The building energy consumption of Apartment A is driven by the density factor, that of Apartment B is the activity intensity factor, and that of Apartment C is the appliances/load factor.

However, people in apartments A and B could live their daily lives depending on the fan to regulate the room's thermal comfort. Energy conservation behavior can be practiced by people in the two apartments despite the scorching heat of the tropical climate of Indonesia. Provided that people in Apartment C can reduce their dependence on air conditioners and use fans for ventilation, the building will consume less energy. In the future, there is a need to study the perceived thermal sensation of people in apartments A and B to obtain a key for energy efficiency in this type of middle-rise building in Gorontalo.

Based on the results above, it is clear that NZEB is feasible in Gorontalo apartments using rooftop PV. The power generated by the renewable energy technology (in Scheme 2) can provide the apartment's energy needs, and the roof space is more than enough to cover the PV installation. However, the research has not yet considered energy efficiency measures to reduce energy consumption and decrease PV capacity. Therefore, the NZEB concept has potential for application.

3.7. Enhancing adoption of net zero energy building

Given that NZEB is applicable, the next step is to encourage its adoption in buildings. NZEB can be applied by retrofitting an old building and constructing a new NZEB. However, the retrofitting method is a more favorable approach for the adoption of NZEB than developing a new building, as it is a practical way to save more energy from an existing structure and reduce the environmental burden that comes from new construction [27]. Financial support mechanisms should facilitate the development of net-zero energy in the building sector. A well-structured financial incentive can effectively stimulate the market demand for energy-efficient buildings [28]. Indonesia is on the track of green building construction and net-zero goals. Nevertheless, the current regulation is only mandatory for large buildings (floor areas above 5000 m^2) and lacks specific requirements for renewable energy, thereby inhibiting the introduction of NZEB in small-scale buildings [29]. More research is needed to highlight the urgency of NZEB adoption in Indonesia.

3.8. Renewable energy consumption behavior

As stated in a previous study, energy conservation behaviors have a greater effect on energy consumption [30]. A study of the behavior of households installing PV systems on roofs reported an increase of 18% in energy consumption due to changes in the thermostat setting [31]. The presence of renewable energy in buildings has given people the feeling of energy independence and act as if they could use it as much as they want. In Jordan, PV companies encourage people to install renewable energy with capacities higher than the energy demand so that households can utilize the energy freely. Consequently, the average annual energy consumption increased by 41% [32]. To cope with this problem, education on the importance of renewable energy adoption and environmental awareness is an urgent matter before technology is presented to society. This is especially true for low-income people (for example, residents of apartments for low-income people), where the introduction of renewable energy might loosen their financial restrictions on using more energy.

4. CONCLUSION

Rooftop PV cannot meet the energy needs of buildings to achieve NZEB in Scheme 1 because the area of the PV on the roof far exceeds the available space on the roof. To extend the surfaces for PV utilization, the parking lot's roof and building facade could be taken advantage of. Meanwhile, for Scheme 2, rooftop PV is feasible to cover the current tenant energy demand. To ensure access to energy, buildings must be connected to a power grid. The profile of building users significantly affects the fulfillment of renewable energy in buildings. Tenants in Apartment C spend two to three times more electricity than the average usage in other apartments because of their financial capability to use electronic equipment with more power. There is uncertainty regarding the increase in energy demand over time. Building energy efficiency measures and energy conservation behaviors should be considered to suppress the surge in energy consumption in dense residential buildings such as apartments. The method employed in this study is applicable to all researchers due to its convenience, in addition to the open-access program (PVGIS). Each building type has a different energy demand as a result of the activity in the building, density, and building design. Differences in geographical location may contribute to differences in solar radiation gain. Consequently, each building has its own unique energy demand and supply. Utilization of this method on a larger scale (building types and location) will contribute to gaining more reports and analysis. Ultimately, provides more insight into the feasibility of NZEB with respect to the building specific requirement, and local climate.

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AUTHOR CONTRIBUTIONS STATEMENT

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C : **C**onceptualization
M : **M**ethodology
So : **So**ftware
Va : **Va**lidation
Fo : **Fo**rmal analysis
I : **I**nvestigation
R : **R**esources
D : **D**ata Curation
O : Writing - **O**riginal Draft
E : Writing - Review & **E**diting
Vi : **Vi**sualization
Su : **Su**pervision
P : **P**roject administration
Fu : **Fu**nding acquisition

CONFLICT OF INTEREST STATEMENT

Authors state no conflict of interest.

DATA AVAILABILITY

The data that support the findings of this study are available from the corresponding author, [AGD], upon reasonable request.

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