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VERTICAL GREENING APPROACH FOR URBAN KAMPUNG: A SYSTEMATIC REVIEW

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Abstract

Desakota, commonly known as urban kampung, is a distinctive characteristic of urbanization in the Southeast Asian region. These communities are particularly susceptible to urban food insecurity and heat stress, making them highly vulnerable. This article examines a suitable VGS approach to address these concerns based on the characteristics of the urban kampung using a systematic literature review (SLR). The study highlights that the characteristics of urban kampungs, such as the physical environment, income levels, and demand size, determine the suitability of Productive Façade as a viable solution. This study can support the development of green infrastructure for UHI and climate change mitigation and adaptation, improve public health, and promote environmental justice in densely populated urban areas with low-income populations.

Keywords: Food security, thermal comfort, productive façade, social economy, urban kampung, vertical greenery.

1. INTRODUCTION

Southeast Asia is experiencing rapid growth (Ouyang et al., 2016), driven by economic transition (Fan et al., 2022). Urbanization in this region shows a substantial correlation between population growth and economic development (Fan et al., 2022). Urbanization expands urban areas by converting non-urban areas into urban areas (Nuissl & Siedentop, 2021). Southeast Asian countries have experienced a significant increase in urban areas, which is closely related to the Gross Domestic Product (GDP) and urban population (Ouyang et al., 2016). One of the unique characteristics of urbanization in the Southeast Asian region is Desakota, which is popularly known as urban kampung. Urban kampung refers to vernacular settlements located within urban areas. The notable distinctions between urban kampung and contemporary urban lifestyles are their size, cultural ecology, and predominant settlement location (Hawken, 2017).

The conversion of developed urban land has two spatial consequences: first, it results in a higher concentration of buildings in the city center, and second, it extends the city's peripheral into agricultural areas in the peri-urban and rural regions (Shirleyana et al., 2018). The increasing size of urban area can result in increased costs of delivering food (Reardon & Timmer, 2014), which may lead to decreased affordability of food prices (Minten & Kyle, 1999), impede the attainment of ideal household food consumption, and contribute to malnutrition (Huizar et al., 2021), especially among low-income populations, who are dominant in urban kampung. At the same time, heavily populated urban regions and economic hubs tend to worsen air pollution and intensify the Urban Heat Island (UHI) phenomenon (Lestari et al., 2022; Sarker et al., 2024). Urban Heat Island (UHI) is where cities and their suburbs have much warmer air and surface temperatures than rural areas (Z.-H. Wang, 2022). Urbanization encourages the use of materials that tend to absorb and store large amounts of solar radiation (Arnfield, 2003). In addition, an increase in urban atmospheric temperature also occurs through increased levels of Carbon Dioxide (CO_2) ambient and other "greenhouse" gases which are mainly produced by human activities in urban areas (McPherson, 1994).

Extensive research has been conducted for years to investigate the connection between high outdoor temperatures and human health. Urban dwellers with lower socioeconomic status, preexisting health problems, or residing in densely populated areas, which are commonly found in urban kampung, have been observed to experience elevated levels of UHI and its associated detrimental health effects (Chakraborty et al., 2019). Low-income urban populations in Bangkok, Thailand, and Kuala Lumpur, Malaysia are more likely to experience heat stress, leading to adverse health and welfare outcomes (Arifwidodo & Chandrasiri, 2020; Saun et al., 2020). In Jakarta, Indonesia, residents of slum areas face discomfort and risks of heat stress because of their low adaptive capacity (Ufaira et al., 2023). In Sulawesi, Indonesia, the urban kampung communities experience chronic heat stress that exceeds the recommended physical activity threshold (Ramsay et al., 2021). In addition, the UHI effect and climate change increase the economic cost of urbanization by 2.6 times as much as without the UHI effect (Estrada et al., 2017). These findings highlight the urgent need for effective urban planning and adaptation strategies.

Moreover, planting urban green spaces with trees can help to reduce heat temperature (Erlwein & Pauleit, 2021) and contribute to the urban food supply (Grafius et al., 2020). However, achieving the benefits of trees in high-density residential areas like urban kampungs is challenging. The Vertical Greenery System (VGS) is a promising strategy to present green elements and their benefits, but the cooling effect produced by small green spaces is still uncertain (Gál, n.d.) (C. Wu et al., 2021). In addition, most VGS thermal performance studies were conducted in field laboratory experiments, well-planned built environment experiments, or computer simulations. The understanding of VGS methods that synergize with non-uniform urban arrangements or organic patterns, such as urban kampungs, remains inadequate. When applying VGS in the community, it is necessary to consider the local context (Noraduola, 2007)(Cahyadi et al., 2021). Socioeconomic factors influence the supply, demand, and management of ecosystem services (Wilkerson et al., 2018). These concepts are considered when selecting an appropriate VGS method for urban kampung.

2. MATERIAL AND METHOD

2. 1. Material

Urban Kampung in Southeast Asia

The rapid urbanization of Southeast Asian countries has resulted in urban regions with various physical and sociocultural structures. One manifestation of this phenomenon is the development of urban blocks with business and service buildings along the periphery. In contrast, the inner part grows organically as a densely populated settlement, also known as an urban kampung. Urban kampung refers to traditional settlements located within urban areas. Urban kampung can be found in a variety of Southeast Asian countries, including Singapore, Malaysia, Myanmar, Thailand, Cambodia, and Indonesia, with each country having its distinct variation in these communities (Shirleyana et al., 2018). In Indonesia, the word "urban kampungs" refers to vernacular settlements characterized by rural attributes and a conventional manner of living (Shirleyana et al., 2018). Residents of urban kampung build their homes progressively based on their particular needs through informal community interactions ((Lueder, 2018).

Furthermore, urban kampung experience organic growth, forming densely populated areas with a high concentration of buildings and exhibiting uneven and narrow road layouts and zigzag inter-settlement patterns (Paramita & Matzarakis, 2019). Additionally, they have minimal settlement infrastructure, including limited (green) open spaces (Hutama, 2016).

The reduction of green open space in urban areas harms the local air temperature (Shashua-Bar & Hoffman, 2000). Research conducted by Zaki et al. in (Zaki et al., 2020) found that the Kampung Baru community in Malaysia has the highest diurnal air temperature compared to neighboring land uses, largely due to its dense population. (Paramita & Matzarakis, 2019) demonstrated a direct relationship between building density and ambient air temperature increase in urban kampung. Therefore, the urban kampung community is most vulnerable due to increased temperatures, which could cause heat discomfort.

Microclimate Parameters and Outdoor Thermal Comfort

The urban microclimate refers to the unique atmosphere within a small-scale urban area, which is mostly shaped by the adjacent constructed environment (Yang et al., 2018). The urban microclimate is formed by variations in outdoor air temperature, surface temperature, humidity, wind speed and direction (Bherwani et al., 2020). Therefore, the urban microclimate as a physical environment determines the thermal comfort of the outdoors.

Thermal comfort, defined by the ISO 7730 standard, is a multifaceted relationship between air temperature, humidity, and airflow rate. Moreover, it involves factors such as the type of clothing, the level of activity, and the metabolic rate of the individual. It measures people's satisfaction with the air conditions in a given environment. Comfort conditions can be defined as thermal neutrality, indicating that an individual experiences neither excessive coldness nor excessive heat (ISO-7730, 1994). The level of outdoor thermal comfort is determined based on urban microclimate and human factors, that is, air temperature, radiation, temperature, relative humidity, wind speed, body metabolism, and clothing insulation (Elnabawi & Hamza, 2020) .

165 thermal comfort indices have been created (Ghani et al., 2021), but only 4 (PET, PMV, UTCI, SET*) are commonly used to study how people perceive outside temperatures (Kumar & Sharma, 2020). PET is one of the suggested guides in the new German procedures for urban and regional planners and is cast-off to envisage variations in the thermal factor of urban or regional climates (Honjo, 2009). The outdoor thermal environment impacts the spectrum of thermal comfort or discomfort in various climate zones (Potchter et al., 2018). In hot climates, 95% of the studies agree that the "neutral" range of the PET index is between 24 ° C and 26 ° C (Potchter et al., 2018).

VGS Typology

Vertical Greenery System (VGS) includes green façades, green walls, green terraces, green woods, and vertical agriculture (Tablada & Kosorić, 2021; X. Wang et al., 2020). VGS is divided into two categories: Green Façade (GF) and Living Wall (LW) (Manso & Castro-Gomes, 2015; Palermo & Turco, 2020a). Climbing or hanging plants provide vegetative cover in Green Façade (GF) systems (Fernández-Cañero et al., 2012, 2018; Vox et al., 2018). Living Wall (LW) is another type of VGS, a plant arrangement, in which where plants are rooted and developed in a unique medium introduced into walls (Meral et al., 2018). LW can be categorized into two groups according to their technique of application: continuous and modular (Palermo & Turco, 2020b).

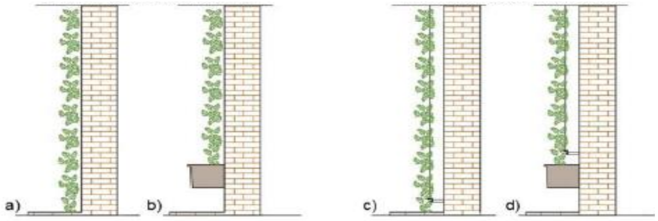

FIGURE 1 - TYPOLOGY OF GREEN FACADE

(a) Direct green façade planted in the soil; (b) direct green façade planted in the container; (c) indirect green façade planted in the soil; (b) indirect green façade planted in the container

Source: (Palermo & Turco, 2020b)

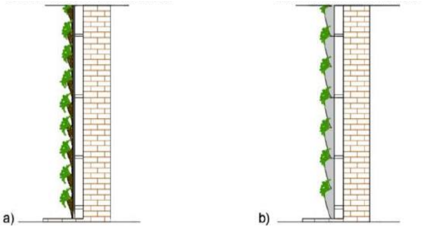

FIGURE 2 - TYPOLOGY OF A LIVING WALL

. (a) Continuous living wall; (b) Modular living wall

Source: (Palermo & Turco, 2020b)

Furthermore, vertical agriculture (VA) is a form of build-integrated agriculture (BIA) that attempts to reduce land use and food miles while increasing production by using urban infrastructure (Tablada & Kosorić, 2021). Building-integrated agriculture (BIA) is a sustainable agricultural system that uses local and renewable energy and water sources, using efficient hydroponic growing systems within buildings (Tablada & Kosorić, 2021). Façade Agriculture (FA), a modification of the vertical farming framework (VF), combines creative development with the use of solar energy on existing surfaces, rooftops, and exteriors (Tablada et al., 2020). Façade Agriculture (FA) applies the technique of vertical farming using building facades as vegetable growth mediums (Tablada et al., 2020). (Mangkoedihardjo & Noraduola, 2023) applied the same principles to the Productive Façade (PF) terminology. PF or Productive (Green) Façade applies climbing crop plants to construct a green layer in front of the building skin (Mangkoedihardjo & Noraduola, 2023).

Incorporating agriculture into urban areas can greatly decrease the use of remnant fuels, improve the ecological balance of cities, improve food security and safety, advance the worth of life of city residents, and conserve energy in buildings (Y. Wang et al., 2023). In addition, it positively impacts the outdoor microclimate and improves the access of urban residents to nature (Noraduola et al., 2024a).

2. 2. Methods

Urban open spaces are a vital component of urban infrastructure, playing a crucial role in fostering a healthier and more livable society (Faragallah, 2018). To comprehend VGS approaches, which refer to vertical urban green spaces that harmonize with the characteristics of urban kampung, one must understand the physical environment and its communities. Socioeconomic factors can influence specific requirements for infrastructure acquisition in low-income communities (Cahyadi et al., 2021; Noraduola, 2007). Specific requirements include factors such as physical environment conditions, demand, type of system, and source of costs associated with the purchase and maintenance. (Wilkerson et al., 2018) argued that socioeconomic factors influence supply, demand, and management of ecosystem services. Therefore, an explanatory discussion is conducted to obtain a VGS system that is appropriate for the character of an urban kampung.

Before examining the specific requirements of an urban kampung's green space provision, a preliminary study is conducted to determine to what extent urban kampung and/or outdoor thermal comfort are discussed in articles on VGS. This article will conduct a *Systematic Literature Review* (SLR) following the PRISMA framework (Shamseer et al., 2015). The SLR executed using Watase Software (www.watase.web.id), consists of the following stages, namely:

1. **Identification**
   Identification involves searching databases of Scopus-based literature using the keywords "Vertical Gardening System", "Living Walls", "Green Facade", and "Vertical Garden". The article publication period is 2014-2024 from the Q1 to Q4 Journal level, concerning the time of research and development of VGS in the urban context, which was assumed to begin around 2013 (Bianco et al., 2017).
2. **Screening**
   Screening is performed to sharpen the focus of the study on the literature to be reviewed. In this stage, a pre-review is of each journal's title, abstract, and keywords. Only journals that present the results of

the experimental study will be used in the next stage since the author is trying to find the VGS design parameters that can reduce temperatures in the OTC range that have been tested theoretically and practically. Therefore, publications that review articles and discuss topics outside of the thermal performance of VGS are not used in the next stage. In addition, publications discussing energy savings are not included in the next stage.

3. **Retrieval**

   Articles at this stage were downloaded for further review of VGS design parameters. At this stage, 15 publications as case studies were selected to be used to review the ability of VGS to reduce air temperature within the thermal comfort range. Only recent experimental studies that have made significant contributions to providing information on the exploration of the cooling effect of VGS and the magnitude of this effect have been investigated.

4. **Report**

   Reporting is the final stage of SLR and summarises the SLR process, from identification to retrieval. At this stage, an SLR diagram will be produced by applying Prisma 2020.

3. RESULTS AND DISCUSSION

3. 1. Urban Kampung Context in the VGS Discussion

The bibliographic database collected articles from several journals, which, based on their keywords, can be detailed as follows: 91 journals with the keyword Vertical Greenery, 250 journals with the keyword Living Walls, 130 journals with the keyword Green Facade, and 40 journals with the keyword Vertical Garden. The graph in Figure 3 shows an increase in the number of publications related to these keywords in the last decade. The results of the bibliographic database selection show that 54 articles discuss the thermal performance of VGS based on experimental studies, as shown in Figure 4.

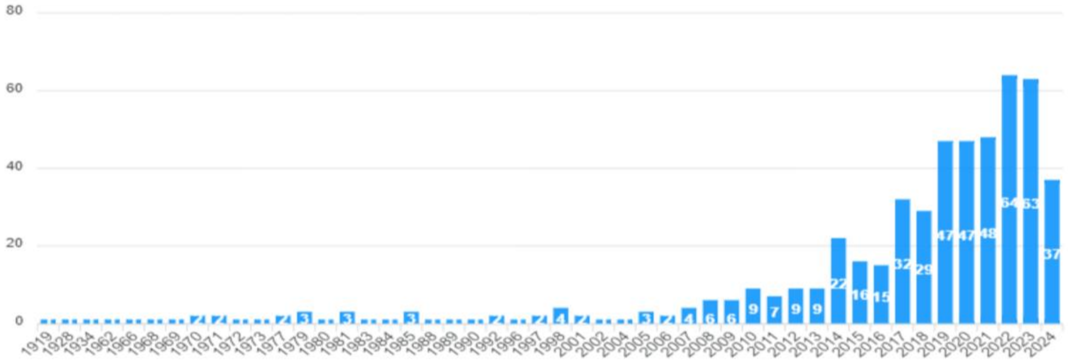

FIGURE 3- NUMBER OF SCOPUS-BASED PUBLICATIONS ON VGS IN 2014-2024

Source: Data analysis based on watase application (2024)

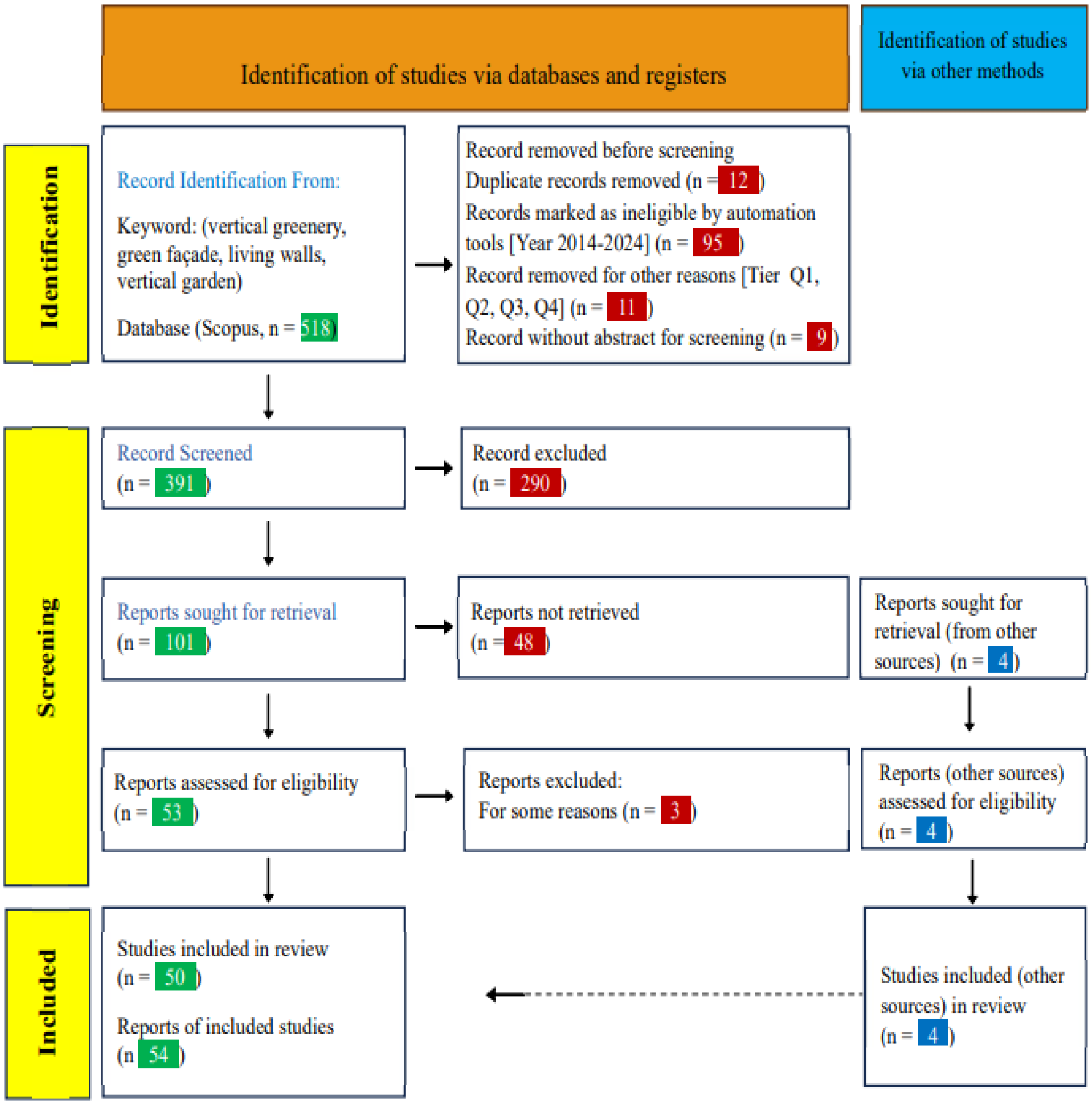

FIGURE 4 – PRISMA FRAMEWORK FOR A BIBLIOMETRIC DATABASE

Source: Data analysis based on Watase application (2024)

Furthermore, research on VGS has been conducted in multiple countries. The bibliometric data obtained in this study indicate that most of the research on VGS was carried out in China and Italy, accounting for 13% of the total research. Meanwhile, research conducted on VGS in Southeast Asian nations, where urban kampung is a prominent feature of settlements, revealed that the prevalence of such research ranges from 2% to 6%. Specifically, Indonesia has a prevalence of 6%, of which Singapore is 4%, of which Thailand is 4%, and of which Malaysia is 2%. However, most of this study does not relate to urban size. Most of the research is experimental, focusing either on a smaller model of building construction or computer simulations. Until now, limited research has been conducted on VGS in urban kampung.

3. 2. OTC in the VGS Discussion

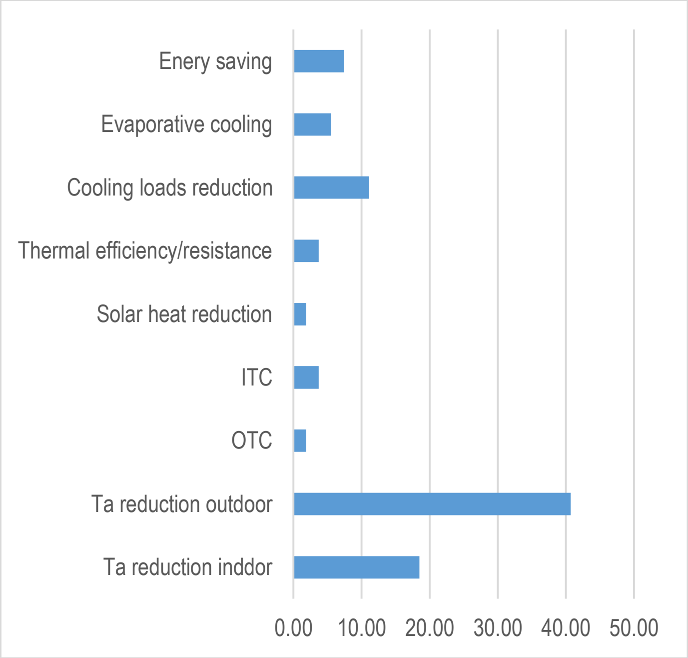

FIGURE 5 – PERCENTAGE OF CONTENT DISCUSSION OF VGS ARTICLE

Source: Data analysis (2024)

Of the 54 articles, only 2% articles specifically discuss OTC as a result of the thermal performance of VGS, however, 41% of the articles discuss outdoor air temperature reduction, as shown in Figure 5. Therefore, to include a sufficient number of case studies, papers addressing air temperature reduction are also considered during the selection process. This resulted in the inclusion of additional references that served as benchmarks for the OTC and air temperature, as described in Section 2.1. Furthermore, of the 15 case studies, there is only 1 article discussing the thermal performance of VGS on the block or neighborhood scale, as shown in Table 1.

3. 3. Potential reduction in outdoor air temperature and thermal comfort due to VGS

According to the selected cases listed in Table 1, VGS can decrease air temperature and enhance thermal comfort in both outdoor and interior environments. However, achieving increases in thermal comfort at a comfort level is possible when the Leaf Area Index (LAI) is greater than or equal to 3 and the highest air temperature is 31 ^{o}C. These were observed in cases 3, 7, 9, and 11.

TABLE 1 - SELECTED CASE STUDY ON THERMAL PERFORMANCE OF VGS

No	Author and Year	Location	Scale		Focus		Air Temp. Reduction	Type of VGs	Thermal Comfort or Existing Air Temperature	Additional Information
			B	M	I	O				
1	(Liu & Meng, 2024)	Qingdao (China)	🟨		🟦		1.45 ◦C	LW	LW-V system improved thermal comfort level by 0.53, Ta Max (Indoor) = 37◦C	Mock-up building experiment
2	(Bakhshoodeh et al., 2023)	Perth (Australia)	🟨			🟦	4 °C	GF	Ta Max=35°C	Mock-up building experiment LAI (mx) = 73%
3.	(Gao et al., 2023)		🟨			🟦	3 °C (Max in hot day)	LW	Max Ta= 30 °C	Envimet Simulaion
4.	(Nugroho et al., 2023)	Malang (Indonesia)		🟨		🟦	1.7°C (Max).	LW	Max Ta = 33.9°C The percentage level of suitability of the house's air temperature is 54% on a neutral scale,	Community-scale experiment
5.	(Tseliou et al., 2023)	Athens (Greek)		🟨		🟦	0.7 ◦C	GF	Max ta = 31. 4°C UTCI reduction of 1.6 ◦C	Envimet simulation
6.	(Azkorra-Larrinaga et al., 2023a)	Araba (Spain)	🟨		🟦	🟦		GF	Max Ta = d 35 ◦C	Mock-up building experiment The vegetation does not influence the air temperature,
7.	(Widiastuti et al., 2022)	Semarang (Indonesia)	🟨			🟦	6.5 ◦C	Direct GF	GF temperatures both 50% and 90% are categorized as warm comfort Up to 80% outdoor air temp. GF50% = comfort Up to 90% outdoor air temp. GF90% = comfort (from comfortable Cool to warm comfort.)	Mock-up building experiment Temperature = 31 C (bare wall). In some cases Temperature >29.1 C for GF_50% and > 27.1 C for GF_90%. The frequency distribution was found out in GF_50% and GF_90% by 25%

No	Author and Year	Location	Scale		Focus		Air Temp. Reduction	Type of VGs	Thermal Comfort or Existing Air Temperature	Additional Information
			B	M	I	O				
			🟨			🟦				at range 25.1–26.0 C.
8.	(Perera et al., 2021)	Colombo (Srilanka)	🟨			🟦	5.06 ◦C (Max)	Modular LW	Existing mean air temperature (barewall) = 40 ◦C.	Building scale experiment and Envimet simulation Thermal performances were evaluated at 20 cm distance in front of the green wall, LAI = 3. 9 and plant height = 5–15 cm
9.	(Widiastuti et al., 2020)	Semarang (Indonesia)	🟨			🟦	3.7 ◦C (max in GF 50% real climate test) 5.7 ◦C (max in GF 90% real climate test)	GF GF	GF_90% was at optimum comfort zone (23.9–26.4 ◦C) GF_50% was in warm comfort zone (24.2–26.2 ◦C) Effective Temperature of Comfort Zone = 20.5 C - 27.1 Barewall air temperature = 26.81	Mock-up building experiment GF also increases relative humidity and potentially creates uncomfortable indoor thermal comfort.
10.	(Acero et al., 2019)	Singapore	🟨			🟦	0. 35 ◦C (in low radiation conditions) 0.15◦C (in High radiation condition)	LW	29.2◦C (max air temperature in Low Radiation) 32,4 ◦C. (max air temperature in High Radiation) Thermal comfort perception can be reduced by one category (e.g. from hot to warm	Simulation experiment The highest |ΔPET| for HR conditions occur in the East-facing façade LAI = 5 Thermal performances were evaluated at 3 m distance in front of the green wall,

No	Author and Year	Location	Scale		Focus		Air Temp. Reduction	Type of VGs	Thermal Comfort or Existing Air Temperature	Additional Information
			B	M	I	O				
11.	(Li et al., 2019a)	Suzhou (China)	🟨			🟦	1-3 ◦C	GF	T air bare wall =43 ◦C	Mock-up building scale Foliage thickness = 7.2 - 30.5 cm Air temperature (0.15 m from leaf) influences microclimate in a limited manner
12.	(Zhang et al., 2019)		🟨		🟦	🟦	3.6 ◦C (peak OT)	GF	a peak OT of 38.8°C (room without the GF) 3.6°C (in the peak OT) The peak WBGT in the outdoor = 2.7°C	Simulation experiment LAI = 4.5
13	(Vox et al., 2018)	Bari (Italy)	🟨			🟦	Max Tsurf = 9 ◦C Avg Tsurf = 6-7 ◦C	GF	Max. Sunny day = 41.4 °C,	Mock-up building experiment LAI = 2-4
14.	(Bianco et al., 2017)	Turin (Itali)	🟨		🟦		7 ◦C	LW	Maximum external air temperature 31 °C, Max internal air temperature = 28 °C.	Mock-up building experiment LAI = 2
15.	(Haggag et al., 2014)	Uni Emirat Arab	🟨		🟦		5 ◦C	LW	Indoor temperatures resulting from VGs are 45–47◦C Comfort temperature of 26–28◦C	Mock-up building experiment

B= Building scale

M = Meso scale

I = Indoor thermal performance

O = Outdoor thermal performance

Source: Data analysis (2024)

3. 4. The physical environment of an urban kampung as a setting for VGS applications

Socioeconomic factors influence the provision of ecosystem services through green open spaces by changing the amount of green open spaces in urban areas (Wilkerson et al., 2018). The availability of green open spaces in urban villages is largely determined by the settlements' way of life and development. Urban kampung settlements that grow organically according to needs and population growth result in not much open space remaining as green open spaces. Urban villages grow as dense settlements with irregular road layouts and road dimensions as dominant open spaces. In this case, the physical environment of urban villages determines the availability of green open spaces.

The high density of buildings, along with the limited size and fragmented layout of open spaces in densely populated places, directly affects the increase in air temperature (Shahmohamadi et al., 2011). As a result, urban areas lean towards heater than neighboring rural areas. The UHI phenomenon primarily arises from the high solar radiation absorption of urban materials, the structural characteristics of cities and urban canyons, the scarcity of green spaces, and the creation of heat by human activities (Fahed et al., 2020).

High-density urban areas, such as urban villages, have a high heat capacity, which allows them to absorb more solar radiation; low albedo, which contributes to the absorption of Shortwave Radiation (SR); impermeability of the area, which makes it difficult for precipitation to penetrate below the ground surface resulting in an evaporative cooling deficit (Shahmohamadi et al., 2011). During this scenario, building walls and other paved surfaces receive SR from the sun, including direct sunlight, dispersed daylight from the atmosphere, and reflected sunlight from the ground and its surroundings (Susorova et al., 2013). In addition, there is an exchange of Longwave Radiation (LR) between the land surface and the surrounding surface and the sky (Susorova et al., 2013), which has the potential to warm the surrounding air when interacting with pollution.

Building facades using VGS can provide significant thermal benefits because of their ability to manage heat differently. The heat transmission courses involved in maintaining leaf energy balance in VGS include the captivation of solar radiation, sensible heat exchange through convection between leaves and the surrounding air, infrared energy exchange between leaves and the environment, latent heat removal through transpiration by plants, and energy storage in tissues (Convertino et al., 2019; Larsen et al., 2014; Susorova et al., 2013). VGS can reduce surface temperatures by providing shade, facilitating air cooling through evapotranspiration, and reducing wind speed (Akram et al., 2023; Mohd Khairul Azhar Mat Sulaiman et al., 2013; Pérez et al., 2022). In addition, VGS can function as a passive energy-saving system (Azkorra-Larrinaga et al., 2023b), thereby reducing greenhouse gas emissions.

Additional physical environmental characteristics of urban kampungs include constrained roadways, limited open areas, and fragmented network configurations. During the daytime, roads and narrow open spaces can reflect and absorb/store short-wave radiation, whereas, at night, the release of heat in the form of infrared radiation is restricted in these areas (Shahmohamadi et al., 2011). In addition, the limited presence of open areas and the fragmented layout of the road network, as well as disconnected open spaces, contribute to the sluggish airflow and the accumulation of hot air (Kartikawati & Kusumawanto, 2013). Weak breezes and limited air movement not only result in stagnant hot air but also contribute to the build-up of pollutants, including carbon dioxide (CO_2) (Shahmohamadi et al., 2011). CO_2 absorbs energy from infrared radiation radiated by urban surfaces, resulting in the heating of the surrounding air (source: https://climate.mit.edu/ask-mit/howdo-greenhouse-gases-trap-heat-atmosphere), Regrettably, the urban microclimate study has not much addressed the correlation between ambient CO_2 concentration in urban kampung and urban warming, nor has it examined the effectiveness of VGS in absorbing CO_2 to reduce air temperature. However, VGS can act as a phytoremediation agent because plants absorb CO_2 for photosynthesis, which can help lower pollution and air temperature in urban kampung.

Furthermore, while relatively little horizontal space is available, a plentiful supply of building facades as a consequence of high building density can be used as vertical green areas in urban kampung. This presents a unique opportunity to achieve a cooling impact by using vertical space as a means of not only reducing surface and air temperatures but also cultivating food.

3. 5. VGS Type and Suitability in Urban Kampung

According to models of innovation adoption, innovations that are economical, visually comprehensive, and adaptive to societal demands are more likely to succeed in poor areas (Nakata & Viswanathan, 2012). Thus, comprehending the VGS can yield specific information about VGS' performance and its appropriateness for the intended area or community, especially in terms of being economically feasible and easy to procure and maintain. This is important in determining the appropriate method of VGS. Table 2. presents various aspects of the VGS that can be used as a basis for selecting a VGS method that suits urban kampung characters.

Regarding the supporting structure, the felt bag method is the simplest lightweight assembly technology. However, it is not recommended for use in large areas or towering buildings (Zareba et al., 2021). In many cases, GF is more widely applied to wide and high walls, because climbing plants can easily and quickly cover the wall surface.

In terms of plant selection, GF promoted the growth of native plants better than LW. However, by cultivating native succulents, perennial herbs, and native grass species using a hydroponic water system and ensuring regular and careful maintenance every one to two months during active growth, a 100% survival rate can be achieved in modular LW (Dvorak et al., 2021). Unfortunately, hydroponic systems used in vertical farming are still considered expensive. In terms of irrigation systems, LW irrigation involves a more high-tech irrigation system, since LW is regarded as an artificial ecosystem. On the other hand, GF only requires a simple plant watering system.

TABLE 2 – COMPARISON BETWEEN THE GREEN FAÇADE AND LIVING WALLS

Components	Green Facade	Living Wall	References
The support structure and air cavity	– Light structure, such as stainless steel wires and meshes. – Flexible: allowing a customized design for each project	The combination of layers Structure made of galvanized steel, polyethylene, or recycled plastic panels	GF: Fernández-Caero et al., 2018 LW: Fernández-Caero et al., 2018
Container	– Rooted within ground soil – Planter box	Non-woven felt and polypropylene pocket	GF : (Li et al., 2019b) LW: Fernández-Caero et al., 2018
Growing medium	– Soil – Substrate	– Hydroponic cultures – Organic substrate, such as coco peat); sphagnum moss; coconut fiber mat, peat moss – Inorganic compounds, such as rock wool, polyurethane foam, perlite, expanded clay, mineral wool, etc.	GF: Fernández-Caero et al., 2018 LW: Fernández-Caero et al., 2018; Zareba et al., 2021
Plants	– Climbing Plants – Hanging plants – Plants with twining or adventitious roots. – Limited to species found to be able to climb or survive – Need time for plants to cover the entire wall	– Epiphytic, lithophytic, and bromeliads species, – Ferns, succulents, herbaceous plants, small shrubs, and climbing plants – Flowers and edible plants – Plant zoning based on sun exposure, wind, and temperature. – Great diversity and density of plants – Species. – Relatively short time for plants to cover the entire wall	GF : Othman et al., 2018; Fernández-Cañero et al., 2018 LW: Fernández-Cañero et al., 2018; (Elghonaimy & Eldardiry, 2020); Thakor, 2020; Palermo & Turco, 2020
Irrigation	naturally, manually or automatically irrigated	Distributed per sector Has horizontal branches with drippers Hidroponics	GF : (Othman et al., 2018) LW: Fernández-Cañero et al., 2018
Maintenance	Easy	Much.	GF : Othman et al., 2018 LW : Ansari, 2021
Cost	Low	Medium to high	GF: Fernández-Cañero et al., 2018 LW: Othman et al., 2018;

Furthermore, GF stands out for its simplicity and ease of construction and maintenance, resulting in lower costs than LW. Regarding planting media and time, GF takes a long time to take advantage of its thermal advantages as a full wall covering. This is because climbing or hanging plants takes a long time to cover the entire wall surface. In contrast, LW takes less time because the plants are cultivated separately and then transferred to the LW system. In general, although the thermal performance of GF was identified as lower than that of LW, GF was regarded as a simpler and easier system, easier to plant native plants, and had lower initial and maintenance costs than LW. These characteristics are the main determinant of low-income communities' VGS adoption.

Additionally, an urban kampung is formed and expanded organically through community-based interactions outside formal planning frameworks, resulting in the construction of homes in multiple stages according to residents' needs (Shirleyana et al., 2018). In an urban kampung, the open spaces creation occurs naturally as leftover areas between buildings, with irregular patterns and sizes. The transformation of neglected city spaces into green spaces by planting crops to support the neighborhood has been applied in the introduction of edible networks as a method of development of productive green open spaces (Nyman, 2019). The concepts of productive open urban spaces vary widely from socioeconomic aspects of urban agriculture to the environmental functions of plants for pollution absorption, flooding control, heat reduction, and biodiversity (Nyman, 2019). In the case of food provision, urban green productive systems are formed from urban farms as a complement to urban structures (Kleszcz, 2018).

Given the context of creating productive open space in urban kampung, the most suitable method would be establishing an edible open space initiative using VGS as a physical feature based on nature. This would involve creating a small productive open space within an urban kampung. VGS has the potential to grow mustard greens, spinach, and kale using the LW system, or to cultivate pumpkin, sweet potatoes, long beans, water spinach, and bitter melon using the GF system. Urban kampung communities regularly eat those vegetables (Taridala et al., 2021).

3. 6 Urban Kampung Demand Adressed by VGS

The outdoor environment affects the indoor room through changes in indoor air temperature, humidity, thermal comfort, pollutant concentration, and building energy consumption. The demand for heating and cooling depends on population density, weather, building stock, and the behavior of the occupants (Staffell et al., 2023). (Murtyas et al., 2021) found that urban kampung microclimate, with external air temperatures ranging from 23 ° C to 36 ° C and relative humidity ranging from 42% to 99%, affects indoor temperature, by which people adapt by opening windows or using electric fans. Another form of thermal adaptation is using transitional spaces such as terraces and hallways for daily activities (Hutama, 2016). In this case, urban kampung communities use outdoor areas for their activities, where air movement gives them a more psychological effect of thermal comfort than closed indoor buildings. This demand fits with the capacity of VGS, that is VGS can reduce both indoor and outdoor temperatures, as shown in Table 2.

Furthermore, the food demand of urban village communities is mainly based on household food consumption patterns, with cereals and leafy vegetable products being the most commonly consumed foods, accounting for 48% of household food (Colozza & Avendano, 2019). The use of food crops in VGS can provide leafy vegetables as food for the community. At the same time, the Leaf Area Index (LAI) is the most imperative aspect in accomplishing a cooling effect (Arpon, 2016; Convertino et al., 2021; Dahanayake et al., 2017; Perera et al., 2021; Pérez et al., 2022). In addition, a study by (Gratani et al., 2016) exhibited that vegetation with high LAI absorbs CO_2 efficiently. CO_2 absorption is expected to reduce the air temperature of urban village settlements in urban blocks because CO_2 heats the ambient air.

4. RESEARCH IMPLICATION

The increase in air temperature and urban food insecurity as spatial consequences of urbanization require effective urban planning and adaptation strategies. Within densely populated areas primarily inhabited by low-income groups, such as urban kampung, the most suitable VGS method to implement is a Green Façade (GF) using crop plants, which can support food provision for the community and improve the microclimate of urban kampung. To address vegetable plants that do not reproduce, it is essential to adapt the Living Wall (LW) to an affordable system, such as a pocket system made from locally available materials. However, based on the selected study case, to obtain environmental cooling in the comfort zone of the outdoor thermal comfort index, the VGS must be developed to reach LAI ≥ 3 and the highest ambient temperature is 31^{o}C.

LAI is a biotic parameter directly associated with photosynthesis and evapotranspiration (Poddar et al., 2017), so it performs an imperative role in defining the extent of the VGS cooling effect. LAI is the portion of the sum one-sided leaf surface of the plant canopy per unit of ground or horizontal surface area (LAI = leaf area/ground area, m2/m2) in broad-leafed canopies (Arpon, 2016; Convertino et al., 2021; Dahanayake et al., 2017; Mohd Khairul Azhar Mat Sulaiman et al., 2013; Pérez et al., 2022; Poddar et al., 2017). In the case of vertical greenery, LAI pronounces the portion of the leaf area to the square meters of the facade as an alternative to the portion of the leaf area to the square meters of the floor as typical (e.g. for green roof applications) (Mohd Khairul Azhar Mat Sulaiman et al., 2013; Perera et al., 2021). To obtain an LAI of 3, choosing the right types of food plants is necessary. Long-term crops with a harvest period of 4-6 months, such as pumpkin and sweet potatoes, have the potential to achieve LAI

≥ 3 when compared with short-term food crops, such as water spinach (*kangkong*). Research conducted by (Noraduola et al., 2024) shows that food crops such as sweet potatoes and pumpkins can be developed to achieve LAI ≥ 3 and produce a cooling effect in the comfort zone. Good LAI development can also be obtained through proper VGS orientation. Several studies have shown that VGS oriented to the east has higher LAI than VGS with other orientations (Fernández-Cañero et al., 2012; Susorova et al., 2013). In the case of Singapore, buildings with an East-West direction will better sustain plant gardening, especially for building typologies without self-shading configurations (Song et al., 2018). In addition, the development of LAI can also be obtained from the arrangement of planting media and irrigation systems.

Moreover, several studies on horizontal green open spaces have shown that connectivity enhances the cooling effect. (Honjo & Takakura, 1990) stated that green open spaces with small dimensions but with the right distance can provide a wider cooling effect than green open spaces with large dimensions such as city parks because they can provide an overlapping cooling effect (Vartholomaios, n.d.). This argument is in line with what was stated by (Zupancic & Bulthuis, 2015) that, small green spaces with trees can provide a greater cooling effect than large parks with wide open grass. Minimizing the distance between small city parks can maximize the cooling effect and increase the flow of cool air and the dispersion of air pollution (Tallis et al., 2011). In this case, the proximity of the distance between VGS as small green spaces will determine the level of structural connectivity of the green open space, which will have implications for the level of cooling or its cooling effect or at least maintain an ambient temperature of less than 31°C in a high-density urban kampung.

Multifunctionality and connectivity are important parameters of ecological infrastructure (X. Wu et al., 2020). Therefore, applying VGS in dense urban settlements, such as urban kampung, requires an ecological infrastructure approach. In the context of Ecological Infrastructure (IE), small open spaces in the urban kampung are developed as productive green open spaces (providing food and supporting the local economy) through VGS productive GF on buildings forming open spaces that are expected to reduce air temperatures, which has an impact on improving the thermal comfort of outdoor spaces. Ecological infrastructure can provide diverse and integrated functional systems (Gong & Hu, 2016). In the application of GF using food crops, GF not only plays a role in lowering air temperature and improving the thermal comfort of outdoor spaces but also acts as a source of food for urban village communities (Noraduola et al., 2024b). The application of food crops in green facades, such as sweet potatoes as a source of carbohydrates and pumpkins as a source of vegetables, vitamins, and minerals, can increase access to food supplies because food needs are provided in the residential environment. This can provide health benefits for the community, especially for households with nutritional adequacy and, cost efficiency in food procurement.

5. CONCLUSIONS

Food insecurity and elevated urban temperatures affect public health. Typically, low-income communities, such as urban kampung, are more susceptible to harm or danger. This article may contribute to improving access to nutritious food and green open space, improving the microclimate of the living environment, more equitable distribution of infrastructure, and mitigating the adverse impacts of UHI and climate change catastrophes for urban kampung communities.

Additional research is required to improve the thermal efficiency of VGS at the mesoscale and its off-the-shelf applications, especially in high-density urban areas. Several studies have shown that appropriate irrigation and fertilizers can increase a plant's evapotranspiration capacity. Thus, investigating the effectiveness of irrigation and fertilizer methods for VGS, and exploring their potential integration with water reuse, recycling, and household or community composting facilities, will improve the thermal performance of VGS and address wastewater and solid waste management in urban rural communities, which suffer from infrastructure deficiencies. Furthermore, research on VGS network connectivity at the block scale is expected to guide the proper layout of VGS to produce optimal cooling effects at the residential scale, as several studies on horizontal green spaces have shown the important role of connectivity in this regard. In addition, it will be useful to study the optimal CO_2 uptake by VGS, which is expected to lower air temperatures in urban kampungs. This is especially relevant considering the street patterns and open spaces in urban kampungs that can trap pollutants and particles. In technological applications, studies are needed on VGS application models that are more accessible and cost-effective for procurement and maintenance. In addition, it is important to examine the possibilities and constraints associated with VGS applications in society.

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