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Original Article

Conceptual Framework for Assessing the Impact of Green Design Strategies on High-Rise Building Performance in Regions Characterised by Heat and High Humidity

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Abstract

Green design focuses on creating buildings that enhance human health and minimise environmental impacts. In Malaysia, especially in urban areas, there is growing attention to green building strategies for high-rise structures. However, the nation's tropical climate, characterised by heat and high humidity, poses significant challenges for these sustainable practices. The science and methodologies behind green design are still developing, and successful implementation faces several obstacles, including limited knowledge among stakeholders such as consultants and contractors. This study aims to assess the performance of green design strategies for high-rise buildings in Malaysia's hot and humid environment. It seeks to establish criteria for evaluating green designs under these climatic conditions and proposes alternatives to improve current practices. Environmental and economic performance are major concerns, as some buildings with green certifications do not always deliver expected outcomes due to execution gaps. By evaluating the efficiency, sustainability, and safety of green features in high-rise buildings, the research intends to facilitate the evolution of Malaysia's construction sector toward more sustainable and environmentally friendly practices. The ultimate goal is to promote healthier and more productive living spaces, reduce greenhouse gas emissions, improve air quality, and conserve natural resources, thus supporting a sustainable future for the built environment in regions facing similar climatic challenges.

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1. Introduction

1.1. Research Background

Green building, also commonly referred to as sustainable building, focuses on the processes implemented that are environmentally efficient and responsible throughout the lifecycle of the building [1]. To design, operate, and maintain buildings, energy, water, and new materials are utilised, as well as amounts of waste, which causes negative effects on health and the environment. To limit these effects, green designs must be introduced, clarified and practised [2].

Furthermore, it is projected that by 2050, the urbanisation rate will 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], which has led to the construction of high-rise buildings to increase urban density. 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.

According to data from the United Nations, in 2016, all regions except Australia and New Zealand had annual mean levels of fine particulate matter (PM2.5) that exceeded the World Health Organisation air quality guidelines of 10 micrograms or less per cubic metre (see Figure 1) [3]. 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 [4]. City buildings consume 32% of global energy and produce around 19% of greenhouse gas emissions. It is expected to increase due to urbanisation in the developing countries [5]. Indeed, high-rise buildings are massive consumers of energy.

Figure 1: Annual Exposure to Ambient Fine Particular Matter (PM2.5) in Urban Areas [3].

The relationship between building designs and the surrounding outdoor environment is a multidisciplinary imperative for urban climate and outdoor thermal comfort. Because of the impacts of the urban heat island effect, it significantly influences urban comfort [6]. It influences the functionality of green design. Designing low-energy buildings for hot and humid regions is a great challenge. 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].

The US Environmental Protection Agency defines green buildings as “the practice of creating structures and using processes that are environmentally responsible and resource-efficient throughout a building’s life cycle”. It focuses on the significant environmental benefits of green building designs. Countries including the United Kingdom, China, Sweden and South Africa have recognised these benefits by developing green building certification systems [9].

1.2. Literature Review

1.2.1. Green Design

Green design concepts cover construction methods, technologies, materials, and products that don’t require a lot of resources or pollute the environment compared to conventional construction [10]. According to the Pacific Northwest National Laboratory, ecologically sound or green architecture originated in the 1960s. The energy crisis in the 1970s further fuelled the development of renewable energy resources, including solar, geothermal and wind energy and more energy-efficient buildings. Authorities worldwide actively promote and implement green designs in building projects. Green roof technologies are one of the most popular green features across the world [11]. For instance, more than 10% of houses in Germany possess green roofs [12].

Since the 1970s, humanity’s yearly demand on the natural world has surpassed what the Earth can renew in a year, and the ecosystem will probably collapse if the current consumption rate continues (see Figure 2) [13]. The rise of greenhouse gas emissions is more rapid than expected, and the world is warming faster in return [14]. This has been irreversibly changing the world through the rise of sea level, droughts, floods, storms and heat waves. Therefore, the green design and its criteria play a crucial role in the sustainability of the construction industry.

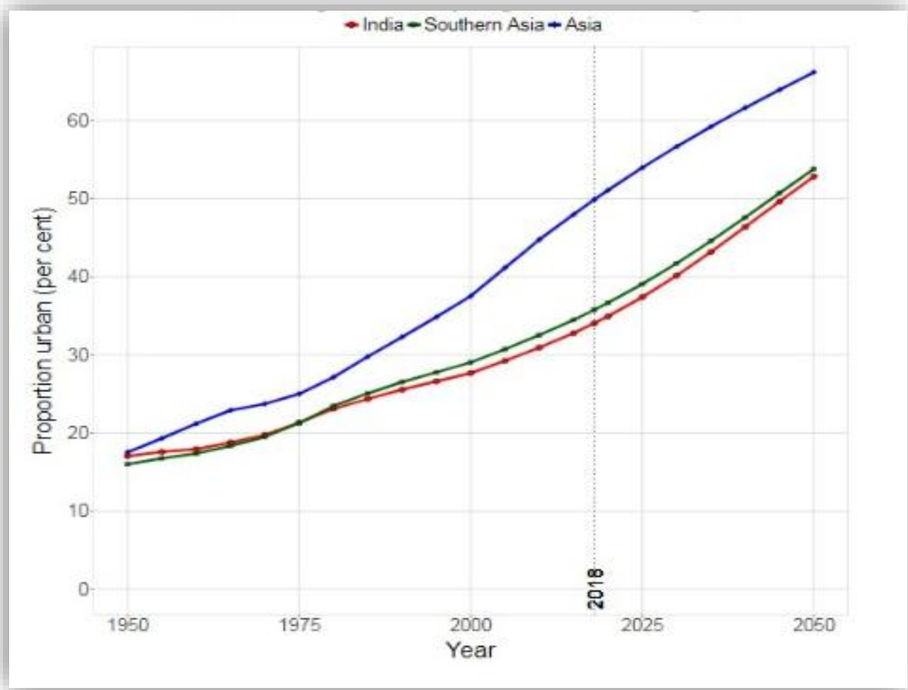

Figure 2: Percentage Urban by Region and Subregion [4].

In 2050, around 68% of humanity will live in cities. These represent only 3% of the plant's surface but consume 78% of energy and produce 60% of greenhouse gas emissions [5]. By 2050, India is projected to have added 416 million urban citizens, China 255 million and Nigeria 189 million [15]. Rapid and unplanned urbanisation has caused environmental problems such as decreased vegetation cover in urban areas because of the expansion of impervious surfaces like buildings, parking lots, and pavements [16]. The effect of climate change has spread around the world. For this reason, in 2016, the UN improved the New Urban Agenda to advise countries on their urbanisation processes and make cities more habitable, inclusive, healthy and sustainable.

About 30% of global greenhouse gas emissions are released from the built environment, while 40% of the energy consumption worldwide [17]. The identified environmental impacts from the built environment include high energy consumption, solid waste generation, rising GHG emissions, and pollution [18]. Green architecture reduces the harmful effects of construction operations [19]. It includes the 3Rs, such as reduce, reuse and recycle, through environmentally beneficial methods [20].

2. Methodology

2.1. Research Process

Three stages were conducted to achieve the research objectives. The literature was reviewed, which helped establish the problem statement, research objectives, scope of research, research significance, and methodology (see Figure 3). 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 encompasses alternatives to evaluating data collected from the questionnaire form and transcribing and organising results, findings, and opinions from the interview session. This phase concludes with a data conclusion and result analysis.

2.2. Questionnaire

The questionnaire survey is conducted to identify the performance of green design for high-rise buildings in hot and humid weather. The questionnaire form is developed by performance of various aspects, including green architectural designs, green features, green materials, green maintenance, energy efficiency and water efficiency (see Table 1). Each identified aspect is assigned a score based on a one to five points Linear Scale (1-strongly disagree, 2 2-disagree, 3 3-neutral, 4 4-agree, 5 5-strongly agree). The respondents are invited to mark the relative significance of each aspect of the performance of 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 research targeted over 30 professionals who have more than five years' experience and are familiar with green design for high-rise buildings in hot and humid weather and participated in this questionnaire. Respondents' profiles include architects, mechanical and electrical engineers, building surveyors, environmental auditors and green building assessors engaged in public, private and academic sectors. The data received from the questionnaire survey were analysed using SPSS Statistics. Below are the questions from a questionnaire survey regarding the performance of various aspects.

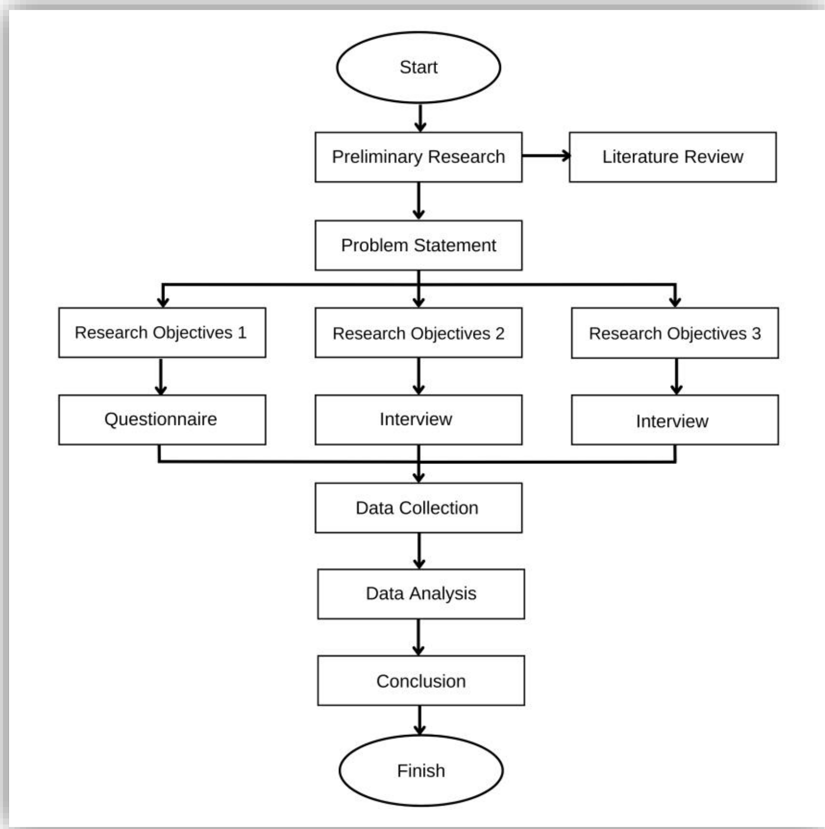

Figure 3: Research Process for Assessing the Impact of Green Design Strategies on High-rise Buildings in Hot and Humid Weather.

Table 1: Questions of Questionnaire Survey.

B1: PERFORMANCE OF GREEN ARCHITECTURAL DESIGNS						
No.	Description	1	2	3	4	5
1.	The overall performance of green architectural design in high-rise buildings in hot and humid climates is good.					
2.	Green architectural designs that incorporate natural ventilation, such as cross-ventilation, reduce the need for mechanical cooling.					
3.	Green architectural design strategies, such as open spaces, can improve thermal comfort and indoor air quality in high-rise buildings in hot and humid regions.					
4.	Green architectural designs help reduce energy consumption through features such as building orientation, shading, or insulation in hot and humid climates.					
5.	The building's layout and design improve natural light penetration and ventilation, reducing the need for artificial lighting and HVAC systems.					
B2: PERFORMANCE OF GREEN FEATURES						
No.	Description	1	2	3	4	5
1.	Green roofs and landscaping are good at reducing the heat absorption of high-rise buildings in hot and humid climates.					
2.	Shading devices such as awnings perform well in protecting high-rise buildings from excessive heat and sun exposure.					

3.	Solar panels and other renewable energy systems effectively reduce the energy demand of high-rise buildings.					
4.	Smart building systems, such as motion sensors, contribute well to optimising energy consumption in high-rise buildings.					
5.	The building uses energy-efficient lighting systems, such as LED lights or compact fluorescent bulbs in order to reduce electricity consumption.					
B3: PERFORMANCE OF GREEN MATERIALS						
No.	Description	1	2	3	4	5
1.	Insulating materials such as thermal insulation and double-glazed windows are good in reducing energy consumption and improving comfort in high-rise buildings in hot and humid climates.					
2.	Sustainable construction materials, such as recycled materials, positively impact the environmental performance.					
3.	The use of locally sourced materials improves the sustainability and performance of high-rise buildings in hot and humid climates.					
4.	The materials used in the building's design are renewable and have minimal environmental impact.					
5.	The building's materials are flexible, allowing it to accommodate changes in function or layout with minimal environmental impact.					
B4: PERFORMANCE OF GREEN MAINTENANCE						
No.	Description	1	2	3	4	5
1.	Ongoing maintenance practices positively affect the long-term performance of green features in high-rise buildings in hot and humid climates.					
2.	Maintenance of energy-efficient systems effectively ensures consistent energy savings and performance in high-rise buildings.					
3.	The materials used in green buildings are sustainable in hot and humid weather.					
4.	Water conservation systems, such as rainwater harvesting systems, are reliable in the long term for high-rise buildings in hot and humid climates.					
5.	Regular maintenance of energy-efficient equipment ensures minimal energy wastage and reduces the building's overall energy consumption.					
B5: PERFORMANCE OF ENERGY EFFICIENCY						
No.	Description	1	2	3	4	5
1.	Green design features such as passive cooling help save energy in high-rise buildings in hot and humid climates.					
2.	HVAC systems in high-rise buildings in hot and humid climates perform effectively when integrated with green design strategies such as natural ventilation.					
3.	Energy-efficient lighting and building systems, such as LED lights, can reduce energy consumption in high-rise buildings.					
4.	The building's insulation, such as walls and windows, effectively minimises heat loss during winter and heat gain during summer, reducing the need for mechanical heating and cooling.					
5.	The building incorporates renewable energy sources such as solar panels that significantly reduce reliance on grid power.					
B6: PERFORMANCE OF WATER EFFICIENCY						
No.	Description	1	2	3	4	5
1.	Rainwater harvesting systems in high-rise buildings are good at reducing water consumption in hot and humid climates.					
2.	Water-efficient fixtures like low-flow faucets reduce water usage in high-rise buildings in hot and humid climates.					
3.	Water-saving landscaping, such as efficient irrigation systems, can reduce water consumption for high-rise buildings in hot and humid climates.					
4.	The building's water efficiency measures have effectively reduced water consumption and minimised environmental impact.					
5.	The water-efficient systems in the building perform well and contribute to the building's sustainability goals.					

2.3. Study Populations

The targeted population is selected based on respondents' expertise and direct involvement in the construction industry (see Table 2). The research questions can be addressed effectively by them from their professional knowledge 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 2: 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

The analysis relied primarily on a linear scale to evaluate responses from the questionnaire, which helped determine the performance of green designs in high-rise buildings in hot and humid climates. Each aspect was rated on a one-to-five scale—ranging from "strongly disagree" (1) to "strongly agree" (5)—and the data were processed using Statistical Product and Service Solutions software, which generated corresponding charts.

Understanding the influence of green building materials and design strategies on the performance of high-rise buildings in hot and humid regions is critical for advancing sustainability. These climates pose unique challenges, including elevated temperatures, high humidity, and frequent rainfall, which call for specialised approaches to building efficiency, comfort, and resilience [21–49]. Buildings in such environments must limit heat gain, control moisture, and reduce cooling energy consumption while preserving their structural integrity [50–55]. Green materials and strategies are crucial in addressing these needs by lowering the environmental footprint, supporting occupant wellness, and improving overall performance.

High-rise structures in these climates are especially exposed to strong solar radiation and persistent humidity, raising the demand for cooling and increasing energy use and carbon emissions. Incorporating green materials, such as high-performance insulation, reflective coatings, and low-emissivity (Low-E) glass, helps reduce solar heat gain and improves the thermal efficiency of the building envelope [56,57]. For example, using rigid foam board, spray foam, or insulated concrete forms for insulation decreases heat transfer to the interior, thereby lightening the load on air-conditioning systems. Adding reflective finishes or light-coloured surfaces to roofs and facades helps reflect much of the sun's energy, resulting in lower building and ambient temperatures and increased energy efficiency, reducing the urban heat island effect [58]. Low-E glass further assists in moderating solar heat while allowing abundant natural daylight, making interior spaces comfortable without excessive artificial lighting or cooling [59]. These strategies reduce the need for energy-intensive cooling, a key factor in climates where energy costs and sustainability targets are important [60].

Moisture management is another vital concern, as persistent humidity can cause mould, material decay, and poor indoor air quality. Materials like moisture-resistant gypsum board, fibre-cement cladding, and water-repellent paints help protect the building envelope from moisture damage and block mould and mildew, supporting healthier indoor spaces and reducing maintenance costs [61]. Advanced ventilation systems, such as heat recovery ventilators (HRVs) and energy recovery ventilators, help regulate indoor air and moisture by exchanging heat or humidity between inbound and outbound air, improving efficiency and supporting comfort [62–66]. The use of breathable materials—such as natural fibres and timber, further aids in air circulation, reducing moisture buildup and supporting a healthy environment [67]. Effective moisture control is essential to ensure the building's longevity, preventing problems like material deterioration or steel rusting [68].

Passive ventilation and other green design strategies are also important. By utilising natural forces—wind, air pressure, and temperature differentials, through design features like operable windows, vents, and cross-ventilation openings, buildings can maintain airflow and natural cooling while reducing reliance on mechanical ventilation [69]. Elements such as shading devices and overhangs help block direct sun, while green roofs and terraces provide extra insulation and promote evaporative cooling, decreasing energy demand [70,71].

Green materials generally provide environmental benefits over traditional ones. Using recycled items such as reclaimed wood, recycled steel, or fly ash-based concrete reduces the need for new resources and minimises the building's carbon footprint. Sourcing materials locally also decreases transportation energy use. In tropical and coastal areas, options like bamboo, local stone, or clay often offer both sustainable and performance advantages, naturally suited to resist heat and humidity. Renewable resources—such as sustainably harvested timber, bamboo, and bio-based composites—support responsible sourcing and environmental stewardship.

Integrating solar panels, rainwater harvesting, and energy storage further enhances sustainability. Solar panels supply on-site renewable energy, rainwater systems conserve potable water, and batteries store surplus energy for periods of high need. These measures encourage comprehensive energy and water conservation and lessen the overall environmental impact [72–74].

Beyond environmental and economic improvements, these green approaches also enhance occupant well-being by ensuring thermal comfort and better air quality. This benefits residents and attracts tenants and investors who prioritise sustainability. Additionally, the increased efficiency of green buildings frequently results in lower operational costs, boosting long-term economic viability [75–77]. The combined environmental, financial, and social advantages underscore the significant positive impacts of employing green materials and strategies in high-rise buildings in hot and humid climates [78,79].

To conclude, evaluating the impact of green building materials and design strategies on the performance of high-rise buildings in challenging hot and humid climates demonstrates that these measures are essential for improving energy efficiency, minimising environmental consequences, enhancing occupant comfort, and ensuring the structure's durability. Incorporating thermal-resistant, moisture-managing, and durable materials alongside green technologies such as solar panels and rainwater harvesting supports sustainability, reduces energy use, and shrinks the building's carbon footprint, contributing to a more sustainable future even in the most demanding conditions.

4. Conclusions

Green design is crucial in reducing energy consumption, maximising resource allocation, mitigating environmental impacts, and enhancing occupants' well-being. By conducting this research, the performance of green design of high-rise buildings in tropical hot climates can be identified. In addition, green design criteria are established based on the insights and experiences of respondents from data collection methods to increase the efficiency of green designs, green materials and green fixtures. By implementing data collection methods such as qualitative methods, the research objective in terms of green design criteria and best practices of green design for high-rise buildings in hot and humid weather can be achieved.

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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