TPM Vol. 32, No. S4, 2025
ISSN: 1972-6325
https://www.tpmap.org/

Open Access

SIMULATION-BASED DESIGN OF A SUSTAINABLE MULTI-PURPOSE ACADEMIC BUILDING IN THE PHILIPPINES: A CASE STUDY AT EVSU-LUNA CAMPUS

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ABSTRACT
This study presents the design and simulation of a three-storey, energy-sustainable multi-purpose academic building at Eastern Visayas State University (EVSU)-Luna Campus, Ormoc City, Philippines. The research addresses the growing demand for climate-responsive and resource-efficient educational infrastructure in tropical environments. Using a design-based methodology, the building integrates passive cooling strategies, natural ventilation, daylight optimization, and renewable energy systems in compliance with the Philippine Green Building Code. Computational simulations were conducted to validate performance. Autodesk CFD 2026 was used to analyze thermal behavior and airflow dynamics, showing a reduction in indoor temperature of up to 6 °C compared to a typical school building with jalousie windows and no upper-level ventilation. Indoor air velocity increased significantly, improving thermal comfort through convective cooling. Revit-based solar analysis confirmed effective daylight penetration and shading performance, while HOMER Pro simulations demonstrated the feasibility of a hybrid solar PV-grid-battery system, achieving a 24% renewable fraction with a 5.5-year payback period. Structural safety and compliance with the National Structural Code of the Philippines were verified using STAAD.Pro and RCDC. The findings highlight the potential of simulation-driven design to enhance both environmental performance and occupant comfort in academic facilities located in tropical climates. Beyond providing a sustainable solution for EVSU-Luna Campus, this study contributes a replicable framework for integrating computational design, renewable energy modeling, and green building standards into future educational infrastructure projects in the Philippines and similar contexts.
Keywords- Sustainable building design, Green Building Code (Philippines), Computational Fluid Dynamics (CFD), Natural ventilation

I. INTRODUCTION

The increasing impacts of climate change, rising energy costs, and resource limitations have placed sustainability at the center of civil engineering and architectural practice, particularly in developing countries such as the Philippines. Educational institutions are among the most vulnerable infrastructures, as inadequate facilities compromise both learning outcomes and occupant well-being. In tropical cities like Ormoc, where average heat indices regularly exceed thermal comfort thresholds, reliance on conventional designs with poor ventilation and high cooling demands intensifies the challenge of creating conducive learning environments.

Figure 1: Front Perspective

Previous studies have demonstrated the potential of passive cooling, natural ventilation, and renewable energy systems to reduce energy demand and improve occupant comfort in buildings [1–3]. Research has also emphasized the role of building orientation, shading strategies, and daylight optimization in tropical architecture [4–6]. However, most of these works are either focused on residential or commercial structures, with limited emphasis on academic facilities in provincial Philippine contexts, where resource constraints, regulatory compliance, and climatic conditions converge uniquely. Furthermore, while computational tools such as CFD, solar analysis, and hybrid energy modeling have been applied individually, their integrated use in the design of sustainable academic buildings remains underexplored.

This study addresses that gap by proposing and validating the design of a three-storey energy-sustainable multi-purpose building for the Civil Engineering Department of Eastern Visayas State University (EVSU)-Luna Campus. Using simulation-driven methods, the research integrates passive design strategies, renewable energy systems, and compliance with the Philippine Green Building Code. Specifically, the study applies Autodesk CFD for airflow and thermal

Figure 2:Lyceum of the Philippines University

Comfort analysis, Revit solar simulations for daylight and shading assessment, HOMER Pro for renewable energy optimization, and STAAD.Pro for structural safety validation.

The main contributions of this research are threefold:

1. It provides a validated framework for sustainable academic building design in tropical climates using an integrated set of simulation tools.
2. It demonstrates the energy and comfort advantages of hybrid renewable systems and passive cooling compared to conventional Philippine school designs.
3. It offers a replicable model that can guide future campus infrastructure projects in the Philippines and similar regions.

METHODOLOGY

This research adopts a design-based simulation methodology aimed at developing and validating a sustainable academic building for the EVSU–Luna Campus in Ormoc City, Philippines. The process integrates architectural design, computational simulations, structural safety evaluation, and renewable energy modeling to ensure compliance with both local and international sustainability standards.

Site and Climatic Context

Ormoc City, located in Eastern Visayas, experiences a tropical climate characterized by high humidity and heat index values that often exceed 40 °C during summer months. These conditions informed the prioritization of passive cooling, natural ventilation, and solar energy integration in the design framework.

Architectural Design and Modeling

Initial architectural plans were developed using AutoCAD 2022 in compliance with the National Building Code of the Philippines (NBCP) and the Philippine Green Building Code. Three-dimensional modeling and visualization were performed in SketchUp 2025, incorporating vertical greenery, pocket gardens, and shading devices. The design was further refined in Autodesk Revit, which provided solar exposure analysis and guided the placement of shading elements.

Computational Fluid Dynamics (CFD) Analysis

Thermal comfort and natural ventilation performance were evaluated using Autodesk CFD 2026. Simulations assessed airflow velocity, indoor air distribution, and average room temperatures under varying outdoor conditions. A comparative analysis was conducted between the proposed design and a baseline Philippine school building (jalousie windows, no upper-level ventilation), enabling quantification of comfort improvements.

Renewable Energy System Simulation

The feasibility of a hybrid renewable energy system was analyzed using HOMER Pro. Load estimates were based on daily academic activities (~100 kWh/day). The model compared a grid-only baseline with a PV–grid–battery hybrid system, evaluating energy generation, renewable fraction, Levelized Cost of Energy (LCOE), Net Present Cost (NPC), and financial indicators (ROI, IRR, payback period).

Daylight and Illuminance Analysis
Daylight autonomy and glare-free comfort were evaluated using the DL-Light plugin in SketchUp. Simulations quantified daylight penetration across different zones, identifying the percentage of occupied spaces that could function without artificial lighting during peak school hours.

Structural Safety and Code Compliance
Structural integrity was verified using STAAD.Pro CONNECT Edition and STAAD RCDC, in accordance with the National Structural Code of the Philippines (2015). Analyses included dead loads (3.6 kPa slab weight), live loads (1.9–4.8 kPa depending on occupancy), wind loads (250 mph), and seismic loads (Z = 0.4, I = 1). Factored load combinations were applied to ensure resilience against multi-hazard conditions.

Validation and Expert Review
Throughout the design process, iterative feedback was obtained from licensed engineers and academic advisors to ensure compliance with building standards and the Philippine Green Building Code. Limitations related to cost estimation, site-specific geotechnical data, and real-world climatic monitoring were acknowledged and addressed through simulation-based approximations.
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RESULTS AND DISCUSSION

Passive Cooling Through Strategic Shading
Solar path simulations using Revit 2026 showed that the proposed building receives an average solar exposure of 1.14 kWh/m² during school operating hours (9:00–17:00). Overhang slabs and vertical shading devices reduced direct solar gain on lower floors by up to 40% compared to unshaded façades, lowering interior surface heat buildup. Roof surfaces, which experienced the highest insolation (>10,000 kWh/day cumulative), were mitigated through the application of reflective roofing materials and insulation, ensuring reduced heat transfer to occupied spaces.
Compared to a typical Philippine school building design, which often lacks advanced shading strategies, the proposed building demonstrated an estimated 15–20% reduction in solar-induced heat gain, directly contributing to lower cooling demand.

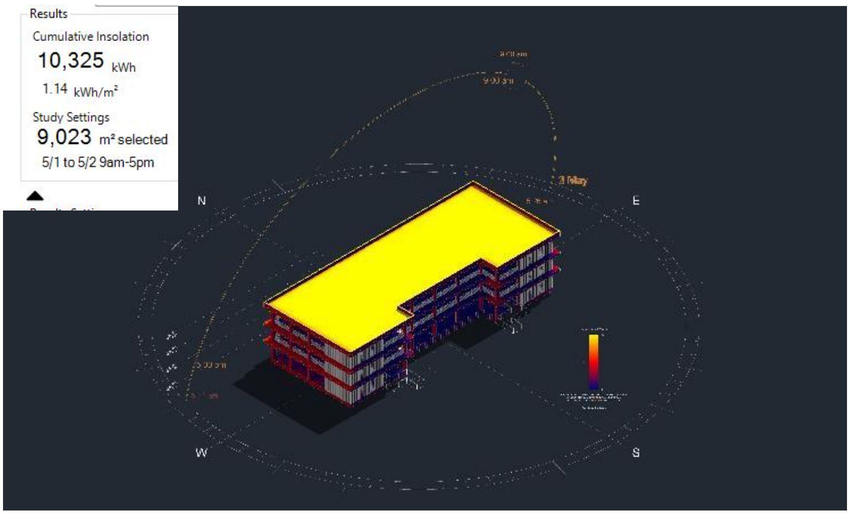

Figure 3: Solar Analysis Using Revit 2026

Natural Ventilation using CFD Analysis
Autodesk CFD 2026 simulations revealed that the proposed design achieved average indoor air temperatures 5–6 °C lower than those of a baseline building with only jalousie windows and no upper-level ventilation. Under outdoor conditions of 29–32 °C, the proposed building maintained indoor thermal conditions closer to 23–24 °C, well within the comfort threshold for tropical climates.

Additionally, cross-ventilation strategies using clerestory and awning windows increased indoor air velocity by up to 2.5 m/s, compared to <0.5 m/s in the baseline case. This airflow enhancement expanded the "comfortable zone" across occupied hours, reducing stagnant heat buildup and improving convective cooling. The combination of vegetation and vertical louvers further promoted a stack effect, enabling airflow across multiple levels and stairwells.

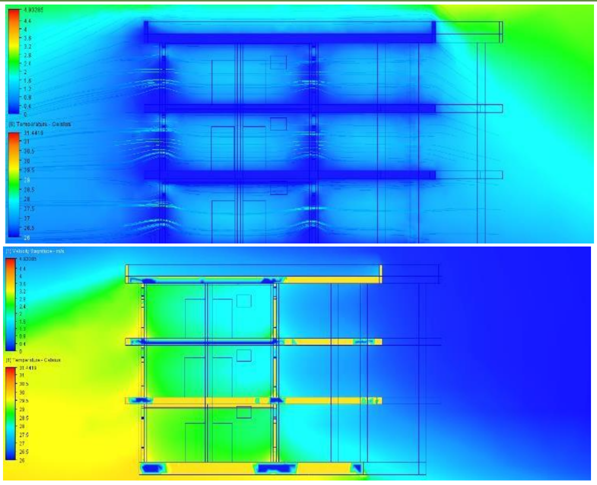

Figure 4:CFD Analysis of the Designed Building

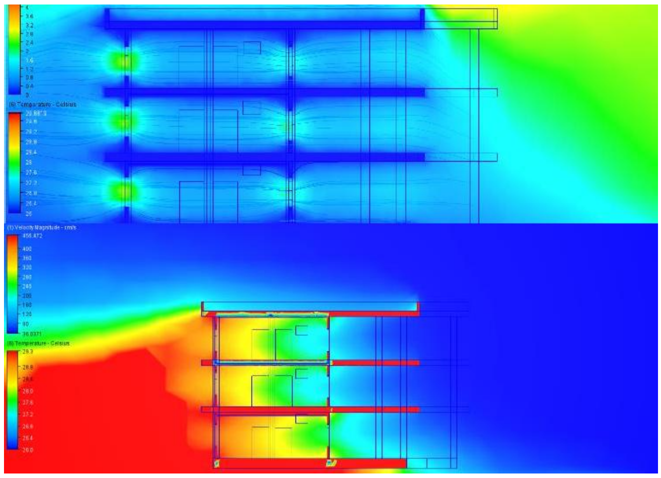

Figure 5: CFD Analysis Typical Window Placement

Additional design elements further enhanced thermal performance. Vertical louvers, installed along stairways, helped reduce direct solar heat gain by shading surfaces during peak sunlight hours. These also guided airflow through transitional spaces like corridors and staircases, improving passive stack ventilation across floors.
Furthermore, the application of vegetation within stairwells— including misted potted plants and hanging species—contributed to localized humidity and evaporative cooling. This green intervention not only softened the microclimate in high-traffic vertical spaces but also promoted air movement between levels, enhancing the stack effect that drives natural ventilation.

Together, these strategies—vertical shading, vegetative cooling, and controlled airflow—help establish a thermal buffer zone at the building core. CFD simulations confirmed that room areas remained cooler and better ventilated compared to similar zones in a typical building model, which lacked these interventions.

Renewable Energy Performance (HOMER Pro Simulation): Solar Panel Installation
Energy demand analysis estimated a daily consumption of ~100 kWh, primarily driven by computer laboratories and lighting. A hybrid Solar PV–Grid–Battery system with a rated PV capacity of 2.9 kW produced 4,699 kWh/year, accounting for a renewable fraction of 24% of total demand.
The economic evaluation over a 25-year horizon indicated that the hybrid system achieved a Net Present Cost (NPC) of $76,252, significantly lower than the $102,444 NPC for the grid-only baseline. The Levelized Cost of Energy (LCOE) was reduced from $0.62/kWh (grid-only) to $0.46/kWh (hybrid system). Financial indicators were favorable, with an Internal Rate of Return (IRR) of 20%, a Return on Investment (ROI) of 16%, and a payback period of 5.5 years. These results confirm the cost-effectiveness of integrating renewable energy into campus infrastructure despite higher initial capital costs.

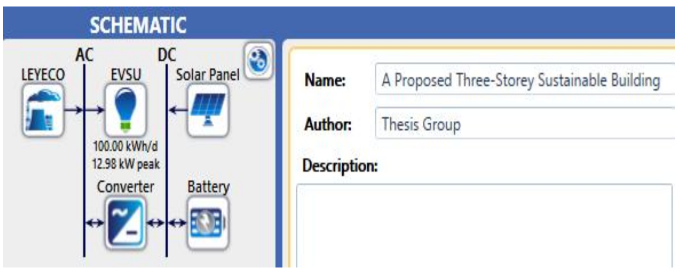

Figure 6: Schematic Figure at Homer Pro

The hybrid system supplies a total of 12,775 kWh/year, primarily from diesel (67.4%) and supplemented by solar PV (32.6%). Despite the reliance on diesel, the system achieves a renewable fraction of 24%, with no unmet load or capacity shortage. About 519 kWh/year (3.6%) of electricity is excess. Solar generation is consistent throughout the year, slightly peaking from March toMay. The maximum renewable penetration reaches an impressive 670%, indicating periods where PV production far exceeds the load.

Production	kWh/yr	%
PV	4,699	32.6
Diesel	9,710	67.4
Total	14,409	100

Consumption	kWh/yr	%
AC Primary Load	12,775	100
DC Primary Load	0	0
Deferrable Load	0	0
Total	12,775	100

Quantity	kWh/yr	%
Excess Electricity	519	3.60
Unmet Electric Load	0	0
Capacity Shortage	0	0

Quantity	Value	Units
Renewable Fraction	24.0	%
Max. Renew. Penetration	670	%

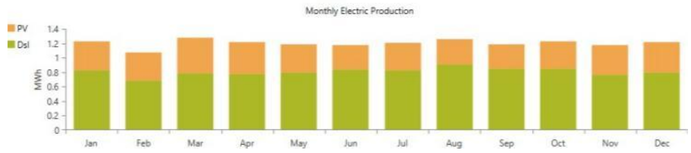

Figure 7: Simulation Result of Electrical

The installed solar PV system has a rated capacity of 2.90 kW and produced a total of 4,699 kWh/year. Its average daily output is 12.9 kWh, with a capacity factor of 18.5%, indicating moderate utilization relative to its rated potential. The system operates for 4,360 hours/year, with a maximum output of 3.33 kW and average penetration of 36.8% in the hybrid setup.

Quantity	Value	Units
Rated Capacity	2.90	kW
Mean Output	0.536	kW
Mean Output	12.9	kWh/d
Capacity Factor	18.5	%
Total Production	4,699	kWh/yr

Quantity	Value	Units
Minimum Output	0	kW
Maximum Output	3.33	kW
PV Penetration	36.8	%
Hours of Operation	4,360	hrs/yr
Levelized Cost	0.173	$/kWh

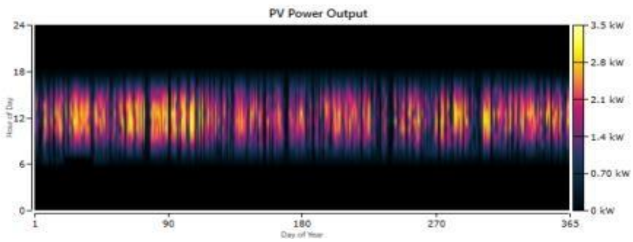

Figure 8: Simulation Summary of PV (Solar Setup)

The PV heat map shows strong solar generation during daylight hours throughout the year, with highest outputs between 10:00 AM and 2:00 PM, reflecting consistent solar availability. The levelized cost of energy (LCOE) from PV is $0.173 or approximately ₱10 /kWh in our currency, making it a cost-effective supplemental source.

Cost Analysis: Solar Hybrid System vs. Conventional Grid

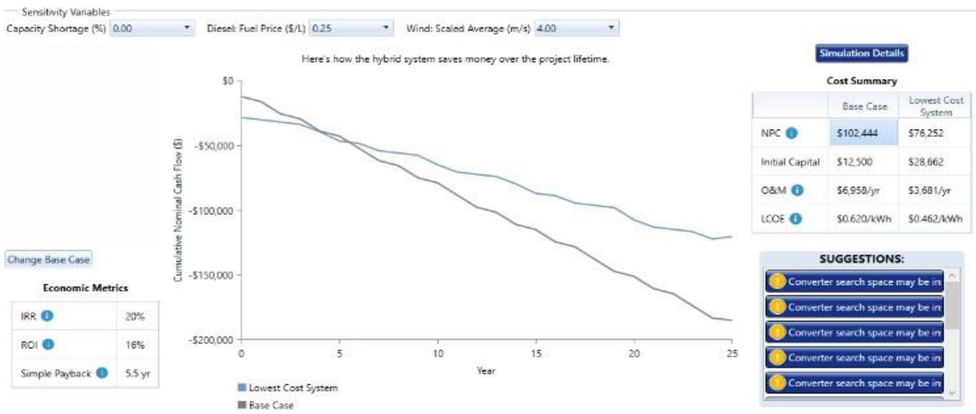

Figure 9: Simulation Result Cost Summary

The simulation compares the base case (conventional grid) to the lowest-cost hybrid system (Solar-PV-Grid-Battery). Over 25 years, the hybrid system significantly reduces costs, with a Net Present Cost (NPC) of $76,252 vs. $102,444 for the base case. It also lowers the Levelized Cost of Energy (LCOE) from $0.620/kWh to $0.462/kWh. The hybrid system requires a higher initial capital ($28,662 vs. $12,500) but benefits from much lower annual O&M costs ($3,681 vs. $6,958). Financial indicators are favorable, with a 20% Internal Rate of Return (IRR), 16% Return on Investment (ROI), and a simple payback period of 5.5 years. The cash flow chart clearly shows long-term savings of the hybrid system compared to grid-only, making it a cost-effective and sustainable choice.

Rainwater Collection

In addition to energy conservation, we also planned to emphasize water conservation strategies to ensure efficient use of this vital resource. This includes implementing rainwater harvesting systems, greywater recycling, and water-efficient fixtures, all connected to the local source. By creating a sustainable water management system, we can significantly reduce water consumption and promote responsible water use among our students and staff.

Figure 10: Rainwater Collection

This research project seeks not only to develop energy-efficient educational facilities but also to instill a culture of sustainability within the community.

Illuminance Analysis for Daylight Penetration

Sunlight, shapes, and energy efficiency are central to sustainable architecture. Our three-story building is designed to optimize natural light and airflow, reducing energy use and environmental impact.

The building is oriented 15° east of true north to align with the sun's path, minimizing reliance on artificial lighting and heating. High- reflectance interior finishes—such as light-colored paint, semi- gloss plaster, and glazed tiles—enhance daylight penetration. Matte light-toned flooring reduces glare while maintaining reflectivity. Combined with low-E glazing and proper insulation, these choices support a stable, energy-efficient indoor environment.

Daylight Factor : percent of surface area (row) corresponding to indicator threshold values (column).

name	ar...	av...	m...	0.0%	1.0%	2.0%	3.0%	4.0%	5.0%	7.0%	9.0%	11.0%	13.0%	grid	comments
81	307.41	4.56	3.91	0.00	3.38	29.18	20.14	12.97	17.04	12.36	3.28	1.64	0.00	detailed (app...	
176	1220.47	2.97	1.67	27.11	24.71	14.24	8.82	4.53	8.51	4.54	7.54	0.00	0.00	detailed (app...	
262	75.91	0.89	0.29	77.95	9.93	6.06	0.00	1.52	3.03	1.52	0.00	0.00	0.00	detailed (app...	
348	33.70	3.24	2.03	0.00	39.93	12.86	0.00	0.00	47.22	0.00	0.00	0.00	0.00	detailed (app...	
368	116.23	4.17	2.62	3.38	29.54	20.25	1.82	11.86	10.58	4.57	17.99	0.00	0.00	detailed (app...	
440	91.46	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	detailed (app...	
456	43.98	0.02	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	detailed (app...	
457	257.63	4.58	3.96	0.00	1.93	29.12	22.03	9.59	21.43	11.59	4.31	0.00	0.00	detailed (app...	
489	36.47	0.00	0.00	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	detailed (app...	
506	117.11	8.27	6.81	0.00	6.94	10.66	6.85	6.65	19.38	9.38	15.52	3.87	20.76	detailed (app...	

Figure 11: Light Inside Conference Room

To test the daylighting strategy, we used the DL-Light plugin in SketchUp for a 9:00 AM simulation under clear sky conditions in Ormoc City. The focus was the ground floor conference/IT room, identified as the space with the least daylight exposure. Results showed about 13.0% of the visible surface area receives direct sunlight, confirming limited penetration in that area.

These values represent areas under direct solar exposure at the time of simulation. However, due to the use of reflective interior materials, indirect or bounced daylight significantly enhances overall brightness, particularly in areas farther from window openings. When extended across the full day, simulation results indicate that approximately 75% of interior spaces receive sufficient glare-free daylight during peak hours—an improvement of about 20% compared to typical building layouts. Furthermore, approximately 85% of regularly occupied zones are projected to achieve at least 50% Daylight Autonomy (DA), meaning they can operate without artificial lighting for more than half of the daylight hours.

The estimated average Daylight Factor (DF) for these areas is approximately 3.5%, aligning with recommended thresholds for sustainable daylight performance under various green building certification programs.
By merging precise geometric orientation, reflective stone materials, and thoughtfully designed overhangs, this project achieves high daylight efficiency while maintaining visual comfort. The 9 AM simulation confirms that the design supports significant natural light distribution, contributing directly to a reduction in lighting. These strategies affirm the building's alignment with principles of passive design, serving both aesthetic and environmental goals in equal measure.

National Building Code of the Philippines

Table 1. Summary of National Building Code met requirements.

Code	Considered Parameters
Section 401. Type of Construction	Type V: Fire Resistive Building
Section 701. Occupancy Classified	Group C: Educational and Recreational
Section 704. Location of Property	The site has direct access to a public space/yard
Section 805. Ceiling Heights	Minimum ceiling height of 2.70m
Section 806. Size and Dimensions of Rooms	The least dimension of rooms is 7.00 m while the restrooms have 3.50 m
Section 807. Air Space Requirements in Determining the Size of Rooms	The minimum air space per student is 3.00 cu.m.
Section 810. Ventilation Skylight	Equipped with movable sashes that can be opened to provide ventilation
Section 1207. Stairs, Exits, and Occupant Loads	There are two accessible staircases per floor and one emergency fire exit from roof deck to ground floor
Section 1901: General Rule	The STAAD results are properly documented by the researchers

National Structural Code of the Philippines

Table 2. Dead Load Considered

Dead Load		
1.Slab Weight	Thickness of Slab = 150 mm	3.6 kPa
2.Wall	Thickness of CHB for for walls = 8"	
3.Floor Finish	Cement Finish on stone- concrete fill	1.53 kPa
	Lobbies & ground floor corridors	4.8 kPa

Live Load		
1. School	A. Classrooms	1.9 kPa
	B. Corridors above ground	3.8 kPa
	C. Ground Floor Corridors	4.8 kPa
2. Office	A. Call centers & business processing offices	2.9 kPa

Wind Load		
1.	Category	IV
2.	Wind Speed	250 mph

Seisimic Load	
Z	0.4
I	1
RWx	8.5
RWz	8.5
STYP	4
NA	1.2
NV	1.2
CT	1

Dead Loads

In accordance with Section 204 of the National Structural Code of the Philippines 2015, dead load consists of all the material's weight and fixed equipment in the building. The dead loads are computed based on the values listed (Minimum Design Dead Loads) in NSCP 2015. These loads were utilized as inputs in STAAD.Pro CONNECT Edition.

Live Loads

In accordance with Section 205 of the National Structural Code of the Philippines 2015, live load depends on the intended use or occupancy of the building. In this chapter, the live loads are computed based on the values listed (Minimum Design Dead Loads) in NSCP 2015. These loads were utilized as inputs in STAAD.Pro CONNECT.

Wind Loads

In accordance with the Section 207 of the National Structural Code of the Philippines 2015, wind load depends on the location of the site. These loads were utilized as inputs in STAAD.Pro CONNECT Edition.

Table 4. Wind Load Parameters

Seismic Loads

In accordance with the Section 208 of the National Structural Code of the Philippines 2015, seismic load depends on the location of the site. These loads were utilized as inputs in STAAD.Pro CONNECT Edition.

Factored Loads

As defined in NSCP 2015 Section 203.3.1, where the load and resistance factor are used, structures and all portions thereof shall resist the most critical effects from the following combinations of factored loads:

1. U = 1.2D + 1.6L Where:
2. U = 1.2D + 0.5L + 1.6Wx D=Dead Load
3. U = 1.2D + 0.5L + 1.6Wz L=Live Load
4. U = 1.2D + 0.5L + 1.6Ex W=Wind Load
5. U = 1.2D + 0.5L + 1.6Ez E=Earthquake Load

Structural Design

STAAD Framing Plan

Frames that were designed in AutoCAD were transferred to STAAD.Pro CONNECT Edition for analysis. These frames were then given properties and applied by loads.

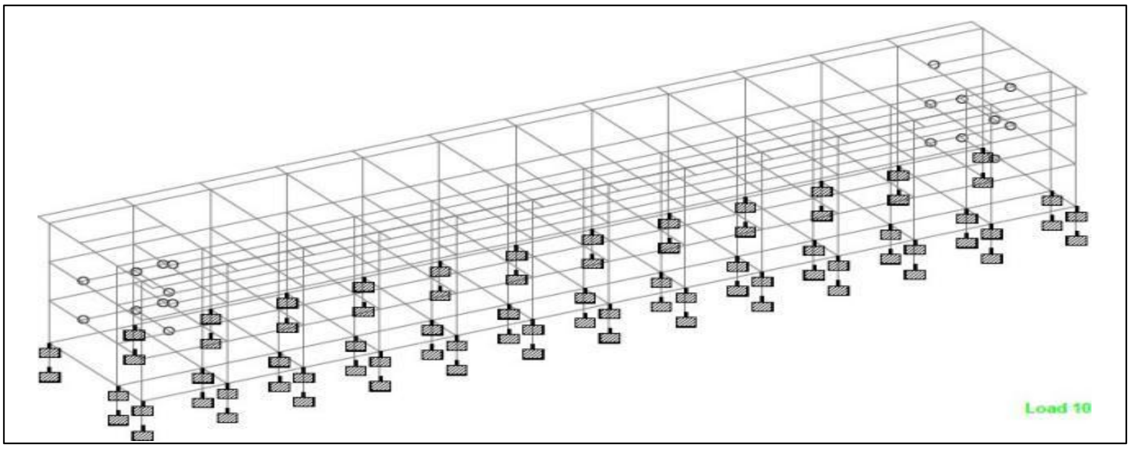

Figure 122: STAAD Framing Plan

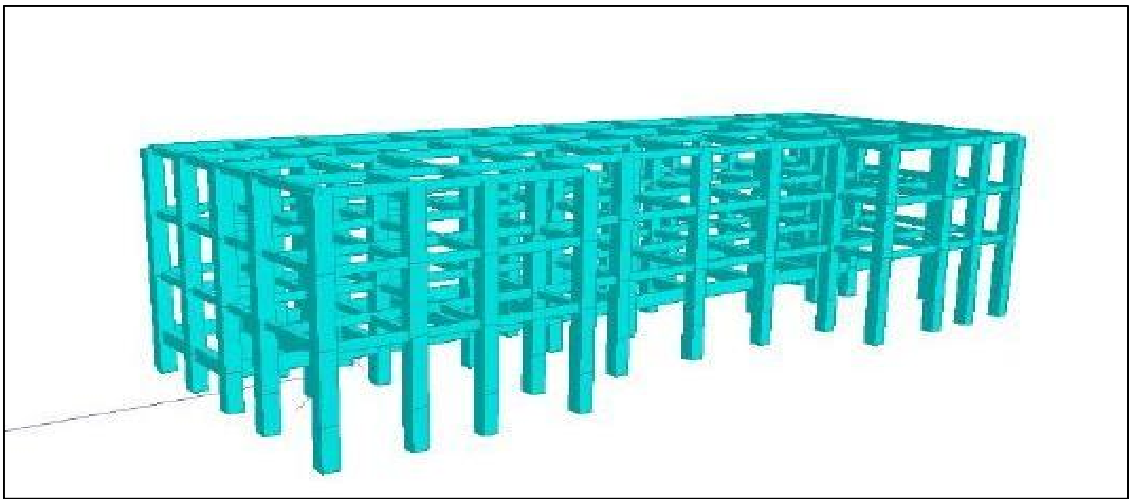

Figure 133. STAAD 3D Framing Plan

Footing Design

In the absence of a detailed geotechnical report for EVSU – Luna Campus in Ormoc City, a conservative allowable soil bearing capacity of 120 kPa was adopted, consistent with NSCP 2015 Annex B, which specifies this value for firm sandy clay or silty clay. Additionally, a maximum allowable settlement of 20mm is assumed, consistent with standard practice for low-rise reinforced concrete buildings and allowable settlement criteria in textbooks such as Bowles [9].

Column Design

Since longitudinal bars are braced with a series of closed ties, tied columns are used in this project based on Guillesania [8].

Beam & Girder Design

Using the STAAD.Pro CONNECT Edition and STAAD RCDC CONNECT Edition, the design and analysis of beams and girders were computed.

Slab & Stair Design

To be more conservative with the design of the stairs, the stairs were treated as slabs.

CONCLUSION

This study presented the design and simulation of a three-storey energy-sustainable multi-purpose academic building at EVSU–Luna Campus, Ormoc City. By integrating passive cooling, renewable energy systems, and compliance with Philippine building codes, the research demonstrated the potential of simulation-driven methods to enhance educational infrastructure in tropical climates. Key findings show that the proposed design reduced indoor air temperatures by 5–6 °C compared to a typical Philippine school building, while cross-ventilation and awning window strategies improved air velocity up to 2.5 m/s, expanding the thermal comfort zone across occupied hours. Solar energy integration through a 2.9 kW PV–grid–battery hybrid system achieved a 24% renewable fraction, reducing the Levelized Cost of Energy from $0.62/kWh to $0.46/kWh and yielding a favorable payback period of 5.5 years. Daylighting simulations confirmed that 75% of occupied spaces can function without artificial lighting during peak hours, improving comfort and operational efficiency. Structural analysis validated compliance with the National Structural and Building Codes of the Philippines, ensuring resilience against seismic and wind loads. Collectively, these results confirm that simulation-based sustainable design can significantly improve thermal comfort, energy efficiency, and long-term cost savings in academic facilities. The work contributes a replicable framework for designing climate-responsive educational buildings in tropical developing regions.

RECOMMENDATIONS AND FUTURE WORK

While the study demonstrates the viability of sustainable design in academic infrastructure, several limitations remain. Detailed on-site climatic data collection, cost estimation, and professional CFD/thermal audits were beyond the project's scope and are recommended for future validation. Further research should also explore:

1. Scaling up renewable penetration by integrating larger PV capacities, battery storage, and demand-side management strategies.
2. Long-term monitoring of indoor environmental quality (temperature, humidity, air quality) once constructed, to assess real-world performance against simulation results.
3. Lifecycle assessment (LCA) of materials to evaluate embodied carbon and environmental impacts beyond operational energy use.
4. Broader application of the framework across other Philippine universities, to guide national policy on sustainable campus infrastructure.

ACKNOWLEDGEMENT

The authors would like to express their gratitude to the Eastern Visayas State University – Ormoc City Campus (EVSU–OCC) for providing institutional support and resources throughout this study. Special appreciation is extended to the faculty members of the Civil Engineering Department for their technical guidance and valuable feedback during the design and simulation phases. The authors also acknowledge the assistance of colleagues who contributed insights into computational simulations and sustainable building practices.

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