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Hydroclimatology-Based Green Building Planning for a Two-Story Office Building in Gunung Pangilun, Padang, Indonesia

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ABSTRACT

The implementation of green building principles in office buildings located in humid tropical climates is a strategic approach to reducing fossil energy consumption and improving freshwater harvesting potential, and carbon-emission reduction for a two-story office building with a total floor area of 3000 m^2 in Gunung Pangilun, Padang, Indonesia. The analysis refers to Indonesia National Standards SNI 03-6397-2000 and SNI 03-7065-2005, as well as the Greenship assessment criterial developed by the Green Building Council Indonesia. Based on data from the Indonesia Agency for Meteorology, Climatology, and Geophysics, the study area receives an average annual rainfall of 3,900 mm. with an occupancy capacity of 300 people, passive and active energy-efficiency strategies are estimated to reduce energy consumption by 30%. A 75 kWp rooftop solar photovoltaic system is projected to generate 101,250kWh annually. Overall, these measures reduce electricity demand from the national grid by 48.75% and lower carbon emission by 223.76 tonnes of CO_2 per year. Rainwater harvesting from a 1,500 m^2 roof area could provide 4,972.5 m^3 annually, fully meeting the buildings operational water demand of 2,812.5 m^3 after 25% reduction through water-efficient fixtures under the proposed design.

INTRODUCTION

The building sector accounts for a substantial proportion of global energy consumption and greenhouse gas (GHG) emissions[1]. In Indonesia, the rapid development of office facilities has contributed to an increasing national electricity demand and accelerated groundwater exploitation. The implementation of green building principles has therefore become an instrumental strategy for achieving environmental sustainability through efficient resource utilization throughout the building life cycle.

Padang City, particularly Gunung Pangilun Urban Village in North Padang District, has distinctive hydro-climatological characteristics, with annual rainfall ranging from approximately 3,800 to 4,000 mm, based on data obtained from the Meteorology, Climatology, and Geophysics Agency (BMKG) meteorological station. This humid tropical climate provides considerable potential for rainwater harvesting as an alternative source that can partially or fully substitute the use of municipal freshwater.

This study presents mathematical formulations and a technical analysis for the green building planning of a two-story office building with a total floor area of 3,000 m^2. The analysis covers daily and annual electricity consumption efficiency, the contribution of renewable energy from a rooftop solar photovoltaic system, freshwater-use efficiency based on office occupancy standards, rainwater harvesting potential derived from local BMKG data, and the reduction of carbon dioxide equivalent emissions.

The integration of energy and water management is particularly important for office buildings in humid tropical regions, where cooling demand and water consumption may contribute substantially to the overall environmental performance of the building. In such climatic conditions, green building planning should not focus solely on reducing electricity consumption, but should also consider the utilization of locally available renewable resources. Solar energy and abundant rainfall therefore represent two important environmental resources that can be incorporated into building design to reduce dependence on conventional electricity and freshwater supplies.

In Padang, the combination of relatively high annual rainfall and year-round solar availability creates favorable conditions for implementing an integrated green building approach. Rainwater collected from large roof surfaces can potentially substitute part of the building's operational freshwater demand, while rooftop solar photovoltaic systems can contribute to electricity generation. When these measures are combined with passive architectural strategies, efficient air-conditioning systems, LED lighting, occupancy sensors, and water-efficient fixtures[2], the overall demand for externally supplied energy and water can be substantially reduced[3].

However, green building performance is strongly influenced by local climatic conditions, building geometry, occupancy characteristics, and operational patterns[4]. Therefore, applying generic green building recommendations without considering site-specific hydroclimatological characteristics may result in inaccurate estimations of energy savings, renewable energy production, and rainwater availability[5]. A quantitative planning approach that incorporates local rainfall data, building floor and roof areas, occupancy levels, energy-use intensity, photovoltaic capacity, and water-use standards is consequently required to evaluate the feasibility and environmental performance of the proposed building[6].

Accordingly, this study develops a hydroclimatology-based green building planning framework for a two-story office building in Gunung Pangilun, Padang, Indonesia. The study quantitatively evaluates four principal performance components: building energy efficiency, rooftop solar photovoltaic contribution, freshwater conservation and rainwater harvesting, and electricity-related carbon-emission reduction. The results are expected to provide a practical basis for designing office buildings that respond to Padang's humid tropical climate while reducing dependence on grid electricity and conventional freshwater resources[7].

BUILDING SPECIFICATIONS AND PLANNING ASSUMPTIONS

The initial technical parameters used in this study were established based on relevant Indonesian National Standards and the Green Building Council Indonesia's Greenship criteria for new buildings:

a. **Building Function**: A two-story non-governmental or privately-operated office building.
b. **Total Building Floor Area (A_total)**: 3,000 m², consisting of 1,500 m² per floor.
c. **Roof Area (A_roof)**: 1,500 m², measured as the horizontal projection of the roof surface.
d. **Occupancy Density**: Based on the office occupancy standard specified in SNI 03-6572-2001, which assigns 10 m² per person, the total number of occupants (*N*) is calculated as follows:
   N = 3,000 m² / 10 m²/person = 300 persons
e. **Operational Days** (D_{op}): 250 working days per year, assuming a five-day working week.
f. **Baseline Energy Use Intensity (EUI_{base})**: 180 kWh/m²/year, based on the reference value for conventional office buildings in Indonesia.
g. **Targeted Energy Savings through Passive Design and Active Efficiency Measures**: 30%, achieved through the use of LED lighting, inverter-based VRF/VRV air-conditioning systems, occupancy sensors, and passive shading devices.
h. **Solar Photovoltaic System Capacity** (P_{pv}): 75 kWp, utilizing approximately 50% of the total roof area of 1,500 m².
i. **Specific Rooftop Solar PV Yield** (Y_{pv}): 1,350 kWh/kWp/year, based on the average solar irradiation conditions in Padang City.
j. **Standard Freshwater Consumption** (W_{base}): 50 litres/person/working day, in accordance with SNI 03-7065-2005.
k. **Water Savings from Efficient Sanitary Fixtures** (S_{water}): 25%, achieved through the use of low-flow faucets, dual-flush toilets, and faucet aerators.
l. **Annual Rainfall** (R_{annual}): 3,900 mm/year, equivalent to 3.9 m/year, based on spatial rainfall data for Gunung Pangilun, Padang, provided by BMKG.

m. **Roof Runoff Coefficient** (C_{roof}): 0.85, representing a standard reinforced-concrete flat roof or metal-cladding roof.
n. **Grid Electricity Emission Factor** (EF_{grid}): 0.85 kg CO_2/kWh, representing the electricity emission factor for the Sumatra or national power system.

RESEARCH METHODS

This study employed a quantitative descriptive research method with an engineering design approach[8]. The research was conducted through numerical calculations and comparative analysis to evaluate the performance of a conventional building and the proposed green building design. The analysis focused on energy consumption, rooftop solar photovoltaic energy production, freshwater demand, rainwater harvesting potential, and carbon-emission reduction. The calculation parameters were established based on relevant Indonesian National Standards (SNI), Greenship criteria of the Green Building Council Indonesia (GBCI), and local hydroclimatological data for Gunung Pangilun, Padang.

The sample or object of analysis was a proposed two-story office building located in Gunung Pangilun, Padang, Indonesia, with a total floor area of 3,000 m², consisting of 1,500 m² per floor and a roof catchment area of 1,500 m². The building was assumed to accommodate 300 occupants based on an office occupancy standard of 10 m² per person and to operate for 250 working days per year. This building was selected as a representative planning case for evaluating the application of green building principles under the humid tropical and high-rainfall conditions of Padang City.

1. **Electrical Energy Efficiency:**
   a. **Baseline Energy Consumption (Before Green Building):**
   The baseline annual energy consumption is calculated using the total building floor area and the baseline energy use intensity:
   $$E_{base} = A_{total} \times IKE_{base}$$
   $$E_{base} = 3000\ m^2 \times 180\ kWh/m^2/year = 540000\ kWh/year$$

   b. **Energy consumption after passive and active efficiency measures**
   The implementation of passive design strategies and active energy-efficiency measures is assumed to reduce energy consumption by 30%. Annual energy demand is calculated as follows:
   $$E_{eff} = E_{base} \times (1 - 0.30)$$
   $$E_{eff} = 540000\ \text{kWh/year} \times 0.70 = 378000\ \text{kWh/year}$$

   c. **Annual electricity generation from the rooftop solar PV system**
   The annual electricity production of the 75 kWp rooftop solar photovoltaic system is calculated using its specific annual yield:
   $$E_{pv} = P_{pv} \times Y_{pv}$$
   $$E_{pv} = 75\ \text{kWp} \times 1350\ \text{kWh/kWp/year} = 101250\ \text{kWh/year}$$

   d. **Elecetricity demand supplied by the public grid**
   The remaining electricity demand that must be supplied by the national electricity grid is determined by subtracting the electricity generated by the rooftop solar PV system from the energy demand after efficiency measures:
   $$E_{grid} = E_{eff} - E_{pv}$$
   $$E_{grid} = 378000 - 101250 = 276750\ kWh/year$$

   e. **Reduction in electricity consumption from the national grid (PLN)**
   The percentage reduction in grid-supplied electiricity relative to be baseline condition is calculated as follows:
   $$\%\text{Reduction} = \frac{E_{base} - E_{grid}}{E_{base}} \times 100\%$$
   $$\%\text{Reduction} = \frac{540000 - 276750}{540000} \times 100\% = 48.75\%$$

2. **Water conservation and rainwater harvesting**
   a. **Baseline annual freshwater demand**

$$W_{base\_annual} = \frac{N \times W_{base} \times D_{op}}{1000}$$

$$W_{base\_annual} = \frac{300 \text{ person} \times 50 \text{ L/person/day} \times 250 \text{ day/year}}{1000} = 3750 \text{ m}^3\text{/year}$$

   b. **Freshwater demand after the application of water-efficient fixtures**

$$W_{green\_annual} = W_{base\_annual} \times (1 - 0.25)$$

$$W_{green\_annual} = 3750 \text{ m}^3\text{/year} \times 0.75 = 2812.5 \text{ m}^3\text{/year}$$

   c. **Rainwater harvesting potential in Gunung Pangilun [9]**

$$V_{rain} = R_{annual} \times A_{roof} \times C_{roof}$$

$$V_{rain} = 3.9 \text{ m/year} \times 1500 \text{ m}^2 \times 0.85 = 4972.5 \text{ m}^3\text{/year}$$

   d. **Municipal freshwater balance**

$$W_{net\_grid} = \max\left(0,\ W_{green\_annual} - V_{rain}\right)$$

$$W_{net\_grid} = \max(0,\ 2812.5 - 4972.5) = 0 \text{ m}^3\text{/year}$$

$$Rainfall\ Surplus = 4972.5 - 2812.5 = 2160\ m^3/year$$

3. r**Decarbonization and Carbon Emission Reduction [10]**
   a. **Annual carbon emission reduction**

$$CO_2\ Reduction = \frac{\left(E_{base} - E_{grid}\right) \times EF_{grid}}{1000}$$

$$CO_2\ Reduction = \frac{(540000 - 276750)\ kWh/year \times 0.85\ kg\ CO_2/kWh}{1000} = 223.76\ tonnes\ CO_2/year$$

RESULTS AND DISCUSSION

The results of the comprehensive analysis of the design parameters for the proposed two-story office building with a total floor area of 3000 m^2 in Gunung Pangilun, Padang, are summarized in table 1.

Table 1. Summary of the Planning Performance Comparison for the Gunung Pangilun Office Building.

Planning Parameter	Conventional Condition (Baseline)	Green Building Condition	Difference/Efficiency Level
Energy Use Intensity (EUI)	180 kWh/m2/year	126 kWh/m3/year	30.000% reduction
Total Building Energy Consumtion	540,000 kWh/year	378,000 kWh/year	Reduced by 162,000 kWh/year
Rooftop Solar PV Electricity Production	0 kWh/year	101,250 kWh/year	26.79% self-supplies energy
Grid Electricity Consumption	540,000 kWh/year	276,750 kWh/year	48.75% reduction in grid electricity use
Total Freshwater demand	3,750.0 m3/year	2,812.5 m3/year	25.00% reduction
Rainwater Harvesting Potential	0 m3/year	4,972.5 m3/year	Abundant supply (high annual rainfall)
Municipal/Groundwater Supply Requirement	3,750.0 m3/year	0 m3/year	100% water self-sufficiency (surplus of 2,160 m3)
Electricity-Related Carbon Emission	459.00 tonnes CO2/year	235.24 tonnes CO2/year	Reduction of 223.76 tonnes CO2/year

Based on the water balance analysis, the microclimatic conditions of Gunung Pangilun, characterized by high annual rainfall (3,900 mm/year), provide substantial ecological advantages. The rainwater harvesting potential from the 1,500 m^3 roof area reaches 4,972.5 m^3/year, which significantly exceeds the building's reduced operational water demand of 2,812.5 m^3/year. The surplus water volume of 2,160 m^3/year recharge wells and biopore infiltration systems to support local groundwater conservation in Padang[11].

The design of the proposed two-story office building I illustrated in the following figures:

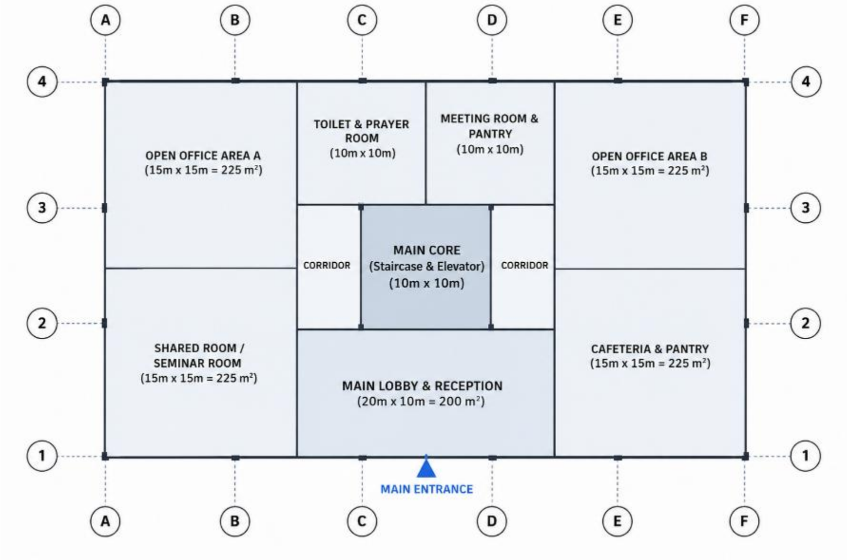

Figure 1. Ground floor plan, scale 1:200.
Floor area: 1,500 m^2 (building dimensions: 50 m x 30 m)

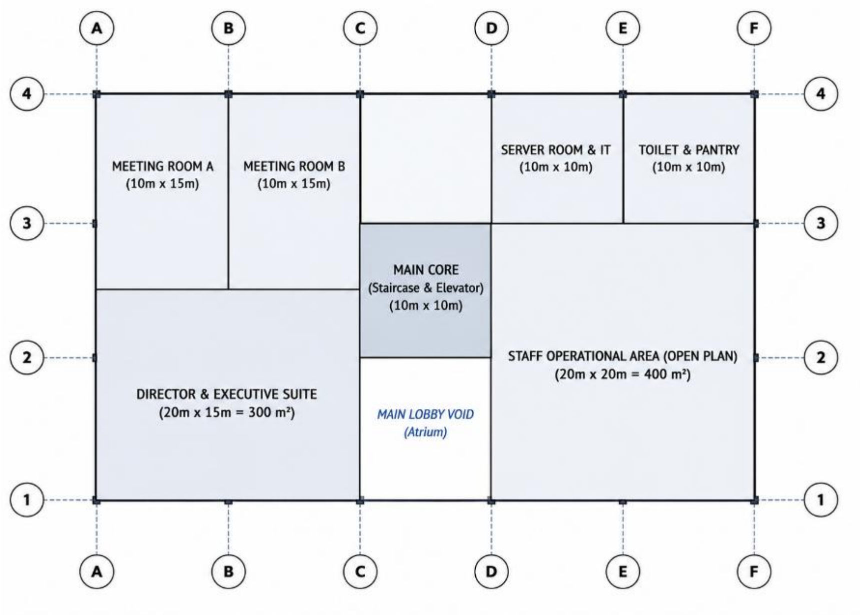

Figure 2. Second floor plan, scale 1:200.
Floor area 1,500 m^2 (building dimension 50 m x 30 m)

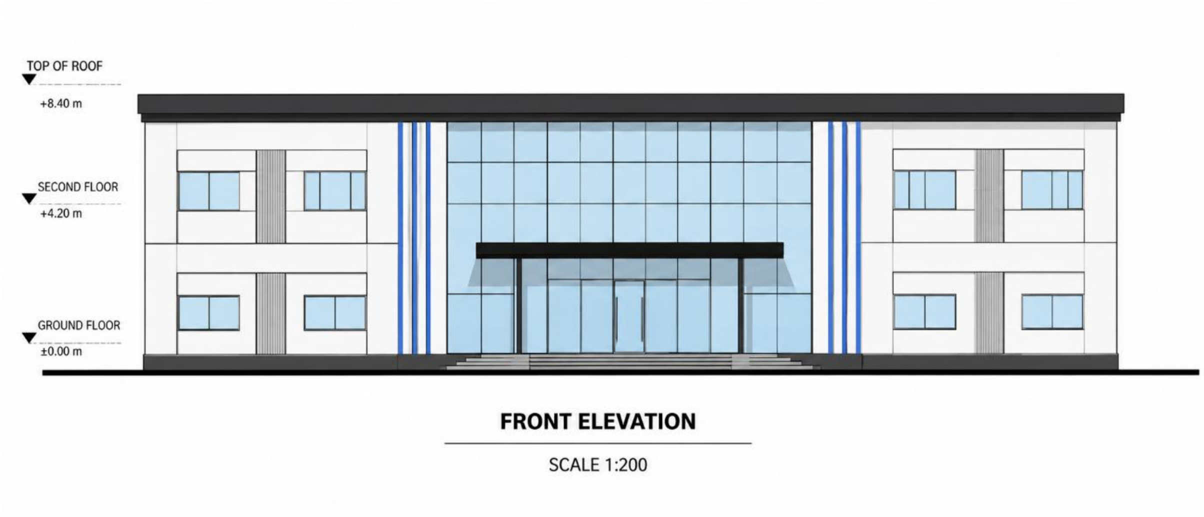

Figure 3. Front elevation, scale 1:200.

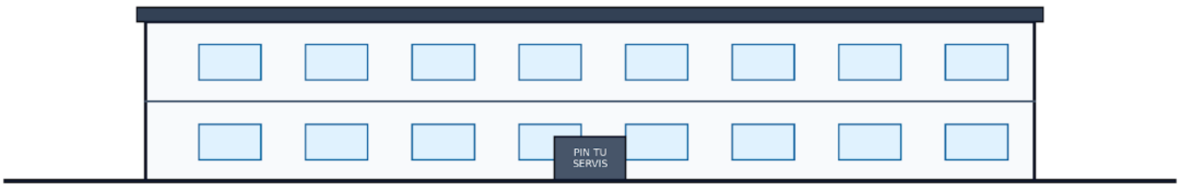

Figure 4. Rear elevation, scale 1:200.

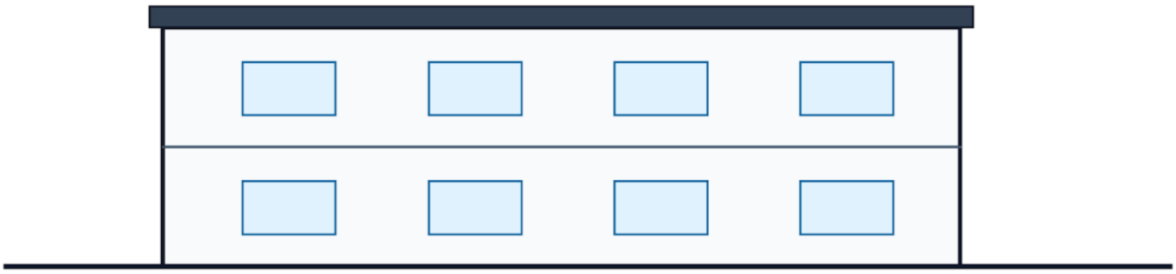

Figure 5. Left elevation, scale 1:200.

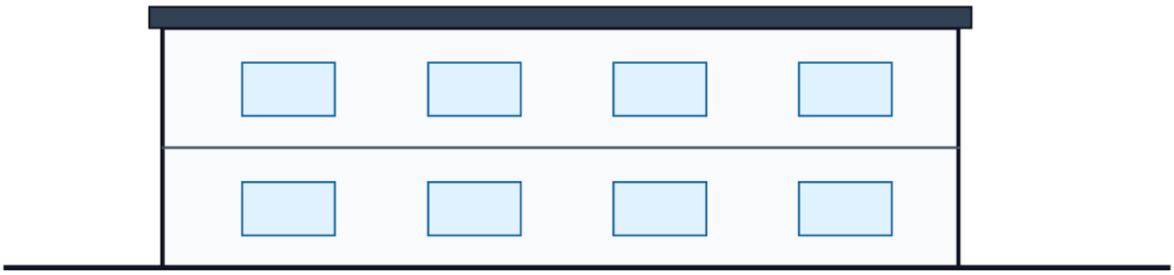

Figure 6. Right elevation, scale 1:200

Site-specific Green Building Strategies

Considering the geographical setting of Gunung Pangilun, Padang, which lies within a humid tropical zone, the following integrated strategies are recommended:

1. Daylighting Orientation and Passive Façade Design

   The building should be elongated along the east-west axis to minimize direct solar heat gain. Perforated secondary skins or wooden/aluminium louvers are recommended on the western facade to reduce heat transmission without obstructing natural daylight[12], [13].

2. Optimization of On-Grid Rooftop Solar PV

   Approximately 180–200 monocrystalline solar panels covering around 750 m^2 of roof area should be installed with a tilt angle of 10°–15°, oriented northward or southward to maximize photovoltaic energy capture.
3. Rainwater Harvesting System

   The building roof should be integrated with high-capacity gutters, a first-flush diverter, a sedimentation tank, and an underground storage tank with a capacity of 50–80 m^3. The system should also include appropriate filtration and disinfection to enable the safe reuse of harvested rainwater for non-potable purposes such as toilet flushing and landscape irrigation.
4. Independent Water Infiltration System (Zero Runoff Concept)

   At least six deep recharge wells should be constructed, and the parking area should use permeable paving blocks to reduce surface runoff and mitigate localized flooding in the Gunung Pangilun area.
5. Smart Air-Conditioning and Eco-Friendly Materials

   The building should employ VRF/VRV air-conditioning systems using environmentally friendly refrigerants such as R-32 or R-410A, integrated with occupancy sensors. In addition, local building materials with low volatile organic compound (VOC) emissions, including low-VOC paints and sealants, should be prioritized.
6. High-Performance Building Envelope

   The building envelope should be designed to reduce external heat transfer into indoor spaces. Roof insulation, light-reflective roofing materials, appropriate glazing, and external shading devices can be incorporated to reduce solar heat gain and consequently decrease cooling demand. Particular attention should be given to the western and eastern façades, which are exposed to relatively high levels of direct solar radiation during the morning and afternoon[14].
7. Natural Ventilation and Indoor Air Quality

   Natural ventilation should be optimized in circulation areas, transitional spaces, and other suitable zones to reduce dependence on mechanical cooling[15]. Operable windows, cross-ventilation openings, and appropriate internal layouts can facilitate natural airflow where climatic conditions permit. Mechanical ventilation systems should also maintain adequate fresh-air exchange to support occupant health and indoor environmental quality[16].
8. Sustainable Landscape and Microclimate Management

   Vegetation should be incorporated around the building and parking areas to improve the local microclimate, provide shading, and reduce surface temperatures. Native or locally adapted plant species with relatively low irrigation requirements should be prioritized. Shaded pedestrian areas and vegetated open spaces can further reduce heat accumulation around the building while improving outdoor thermal comfort.
9. Integrated Stormwater Management

   In addition to rainwater harvesting and recharge wells, the site should incorporate an integrated stormwater-management system consisting of vegetated drainage channels, infiltration areas, permeable surfaces, and controlled overflow pathways. These measures are particularly relevant to the high-rainfall conditions of Padang and can reduce peak surface runoff during intense rainfall events while improving groundwater infiltration.
10. Smart Energy and Water Monitoring System

   A building monitoring system should be installed to continuously record electricity consumption, rooftop PV production, freshwater consumption, and rainwater utilization. Separate sub-metering for major energy-consuming equipment, particularly air-conditioning and lighting systems[17], would enable building managers to identify inefficient operational patterns. Real-time monitoring can also support preventive maintenance and ensure that the projected green-building performance is maintained throughout the building's operational life[18].
11. Waste Management and Resource Efficiency

Dedicated areas should be provided for the separation and temporary storage of recyclable, organic, and residual waste. During construction, material use should be optimized to minimize waste generation, while recycled or locally sourced materials should be considered where technically appropriate. During the operational stage, waste-separation facilities can support more sustainable building management practices.

12. Integrated Green Building Performance

The proposed strategies should be implemented as an integrated system rather than as independent measures. Passive design reduces the initial energy demand, efficient building systems minimize operational consumption, rooftop solar PV supplies renewable electricity, while rainwater harvesting and infiltration systems improve water-resource efficiency. The combination of these strategies provides a site-responsive green building concept that addresses the humid tropical climate and high annual rainfall characteristics of Gunung Pangilun, Padang.

CONCLUSION

The green building planning for a two-story building with a total floor area of 3,000 m^2 in Gunug Pangilun, Padang, demonstrated significant ecological and financial benefits. The integration of energy-efficient design measures and a 75 kWp rooftop solar photovoltaic system reduces electricity consumption from the national grid by 48.75% and prevents the release of approximately 223.76 tonnes of CO^2 per year. Furthermore, owing to the high local annual of 3,900 mm/year, rainwater harvesting from the 1,500 m^2 roof area is capable of meeting 100% of the building's operation freshwater demand, while also generating surplus water for groundwater recharge and supporting the long-term sustainability of the city

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