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Original Article

Enhancing Sustainable Design Approaches for High-Rise Buildings in Hot and Humid Climate Regions

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Abstract

Green design is designing and developing an approach that focuses on human health and 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 the science and approach underlying the 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

Most stakeholders in Malaysia believe that adopting green practices requires high costs for materials, resources, technologies and skilled workers [1]. Commonly, there is always the perspective of communities that the cost needed for the green building designs is always higher than that of conventional building designs. The additional costs can be affected by other aspects, including higher purchase cost, learning curve cost, skilled labour cost or special design work [2]. Integrating green design and sustainable infrastructure in high-rise buildings presents various challenges. It includes structural, maintenance, and water management issues [3]. The additional load on the high-rise building structure due to the weight of vegetation, soil and water results in structural challenges in implementing green infrastructure in high-rise buildings [4]. Furthermore, the wind resistance of green facades and vertical gardens also affects the stability and integrity of the tall buildings [5]. The accessibility and safety concerns of maintaining vegetation at great heights can lead to increased maintenance costs and potential risks for maintenance personnel [6].

The community has questioned the effectiveness of the implementation of some current green design policies [7]. Some countries' current green design evaluation policies are not standardised or equitable for different cities with regional differences in economic development. A case study in China found that the green design evaluation standards in developed cities such as Beijing and Shanghai are extremely low, resulting in many development projects that can easily achieve the requirements. However, in regions with a lagged economic development, such as Guizhou and Gansu, the green design evaluation standards are considered high, and few projects can achieve the requirements [8]. In addition, there is a need to pay enough attention during the process of policy revision and criteria formulation to feedback from the public. Moreover, increased penalties and tougher legislation for non-compliance are feasible ways to promote green design development [9].

Green design material costs 3-4% more than conventional materials [10]. The cost for green buildings ranges from 1% to 25% more than traditional buildings due to the complexity of the design layout associated with modelling and green practices [11]. Unfamiliarity with green design technologies adversely affects the project performance and outcome [12]. Furthermore, in tropical or subtropical climates, a lot of energy is consumed for cooling and conventional air conditioners are widely used [13].

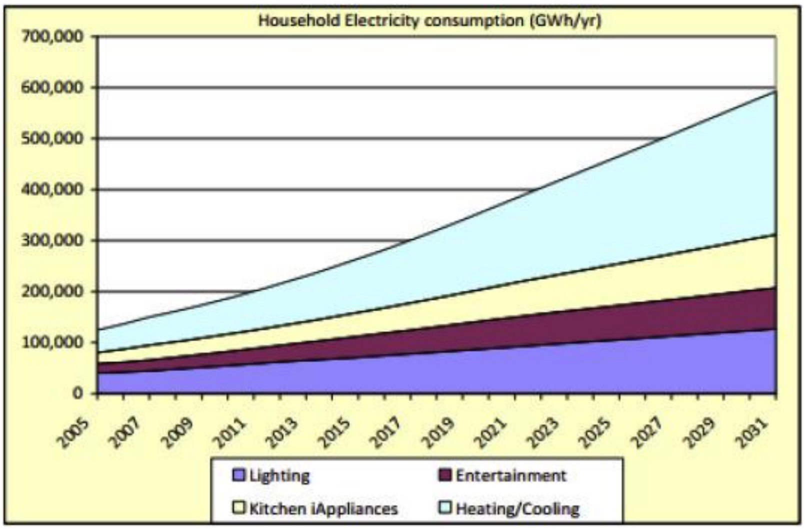

Figure 1: Household Electricity Consumption in India.

As the economy grows and more people get used to a higher standard of living, the energy consumption increases in India, as shown in Figure 1 above. The heating and cooling requirement of Indian households was about 35% of the energy used in 2008 [16]. In the subtropical climates of China, solar energy was the main part of the cooling load [14]. Well-ventilated designs help save energy and control the exhaust flow [15]. Green products should always innovate, update, and advance in economic, environmental, operational, and technical aspects to achieve greater effectiveness.

1.2. Literature Review

1.2.1. Green Design in Hot and Humid Weather

As the economy grows and more people get used to a higher standard of living, energy consumption increases. According to the report published by the World Bank India in 2008, the heating and cooling requirement was about 35% of the energy used in Indian households in 2008 [16]. In tropical climates, much energy is consumed for cooling, and conventional air-conditioners are widely used. Commercial cooling systems are inefficient, require a lot of energy to run and cause pollution [17]. Furthermore, given global warming and the increasing intensity of heat waves, the demand for urban green spaces is increasing, and studies about improving urban microclimates are being conducted. There is sample evidence from several parts of the world that urban green spaces reduce heat and enhance human thermal comfort during warm seasons [18]. However, landscape practitioners still face difficulty translating those insights into implementations because green or blue spaces and interventions mitigate heat stress at different levels under different environmental contexts [19].

The difference between the expected and actual building energy consumption depended on occupancy and their behavioural patterns [20]. For instance, a lack of quality insulation in exterior walls will lead to high cooling demand in a tropical hot climate. Building orientation is also a major contributor to thermal discomfort. It has been identified that the buildings facing southwest received the highest solar radiation levels in July and August 2020, leading to a peak demand for cooling energy. The building with the highest exposure to solar radiation will have the highest risk of overheating, resulting in increased cooling demand.

A study on three Malaysian government office buildings found that the air-conditioning system consumed the most energy at 51%, followed by the lighting system (34%), plug load (8%) and other office appliances at 7% [21]. According to Figure 2, solar radiation in Malaysia in August 2018 recorded the lowest monthly average of daily solar radiation at 120W/m^2/day, while February 2018 recorded the highest monthly average of daily radiation at 191W/m^2/day, corresponding to February 2018 recorded a high maximum outdoor temperature of 30.28℃. However, buildings in Singapore contribute about 31% of total electricity consumption and produce about 16% of greenhouse gas emissions [22]. Singapore's high demand for electricity is largely due to its tropical weather, leading to a high demand for occupants for cooling purposes [23].

Based on the reviewed literature, it can be concluded that there is a significant need for green design practices across countries, particularly in hot and humid regions. Green design practices are necessary in hot and humid climates to achieve sustainability by reducing energy consumption for cooling, enhancing human thermal comfort, and improving urban microclimates.

These findings underscore the complex interplay between climate, building design choices, and energy consumption patterns in tropical and subtropical regions. While innovative materials and policy refinements can potentially reduce environmental impacts, successful implementation hinges on addressing region-specific challenges, such as local economic disparities, technological familiarity, and occupant behaviour. A more holistic approach, one that integrates robust technical standards, responsive legislation, and meaningful stakeholder engagement, can drive the effectiveness of green design across diverse urban contexts.

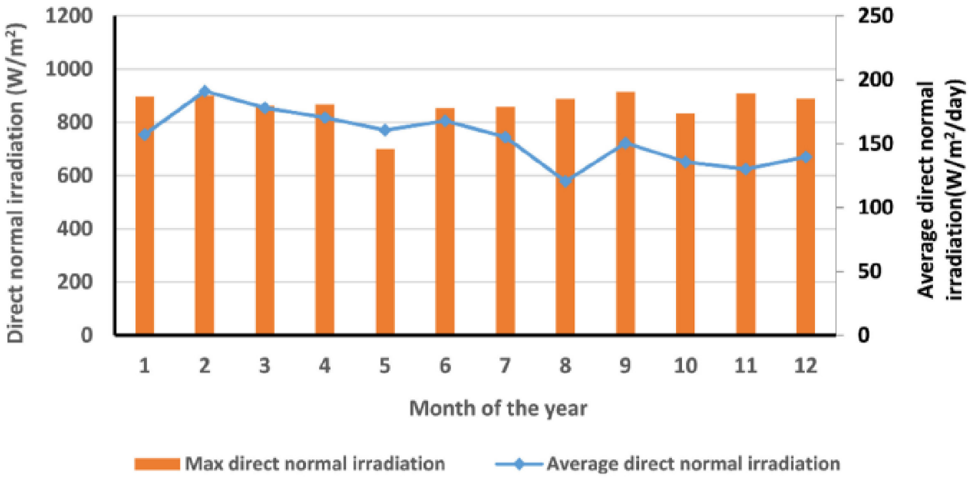

Figure 2: Solar Radiation in Malaysia.

2. Methodology

2.1. Research Process

Three stages were conducted to achieve the research objectives (see Figure 3). Reviewed literature 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 a review of previous articles, journals, and documents related to green design directives, including the efficiency of green designs, criteria for green designs, and alternatives for green design practice improvement in high-rise buildings and hot and humid weather.

II: Stage 2 encompasses an approach to identifying the problem statement, research objectives, research questions, and research methodology, as well as determining the sampling method and the population target group of respondents. This phase also included preparing interview questions for the research objectives.

III: Stage 3 encompasses alternatives to evaluating data collected from the questionnaire form, as well as transcribing and organising results, findings, and opinions from the interview session. This phase concludes with a data conclusion and result analysis.

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 research targeted over 8 professionals with more than five years of experience, familiar with green design for high-rise buildings in hot and humid weather, who participated in this semi-structured interview. 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 were analysed using QDAS Statistics. Below are the questions from semi-structured interviews based on respondents' expertise and involvement in the construction industry (see Tables 1 – 3).

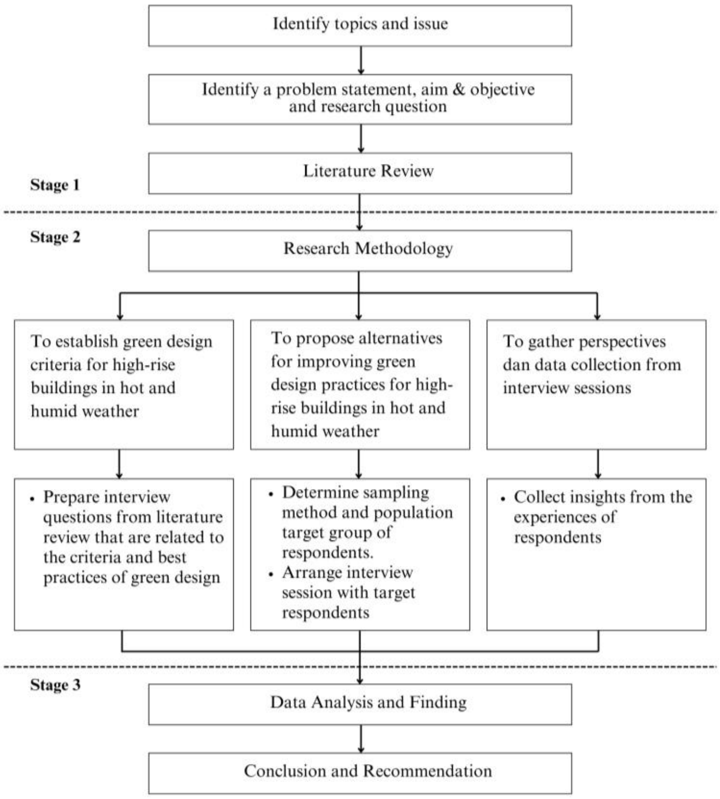

Figure 3: Research Process for Appraisal of Green Design Directives for High-rise Buildings in Hot and Humid Weather.

Table 1: 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. Which 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. What materials are most suitable for high-rise buildings in hot and humid climates from an environmental perspective? 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 2: 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 located in hot and humid regions? 12. What alternative energy-efficient systems, such as solar and wind power, 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 3: 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 specific design features are essential for a green high-rise building in hot and humid weather? 8. What considerations 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 the comfort of occupants 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 minimize energy consumption in hot and humid climates? 15. What alternative approaches can be used to 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 could 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 (see Table 4). 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 4: 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 and Discussion

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 [25].

The significance of building materials in the improvement of sustainable design practices for high-rise buildings in hot and humid climates is a critical aspect of addressing the unique challenges posed by these environments, where extreme heat, high humidity, and heavy rainfall can significantly affect building performance, energy efficiency, and occupant comfort [26]. In these climates, high-rise buildings face the constant challenge of maintaining indoor comfort while minimising energy consumption, and material selection plays a key role in achieving this delicate balance [27-45]. The most effective building materials for hot and humid climates offer thermal resistance, moisture control, durability, and energy efficiency, while also contributing to environmental sustainability by reducing the building's carbon footprint and supporting the health and well-being of its occupants [46-61].

Thermal performance is one of the most important considerations when selecting materials for high-rise buildings in these climates. The building's envelope, including walls, roofs, windows, and facades, plays a pivotal role in regulating indoor temperatures and minimising the need for mechanical cooling systems [62]. Materials with high thermal mass, such as concrete, brick, and stone, are commonly used because they can absorb and store heat during the day and release it during cooler night hours, helping to moderate temperature fluctuations within the building and reducing the reliance on air conditioning [63]. However, the thermal mass must be balanced with the need for insulating properties to prevent heat from penetrating the building. This is where materials such as insulated concrete forms (ICFs), reflective coatings, and insulated glass come into play. Insulated walls, roofs, and windows help prevent heat transfer into the building, reducing the need for energy-intensive cooling systems and ensuring that indoor temperatures remain comfortable without excessive energy consumption [64]. Furthermore, advanced glazing technologies, such as low-emissivity (Low-E) glass, can be used in windows to minimise solar heat gain while allowing natural light to enter the building.

Another significant consideration in material selection is moisture resistance. Hot and humid climates are characterised by high levels of moisture in the air, which can lead to mould growth, corrosion, and deterioration of building materials if not properly managed [65-72]. To address this, building materials must be selected for their ability to resist moisture penetration and maintain structural integrity over time. For example, concrete and brick are often favoured for resisting water absorption and preventing moisture from entering the building envelope. Additionally, materials such as moisture-resistant gypsum board, fibre-cement cladding, and treated wood can protect the interior and exterior surfaces from the damaging effects of high humidity. Proper ventilation and using breathable materials also play a role in moisture control. Materials that allow for natural air flow can help reduce humidity buildup and prevent condensation within the building, minimising the risk of mould and mildew formation.

Furthermore, the choice of roofing materials is particularly important in hot and humid climates, where heavy rainfall and intense sun exposure can cause rapid deterioration [73]. Cool roofs, which are typically made from reflective materials or coatings, can significantly reduce the heat island effect and improve energy efficiency by reflecting sunlight away from the building. These roofs can also help mitigate the temperature extremes that buildings in hot and humid climates are subjected to, enhancing comfort and reducing the energy required for cooling [74].

Another important aspect of sustainable building material selection in high-rise buildings is durability. In hot and humid climates, buildings are subjected to harsh environmental conditions, including saltwater exposure (in coastal areas), frequent storms, and the potential for rapid deterioration of materials due to heat and moisture [75]. Therefore, selecting materials resistant to corrosion, weathering, and other forms of damage is essential. For example, stainless steel, aluminium, and certain types of treated timber are commonly used in constructing facades, balconies, and other external elements because they offer enhanced durability and resistance to the corrosive effects of humidity and salt. Furthermore, long-lasting materials reduce the need for frequent repairs and replacements, lowering the building's overall environmental impact and resource consumption over its lifecycle.

Using local and renewable materials is also a key factor in improving the sustainability of high-rise buildings in hot and humid climates. By sourcing materials locally, transportation energy and associated carbon emissions can be minimised, making the building more environmentally responsible. Additionally, local materials such as bamboo, timber, or clay may better suit the climate, provide natural insulation and reduce the overall energy demand [76]. Renewable materials, such as sustainably harvested wood or bio-based composites, further enhance the sustainability of the building by supporting responsible resource management and reducing reliance on finite resources. Additionally, the integration of sustainable construction practices, such as using recycled materials or materials with a high percentage of recycled content, can further reduce the environmental impact of building construction.

High-rise buildings in hot and humid climates can also benefit from incorporating green building technologies and materials that contribute to energy efficiency and environmental sustainability. For example, using photovoltaic panels, green roofs, and rainwater harvesting systems can significantly reduce a building's reliance on external energy sources and water consumption. Solar panels can generate renewable energy, while green roofs provide insulation and reduce heat absorption, contributing to better temperature regulation within the building. Rainwater harvesting systems, meanwhile, can be used to collect and store rainwater for irrigation and other non-potable uses, reducing the demand for municipal water supply and supporting water conservation efforts.

Another aspect of sustainable design in high-rise buildings in hot and humid climates is the integration of passive design strategies, which focus on reducing the need for mechanical cooling and heating by harnessing natural forces such as air flow, sun shading, and natural ventilation [77]. The materials used in the building envelope, such as thermal insulation, high-performance glazing, and shading devices, should be carefully selected to facilitate these passive strategies. For example, shading materials such as louvres, pergolas, or overhangs can reduce direct solar gain and minimise heat buildup within the building, while strategically placed windows and vents can encourage cross-ventilation and improve air circulation.

Finally, considering occupant health and comfort is integral to sustainable building material selection. In hot and humid climates, ensuring that the materials used in the construction of high-rise buildings do not contribute to indoor air pollution, allergic reactions, or other health issues is essential. Using non-toxic, low-VOC materials in paints, adhesives, and finishes is vital to creating a healthy indoor environment [78]. Furthermore, materials that promote thermal comfort and reduce glare, such as light-reflecting surfaces or UV-blocking films, contribute to occupant well-being by enhancing visual comfort and reducing the negative effects of excessive heat and sunlight.

In conclusion, selecting materials for high-rise buildings in hot and humid climates is a fundamental aspect of sustainable design that significantly influences the building's performance, energy efficiency, and environmental impact [79]. By carefully choosing materials that offer thermal resistance, moisture control, durability, and environmental sustainability, designers and builders can create high-rise buildings that are comfortable, energy-efficient, and environmentally responsible, ultimately contributing to a more sustainable future.

4. Conclusions

Implementing effective green design directives in high-rise buildings will help optimise energy consumption, lower energy consumption, and achieve energy efficiency. Green designs that utilise natural lighting and ventilation can drastically cut energy consumption. Green design directives also significantly contribute to energy efficiency by reducing resource consumption and dependence on high-energy-consuming machinery. In addition, implementing good performance of green designs in high-rise buildings in hot weather regions will help optimise environmental resources. By coordinating with green designs such as rainwater harvesting systems, the resource consumption of high-rise buildings will be lower, particularly high-rise buildings with high density and water usage. Moreover, using recycled and upcycled materials, green designs help reduce the demand for new materials and resources. Green designs also help lower greenhouse gas emissions by reducing energy usage.

Improving green design directives for high-rise buildings in hot and humid weather will help optimise economic resources. By utilising a more efficient green design product, green designs help decrease maintenance costs and installation costs, which can lead to significant cost savings in the long run compared with an older version of the green product. Advanced green design products also optimise building energy consumption while helping to minimise the carbon footprint and greenhouse gas emissions. In addition, the improvement of green design directives also significantly contributes to operational efficiency by innovating advanced technologies. By implementing and integrating IoT solutions, potential risks and maintenance of green products can be more easily monitored and controlled. It helps enhance the functionality, sustainability and durability of the innovative green design compared to conventional green products. Improving green design practices dramatically boosts occupants' health and well-being by increasing product quality and user satisfaction. Improvement of green practices also helps optimise resources by enhancing water conservation and material utilisation.

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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