

Sustainable Building Design in Tropical Climate: A Pathway to Green Building in Malaysia

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Abstract. This paper explores the development path of sustainable building design in Malaysia in a tropical climate, focusing on the application and challenges of green building technologies. As a tropical country, Malaysia's construction industry has to cope with extreme climatic conditions, such as high temperatures and humidity, and address high energy consumption and carbon emissions. Malaysia has gradually developed a unique green building development path through policy support and technological innovation. This paper reviews the history of green building development in Malaysia and highlights representative cases such as the Low Energy Office (LEO), the Green Tech Malaysia Building (GEO), and the ST Diamond Building. These buildings have significantly improved energy efficiency and reduced carbon emissions by integrating energy-saving technologies such as photovoltaic systems, rainwater recycling, and natural ventilation. In addition, this paper evaluates the role of the Malaysian Green Building Index (GBI) in contributing to the development of the industry and provides recommendations for further optimizing designs and policies. The study indicates that Malaysia has achieved significant results in sustainable building, but still faces challenges such as technology diffusion and industry education. In the future, Malaysia can further promote the development of the green building industry by strengthening the popularization of green building technologies, enhancing public awareness, and optimizing government policy support. At the same time, Malaysia's experience is significant for other tropical countries, providing valuable lessons for combating climate change and promoting sustainable development in the construction sector.

Keywords: Tropical Climate, Malaysia, Sustainable Building, Green Building.

1. Introduction

Changes in industries to cope with global climate change have become one of the key issues of the 21st century. As a significant source of energy consumption and carbon emissions, the building industry needs to take responsibility for reducing the environmental burden [1]. Globally, sustainable buildings are considered an effective way to address this challenge, especially in tropical climates where balancing energy demand with environmental protection has become a central issue in building design [2]. Located at 1°–7°N latitude, Malaysia has a typical tropical climate and faces extreme climatic conditions such as high temperatures, high humidity, and frequent precipitation. This effect is exacerbated by global warming, which is expected to increase annual rainfall by 1.2-8.7% and maximum temperature by 0.6-2.1°C in northern Malaysia [3]. In Malaysia, the building industry uses 14.3% of the nation's overall energy consumption, with 53% of the power used by the commercial and residential sectors. Compared to other Asian countries, Malaysia's CO₂ emissions are lower than those of China, India, and Indonesia, but still at a high level [4]. Against this background, the Malaysian government has promoted sustainable building development through several policies, eventually achieving significant results [5].

However, although green building technologies have been applied globally, building design in tropical climates still faces unique challenges, and the development of sustainable buildings in many tropical countries is lagging. An important research topic is how to balance energy efficiency, comfort, and environmental protection by incorporating local climate characteristics. Therefore, this paper takes the development path of sustainable buildings in Malaysia under a tropical climate as the theme and discusses sustainable building design strategies applicable to tropical climates with specific cases.

Scholars at home and abroad have conducted extensive research to address the challenges of sustainable, energy-efficient building design in tropical climates and have proposed various solutions. Gupta, V. suggests that the thermal insulation properties of the building envelope have the most significant impact on building energy efficiency compared to variables such as building orientation, thermal mass of building materials, and so on. The results of the study indicated that optimizing glazing properties and window-to-wall ratios (WWR) can reduce the annual energy consumption of a building by 35% and is a promising solution for improving energy efficiency in tropical buildings [6]. Meanwhile, Kwong, Q. J., suggested that through rational building layout and window design, occupants can be made to feel thermally comfortable by increasing building ventilation, significantly reducing air-conditioning energy consumption, and improving energy efficiency [7]. In addition, other scholars have explored the combined application of innovative building technology and renewable energy. Ohene, E.'s study on the Ghana residential building shows that after reducing the total building energy demand by retrofitting the building, the extended solar photovoltaic system can meet the remaining energy demand of the building, thus transforming the building into a Net Zero Energy Building (NZEB) and even achieving “net-positive energy” [8]. Additionally, in a simulation of an Indonesian office building, Odiyur employed an intelligent lighting control system to collect and utilize daylight effectively, meeting the lighting needs in various building areas and enhancing energy efficiency [9].

The research objectives of this paper include summarizing Malaysia's development experience in sustainable building, analyzing key technologies for green building design in tropical climates, and evaluating the effectiveness of practical application in representative cases. First, the article reviews the development history of sustainable buildings in Malaysia and summarizes the relevant policies and technology applications. Subsequently, the analysis of three building cases—the Green Tech Malaysia Building, the Green Tech Diamond Building, and the ST Malaysia Building—explores the application of different energy-saving technologies and their impact on building performance. Finally, the paper summarizes the successful experience of green buildings in Malaysia, proposes suggestions to optimize the energy-efficient design of buildings further, and explores its implications for other tropical countries.

2. Methodology

Malaysia's hot and humid climatic conditions pose special challenges for building design. Over the past few decades, the Malaysian building industry has gradually begun to emphasize sustainable design as the environmental problems and energy crisis caused by rapid development have intensified. Since the late 1990s, the Malaysian government has introduced the Green Building Index (GBI) to encourage and regulate the building industry toward green and low energy consumption. The GBI assesses multiple aspects of a building's energy efficiency, sustainable site management, interior environmental quality, water use efficiency, materials and resources, and innovation, facilitating the transformation of Malaysian buildings. The GBI system has profoundly influenced architectural design regarding energy efficiency and water management. In addition, the Leadership in Energy and Environmental Design (LEED) certification system is gaining popularity in Malaysia, especially in the commercial building sector. Recently, zero-energy and smart buildings have become increasingly popular. These buildings are not only required to reduce energy consumption but also to produce energy self-sufficiently. In terms of technology, the Malaysian building industry has gradually introduced advanced green building technologies such as Building Integrated Photovoltaics (BIPV), rainwater recycling, wind energy utilization, and intelligent control. Meanwhile, the green building market in Malaysia is gradually maturing, and more building projects are beginning to integrate these technologies with the government's policy support, which promotes the sustainable development of the whole industry.

The research objectives of this paper are to summarize the development experience of sustainable building in Malaysia, analyze the key technologies of green building design in tropical climates, and

evaluate the practical effects of representative cases. The research process includes literature review, case study analysis, and technology assessment. First, the current status of green building design is sorted out through the literature review, followed by analyzing three sustainable building cases in Malaysia and assessing the effectiveness of their energy-saving technology applications. Finally, suggestions for further development and implications for other countries are presented. The pipeline of the study is shown in Fig. 1.

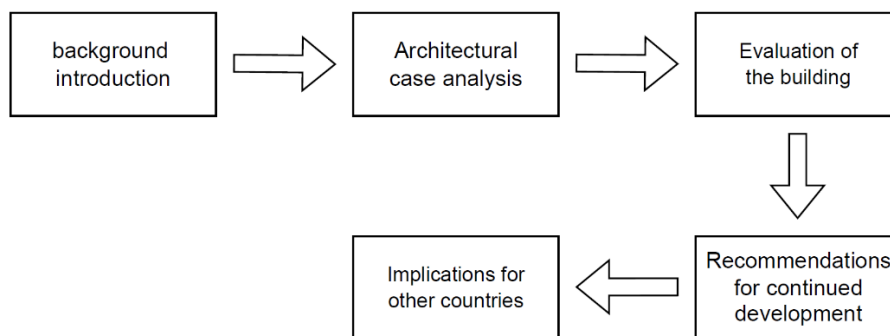


Figure 1. The pipeline of this study (Photo credit: Original)

2.1. Case 1: Low Energy Office (LEO)

LEO, situated in Kuala Lumpur, was finalized in 2004, as illustrated in Fig. 2. The LEO Building was the inaugural structure in Malaysia to use a range of extensive energy efficiency strategies in its architecture and mechanical and electrical systems, including a Building Management System (BMS) and thorough energy conservation initiatives. The LEO Building was the inaugural structure in Malaysia to use a range of extensive energy conservation strategies in its architecture and mechanical and electrical systems, featuring a BMS and thorough energy management practices. The building was confirmed to possess an energy index of 114 kWh/m²/year, representing a 55% reduction from the standard level, resulting in the ASEAN Energy Efficiency Award 2006. The supplementary energy efficiency (EE) expense constituted merely 8% of the construction cost, with half allocated to the extensive double roof. LEO was the inaugural full-scale energy-efficient structure in Malaysia and significantly contributed to the initial phase of the energy-efficient building movement in the country.

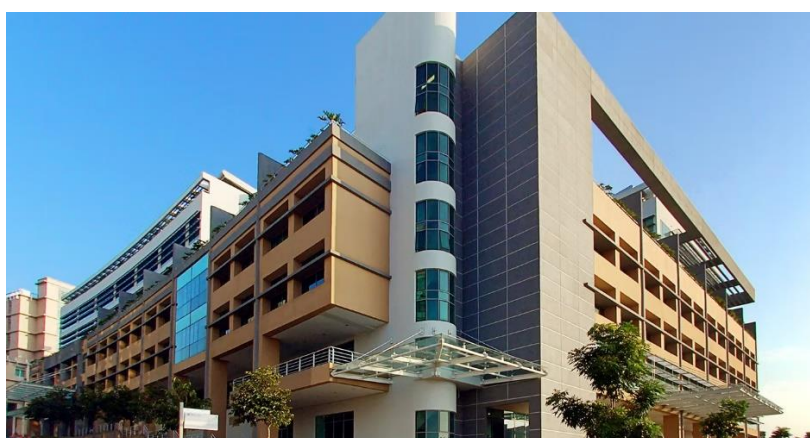


Figure 2. Low Energy Office (LEO) (Photo credit: Original)

The highlight of the building is the atrium, as shown in Fig. 3: it is naturally lit and ventilated through landscaping and water features, evaporative cooling, and a “thermal flue” forming a passive solar wall. Other innovations include using an energy management system to monitor and optimize energy consumption, the efficient recycling of large amounts of precipitation through a rainwater harvesting system, and effective thermal insulation through a double roof system. The building's orientation, façade design, and window layouts were optimized to maximize natural light and ventilation, reducing the need for artificial lighting and air conditioning. In addition, the LEO building

employs renewable energy with the installation of a 3-kWp grid-connected photovoltaic system on its roof.



Figure 3. Atrium (Photo credit: Original)

2.2. Case 2: Green Tech Malaysia Building

The Green Tech Malaysia Building, usually referred to as the Green Energy Office (GEO), located in Kuala Lumpur, was finalized in 2007 (shown in Fig. 4). The GEO Building was the inaugural office structure in Malaysia to obtain GBI certification and a green rating. The GEO building was Malaysia's inaugural GBI-certified and green-rated office structure, representing the first endeavor to design and run a zero-energy building in Asia. The project illustrates the feasibility of constructing a building powered by integrated renewable energy sources while ensuring a suitable occupancy level. The GEO building exhibits a Building Energy Index (BEI) ranging from 20 to 30 kWh/m²/year, in contrast to a conventional Malaysian office building, which has a BEI between 220 and 300 kWh/m²/year and incurs an electricity expense of approximately RM5,000 per month. The GEO building conserves around 500,000 kWh of electricity annually and mitigates 360 tons of carbon emissions.



Figure 4. Green Tech Malaysia Building (GEO) (Photo credit: Original)

Every facet of the GEO building's energy consumption has been analyzed and refined. Consequently, several energy-efficient designs have been incorporated into the architectural and electromechanical design of the structure. The structure optimally utilizes daylight through skylights, as illustrated in Fig. 5. Illumination is activated 12% of the time from 08:00 to 17:00, with the recorded light consumption at a mere 0.56 W/m², 25 times below the code stipulation. The structure

is equipped with a Radiant Cooling Air Conditioning System. The cooling system comprises 50% radiant and 50% air cooling, facilitating a high-comfort, draft-free workspace while ensuring elevated comfort levels. The cooling system shall consist of 50% radiant cooling and 50% air cooling, facilitating a high-comfort, draft-free workspace while enhancing efficiency by operating the chillers more effectively at elevated temperatures. To improve the interior lighting conditions, a mirror's light shelf is employed to facilitate the penetration of diffused daylight further into the building, optimizing daylight utilization to augment indoor brightness while mitigating glare.

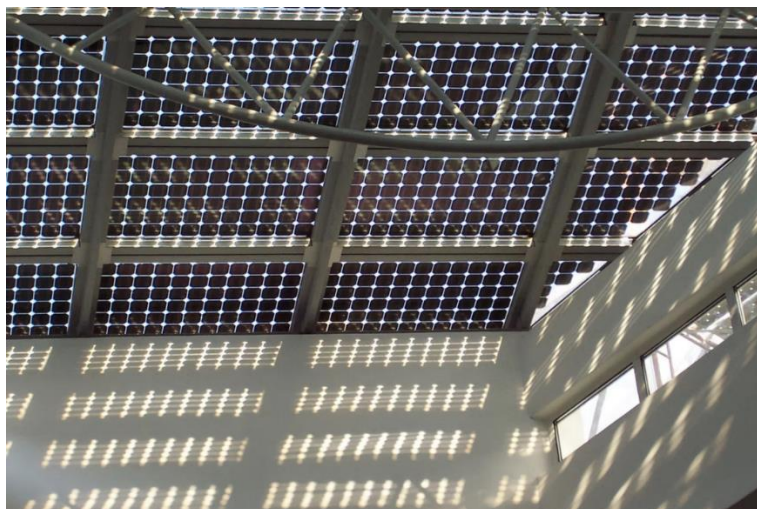


Figure 5. Roof Light (Photo credit: Original)

2.3. Case 3: ST Diamond Building

The ST Diamond Building (Fig. 6) is a notable energy-efficient and environmentally sustainable structure of the Energy Commission of Malaysia, located in Putrajaya District 2, Malaysia, and was completed in 2011. The ST Diamond structure, equipped with comprehensive energy simulation (IES) and intricate daylighting simulation (Radiance), is the inaugural office structure in Malaysia to attain the prestigious GBI Platinum green building certification. This is the inaugural structure outside Singapore to obtain Green Mark Platinum certification.



Figure 6. ST Diamond Building (Photo credit: Original)

The local climate significantly influenced the building's design, resulting in the Diamond Building's self-shading feature, which obstructs direct solar radiation on the north and south elevations to lower indoor temperatures. The atrium is designed to channel diffuse daylight effectively into the building, facilitating interior lighting with a minimal energy consumption of 0.9

W/m². The Diamond Building incorporates an integrated cooling system utilizing Peer Exchange (PEX) ducts embedded within the concrete slab, as illustrated in Fig. 7. This design facilitates the storage of cooler air in the building's concrete slab during nighttime, effectively utilizing the concrete for thermal retention. This design enables a 40% increase in nighttime cooling by utilizing the building's concrete structure to store cool air, decreasing peak cooling demands during the day. The stored cool air is passively released into the indoor environment throughout the day, resulting in temperature fluctuations in the concrete floor slabs of 1.5°C, from 21°C at the beginning of office hours to 22.5°C in the afternoon after office hours. The Diamond Building incorporates sustainable technologies, including BIPV, energy-efficient plug loads, and rainwater harvesting and recycling systems.



Figure 7. Floor slab cooling system (Photo credit: Original)

3. Results and Discussion

3.1. Evaluation of the Above Three Building Cases

These three cases—LEO, GEO, and the ST Diamond Building—are important demonstrations promoting sustainable building development in Malaysia. Firstly, these buildings have contributed to popularizing and developing green building standards through the practical application of green building certification systems (e.g., GBI and LEED) and their corresponding design concepts. As the first pooled energy-efficient building in Malaysia, LEO has demonstrated the effectiveness of technologies such as BMS and comprehensive energy management, which provide valuable experience in implementing green buildings; GEO has given valuable experience through its zero-energy design. LEO, the first energy-efficient building in Malaysia, shows how well technologies like BMS and energy management work, providing essential lessons for building green structures; GEO supports low-energy buildings with its zero-energy design and use of renewable energy; and the ST Diamond Building, with its top-notch energy-efficient design and GBI Platinum certification, has raised the standard for sustainable buildings in Malaysia. Secondly, these examples show how using advanced energy-saving tools like solar panels, shading, lighting systems, and nighttime energy storage can improve energy efficiency and comfort for people in buildings. Secondly, these examples demonstrate the effectiveness of combining advanced energy-saving tools such as solar panels, shading, lighting systems, and nighttime energy storage to enhance energy efficiency and occupant comfort within buildings. Finally, these building projects have led the trend of sustainable

development in the Malaysian building industry, promoted the implementation of government policies, and provided critical technical references and lessons learned for subsequent building projects, especially in zero-energy and smart buildings.

3.2. Suggestions for The Continued Development of The Sustainable Building Industry in Malaysia

The sustainable building industry in Malaysia has developed rapidly over the past two decades, but many aspects can continue to be improved. Three key factors are suggested for the continued development of the green building industry [10]:

1) Strengthening education and training for practitioners. The Malaysian government should strengthen the education and training related to green buildings, especially in the architectural areas of design, construction, and management. It should further collaborate with universities to offer green building courses and promote regular training of employees by construction companies to improve the overall industry's green building skills, thus ensuring the full implementation of the green building concept.

2) Increase customer awareness and willingness to invest in green buildings. Currently, many developers and consumers do not understand the long-term benefits of green buildings. The government should popularize the advantages and successful cases of green buildings through publicity, exhibitions, and seminars to enhance public recognition. At the same time, financial institutions can provide preferential loan policies for green building projects to reduce developers' investment costs and encourage more enterprises to participate.

3) The government should increase incentives and policy support. The government should enhance policy incentives for green buildings, particularly through tax breaks and financial subsidies. By providing tax incentives or financial subsidies to projects that meet green building certification, the implementation costs for developers can be reduced. In addition, the government has formulated mandatory green building standards requiring new projects to meet certain green standards to popularize green buildings further. Through these measures, Malaysia's sustainable building industry will accelerate its development in the direction of low carbon and environmental protection, further promoting the green transformation of the construction industry.

3.3. Implications for Other Countries

Malaysia's successful experience in green building has important lessons for other tropical countries. Despite facing similar climate challenges, many Tropical countries, such as India, Indonesia, and the African region, are still lagging in developing green buildings due to economic, technological, or policy reasons. Malaysia's experience, especially in solar energy utilization and rainwater recycling technologies, can provide valuable references for these countries. At the same time, Malaysia has also made technological innovations in energy-efficient building design, such as photovoltaic systems, shading design, and intelligent lighting systems, demonstrating the potential of buildings to utilize natural resources efficiently. Other countries can adapt these technologies to climate conditions, achieving a mutually beneficial balance between building energy efficiency and environmental protection.

Malaysia's innovations in green building policies are also worthy of reference for other countries, such as the GBI certification system and government tax incentives, which have successfully promoted the popularization of green buildings. Other countries can promote the market-based development of green buildings and the application of renewable energy by developing similar policy frameworks. In addition, the green building market in Malaysia has matured, and the cooperation between the government and enterprises has promoted the continuous development of green building projects. This provides a model for other countries, showing that the green building industry can flourish and help combat climate change under the dual drive of government support and market demand. By learning from Malaysia's successful experience, other countries can more effectively promote the development of green buildings and address the challenges posed by climate change.

4. Conclusion

As global climate change intensifies, the building industry is increasingly responsible for conserving energy and improving energy efficiency. Malaysia has been at the forefront of green building practices, especially in applying energy-efficient designs and sustainable building technologies in tropical climates, with remarkable results. By analyzing case studies such as LEO, GEO, and the ST Diamond Building, it can be seen that building designs adapted to tropical climates rely on advanced energy-efficient technologies and require flexible design strategies and integrated management systems. Despite the considerable advancements in green building in Malaysia, several challenges remain to be addressed, especially in technology diffusion, industry education, and government incentives. In the future, Malaysia is expected to play a more significant role in the global development of green buildings, thanks to ongoing improvements in the system for certifying green buildings and advancements in technological innovation. In addition, Malaysia's successful experience is an essential model for other tropical countries, especially those resource-poor regions. By learning from Malaysia's development experience, these countries will be able to meet climate change's challenges better and realize the construction industry's sustainable development.

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