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Assessing Green Building Performance on UNU and UNISA Campuses Using Spatial Analysis

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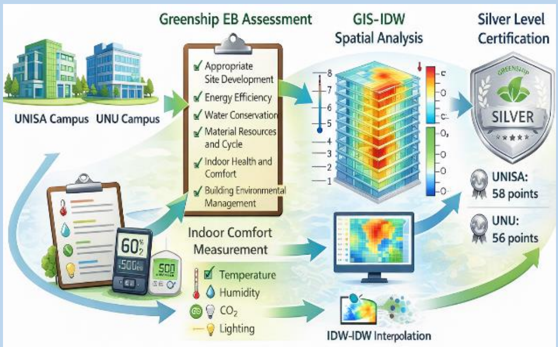
Abstract: The building sector significantly contributes to global energy use and CO2 emissions, emphasizing the need for sustainable green building practices. University buildings, as high energy-intensive facilities, require systematic sustainability assessments. This study evaluates the sustainability performance of buildings at UNU and UNISA using the Greenship Existing Building rating system and examines indoor environmental comfort parameters, including temperature, humidity, CO2 concentration, and lighting intensity. The methodology includes document assessments, field observations, and direct measurements of indoor comfort across multiple rooms and floor. Data were quantitatively analyzed and spatially visualized using GIS-based IDW interpolation to illustrate horizontal and vertical comfort distribution. Results show that UNISA scored 58 points (49.57%) and UNU 56 points (47.86), both achieving Silver certification. UNISA performed better in site development, water conservation, and material cycles, while UNU excelled in energy efficiency, indoor comfort, and environmental management. The study highlights the need for further sustainability improvements.



Keywords: Green Building Assessment, Greenship Existing Building, Indoor Environmental Quality, IDW Interpolation.

Introduction

The construction industry is one of the biggest users of energy and producers of carbon emissions in the world. Buildings are thought to use about 40% of the world's energy and release more than 30% of the world's carbon dioxide (CO2) emissions. This big contribution is mostly due to the energy-intensive needs for getting good indoor environmental quality, especially for controlling the temperature and using artificial light [1-3]. This issue highlights the need to reduce energy consumption while maintaining acceptable levels of indoor comfort. Cutting down on emissions from the building industry is also very important for reaching long-term social and economic development goals [3, 4].

One way to deal with these problems is to use green construction concepts. This method aims to reduce negative effects on the environment by making better use of energy and resources, while also making interior spaces healthier and more pleasant. But there is still no one worldwide standard since the definitions and assessment criteria for green buildings are changed to fit the needs of each country. The World Green Building Council says that a green building is one that is planned, built, and managed in a way that minimizes damage to the environment throughout its entire life cycle while also improving the climate and environment around it [5, 6].

Past studies show that the idea of a green building focuses on using eco-friendly materials, sustainable design strategies, and good building management systems to improve energy and water efficiency while reducing pollution and waste [7-9]. People don't usually build green buildings because they cost more up front, usually 10–15% more than regular buildings. The higher costs are mostly because they used green technology, chose building materials that are good for the environment, and made the design and construction processes more complicated [10, 11].

To make sure that green building assessment methods work, many have been created. BREEAM was the first evaluation method to be utilized in the UK in 1990. Green Star and LEED are also frequently used [12]. The Green Building Council Indonesia (GBCI) established the Greenship rating system for Indonesia keeping the needs of the country in mind. There are several groups, including New Building, Interior Space, Neighborhood, Homes, and Existing Building [13]. The evaluation for Greenship Existing Buildings centers on the administration and upkeep of edifices that have been functional for at least one year [14].

Bray, Ford [15] say that schools and colleges use about 60% more energy than businesses do. Ridhosari and Rahman [16] also found that energy use is responsible for 92.3% of the carbon

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emissions on campus. These results show that making schools use less energy and following green building rules are important steps toward making campuses more environmentally friendly.

Numerous research has been done on green buildings in schools, but most of it is still about new buildings or planning and policy. There aren't many studies that look at how well existing educational buildings are doing in terms of sustainability, especially those that use Greenship Existing Building assessments along with direct measurements of indoor environmental comfort parameters and Geographic Information System (GIS)-based spatial analysis. You can get a thorough and up-to-date picture of how a building is doing and utilize data to figure out which components need to be corrected to save energy if you use both of these strategies together.

This study evaluates the sustainability performance of buildings at the X and Y campuses using the Greenship Existing Building (EB) assessment framework. The assessment is complemented by direct field measurements of indoor environmental comfort parameters, including air temperature, relative humidity, carbon dioxide (CO_2) concentration, and lighting intensity.

This study further contributes to green building research by integrating the Greenship Existing Building assessment with GIS-based spatial visualization of indoor environmental comfort conditions. Rather than relying solely on certification scores or descriptive evaluation, this approach enables a spatial interpretation of comfort distribution across multiple floors of existing higher education buildings. Such integration provides insights into floor-specific performance variability, which is often overlooked in conventional sustainability assessments of educational buildings.

All statements presented in this study are supported by cited literature and empirical data obtained from field measurements, ensuring that no speculative or unsupported claims are included in the analysis.

Literature Review

Higher education buildings accommodate diverse activities and intensive occupancy patterns. These traits make campuses a place where a lot of energy is used and where the environment might be harmed in a big way. In the framework of sustainable development, educational institutions serve a pivotal function, not just as consumers of physical infrastructure but also as hubs for cultivating environmentally sensitive behavior and knowledge. Syidanova, Çağnan [17] assert that campuses may serve as catalysts for sustainability implementation through energy management, facility management, and the incorporation of environmental education. Prior studies have demonstrated that green buildings in educational settings may enhance energy efficiency and elevate indoor environmental quality. Khoshbakht, Gou [18] discovered that green buildings yield more occupant satisfaction compared to traditional buildings, whereas Altomonte, Allen [19] validated that air quality, illumination, and thermal comfort directly affect the efficacy of the learning process. These results show how important it is to use green construction concepts in higher education.

Green Building Concept

The idea of green buildings has grown quickly since the energy crisis of the 1970s, which showed how limited resources were and how greenhouse gas emissions were rising. Green buildings have become an essential way to lessen the harm that growth does to the environment all around the world [20]. The World Green Building Council (WorldGBC) claims that there is no one definition of "green buildings" because the way they are designed depends on the history, climate, culture, and social circumstances of each country. The Green Building Council Indonesia (GBCI) says that green buildings are those that follow the rules of protection, using fewer resources, and keeping the health of the people who live in them throughout their life cycle [21]. Numerous studies affirm that the principal objective of green buildings is to enhance human well-being and ensure environmental sustainability [10, 22].

Green Building Assessment Tools

A range of green building rating systems has been introduced worldwide, including BREEAM in the United Kingdom, LEED in the United States, Green Star in Australia, and CASBEE in Japan. These assessment frameworks evaluate building performance using indicators such as energy efficiency, indoor environmental quality, water efficiency, material use, and innovation in design [23]. In Indonesia, the Green Building Council Indonesia (GBCI) set up Greenship as a mechanism for assessing green buildings that is used all throughout the country. Greenship is structured into five assessment schemes, namely New Building, Existing Building, Interior Space, Neighborhood, and Homes. The assessment is conducted in two stages: design recognition and final assessment. Many studies have shown that Greenship can give a building a quantifiable score for how sustainable it is. Sangadji, Buyang [24] indicated that the Faculty of Social and Political Sciences Building at Pattimura University exhibited commendable outcomes in the Indoor Health and Comfort category. Concurrently, Maryam, Fanani [25] validated that the amalgamation of Greenship and UI GreenMetric facilitates the advancement of sustainable campuses in Indonesia.

Greenship Existing Building Tools

Greenship Existing Building (EB) is a green building certification system developed by the Green Building Council Indonesia (GBCI) to evaluate the sustainability performance of buildings that have been in operation for at least one year. Unlike the assessment of new buildings, Greenship EB focuses on operational aspects, maintenance, and building management, so sustainability is determined by the consistency of long-term building management [13].

Table (1): Greenship Existing Building Assessment Criteria.

Category	Criteria		Percentage
	Prerequisites	Credit	
Appropriate Site Development-ASD	2	16	13.68%
Energy Efficiency and Conservation-EEC	2	36	30.77%
Water Conservation-WAC	1	20	17.09%
Material Resources and Cycle-MRC	3	12	10.26%
Indoor Health and Comfort-IHC	1	20	17.09%
Building Environment Management-BEM	1	13	11.11%
Total Points	**10**	**117**	**100%**

This research employs the Greenship Existing Building Version 1.1 framework, comprising six principal evaluation categories: Appropriate Site Development (ASD), Energy Efficiency and Conservation (EEC), Water Conservation (WAC), Material Resources and Cycle (MRC), Indoor Health and Comfort (IHC), and Building Environmental Management (BEM).

These categories are supposed to quantify crucial components of building sustainability, like how land is used, how well energy and water are used, how well materials are maintained throughout their life cycles, how well the inside environment is kept clean, and how well environmental management is done. Table 1 shows the distribution of assessment criteria and the weights that go with them for each category.

Each category in the Greenship EB consists of three types of criteria: prerequisites, credits, and bonus credits. Prerequisite criteria are mandatory and must be met for a category to be assessed. Credit criteria award points if technical requirements are met, while bonus credits are optional and awarded for performance exceeding established standards [26].

The final Greenship assessment is determined based on the actual number of points earned across all assessment categories. This total is then expressed as a percentage of the maximum points to determine the level of certification achievement. Based on this percentage, buildings are classified into four certification levels, as shown in Table 2 [27]. These levels reflect the building's level of success in implementing green building principles during the operational and maintenance phases.

Table (2): Rating Category for Greenship Existing Building.

Predicate	Minimum Point	Percentage (%)
Platinum	86	73
Gold	67	57
Silver	53	45
Bronze	41	35

Inverse Distance Weighting Spatial Interpolation

Spatial interpolation is a technique used to estimate parameter values at locations without direct measurement data. Among deterministic approaches, Inverse Distance Weighting (IDW) is widely applied due to its conceptual simplicity and low computational demand [28]. Previous studies have demonstrated the effectiveness of IDW in mapping indoor environmental parameters and air quality distributions [29-32].

In this study, GIS-based spatial analysis focuses on the visualization and interpretation of vertical distribution patterns of indoor environmental comfort parameters within buildings. IDW interpolation was applied as an exploratory method suitable for building-scale datasets with limited sampling points, with interpolation boundaries constrained by floor layouts to avoid extrapolation beyond functional spaces. The resulting maps are intended to support spatial pattern interpretation rather than predictive modeling.

Although numerous studies assess the sustainability performance of higher education buildings or analyze indoor environmental comfort, the integration of Greenship Existing Building assessments and GIS-based spatial visualization remains limited. This study addresses this gap by combining Greenship EB evaluation with IDW-based spatial mapping to provide a more comprehensive assessment of environmental performance in existing higher education buildings.

Methods

Research Location

This research was conducted at two higher education institutions in Yogyakarta: University Aisyiyah Yogyakarta (UNISA), located in the Gamping West Ringroad area, and University Nahdlatul Ulama (UNU) Yogyakarta, located in the Umbulharjo area. Both campuses were selected because they represent multi-story educational buildings with high levels of academic activity and differing building design characteristics and environmental management systems. The locations of the campus buildings analyzed are shown in Figures 1 and 2.

The research object at University Aisyiyah Yogyakarta was the Siti Moendijah Building, a nine-story building with a total floor area of 10,611 m² that serves as a library, administration center, and high-activity lecture hall. The main campus building at University Nahdlatul Ulama Yogyakarta is where the research took place. It has nine floors and a floor area of 16,769 m². It has a lot of academic and administrative functions. Because of permit requirements, data collection was only allowed on the sixth floor. But it was still a good representation because it included the area where most of the academic work was being done.

Figure (1): University Nahdatul Ulama.

Figure (2): University Aisyiyah Yogyakarta.

Research Instruments

The research instruments included a carbon dioxide detector equipped with temperature and humidity sensors, and a digital lux meter to measure lighting intensity. Both instruments were chosen because they offer sufficient accuracy to obtain the quantitative data needed for spatial comfort analysis and environmental parameter distribution mapping.

The carbon dioxide detector used in this study, as shown in Figure 3, measures indoor carbon dioxide (CO2) concentrations with a measurement range of 400–5000 ppm and an accuracy of ±50 ppm. This instrument is also equipped with temperature and humidity sensors, each with an accuracy of ±0.5°C and ±3% RH, respectively. The integration of these three parameters in a single device allows for simultaneous measurements at the same point, thereby increasing the consistency and validity of the measurement data. Indoor CO2 concentrations were evaluated at a safe limit of less than 1,000 ppm.

Figure (3): Carbon Dioxide Detector.

The digital lux meter used in this study is shown in Figure 4 and measures the lighting intensity in each room and floor of the building under study. This instrument has a measurement range of 0–200,000 lux with an accuracy of approximately ±3%. Measurement results were compared with visual comfort standards based on SNI 03-6197-2000, which requires lighting levels of approximately 250 lux for classrooms and 500 lux for laboratories. The selection of SNI 03-6197-2000 is consistent with the technical standards referenced within the Greenship Existing Building framework adopted by the Green Building Council Indonesia. As this study evaluates building performance within the national green building certification context, the use of Indonesian standards ensures regulatory relevance and methodological consistency for assessing visual comfort in educational buildings.

Figure (4): Digital Lux Meter.

Research Stages

This study employed primary and secondary data. Primary data were obtained through measurements of temperature, humidity, CO_2 concentration, and lighting levels on each floor at three time periods (08:00, 12:00, and 16:00) over five working days, complemented by building condition observations, management interviews, and completion of the Greenship Existing Building assessment. Secondary data included building drawings, operational records, energy and water consumption data, and maintenance documents. Data collection was conducted through field measurements, observations, interviews, and document review to support assessment verification.

The research was conducted through literature review, measurement preparation, field data collection, spatial analysis, and assessment of the Greenship Existing Building. Data analysis used two approaches: a quantitative Greenship assessment based on technical criteria and supporting documentation, and a GIS-based spatial analysis using the Inverse Distance Weighting (IDW) method. IDW interpolation is used to map the distribution of temperature, humidity, CO2 concentration, and light intensity, so that distribution patterns and areas with potential for non-conformity in space comfort can be identified, which then becomes the basis for compiling recommendations for improving building performance.

Spatial Sampling Strategy and Data Preparation

Indoor environmental measurements were conducted in representative functional rooms on each accessible floor of both campus buildings. The number of measured rooms per floor varied depending on room availability during the measurement period. Room selection followed a convenience-based sampling approach constrained by access permission and ongoing academic activities, potentially limiting full spatial coverage across all floors. Despite this limitation, the selected rooms represent typical campus functions, including classrooms, administrative offices, libraries, and laboratories, thereby ensuring functional representativeness across floors.

For spatial analysis purposes, measurement values obtained from repeated daily observations were first aggregated at the room level using arithmetic mean values, which served as the input dataset for interpolation. Spatial visualization of indoor environmental comfort parameters was performed using the Inverse Distance Weighting (IDW) method within a Geographic Information System (GIS) environment. IDW interpolation was applied using standard default settings commonly adopted in building-scale indoor environmental mapping, where closer observation points exert greater influence on estimated values.

Interpolation boundaries were strictly constrained by individual floor layouts to prevent extrapolation beyond functional spaces. The resulting IDW maps are intended to support qualitative interpretation of spatial distribution patterns across floors rather than predictive modeling or exact numerical replication.

Results and Discussion

Appropriate Site Development

The Appropriate Site Development category evaluates land sustainability, accessibility, and the integration of buildings with their surrounding environment. The assessment results show that, from a maximum of 16 points, UNISA obtained 12 points (10.26%), while UNU achieved 10 points (8.55%), indicating differences in the implementation of site sustainability strategies on the two campuses. Both campuses benefit from access to public transportation, with bus stops located approximately 79.4 m from UNISA and 30 m from UNU, supporting sustainable mobility. Distances to public transportation facilities were calculated using direct (Euclidean) distance measurements, which are appropriate for campus-scale analysis and compliance verification under Greenship Existing Building criteria. Considering the limited spatial extent of university campuses, this approach adequately represents accessibility conditions without significantly influencing the overall ASD assessment results.

However, variations are evident in the provision of non-motorized transportation facilities, where UNISA is supported by dedicated bicycle parking, while UNU lacks comparable supporting infrastructure. These differences reflect variations in land-use and transportation management approaches and highlight the role of non-motorized facility provision in strengthening campus sustainability in accordance with standards set by the Green Building Council Indonesia.

Energy Efficiency and Conservation

The Energy Efficiency and Conservation (EEC) category evaluates energy reduction efforts while maintaining indoor comfort. The assessment results revealed limited energy efficiency performance on both campuses, with UNISA obtaining 10 points (8.55%) and UNU 11 points (9.40%) out of a possible 36. This limited achievement was primarily due to the lack of documented Energy Consumption Intensity data, which hinders a comprehensive and objective evaluation of the buildings' energy performance. Without accurate data on energy use, it is impossible to effectively target efforts to make green buildings more efficient and improve operational strategies. So, accurate analysis of how much electricity is used is very important for data-driven energy management and for making energy-saving measures work better [33]. Even though using renewable energy is still limited, putting up solar panels at UNU is a first step toward using cleaner energy sources.

Water Conservation

The Water Conservation assessment demonstrates that water management practices at both campuses have not yet reached optimal performance when measured against the maximum weighting of 20 points. UNISA attained 8 points (6.84%), while UNU recorded 6 points (5.13%), indicating variations in the implementation of water conservation measures. Although both campuses satisfy the requirements for water monitoring, control, and water quality, the lack of water sub-metering systems and limited availability of consumption data restrict efforts to enhance clean water efficiency. UNU has implemented the use of recycled water for toilet flushing and landscape irrigation, whereas UNISA prioritizes the provision of potable water and the reduction of groundwater extraction. Overall, these results underscore the necessity for integrated water monitoring systems and the reinforcement of water conservation policies in alignment with Green Building Council Indonesia standards.

Material Resources and Cycle

The Material Resources and Cycle MRC category assesses efforts to reduce environmental impact through sustainable material management throughout the building's life cycle. Based on the research results, the University Aisyiyah Yogyakarta (UNISA) Campus obtained 9 points and University Nahdlatul Ulama (UNU) obtained 8 points, indicating that both campuses have implemented material management practices, although not evenly across all criteria and are still at a moderate performance level.

The Waste Management Practice criterion scored the highest on both campuses, indicating that waste sorting and management systems have been adequately implemented through facilities at the source and supported by external collaborations, in line with the findings of [34]. Conversely, the Material Purchasing Practice criterion did not receive any points, indicating that a sustainable material procurement policy has not yet been implemented, as also noted by [35]. Therefore, strengthening green procurement strategies is key to sustainably improving MRC performance.

Indoor Health and Comfort

The Indoor Health and Comfort (IHC) category assesses indoor environmental conditions such as thermal comfort, indoor air quality, lighting performance, and acoustic quality, all of which play a significant role in supporting occupants' health, comfort, and productivity [13]. This category consists of one mandatory prerequisite, namely the No Smoking Campaign, along with eight evaluation criteria that together carry a maximum score of 20 points. The assessment results indicate that IHC achievement at both campuses is still relatively low, especially in the Thermal Comfort, Outdoor Air Introduction, and Acoustic Level criteria, reflecting limited compliance with overall environmental comfort standards.

The Thermal Comfort criterion did not receive any points because the measured temperature and humidity values did not meet the requirements of SNI 6390:2011, indicating indoor conditions outside the recommended comfort range. Meanwhile, the Outdoor Air Introduction and Acoustic Level criteria scored zero due to the absence of quantitative measurements, which was primarily caused by equipment limitations and restricted access to mechanical ventilation systems. In accordance with the Greenship Existing Building guidelines, these zero scores represent a conservative assessment and do not necessarily indicate inadequate indoor environmental performance or the absence of such systems in the assessed buildings.

These findings indicate that IHC performance is influenced not only by building design and operation but also by the limited availability of quantitative environmental monitoring. Previous research on sustainable buildings stresses the importance of objectively and through simulation evaluating indoor air quality to make sure that indoor environments are healthy, especially when the choice of materials and the performance of ventilation affect pollutant exposure [36].

Building Environment Management

The Building Environment Management (BEM) category evaluates the sustainability of building management and maintenance during the operational phase, including policies, training, and innovation (GBCI, 2019). The assessment results show that UNISA obtained 11 out of 13 points (9.40%) and UNU 12 points (10.26%), indicating relatively good implementation of green building management at both campuses.

Most of the assessed criteria, namely Design Intent and Owner's Project Requirement, Green Operational and Maintenance Team, Green Occupancy/Lease, and Operation and Maintenance Training, achieved full scores at both campuses, indicating that operational and maintenance management systems are well established. In contrast, the Innovation criterion showed comparatively lower results, with UNISA obtaining 3 out of 5 points and UNU 4 out of 5 points, suggesting existing constraints in the adoption of technological innovations and more advanced operational efficiency strategies. This finding aligns with Purumal, Ali [37] who stated that the implementation of innovation in green building management still faces technical and technological challenges. Therefore, strengthening the innovation aspect is the key to improving building operational performance optimally and sustainably.

Assessment Result of Greenship Existing Building

The overall results of the Greenship Existing Building assessment across the six main criteria are summarized in Table

3. The UNISA campus achieved a total score of 58 points (49.57%), while the UNU campus obtained 56 points (47.86%). According to the certification thresholds established by the Green Building Council Indonesia (GBCI), both campuses fall within the Silver certification level (≥53 points or ≥45%). In terms of category performance, UNISA recorded higher scores in Appropriate Site Development (ASD), Water Conservation (WAC), and Material Resources and Cycle (MRC). Conversely, UNU demonstrated stronger performance in Energy Efficiency and Conservation (EEC), Indoor Health and Comfort (IHC), and Building Environment Management (BEM). In general, these results show that the basic concepts of green building have been used to some extent on both campuses. Energy efficiency, indoor air quality, and building management practices still have a long way to go before they can reach higher certification levels, like Gold (≥67 points) or Platinum (≥86 points). The Greenship Existing Building evaluation not only tells us how sustainable the campus buildings are right now, but it also helps us decide which steps to take first to make them more sustainable in the future.

When compared with previous studies on Greenship-certified educational buildings and international campus sustainability assessments, the Silver-level achievement observed in both campuses aligns with typical performance patterns reported in higher education buildings in tropical climates. Studies conducted on Indonesian and Southeast Asian campuses similarly report moderate performance in water conservation and energy efficiency due to operational constraints and limited monitoring systems. The stronger performance of Campus Y in water conservation may be attributed to differences in fixture efficiency, maintenance practices, and facility management policies, while Campus X demonstrates comparatively better performance in energy efficiency and indoor comfort, likely influenced by building orientation and ventilation design. These findings suggest that institutional management strategies and infrastructure investment play a critical role in shaping sustainability outcomes beyond architectural design alone.

Table (3): Greenship Existing Building Tools Assessment Results.

No	Category	UNISA		UNU	
		Points	Percentage	Points	Percentage
1	Appropriate Site Development -ASD	12	10.26%	10	8.55%
2	Energy Efficiency and Conservation -EEC	10	8.55%	11	9.40%
3	Water Conservation -WAC	8	6.84%	6	5.13%
4	Material Resources and Cycle-MRC	9	7.69%	8	6.84%
5	Indoor Health and Comfort-IHC	8	6.84%	9	7.69%
6	Building Environment Management -BEM	11	9.40%	12	10.26%
Total Points		**58**	**49.57%**	**56**	**47.86%**

Carbon Dioxide Monitoring

Carbon dioxide (CO_2) concentration monitoring was conducted on each floor of the building at three time periods (morning, noon, and evening) to capture variations in indoor air quality due to changes in activity. In the UNISA SM building, CO_2 concentrations ranged from 411.3 to 822.5 ppm, as seen in Figure 5, with the highest values on the middle floors, which are dominated by high-intensity classrooms. This pattern indicates the influence of occupant density and limited fresh air exchange on CO_2 accumulation, consistent with the findings of [38]. Even though all values stayed below the 1000 ppm limit set by SNI 19-0232-2005, the fact that the middle floors had higher concentrations shows that ventilation systems need to be improved to keep the air quality stable. Furthermore, elevated CO_2 levels in educational environments are known to potentially reduce cognitive function and decision-making quality [39].

In contrast, UNU buildings exhibit low and stable CO_2 concentrations, ranging from 400–434.1 ppm on all floors, with relatively little vertical variation. This reflects effective ventilation and air circulation performance in maintaining fresh air supply, supported by optimal building design and natural opening layout [40, 41]. With all values well below the standard threshold, indoor air quality in UNU buildings can be categorized as very good and supports academic comfort and productivity.

Thermal Comfort

Thermal comfort is an important part of indoor environmental quality because it affects both the health of the people who live there and the amount of energy used in buildings. Previous studies have shown that architectural elements, including building form, ventilation strategies, spatial configuration, and envelope design, play a significant role in shaping indoor thermal conditions and comfort performance in buildings [42]. In this study, the level of thermal comfort was measured using air temperature and relative humidity indicators, as required by SNI 6390:2011, which deals with how to make building air-conditioning systems more energy efficient. The measurement results, shown in Figure 6, show that the average temperature in the UNISA SM Building was in the range of 27.2–28.5°C, while in the UNU Building it ranged between 28.2–28.6°C. Vertical temperature variation in the UNU building was relatively smaller than in UNISA.

Based on the thermal comfort criteria for tropical climates stipulated in SNI 6390:2011 (24–27°C), indoor air temperatures across all floors of both buildings exceeded the upper comfort boundary. This situation indicates a consistently warm indoor environment, which may lead to decreased thermal comfort and reduced occupant concentration. These findings align with studies that suggest high classroom temperatures can reduce students' cognitive performance and learning effectiveness [43, 44]. Furthermore, the pattern of vertical temperature increase is consistent with the findings of Dahlblom and Jensen [45], who explained the accumulation of heat between floors due to heat transfer through floor slabs, the building envelope, and limited air circulation. Building design factors, solar radiation exposure, and the humid tropical climate further exacerbate the difficulty of achieving ideal thermal conditions in multi-story educational buildings [46].

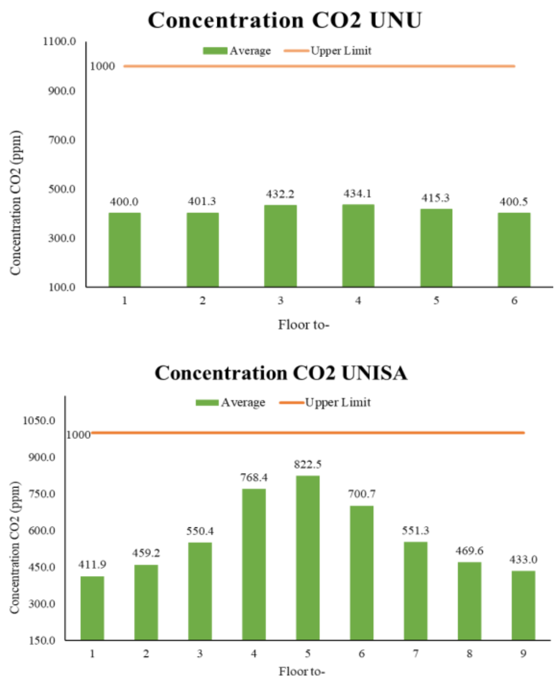

Figure (5): Recapitulation of CO2 concentration.

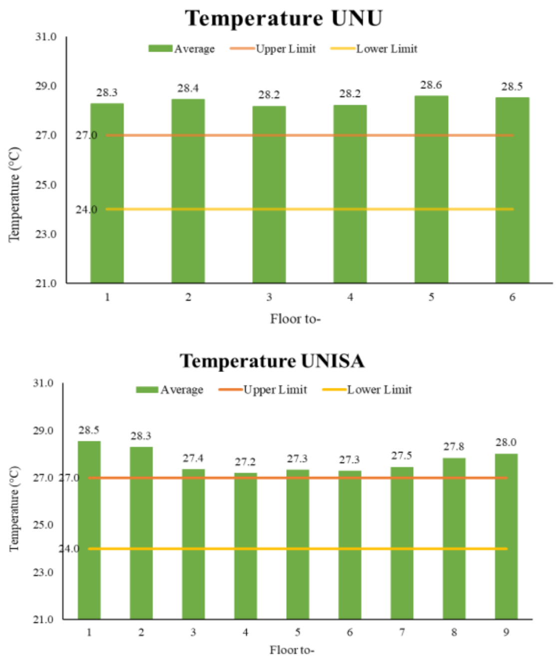

Figure (6): Recapitulation of Temperature.

Furthermore, humidity is also an important parameter in thermal comfort because it affects health and indoor air quality. Measurement results, shown in Figure 7, at the UNISA SM Building, show relative humidity values ranging from 53.4%–69%, with the highest value on the first floor and the lowest on the third floor. According to SNI 6390:2011, the ideal humidity range is 55%–65%, so the first floor exceeds the upper limit, and the third floor falls below the lower limit. The high humidity on the lower floors is thought to be influenced by the migration of water vapor from the ground through the building structure, as explained by [47].

Meanwhile, relative humidity in the UNU Building ranged from 63.6%–70.8%, with the third and sixth floors exceeding the upper limit. This pattern of increasing humidity on the upper floors aligns with the findings of Francisco and Rose [48], who stated that the vertical distribution of water vapor is influenced by thermal buoyancy due to differences in air temperature. In general, most humidity values in both buildings remained within the standard range, although some floors deviated. This is a concern because high humidity can increase the risk of microbial growth Seppänen [49], while low humidity can potentially cause respiratory problems and irritation in occupants [50].

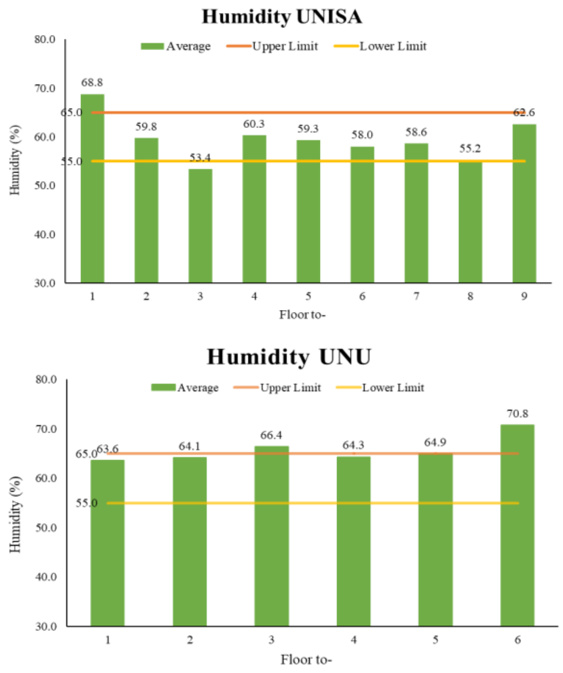

Figure (7): Recapitulation of Humidity.

Visual Comfort

Visual comfort evaluations of the UNU and UNISA campus buildings were conducted to assess the suitability of room lighting levels to the SNI 6197:2000 standard for lighting systems for buildings and work environments. The measurement results, shown in Figure 8, of the UNISA SM Building, show significant variations in light intensity between floors, with the highest value on the 9th floor (521.4 lux) and the lowest on the 7th floor (133.3 lux). Based on the minimum standard of 250 lux for study spaces, only floors 1, 3, 4, and 9 meet the criteria, while the other floors fall below the visual comfort threshold.

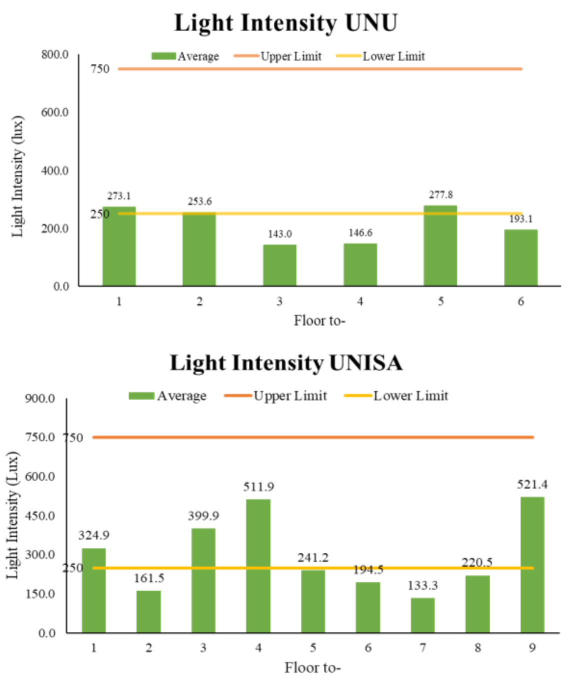

Figure (8): Recapitulation of Light Intensity.

In the UNU Building, light intensity is relatively stable but not evenly distributed vertically. The highest value was recorded on the 5th floor (277.8 lux), while the lowest was on the 3rd floor (143 lux). Referring to SNI 6197:2000, only floors 1, 2, and 5 meet the minimum lighting standard, while floors 3, 4, and 6 still do not. This uneven lighting distribution is influenced by building orientation, the position and dimensions of openings, the type of glazing, and the surrounding environmental conditions [51-53]. Lighting intensity below 250 lux in classrooms has the potential to reduce visual comfort and the quality of the learning process [54].

Vertical Analysis of the UNU Campus

This study analyzes the vertical distribution of four indoor environmental parameters; air temperature, relative humidity, CO2 concentration, and light intensity, within the UNU campus building. The interpolation results presented in Figure 9 demonstrate clear variations across floors, indicating vertical microclimatic differences influenced by floor elevation, space function, building orientation, and occupant activity.

As you go up the floor, the air gets warmer, with the warmest air on the upper levels. This means that the temperature changes with height and that the area gets more sunlight. This pattern is consistent with the results of Song, Yoon [55], who found that upper floors were warmer because air moves up and heat builds up. The measured temperatures are higher than the recommended range for thermal comfort, which is 24–27 °C. This shows that SNI 6390:2011 requires floor-specific thermal control strategies.

Relative humidity reaches its highest levels on floors with intensive water-related activities and high occupancy, confirming the dominant role of internal moisture sources and limited ventilation [56]. In addition, an inverse relationship between temperature and humidity is observed, where increased temperature corresponds to reduced relative humidity [57].

The middle floors have the highest levels of CO2, over 430 ppm, which is due to classrooms that are full of students and activities that last a long time. Even though these numbers are still below the widely accepted limit of 1000 ppm Allen, MacNaughton [58], the observed buildup shows that the air is not evenly distributed vertically and that there is not enough ventilation, which is in line with [59].

Light intensity varies significantly vertically, with diminished illuminance on the middle floors attributable to room orientation, shading from structural components, and decreased daylight penetration. This result backs up earlier research that showed how the layout of a space and the direction of a building can affect how well it gets natural light [60, 61]. These spatial patterns indicate that building design characteristics, space function, and operational practices jointly influence indoor environmental conditions across floors.

Vertical Analysis of the UNISA Campus

Figure 10 shows that the vertical analysis of the nine-story UNISA campus building shows big differences in indoor environmental conditions on different floors. This shows how the building's layout, ventilation strategy, and occupancy patterns all work together. These differences tell us a lot about how well the interior environmental quality works in a school building with more than one floor.

The temperature profile is not a straight line; it is higher on the top and bottom floors and lower on the middle floors. This pattern suggests that the building has complicated thermal stratification because it gets heat from inside, doesn't move air up and down very well, and gets different amounts of solar radiation and roof heat transfer. Wang, Zhang [62] found similar vertical temperature gradients in multi-story buildings where the flow of air and the loads inside the building are very different from floor to floor.

Relative humidity usually goes down as temperature goes up, so floors with higher temperatures tend to have lower humidity levels. This behavior shows that warmer air can hold more moisture when there isn't much moisture coming in. However, several floors show high temperature and humidity at the same time, which is likely due to a high number of people living there and not enough ventilation, which can make moisture build up more quickly in occupied spaces [63, 64].

This distribution shows that natural ventilation works less well at higher elevations, especially in classrooms with single-sided openings that are used a lot. Long-term occupancy without breaks for ventilation makes the buildup of CO2 even worse, which is in line with research that shows that high-density educational spaces with limited air exchange often go above the recommended CO2 levels [65, 66]. High levels of CO2 (over 1000 ppm) are known to make people less alert and less able to think clearly. This shows that upper-floor classrooms need better ways to get fresh air [67].

Light intensity distribution is primarily influenced by façade transparency, opening orientation, and room function. Floors with extensive glazing, such as the library level, exhibit higher and more uniform daylight availability due to greater visible transmittance and deeper light penetration. In contrast, classrooms and corridors with single-sided openings show uneven illumination, with light levels decreasing sharply toward interior zones. Additionally, spaces oriented toward east and west façades demonstrate greater variability in light intensity due to direct solar exposure at different times of day, whereas north–south orientations provide more stable daylight conditions [68-70].

The fact that the temperature, humidity, CO2 levels, and light intensity were different on each floor at UNISA shows that the quality of the interior environment is not the same on all floors. These results show how important it is to control the environment on each level separately and to use better ways to let in light and air, especially on the upper floors, to make the whole building work better.

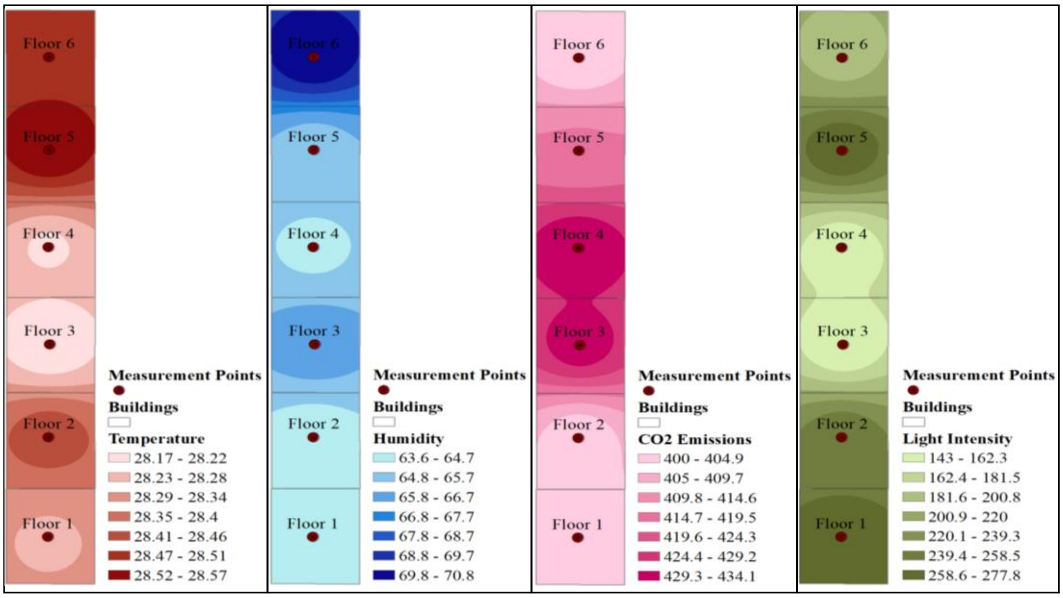

Figure (9): Vertical Distribution in the UNU Campus Building.

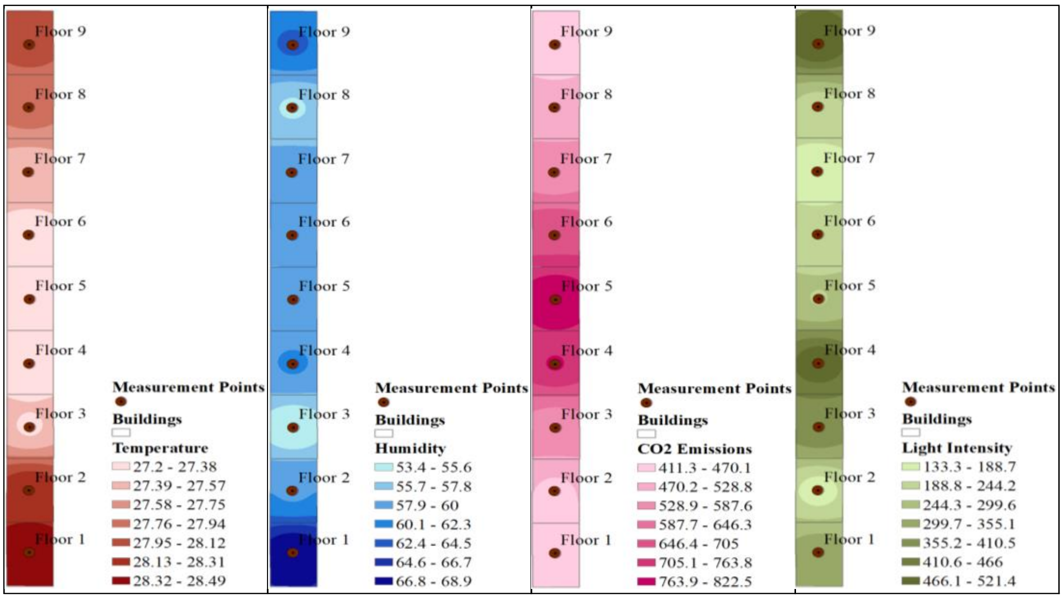

Figure (10): Vertical Distribution in the UNISA Campus Building.

Conclusion

Based on the research results, the following conclusions were obtained:

1. The Greenship Existing Building assessment shows that the UNISA Campus received 58 points (49.57%) and the UNU Campus obtained 56 points (47.86%). Both campuses met the Silver designation according to the Green Building Council Indonesia (GBCI) standards, which indicates that the implementation of green building principles has been running at a medium level and meets most of the sustainability indicators.
2. Comparison of performance between categories shows different superior characteristics on each campus. The UNISA Campus excels in the Appropriate Site Development (ASD), Water Conservation (WAC), and Material Resources and Cycle (MRC) categories, while the UNU Campus shows better performance in the Energy Efficiency and Conservation (EEC), Indoor Health and Comfort (IHC), and Building Environmental Management (BEM) categories.
3. Analysis of the vertical distribution of indoor environmental parameters shows variations in conditions between floors on both campuses. The UNU campus tends to experience an increase in temperature and CO2 concentrations on the upper floors due to heat accumulation and lecture activities, while the UNISA campus shows a more fluctuating pattern due to variations in space function. Humidity and light intensity also show differences in vertical characteristics, which confirms that indoor environmental control is not evenly distributed and still requires improved sustainability strategies to achieve Gold or Platinum designation.

4. This study has several limitations that should be acknowledged. The assessment of Indoor Health and Comfort was limited to measurable parameters such as thermal conditions, indoor air quality, and lighting, while acoustic performance and mechanical outdoor air introduction could not be quantitatively evaluated due to access and equipment constraints, potentially leading to conservative estimates in certain assessment categories. Furthermore, the spatial analysis was conducted at the building scale using IDW interpolation, primarily for spatial pattern visualization rather than predictive modeling. Despite these limitations, this study contributes methodologically by integrating the Greenship Existing Building assessment with GIS-based spatial visualization of indoor environmental comfort parameters in existing higher education buildings. Future research may incorporate real-time environmental monitoring, occupant perception surveys, and advanced analytical techniques to enhance the comprehensiveness of campus sustainability evaluations.

Disclosure Statement

- **Ethics approval and consent to participate:** This study was conducted at Universitas 'Aisyiyah Yogyakarta (UNISA) and Universitas Nahdlatul Ulama Yogyakarta (UNU Yogyakarta) and received formal permission from the respective universities. Ethical approval from an institutional ethics committee was waived because this research did not involve medical procedures, experiments on humans, or sensitive personal data. All participants were informed about the objectives and procedures of the study, and informed consent was obtained prior to data collection.
- **Consent for publication:** Not applicable
- **Availability of data and materials:** The raw data required to reproduce these findings are available in the body and illustrations of this manuscript.
- **Author's contribution:** The authors confirm their contributions to the paper as follows: study conception and design, data collection, data analysis, spatial analysis, and draft manuscript preparation were conducted by Lia Indriani under the supervision of Ahmad Zaki and Nursetiawan. All authors contributed to data interpretation, manuscript revision, and approved the final version of the manuscript.
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References

1] Firsani T, Utomo C. Analisa life cycle cost pada green building diamond building Malaysia. Jurnal Teknik ITS. 2012;1(1):D34-D9.

2] Mancini E. Energy Efficiency and Climate-Resilient Strategies towards Zero-Emission Buildings: Politecnico di Torino; 2025.

3] Rahmat MK, Aziz MFA, Mahmud AM, Ismail IH, Ghazali R. Mock-Up Green Building Thermal Comfort Studies. Advanced Materials and Engineering Technologies. 2022:361-72.

4] Sun Y, Yan C, Xing H. Can green buildings reduce carbon dioxide emissions? Energy. 2024;312:133613.

5] Bungau CC, Bungau T, Prada IF, Prada MF. Green buildings as a necessity for sustainable environment development: dilemmas and challenges. Sustainability. 2022;14(20):13121.

6] Darko A, Chan APC, Yang Y, Shan M, He B-J, Gou Z. Influences of barriers, drivers, and promotion strategies on green building technologies adoption in developing countries: The Ghanaian case. Journal of Cleaner Production. 2018;200:687-703.

7] Zhang L, Wu J, Liu H. Turning green into gold: A review on the economics of green buildings. Journal of cleaner production. 2018;172:2234-45.

8] Chen Y, Luo L, editors. Analysis of environmental benefits of green buildings from the perspective of carbon emissions. E3S Web of Conferences; 2020: EDP Sciences.

9] Oluwunmi AO, Oladayo O, Role B, Afolabi T, editors. Benefits and barriers to the implementation of green building standards in universities: what are students' views? IOP Conference Series: Materials Science and Engineering; 2019: IOP Publishing.

10] Berawi MA, Miraj P, Windrayani R, Berawi ARB. Stakeholders' perspectives on green building rating: A case study in Indonesia. Heliyon. 2019;5(3).

11] Hwang BG, Tan JS. Green building project management: obstacles and solutions for sustainable development. Sustainable development. 2012;20(5):335-49.

12] Ding Z, Fan Z, Tam VW, Bian Y, Li S, Illankoon ICS, et al. Green building evaluation system implementation. Building and Environment. 2018;133:32-40.

13] Rahardhani AFS, Putra AB, editors. Green building analysis using Greenship for existing building method v. 1.1., Case Study of a Campus Building in West Jakarta. IOP Conference Series: Earth and Environmental Science; 2025: IOP Publishing.

14] Purbantoro F, Siregar M, editors. Implementation of Green Building Concept in Office Building Jakarta. Journal of Physics: Conference Series; 2019: IOP Publishing.

15] Bray R, Ford R, Morris M, Hardy J, Gooding L. The co-benefits and risks of smart local energy systems: A systematic review. Energy Research & Social Science. 2024;115:103608.

16] Ridhosari B, Rahman A. Carbon footprint assessment at Universitas Pertamina from the scope of electricity, transportation, and waste generation: Toward a green campus and promotion of environmental sustainability. Journal of Cleaner Production. 2020;246:119172.

17] Syidanova A, Çağnan Ç, Ozsahin DU. Evaluation of the Green Campus and Sustainable Campus: Green Building Rating System and Sustainability Approach in Higher Education. Decision Analysis Applied to the Field of Environmental Health: Springer; 2022. p. 37-46.

18] Khoshbakht M, Gou Z, Xie X, He B, Darko A. Green building occupant satisfaction: Evidence from the Australian higher education sector. Sustainability. 2018;10(8):2890.

19] Altomonte S, Allen J, Bluyssen PM, Brager G, Heschong L, Loder A, et al. Ten questions concerning well-being in the built environment. Building and Environment. 2020;180:106949.

20] Aktas B, Ozorhon B. Green building certification process of existing buildings in developing countries: cases from Turkey. Journal of Management in Engineering. 2015;31(6):05015002.

21] GBCI. Green Building Council Indonesia (GBCI), Greenship Existing Buildings; 2010.

22] Robichaud LB, Anantatmula VS. Greening project management practices for sustainable construction. Journal of management in engineering. 2011;27(1):48-57.

23] Atanda JO, Öztürk A. Social criteria of sustainable development in relation to green building assessment tools. Environment, Development & Sustainability. 2020;22(1).

24] Sangadji FA, Buyang CG, Soplanit SN. Penilaian Kriteria Green Building pada Fakultas FISIP Universitas Pattimura. Jurnal Teknik Sipil Institut Teknologi Padang. 2024;11(1):33-9.

25] Maryam M, Fanani F, Efendi H. Penerapan Konsep Green Building pada Perguruan Tinggi di Daerah Istimewa Yogyakarta dalam Mendukung Program Pengembangan Kota Hijau. SPECTA Journal of Technology. 2021;5(3):261-72.

26] GBCI. Green Building Council Indonesia (GBCI),; 2019.

27] Sudarsana DK, Harmayani KD, Kristianty M. Analisis Penerapan Greenship Existing Building Versi 1.1 Pada Bangunan Gedung Umalas Hotel Dan Residence A Scientific Journal of Civil Engineering. (2020);24:161-67.

28] Li J, Heap AD. A review of comparative studies of spatial interpolation methods in environmental sciences: Performance and impact factors. Ecological Informatics. 2011;6(3-4):228-41.

29] Yudison AP. Development of Indoor Air Pollution Concentration Prediction by Geospatial Analysis. Journal of Engineering & Technological Sciences. 2015;47(3).

30] Jung S, Han S, Choi H. Enhancing Indoor air quality estimation: a spatially aware interpolation scheme. ISPRS International Journal of Geo-Information. 2023;12(8):347.

31] Panhalkar S, Jarag AP. Assessment of spatial interpolation techniques for river bathymetry generation of Panchganga River basin using geoinformatic techniques. Asian Journal of Geoinformatics. 2016;15(3):10-5.

32] Barid B, Putra PFA, Nursetiawan, Robial SM, editors. Distribution of river pollutants through the urban area in Winongo river. AIP Conference Proceedings; 2025: AIP Publishing LLC.

33] Utomo NW, Zaki A, Riyadi S, editors. Optimizing electricity consumption prediction in Indonesia through neural networks and green building considerations. AIP Conference Proceedings; 2025: AIP Publishing LLC.

34] Rodríguez-Guerreiro M-J, Torrijos V, Soto M. A Review of Waste Management in Higher Education Institutions: The Road to Zero Waste and Sustainability. Environments. 2024;11(12):293.

35] Razali N, Khalil N, Bohari AAM, Husin HN. Green procurement in construction: Analysis of the readiness level and key catalyst among construction enablers. International Journal of Sustainable Construction Engineering and Technology. 2021;12(1):1-11.

36] Fuqaha S, Zaki A, Nugroho G. Optimizing indoor air quality in sustainable homes: A simulation-based evaluation of VOC emissions from bamboo-based materials. Res Eng Struct Mater. 2025;11(4):1767-86.

37] Purumal K, Ali AS, Zakaria N, Baaki TK. Systematic literature review on green maintenance principles and maintenance performance indicators for green buildings design. Journal of Design and Built Environment. 2021;21(2):59-75.

38] Sari LH, Rauzi EN, Allaily A, Pertiwi AL. Evaluasi kualitas udara dan kenyamanan termal pada ruang kelas pada masa pandemi Covid-19. Arsitekno. 2022;9(1):21-30.

39] Nasir I, Haider H, Shafiquzzaman M, Alinizzi M, Hu G, Ghumman AR. Investigating the Effects of Occupancy and Natural Ventilation on the Indoor Air Quality of Dormitories in Cold Regions. Buildings. 2025;15(6):896.

40] Afroz R, Guo X, Cheng C-W, Delorme A, Duruisseau-Kuntz R, Zhao R. Investigation of indoor air quality in university residences using low-cost sensors. Environmental Science: Atmospheres. 2023;3(2):347-62.

41] Ii H, Taguchi K, Yamashita M. Natural Ventilation Effect On Co2 Concentrations In Classrooms, Wakayama University, Japan. GEOMATE Journal. 2016;10(21):1936-42.

42] Jamala N, Hamzah B, Mulyadi R. Architectural Elements Shaping Thermal Comfort in Floating Houses on Tempe Lake. An-Najah University Journal for Research-A (Natural Sciences). 2025;9999(9999):None-None.

43] Muhaimin M, Jumriani J, Alviawati E, Angriani P. Urgensi Kenyamanan Termal dalam Perspektif Pembelajaran. Geodika: Jurnal Kajian Ilmu dan Pendidikan Geografi. 2023;7(1):23-32.

44] Nurfajriyani I, Fadilatussaniatun Q. Pengaruh Suhu Ruangan Kelas Terhadap Konsentrasi Belajar Mahasiswa Pendidikan Biologi Semester Vii (B). Bio Educatio. 2020;5(1):377461.

45] Dahlblom M, Jensen L, editors. Vertical temperature increase in multi-storey buildings. 10th Nordic Symposium on Building Physics; 2014.

46] Santoso EI. Kenyamanan termal indoor pada bangunan di daerah beriklim tropis lembab. The Indonesian Green Technology Journal. 2012;1(1):13-9.

47] Ni Z, Hupkes J, Eriksson P, Leijonhufvud G, Karlsson M, Gong S. Parametric Digital Twins for Preserving Historic Buildings: A Case Study at Löfstad Castle in Östergötland, Sweden. IEEE Access. 2025.

48] Francisco PW, Rose WB, editors. Temperature and humidity measurements in 71 homes participating in an iaq improvement program. 11th International Conference on Thermal Performance of the Exterior Envelopes of Whole Buildings, Buildings XI; 2010.

49] Seppänen O. Effects of indoor air humidity. REHVA App. 2021:202124.

50] Wolkoff P. Indoor air humidity, air quality, and health–An overview. International journal of hygiene and environmental health. 2018;221(3):376-90.

51] Li DH, Tsang EK. An analysis of daylighting performance for office buildings in Hong Kong. Building and environment. 2008;43(9):1446-58.

52] Budiarti FM, Puspitasari P, Lahji K. Natural Lighting's Contour, Case: Classroom-Studio, Floor 6th Building C, Universitas Trisakti International Journal on Livable Space. 2022;7(1):19-23.

53] Wan Abdullah WNH, Hamimi A, Ismail A. Systematic literature review (SLR) on the factors affecting distribution of natural lighting inside classrooms. 2019.

54] Suwarlan SA. Evaluasi Kenyamanan Visual Pada Pencahayaan Ruang Kelas Melalui Simulasi Komputansi Arsitektur Digital. Jurnal Arsitektur ARCADE. 2021;5(2):165-70.

55] Song D, Yoon S, Jeong C, Kim J, Lim H. Heat, vapor, and CO2 transportation caused by airflow in high-rise residential buildings. Building and Environment. 2019;160:106176.

56] Künzel HM. Indoor relative humidity in residential buildings–a necessary boundary condition to assess the moisture performance of building envelope systems. Download: http://www hoki ibp fraunhofer de/ibp/publikationen/fachzeitschriften/wksb% 20Raumluftfeuchte1_E pdf. 2015.

57] Prasetyo S, Hidayat U, Haryanto YD, Riama NF. Karakteristik Suhu Udara di Pulau Jawa Kaitannya Dengan Kelembapan Udara, Curah Hujan, SOI, dan DMI. Jurnal Geografi, Edukasi dan Lingkungan (JGEL). 2021;5(1):15-26.

58] Allen JG, MacNaughton P, Satish U, Santanam S, Vallarino J, Spengler JD. Associations of cognitive function scores with carbon dioxide, ventilation, and volatile organic compound exposures in office workers: a controlled exposure study of green and conventional office environments. Environmental health perspectives. 2016;124(6):805-12.

59] Duarte R, Moret Rodrigues A, Pimentel F, Gomes MdG. The Effect of Occupancy and Environmental Physical Variables on Classrooms' Natural Ventilation: A Path Modeling Approach. Applied Sciences. 2024;14(24):11705.

60] Mumpuni PW, Widayat R, Aryani SM. Pencahayaan Alami Pada Ruang Baca Perpustakaan Umum Kota Surabaya. Vitruvian: Jurnal Arsitektur, Bangunan, dan Lingkungan. 2017;6(2):185908.

61] Kaminska A. Impact of building orientation on daylight availability and energy savings potential in an academic classroom. Energies. 2020;13(18):4916.

62] Wang L, Zhang X, Qi D. Indoor thermal stratification and its statistical distribution. Indoor air. 2019;29(2):347-63.

63] Gilani S, Montazeri H, Blocken B. CFD simulation of stratified indoor environment in displacement ventilation: Validation and sensitivity analysis. Building and Environment. 2016;95:299-313.

64] Bonello M, Micallef D, Borg SP. Humidity distribution in high-occupancy indoor micro-climates. Energies. 2021;14(3):681.

65] Fikry A, Elsayed A. Improving the indoor air quality (IAQ) in naturally ventilated lecture hall with a single facade by solar chimneys. Journal of Engineering and Applied Science. 2021;68(1):29.

66] Yu J, Wang H, Sui Y, Xu Y, Chen Y. Optimising Ventilation Strategies Based on Predicted Mean Vote and Indoor CO2 Concentration: A Case Study of University Teaching Spaces in Cold Region of China. Buildings. 2024;14(12):3822.

67] Rosbach JT, Vonk M, Duijm F, Van Ginkel JT, Gehring U, Brunekreef B. A ventilation intervention study in classrooms to improve indoor air quality: the FRESH study. Environmental health. 2013;12(1):110.

68] Tyas WI, Nabilah F, Puspita A, Syafitri SI. Orientasi Bangunan Terhadap Kenyamanan Termal pada Rumah Susun Leuwigajah Cimahi. Reka Karsa: Jurnal Arsitektur. 2015;3(1).

69] Wiyanto AFE. Analisis pencahayaan alami dan buatan pada ruang kantor terhadap kenyamanan visual pengguna. Jurnal Patra. 2021;3(1):33-42.

70] Abdullah WNHW, Ismail A, Tharim AHA, Ibrahim FS, Mohammad WNSW. Identifying Optimal Window-To-Wall Ratio (WWR) And Window-To-Floor Ratio (WFR) For Typical Higher Educational Classrooms To Address Deficiencies In Daylighting Design. Malaysian Journal of Sustainable Environment. 2025;12(2):81-102.