Comparative Analysis of Net-Zero Energy and Well-Lit Schematic Design Layouts for Homes in Semi-Arid Regions

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Abstract: Residential buildings contribute to 21% of global energy consumption and 17% of CO_2 emissions (Citaristi, 2022). In line with 2050 climate targets, achieving net-zero energy and well-lit home design is becoming more crucial. This study evaluates two schematic layouts, including Layout 1 – Typical Design, and Layout 2 – Courtyard Home, and their energy-optimized alternatives in Amman, Jordan, a 3B ASHRAE Climate Zone. Results show that Optimized Layout 2 outperforms Optimized Layout 1, achieving net-positive energy, and well-lit design outcomes. This study offers a scalable model for semi-arid contexts, adaptable to local regulations and user needs while supporting the broader goals for universal renewable energy access.

Keywords: Net-zero energy, daylighting, residential, schematic design, semi-arid.

1. Introduction

The architectural design layout can enhance or hinder buildings' energy efficiency and daylighting (Kamel et al., 2024; Godin et al. 2021). Conducting early-stage simulations of schematic layouts enables architects to make informed design decisions that influence first and operational costs while optimizing geometry, massing, and orientation to enhance energy efficiency and long-term resilience (Nahan, 2019). This study proposes an innovative, ready-to-use workflow that integrates Ladybug, ClimateStudio, and Sefaira tools to evaluate energy and daylighting performance of two proposed layouts with their optimized alternatives for a home in a 3B (warm-dry, ASHRAE) climate zone, and Csa (hot-summer Mediterranean, Köppen) classification. While existing methods often evaluate daylighting and energy separately or after schematic phases, this paper allows informed trade-off decisions across multiple alternatives in conceptual design phases. It investigates the following question, *to what extent can the schematic design layout enhance or hinder net-zero energy and daylighting goals for homes in semi-arid climates?*

1.1. Climatic Analysis Summary of Amman, Jordan

The project site is in northern Amman. The area experiences four distinct seasons. The dry summer season (May to September) has 40-53% relative humidity, average temperatures between 71°-78° F, and west and northwest winds of 8.7 mph. The winter season (December to February) has 66-76% relative humidity, average temperatures between 46°-52° F, and southwest winds of 8.5 mph (Fig.1). The spring and fall seasons (March to April, and October to November) are moderate with average temperatures between 55°-68° F. Daily temperatures can drop to 40° F in January and rise to 92° F in

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July. The total annual heating degree days (HDD 60° F) are 1577, and cooling degree days (CDD 75° F) are 793.

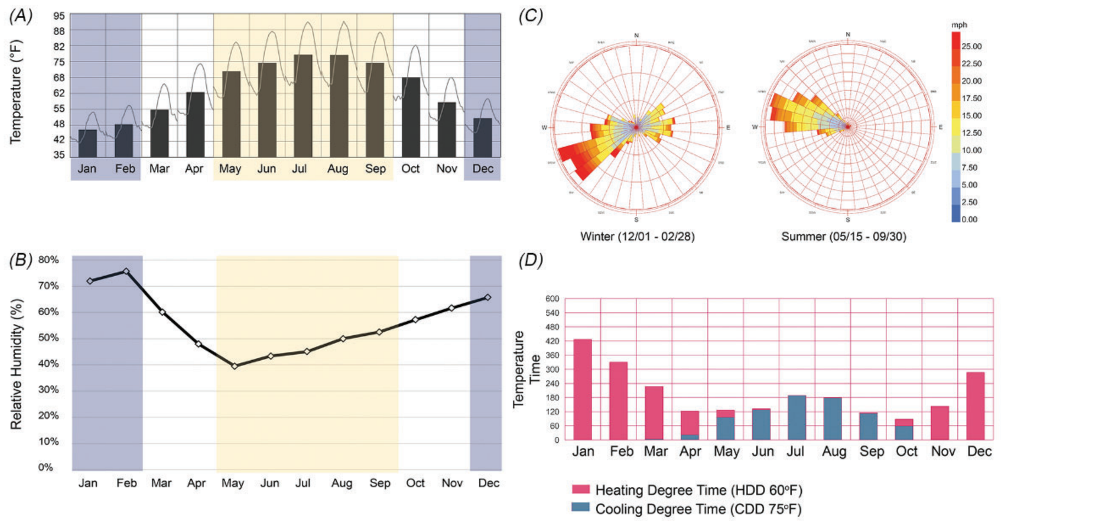

Fig. 1: (A): Mean monthly dry-bulb temperatures (bar graphs) with per-hour temperatures (curves), yellow highlighted for summer, and blue for winter. (B): Mean monthly relative humidity, yellow highlighted for summer, and blue for winter. (C): Wind rose plots for Winter (left), and Summer (right), (D): Monthly heating and cooling degree days. Weather data: Amman- Alia International Airport (TMYx), source: climate.onebuilding.org, graphs generated using Ladybug Tools for Rhino, and Excel.

2. Methods and Approach

The methodology of this study involves the following five phases, Space Planning and Building Description, Baseline Analysis, Passive Design Enhancements, Active Design, and Comparative Analysis. The land has a trapezoid shape of 8,858 sq. ft (823 m²), a buildable area of 45%, and northern street access. The two proposed alternatives include Layout 1, which is a 3-bedroom, 4-bathroom residence of 2,916 ft^2, and Layout 2, which is a 4-bedroom, 4-bathroom home offering 3,424 ft^2. Typical wall assemblies consist of 4” brick, 1.5” extruded polystyrene (thermal insulation), 4.75” lightweight concrete, and 2” white stone -from interior to exterior- meeting R-10 ft²·h·°F/Btu per national code (ASHRAE 90.1-2013 compliant). Roofs use 6” reinforced concrete with waterproofing and thermal insulation, achieving R-14. The baseline applies the code’s minimum requirement, and the optimized alternatives exceed it by applying the following strategies.

- Passive envelope design, e.g., high-performance walls (R-25), roofs (R-26), and windows (U-value = 0.10 Btu/(ft^2.h.°F), SHGC = 0.20).
- Shading devices, optimized for each window orientation.
- Efficient lighting, e.g., optimized daylighting strategies, use of LEDs, and reducing the lighting power density from 0.9 W/ft^2 to 0.5 W/ft^2.
- Extending the thermal comfort range by adjusting the thermostat setpoints from (65 to 60°F for heating, and 77 to 80°F for cooling), while promoting cross-ventilation through an open-plan layout with operable openings on opposing façades aligned with summer winds, and enabling night-flush ventilation.

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- Solar system with 16 polycrystalline silicon panels in four arrays, tilted 25° south, with panel efficiency 14-16%, and two capacity options: 3.5 kW (220 W panels, cheaper) and 5 kW (315 W panels, more efficient); site receives 3072 sunshine hours/year.

The study utilizes multiple software programs to model and simulate the different layouts, e.g., SketchUp, Sefaira, Rhino, Ladybug Tools, and ClimateStudio. Eventually, we conduct a comparative analysis using annual metrics, e.g., energy use intensity (EUI), spatial daylight autonomy (sDA $_{300\ lux/50\%}$), and spatial daylight glare (sDG>5%). Occupancy, lighting, and equipment schedules followed Sefaira's default residential profile, and daylighting simulations followed the LEED Daylight credit settings.

3. Results and Discussion

We simulate annual energy consumption of the two baseline layouts using Sefaira for SketchUp. Layout 1 has an EUI of 22 kBtu/ft^2/yr and Layout 2 has an EUI of 23 kBtu/ft^2/yr (Fig. 2, Fig. 3). After applying four passive strategies – envelope upgrades with high performance walls and roofs, shading, efficient lighting, and better thermostat controls – EUI drops to 13, and 14; respectively. Daylighting performance, analyzed in ClimateStudio, shows sDA and sDG of 83%, 13.8% for Layout 1, and 89% / 5.4% for Layout 2. In optimized layouts, sDA and sDG drop to 73.2%, 6.5% for optimized Layout 1, and 81.5 %, 1.1% for optimized Layout 2. Although sDA is reduced with added shading, the elimination of direct sunlight also lowers glare risk. This underscores a common passive design trade-off: improvements in visual comfort and energy performance may reduce daylighting availability but enhance its uniformity and diffusion within the space.

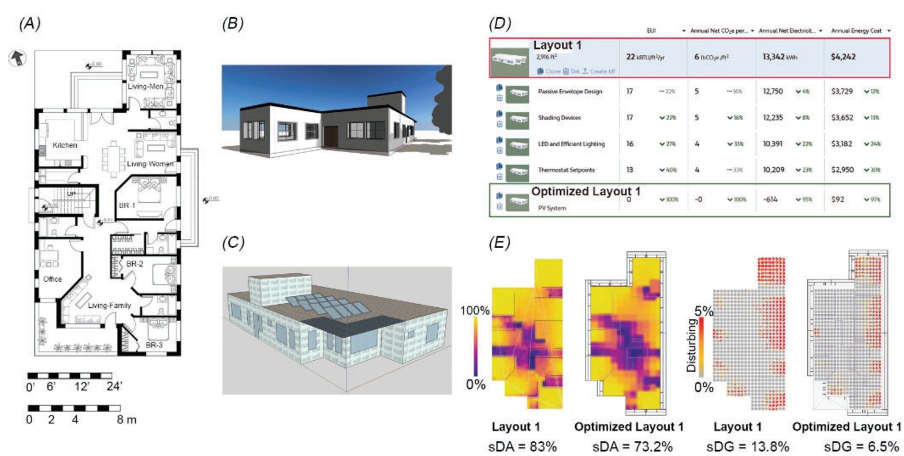

Fig. 2: (A): Layout 1 floor plan, (B) Northwest view of Layout 1 generated using Revit, (C) Southwest view of optimized Layout 1 generated using Sefaira and SketchUp, (D) Cumulative analysis of energy consumption and CO_2 emissions for Layout 1 and optimized Layout 1 generated using Sefaira Web. Note: energy cost is $0.28 per kWh. (E) Spatial daylight autonomy (sDA) and spatial daylight glare (sDG) of Layout 1 and optimized Layout 1 generated using Climate Studio.

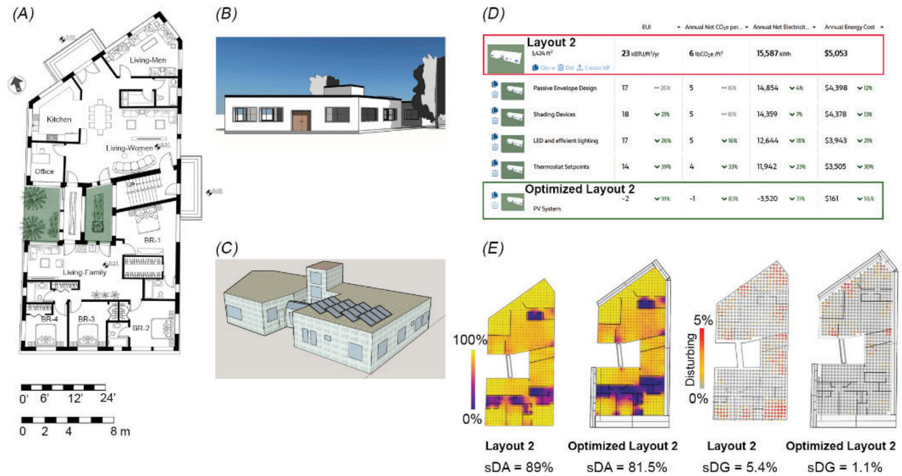

Fig. 3: (A): Layout 2 floor plan, (B) Northwest view of Layout 2 generated using Revit, (C) Southwest view of optimized Layout 2 generated using Sefaira and SketchUp, (D) Cumulative analysis of energy consumption and CO_2 emissions for Layout 2 and optimized Layout 2 generated using Sefaira Web. Note: energy cost is $0.28 per kWh. (E) Spatial daylight autonomy (sDA) and spatial daylight glare (sDG) of Layout 2 and optimized Layout 2 generated using Climate Studio.

4. Conclusions

This research presents a combined simulation approach for evaluating energy and daylighting, while incorporating four passive design strategies to reduce EUI, and an active PV system. Moreover, including an outdoor courtyard which expanded the building perimeter, allowed an improved daylighting access (window-to-wall ratio increase from 21% to 25%), and enhanced cross ventilation. The proposed approach offers practical steps for designing homes in arid and mixed climate contexts with transferable strategies, e.g., courtyard integration, orientation-based window placements, and extending the thermal comfort range. This paper offers a workflow to advance net-zero, well-lit home design and promote universal renewable energy access.

5. Acknowledgments

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6. References

Citaristi, I. (2022). International Energy Agency—IEA. In *The Europa directory of international organizations 2022* (pp. 701-702). Routledge.

Godin, K., Sapinski, J. P., & Dupuis, S. (2021). The transition to net zero energy (NZE) housing: An integrated approach to market, state, and other barriers. *Cleaner and Responsible Consumption, 3*, 100043. https://doi.org/10.1016/j.clrc.2021.100043.

Kamel, T. M., Khalil, A., Lakousha, M. M., Khalil, R., & Hamdy, M. (2024). Optimizing the View Percentage, Daylight Autonomy, Sunlight Exposure, and Energy Use: Data-Driven-Based Approach for Maximum Space Utilization in Residential

 https://doi.org/10.52202/083252-0003

Building Stock in Hot Climates. *Energies, 17*(3), 684. https://doi.org/10.3390/en17030684.

Nahan, R. T. (2019). *Architect's guide to building performance: Integrating performance simulation in the design process.* American Institute of Architects.