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Original Article

Setting Sustainability Benchmarks for High-Rise Building Design in the Context of Hot and Humid Urban Climates

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Abstract

Green design is the process of designing and a development approach that focuses on human health and a way that minimises environmental impacts. In line with the rapid development and growth of the construction industry in Malaysia, green building design has become familiar, especially in high-rise buildings in city areas with many citizens. However, the hot and humid weather is a limitation of green designs for high-rise buildings due to the tropical location of Malaysia. Green design remains in the early phase of science and the approach underlying green building concepts. Numerous concerns persist, and obstacles must be addressed before the industry can achieve substantial advancement in the implementation of efficient green design programs. Malaysia faces innumerable issues regarding the environmental and economic performance of green buildings. A considerable volume of critiques regarding the actual environmental performance of buildings that have received green building certifications for new construction. The execution is deficient due to inadequate knowledge among stakeholders, consultants, and contractors. This study aims to determine the performance of the green designs for high-rise buildings in hot and humid weather. The research also covered establishing a criterion for green design in high-rise buildings under hot and humid weather. However, the last objective of this research is to propose alternatives for improving green design practice for high-rise buildings in hot and humid weather. In addition, the study aims to determine the efficiency, sustainability and security of green designs that can be used in high-rise buildings to transform Malaysia's construction industry into a more sustainable and environmentally friendly sector. It will ultimately create healthier and more productive spaces by reducing greenhouse gas emissions, improving air quality and saving natural resources.

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1. Introduction

1.1. Research Background

Green design is to design, operate, and maintain buildings, energy, water, and new materials that are utilised, as well as reduce the amounts of waste that cause negative effects on health and the environment. To limit these effects, green designs must be introduced, clarified and practised [1]. From an experienced art and architecture expert's perspective, green design is an approach to building that minimises the harmful effects of construction projects on human health and the environment [2]. By 2050, the urbanisation rate is projected to increase to 69%. Currently, over 4.2 billion people or 55% of the global population live in urban regions compared to 30% in 1950 [3].

According to 2019 data, from 610 cities in 95 countries, only half the world's urban population has convenient access to public transportation (see Figure 1) [4]. As urban growth increases, it gives rise to problems that threaten the sustainability of the environment, such as overpopulation, increased energy consumption, noise pollution, lack of housing and poor living conditions. It is important to note that cities use about 80% of the resources and are responsible for almost 80% of global CO_2 emissions, even though they are located on only 5% of the Earth's surface [5]. City buildings consume 32% of global energy and produce around 19% of greenhouse gas emissions.

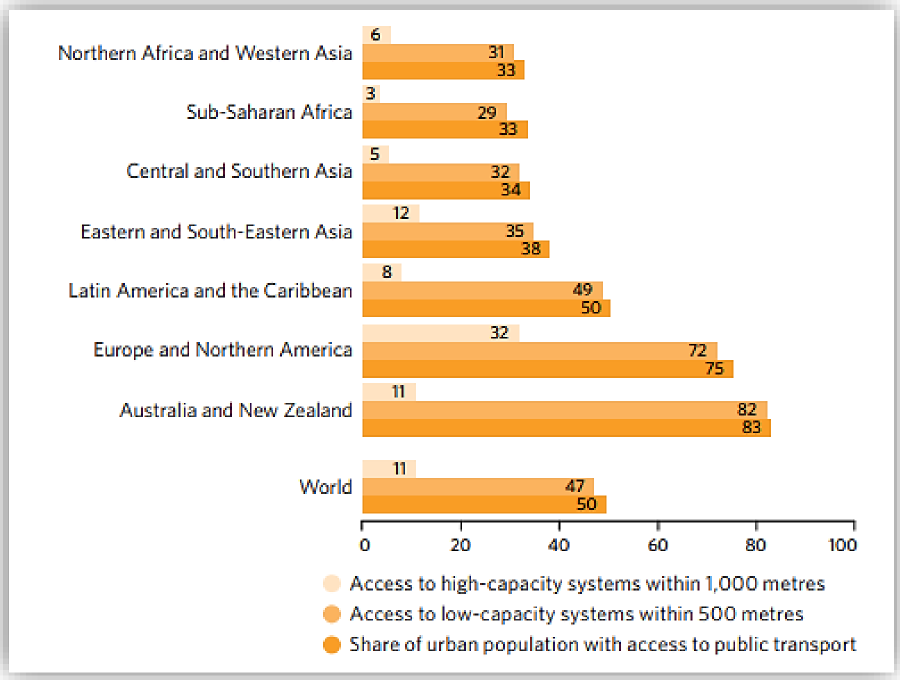

Figure 1: Proportion of urban population with convenient access to public transport.

Designing low-energy buildings for urban areas under a hot and humid climate is challenging. Given the impacts of the urban heat island effect, it significantly influences urban comfort [6]. Under climatic conditions of increased rainfall and humidity coupled with high ambient temperature, typical energy efficiency technologies are not always sufficient [7]. In this case, people tend to spend excessive time in air-conditioned indoor spaces, which negatively affects health and increases building energy consumption [8]. Green design should have a minimal impact on the environment, both in terms of products and materials used in the construction, but also in the functionality of the building. It should always seek to amalgamate environmentally preferred outcomes throughout the whole life cycle of the building [9].

1.2. Literature Review

1.2.1. Green Design Criteria

The world's first green building standard was introduced in the UK in 1990, followed by the formation of the U.S Green Building Council in 1993. Throughout the 1990s, national and global initiatives developed sustainable development practices and policies. Green building certification is one of the initiatives that stimulates those practices. Green building rating systems are abundant worldwide, including LEED, BREEAM and Green Star [10]. Moreover, introducing green building certification systems into the construction industry was welcomed and beneficial as it motivated the growing global sustainability approach [11]. Green building certification systems were part of the sustainable development process and have retained their value until today [12]. The case study of Blackburne et al. [13] found that a flaw in the rating system is the lack of consideration of buildings in a specific region under the same environmental and weather conditions. One factor that might contribute to this confusion is that different areas use diverse green rating systems.

More than 82,000 commercial projects are participating in the LEED programme worldwide [14]. The world's second-tallest building, Taipei 101, was intended to apply for the LEED certification; it aims to become the first skyscraper to obtain the LEED Gold certification [15]. China's tallest green skyscraper, Shanghai Tower, achieved a China Green Building Three-Star Rating and LEED Platinum Certification in 2015. In Kuwait, very few tall buildings have received LEED certification, only one has received LEED pre-certification, and others are in the process [16]. In Singapore, the GM scheme was initiated by Singapore's Building and Construction Authority (BCA) in January 2005, aiming to develop an environmentally friendly construction industry and create sustainability awareness. Singapore's government set Building Control Regulations in April 2008 that require all new buildings and retrofitting to meet a minimum environmental sustainability standard [17]. The Singapore Government took various initiatives, including providing a $100 million fund for developers to retrofit their buildings to green standards and $20 million for building owners and other relevant stakeholders to implement green design techniques [18].

In addition, the most widely used green building rating in the world is LEED, Leadership in Energy and Environmental Design, developed by the United States Green Building Council. LEED certification is a global solution that can help buildings reduce carbon emissions, energy and waste, conserve water, prioritise safer materials and lower exposure to toxins [14]. It provides guidelines for evaluating the sustainability of different types of projects. The LEED rating system includes LEED for building design and construction, LEED for interior design and construction, LEED for neighbourhood development, LEED for homes, LEED for cities and communities, LEED for retail, LEED for schools, etc. LEED works by creating a thorough assessment towards the key environmental properties that are included in the buildings. The elements may include site impacts, energy and water consumption, material and resource conservation and indoor air quality [19]. When the buildings meet certain criteria or several credits and points, they will become certified at different levels, depending on the score collected [20].

Moreover, Malaysia has scored an impressive performance in the green building niche, the Green Building Index (GBI). GBI is the nation's first comprehensive rating system for evaluating the environmental design and performance of buildings, towns and factories [21]. However, GBI is a rating system developed by the Malaysian Institute of Architects (PAM) and the Association of Consulting Engineers Malaysia (ACEM). GBI has been divided into various grades, which are certified, silver, gold and platinum. In addition, the GBI index looks at the building's energy efficiency, orientation, HVAC systems, lighting management system, materials or resources used, indoor air quality, and water used. Green Building Index Sdn Bhd stated that GBI is open to all construction industry players to validate the environmental initiatives at the design, construction, and procurement phases. Lam Soon Edible Oils Distribution Centre, which is located at Seberang Perai, is Malaysia's first GBI industrial-certified distribution centre [22]. It benefits from 33% savings in potable water consumption and achieves 40% energy consumption savings by developing for maximum natural daylight penetration and natural ventilation.

1.2.2. Green Design in High-rise Buildings

Structures with a height of 14 stories or 50 meters are considered tall buildings, and structures with 300 meters to 600 meters are considered super tall buildings or skyscrapers [23]. In Middle Eastern nations, skyscrapers have emerged as the prevalent architectural trend due to rapid economic growth in these regions [24]. This development continues vigorously, in the Middle East, establishing the area as one of the most active centres for high-rise building construction [25].

The Construction Industry Development Board (CIDB) highlighted that adopting green building concepts is transforming construction practices in Malaysia. Malaysia stands ready to embrace it early on, acknowledging its potential economic and environmental advantages. Moreover, the growing number of green buildings erected in the middle of Kuala Lumpur strengthens the demand for evidence of sustainable building practices in Malaysia. One of the reasons behind this booming trend is the potential cost savings associated with green buildings, particularly in electricity [26]. Thus, it can be seen that green practice has become increasingly common in all types of buildings in Malaysia.

Most Malaysian government office buildings consume energy inefficiently due to insufficient energy optimisation, leading to high energy consumption [27]. Office buildings use the most electrical energy during the maintenance and operating stage, such as elevator systems, office appliances, and the heating, ventilation, and air-conditioning (HVAC) system. A case study on multiple-rise office buildings found that the largest air-conditioned area consumes the most energy.

A case study on multiple-rise office buildings found that the largest air-conditioned area (Building F) at 19,777.81m^2 consumed the highest energy consumption with 2,665,940.60 kWh annual in 2019 and 2,614,779.99 kWh in 2020, illustrated in Tables 1 and 2 and Figure 2. The room function of the area is mainly individual office rooms and open space office areas [28]. Skyscrapers are one of the most un-ecological of tall building types, which utilise 30% more energy and material resources from building, operating and even demolishing [29]. Life-cycle engineering is the central consideration for any high-rise building design. The result showed that the operating energy consumption represents around 85% of the total energy consumed at the end of the 50-year cycle of the building [30].

Table 1: Building Floor Area.

Building	Number of Floors	Number of Occupants	Area (m^2)	Air-conditioned
A	4	34	2,475	1,975.56
B	4	11	2,115	1,652.11
C	4	189	2,525	1,978.28
D	4	138	2,515	1,990.38
E	3	9	1,880	1,278.85
F	17	687	26,460	19,777.81

Table 2: Annual Energy Consumption of Each Building.

Building	Annual Energy Consumption (kWh)	
	2019	2020
A	146,349.60	138,272.06
B	134,870.43	119,303.05
C	252,577.92	215,649.04
D	180,688.67	155,244.82
E	154,441.53	209,143.66
F	2,665,940.60	2,614,779.99

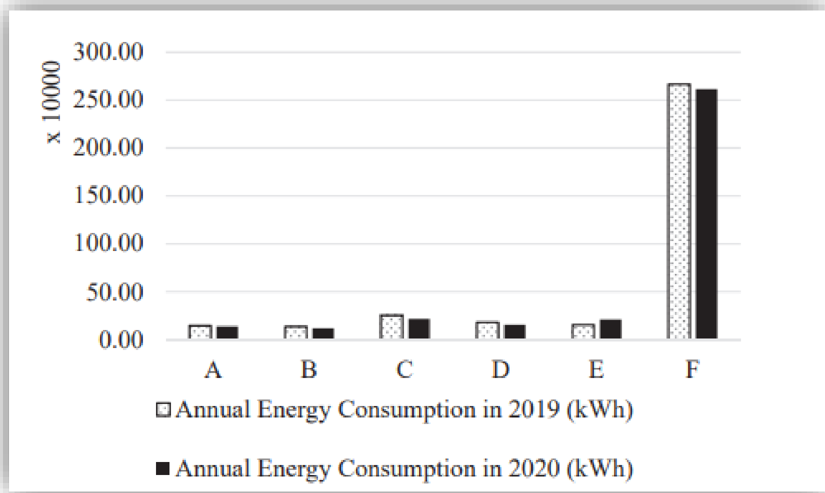

Figure 2: Annual Energy Consumption of Each Building.

2. Methodology

2.1. Research Process

Three stages were conducted to achieve the research objectives (see Figure 3). The literature was reviewed, which helped establish the problem statement, research objectives, scope of research, research significance, and methodology. The outcomes involved determining performance, establishing criteria, and proposing alternatives for green design practices for high-rise buildings in hot and humid weather.

I: Stage 1 encompasses preparing a questionnaire form related to RO1, which is the performance of green design for high-rise buildings in hot and humid weather. This phase also determines the sampling method and population target group of respondents to identify scores of each aspect based on a one-to-five-point linear scale.

II: Stage 2 encompasses the preparation of interview questions from the literature review related to the RO2 and RO3, which are the criteria and best practices improvements of green design for high-rise buildings in hot and humid weather. This phase also determines the sampling method and population target group of respondents to gather their actionable insights and perspectives on green design from their experiences. An arrangement of interview sessions is also implemented in this section after determining the targeted respondents.

III: Stage 3 encompassing alternatives to evaluate data collected from questionnaire form as well as transcribe and organize results, findings, and opinions from the interview session. This phase comes out with data conclusion and result analysis.

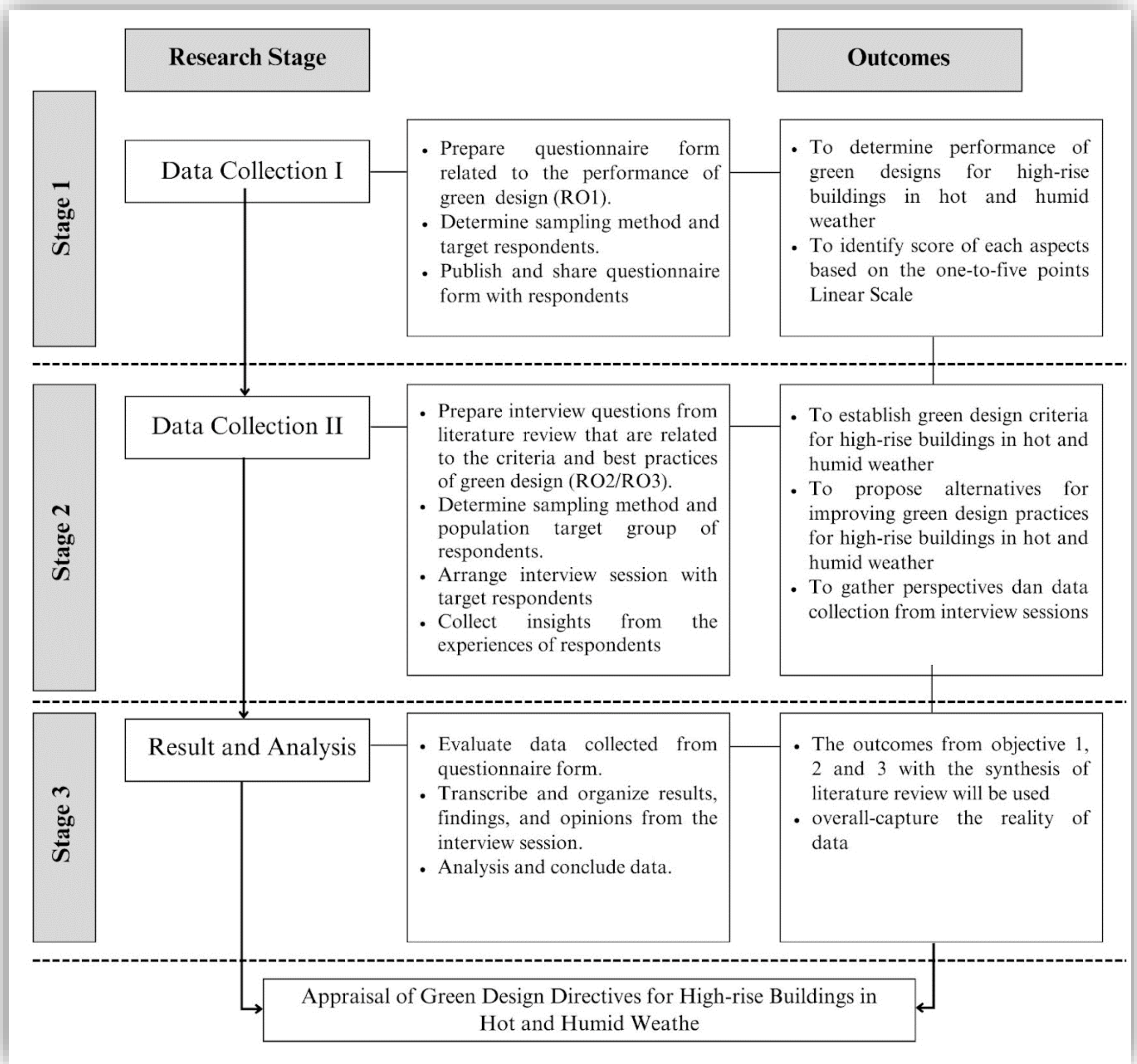

Figure 3: Research Process for Appraisal of Green Design Directives for High-rise Buildings in Hot and Humid Weather.

2.2. Semi-structured Interview

The semi-structured interview with construction stakeholders is conducted to achieve research objectives, which are to establish green design criteria and alternatives for improving green design practices for high-rise buildings in hot and humid weather. The interview session is conducted online and face-to-face, depending on the interviewee. The expertise and involvement of professionals in the green design construction industry develop the interview questions. The respondents are invited to provide their relative insights, perspectives, recommendations, and opinions regarding the criteria for improving green designs for high-rise buildings in hot and humid weather. The sampling method used for this data collection is non-probability sampling, which includes snowball and purposive sampling. The study engaged over eight professionals with more than five years of experience in green design for high-rise buildings in hot and humid climates. They contributed their insights through semi-structured interviews. Respondents' profiles include architects, mechanical and electrical engineers, building surveyors, environmental auditors and green building assessors engaged in public, private and academic sectors. The results from the semi-structured interview session are analysed using QDAS Statistics. Tables 3 to 5 illustrate the questions from semi-structured interviews based on respondents' expertise and involvement in the construction industry.

Table 3: Interview Questions for Building Surveyors.

Questions for Building Surveyors
1. What is your role in this high-rise building?
2. How many years of experience do you have in your field?
3. What education level have you achieved?
4. How would you define "green design" in the context of high-rise buildings?
5. What are the main sustainability considerations in green building designs for hot and humid climates?
6. What specific design features are essential for a green high-rise building in hot and humid weather?
7. From an environmental perspective, what materials are most suitable for high-rise buildings in hot and humid climates?
8. How do factors like solar exposure, natural ventilation, and heat management play a role in green designs for buildings in hot and humid weather?
9. How do green buildings address energy efficiency in hot and humid regions?
10. What are the limitations of existing green design practices in hot and humid weather?
11. Can you share any alternative green design strategies that could significantly improve the performance of high-rise buildings in hot and humid climates?

Table 4: Interview Questions for Architects and M&E Engineers.

Questions for Architects and M&E Engineers
1. What is your role in this high-rise building?
2. How many years of experience do you have in your field?
3. Which education level have you achieved?
4. How would you define "green design" in the context of high-rise buildings?
5. What specific design features are essential for a green high-rise building in hot and humid weather?
6. What site-specific considerations influence the design of green high-rise buildings?
7. What materials are most suitable for high-rise buildings in hot and humid climates from an environmental perspective?
8. How does incorporating green technologies such as solar panels, rainwater harvesting, or energy-efficient HVAC systems improve the sustainability of high-rise buildings in hot and humid climates?
9. What challenges do you face when designing high-rise buildings in hot and humid climates, specifically related to green design?
10. What are some new technologies or systems that could help reduce energy consumption and improve the comfort of occupants in hot and humid environments?
11. What alternative building materials would you recommend for improving green design in high-rise buildings in hot and humid regions?
12. What alternative energy-efficient systems, such as solar power and wind energy, could be used in high-rise buildings to minimise energy consumption in hot and humid climates?
13. What alternative approaches can be used to optimise the performance of heating, ventilation, and air conditioning (HVAC) systems in hot and humid environments?
14. What alternative green design solutions are cost-effective for improving the sustainability of high-rise buildings in hot and humid climates?
15. What alternative design practices can be adopted to improve the health and well-being of building occupants in high-rise buildings in hot and humid climates?
16. What future innovations could improve green design practices for high-rise buildings in hot and humid climates?

Table 5: Interview Questions for Green Building Assessors and Environmental Auditors.

Questions for Green Building Assessors and Environmental Auditors
1. What is your role in this high-rise building? 2. How many years of experience do you have in your field? 3. Which education level have you achieved? 4. Do you frequently use green facilities in your daily life? 5. How would you define "green design" in the context of high-rise buildings? 6. What are the main sustainability considerations in green building designs for hot and humid climates? 7. What design features are essential for a green high-rise building in hot and humid weather? 8. What are the considerations that influence the design of green high-rise buildings? 9. What are your main challenges in implementing green design practices for high-rise buildings in hot and humid climates? 10. What are the limitations of existing green design practices in hot and humid weather? 11. Can you share any alternative green design strategies that could significantly improve the performance of high-rise buildings in hot and humid climates? 12. What are some new technologies or systems that could help reduce energy consumption and improve occupant comfort in hot and humid environments? 13. What alternative materials would you recommend for improving green design in high-rise buildings in hot and humid regions? 14. What are some alternative energy-efficient systems, such as solar power and wind energy, that could be used in high-rise buildings to minimise energy consumption in hot and humid climates? 15. What alternative approaches can optimise the performance of heating, ventilation, and air conditioning (HVAC) systems in hot and humid environments? 16. What alternative green design solutions are cost-effective for improving the sustainability of high-rise buildings in hot and humid climates? 17. What alternative design practices can be adopted to improve the health and well-being of building occupants in high-rise buildings in hot and humid climates? 18. What future innovations do you foresee that could further improve green design practices for high-rise buildings in hot and humid climates?

2.3. Study Populations

The targeted population is selected based on respondents' expertise and direct involvement in the construction industry. The research questions can be addressed effectively by them from their professionals, expertise, and experiences. The professionals involved in this research include building surveyors, mechanical and electrical engineers, environmental auditors, architects, and green building assessors. Intended to achieve research objectives regarding green design directives for high-rise buildings in hot and humid weather.

Table 6: The Study Populations.

No.	Professional	RO1	RO2	RO3
1	Building Surveyors	✓	✓	✓
2	Mechanical and Electrical Engineers	✓	✓	✓
3	Green Building Assessors	✓	✓	✓
4	Architects	✓	✓	✓
5	Environmental Auditors		✓	✓

Building surveyors can play their roles in assessing the functional performance of building services (RO1), identifying practical criteria from an operational perspective and how green design can meet building regulations (RO2), as well as assessing the feasibility of green fixture alternatives (RO3). However, M&E engineers can evaluate the efficiency of energy, ventilation, and cooling systems (RO1), provide technical criteria for energy-efficient systems (RO2), and recommend alternative technologies

(RO3). In addition, green building assessors can give insight into the overall performance of green building certifications and benchmarks (RO1), offer insights into green certification systems and their criteria suitable for tropical weather (RO2), as well as highlight gaps in current green practices and give their recommendations (RO3). Moreover, architects can provide insight into the design intent, material selections, and techniques in green design (RO1); describe design principles, material selection, and spatial planning (RO2); as well as suggest innovative design solutions (RO3). Besides that, environmental auditors can ensure established or current criteria align with ecological regulations (RO2) and provide their insights into sustainable alternatives (RO3).

3. Results

3.1. Data Analysis

The data collected from semi-structured interview sessions and the answers to interview questions will be gathered from different construction stakeholders' perspectives and evaluated using quantitative data analysis software, Atlas. The results are analysed, and a conclusion is drawn. All information from the data collection is evaluated by technological software, and the results that can be used in decision-making are further analysed.

The selection of building materials is essential for improving sustainable design practices in high-rise buildings located in hot and humid climates, as it addresses the unique challenges these environments present, including extreme heat, high humidity, and frequent rainfall, all of which can impact building performance, energy efficiency, and occupant comfort [31–46]. High-rise buildings in these climates must balance maintaining indoor comfort and reducing energy consumption, with material choices playing a pivotal role in achieving this goal [47]. The ideal materials for these environments are those that provide thermal resistance, moisture management, durability, and energy efficiency, while also supporting environmental sustainability by lowering the building's carbon footprint and promoting the health of its occupants [48–55]. A primary consideration in material selection is thermal performance, where materials with high thermal mass, such as concrete, brick, and stone, are favoured because they absorb heat during the day and release it during cooler nighttime hours, helping to moderate indoor temperatures and reduce reliance on cooling systems [56]. However, these materials must be paired with insulating materials such as insulated concrete forms, reflective coatings, and insulated glass, which prevent heat from entering the building and reduce the need for energy-intensive cooling. Advanced glazing technologies, such as low-emissivity glass, can further reduce solar heat gain while allowing natural light to enter the building [57–65].

Moisture resistance is another critical consideration, as high humidity levels can cause mould, corrosion, and material degradation. Materials like concrete and brick are resistant to water penetration. They are often used to protect the building envelope, while moisture-resistant gypsum board, fibre-cement cladding, and treated wood help safeguard interior and exterior surfaces. Proper ventilation and breathable materials are also vital in controlling moisture and minimising condensation, reducing the risk of mould growth. Roofing materials are equally important in these climates, as they are exposed to heavy rainfall and intense sunlight. Cool roofs, made from reflective materials or coatings, help reduce heat absorption and improve energy efficiency by reflecting sunlight away from the building.

Durability is another key aspect of material selection [66]. Given the harsh conditions of hot and humid climates, such as saltwater exposure, frequent storms, and rapid deterioration, materials resistant to corrosion and weathering are essential. Stainless steel, aluminium, and treated timber are commonly used for facades and external elements, as they offer durability and resistance to the damaging effects of humidity and salt [67,68]. Using local and renewable materials, such as bamboo, timber, or clay, can further enhance sustainability by reducing transportation energy and carbon emissions and providing natural insulation. Additionally, using sustainably harvested wood or bio-based composites supports responsible resource management and reduces reliance on finite resources. Incorporating recycled materials, such as those with a high percentage of recycled content, can also help reduce the environmental impact of construction.

Integrating green building technologies, such as photovoltaic panels, green roofs, and rainwater harvesting systems, can enhance the building's energy efficiency and sustainability [69–76]. Solar panels generate renewable energy, green roofs reduce heat absorption and provide insulation, and rainwater harvesting systems minimise water consumption by collecting rainwater for non-potable uses. Passive design strategies are also crucial for reducing the need for mechanical heating and cooling by utilising natural resources like airflow, sun shading, and ventilation [77,78]. Carefully selected materials for thermal insulation, high-performance glazing, and shading devices help support these strategies, ensuring that buildings remain comfortable while minimising energy use [79]. Additionally, selecting materials contributing to occupant health and comfort is crucial in hot and humid climates [80–83]. Non-toxic, low-VOC materials in paints, adhesives, and finishes help create healthy indoor environments. In contrast, materials that reduce glare and promote thermal comfort, such as light-reflecting surfaces or UV-blocking films, contribute to occupant well-being by improving visual comfort and minimising the effects of excessive heat.

In conclusion, the thoughtful selection of building materials plays a vital role in enhancing the sustainability of high-rise buildings in hot and humid climates. By choosing materials that provide thermal resistance, moisture control, durability, and energy efficiency, while also supporting environmental and occupant health, designers can create buildings that are energy-efficient, comfortable, and environmentally responsible, contributing to a more sustainable and resilient built environment.

4. Conclusions

As development and urbanisation continue to increase in Malaysia, this study will be an important source for developing a framework to enhance people's awareness of protecting and saving the environment's resources. This study contributes significantly to construction players, including interior designers, developers, contractors, architects, and building occupants, to design a more sustainable and efficient high-rise building. The study makes a significant contribution to broader problems in the field of sustainable development and environmental protection. Establishing effective criteria for green design directives for high-rise buildings in hot and humid weather will contribute to the theoretical framework of sustainable design. It expands understanding and develops new conceptual models for green design sustainability assessment. Establishing a standardised approach not only provides structured methods for future studies but also creates a foundation as a comprehensive assessment framework for comparative analysis. Furthermore, green design criteria advance green design directives, quality, techniques and methodologies. Evidence-based design recommendations and practical guidelines can be identified by highlighting gaps in existing green design. Green design criteria also significantly contribute to regulatory development by supporting regulation updates and guiding compliance requirements, such as resource allocation and green practices policies.

Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party on the publication of the current work.

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