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Research Article

Thermal, Visual, and Acoustic Comfort Assessment in Sustainable Elementary School Classrooms: A Case Study at SD Negeri 8 Ragunan, Jakarta

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Abstract

This research investigates the environmental comfort conditions thermal, visual, and acoustic in six functional spaces at SD Negeri 8 Ragunan, South Jakarta, a public elementary school recognized for its sustainability-focused infrastructure. The study emphasizes the relevance of indoor environmental quality in shaping students' cognitive performance, well-being, and overall learning experience. A mixed-methods design was employed, combining quantitative field measurements with qualitative spatial analysis. Data collection included temperature (28.5°C–32.1°C), relative humidity (65%–78%), light intensity (263–712 lux), and sound levels (41.3–64.5 dBA), measured in four classrooms, one hall, and one teachers' room. Qualitative data involved architectural observations on ventilation, daylight access, and environmental policy signage. Results were benchmarked against Indonesian national standards (SNI 6390:2011, SNI 6197:2020, SNI 6386:2000) and international guidelines (ASHRAE 55-2017, GBCI). Findings indicate that temperature and illumination were within permissible thresholds, and visual connectivity reached 94.83%, exceeding GBCI's 75% standard. However, humidity levels consistently surpassed the 60% threshold, and noise levels occasionally exceeded recommended limits, particularly in rooms near traffic exposure. Moreover, anti-smoking signage was insufficient and inconsistently placed. These results highlight the need for integrated environmental management strategies in school buildings. The study contributes to the discourse on sustainable educational facilities and supports the implementation of SDG 4 (Quality Education) and SDG 11 (Sustainable Cities and Communities), particularly in rapidly urbanizing tropical regions.

Keywords: *Acoustic Quality; Indoor Enviromental Quality; Sustainable School; Thermal; Visual*

INTRODUCTION

Ensuring a healthy and comfortable indoor environment is a foundational requirement for promoting optimal learning, particularly at the elementary school level where cognitive development and psychological well-being are highly sensitive to physical surroundings. In the context of tropical urban regions such as Jakarta, educational facilities are frequently challenged by elevated ambient temperatures, persistent humidity, and inconsistent access to natural daylight [1], [2]. In the context of tropical urban regions such as Jakarta, educational facilities are frequently challenged by elevated ambient temperatures, persistent humidity, and inconsistent access to natural daylight [3]. A growing body of research in environmental psychology and educational architecture has consistently demonstrated that thermal, visual, and acoustic comfort are closely associated with academic performance, behavioral regulation, and emotional health among school-aged children [4], [5]. Noise exposure, particularly from motor vehicle traffic, has also been reported as a significant contributor to reduced classroom comfort and learning quality [6]. Consequently, the physical environment within schools must be deliberately designed and routinely assessed to support learning efficacy and student development.

In response to the global momentum toward sustainable development, there has been a notable shift in educational infrastructure planning toward environmentally responsible and child-centered design approaches [7], [8], [9]. The adoption of passive design strategies such as maximizing natural ventilation, optimizing daylight entry, and minimizing heat gain has become a core element in school development policies [10], [11], [12]. These strategies are further reinforced by international frameworks, such as the Sustainable Development Goals (SDGs), specifically SDG 4, which promotes inclusive and equitable quality education, and SDG 11, which advocates for safe and sustainable urban environments. SD Negeri 8 Ragunan, a public elementary school situated in South Jakarta, exemplifies a local effort to translate these global mandates into practice. The school features architectural configurations including large operable windows, room partitioning for airflow control, and building orientation aligned with solar paths, all of which aim to enhance indoor environmental quality. Such infrastructural efforts are complemented by institutional policies promoting clean air and healthy spaces, such as the establishment of smoke-free zones.

Nevertheless, the extent to which these design interventions and policies translate into measurable environmental comfort remains insufficiently explored. While physical elements may conform to green design principles, their actual performance in supporting acceptable temperature, humidity, illumination, and noise levels requires empirical verification [12], [13]. Moreover, existing regulatory benchmarks such as the Indonesian National Standards (SNI 6390:2011 for thermal comfort, SNI 6197:2020 for lighting, and SNI 6386:2000 for acoustic conditions) provide explicit thresholds, yet compliance in real-world educational settings is not consistently monitored or reported. Additionally, health-promoting policies such as the Kawasan Tanpa Rokok (smoke-free zones) often lack systematic evaluation in terms of implementation effectiveness within school environments. Without rigorous data collection and integrated assessment models, there is a risk of overestimating the efficacy of built infrastructure in delivering the desired educational and environmental outcomes.

While extensive reviews have been conducted on thermal comfort models [14], [15] and the evolution of adaptive comfort theory in response to global climate demands, the majority of studies are concentrated on adult-centric environments such as hospitals [16], residential buildings [17], and commercial offices [18]. Research on indoor environmental quality (IEQ) has also gained momentum, focusing on its effects on cognitive performance [19], risk factors from retrofitted housing [20], and parameter modeling using machine learning and simulation [21], [22]. However, very few of these investigations address educational settings, and even fewer are dedicated to elementary schools in tropical developing regions. Studies that examine visual comfort tend to focus on university contexts [23] or energy-saving technologies [24], while acoustic comfort is often embedded within broader IEQ reviews without specific emphasis on its role in early-age learning environments. Furthermore, although tools such as pythermalcomfort and the CBE Thermal Comfort Tool [24] have advanced computational capabilities, their application in field-based classroom studies remains limited. This fragmentation underscores a significant research gap in holistic, in-situ evaluations of thermal, visual, and acoustic comfort in elementary classrooms particularly those that integrate spatial configuration, passive design strategies, and school-level policy enforcement (e.g., no-smoking zones), within the framework of national standards and SDG-linked sustainability mandates.

This study aims to evaluate the extent to which the indoor environments of classrooms at SD Negeri 8 Ragunan fulfill nationally and internationally recognized standards for thermal, visual, and acoustic comfort. It also seeks to examine the spatial suitability and implementation of smoke-free policies, offering a comprehensive analysis that can inform future planning of sustainable and health-supportive educational facilities in urban tropical settings.

METHODS

Reasearch Design

This study adopted a mixed-methods approach that integrates both quantitative and qualitative data collection and analysis techniques. The quantitative aspect involved direct measurements of key environmental parameters, while the qualitative aspect focused on spatial observations and policy compliance related to indoor environmental quality. This design was chosen to allow a more comprehensive understanding of comfort performance in real-time classroom conditions, aligning with the practical complexities of elementary school environments.

Study Location and Scope

The research was conducted at SD Negeri 8 Ragunan, an elementary public school in South Jakarta, Indonesia, which has implemented architectural strategies aimed at achieving environmental sustainability. The study covered three primary spatial typologies within the school:

(1) classrooms used for daily instructional activities, (2) the teacher's office representing administrative space with mechanical conditioning, and (3) a large multipurpose hall designed for assemblies and physical gatherings. These spaces were selected to represent a range of functional indoor environments commonly found in educational institutions.

Figure 1. SD Negeri 8 Ragunan, Jakarta

Instruments and Tools

Environmental parameters were measured using accessible and practical tools:

- Temperature and Relative Humidity: Measured using a calibrated smartphone application integrated with a digital sensor. While this method offers rapid deployment, it is subject to limitations in precision, particularly under prolonged exposure to heat-emitting surfaces. To mitigate this, measurements were taken under stable conditions and cross-checked with external thermohygrometric references where available.
- Illuminance: Light intensity was measured using a digital lux meter, with readings taken at multiple positions across each room—both horizontally at desk level (approximately 80 cm from the floor) and vertically at the board level—to capture variation in lighting distribution from natural and artificial sources.
- Sound Level: Acoustic data were collected using a sound level meter, capable of capturing noise fluctuations in decibels (dBA) over time. Measurements were taken during active teaching sessions to reflect peak exposure conditions.

All measurement results were analyzed by comparing them to relevant Indonesian National Standards (SNI), specifically:

- SNI 6390:2011 for recommended classroom temperature and humidity (24–27°C; RH 60%)
- SNI 6197:2020 for illuminance levels (minimum 350 lux with CRI ≥80),
- SNI 6386:2000 for acceptable classroom noise levels (40–55 dBA).

Observational Framework

To complement the instrument-based data, structured observations were conducted to document the school's architectural features and policy enforcement practices. This included:

- Ventilation System Evaluation: Analysis of natural ventilation design (window size, position, cross-ventilation potential), presence of mechanical air conditioning, and flexibility of room partitioning that may affect airflow.
- Spatial Adequacy Assessment: Calculations of student space per person (m^2/student) based on floor plans, evaluated against the minimum requirement of 2.00 m^2/student set by national infrastructure standards (Permendikbudristek No. 22 Tahun 2023).
- Smoke-Free Policy Compliance: Field inspection for smoke-free signage in student-access areas (e.g., corridors, classrooms, staff rooms), with documentation of placement, visibility, and supporting communication materials such as posters or announcements.

Observations were recorded through field notes, photographic documentation, and manual sketches. Where applicable, data were cross-referenced with architect-issued building layouts and prior sustainability audit reports.

Data Collection Procedure

Data collection was conducted during a regular school day to ensure environmental readings reflect actual conditions experienced by students and teachers. The procedure followed these steps:

1. Timing: Measurements were taken at three intervals—morning (08:00–09:00), midday (11:30–12:30), and afternoon (14:00–15:00)—to account for diurnal variation in sunlight, temperature, and occupancy.
2. Sampling Points: At least five sampling points per room were used for temperature, humidity, and lux measurements to capture spatial variability. Noise levels were monitored continuously for 15-minute intervals using data logging mode.
3. Environmental Conditions: Conditions such as window status (open/closed), artificial lighting use, and AC operation were recorded to contextualize each data point.

Data Analysis

The collected quantitative data were tabulated, cleaned, and analyzed using descriptive statistics. Key values such as mean, minimum, and maximum were calculated for each parameter across all rooms. These values were then compared to relevant regulatory thresholds. Qualitative data from spatial observations were analyzed thematically to identify (1) the effectiveness of passive design elements, (2) potential conflicts between user behavior and design intent, and (3) the visibility and enforcement of health-related school policies. Findings were triangulated across data types to enhance validity and produce holistic interpretations of the indoor environmental quality (IEQ) performance.

RESULT AND DISCUSSIONS

Indoor Vertilation and Air Conditioning Design

The architectural layout of SD Negeri 8 Ragunan demonstrates a clear intention to incorporate passive design strategies that enhance thermal comfort through natural ventilation. Classrooms are equipped with six operable windows and upper wall ventilation grilles, promoting both horizontal and vertical air circulation. The presence of openings at opposing wall sides encourages cross-ventilation, a principle widely recognized in tropical climate architecture for reducing indoor heat buildup and enhancing airflow efficiency. In addition, the building's orientation minimizes direct solar exposure on fenestration, effectively maintaining a cool indoor microclimate while reducing reliance on mechanical air conditioning systems.

Measured against national standards, the spatial arrangement proves compliant. Referring to Permendikbudristek No. 22/2023, which mandates a minimum classroom area of 2 m² per student, the 8x8 m² classrooms serving 30 students yield an individual space allocation of 2.13 m², slightly surpassing the minimum threshold. This spatial adequacy is essential not only for comfort but also to allow optimal air movement within the classroom. Furthermore, based on the Indonesian National Standard (SNI) 03-6572-2001 regarding ventilation, the classroom provides a ventilation opening area of approximately 3.5 m²—equivalent to 5.46% of its total floor area—thus meeting the minimum requirement of 5%. This empirical evidence confirms that the school facilities provide an acceptable level of thermal comfort and satisfy regulatory norms for air quality and air exchange.

The design of the school hall further reflects these principles. With a size of 8x16 meters, it benefits from cross-ventilation on three sides (east, west, and south), with large ventilation panels on the upper sections of the east and west walls, and decorative masonry blocks (roster) on the south wall serving dual functions—enhancing airflow while contributing aesthetic value. Such integration of ventilation and spatial openness is consistent with energy-efficient architectural standards for communal learning environments.

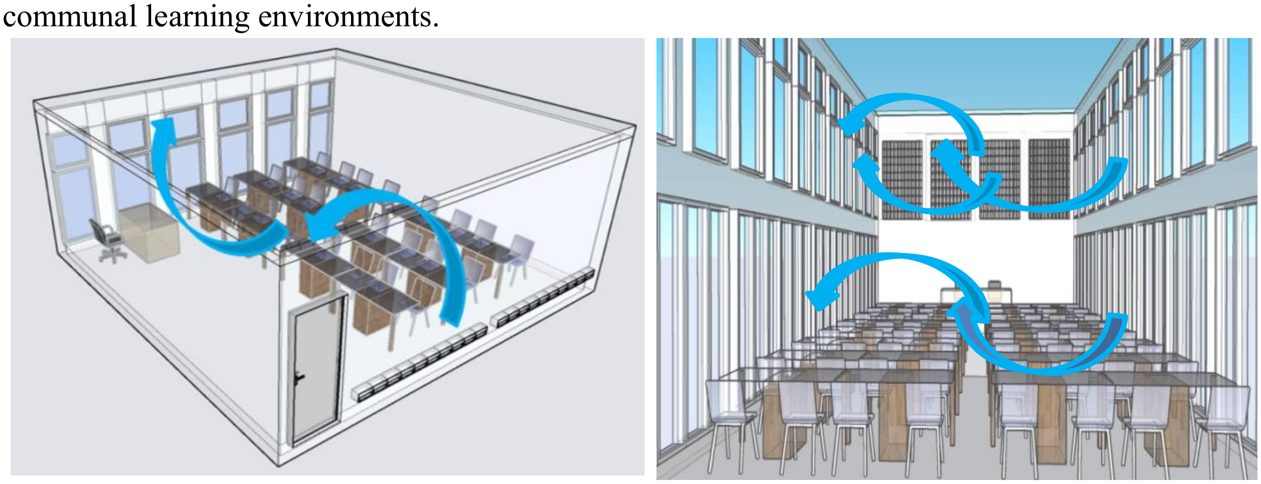


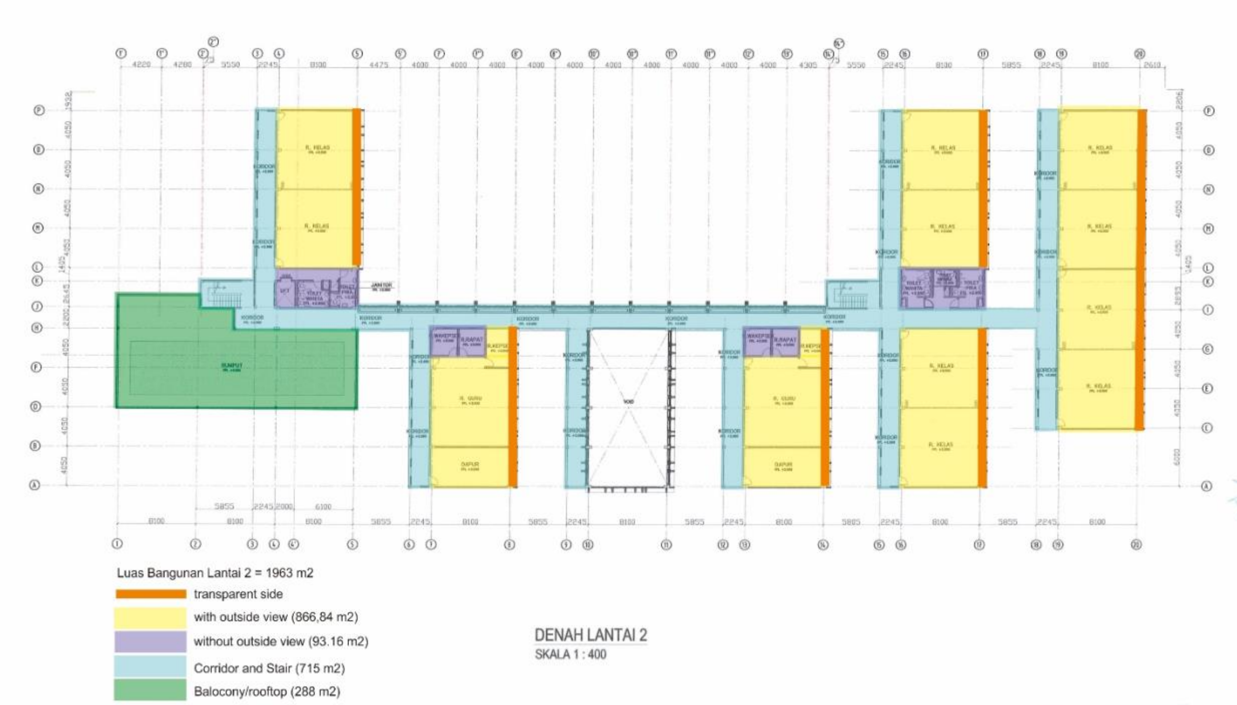
Figure 2. Ventilasi dan Pengkondisian Udara Ruang Kelas dan Aula

Visual Comfort and Daylighting

Visual comfort within learning environments directly impacts students' concentration, mood, and academic engagement. Classrooms at SD Negeri 8 Ragunan allow abundant daylight through strategically placed windows and limited eastern solar exposure, reducing glare while ensuring sufficient illuminance in the morning hours. The integration of daylighting strategies, without relying on artificial lighting during daytime, contributes to energy efficiency and visual well-being.

Moreover, the spatial distribution of transparent openings across the building significantly enhances the connection between indoor and outdoor environments. Referring to the Green Building Council Indonesia (GBCI) visual comfort criteria, a minimum of 75% of the Net Lettable Area (NLA) should provide outdoor views via transparent apertures. Analysis reveals that the school building achieves 94.83% transparent openings relative to the total NLA—exceeding the GBCI benchmark. The breakdown across floors shows consistency: 93.01% on the first floor, 95.25% on the second, and 96.45% on the third. These findings underline the building's exemplary adherence to green design principles, supporting both natural lighting and psychological comfort through maintained visual connectivity to the external environment.

This elevated daylight exposure not only aligns with global sustainable building standards but also provides indirect benefits to student performance and mental alertness, as substantiated by prior research in educational architecture and neuroscience. The absence of visual obstructions and the integration of panoramic openings foster a brighter and more engaging learning space, contributing to long-term academic effectiveness and positive student behavior.



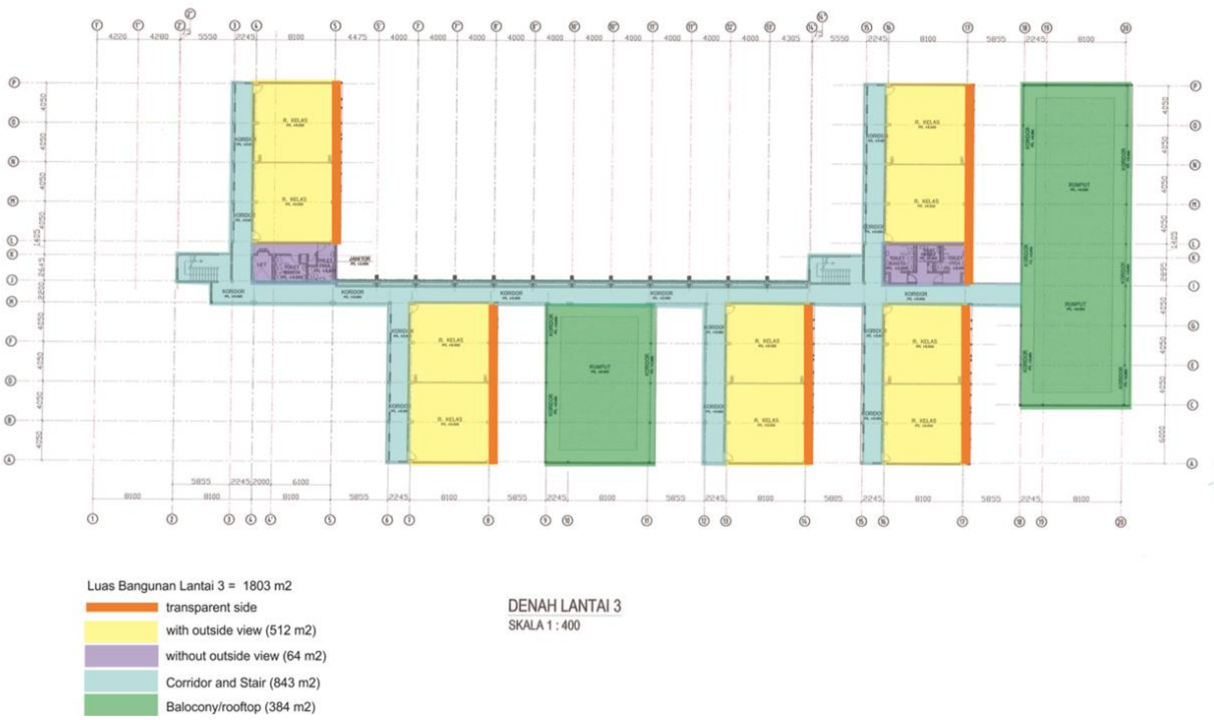


Figure 3. Classroom in SD Negeri 8 Ragunan, Jakarta

Table 1. Parameter Condition in SD Negeri 8 Ragunan, Jakarta

Floor	Area (m2)	Outside View	Without Outsite View	Corridor and Stair	Balcony and Rooftop	Visual Outside	Persentase
I	2091	1010	146	935	-	1945	93.01%
II	1963	866.84	93.16	715	288	1869.84	95.25%
III	1803	512	64	834	384	1739	96.45%
Total	5857	2388.84	303.16	2493	672	5553.84	94.83%

Acoustic Enviroment

In addition to thermal and visual factors, acoustic quality is a pivotal component of a conducive learning environment. High background noise levels, whether from outdoor sources or reverberations within a room, have been shown to hinder verbal communication, reduce speech intelligibility, and negatively impact student concentration and memory retention. Although detailed sound level measurements were not provided in the current assessment, qualitative observations suggest that the architectural features including openable partitions, window arrangements, and room orientations may contribute to both sound propagation and attenuation.

The partitionable walls in classrooms offer flexible spatial configurations; however, they may also pose a risk of increased sound leakage between adjacent rooms if not properly insulated. Therefore, future acoustic evaluations should include measurements of reverberation time, background noise levels, and speech transmission indices to ensure compliance with accepted educational acoustic standards (e.g., ANSI/ASA S12.60). Incorporating sound-absorbing materials on ceilings and walls may further enhance auditory comfort, particularly in larger spaces such as the school hall.

Discussion

Based on the evaluation of the spatial and environmental design of SD Negeri 8 Ragunan, it is evident that the school has successfully integrated passive architectural strategies to support thermal, visual, and acoustic comfort in alignment with national regulations and green building principles. The classrooms, designed with optimal window placement and dual ventilation paths, not only exceed the minimum area requirement of 2 m^2 per student as stipulated in Permendikbudristek No. 22 of 2023, but also fulfill the minimum 5% ventilation opening standard outlined in SNI 03-6572-2001. This indicates a strong commitment to maintaining indoor air quality through natural ventilation, thereby reducing dependence on mechanical cooling systems and contributing to lower operational energy use.

Furthermore, the strategic orientation of the building and extensive use of transparent openings have resulted in a daylight penetration rate of 94.83% across the net lettable area, surpassing the 75% visual connectivity benchmark set by the Green Building Council Indonesia. This not only enhances visual comfort but also reinforces psychological well-being and circadian alignment through consistent exposure to natural light [25], [26]. From an acoustic perspective, while quantitative data on noise levels are not yet available, the flexible room partitions and open-plan configurations suggest both opportunities and challenges for sound control, underscoring the need for future research using standardized acoustic metrics such as SNI 03-6386-2011 or ISO 3382-2 for educational spaces.

Beyond the primary comfort parameters, the school's design exhibits potential for holistic sustainability performance. The integration of passive ventilation and daylighting implies significant energy conservation potential, aligning with findings that naturally ventilated, daylit schools can reduce energy consumption by up to 40% compared to conventional designs. Future simulation-based assessments using tools such as EnergyPlus or Ecotect could quantify these impacts, providing evidence for the long-term environmental and economic benefits of such strategies. In terms of material selection and environmental impact, future iterations of the project could benefit from the use of locally sourced, low-VOC, and high-reflectance materials to further enhance embodied carbon efficiency and thermal performance [27]. Incorporating biophilic elements, such as vegetated façades or native landscape species, could also improve microclimate regulation and user well-being, in line with GBCI's Greenship for New Building criteria.

Similarly, water-sensitive design principles including rainwater harvesting, permeable paving, and infiltration gardens could complement the building's passive design strategy by reducing stormwater runoff and enhancing site resilience. These interventions would not only improve the ecological footprint but also serve as educational tools for students to learn sustainability through direct interaction with their environment. It is also important to recognize the role of occupant behavior and adaptive comfort in sustaining passive design effectiveness. The ability of teachers and students to operate windows, blinds, and fans appropriately can significantly influence thermal and visual comfort outcomes [28]. Therefore, incorporating user training programs and behavioral monitoring could ensure that the building performs as intended while fostering environmental literacy among students.

Finally, the long-term success of these strategies relies on preventive maintenance and post-occupancy evaluation. Regular inspection of ventilation openings, daylight control systems, and acoustic materials is essential to preserve performance integrity over time. In this context, SD Negeri 8 Ragunan represents a prototype for sustainable school design in Indonesia. Its alignment with both national standards and the GBCI Greenship framework provides a replicable model for educational infrastructure planning, supporting the national agenda toward low-carbon and health-promoting learning environments.

CONCLUSION

The assessment of SD Negeri 8 Ragunan demonstrates the effective application of passive design strategies that enhance thermal, visual, and acoustic comfort while complying with Permendikbudristek No. 22 of 2023, SNI 03-6572-2001, and GBCI Greenship standards. The classrooms' optimized ventilation, daylight access, and visual connectivity exceeding the 75% GBCI benchmark—reflect a strong commitment to environmental quality and occupant well-being. Beyond meeting regulatory requirements, these strategies contribute to energy efficiency, reduced carbon emissions, and operational sustainability. The findings highlight the importance of user behavior, maintenance, and post-occupancy evaluation to ensure long-term performance. Future studies focusing on acoustic measurements and energy simulations are recommended to strengthen holistic environmental assessment. Overall, SD Negeri 8 Ragunan serves as a replicable model of sustainable educational design that supports Indonesia's efforts toward SDG 4 (Quality Education) and SDG 11 (Sustainable Cities and Communities) through climate-responsive and health-promoting architecture.

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AUTHORS CONTIBUTIONS

Siti Munawarah Panggabean conceptualized the study, supervised the overall research framework, and provided critical feedback to enhance the academic rigor, structure, and clarity of the manuscript while ensuring alignment with the objectives of sustainable architectural development. Della Andadaningrum contributed to the literature review, data collection, and initial drafting of the manuscript, as well as data interpretation and refinement of the discussion to integrate biological education perspectives with architectural sustainability concepts. Vitria Susanti assisted in data verification, comparative analysis, and language refinement, contributing to the alignment of the discussion with international sustainability education practices and improving the manuscript's overall coherence and readability. All authors have read and approved the final version of the manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this article. All stages of research, from data collection to analysis and manuscript preparation, were conducted independently without any financial, commercial, or institutional influence that could be perceived as a potential conflict. The interpretations and conclusions presented in this study are solely those of the authors and do not reflect the views of any affiliated institution.

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