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COMPARATIVE REVIEW OF VERTICAL GREENERY SYSTEMS IN CHINA AND MALAYSIA

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ABSTRACT

The current research provides a comparative overview of Vertical Greenery Systems (VGS) investigations in China and Malaysia covering the time period of 2010 to 2024. The PRISMA framework was applied for the analysis of 61 empirical studies 45 from China and 16 from Malaysia. Both countries aim at sustainability but emphasize different aspects in their research, which is impacted by climate, socio-economic factors, and policy frameworks. Chinese research, which is backed by a government initiative, points at environmental impacts like thermal regulation, air quality, and carbon reduction. Malaysian research, though limited, emphasizes passive cooling, thermal comfort, and cost-effectiveness in a tropical climate. The Chinese research is mostly in the field of environmental sciences with 28.9% of the total while Malaysia has a more even representation of environmental, architectural, and interdisciplinary fields (each 18.8%). In terms of focus, Chinese studies dominate with environmental aspects (51.1%), whereas Malaysian studies share between economic (50.0%) and social benefits (31.2%). The results indicate that climate and governance are factors that determine VGS research direction and application. China has managed to integrate urban areas on a large scale, whereas Malaysia still struggles with policy and maintenance issues. The impact of this study is that it sets the stage for cross-country learning in order to promote the adoption of sustainable urban development.

Keywords: *Vertical greenery system, Urban sustainability, Comparative*

Analysis, China, Malaysia

INTRODUCTION

Urbanization has intensified environmental challenges such as urban heat island (UHI) effect, rising energy consumption, and deteriorating air quality (Singh et al., 2020; Santamouris, 2015). Vertical greenery systems (VGS) have emerged as a sustainable design strategy to mitigate these issues by improving thermal regulation, capturing airborne particulates, enhancing biodiversity, and providing psychological and aesthetic benefits (Perini et al., 2011; Wong et al., 2009). In addition to their environmental contributions, VGS can deliver economic gains through energy cost savings and increased property value, as well as social benefits including stress reduction and enhanced urban liveability (Lee & Jim, 2019; Köhler, 2008).

Climatic conditions in China and Malaysia differ significantly, influencing VGS design, performance, and maintenance strategies. In China, average surface air temperatures range from below 0 °C in winter to over 27 °C in summer, with pronounced seasonal variation and concentrated summer rainfall (Figure 1). In contrast, Malaysia maintains relatively stable temperatures year-round (approximately 24–32 °C) and experiences high annual rainfall distributed across monsoon cycles (Figure 1). These climatic contrasts dictate distinct research and application priorities. In China, VGS studies often focus on thermal insulation, heating, cooling load reduction, and seasonal vegetation performance. However, in Malaysia, emphasis is placed on passive cooling, high-humidity resilience, and rainwater management.

Research on VGS in China has expanded significantly over the past decade, supported by strong policy incentives and technological innovation. Studies frequently apply advanced modelling techniques such as 3D printing, digital twin (DT) simulation, and precise solar radiation analysis, and evaluate multiple performance dimensions, including environmental, economic, and social impacts (Li et al., 2019; Zhang et al., 2022). In Malaysia, research has focused on passive design strategies tailored to tropical climates, highlighting thermal comfort, air quality improvement, and energy savings in small to medium-scale applications such as university campuses and certified green buildings (Farid et al., 2016; Abd-Ghafar et al., 2020). However, large scale adoption in Malaysia remains limited by high installation costs, maintenance challenges, and weak policy enforcement (Yahya et al., 2024; Shuhaimi et al., 2024). Despite these differences, both countries share the goal of integrating VGS into sustainable urban development agendas.

Moreover, policy frameworks and green building standards vary between the two countries. China has been actively promoting green building initiatives and has established policies to integrate VGS into sustainable urban development. The country's stringent environmental regulations and commitment to carbon neutrality have led to increased adoption of VGS as part of broader climate mitigation strategies. Malaysia, on the other hand, has a relatively nascent green building industry, with limited regulations mandating the use of VGS in urban developments. As a result, VGS in Malaysia remains largely underutilized for its environmental benefits, requiring greater policy intervention and technical research to enhance its adoption for sustainable development.

Although research on VGS has expanded in both countries, a gap remains in comparative analyses that systematically evaluate similarities and differences. Existing reviews often focus on a single national context or a specific benefit dimension. This paper addresses that gap by conducting a comparative literature review of 61 empirical studies published between 2010 and 2024, analysing thematic trends, disciplinary coverage, and benefit orientation. By synthesizing research trajectories in China and Malaysia, this review provides a comprehensive understanding of how climatic and policy contexts shape VGS development, offering insights for future research and sustainable urban greening strategies.

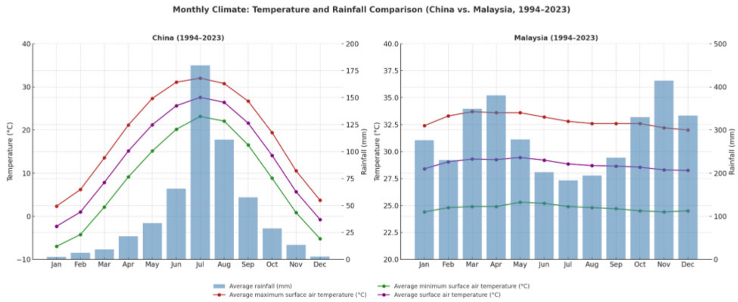

Figure 1: Monthly climate of mean minimum surface air temperature, mean surface air temperature, mean maximum surface air temperature, and rainfall in China and Malaysia from 1994 to 2023
(Original source: China Meteorological Administration and Malaysian Meteorological Department)

LITERATURE REVIEW

Vertical Greenery Systems in China

Starting from 2010, China's research on Vertical Greenery Systems (VGS) gained remarkable momentum. One of the major factors that contributed to this was the implementation of national sustainability programs and the urgency to solve the problems related to urban climates. The environmental impact of VGS has been the subject of a large number of studies, particularly in terms of the regulation of microclimates and the subsequent decrease of energy consumption. Notably, the works of Lv & Chen (2012) along with Zhang et al. (2022) stated that the energy saved in high-rise buildings was as much as 39.97% with the façade temperatures being reduced by a maximum of 21.6 °C. Moreover, the use of advanced modelling techniques such as ENVI-met, TRNSYS, and EnergyPlus along with digital simulations and field measurements has become a common practice in most of the studies (Zheng et al., 2021; Shi et al., 2021).

Research activities in China encompass technological innovations, among them 3D-printed modules, automated irrigation systems, and digital twin simulations (Li et al., 2019; Tang et al., 2023). Besides, policy-oriented research emphasizes various local government initiatives, particularly in

Shanghai and Nanjing, that offer regulatory support and incentives for the incorporation of VGS into green infrastructures (Xu et al., 2018; Shi et al., 2018).

Social impact has been evaluated in terms of visual comfort, psychological restoration, and even society's acceptance, the latter being the most uncontroversial aspect of these studies, and there was a preference for evergreens and colourful plants (Chen et al., 2023; Wang et al., 2020). Besides, biodiversity restoration is one of the themes the literature is getting more focus with; it deals with the adaptability and resilience of different species to given conditions (Liu et al., 2020). All in all, the body of the VGS literature coming from China points to a high environmental concern, a sound integration of technology, policy, and public perception in the process.

Vertical Greenery Systems in Malaysia

On the other hand, the Malaysian VGS research, although not as detailed, has directed its attention to the passive design methods that are appropriate for the tropical climate and have given priority to thermal comfort, humidity management, and energy efficiency. Among others, Safikhani et al. (2014) and Shuhaimi et al. (2022) reveal that indoor cooling can be as much as 4.71 °C and that up to 16.9% cooling energy can be saved. Modular VGS systems composed of tropical plant species such as Nephrolepis Exaltata are reported to be very effective in both air quality enhancement and thermal regulation (Abd-Ghafar et al., 2020).

Economic analyses are very common in Malaysian literature and they show the cost-benefit dynamics of VGS adoption clearly. Despite the fact that the initial installation costs are high, the savings in the long run as well as the increase in the value of the property are often mentioned as the reasons (Hong et al., 2019; Yahya et al., 2024). Research on social perceptions indicates that the public is mainly positive to the idea of integrating plants into the buildings, particularly in the case of schools and commercial areas (Bakar et al., 2015; Leong et al., 2021).

Nonetheless, there are still some limitations. Research shows that poor policy enforcement, lack of skilled maintenance, and no national guidelines are drawbacks to wider adoption. Compared to China, very few studies provide quantitative data on carbon sequestration or large-scale urban integration, which indicates a considerable gap in empirical and policy-driven research (Wang et al., 2014).

Comparative Gaps in Existing Literature

Both countries appreciate the multifunctional advantages of VGS, but there are very few direct comparative studies available. The majority of the research has been done focusing on one country or through a few specific case studies. Earlier reviews usually lacked a thorough evaluation of the performances and thus they were more descriptive than analytical. There was no consistent framework for assessing performance considering the varying climates, technologies, and governance. The current study manages to fill this void by offering a systematic and comparative review of VGS literature in China and Malaysia over the period from 2010 to 2024.

METHODOLOGY

This study adopts a systematic review approach to evaluate and compare the development, implementation, and performance of VGS in China and Malaysia. The methodology follows the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) framework to ensure transparent selection, screening, and synthesis of the literature across multidisciplinary sources.

Prisma

The review was conducted following the systematic approach outlined in the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) protocol, which facilitates structured selection, assessment, and synthesis of relevant studies. PRISMA is widely recognized for improving the transparency, comprehensiveness, and replicability of literature reviews across environmental, urban, and policy-related disciplines (Page et al., 2021). In this study, the PRISMA framework was adopted to identify and evaluate published research on VGS in China and Malaysia. The approach was suitable for synthesizing regional differences in implementation strategies, technological development, and policy support under diverse climatic and socio-economic conditions (Islam & Rafique, 2025). This method provides a systematic foundation for comparing national trajectories and informing future urban greening strategies in climate vulnerable urban environments.

Search Strategy and Data Sources

A systematic literature search was conducted using two major databases: China National Knowledge Infrastructure (CNKI) and Google Scholar. The search focused on studies published between 2010 and 2024, in both English and Chinese, pertaining to VGS implemented in China and Malaysia.

Boolean search strategies were developed using combinations of the following keywords:

- (“vertical greenery system” OR “green wall” OR “living wall” OR “modular green façade”)
- AND (“China” OR “Malaysia”)
- AND (“urban heat island” OR “air quality” OR “thermal performance” OR “energy saving” OR “policy” OR “implementation”).

A total of 3,021 records were retrieved from the two databases: 1,781 from Google Scholar and 1,246 from CNKI. After removing non-relevant entries based on title and abstract screening, 178 articles from Google Scholar and 212 from CNKI were shortlisted for full-text review, resulting in 390 articles.

The inclusion and exclusion criteria (Table 1) were applied to assess each article’s relevance, focusing on publication type, language, geographic setting, and thematic alignment with VGS. Additionally, a snowballing technique was used to identify further literature by reviewing the reference lists of selected articles.

Subsequently, 324 articles were excluded for not meeting the criteria, and 5 duplicates were removed, resulting in a final dataset of 61 articles for analysis (45 papers from China and 16 papers from Malaysia). The literature selection process followed the PRISMA protocol and is illustrated in Figure 2.

Table 1. Inclusion and Exclusion Criteria for VGS Literature Review

Criteria	Inclusion	Exclusion
Literature type	Peer-reviewed journal articles and conference paper	News articles, blogs, grey literature, reviews, book chapters
Language	English or Chinese	Other languages
Publication year	2010 to 2024	Before 2010
Research location	China or Malaysia	Research not related to China or Malaysia
Empirical research	Empirical research	Purely theoretical analysis, commentary, summary, and review articles
Research focus	Articles where VGS is a central	Articles with only peripheral mention of VGS
Research question	Studies addressing environmental, thermal, air quality, or urban integration aspects of VGS	Studies without clear environmental or urban greening relevance
Availability	Full-text available for download or institutional access	Only abstract or inaccessible full text

Source: Author

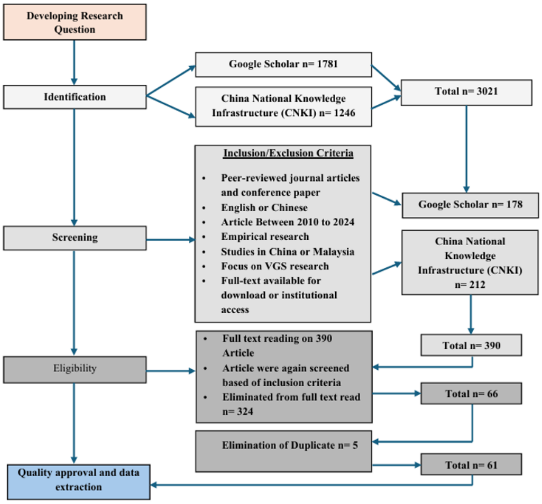

Figure 2. Flow Diagram of the Systematic Search Strategy by Steps

Source: Author

Data Construction and Analysis

To ensure the rigor of the comparative study, this research conducted a full text review of 61 selected articles that met the inclusion criteria. After extracting key information, a structured electronic spreadsheet was used for systematic organization. The process consisted of two main stages: an initial screening of abstracts and conclusions to assess thematic relevance, followed by full text evaluation for detailed content analysis. For each publication, the following data fields were recorded: author(s), year of publication, methodology, country/region, type of VGS, research focus, and key findings.

The extracted data were subsequently categorized into three main analytical dimensions for cross-national comparison: technological strategies, policy and governance mechanisms, and functional performance objectives. This matrix based classification approach facilitated the identification of similarities, differences, implementation trends, and research gaps. A descriptive summary and qualitative synthesis were employed to analyse recurring themes and to highlight the major differences in the development and application of VGS research between China and Malaysia. All data organization and analysis were conducted using WPS Office (2022) (Yuting et al., 2024).

VERTICAL GREENERY SYSTEMS

VGS refers to the strategic use of vertical surfaces, such as walls, balconies, and trellises, for cultivating climbing or modular plants. This approach addresses the lack of horizontal greening space in dense urban environments by increasing spatial green volume, thus improving air quality, mitigating UHI effects, regulating microclimate, and enhancing visual appeal (Elsadek et al., 2024). While the terminology varies such as green walls, living walls, and green façades, the term “vertical greenery” is widely adopted to encompass all forms of vegetated vertical structures (Safikhani et al., 2014; Pérez et al., 2014; Francis & Lorimer, 2011).

Significances of Implementing Vertical Greenery Systems

The implementation of VGS provides multiple benefits that can be categorized into three main aspects: environmental, economic, and social benefits. These benefits are crucial in addressing urban challenges in both China and Malaysia.

Environmental benefits

VGS offers significant environmental benefits, particularly in regulating ambient temperatures and improving urban microclimates. Alexandri & Jones, (2007) reported that vertical and rooftop greenery in Hong Kong reduced building surface temperatures by 8 to 9 °C, enhancing overall energy efficiency. This cooling effect is primarily attributed to shading, evapotranspiration, and the creation of buffer zones that reduce wind exposure in colder seasons (Raji et al., 2015; Sharp et al., 2008). As a bioclimatic design element, VGS mitigates the UHI effect by absorbing solar radiation during photosynthesis, transpiration, and respiration (Wong et al., 2015; Gomez et al., 1998; Kontoleon & Eumorfopoulou, 2009; Sheweka & Mohamed, 2012).

Beyond thermal regulation, VGS contributes to ecological restoration by offering habitats for flora and fauna. Climbing species such as Clematis Montana and Ipomoea Nil are effective in attracting pollinators like butterflies and hummingbirds (Sharp et al., 2008). Additionally, VGS improves air quality by filtering dust and sequestering carbon dioxide CO_2, thereby reducing greenhouse gas concentrations (Amir et al., 2011). Systems using hydroponics can also collect and reuse rainwater for irrigation, promoting water conservation and sustainable urban resource management (Ottelé et al., 2009).

Economic Benefits

VGS offers considerable economic advantages, particularly in energy efficiency and urban retrofitting. By blocking solar radiation, VGS reduces heat gain and cooling loads in buildings (Pérez et al., 2014). When used as window shading, it improves daylight penetration while minimizing glare (Kim et al., 2011). In Hong Kong, Yoshimi & Altan, (2011) reported a 16% reduction in daily electricity consumption during summer following VGS installation. Given that 32% of building energy use stems from heating and cooling, VGS serves as a cost-effective strategy, especially for retrofitting aged structures (Paradis, 2016; Birkeland, 2009).

VGS also enhances acoustic performance. Its substrate and plant layers function as sound absorbers, reducing external noise and improving indoor speech privacy (Wong et al., 2009; Azkorra et al., 2014). Additionally, it stimulates economic growth by creating green jobs and expanding market opportunities in the sustainable construction sector (Başdoğan & Çiğ, 2016). Public and private investment in VGS can increase property values, as buildings with vertical greenery are perceived as both aesthetically pleasing and environmentally responsible, thereby improving market competitiveness.

Social Benefits

VGS significantly enhances urban aesthetics by transforming unattractive façades and concealing deformed or utilitarian building elements such as mechanical and electrical units ((Pérez et al., 2016; Basher et al., 2016). In high-density cities, this visual enhancement contributes to improved streetscapes and architectural appeal.

Beyond aesthetics, VGS provides measurable benefits to human health and well-being. Exposure to greenery has been shown to reduce symptoms such as headaches by up to 20% (Bringslimark et al., 2009), while workplace and educational environments with plants report a 5 to 15% decrease in absenteeism and a 12% increase in student productivity (Butkovich et al., 2008). The integration of green infrastructure also fosters stress reduction, psychological comfort, and user satisfaction (Wood et al., 2014).

As urbanization accelerates, VGS presents an alternative for providing accessible green spaces in constrained environments, contributing to a healthier and more liveable urban experience (Basher et al., 2016). These benefits underscore the role of vertical greenery not only in ecological and economic domains but also in enhancing urban quality of life.

Advantages of Vertical Greenery Systems

VGS introduces vegetation onto building façades and into urban interstices. As shown in Table 2, VGS deliver multidimensional benefits:

through shading and evapotranspiration they lower façade and indoor temperatures, thereby reducing cooling demand and mitigating urban heat-island effects; rough leaf surfaces capture PM2.5/PM10 and contribute to carbon sequestration and oxygen release; foliage layers attenuate noise via barrier and scattering effects; substrates and vegetation detain stormwater and reduce runoff (Timur & Karaca, 2013; Charoenkit & Yiemwattana, 2017; Wolch et al., 2014; Tang et al., 2023). At the same time, VGS enhance biodiversity and visual amenity, improve mental well-being and the pedestrian experience, and given their small land take, support urban regeneration and ecological value gains in high-density cities (Perini & Rosasco, 2013; Abhijith et al., 2017; Galagoda et al., 2018).

Table 2. Advantages of Vertical Greenery Systems

Advantages	Descriptive Detail	Climate	Country	Author
Environmental Advantages				
Reduce Urban Heat Island (UHI) Effect	Façade temperature reductions up to 21.6°C and indoor cooling of 5.2°C using VGS in high-density urban areas	Cfa – Humid Subtropical	China	Lv & Chen, 2012
	Indoor temperature reductions of 3.0–4.0°C in tropical retrofitted buildings	Af – Tropical Rainforest	Malaysia	Jaafar et al., 2013
Improved Air Quality	PM2.5 levels reduced by 9.38% and CO_2 by 1.7 μg/m³ through green wall installations in industrial zones	Cfa	China	Wang et al., 2023
	Green walls reduced RH by 1.6–1.81% and CO_2 by 0.63% near wall surfaces	Af	Malaysia	Galagoda et al., 2018
Noise Reduction	Sound insulation performance improved by up to 15 dB with planted façades	Cfa	China	Azkorra et al., 2014
	Moderate sound attenuation reported in educational buildings with modular VGS	Af	Malaysia	Leong et al., 2021
Social Advantages				
Aesthetic Improvement	High public preference for evergreen and layered plants; enhanced urban image in Shanghai VGS projects	Cfa	China	Wang et al., 2020

	Vertical greenery in public art installations improved aesthetic perception and property value	Af	Malaysia	Bakar et al., 2015
Health Improvement	Vertical greenery improves psychological recovery and reduces urban stress in dense residential areas	Cfa	China	Chen et al., 2023
	Surveys indicate stress reduction and enhanced comfort in VGS-equipped buildings	Af	Malaysia	Yahya et al., 2024
Economic Advantages				
Improved Energy Efficiency	Annual energy savings of up to 39.97% in air-conditioning from VGS installations on façades	Cfa	China	Zhou & Zhou, 2017
	Cooling load reduction of 16.9% in tropical office buildings	Af	Malaysia	Shuhaimi et al., 2022
Reduce Indoor Temperature	Interior cooling of 1.1–5.2°C through planted vertical systems	Cfa	China	Zhang et al., 2022
	Temperature drop of 4.71°C and improved OTTV (1.32–6.87%) from VGS application	Af	Malaysia	Sunakorn & Yimprayoon, 2011

Source: Author

Comparison of Research Methods

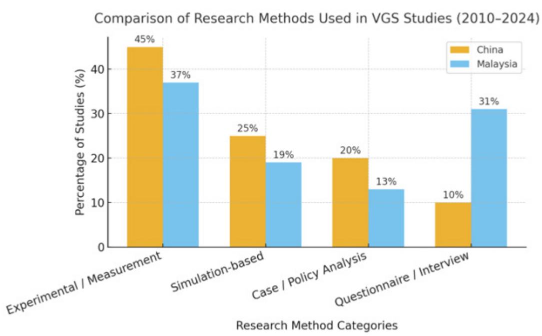

Figure 3. Comparison of Research Methods (China vs Malaysia)

Source: Author

A comparative evaluation of research methods used in China and Malaysia from 2010 to 2024 demonstrates both convergence and divergence in methodological focus. As shown in Figure 3, experimental and actual measurement-based studies dominate in both countries, accounting for 45% of Chinese and 37% of Malaysian VGS research. These approaches emphasize quantitative evaluation of environmental and thermal performance, particularly regarding temperature reduction, humidity regulation, and particulate matter capture. Simulation-based analyses (e.g., ENVI-met, CFD, TRNSYS, IESVE, BIM) represent 25% in China and 19% in Malaysia, highlighting a regional trend toward integrating digital environmental modelling into performance prediction. Meanwhile, case studies and policy analyses comprise 20% of Chinese studies but only 13% in Malaysia, suggesting that China's research community has placed stronger emphasis on planning strategies and governance frameworks. In contrast, questionnaire and interview methods are considerably more frequent in Malaysia (31%) than in China (10%), reflecting Malaysia's growing interest in social perception, cultural adaptation, and user-oriented VGS evaluation. Overall, the comparison indicates that while China's methodological structure remains dominated by technical experimentation and simulation, Malaysia presents a more balanced mixed methods orientation combining environmental measurement and social inquiry. This complementarity underscores the importance of integrating quantitative precision and qualitative insight for future cross-country VGS research.

RESULTS

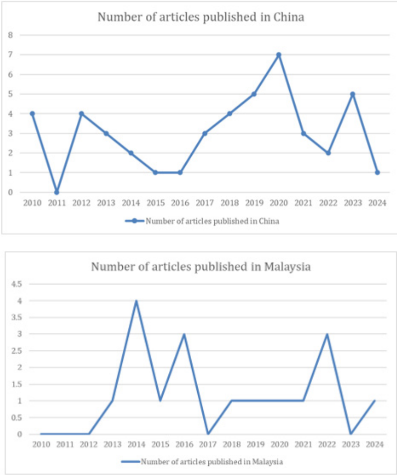

Figure 4. Number of published articles from 2010 to 2024 (China vs Malaysia)

Source: Author

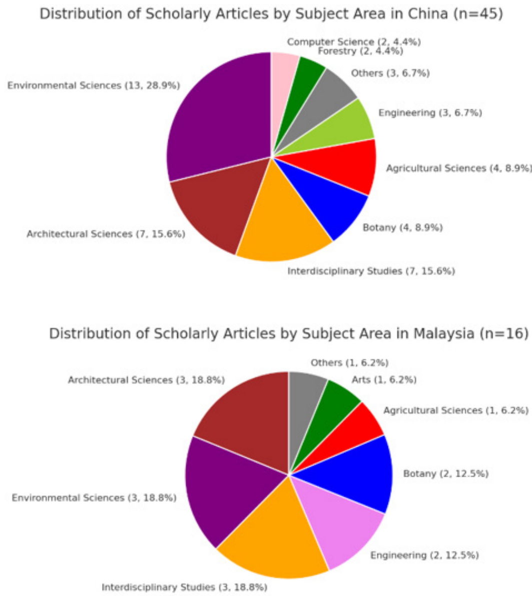

Figure 5. Subject Area Classification 2010 to 2024 (China vs Malaysia)

Source: Author

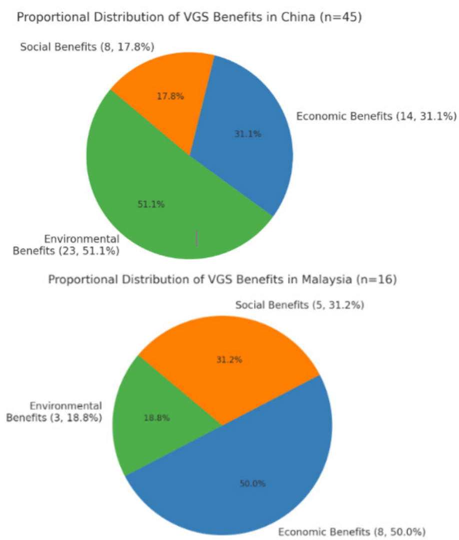

Figure 6. Research focus 2010 to 2024 (China vs Malaysia)

Source: Author

Based on the dataset and visual statistics in Figure 4, Figure 5, and Figure 6, the comparative analysis of 61 empirical studies (45 from China, 16 from Malaysia) between 2010 and 2024 reveals distinct trends in publication output, subject area distribution, and benefit focus for VGS.

China's research output fluctuated annually but peaked in 2018 with seven publications, showing sustained academic interest across multiple disciplines. The subject area classification (Figure 5) is dominated by Environmental Sciences (28.9%), followed by Architectural Sciences (15.6%), Interdisciplinary Studies (15.6%), and Botany (8.9%). The proportional distribution of VGS benefits in Chinese studies highlights a strong environmental orientation, 51.1% environmental benefits, alongside 31.1% economic benefits and 17.8% social benefits. This suggests a performance-driven research culture prioritizing quantitative evaluations of environmental impacts, such as façade surface temperature reductions up to 21.6 °C, indoor cooling up to 5.2 °C, and air quality improvements (e.g., PM2.5 reduction by 9.38%).

In contrast, Malaysia's annual publication numbers are lower, with a notable rise in 2014 and moderate peaks thereafter. The subject area distribution shows Environmental Sciences, Architectural Sciences, and Interdisciplinary Studies each accounting for 18.8%, with Botany and Engineering at 12.5% each. The benefits distribution is more balanced between Economic benefits (50%), Social benefits (31.2%), and Environmental benefits (18.8%). This reflects a focus on applied economic performance and socio-cultural impacts, e.g., cooling load energy savings up to 16.9%, improvements in thermal comfort and relative humidity (+7.4%), and enhanced visual quality linked to increased property values.

From a comparative perspective, China's dominance in environmental research aligns with its broader climatic coverage, multi-scale simulation–measurement integration (ENVI-met, TRNSYS, Energy Plus), and stronger policy backing. This enables large-scale evaluations linking VGS performance to urban climate mitigation and policy frameworks. Conversely, Malaysia's smaller but targeted evidence base reflects its tropical climatic context, where passive cooling and economic feasibility are primary drivers, although policy and regulatory gaps limit scaling potential.

Overall, Figure4, Figure 5, and Figure 6: Proportional Distribution of VGS Benefits collectively demonstrate that China's VGS research is more environmentally and technologically driven, whereas Malaysia's is more economically and socially oriented. This divergence suggests that Malaysia could enhance VGS adoption by adapting China's integrated environmental policy approach, while China could draw from Malaysia's emphasis on socio-economic valuation to strengthen community engagement and uptake.

Research Status of Vertical Greenery Systems in China

A total of 45 empirical studies on VGS in China, published between 2010 and 2024, reveal a strong focus on environmental performance, energy efficiency, and urban microclimate improvement. Many studies demonstrate significant thermal regulation benefits, with maximum reductions in façade surface temperature of up to 21.6 °C, indoor temperature decreases of 1.1 to 5.2 °C, and annual air conditioning energy savings reaching 39.97% (Lv & Chen, 2012; Zhou & Zhou, 2017). Air quality enhancement is also evident, with reductions in PM2.5 concentrations by 9.38% and annual decreases of approximately 1.7 μg/m³ (Yan et al., 2018; Wang et al., 2023). These studies often adopt integrated methodologies combining field measurements with simulation tools such as ENVI-met, TRNSYS, and Energy Plus, enabling multi-scale assessments of VGS performance in diverse climatic zones (Zheng et al., 2021; Shi et al., 2021).

Beyond environmental effects, VGS in China has been linked to notable social and psychological benefits. Research has documented improvements in residents' emotional regulation, psychological recovery, and visual comfort when exposed to vertical greenery (Chen et al., 2023; Feng & Hu, 2019). Public preference studies emphasize plant combinations that are evergreen, colourful, and layered with vines and shrubs to enhance aesthetic appeal (Wang et al., 2020). In addition, socio-economic evaluations indicate that residents show a willingness to pay for the ecological services provided by green walls, while technological innovations such as real-time irrigation monitoring systems have improved plant survival and reduced maintenance costs (Gao & Hong, 2019).

Chinese VGS research also highlights broader ecological and policy implications. Biodiversity focused studies have identified plant species with strong adaptability to local climates, improving both resilience and ecological function (Liu et al., 2020). GIS and CFD based planning analyses have mapped vertical greenery potential in high density urban districts, supporting integration into municipal green infrastructure strategies (Shi et al., 2018). Policy-oriented research has established comprehensive frameworks, such as in Shanghai, which combine spatial layout guidelines with incentive mechanisms to promote large-scale implementation (Xu et al., 2018). These findings reflect a mature and interdisciplinary approach to VGS in China, where technological advancement, policy support, and cross-sector collaboration drive sustainable urban greening.

Research Status of Vertical Greenery Systems in Malaysia

Between 2010 and 2024, 16 empirical studies on VGS in Malaysia were identified, with research predominantly focusing on the tropical climatic context and its implications for thermal performance, humidity regulation, and building energy efficiency. Field measurements and experimental studies consistently reported significant cooling effects, with indoor air temperature reductions ranging from 3.0 °C to 4.0 °C and relative humidity increases of up to 7.4% (Jaafar et al., 2013; Safikhani et al., 2014). Energy performance assessments indicated cooling load savings of 16.9% in retrofitted buildings and reductions in Overall Thermal Transfer Value (OTTV) by 1.32%-6.87%, depending on system type and plant selection (Shuhaimi et al., 2022; Basher et al., 2022). Modular systems generally outperformed linear arrangements in both cooling and humidifying capacities, while species such as Nephrolepis Exaltata achieved the highest average leaf area index (LAI = 5.39) (Abd- Ghafar et al., 2020).

Beyond thermal regulation, Malaysian studies emphasize economic and social dimensions of VGS. Several benefits of cost analyses demonstrated that, although initial installation costs may be high, long term operational savings from reduced energy consumption and enhanced property values can offset these investments (Hong et al., 2019; Yahya et al., 2024). Surveys and interviews further revealed positive public perceptions, with respondents associating VGS with stress reduction, improved visual quality, and a more comfortable indoor environment (Bakar et al., 2015). However, recurring constraints include insufficient policy incentives, lack of skilled maintenance personnel, and limited technical training, which hinder the broader adoption of VGS across urban developments (Leong et al., 2021).

Ecological and environmental research in Malaysia also highlights VGS contributions to urban biodiversity, air quality improvement, and stormwater management. Studies found that plant covered façades can lower surface temperatures, filter particulate matter, and reduce rainwater runoff, contributing to urban resilience (Wang et al., 2014; Safikhani et al., 2014). Comparative research between system types has guided species selection strategies, favouring plants with high leaf density, drought tolerance, and adaptability to vertical installation (Jasmi & Mohama, 2016). While Malaysia's VGS research base is smaller than China's, it provides robust tropical climate evidence and a clear foundation for expanding applications through targeted policy support, standardized maintenance protocols, and integrated urban greening strategies.

DISCUSSION

Comparison of Research Trends in China and Malaysia

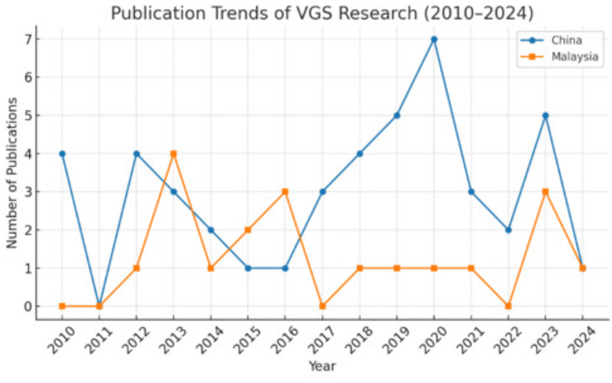

Figure 7. Comparison of Research Trends in China and Malaysia (2010-2024)

Source: Author

From 2010 to 2024, the number of published studies on VGS in China shows an overall upward trend, peaking at seven publications in 2020, followed by moderate fluctuations. In contrast, Malaysia's research output remains relatively low and inconsistent, with small peaks in 2013 (four publications) and 2016 (three publications), and sporadic activity in other years (Figure 7). This indicates that while China's VGS research has developed into a more continuous and expanding body of work, Malaysia's research remains intermittent, reflecting differences in research capacity, funding priorities, and policy support between the two countries (Zhang et al., 2020; Feng & Hu, 2019; Xu et al., 2018; Bakar et al., 2015; Farid et al., 2016)

Comparative Analysis of Similarities and Differences in Vertical Greenery Development Between China and Malaysia

Table 3 provides a structured comparison of VGS development in China and Malaysia across key thematic categories. The data highlight several shared objectives but reveal major contrasts in technological integration, policy enforcement, and implementation scale.

China's VGS development is characterized by strong governmental support, financial incentives, and integration with advanced technologies such as digital twin modelling and automated irrigation systems. These innovations enable dynamic energy modelling and large-scale implementation, positioning VGS as a standard component of urban planning. Conversely, Malaysia emphasizes passive strategies, such as façade orientation and plant selection, and relies on small scale or experimental projects with limited policy backing.

A noteworthy distinction lies in carbon sequestration data: China has quantified CO_2 absorption at 1.4 kg/m² for green façades, while Malaysia's studies, although supportive of VGS's air purification benefits, lack detailed carbon data. This indicates a gap in empirical measurements and underscores the need for further research in the Malaysian context.

Moreover, while both countries acknowledge the aesthetic and psychological advantages of VGS, social benefits are more extensively explored in Chinese studies. Malaysia's research, though recognizing aesthetic value, would benefit from deeper investigations into user perception and community well-being.

Overall, Table 3 illustrates that China has adopted a more policy driven and technology enhanced VGS model, whereas Malaysia remains at an early adoption stage. Enhancing cross-country collaboration and knowledge exchange could support Malaysia's transition toward wider implementation and policy integration.

Table 3. Comparative Analysis of Vertical Greenery Systems Development in China and Malaysia

Category	China	Malaysia
Urban Heat Island (UHI) Mitigation and Thermal Comfort	VGS reduces indoor temperatures by up to 3.6°C; large-scale studies confirm its role in urban cooling.	VGS lowers indoor temperatures by up to 4°C; mainly studied in small-scale applications like universities and green-certified buildings.
Energy Efficiency and Cooling Loads	Advanced modeling and technology-driven strategies (e.g., 3D-printed green walls, automated irrigation).	Focuses on passive cooling strategies, including façade orientation and shading techniques.
Air Quality Improvement and Carbon Sequestration	Quantified carbon sequestration (1.4 kg/m^2 CO_2 absorption by green walls).	Limited research on carbon sequestration, but studies emphasize air pollution reduction.
Technological Innovations	Utilizes digital twin (DT) modeling, 3D-printed green walls, and automated irrigation for optimization.	Research primarily focuses on plant selection, façade orientation, and passive cooling strategies.
Government Policies and Regulations	Strong regulatory frameworks mandate urban greening in high-density cities.	Policies exist, but enforcement and incentives for urban greening are inconsistent.
Scale of Implementation	Large-scale VGS projects integrated into urban planning; interdisciplinary research across multiple sectors.	Limited implementation beyond experimental research and isolated projects.
Economic Incentives and Investment	The government provides financial support and subsidies to promote VGS adoption.	High initial costs limit adoption; lacks structured financial incentives for developers.
Social and Aesthetic Benefits	Green walls enhance building aesthetics, promote well-being, and provide social spaces.	Recognized for its visual appeal, but social benefits remain underexplored in research.

Source: Author

CONCLUSION

This review synthesized 61 empirical studies on VGS in China and Malaysia published between 2010 and 2024, revealing distinct trajectories shaped by climatic, policy, and socio-economic contexts. China's research, supported by policy incentives and interdisciplinary approaches, emphasizes environmental performance, including significant reductions in surface temperature, energy demand, and particulate matter. In contrast, Malaysia's smaller but targeted research base prioritizes thermal comfort, energy savings, and socio-economic feasibility within the tropical climate.

Despite differences, both countries recognize the multi-dimensional benefits of VGS in addressing urban challenges such as heat mitigation, air quality improvement, and enhanced liveability. China demonstrates strong integration of VGS into large-scale urban planning, while Malaysia shows potential for expansion but is constrained by high costs, limited maintenance capacity, and weaker policy enforcement. These divergences highlight how governance frameworks and climatic conditions shape the scale and direction of VGS research and practice.

Future research should strengthen cross-country collaboration to enable knowledge exchange and methodological harmonization. Malaysia could benefit from adopting China's policy driven frameworks and quantitative environmental assessments, while China could incorporate Malaysia's emphasis on socio-economic and cultural benefits to improve community acceptance. A more balanced approach, integrating environmental, economic, and social dimensions, is essential for optimizing the role of VGS in sustainable urban development across diverse contexts.

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DECLARATION OF AI-GENERATED CONTENT

The author declares that artificial intelligence (AI) tools were used solely to generate Figures 1, 4, 5, 6, and 7 based on the author's own statistical results, and to assist with English grammar correction. All data collection, statistical analyses, interpretations, and conclusions were independently conducted by the author, and no aspect of the research design or intellectual content involved the use of AI.

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AUTHOR CONTRIBUTIONS

All authors contributed to the design of the research and the write-up. All authors have read and approved the final manuscript.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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