

*Review Article*

## **An Overview of Vertical Farming: Highlighting the Potential in Malaysian High-Rise Buildings**

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### **ABSTRACT**

Recently, there has been a surge of interest in sustainable agriculture to address the impact of urban paradigm shifts on food demand and supply. Vertical Farming (VF) has attracted considerable attention, both scholarly and economically, as a way forward to improve food security in urban areas. Previous studies have documented and reviewed the benefits of VF against traditional agriculture. However, most research papers have only focused on case studies from temperate climate regions. There is a surprising paucity of empirical research in urban farming specifically related to VF in tropical countries. This study set out to examine the new emerging agricultural innovation—VF—in various building typologies the growing system and explores the feasibility in Malaysian high-rise buildings. The findings also revealed several successful outcomes of ongoing urban farming projects in Malaysia, Singapore and Thailand, which can significantly contribute to the planning and development of VF in a tropical climate. As a result, critical assessment criteria were identified for the successful development of the VF system in urban areas. This study implies significant opportunities for Malaysia to implement VF in local high-rise buildings.

*Keywords:* Building integrated agriculture, control environment agriculture, high-rise building, tropical climate, typology, urban farming, vertical farming

### ARTICLE INFO

*Article history:*

Received: 29 August 2021

Accepted: 15 December 2021

Published: 03 March 2022

DOI: <https://doi.org/10.47836/pjst.30.2.06>

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ISSN: 0128-7680

e-ISSN: 2231-8526

### **INTRODUCTION**

Located in Southeast Asia, Malaysia is blessed with a consistent year-round temperature ranging from 23°C to 34°C that varies based on the altitudes. Malaysia is also rich in water resources due to heavy rainfall between 1801.6 mm and 4581.8 mm per year (Federal Research Division,

2006). With high precipitation, the mean relative humidity in Malaysia ranges between 72.7% and 89.3% (DOSM, 2019). The distinct tropical climate aspects significantly influence maintaining a diverse ecosystem. The constant warm temperature, ample sunlight and sufficient rainfall enrich plant growth year-round (National Research Council, 1993). However, recent urban sprawl has inevitably led to insufficient resources in local agricultural development. Based on statistics, due to rapid industrialisation, the contribution of agriculture to the gross national product (GDP) substantially declined from 28.8% in 1970 to 8.2% in 2017 (HRD Corp, 2019).

Locally, most vegetable growers originate from smallholders or private industries (FAO, 2011a). Based on the 2019 Human Capital Report by Human Resource Development Corporation (HRD Corp), the major challenges encountered by the Malaysian agriculture sector involves high production costs, an inadequate number of competent farmers, limited financing, insufficient investors, low rate adoption in technology and advanced techniques, climate shifts, change in government policy, land quality, and lack of value-added activities. The report also added that despite the attempts to diversify food production, Malaysian agriculture leaned towards export-oriented agriculture, such as palm oil (HRD Corp, 2019).

One of the primary challenges involving low labour productivity in the local agricultural sector is insufficient technology advancement and innovation. Local farming methods require transformation by adapting precision agriculture techniques to improve production efficiency and reduce labour dependency (HRD Corp, 2019). Although Malaysia perceives the need for bigger commercial-size farmland cultivation, local arable lands remain scarce. Following an estimation in 2001, merely 5.5% of the local lands were arable (Federal Research Division, 2006), while the remaining counterparts were cleared for urban utilisation, settlements, and industrial and palm plantations (Yahya, 2001).

Furthermore, the drastic rise in global population in the last two decades has drawn global attention to food insecurity, specifically in urban areas. Food and Agriculture Organisation, FAO (2018) predicted that food production would increase by 70% to feed the global population in 2050. Similar to many least developed nations that would predictably double in population between 2019 and 2050 (United Nations, 2019), the total Malaysian population increased from 8 million (in 1960) to 32.6 million (in 2019) and would project to steadily increase to 41.5 million in 2040 (DOSM, 2016).

Rice is the staple food that accounts for the highest food supply of all food categories in Malaysia. Recent statistics show that rice production has increased 3-fold since 1961 from 0.7 million tonnes to 2.1 million tonnes in 2015. Along with the production, Malaysia imported 1.2 million tonnes of rice in 2015 to sustain increasing population demand (Sundaram & Gen, 2019). Figure 1 illustrates the increase in rice imports, keeping abreast with the population increase.

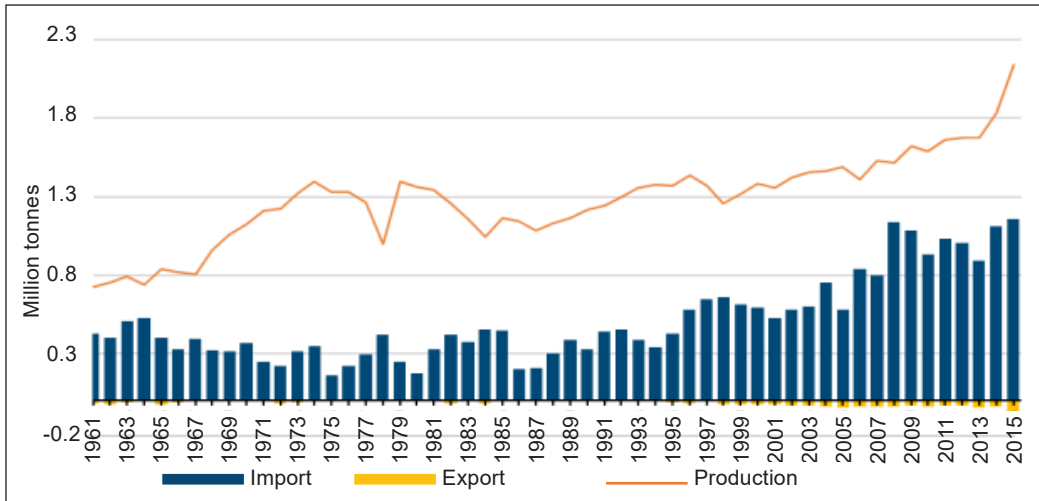


Figure 1. Rice production, imports and exports, 1961-2015 (Sundaram & Gen, 2019)

Similarly, the production of vegetables increased 10-fold from 134,000 tonnes in 1961 to 1.4 million tonnes in 2013, and the number of vegetables imported rose from 79,000 tonnes in 1961 to 1.1 million tonnes in 2013 (Sundaram & Gen, 2019). Figure 2 illustrates that more vegetables were imported than produced during the year 1995-2015. The trend continued till 2019. It is supported by statistics from the Ministry of Agriculture and Food Industries, where Malaysia imported vegetables worth RM 4,635 million mainly from these top 5 countries: China, India, USA, Thailand and Netherlands (MAFI, 2019). This value is more than 4-fold of exported vegetable value which is RM999.7 million (MAFI, 2019). Figure 3 illustrates the increasing trend of vegetable imports.

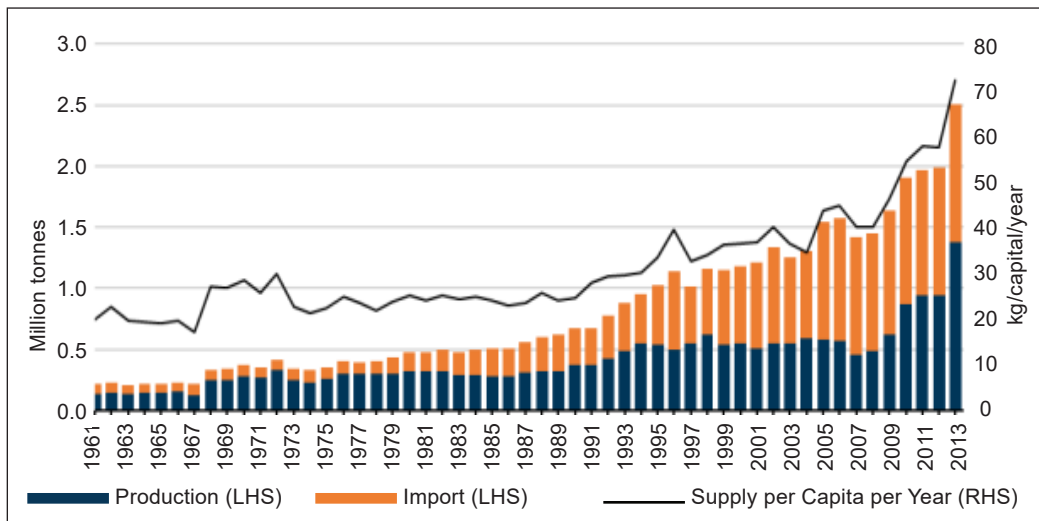


Figure 2. Vegetable production, import and supply per capita, 1961-2013 (Sundaram & Gen, 2019)

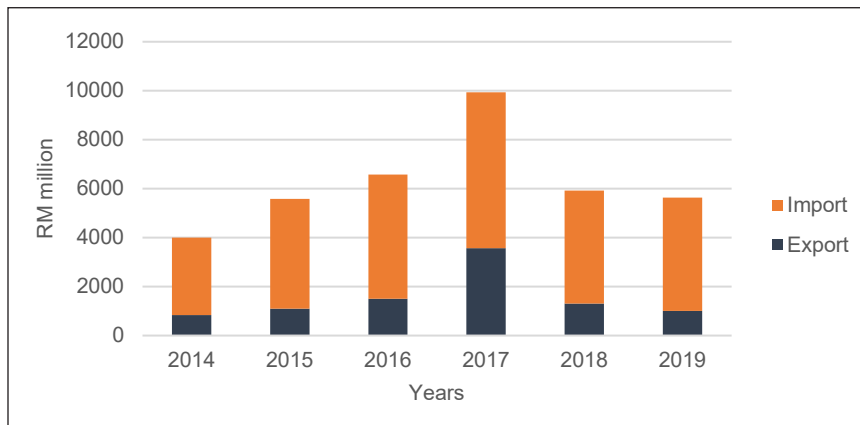


Figure 3. Vegetable trade in Malaysia, 2014-2019 (MAFI, 2019)

The above statistics show that local production of crops has increased to cater to consumer demand; however, imports have also increased to ensure food availability. Several factors are contributing to the decline in vegetable production lately. Harvest and post-harvest food losses during production, crop disease, poor soil condition and climate change are among the reasons constraining raising outputs. Besides, the population increase also resulted in limited arable lands, inadequate natural resources, contaminated soil and water (Despommier, 2011). Hence, Malaysia is not fully self-sufficient in the food supply.

Additionally, the industrial revolutionisation continued attracting rural area residents to the cities for better employment and income opportunities (Garcia & Briceño, 2018). Based on the FAO (2018) forecast, two-thirds of the global population could be residing in urban areas by 2050. It is supported by statistical evidence from the Department of Statistics Malaysia (DOSM), where the percentage of the Malaysian population in urban areas has increased from 25% to 76.2% in 2019 (DOSM, 2019). The demographic shifts and expansion will induce substantial pressure in food demand from rural agricultural sectors. A larger share of total food demand and crop diversification is also needed to satisfy dietary shifts among urban consumers. Urban consumers demand higher quality, greater food choices and convenience due to longer working hours and traffic congestion. For example, demand for Mediterranean food choices with more greens and healthy diets will pose major challenges to rural farmers. Suppose production does not become more diversified in response to changes in consumer demand. In that case, more food will be imported, affecting the country trade balance and consumer price, as evidenced in the current rising price of fruits and vegetables. It brings the much-debated question on the ability of the agricultural industry to meet the growing food demand and crop diversification.

Given the above circumstances, many researchers and scientists have been interested in developing new farming techniques to enhance food productivity. As a result, multiple groundbreaking technologies were presented to upscale traditional farming, such as soilless

cultivation using hydroponic techniques, indoor farming systems with control environment agriculture (CEA) technologies, genetically modified seeds, and biofortification to enhance the micronutrient concentration in plants (Benke & Tomkins, 2017; SharathKumar et al., 2020; Zeidler & Schubert, 2015). Although indoor farming was initially developed for nations in temperate climates to obtain year-round supplies and high-value crops, the shift from horizontal growing proved necessary to maximise yield, offset high investment costs related to CEA, and remain competitive against conventional agriculture productions (Somerville et al., 2014). As a result, the vertical farming concept was introduced to increase the intensity of indoor farming production in line with the growing urban population demand.

In the era of globalisation, with much emphasis on highly efficient and productive technologies, Malaysia should acquire the innovations above to be integrated into the local agricultural sector. Specifically, VF using hydroponics techniques in high-rise buildings must be duly regarded to alleviate issues concerning limited arable lands and other pertinent challenges in traditional agriculture. Furthermore, it was deemed crucial for urban consumers to be self-sufficient regarding essentials, such as food (growing food locally and closer to home), water, and energy towards forming a self-sustaining community. Therefore, this study aimed to develop a better understanding of the VF system, its application in various typologies and its potential in Malaysian high-rise buildings.

## **OVERVIEW OF VERTICAL FARMING SYSTEM**

The VF concept has garnered scholarly interest and investors' attention (Despommier, 2010). Despommier and Ellingsen (2008) and Platt (2007) emphasised the need for a drastic shift from traditional farming to address high food demand and limited arable lands in urban areas. As a result, crop cultivation within multi-story buildings, stacked on top of one another, under rigorously monitored conditions with precision agricultural techniques are recommended for food production all year round (Despommier, 2013). Al-Kodmany (2018) further indicated that vertical farming in controlled and closed-loop settings could substantially improve yield, prevent water wastage, and eliminate the excessive use of fertilisers, pesticides, and herbicides.

### **The Controlled Environment Agriculture (CEA)**

The CEA is a prime element in VF and was developed many years ago to upscale indoor urban farming. The CEA technologies monitors and controls essential plant growth parameters, such as nutrient solution amount, light quality and quantity, temperature, relative humidity, and carbon dioxide (CO<sub>2</sub>) gas injection (Zeidler & Schubert, 2014). As a result, the CEA growing method implemented Despommier's vision to grow plants vertically in skyscrapers. Despommier (2011) pointed out that controlled environment

farming within a tall building is more beneficial than traditional agriculture in regard to year-round supply, zero crop failure due to natural disasters (hurricanes, floods, and droughts), no heavy machinery, and minimal water usage. More importantly, Zeidler and Schubert (2015) stated that VF facilitates consumers' access to local produce and increases food supply resilience. Despommier (2018) foresees that VF would be commercialised worldwide within the next 10 to 20 years. As a result, various governments have begun advocating VF and funding not-for-profit and profit organisations that strive to fulfil the demand for local produce (Despommier, 2014).

### The Vertical Farming System Components

A VF system is generally viewed as an indoor-based farm in a high-rise building with climate control technologies and advanced agricultural systems. The system encompasses the following essential components: lights, heating or ventilation, irrigation supply units, nutrient solution, CO<sub>2</sub>, a soilless medium, the farming structure to support the growing units and irrigation (Zeidler & Schubert, 2015). Another vital VF element is the automation system and sensor technologies. These technologies are currently being employed in multiple greenhouses and indoor farms globally for consistent, stable growth conditions all year round (Hallock, 2013). Furthermore, as labour costs in farming account for half the production costs, automated systems are utilised to minimise the operating costs (Bertram, 2019). The eight primary components in the VF system are illustrated in Figure 4.

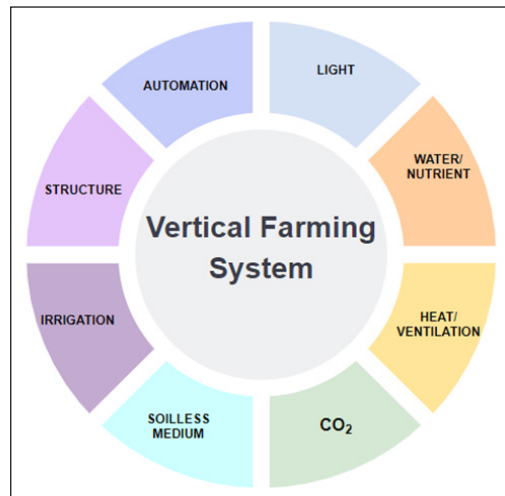


Figure 4. Vertical farming system primary components (Bertram, 2019; Despommier, 2009; Hallock, 2013; Zeidler & Schubert, 2015)

The essential component in indoor based vertical farming is light. Plants grow best when exposed to full sunlight for 8 hours each day as it is the energy source for photosynthesis. Conversely, plants having slow growth and spindly looking are the signs of inadequate light (Jones Jr, 2014). Therefore, in CEA, artificial lights are installed to substitute or supplement daylight to ensure the best growth. The artificial light technology evolved from fluorescent (FL), high-pressure sodium (HPS), metal halide (MH), and incandescent (INC) lamps to a recent innovation, horticultural light-emitting diode (LED). These LEDs provide better solutions in terms of environment, cost and energy consumption (Bian et

al., 2018). However, the art of growing plants with artificial lights will continue to evolve to reduce energy consumption and provide optimal growth light spectrum for higher yield.

### The Vertical Farming Techniques

Studies on soilless plant-growing techniques have a long history. In 1851, Boussingault (a chemist) affirmed that plants absorb natural elements and minerals from air, water, and soil (Resh, 2013). Between 1860 and 1861, Sachs and Knop (two German scientists) studied soilless plant growth by directly supplying the required minerals to plant roots using mixed nutrient solutions (Resh, 2013). It was revealed that plants could grow naturally when the roots are immersed in water solutions containing the following salt types: nitrogen (N), phosphorus (P), sulphur (S), potassium (K), calcium (Ca), and magnesium (Mg) (Resh, 2013). Eventually, Gericke (1940) wrote a book entitled “Complete Guide to Soilless Gardening,” where the term ‘hydroponics’ is presented as a soilless technique. The hydroponics technique has become a primary agricultural scientific breakthrough in the past two centuries.

Although true hydroponics utilises water as a medium with added essential nutrient solutions, some counterparts use inert substrates for better aeration and root support. Typically, plants acquire nutrients through minerals from soil and water (Resh, 2013). In soilless technique, appropriate mineral elements in adequate quantities must be provided through water dilution. However, the plant types, choice of growing medium, and hydroponic techniques significantly influence the right nutrient elements and quantities. In general, 16 essential minerals should be provided for enhanced plant growth (Hochmuth & Hochmuth, 2015). A summary of the mineral elements in soil-based and soilless hydroponics are presented in Figure 5.

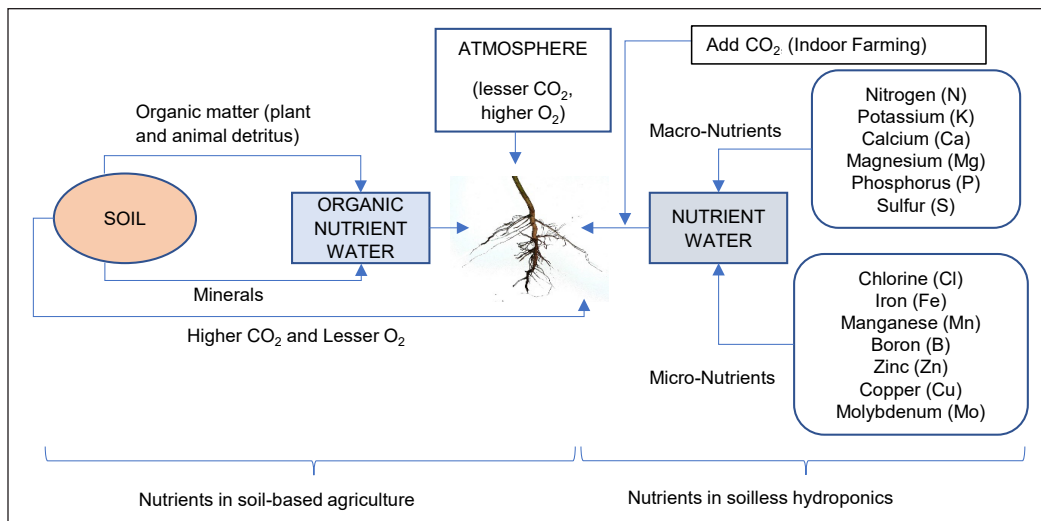


Figure 5. Essential soil-based and soilless elements (Hochmuth & Hochmuth, 2015; Jones Jr, 2014; Resh, 2013)

There are various growing techniques for soilless culture, but they evolved from traditional hydroponic techniques. These are aeroponics, aquaponics, deep water culture (DWC), nutrient film technique (NFT), drip irrigation, and the ebb and flow and wicking systems (Figure 6). In aeroponics, plants dangle in the air without any substrates. It is a space-science technological evolution developed by Hubick et al. (1982) and subsequently enhanced by NASA scientists (Al-Kodmany, 2018; Despommier, 2009). The plant roots are misted with nutrient solution water using a high-pressure atomisation technique in this system. Aquaponics is a zero-wastage closed-loop system. In this ecosystem, fish or other aquatic animals are reared for their by-products which act as waste disposal containing high nutrient concentrations for plant growth (Dahlberg & Linden, 2019). Basically, good microbes are cultivated from fish waste while the plants help purify the solution by absorbing the bio-fertiliser (Sedacca, 2017).

In DWC, plant roots are submerged in nutrient solution containers. The containers could resemble small mason jars for home applications or large tanks for commercial farming. Notably, air pumps should be incorporated into the tanks for gentle solution aeration and high root-zone oxygen (Pandey et al., 2009). In contrast to DWC, NFT allows the nutrient solution to flow past the roots in extremely shallow streams (resembling a film of water) and leaves parts of the roots exposed to air for oxygen absorption. This method is prevalent among hydroponics users. However, NFT requires gentle slopes along the channels for excess nutrients drainage by gravity (Bray, 2018). Drip irrigation (also known as a trickle or micro-irrigation) is an irrigation method that facilitates the precisely controlled application of water and fertiliser through slow water drips near plant roots using a network of valves, pipes, tubing, and emitters (Simonne et al., 2008).

The flood and drain or ebb and flow (E & F) system immerse the root systems with nutrient solutions using submersible pumps for a specific period. Then, the solution would be drained back to the same reservoir by gravity to facilitate plant root aeration upon soaking the roots. This technique is mostly used for seedlings production (Bezuidenhout, 2016). Finally, the wicking system is a passive growing technique where nutrient solutions from a separate reservoir move up the wicks into the roots through capillary action. As such, the capillary wicks remain saturated with nutrient solutions (Agritecture, 2019).

Basically, there is no one best method to determine which works best for the growers or the plants. The DWC is the simplest system, whereas aeroponic is regarded as an expensive and complex system (Maucieri et al., 2019). However, plant roots receive more oxygen in an aeroponics system compared to any other technique, resulting in higher and healthier yields. This technique also uses less water than any other hydroponic system (Eldridge et al., 2020). Although aeroponics seems attractive, the tiny nozzles that spray the mist are often clogged with nutrient sediments and call for frequent maintenance. NFT, on the other hand, allows a large number of plants to grow. Therefore, NFT is highly recommended by



commercial and home growers (Bray, 2018). NFT, wicking system and DWC are the best suits for low cost and low maintenance and easy to operate by new growers. Advanced growers looking for greater yield with stronger monitoring processes could go for drip irrigation, aquaponics and aeroponics.

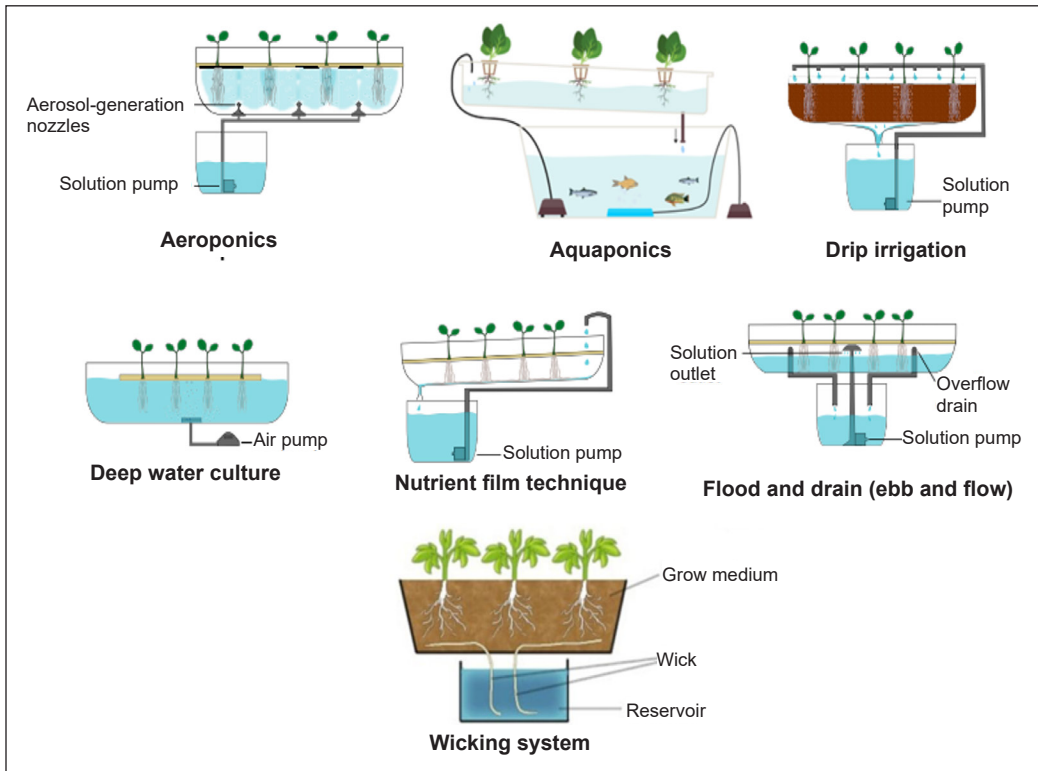


Figure 6. Hydroponics techniques (Agritecture, 2019; E-Hydroponicsystems.com, 2020; Eldridge et al., 2020)

A crucial factor in determining the choice of growing technique is the site of hydroponic system is being placed, whether in a controlled environment space, in a greenhouse with precision agricultural technologies or outdoors. In addition, specific regions with varying weather conditions (temperatures, humidity levels, light intensity and duration) also will govern which technique is required to be successful (Jones Jr, 2014). Table 1 presents the scoring of the hydroponic techniques tabulated by Wynand Bezuidenhout, the founder and owner of Grow Machines, with more than 12 years of experience in hydroponic system development. Wynand points out that the choice of growing techniques also depends on the cultivar and application (seedling or plant) (Bezuidenhout, 2016). Based on his personal experience, Bezuidenhout (2016) concludes that NFT is the easiest and most cost-effective system compared to DWC, aeroponics, and E&F. The constant flow technique does not require much capital to construct the structures, and the operating cost is also less.

Table 1  
Scoring of the hydroponics techniques (Bezuidenhout, 2016)

Feature	NFT	DWC	Aeroponics	E&F
Flexibility (multiple varieties)	7	3	9	6
Dissolved Oxygen	8	4	10	7
Use of Water	9	5	9	8
Use of Fertilisers	9	5	9	8
Growth Rates	9	8	9	6
Hygiene	9	5	6	6
Simplicity to Operate	8	5	3	7
Capital	6	7	3	5
Ease of Assembly	7	7	3	5
Ease of Cleaning	7	5	2	6
Running Cost	8	7	5	6
<b>Score</b>	<b>87</b>	<b>61</b>	<b>68</b>	<b>70</b>

\*Note: 1 = bad; 10 = good

### The Vertical Farming Growing Media or Substrate

Appropriate growing media selection is essential in VF. Soilless media must resemble soil characteristics: facilitate adequate oxygen, water, and nutrients and support plant roots. Examples of soilless media include water, gravel, sand, expanded clay, rock wool, peat moss, coco coir, vermiculite, perlite, foam, and polyester matting (Farhan et al., 2017; Maucieri et al., 2019; Pandey et al., 2009; Resh, 2013). The choice of a media depends on the media characteristics, availability, cost, quality, and plant-growing technique types (Bray, 2018). Among these factors, media characteristics significantly influence optimal plant growth. For example, the particle size, shape, and porosity determine moisture retention in a substrate. For instance, irregularly shaped particles have higher surface areas and bigger pore space compared to smaller, circular particles that are closely packed where water retention is perceivably higher. Alternatively, Resh (2013) stressed that excessively fine materials must be avoided due to poor drainage and insufficient oxygen movement in the media. Table 2 shows the characteristics of some of the growing media.

Table 2  
Characteristics of growing media (Bray, 2018; Jones Jr, 2014; Resh, 2013)

Growing Media	Characteristics
Rockwool and stonewool	Clean, nontoxic (can cause skin irritation), slightly alkaline, pH is 7 to 8.5, lightweight when dry, reusable, high water-holding capacity (80%), good aeration (17% air-holding), no cation exchange or buffering capacity, provides ideal root environment for seed germination and long-term plant growth, prone to algae growth, biologically non-degradable
Vermiculite	Micaceous mineral, porous, sponge-like, sterile material, lightweight, high water absorption capacity (five times its weight), easily become waterlogged, relatively high cation exchange capacity, popular media for drip irrigation and ebb and flow

Table 2 (continue)

Growing Media	Characteristics
Perlite	Siliceous, sterile, sponge-like, very light, free-draining, no cation exchange or buffer capacity, mainly used as soil additives, good germination medium when mixed with vermiculite; dries out very quickly, dust can cause respiratory irritation
Gravel	Particle size ranges from 5 to 15 mm in diameter; free-draining; low water-holding capacity; high weight density, may require thorough water leaching and sterilization before use to avoid pH shifts, fairly cheap
Sand	Small rock grains of varying grain size (ideal size: 0.6 to 2.5 mm in diameter) and mineral composition; may be contaminated with clay and silt particles, which must be removed prior to hydroponic use; low water-holding capacity as tend to pack tightly together, high weight density; frequently added to an organic soilless mix to add weight and improve drainage
Expanded clay	Sterile, inert, lightweight, range in pebble size of 1 to 18 mm, free-draining, a physical structure can allow for the accumulation of water and nutrient elements, reusable if sterilized, good aeration and root support, need thorough washing before use.
Pumice	Siliceous material of volcanic origin, heavier than perlite, inert, has higher water-holding capacity than sand, high air-filled porosity
Scoria	Porous, volcanic rock, fine grades used in germination mix, lighter and retains a fair amount of water, sharp edges of the rock can cause rootDamage
Coco coir	Popular and organic, fibre from coconut husk, larger oxygen capacity (40% air capacity at saturation) than rock wool, high water holding capacity, high in root stimulating hormones, protection against root diseases, higher pH, relatively high cation exchange capacity.
Polyurethane grow slabs	New material, which has a 75% to 80% air space and 15% water-holding capacity

Rockwool is probably the most widely used substrate in a hydroponics system. It provides good moisture retention and aeration for the roots. However, the disposal of used rockwool slabs is a threat to the environment. Another most versatile, environment-friendly and cost-effective media is coco coir. Coco coir slabs are very stable and have a long lifespan. In addition, the used coir may be recycled as soil fertiliser or conditioner (Resh, 2013).

## THE VERTICAL FARMING TYPOLOGY

The VF is mainly seen as a form of building-integrated agriculture where the cultivating activities can be carried out within a multi-story building, on the rooftop of a building, or in any open space within and outside buildings (façade, balcony, or interior). Several studies refer to VF as “Zero-acreage farming” or Zfarming with no utilisation of farmland or open green space (Specht et al., 2014; Thomaier et al., 2015). Figure 7 shows a “zero acreage farming” architecture design on a devastated urban site in Singapore. The EDITT Tower (“Ecological Design in The Tropics”) design approach is to restore the inorganic nature of the site. The 26- storey tower is designed to cover half its surface area with local organic

vegetation. Solar panels are expected to generate up to 40% of the building's energy demands. The design also includes a curvilinear rooftop rainwater collection and recycling system (Yeang & Powell, 2007).

Generally, the VF typology can be divided into three categories: holistic approach, transformation, and retrofitted onto existing buildings.

### Holistic Approach

Despite multiple conceptual designs involving a holistic approach, the actual structures are yet to materialise following ongoing studies by potential investors on financial viability. In a holistic approach, the VF system prerequisites are integrated during the planning and building design concept stage. This typology can further be classified into two categories: i) maximise usage of natural light and ii) primary reliance on artificial lighting (Heath et al.,

2012). The first technique (sun-fed) requires optimised building designs. For example, the buildings should be fitted with light-reflecting/ delivering structures or—equipment such as conveyors for plants to obtain solar radiation. Hence, supplementary artificial lights could be minimised or omitted altogether, resulting in lower start-up and operating costs. However, such building designs imply various architectural complexities in evenly distributing sunlight to all the crops while maximising building spaces for more yields (Heath et al., 2012).

The second building category involves a plant-building concept with artificial lighting and other sophisticated technologies, including air-tight and well-insulated facilities, multi-layered crop and water reclamation systems (Zeidler & Schubert, 2015). This method is completely independent of natural environment settings. Moreover, given the high energy consumption and cost of replacing sunlight with artificial light, the technique is sustainable for locations with low solar radiation and limited sunlight (Al-Chalabi, 2015). However, potential design integrations with renewable energies are expected to reduce operating costs and increase VF affordability in the near future. Figure 8 shows a proposed holistic farmhouse design by Bruno Viganò & Florencia Costa. The 10-storey urban lot prototype



Figure 7. Ecological design in the Tropics (EDITT) Tower, Singapore. Reprinted from *e-architect*, w. a., Retrieved October 8, 2021, from <https://www.e-architect.com/singapore/editt-tower>. Copyright 2010 by T.R Hamzah & Yeang Sdn. Bhd.

is expected to produce 6 acres of farmland crops. The cylindrical glass wall allowed plants to access natural sunlight during the day and supplemented with artificial lights (powered by solar PV panels) than after (Agritecture, 2012).

### Building Transformation

The transformation of abandoned buildings, warehouses, or factories is another affordable means of implementing large-scale VF within the city. In other words, the structures above are converted into VF houses. Transforming empty residential or office buildings for VF helps address the surplus of urban real estate (Benke & Tomkins, 2017). For example, several private investors in Suwon, Korea and

Kyoto, Japan, converted abandoned factories into profitable VF businesses (Heath et al., 2012). Although the VF method could cut a huge fraction of the capital construction cost, the renovation and operating costs in integrating CEA technologies for healthy indoor plant growth are high. It is because the buildings are not originally designed for farming purposes. In most cases, the high renovation cost is due to plumbing, structural, ventilation, thermal condition, lighting, and spatial planning. For example, Figure 9 shows that The



Figure 8. Clepsydra Urban Farm. Reprinted from Clepsydra Urban Farming, In *Buckminster Fuller Institute*, Retrieved October 15, 2021, from <https://www.bfi.org/ideaindex/projects/2011/clepsydra-urban-farming>. Copyright 2011 by Bruno Viganò & Florencia Costa



Figure 9. The Plant, Chicago. Reprinted from Abandoned Food Factory to be Transformed into Chicago's First Zero-Energy Vertical Farm, In *Inhabitat*, b.m., Retrieved June 21, 2021, from <https://inhabitat.com/abandoned-food-factory-to-be-transformed-into-chicagos-first-zero-energy-vertical-farm/>. Copyright 2012 by The Plant

Plant in Chicago is a closed-loop aquaponics VF converted from a four-storey meatpacking warehouse (Yarina, 2012). Apart from growing mushrooms and greens, The Plant was restored to include a tilapia farm, beer brewery, kombucha brewery, a communal kitchen, aquaponics and energy production. The facility is powered by combined heat and power (CHP) system from methane fuel generated by an in-house anaerobic digester. In addition, the factory was refurbished and cleaned to have gutters, shipping container garden shed, aquaponics grow rooms, new energy-efficient windows and a CHP system (Inhabitat, 2012).

### **Shipping Container Transformation**

Some community growers have taken an interest in transforming shipping containers into the farming business. The farmers replicate indoor farming for food growth by retrofitting CEA technologies in shipping containers (Chatterjee et al., 2020). The main benefit is mobility as the 12m containers can be easily relocated to other locations when required. Additionally, VF in containers enables growers to rapidly develop farming systems and initiate plant growth without worrying about constructing greenhouses or obtaining safe building approval from the city council. Nevertheless, several shortcomings are identified. Due to limited container space and restricted movement within the containers, the resultant crop yield is low and could only benefit a small local community. Similar to building transformation, shipping containers are not designed for farming purposes (Sparks & Stwalley III, 2018). Therefore, growers need to mitigate extreme container heat or humidity, which could lead to plant diseases.

In general, capital expenses are large to buy a container and associated equipment to transform the container to facilitate VF. In the United States, the cost is around \$50,000 to \$100,000 for pre-made 40-foot commercial container farms. Energy and labour cost account largest amount in operational cost. Other operating expenses include seed, fertilizer, water, packaging and advertising. Container farms need a significant amount of energy to power the lights and Heat, Ventilation and Air conditioning (HVAC) system. In the Midwest United States, around 79% of energy goes to heating and cooling, and the balance was utilised for lighting and water pumps. However, this may not be the same for tropical climate regions. Therefore, it is advised to spend more on capital for proper insulation to reduce the heating expenses during the operation (Discover Containers, 2021). Figure 10 illustrates VF in a shipping container placed in the heart of Ra'anana, a city in Israel. Haim Shestel, the owner, found that it is expensive to import temperate climate crops for his restaurant and struggled to keep his business going all year round. It spurred him to open a 'farm to table' restaurant. He realised indoor urban farming has a shorter growing cycle and can produce desired crops throughout the year (VerticalField, 2021).



Figure 10. VF in a Shipping Container. Reprinted from VerticalField, In *VerticalField*, Retrieved July 24, 2021, from <https://www.verticalfield.com/makom-balev/>. Copyright by VerticalField

### Retrofitted onto Existing Buildings

The VF development by retrofitting onto existing buildings are widespread. This design typically involves the integration of VF onto existing commercial, office, or high-rise residential buildings. Figure 11 shows four possible methods to integrate VF onto a building: rooftops, balcony or interior, façade, and the underground (AVF, 2020).

Rooftops have been utilised for in-house vegetation purposes with simple pots and beds over the past decades. However, as the idea of VF is gaining popularity, the growers' focus is shifted to producing crops commercially on rooftops. Unfortunately, most commercial

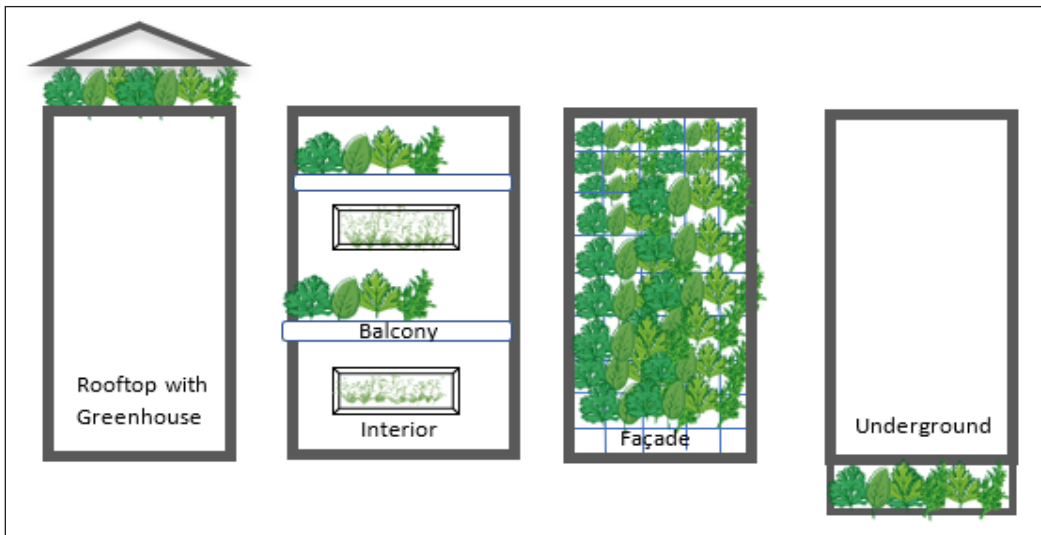


Figure 11. Retrofitted onto existing buildings

rooftop VF is built with greenhouse structures that pose additional load to the rooftop. Thus, building safety and integrity verification must first be carried out and approved by the city council before any VF implementation (Astee & Kishnani, 2010). Nevertheless, Lufa Farm (the world's first commercial rooftop greenhouse in Montreal, Quebec, Canada) successfully launched the fourth largest commercial rooftop greenhouse farm in 2020. The agricultural greenhouse is made of double glass with an anti-light pollution blackout curtain, and the farm responsibly practices recirculating irrigation by capturing rainwater and using high-intensity discharge (HID) lights, a CO<sub>2</sub> injection system, and new software tools (Markets Insider, 2020; Resh, 2013).

Besides the rooftops, balconies are also ideal for urban residents strapped for agriculture space. Previously, balconies are utilised for domestic purposes and displaying ornamental plants (Suparwoko & Taufani, 2017). By cultivating vegetables on balconies, the family enjoys fresh vegetables for daily consumption. However, the success rate in implementing VF on a balcony primarily depends on the choice of plants to grow as the plants fully depend on climate quality (Taib & Prihatmanti, 2018). For example, plants that normally grow in cool climates might not sustain or wilt easily with strong sunlight exposure. Moreover, the aesthetics of VF on balconies during setups require due consideration, too (Tablada et al., 2020). Nonetheless, the VF implementation on balconies is advantageous to urban residents who intend to grow food for family consumption with minimal setup cost.

While enclosed or open balconies rely mainly on sunlight orientation and position, a VF modular within the building provide alternatives for growers to produce vegetables. A German start-up company, neoFarm, constructed a complete indoor VF micro modular with built-in sensors, irrigation, lighting, and in-house monitoring software that automatically regulate crop growth cycles (neoFarms, 2016). The aeroponics-based system modular minimises human intervention through artificial intelligence (AI) for optimal plant growth cycle from germination to harvest. Growers do not require agricultural competence, soil, and water irrigation fittings. Although the model could conveniently and aesthetically fit into house corners, Jansen et al. (2016) study on fully-automated VF modular revealed that most case study respondents preferred to personally care for the plants with clear visibility and authentic feelings.

The third retrofitted design is the green facades. These are becoming a sustainable VF concept trend in curbing urban air pollution. The concept, also known as a vertical garden, require supporting structures or artificial walls for the irrigation system. There are two types of green façade: green walls and living walls. Typically, the green wall concept consists of vine crops rooted to the ground and duly supported and directed by the structures constructed along the building wall surfaces. Contrarily, living walls imply a perpetual or modular form where various pre-grown plants are individually inserted into permeable screens. The modular panels contain either soil or soilless growing medium to support plant



growth. The living walls appeared to cover a large surface area, thus providing a more balanced plant growth compared to green walls (Golasz-Szolomicka & Szolomick, 2019). Green and living wall designs are increasingly popular as they are aesthetically pleasing and can be used for food or fauna production, as a pollution barrier and provide heating and cooling effects for building interiors.

Lastly, underground farming involves basement and below-building ground agricultural activities. Similar to holistically integrated farming, underground VF needs to integrate CEA technologies. For example, Cycloponics, a French start-up organisation located in Paris, transformed abandoned urban underground car parks into farms. The underground car parks are transformed into organic food production environments to grow vegetables, such as mushrooms, chicory, and microgreens (Agritecture, 2017). Only plants that do not require much light for growth are meticulously chosen for underground farming.

Although there are various options in VF typology, the purpose of erecting VF and the cost/benefit analysis determines the location and placement of the system (Allegaert, 2019). Ultimately, most farming business goal aims for high productivity from a small space (Bezuidenhout, 2015).

## VERTICAL FARMING IN MALAYSIAN HIGH-RISE BUILDING: THE FEASIBILITY

The key requirement in VF is the adequacy of light for plant growth. Malaysia receives year-round sunshine for about four to eight hours daily with solar radiation between 4.96 to 5.56 kWh/m<sup>2</sup> (Azhari et al., 2008; Mohammad et al., 2020). The highest solar radiation is forecasted at 6.8 kWh/m<sup>2</sup> in August and November, while the lowest counterpart reflects 0.61 kWh/m<sup>2</sup> in December. The highest radiation is prominent in the northern region of Peninsular Malaysia (Azhari et al., 2008), where sunshine lasts an average of 10 hours daily (Ho et al., 2019). Table 3 shows the annual solar radiation in Malaysian cities.

With plenty of sunlight, Malaysia has the potential to explore VF in a holistically integrated building or retrofitted onto existing buildings (open building envelopes, such as rooftops, balconies, and façades) as these buildings typologies could incorporate natural sunlight to penetrate through glasshouses or greenhouses. Typologies that require CEA technology, such as building transformation, shipping containers, or building interiors, are encouraged to harvest

Table 3  
*Annual solar radiation in Malaysian Cities (Soonmin et al., 2019)*

Cities	Annual Average Value (kWh/m <sup>2</sup> )
Kuching	1470
Kuala Lumpur	1571
Seremban	1572
Kuantan	1601
Johor Bahru	1625
Kota Bahru	1705
Ipoh	1739
Georgetown	1785
Kota Kinabalu	1900

solar energy sustainably to power artificial lighting and ventilation equipment. For instance, the Dream Harvest farm in Houston, which produces high-quality herbs and greens, is a carbon-negative indoor VF that utilises 100% wind energy.

**VF on High-rise Rooftops**

In Malaysia, green roofs are extensively studied to address environmental concerns and increase green spaces in urban areas (Ismail et al., 2016). Table 4 illustrates the green rooftops that have been successfully implemented in several Malaysian buildings. The prominent green roof example here is Rice Garden Museum (Figure 12) which cultivates paddy. The building management has successfully harvested the paddy four times annually since 1998 (Zahir et al., 2014). Meanwhile, the other buildings in Table 4 only planted garden trees, plants, and turfgrass for easy maintenance.



Figure 12. Rice Garden Museum Malaysia. Reprinted from Langkawi by Hotels.com, In *Langkawi-info*, p.w, Retrieved May 21, 2021 from <http://www.langkawi-info.com/attractions/rice-garden-museum.htm>. Copyright by Laman Padi Langkawi

Table 4  
List of Malaysian green roof buildings (Ismail et al., 2016; Zahir et al., 2014)

Building	Type	Year
Rice Garden Museum (Laman Padi), Langkawi	Educational	1998
Ministry of Finance, Putrajaya	Office	2002
Putrajaya International Convention Centre (PICC)	Convention Building	2003
Malaysian Design Technology Centre (MDTC), Cyberjaya	Office	2004
Serdang Hospital	Hospital	2005
Faculty of Social Sciences and Humanities, UKM	Institutional	2007
Sime Darby Oasis, Damansara	Office	2009
KL Sentral Park @ Platinum	Office	2009
Newcastle University Medicine Malaysia, Nusajaya	Institutional	2011
Laman PKNS, Shah Alam	Office	2013
The ARC, Bandar Rimbayu	Community Centre	2015
Heriot-Watt University, Putrajaya	Institutional	2015
Acapella Hotel Suite	Hotel	2015

The previous projects in Table 4 can serve as a benchmark for Malaysia to examine the VF feasibility on rooftops and other building envelopes within urban locations. Typically, rooftop farming has gained more popularity compared to the two remaining retrofitted typologies. The three primary VF benefits on rooftops are full sunlight exposure, larger

space compared to façade and balcony, trouble-free rainwater management and PV installation. In the same climate zone as Malaysia, Singapore successfully awarded nine-car park rooftops to six tenderers for urban farming activities. The VF tender proposals included VF systems with various innovative features, such as IoT (Internet of Things), blockchain technology, and automated climate control. It was estimated that the sites would produce approximately 1600 tonnes of vegetables annually (The Straits Times, 2020). However, the VF on existing rooftops requires thorough planning (similar to ground-level greenhouse construction) to compute building roof capacities in withstanding the weight of the farm, additional equipment and personnel (Whittinghill & Starry, 2016). In some cases, rooftops are partially occupied by HVAC units and other building utilities that limit the space for VF.

Nevertheless, a hotel rooftop with 60sqft space could produce 40kg of vegetables every month. A Malaysian based company, 'farm2fork,' owned by Waterco Far East, Malaysia, built a vertical farm on a 1000sqft plot in the peri-urban area in Puchong, Malaysia costing RM 148,800, and the farm produces about 730kg of vegetables per month. The founder of farm2fork, Dr Richard, has also built an aquaponics VF system in Malaysia, Singapore, Indonesia, Brunei, Japan, Slovenia and US. Dr Richard reports that a commercial aquaponics farm will cost around RM57,800 on a 300sqft space producing 190kg fresh produce per month (Vulcon Post, 2021). The cost of aquaponics is more expensive than any other hydroponics system. Aquaponics rear fishes or other aquatic animals' fish excretion becomes the nutrients to the crops. This organic nutrient-rich water replaces store-bought formulated synthetic nutrients for hydroponics. In other words, the aquaponics system is a self-sustaining system requiring less maintenance, unlike other hydroponics systems that needs a change of nutrient water every 2–3 weeks to maintain the optimal pH. An aquaponics VF on a hotel rooftop brings a whole new revolution to the food industry by transporting fresh and high-quality 'living' produce within minutes to restaurants and cafes as per the customers need. There is no food wastage. Figure 13 shows an aquaponic system that rears lobsters and grows plants for commercial purposes.

### **VF on High-Rise Residential Balconies**

As researchers and investors focus on large-scale VF, home farming in an urban environment has received less attention and is under-studied (Kirkpatrick & Davison, 2018). Urban home farming enables family members to enjoy healthy and fresh vegetables from small-scale farms. Senior citizens or homemakers could also engage in social value activities and entrepreneurial services with excess crops. For example, selling the excess yields to neighbours could earn income in urban communities (Tablada & Zhao, 2016).

However, balconies are less attractive for VF due to insufficient solar radiation on these spaces. The solar radiation for both spaces is highly influenced by building orientation and structure design. For example, the balcony North-South orientation may not receive



Figure 13. Commercial vertical farming aquaponic set-up in Klang, Malaysia. Reprinted from Vulcon Post, f.l., In *vulconpost*, Retrieved October 19, 2021, from <https://vulcanpost.com/751780/aquaponics-farming-malaysia-features-cost/>. Copyright by Waterco.

adequate sunlight to grow plants. In contrast, buildings in east-west orientation that receive direct midday sunlight would be impacted by excessive photosynthetically active radiation (PAR) and high temperatures (Song et al., 2018). While leafy crops, such as kailan, pak choy, and spinach are resilient to high temperatures and sun rays, temperate climate plants, such as salad leaves, strawberries and tomatoes are not. Therefore, careful plant selection is necessary for VF on balconies. Another concern is the stormy weather during the monsoon season. Balconies partially enclosed with an overhead roof may be ideal for home farming in an urban high-rise building.

Besides, the VF system requires distilled water qualities to make nutrient solutions. The water discharged from air-condition (AC) compressors (typically installed on balcony walls) offers close to distilled water qualities compared to chlorinated and contaminated tap water that could plug the valves and instigate structural breakdowns in the growing media (Resh, 2013). A study that was carried out at Technology Center UFRN-Brazil indicates an AC unit (set to run from 8 AM to 6 PM) with 12000 BTU generates approximately 1.06 L/h and 2.25 L/h for a 24000 BTU unit amounting to an average 10- 20L condensate per day (Silveira et al., 2016, as cited in Scalize et al., 2018). Similarly, high condensation is anticipated for Malaysian weather due to high humidity. Since hydroponics irrigation utilises water as little as 1/20th of a regular farm (Pandey et al., 2009), the daily amount gathered by running the AC only for 5 hours is more than sufficient to irrigate micro-model VF on a balcony.

Furthermore, the above study concluded that the condensate has physiochemical qualities similar to ultrapure water. Therefore, another experiment was conducted in

Palestine to use AC condensate water as an alternative source for irrigation. The data evaluation of physical, chemical, and microbial elements of the by-product showed that the condensate has good water quality properties and conform to the Palestinian standards for irrigation (Siam et al., 2019). Additionally, with the rise in water demand from 5.7% in 2014 to 28% in 2018 within Malaysian urban areas, repurposing the AC by-product has potentially saved water and minimises family expenses on utility bills.

The cost of building a micro model vertical farm on a 3x10ft balcony ranges from RM500 to a few thousand; this depends on the number of tiers, structure material, the growing techniques, growing media, nutrients, seedling prep equipment, size of the water pump and selection of cultivars. Placing the VF model on a balcony for plants to access natural sunlight, O<sub>2</sub>, and CO<sub>2</sub> reduces the cost of capital expenses on artificial lights and HVAC. The cost for a ready-made, outdoor, home-use NFT system with 32 plants capacity in 4 tiers (8 plants per tier) and the dimension is 4.6ft(L) x 2.2ft(W) x 3.2ft(H) comes around RM600 (Figure 14) (Cityfarm, 2021). Assuming locally grown Pak Choy from the conventional farm is around RM1.50/100g. In this NFT system, 32 Pak Choy can be grown in 30 days and, if multiplied for 12 months, will give 384 crops. These could be sold at the same price to the neighbourhood within the same building for an extra income which will amount to RM576/year. The grower will benefit from the return on investment (ROI) within two years.



Figure 14. Cityfarm 4-Tier Waterfall Home Garden. Reprinted from Cityfarm, In *Cityfarm*, Retrieved October 19, 2021, from <https://cityfarm.my/collections/all-hydroponic-setup/products/cityfarm-home-planter>. Copyright by Cityfarm.

### Challenges in Tropical Climate

In contrast to temperate climate countries, tropical counterparts encounter high temperatures and humidity during drought seasons. The impact of urban heating would further increase the environmental temperatures around buildings (Benis et al., 2018). The most significant effect would be seedlings, plant growth, and nutrient solution. Non-native crops that are foreign to tropical climate (tomatoes, strawberries, cucumbers, lettuce, cabbage, celery, and specific herbs) are unsuitable for growing in high temperature and humidity environments (Resh, 2013). Therefore, VF in buildings requires a well-planned climate control system with good ventilation or cooling effects as opposed to heating components in cold countries. For example, VF on rooftops requires a careful study on the choice of

material in greenhouse construction. The material constraints include good insulation (twin or triple walls), transparency, long lifespan, high water resistance, high resilience to withstand a storm, and possibly retractable thermal screens on cloudy days (Benis et al., 2018; Despommier, 2011; Resh, 2013).

Alternatively, holistic approach typology could also be highly appealing in tropical nations. The Sky Green in Singapore is a successful commercial VF business enterprise that cultivates leafy tropical crops, lettuce, and spinach in a glasshouse (Beacham et al., 2019). In 2011, Jack Ng (Sky Green founder) innovated a 9-metre tall rotating, stacked, and layered VF system to optimise space and yield. The system is patented under “A-Go-Gro” and uses a growing medium to grow vegetables. It uses a water-pulley system powered by flowing water and gravity to rotate the vegetable trays. The layers are rotated for access to 30 minutes of sunlight and nutrients every eight hours (Khoo, 2016). The towers consist of 38 tiers each, producing around 1 tonne of vegetables daily; higher yields than conventional farming with the same footprint. The farm currently focuses on leafy greens such as lettuce, Bok choy and Chinese cabbage. The vegetables are sold at 10% higher than the imported price. Nonetheless, consumers buy chemical-free, fresh and local produce. The Sky Green produce accounts for 10% of vegetable supplies in the Singapore market. The VF initiative receives government and citizen support to become less reliant on food imports (Proksch, 2017). Although the glasshouse is not a multi-story building, this concept can be a good reference on the VF technological know-how in Malaysia due to the similarity in climate conditions (Khalid, 2013a).

Another local example for Malaysia to learn from is the swiftlet farming industry. Swiftlet farming produces edible bird nests by breeding swiftlets or swallows. The birdhouse resembles a multi-story building that provides a conducive environment for bird-breeding. The nests are popular among the Chinese community, generate billions of Ringgits, and are sold for health reasons. The 900 swiftlet farms developed in 1998 exponentially rose to 36,000 farms in 2006 and is anticipated to reach 63,000 in 2020, thus generating 870 metric tonnes of bird nests annually (Khalid, 2013b).

### **Vertical Farming Investment and Operational Challenges**

An effective business model is vital to the success of any VF initiative: from farm construction to production and marketing strategy. The main considerations are start-up funding, financing, and profitability. The conventional food system grows food at a distance and travels miles before reaching consumers. The extended food mile increases untenable energy use during transportation, storage and repackaging. They were estimated that 1/3 of food produced globally goes to waste, with most of the losses occurring during distribution, handling, storing and cooling (FAO, 2011b). The longer the value chain means the crops are harvested prematurely, and the fresh produce are added with chemicals to

stay fresh. Therefore, those planning VF business must address the above constraints and must be aware of the complexities of the short supply chain. The system must adapt to the local climate, culture and needs by recycling waste materials (organic waste, by-products, rainwater, greywater). The output value is determined by price, quality, transparency and establishing a trusting relationship with the local community (Proksch, 2017).

Unlike traditional farming, VF grows cultivars that are often highly perishable, hard to find commercially, special herbs and microgreens targeted specifically to the local community. These niche products are critical to the success of VF business ventures. The consumer trend is to buy organic, locally grown, tastes fresh and competitively priced vegetables. Currently, the greenhouse or vertical farming crops are three to five times more expensive than growing on a conventional outdoor farm. However, conventionally grown crops are priced equally as high as VF crops in some countries due to the cost incurred in the supply chain and food mile. In countries like Singapore, Kuwait and Netherlands, where the natural resources are scarce, consumers may find the price of the imported crops and locally grown in vertical farms are similar. Nevertheless, for many other countries, the price of crops from VF remains expensive. Therefore, only selective niche crops targeting the local community are grown in VF. Table 5 shows a comparison of commercial model farm type, site ownership model, recommended crops, growing season, investment and operation costs adapted from several case studies in temperate climate regions: Growing Power, Brooklyn Grange, The Plant, Lufa Farm, Gotham Greens, Bright Farms, Alterrus, Farmedhere, Aerofarms, Growing Underground, Mirai and research facilities (Calibre Biotherapeutics and Plantlab)

The start-up funding varies greatly for different farm models and ranges from \$0.50/ft<sup>2</sup> to \$50/ft<sup>2</sup>. Table 5 reveals that the indoor VF produces the highest yield with 80–90 tons per year per layer. Six layers will amount to 480–540 tons per year. However, it is the norm to anticipate higher operating costs in labour work to harvest crops from stacked layers, also high expenses from CEA technologies and automation. Although the first two types of farms indicate less yield, operating costs are very low for outdoor growing methods. Any indoor farming will incur a very high start-up cost; nonetheless, in the tropical region,

Table 5  
Types of farm operation in urban region (Proksch, 2017)


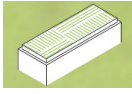
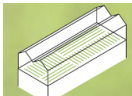
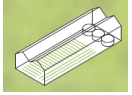
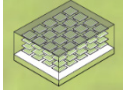
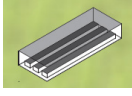
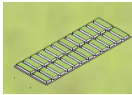
Farm Type	Ownership Model	Crops and Yields	Growing Season	Crop cycles	Investment for infrastructure	Operation cost labour input
 <b>Soil-based urban farm</b>	Land leased or owned	All vegetables, crops for niche market,	outdoors, natural growing season, 6-9 months	2-3 crops per growing bed, 12-16 tons/ year	\$0.50-1/ ft2 (start-up fund: \$45k for 2 acres)	low, after system has been set up well

Table 5 (continue)

Farm Type	Ownership Model	Crops and Yields	Growing Season	Crop cycles	Investment for infrastructure	Operation cost labour input
 <b>Green roof farm</b>	long-term lease of rooftop, (at least ten years)	all vegetables, crops for niche market,	outdoors, natural growing season, 6-9 months	3-4 crops per growing bed, 10-12 tons/ year	medium-high, installation cost for green roof \$5-\$14 per ft2 (Start-up fund: \$200k-600k for 1 acre)	medium, one farm manager, and 2-3 support staff
 <b>Hydroponic rooftop farm</b>	long-term lease of the rooftop (at least ten years), ownership of greenhouse	lettuce, leafy greens, and tomatoes,	indoors, 12 months year-round	12 harvests of lettuce, continuous harvesting of vine crops 200 tons/year	very high, the installation cost for greenhouse \$40-\$50 per ft2 (Start-up fund: \$2M for 1 acre)	high energy and labour costs, greenhouse experts and daily harvest team
 <b>Aquaponic farm</b>	long-term lease of grow space, ownership of equipment	lettuce, leafy greens, and tomatoes,	indoors, 12 months year-round	12 harvests of lettuce, harvest of fish every 9-12 months	high, depends on the level of technology integrated	depending on size, aquaponic expert and harvest team
 <b>Indoor VF</b>	abandoned warehouse, long-term lease, ownership of equipment	lettuce, leafy greens, tomatoes and microgreens,	indoors, 12 months year-round	12-15 harvests of lettuce, continuous harvesting of microgreens (80-90 tons/ year per acre for each layer)	very high, depends on host building CEA tech, \$20-\$50 per ft2 (Start-up fund: \$1-2M for 1 acre-6 stacked layers)	high energy and labour costs, indoor farm experts and daily harvest team
 <b>Underground farming (mushroom culture)</b>	abandoned warehouse or basement, low rent or left-over spaces	speciality mushrooms	indoors, 12 months year-round	continuous harvesting	low, requires low-tech infrastructure	expert knowledge and low maintenance
 <b>Microgreens</b>	very space efficient, often in existing greenhouse or indoor space	microgreens and baby leafy greens	indoors, 12 months year-round	harvests every 7-10 days, 36-50 harvests per year	medium, depends on existing infrastructure	high energy, material, and labour costs



taking advantage of natural sunlight and rainwater, the operating cost for rooftop VF is expected to be slightly lower. In general, the location and the choice of the VF growing technique will heavily determine the start-up costs. It is crucial to procure long term leases to keep the overhead expenses low. Unlike traditional farms, VF operations do not use any mechanised equipment. The high cost may also come from labour wages. Different growing techniques have different labour needs. Successful commercial urban farms also have staffs who work in public relations. These specialists build the farm's brand and sales. The simplest way to sell is the farmer selling directly to the consumer: at markets, restaurants, or residential building stands. This approach involves minimal overhead.

A Thai university in Bangkok has recently become the largest urban rooftop farm in Asia, transforming 236,806sqft of its rooftop into an agriculture hub. Thammasat University Rooftop Farm (TURF) incorporates sustainable food production, renewable energy, organic waste, water management and public space (Figure 15). The \$31 million projects was completed in December 2019. 32% (1.7 acres) of the green rooftop is dedicated to urban farming activities. The urban farm is powered by solar panels capable of producing up to 500,000 watts per hour and also powers the building beneath it. The farm grows more than 40 plant varieties, including rice, indigenous vegetables and herbs, and fruit trees, yielding up to 20 tons of organic food per year. The campus canteen uses the concept of 'farm to table,' and waste was used as compost to fertilise crops. The rainwater goes down to each slope and finally to the retention ponds (Greenroofs, 2021). The above concept could be adapted in the Malaysian government building where the cafes and in-house canteen harvest the crops from the rooftop farm.

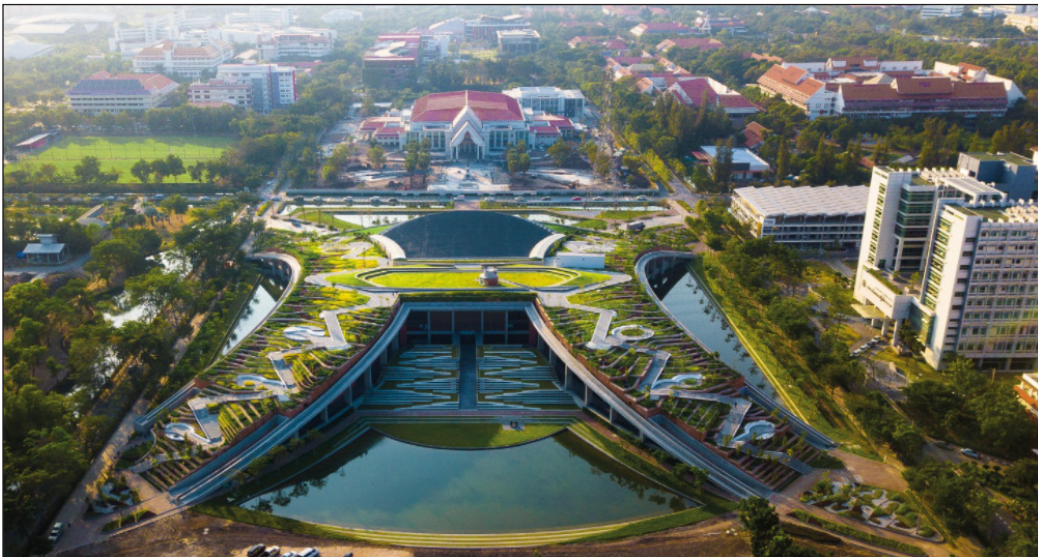


Figure 15. Thammasat University Rooftop Farm (TURF), Thailand. Reprinted from Greenroofs.com, In Greenroofs.com, Retrieved October 20, 2021, from <https://www.greenroofs.com/projects/thammasat-university-urban-rooftop-farm-turf/>. Copyright by Greenroof.com

Fundamentally, below are the key assessment criteria in designing a VF project in a high-rise building:

- i) Governmental support and incentives;
- ii) Return on investment and profitability;
- iii) Building guidelines for urban agriculture;
- iv) Architectural planning and building feasibility;
- v) Energy efficiency and renewable energy;
- vi) Waste disposal;
- vii) Cultivar and growing techniques;
- viii) Climate study;
- ix) Technical know-how and expertise in hydroponics;
- x) Socioeconomic benefits;
- xi) Demographic analysis of local society;
- xii) Empirical studies on local produce demand;
- xiii) Geographical conditions.

## CONCLUSION AND RECOMMENDATION

Numerous sources have evaluated and concluded that VF is a solution to urban agriculture (den Besten, 2019; Goldstein, 2018; Jennings, 2017; Kalantari et al., 2017; Prisca, 2020). Cultivating vacant lots, converting rooftops, and harvesting abandoned buildings and shipping containers have become the new norm in many Western countries and Asian nations. However, VF remains a niche industry due to high initial start-up and operating costs to date. In addition, existing VF companies are facing challenges of high-power costs. The empirical findings in this study revealed that greenhouses constructed on the rooftops of existing high-rise buildings (office, institutions, and residents) stand greater possibilities in becoming a successful food-producing industry in metropolitan areas. More importantly, sustainability features such as solar power to offset high energy costs, sunlight for plant growth, rainwater for irrigation, and AC by-products for cooling effect should be integrated to make the VF industry profitable.

Urban farming is still in its infancy (Chee, 2014; The Edge Market, 2017; The Star, 2020). Although Malaysia has a huge potential, building a large commercial VF depends on good cooperation between multiple stakeholders, including investors, architects, designers, engineers, project managers, government authorities, contractors, financial planners, hydroponics experts, and phytologists (Abraham & Gundimeda, 2017). Collaborative work among various sectors is necessary to address the eight VF system components discussed earlier in this article. Failing to communicate can result in additional costs and schedule delays that would badly affect the yield. Nevertheless, VF will be seen as the

way to produce high-quality food in urban areas. As technology improves and becomes more price-competitive, many investors are expected to delve into VF in feeding the ever-growing population.

Therefore, the local urban planning sector should incorporate the VF concept in future urban planning projects to promote and develop sustainable food production in urban areas and simultaneously restore contact with nature (Benis et al., 2018). There is a continued need for greater knowledge regarding the concept and constraints of VF in high-rise buildings. This paper strived to identify the opportunities to develop VF in Malaysian high-rise buildings. However, more information is needed on the impact of VF in urban systems and subsequent contributions to food security to determine how urban planners could best amend or create policies to facilitate VF in urban planning. It is recommended to look into VF operations in neighbouring countries or similar tropical counterparts for successful implementations and to deter costly mistakes.

## ACKNOWLEDGEMENT

The author would like to express gratitude to the lecturer, Prof. Ir. Ts. Dr Mohamed Thariq bin Haji Hameed Sultan, Prof. Ir. Ts, Dr Abd. Rahim Abu Talib and the supervisor Dr Ahmad Salahuddin Mohd Harithuddin, for their continued support and encouragement.

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