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The impact of regenerative design solutions on indoor temperature and daylight access in a medium-rise residential building in a tropical city—A case study in Jakarta, Indonesia

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Abstract: Regenerative design is a new paradigm that goes beyond simply reducing negative impacts. This study explored the impact of regenerative design solutions on indoor thermal and daylight performance in a medium-rise residential building in Jakarta, Indonesia under current and future climate scenarios. Using DesignBuilder simulation, the study assessed passive ventilation, window side fins, light shelves, green roofs, and photovoltaic systems. Results showed significant improvements in thermal comfort, with up to 94% of days meeting ASHRAE-55 standards in the 2020s (A2 scenario). However, by the 2080s (A2 scenario), energy analysis showed that photovoltaic panels could only cover up to 30% of cooling demand for an eight-hour operation. Moreover, the useful daylight illuminance level decreased by up to 61.4% in the 2020s (A2 scenario). The study highlights the potential of positive energy in a free-running building with integrated photovoltaic green roofs and suggests further research on various regenerative design solutions effects.
Keywords: Regenerative design, thermal comfort, daylight, and renewable energy.

1. Introduction

Regions with hot climates are disproportionately impacted by climate change, leading to increased indoor overheating in buildings (Rodriguez and D'Alessandro, 2019). Indonesia, situated within tropical rainforest climate zone (Lapisa *et al.*, 2022), faces significant challenges in maintaining indoor thermal comfort due to high temperatures and humidity, which can cause discomfort and health issues, such as heat stress (Abdel-Ghany et al., 2013). Additionally, tendencies to build landed housing and low-density residential in Jakarta contributes to dispersed developments and urban sprawling (Pratama *et al.*, 2022), exacerbating the urban heat island effect (Jumadi *et al.*, 2024).

Paradigms in the built environment have been shifting from sustainability and net zero into regenerative approaches (Mang and Reed, 2012). Regenerative design in the built environment context offers a holistic approach where all living systems interact in a mutually beneficial process (Reed, 2007). Rather than suggesting that a building is self-sufficient or healing, regenerative design acts as a catalyst for positive transformation (Cole, 2012). Integrating regenerative solutions into the built environment has proven effective in addressing climate change challenges (Agboola *et al.*, 2024).

This study aims to evaluate the feasibility of regenerative design in a typical medium-rise residential building in Jakarta, Indonesia. The research will assess the effectiveness of these designs in enhancing indoor thermal and visual comfort while reducing energy consumption from mechanical air conditioning systems under both current and future climate conditions.

2. Literature Review

Regenerative design encompasses an approach that extends beyond buildings to include entire communities, other living organisms, and socio-economic and cultural contexts (Mang and Reed, 2012). The primary goal of regenerative design is to heal damage and restore health, emphasizing health-related solutions (Guenther, 2020). Naboni and Havinga (2019) identify three pillars of regenerative design: climate and energy, ecology and carbon, and human wellbeing. Synthesizing these ideas, regenerative design can be understood as a strategy in which the built environment acts as a catalyst for positive physical and social transformation.

A social housing complex in Bordeaux, France and The Monash University student accomodation were examples of regenerative design projects (Naboni and Havinga, 2019). The Bordeaux project incorporated new balcony to reduce indoor temperature and energy use. Meanwhile, the other utilised a renewable energy production on the rooftop, parametically designed sunshade, and no cooling systems to promote positive energy outcomes.

Although there are frameworks and assessment methods for identifying regenerative design projects, tools specific to regenerative development remain limited (Guenther, 2020). Furthermore, the evaluation of passive design strategies, particularly those related to health and wellbeing, remains underdeveloped despite the growth of green and sustainable assessment methodologies (Kujundzic et al., 2023).

Net zero energy buildings (NZEB) present an opportunity to create sustainable and healthy environments by integrating efficient and renewable energy technologies, thereby reducing energy dependence (Ohene et al., 2022). However, the implementation of NZEB in tropical regions faces significant challenges, as few such buildings have been developed in these climates. Most labelled net zero buildings are located in colder, northern hemisphere countries, suggesting limited application and discussion in warmer regions (Garde *et al.*, 2014; Oree and Anatah, 2017; Feng *et al.*, 2019; Gambato and Zerbi, 2019). Despite some exploration of regenerative projects, there is a notable absence of case studies focused on hot/tropical climates, particularly in the context of multi-storey residential buildings.

The scarcity of resources for regenerative development and the inadequacy of assessment methods in addressing critical elements such as health, wellbeing, and occupant comfort (Kujundzic et al., 2023) highlight the need for inclusive strategies that consider thermal comfort and energy consumption in hot climate regions. It is essential to develop passive-design buildings that adhere to local codes and climate characteristics (Iqbal *et al.*, 2023), particularly for high-density dwellings. Recent studies (Feng et al., 2019; Gambato and Zerbi, 2019; Naboni and Havinga, 2019) on regenerative projects underline the need to deepen the knowledge of naturally ventilated medium-rise residential buildings.

Inadequate practice of acknowledged regenerative design projects that address multi-storey residential buildings in warmer climates and the lack of passive design strategies and thermal comfort studies related to multi-storey residential buildings in Indonesia were identified as knowledge gaps for this study.

3. Methodology

This study utilized a design prototype provided by the Ministry of Public Works and Housing, Indonesia. The base model's geometry, construction, and specifications for openings were aligned with the guidelines from the Ministry. Simulations were conducted on units from three floors—1st, 5th, and 8th—of a south-facing unit in the building. The software used for simulation was DesignBuilder v7.0.2.006, incorporating future weather files for Jakarta (A2 scenario for the 2020s, 2050s, and 2080s) generated by the Climate Change World Weather File Generator Version 1.9 (Energy and Climate Change Division, 2022).

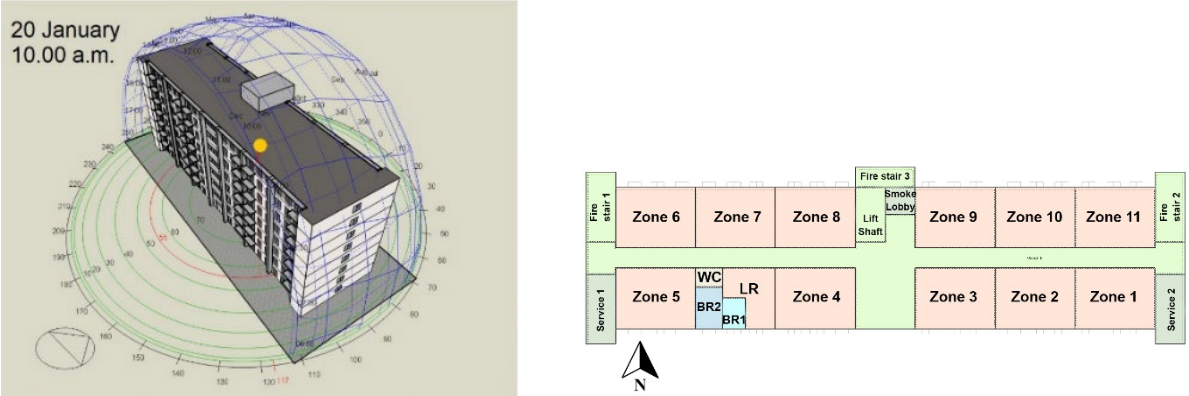

Figure 1 Baseline 3D model (left) and the site plan (right).

The study consisted of three key steps:

1. *Baseline performance analysis:* The initial step involved analyzing the performance of the baseline design across different floors under both current and future climate conditions.
2. *Design optimization:* The base model was then iteratively optimized by integrating regenerative design strategies such as cross ventilation, insulation, external window fins, light shelves, and photovoltaic green roofs.
3. *Comparative evaluation:* Last, the optimized model's performance was compared with the baseline, considering both present and future climate scenarios to assess improvements and adaptability.

Metrics for thermal comfort and daylight access were evaluated. Thermal comfort was assessed using the ASHRAE55 (2023) adaptive model, while daylight performance was measured through climate-based daylight modeling (CBDM), specifically useful daylight illuminance (UDI) and spatial daylight autonomy (sDA). The daylight analysis focused on occupied hours from 8 a.m. to 6 p.m.

Energy generation was also simulated using DesignBuilder. The PV system on the rooftop consisted of 24 arrays, each with 10 panels (2m² per panel), totaling 480m² of surface area and operating at a constant efficiency of 15%. The simulation targeted a typical warm week (October 8th to 15th), with an average outdoor temperature of 28.9°C, comparing the energy performance of the baseline and optimized models over an 8-hour cooling period from 10 am to 6 pm.

Table 1 Building fabric thermal properties of baseline and optimised model.

	S0	**S7**
Roof	Flat roof R-value (m^{2}K/W): 0.47 | U-value (W/m^{2}K): 2.1	Green roof R-value (m^{2}K/W): 3.0 | U-value (W/m^{2}K): 0.3
External wall	R-value (m^{2}K/W): 0.36 | U-value (W/m^{2}K): 2.79	R-value (m^{2}K/W): 2.56 | U-value (W/m^{2}K): 0.3
Glazing type	U-value (W/m^{2}K): 5.7	U-value (W/m^{2}K): 1.27
Internal wall	R-value (m^{2}K/W): 0.36 | U-value (W/m^{2}K): 2.79	R-value (m^{2}K/W): 0.36 | U-value (W/m^{2}K): 2.79
Unit partition	R-value (m^{2}K/W): 1.42 | U-value (W/m^{2}K): 0.7	R-value (m^{2}K/W): 1.42 | U-value (W/m^{2}K): 0.7

4. Results

The base model (S0) and the optimized building model (S7) were assessed for thermal comfort and daylight performance under the A2 climate scenario for the 2020s, 2050s, and 2080s. The S7 model achieved an annual thermal comfort percentage above 90% across all examined zones in the 2020s. Specifically, thermal comfort on the 5th and 8th floors improved significantly, with the percentage of days meeting the ASHRAE-55 adaptive thermal comfort standard rising from 44% and below to approximately 90-95%. However, this dropped below 28% by the 2080s.

Daylight analysis revealed mixed results. The Useful Daylight Illuminance (UDI) 80% metric decreased across most zones, except for the 5th-floor bedroom-1 zone, where UDI 80% increased dramatically from 19% to 98% in the optimized model. Conversely, the 5th floor bedroom-2 and living room zones experienced slight decreases in UDI 80%, from 74% and 57% to 69% and 22%, respectively. Spatial Daylight Autonomy (sDA) showed a significant decline in the optimized model, with the 5th floor bedroom 1 zone's sDA dropping from 100% to 41%, bedroom-2 from 96% to 18%, and the living room from 35% to 6%.

Table 2 Annual number of days of achieving ASHRAE-55 2023 adaptive thermal comfort (A2 scenario) – baseline (S0) and optimised model (S7).

Zones	S0						S7					
	2020s		2050s		2080s		2020s		2050s		2080s	
	n	%	n	%	n	%	n	%	n	%	n	%
1F-BR1	294	81%	262	72%	194	53%	365	100%	365	100%	353	97%
1F-BR2	314	86%	277	76%	212	58%	365	100%	365	100%	361	99%
1F-LR	365	100%	365	100%	362	99%	365	100%	365	100%	362	99%
5F-BR1	84	23%	17	5%	2	1%	346	95%	282	77%	103	28%
5F-BR2	70	19%	9	2%	1	0%	336	92%	253	69%	79	22%
5F-LR	159	44%	33	9%	3	1%	350	96%	278	76%	100	27%
8F-BR1	6	2%	4	1%	2	1%	343	94%	267	73%	91	25%
8F-BR2	4	1%	3	1%	0	0%	329	90%	236	65%	74	20%
8F-LR	2	1%	0	0%	0	0%	347	95%	268	73%	94	26%

Energy generation analysis for the period between October 8th and 15th 2020, indicated that the S7 model produced 3,403 kWh with a total panel area of 480m², equivalent to approximately 0.89 kWh/m² per day. This output covered 31% of the cooling demand for eight hours of operation in the 2020s. However, in future scenarios, energy coverage decreased slightly from 31% in the 2020s to 30% in the 2080s, while cooling demand increased by 8.4% over the same period.

Table 3 Whole building energy generation analysis between the 8th and 15th of October 2020s (A2 scenario).

	Produced electricity per panel surface (kWh/m^2)	Produced Electricity Energy (kWh)	Cooling demand (kWh)	Coverage	Produced electricity per panel surface (kWh/m^2)
2020s	3.7	3403.0	10803.6	31%	7.1
2050s	3.8	3450.3	11511.7	30%	7.2
2080s	3.8	3494.0	11713.6	30%	7.3

5. Discussion

The regenerative design strategies implemented in this study generally enhanced indoor thermal comfort across all zones and floors. However, the study's projections for the 2080s

(A2 scenario) indicate a decline in thermal comfort, particularly on the 5th and 8th floors, with less than 30% of days achieving thermal comfort. This suggests that the strategies tested may be effective for current conditions but may fall short under future climate scenarios.

While vertical louvres found to increase UDI levels (Khidmat *et al.*, 2022), the reduction of UDI and sDA performance in this study might be attributed to the side fins size and configuration. Additionally, light shelves did not significantly distribute light evenly due to the room's shape, consistent with findings by Apriliawan et al., (2023). External window shading presented a trade-off between reducing indoor temperature and maintaining adequate daylight, negatively affecting natural light access.

The study also noted a significant rise in cooling demand, while energy generation remained relatively unchanged, highlighting a potential disparity between energy production and cooling demand. Cooling demand for S7 increased by 8.4% from the 2020s to the 2080s, while energy production rose by only 2.6%. This disparity suggests that relying solely on photovoltaic panels to meet future cooling demands, especially in a warming climate, will be challenging. On the other hand, the discrepancy might be explained by the morphed weather files that did not accurately predict the solar irradiance and exposure in future conditions.

The study acknowledges several limitations, including potential inaccuracies in input data, the use of outdated weather files, and a focus on a single design prototype with a North-South orientation. Additionally, other indoor environmental factors such as air quality and acoustics were not considered, and the assumed constant photovoltaic efficiency of 15% may not reflect real-world conditions. Future research should explore a broader range of regenerative strategies, detailed site contexts, and additional indoor environmental aspects.

The findings offer practical recommendations for policymakers, practitioners, and residents. Authorities should incorporate improved insulation, operable dual-aspect windows, advanced glazing, shading systems, and green roofs with photovoltaic panels into base design models. Practitioners can enhance green roofs with irrigation and rainwater harvesting systems, while residents are encouraged to utilise operable windows for cross-ventilation.

6. Conclusion

The implementation of regenerative design strategies can enhance thermal comfort in medium-rise residential buildings and may lead to positive energy outcomes. This study demonstrated that integrating dual-aspect cross ventilation, improved insulation, and photovoltaic green roof systems effectively improves indoor thermal comfort. However, the use of external window side fins and light shelves was found to reduce daylight access, negatively impacting visual comfort. The energy generation analysis revealed that meeting the energy demands of medium-rise residential buildings solely with photovoltaic panels will be increasingly challenging, particularly if active cooling systems are required in future climates. The study's approach and findings provide valuable references and practical recommendations for architects, designers, policymakers, academics, and building occupants.

7. References

Abdel-Ghany, A.M., Al-Helal, I.M. and Shady, M.R. (2013) 'Human Thermal Comfort and Heat Stress in an Outdoor Urban Arid Environment: A Case Study', *Advances in Meteorology*, 2013, pp. 1–7. Available at: https://doi.org/10.1155/2013/693541.

Agboola, O.P. *et al.* (2024) 'Built environment transformation in Nigeria: the effects of a regenerative framework', *Journal of Asian architecture and building engineering*, ahead-of-print(ahead-of-print), pp. 1–24. Available at: https://doi.org/10.1080/13467581.2023.2238045.

Apriliawan, I., Fadhila, N.S. and Alkadri, M.F. (2023) ‘Implementation of light shelves and WWR to improve daylight performance in university classroom’, *IOP Conference Series: Earth and Environmental Science*, 1267(1), p. 12028. Available at: https://doi.org/10.1088/1755-1315/1267/1/012028.

ASHRAE 55 (2023) *Thermal environmental conditions for human occupancy*. Peachtree Corners, GA: ASHRAE.

Cole, R.J. (2012) ‘Regenerative Design and Development: Current Theory and Practice’, *Building research and information: The international journal of research, development and demonstration*, 40(1), pp. 1–6. Available at: https://doi.org/10.1080/09613218.2012.617516.

Energy and Climate Change Division, U. of S. (2022) *Climate Change World Weather File Generator for World-Wide Weather Data – CCWorldWeatherGen*. Available at: https://energy.soton.ac.uk/ccworldweathergen/ (Accessed: 6 August 2024).

Feng, W. *et al.* (2019) ‘A review of net zero energy buildings in hot and humid climates: Experience learned from 34 case study buildings’, *Renewable & sustainable energy reviews*, 114(C), p. 109303. Available at: https://doi.org/10.1016/j.rser.2019.109303.

Gambato, C. and Zerbi, S. (2019) ‘The regenerative building: A concept of total sustainability’, *IOP Conference Series: Earth and Environmental Science*, 323(1), p. 012061. Available at: https://doi.org/10.1088/1755-1315/323/1/012061.

Garde, F. *et al.* (2014) ‘Design of Net Zero Energy Buildings: Feedback from International Projects’, *Energy Procedia*, 61, pp. 995–998. Available at: https://doi.org/10.1016/j.egypro.2014.11.1011.

Guenther, R. (2020) ‘Regenerative Architecture: Redefining Progress in the Built Environment’, in *Architecture and Health*. 1st edn. Routledge, pp. 280–295. Available at: https://doi.org/10.4324/9780429021169-20.

Iqbal, M. *et al.* (2023) ‘Performance Improvement Plan towards Energy-Efficient Naturally Ventilated Houses in Tropical Climate Regions’, *Sustainability*, 15(16), p. 12173. Available at: https://doi.org/10.3390/su151612173.

Jumadi *et al.* (2024) ‘Influence of urban growth on urban heat island phenomenon around Jakarta, Indonesia: Insight from Depok and South Tangerang city’, *IOP Conference Series: Earth and Environmental Science*, 1291(1), p. 12001. Available at: https://doi.org/10.1088/1755-1315/1291/1/012001.

Khidmat, R.P. *et al.* (2022) ‘Comparison of Daylight Performance in Three Different Sky Conditions for Various Window Shading Types’, *IOP Conference Series: Earth and Environmental Science*, 1058(1), p. 12010. Available at: https://doi.org/10.1088/1755-1315/1058/1/012010.

Kujundzic, K., Stamatovic Vuckovic, S. and Radivojević, A. (2023) ‘Toward Regenerative Sustainability: A Passive Design Comfort Assessment Method of Indoor Environment’, *Sustainability (Basel, Switzerland)*, 15(1), p. 840. Available at: https://doi.org/10.3390/su15010840.

Lapisa, R. *et al.* (2022) ‘Optimized Design of Residential Building Envelope in Tropical Climate Region: Thermal Comfort and Cost Efficiency in an Indonesian Case Study’, *Journal of architectural engineering*, 28(2). Available at: https://doi.org/10.1061/(ASCE)AE.1943-5568.0000529.

Mang, P. and Reed, B. (2012) ‘Designing from place: a regenerative framework and methodology’, *Building research and information : the international journal of research, development and demonstration*, 40(1), pp. 23–38. Available at: https://doi.org/10.1080/09613218.2012.621341.

Naboni, E. and Havinga, L. (2019) *Regenerative Design In Digital Practice. A Handbook for the Built Environment.* Eurac Research. Available at: https://www.researchgate.net/publication/336121907_Regenerative_Design_In_Digital_Practice_A_Handbook_for_the_Built_Environment (Accessed: 20 June 2024).

Ohene, E., Hsu, S.-C. and P. C. Chan, A. (2022) ‘Feasibility and retrofit guidelines towards net-zero energy buildings in tropical climates: A case of Ghana’, *Energy and buildings*, 269, p. 112252. Available at: https://doi.org/10.1016/j.enbuild.2022.112252.

Oree, V. and Anatah, H.K. (2017) ‘Investigating the feasibility of positive energy residential buildings in tropical climates’, *Energy efficiency*, 10(2), pp. 383–404. Available at: https://doi.org/10.1007/s12053-016-9462-7.

Pratama, A.P. *et al.* (2022) ‘Highway expansion and urban sprawl in the Jakarta Metropolitan Area’, *Land use policy*, 112, p. 105856. Available at: https://doi.org/10.1016/j.landusepol.2021.105856.

Reed, B. (2007) ‘Shifting from “sustainability” to regeneration’, *Building research and information : the international journal of research, development and demonstration*, 35(6), pp. 674–680. Available at: https://doi.org/10.1080/09613210701475753.

Rodriguez, C.M. and D’Alessandro, M. (2019) ‘Indoor thermal comfort review: The tropics as the next frontier’, *Urban climate*, 29, p. 100488. Available at: https://doi.org/10.1016/j.uclim.2019.100488.