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Article

Implementing vertical farming at university scale to promote sustainable communities: A feasibility analysis

Zhang He[1], Asutosh, A.T.[2*], Wei Hu[2]

1. M.E. Rinker, Sr. School of Construction Management, University of Florida;rupta00@ufl.edu
2. M.E. Rinker, Sr. School of Construction Management, University of Florida;asishasutosh@ufl.edu
3. School of Statistics, Renmin University of China; huwei2018000727@ruc.edu.cn
4. * Correspondence: asishasutosh@ufl.edu, Tel: +1-(352)-745-9946

Abstract: The world is facing several global issues such as food and energy crisis, climate change and greenhouse gases emissions. To subdue these issues, many entities from academia and industries have innovated alternate techniques of performing regular activities which cause such problems. One of these innovations is the introduction of vertical and zero acreage farming in the field of sustainability. These carry the potential to solve one of the most important affairs of food security in most countries of the world. But, this technology has been in its nascent stage for many years. This paper uses a comprehensive framework proving the feasibility of initiating vertical farming on university campuses to feed the staff and students, which could also set an example to the rest of the world into using this technique on a wider scale. The study chose Huazhong University of science and technology (HUST) in Wuhan city, China for accessing the return on investment and food sufficiency if vertical farming is implemented. Using Central Limit Theorem, a statistical model was developed, and various scenarios were analyzed. The results indicated that if a separate vertical farm is constructed, the breakeven can be achieved in a range of 10-20 depending on parameters such as type of operation, number of floors and amount of vegetation. The study has shown that the use of vertical farming cannot only bring in revenue for the campus but also aid in mitigating climate change.

Keywords: Vertical farming; Zero acreage farming; University; Sustainability; Economics; Climate change

1. Introduction

The issue of food and nutrition security is at crux which we are experiencing on Earth in today's time. A recent study shows that over 815 million people are facing food insecurity which is an increase of 38 million due to climate change and proliferation of vicious conflicts [1]. According to these numbers in our current scenario, we must take the responsibility in mitigating this problem and to chase the Sustainable Development Goals 2030 of United Nations, to eradicate hunger and poverty. At present, the global food system is subjected to pressure in delivering food to the ever-growing population. The consumer behavior and food production practices play important roles inefficiency of every type of food system [2]. By 2050, almost 80 percent of the population will reside in urban areas. According to traditional food production practices, an extra of 1 billion hectares of land will require feeding the growing population in the meanwhile [3]. The scarcity of land and depleting of natural resources have been a driving factor to find smart solutions in this fast-moving world. There have been many

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successful attempts in research and innovative solutions to fight this issue in our built environment. One of such innovation is the integration of farming into the building structure which is termed as "Vertical Farming". It is an alternate method where the food supply chain is shifted directly from the producer to the consumer. This results in significant low carbon footprint and is environmentally sustainable [4]. Although this concept has remained in its nascent state, there are real-time examples which prove that vertical farming is a sustainable way to feed the best quality produce by spending less amount of energy. Countries such as United States, Japan, and Singapore have shown significant results in applying vertical farming to their buildings. This study provides a framework which encourages institutions such as universities into adopting this system for their students. This study also investigates food data from Huazhong University of Science and Technology (HUST) in China which has over 24 canteens and compares the production and financial outcome using vertical farming. This could lead the institution into producing their own food on site and use the financial benefits to something more valuable. Additionally, this could also be a chance for all the commercial and residential sectors in taking the initiative to mankind and environmental responsibility. This study looks at the approach to vertical farming and how it could contribute to saving fossil fuels and reduce resource wastage.

2. Materials and Methods

2.1 Definitions

There are various definitions of Vertical Farming but to put into simple words, it is a method of urban farming of fruits, vegetables, and grains, inside a building in a city or urban centre, in which floors are designed to lodge crops with the absence of soil (Hydroponics & aeroponics) [5]. Using large multistory buildings to cultivate agricultural produce was an incredible idea by Gilbert E. Bailey, who was an American geologist. His book simply titled "Vertical Farming" was revolutionary in the field of modern agriculture [6]. In the early 1980s, Dr. Yeang who was a Malaysian-born architect advanced the ideas of Mr. Gilbert into the subset of arch itectural design. He believed that the way agricultural products were grown, and all human activity must be based upon "eco-mimicry", which means that to be deeply sustainable, all built or devised human environments must mimic the, patterns, characteristics, attributes and cycles of natural ecosystems [7]. Another definition states that Vertical Farming is a system of commercial farming whereby plants, animals, fungi and other life forms are cultivated for food, fuel, fibre or other products or services by artificially stacking them vertically above each other [8]. The concept of supplying food using the city is not modern but the idea of dedicating an entire building/skyscraper to cultivate produce is which is the concept of vertical farming is a large-scale extension of urban agriculture within a building. [9]. Another concept which is recently coined known as "Zero Acreage farming"'. It implies the farming which is carried without using any additional farmland such as using rooftop gardens, indoor farming, rooftop greenhouses. These are categorized as a subset of urban farming which is sustainable and decentralized [10]. This concept has been introduced in cities such as Berlin (Germany) and encourages other cities to incorporate these practices with recognizing its benefits and challenges [10]. This could also be one of the trends which could give the common people control on their produce quality and quantity.

2.2 Causes of vertical farming

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According to the U.N. (United Nations), the population of the world through mid-2017 was 7.6 billion and is projected to reach 9.8 billion by 2050 and 11.2 billion by 2100 [11]. It is estimated that 19.5 million hectares of agriculture land are converted to urban centres and industrial developments annually [12]. This is because cities are the hubs of ideas, science, jobs, productivity, social development, prosperity and more. Due to the rapid urbanizations, resources such as water supplies, sewage, biodiversity, land and soil resources and public health is under pressure. The sustainable development of urban and rural areas requires addressing the demands for social, economic and environmental land use in an integrated approach. Over 2 billion hectares of cultivable land is degraded, and more than 1.5 billion people are living off the degraded land. Severe droughts in 2017 have led to starvation and famine which affected more than 25 million people [13].

A study done by Crawford School of Public Policy and Australian National University estimated 4.3 to 20.2 trillion dollars annually is lost in global land use change [14]. The direct costs of degradation of land amount to approximately USD 66 billion per year [15]. The world needs an increase of 70 percent in food production to feed the 9.5 billion people expected to live by 2050 [16]. China had population of 13,82,710,000 which is a rise of 8,090,000 compared to 2015. With 145 people/square km, it was in the 138th ranking density in 2016 [17]. Interestingly, out of 130 million square kilometres of ice-free land, about 46 percent is currently being for farming and forestry and 7 percent is considered urban/pre-urban [18]. FAO estimates that up to 25 percent of the land is currently highly degraded and 36 percent is moderately degraded while 10 percent is merely improving [19]. Two of the most populated nations in the world have almost 42 percent of its population facing chronic hunger [20]. The unprecedented explosion of megacities may lead to unstainable and ecological disaster. In the year 2000, the megacities in the world took up to 2 percent of the earth's land which accounted for approximately 75 percent of the industrial use of wood, 60 percent of water use and 80 percent of carbon emissions [21].

2.2.1 Food and nutrition security

Over 8.7 million species are thought to have been living on the planet out of which 8 percent are extinct and 22 percent are at risk of extinction due to habitat destruction [22]. There are numerous studies which have indicated the impacts on food security by climate change [23]. Sustainable management of land can minimize the impacts of conventional farming. By introducing vertical farming, externals independents such as pesticides, heavy machinery and others can be reduced significantly. Resources such as water and energy can also be minimized. This will help in improved soil nutrient availability [24]. Fortunately, there are many ways to achieve such as afforestation, pest management, soil erosion control, vegetation management and others.

2.2.2 Climate change

The average global temperature has risen by 0.85°C. For every increase in 1 degree, grain yield decline by about 5 percent. The carbon emission grew rapidly in the last three previous decades from 2000 to 2010 [25]. The figures below demonstrate these increments through recent years which proves climate change is real. Since 2001, the years have shown the warmest temperatures on a span of 136-year record (Figure 1). The Consumption of food with low energy profiles have a substantial effect on serious health issues such as obesity reduction and mitigation of climate change. Also, increase in active transport (i.e. walking and cycling), with public transport for longer journeys could have a

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substantial role in meeting targets for GHG emissions and would result in major public-health benefits [26]. The increase in greenhouse emissions is a major contributor to climate change and the data from some of the largest economies can be observed in (figure 2).

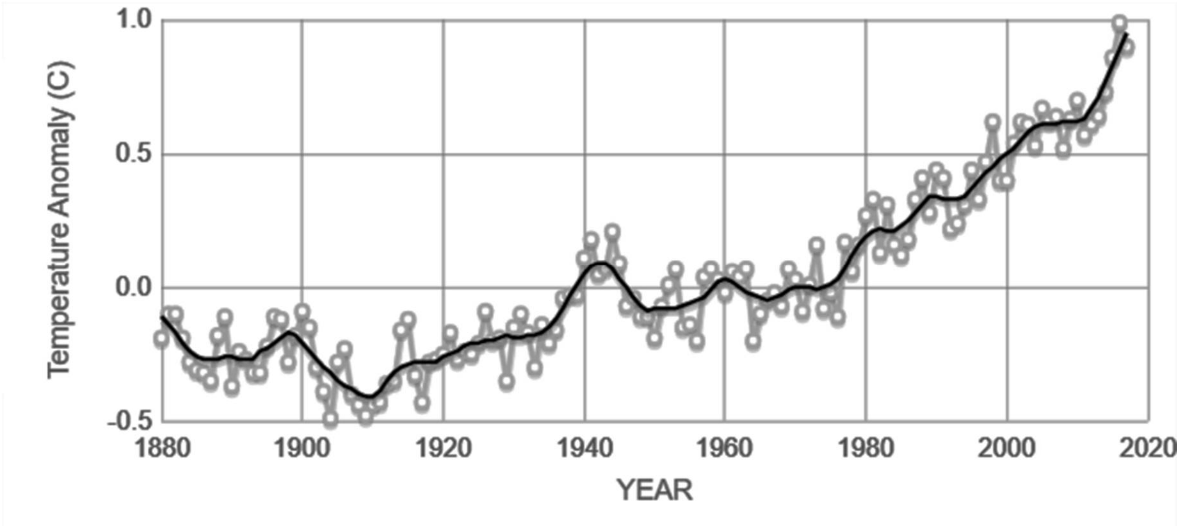

Figure 1: Global land-ocean temperature index

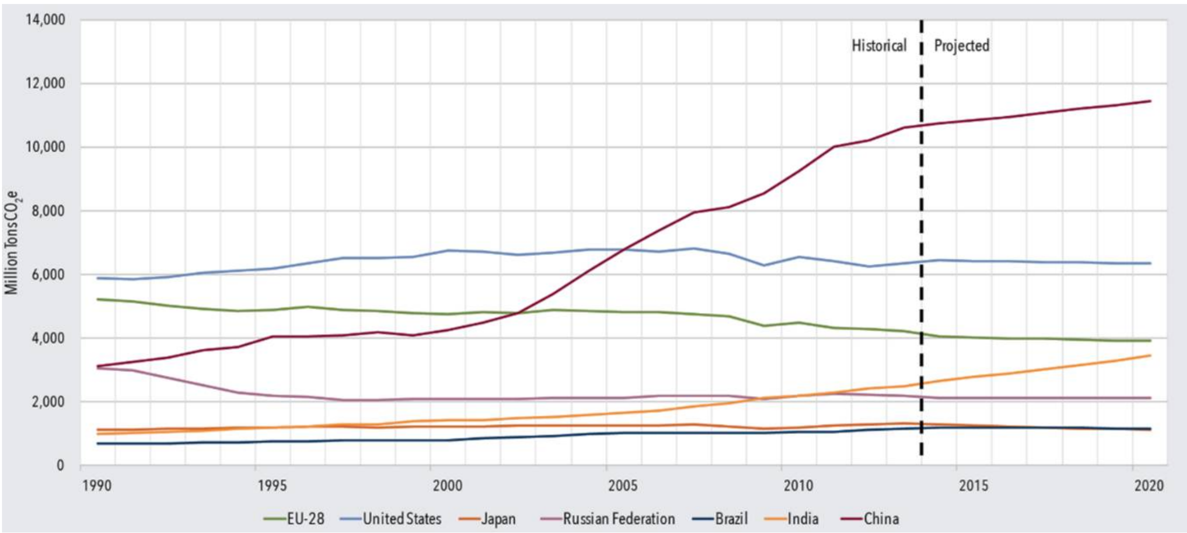

Figure 2: Greenhouse gas emissions for major economies

2.2.3 Energy crisis

Energy is the leading contributor to climate change, accounting for almost 60 percent of total global greenhouse gas emissions. The rapid scaling up of low-carbon, clean and renewable energy sources is a key solution in long-term climate goals. It is a keen factor to consider in the sector of farming. Research shows that almost 1.4 billion people lack access to electricity and 2.7 billion people rely on traditional use of biomass cooking. By 2030, 1.2 billion people will still lack access to electricity out of which 87 percent reside in rural areas [27]. The figure below shows the energy consumption

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The pattern across various industries with respect to different available sources (Figure 3). This indicates that there is an urgent need for shifting from non-renewables to renewables. Also, 92 percent of the petroleum (fossil fuels) are used in transportation industry which can be saved by using techniques such as vertical farming.

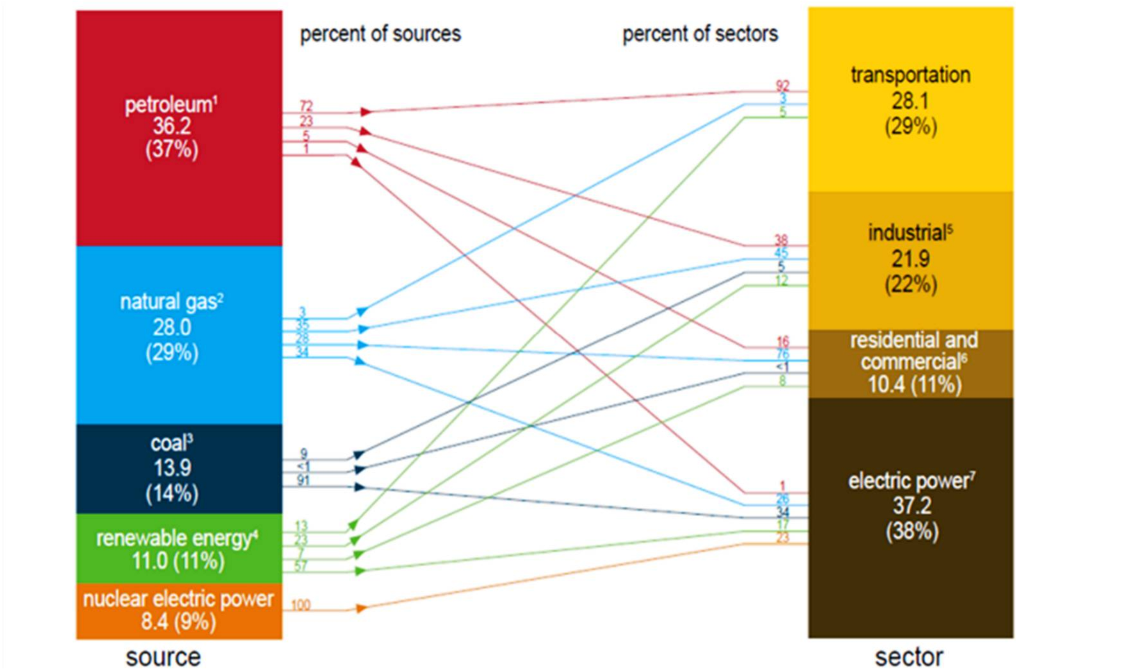

Figure 3: Energy consumption pattern across industries and their sources

2.2.4 Water

A land development is associated with a water decision and water management is very essential. Sustainable land practices must include improvement of water efficiency and quality in a cost-effective way as well as the restoration of ecosystems which are intended to mitigate water scarcity. In case of vertical farming, the issue of water scarcity is significantly minimized. Water scarcity affects almost 40 percent of the global population and with 1.7 billion people living on river basins where recharge is minimal compared to usage, it can be dangerous for survival. Additionally, the water discharge for irrigation peaks to 70 percent in the world of the total consumption and 80 percent of the wastewater are simultaneously put free into the environment [28]. A study at the James Hutton Institute found that up to 10 million of GBP could be saved over 25 years implementing sustainable land management measures in a large drinking water catchment [29]. Vertical farming has a large potential in saving consumption for the food production and the system can be designed to go off grid (municipal supply).

2.2.5 Supply chain logistics

As from the describing the industries contributing to climate change, transportation on the second. This refers to the supply chain logistics of the food industry (figure 4). The flowchart in the figure describes a typical food supply logistics cycle. It can be inferred that using the vertical farming technique, a large portion of fossil fuels and time can be saved. Many resources such as varieties of

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machinery, labour and money are spent in the food industry. The most important resource is the time which is heavily invested in providing food to the people. The rapid depletion of fossil fuels and development of new technology has led to rethinking the process of food production and delivery. Vertical farming can be promising in saving precious resources of the planet and provide better health opportunity to the common man. Most importantly, there is a cost involved in every step of this process which can be diverted into producing more food for the common people [30,31].

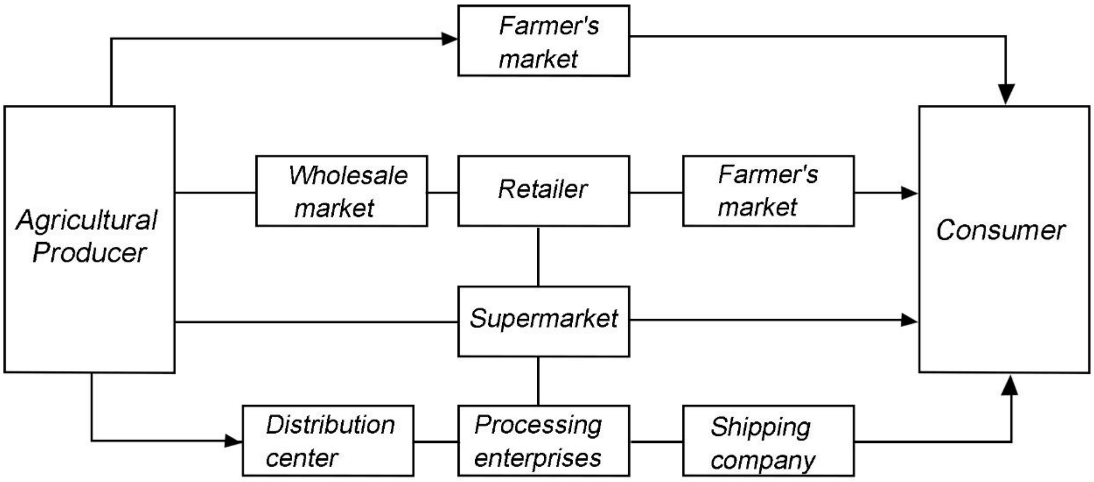

Figure 4: Agricultural producer to consumer logistic cycle

2.3 Types of vertical farming

2.3.1 Aquaponics

This is a type of vegetation production which includes edible and non-edible sources that combine supporting the aquatic ecosystem (fish, snails and others) with a hydroponic system (harvesting with only water & nutrients) in a symbiotic environment. The residue from the aquatic animals being raised in the tank which gets suspended increase the toxicity of the water. These are then broken by the nitrogen-fixing bacteria into nitrates and nitrites which are fed into the hydroponics systems used by the plants as nutrients. It is a continuous cycle where the water is constantly recirculated where the roots of the plants are impeded in nutrient-rich water. The water which has passed through the hydroponic subsystem is cleaned and oxygenated which is returned to the aquaculture tanks. These systems working together enable the ammonia that is toxic to the aquatic animals to be filtered out of the system, while at the same time providing nutrients to the plants [32].

2.3.2 Hydroponics

Hydroponics is a subdivision of hydroculture where the plants are grown without soil, instead of using mineral nutrient solutions in a water solvent. Certain plants such as terrestrial plants can be grown with their roots exposed to the mineral solutions which could be supported by an inert medium. One of the interesting parts of this system is that the nutrients can come from a plethora of sources and not confined to duck manure or fish waste [33]. This requires minimal labour, time and energy. Additionally, there many methods of installation of these systems and can be chosen according to the owner's choice. The shift from traditional irrigation to hydroponics will result in

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decreased use of toxic agrochemicals, pesticides and others. To prevent excess costs and increase profits, hydroponics is based on automation of nutrient supply. Several types of research are aimed at automation of nutrient cycle in closed systems and standardization of the substrate analysis [34].

2.3.3 Aeroponics

Aeroponics is based on the principle of cultivating plants where the roots are not immersed in any kind of substratum or soil but immersed in containers filled with flowing plant nutrition (Figure 5). This method uses a continuous cycle in an enclosed space and enables the workforce to learn the skills in a short time whereas in traditional agriculture the workforce requires skills which are not easily transferable. Putting these systems into perspective, to products 1 kilogram of tomatoes, it requires up to 400 litres in traditional irrigation, 70 litres in hydroponics and only 20 litres in aeroponics [35]. Furthermore, instead of using the richest soil for plants in traditional methods, aeroponics allows the oxygen to provide nutrients to the rhizosphere which is the root zone of the plant [36].

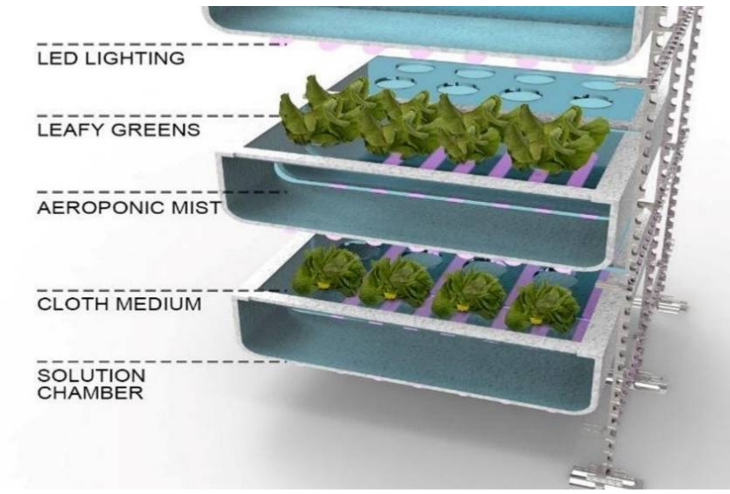

Figure 5: Pictorial representation of an Aeroponics system

2.4 Advantages of vertical farming

Vertical farming can produce a harvest that is environmentally friendly, nutritious and affordable [37]. These farms would not require long-distance transportation resulting in reduced fuel usage, which is currently consumed (20 percent) by of all USA. [38, 39]. Plants would be grown using technologies such as aeroponics or hydroponics which requires little or no soil-based traditional agricultural practices [9,40]. Vertical farming not only produce crops year-round and be more environmentally-friendly but also will make more efficient use of waste. According to Despommier (2007), a city's grey, brown and black water waste could be used for irrigation. Solid waste and plant matter could be converted to methane gas using anaerobic digesters that could then be used to generate electricity for the farm.

A vertical farm could also help diminish unemployment issues faced in many urban settings. The farm would need workers to construct and maintain the structure. Also, they can include a system of grocery stores, organic food markets, and eateries, and local distribution and transportation networks that would offer opportunities for a variety of other food-service related positions [9,41]. From a

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psychosocial perspective, consumers will find confidence and comfort in knowing where their produce came from [42].

By growing food in a neighbourhood, natives would not only have access to a year-round supply of healthy food but also would have the security that their food locally grown and because there is a limited transportation demand, the prices would be lower. Because of lower prices and better access to a healthy diet, the neighbourhood can witness an increase in their general health by lowering their risks of diseases [43]. Employees of the farm can directly sell their produce at reasonable prices to the members of the community. It is reported that these types of farmers feel more satisfied in selling the food to people with whom they have long-term relationships [38]. While using 90 percent less water than a conventional farm, the Den Bosch farm in the Netherlands has been able to achieve yields that are virtually three times greater than the average soil-based production system [44].

2.5 Existing vertical farms

There are several examples in the world that proves that vertical farming is a much better alternative. Although there are many case studies over the world, the right amount of information is still not accessible. The paper investigates four such success stories which have set an example of having vertical farming including (Table 1). The future farm known as 'plant lab' in Den Bosch, Netherlands uses artificial environmental planning for growing strawberries, bananas and other fruits. It showed that the plants grew 3 times faster in LED and hydroponics than in general conditions which would rely on pesticides and agrochemicals [45].

Table 1: Existing vertical farms in the world.

Location	Owner	Details	Location type	URL
South Korea	Rural development authority	Three stories tall Experimental Uses grow lights	Rural	N/A
Japan	Plant factories (numerous-50+) Nuvege	Half use sunlight and the others use grow lights(Nuvege) Many are commercial successful	Peri-domestic	www.nuvege.com
Singapore	Sky Greens	Commercial Uses sunlight Four stories tall	Inside the city limits	www.skygreens.com
Chicago	The plant	Three stories NGO Uses grow lights	Inside the city limits	www.theplant.com
Chicago	Farmed Here	Commercial Uses sunlight	Inside the city limits	www.farmadhere.com

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Vancouver	Alterrus	Uses sunlight Four stories tall	Inside the city limits	www.alterrus.com

An office headquarters of Pasona located in downtown Tokyo which is 9 stories has been using hydroponics and soil-based farming inside the building. Apart from profits of plantation and beauty, the shading causes a reduction in energy usage, improved occupant health, the increased comfort of employees and others. The office contains 200 species of fruits, vegetables and rice which comprises a total space of 43,000 square feet [46]. Other techniques such as underground controlled environment agriculture (CEA) and underground pharming has also been applied. This shows a golden opportunity for commercial sectors to be independent of the current food chain and logistics and becoming self-sustainable. Research has shown there is immense potential in using community and roof gardens to produce vegetables and fruits in dense neighbourhoods. The farming concrete project in New York mapped all the community gardens into tracking the amount of production of plants.

A study at the University of Bonn (Germany) experimented the economic feasibility of vertical farm by constructing. The farm was hosted by 37-floor high building and was simulated in Berlin. The farm yielded about 3500 of vegetables and fruits, 140 tons of tilapia fillets which was 516 times more than a quarter of hectares footprint of stacking multiple harvests. The building costs up to € 210.5 million dollars including equipment. The crop production was around 500 times more than growing them at same area [47]. The building which will house the vertical farm can be net zero for energy, water and waste as there would no human habitat and interior structure will remain simple. The building can go through many programs such as LEED (Leadership in Energy and Environmental Design), LBC (Living Building Challenge) and others to ensure sustainability and generate revenue throughout the lifecycle of the building.

Innovations in Fuji City (Japan) experimented vertical farming in March 2015. The total floor space enclosed 185.5 square meters and focused on leafy vegetables. The production rate is around 12,420 stems/roots/day. The factory grows five varieties of lettuces, mainly frilled lettuce, green leaf and romaine. It has advanced, automatically-controlled equipment that monitors everything from air temperature, humidity, and CO_2 concentration to nutrient liquid. Secondly, a company named SPREAD Co. Ltd. has implemented one of the world's first large-scale vegetation in form of vertical farming that is fully automated. It is proficient of producing 30,000 head of lettuce per day. It encloses an area of 4,400 square meters and is projected to start shipping in summer of 2017. The investment including R&D services and test facilities was approximately 1.6 to 2 billion yuan. The plant recycles 98 percent of the water used for cultivation in the factory. Labor cost has been reduced by 50 percent by fully automating the processes from seeding to harvest. Importantly, Energy cost has been reduced around 30 percent per head of lettuce with the use of LED lights specifically created for SPREAD and the development of a unique air conditioning system with an initial investment reduction of 25 percent cost per head of lettuce [48]. It is estimated that roughly 20 percent of plant factories are making profit, 60 percent are breaking even, and 20 percent are losing money. The number and percentage of plant factories that are profitable have been increasing steadily since 2009. Depreciation costs account for roughly 30 percent, labor costs for 25 percent, and electricity [49]. In 2014, Mirai and Mitsui Fudosan Co., Ltd. initiated a full-scale operation of one of the largest plant factories in Kashiwa-no-ha Smart City, Japan. The facility was targeted to produced 15 types of vegetable. The building enclosed a gross floor area of 1,260 square meters [50]. Singapore has also

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been successful in vertical farms and there are many case studies to learn from. One of them is the Singapore skygreens. The 4 stories rotating greenhouse produces 1 ton of leafy greens on alternate days using a hydraulic-driven system that rotates and provides sunlight for the growing holders. The farm consists of 1,000 vertical towers and produces 800 kilograms of spinach, Chinese cabbage and other greens for everyday use to provide the active Southeast Asian metropolis [51]

2.6 A spotlight on China

China is one of the largest countries in the world with a population of 1.42 Billion as of 2017 [52]. It has experienced high rates of urbanization in the recent years. One of the evidence is the floor space of completed buildings in 2013 was almost double that of 2007 [53]. The United Nations predicted that the percentage of China's urban residents was expected to be 60 percent by 2020, and the urban population would increase 350 million by 2025 with 219 cities having a population of more than 1 million (compared to 35 cities in Europe) [54]. The demand for land for urban housing soared along with demand for business and built-up land use. Consequently, much of the farmland was converted into non-agricultural built-up environments [55,56]. A land alternation survey performed by the Ministry of Land and Resources in 2011 found that about 91.05 percent of the farmland loss was caused by usurpation for construction, cultivated land is down to only 0.08ha/person, nationwide, a figure which is just 40 percent of the world average [57]. For all these reasons, China started the research and practice of vertical farming in early 2004 and being widely introduced in the market since 2011. Meanwhile, because of the Low manufacturing costs and labour costs relative to other developed countries, the industry attracted a huge amount of investment. For instance, in 2014, the Evergrande group from China invested a billion dollars to established 22 vertical farming [58]. Dr Qichang Yang as the chief scientist presided over the research which funded 8 million U.S dollars on intelligent plant factory production technology, national high science and technology project. Organized by Chinese Academy of Agriculture sciences [59]. However, even though the vertical farm in China is growing rapidly, the government policy and economic support are still a very limited contribution to its fullest potential which leads to project defects of operational capability and maintenance defects. Furthermore, it caused low economic benefits and high energy consumption [60]. Under current national policy and legal system, it is hard to solve the problems about lifecycle cost of a vertical farming project such as maintenance, monitoring, marketing and energy utility is hard to increase the acceptability of vertical farming between the public community. Another adverse factor is lack of regional scientific research institution except certain state-level lab doing research on vertical farming, which led to the local vertical farming project cannot effective technical support [61,62]. This paper focuses on developing a framework to look at the feasibility of having vertical farms starting from university scale.

Universities have a huge demand from young people. As of 2016, China had 2596 universities compared to its population of 1.379 billion [63]. This implies the staff and students will be on a constant growing curve in the upcoming years. We believe that educational universities have managed to have stable income sources for many years. A report from 2017 by Economic Commentary states that the individual fees of the students have risen in private and public universities [64]. This is a very big opportunity to introduce vertical farming to showcase the benefits and encourage other industries to apply these techniques.

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According to a 2017 report, the unit price for a kilogram of rice is $0.75-$0.77 . It takes about 100~240 days with two production periods (April-July and August -October) [65]. For 0.0667 hectares (equals to 1 mu), the costs involved are $22.3 for fertilizer, seed and $23 for corresponding pesticide, labour force $46.15 RMB, rent for land $46.5 which equals to a total cost of $107.7 to $138.5 in typical conditions. In 1996, 19.51 hundred million mu of farming area was available but in 2010 only 18.26 hundred million mu of farming area was available. The area of farmland per capita is 1.38 (only 40 percent of World average). Only 6.09 percent of total farming land have an ability which can produce Over 1000 kg per mu. Table 2 is an example where it shows the agricultural demand of China in 2012 and the numbers increase as the population rises. This is a burden on the farmers as well as the acquisition of more fertile land.

Table 2: Average agricultural demand in China in 2012

	Daily Product	Beans& Nuts	Livestock	Fish& Shrimp	Eggs	Vegetables	Fruits	Grains
Daily demand(g/person/day)	300	30-50	50-75	75-100	25-100	300-500	200-400	250-400
Conversion factor (1/edible rate)	1.00	1.30	1.00	1.75	1.19	1.15	1.39	1.19
Annual Min. demand(kg/person)	110	14	18	48	11	126	101	109
Annual Max. demand(kg/person)	110	24	27	64	22	210	203	174
Population 100(million)	13.08	13.08	13.08	13.08	13.08	13.08	13.08	13.08
Annual Min. demand (100 million tons)	1.432	0.186	0.238	0.626	0.142	1.647	1.327	1.420
Annual Max. demand (100 million tons)	1.432	0.310	0.358	0.835	0.284	2.745	2.654	2.272

In Wuhan, which is a city in China has a population of 10.2 million has an urban area of 8494 square kilometres. There is a severe shortage of agricultural land and resources suffer inflation of prices. Only 61.3 percent of agricultural land is cultivable, and rest includes forestland, pasture area, park area and others. The national land contamination rate in China is 19.4 percent. Over 4.7 million hectares of land in steep slope cultivation which gives rise to serious soil erosion, main component parts of erosion matter are coming from farmlands. Additionally, there is a huge economic issue for these farmers and direct farm income is no longer the only source [66]. Wuhan has many universities and one of them is Huazhong University of Science and Technology which is one of the largest universities in China. This university was chosen to test the feasibility of implementing vertical farming on a campus scale.

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2.7 Methodology

This study reviewed the latest trends in technology and best practices on vertical farming from google scholar and trade information around the world. In the first step, the data of existing vertical farm practices was collected through media and literature research. A survey that was carried out in Huazhong University of Science and Technology (HUST) in the city of Wuhan, China to find out the average daily food requirements across campus including students, staff and faculty. HUST is one of the largest universities in China. The campus has 24 canteens which bring food from all over the province to feed its enormous population of 57,839 people. The university as of January 2018 has 24599 undergraduates, 23140 graduates and 5500 staff and 4600 retire [67]. The climate, logistics and demand of the city were taken into consideration while analyzing the demand proportions. In the survey, with the help of General Services Department and Data Information Centre of HUST, food consumption and demand data were collected from all canteens and restaurants in the campus boundary. The data was then segregated into types of food, seasonal variations, amount of consumption and their cost. A mixed method mode was chosen for this research to find the feasibility and challenges to introducing vertical farming on the campus of HUST which could encourage sustainable urban agriculture and be self-sustainable while being independent of external farming conditions. Based on Central Limit Theorem, a statistical concept model was developed to determine the financial scenario if a vertical was built and operated on campus to supply food to the people belonging to the university. Using this model and previous case studies, a qualitative and quantitative analysis was carried out for governing the advantages and challenges of modern urban agriculture in this genre of our built environment. The data focused on two aspects, the one is the production capacity of the current global vertical farms, such as annual output value, production efficiency, vegetable species and economic benefit. And another is the usage condition of vertical farming technologies. In the next step, we chose Huazhong University of science and technology (HUST) as a sample to gather the specific information of all 24 canteens about procurement chain and supply quantity. The data for total fruits and vegetables consumed the year 2016 was collected. According to the annual report, the total amount of fruits and vegetables consumed were 2,639,720.40 and 108,164 kilograms respectively which resulted in a total cost of $2,477,247.38. The individual breakdown of these plants and their costs associated were collected and analyzed.

The Assumptions made for the model to conduct this study were

1. The vertical farm building is simple box-shaped having a building footprint of 5000 square meters.
2. The building can provide more than 6.67 hectares of planting space by Multilayer cultivation.
3. The construction price for each square meter is about 1450 RMB or $227. (In Wuhan, China)
4. Unpredictable factors such as building materials were temporarily ignored, the average building cost resulted in 5.25 million per floor.
5. 0.0667hectares which are equal to 1 mu (Chinese standard farmland area unit)
6. Under typical conditions, the costs included in the cost of 145 RMB fertilizer, corresponding electricity and water 150-RMB, labour force 300 RMB, land 300 RMB equivalent to the total cost of 700 to 900 RMB, is the rent under typical conditions

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7. Annual operating costs are 5,000 RMB ($775.20)
8. We give two types of changes of operating costs per year. One is that the annual cost this year is 500 more than the previous year, and the other is that the annual cost this year is 1.1 times of the previous year.
9. The canteen's vegetable prices are considered fixed each year.
10. Cucumber-30000 kg per 0.0667 hectares
11. Tomatoes, two times a year, 20000 kg/0.0667 hectares, 40000 kilograms per 0.0667 hectares per year
12. Pepper, once a year, 5000 kg/0.0667 hectares
13. Carrots, two times a year, 10000 kg/0.0667 hectares/year
14. Chinese cabbage, once a year, 10000 kg/0.0667 hectares/year
15. Chinese cabbage, 8 times a year, 10000 kg/0.0667 hectares/year
16. Kale, two times a year, 3000/0.0667 hectares,6000 kg/0.0667 hectares per year
17. lotus root, once a year, 2000 kg/0.0667 hectares
18. If the building has only one floor, then we can assume the cost of the building is about 15 million, else if the building has three floors, then we can assume the cost of the building is about 15+10+10=35 million.

3. Results

The goal behind the statistical model was to calculate the following

1. Breakeven time on the initial investment.
2. Profits which can be generated from the vertical farm if the eligible resources are recycled?

From the Central Limit Theorem, the output was set for nine varieties of vegetables to be random variables that satisfy the normal distribution. The mean value is the aforesaid annual output of mu, and the standard deviation parameter is set to 1/10th of the yield per 0.0667 hectares per year as shown in formula 1.

$$\begin{cases} output\_1 \sim N(\mu_1, \sigma_1^2) \\ output\_i \sim N(\mu_i, \sigma_i^2) \\ \vdots \\ output\_10 \sim N(\mu_1, \sigma_1^2) \end{cases} \quad \text{(Formula 1)}$$

The formula shows the annual output of each of the nine varieties of vegetables that satisfies the normal distribution expression. The output of different vegetables does not affect each other independently. (assuming climate conditions are maintained). W is used to indicate the silent costs which are the initial investment of the vertical farm. Op costs (operating costs) is used to represent the annual operating costs, num_unit_i to represent the number of 0.0667 hectares of [i]th vegetables. For example, num_unit_1=2 and num_unit_9=1 means that [2 *0.0667] hectares of cucumber are planted, and cabbage is planted in [0.0667*hectares]. Price [i] represents the price of each vegetable. The “rec” years represents recovery/breakeven years of the recycling cost can be expressed as the total cost divided by the annual profit (Formula 2).

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$$rec\_years = \frac{W}{\sum_{i=1}^{10}(output\_i \times num\_unit\_i \times price\_i) - op\_costs} \quad \text{(Formula 2)}$$

The parameters of the random variables representing the output value of each of nine kinds of vegetables per 0.0667 hectares are calculated. The average value is therefore mentioned per-mu per year and the standard deviation parameter is set to 1/10th of the annual yield per 0.0667 hectares. First, (cucumber, tomato, potato, cabbage, and five kinds of vegetables) are planted on 2*0.0667 hectares and the rest are not planted. They can be expressed as in (Formula 3):

$$\begin{cases} output\_1 \sim N(30000, 3000^2) & straight\ cucumber \\ output\_2 \sim N(40000, 4000^2) & tomato \\ output\_5 \sim N(11000, 1100^2) & big\ potato \\ output\_7 \sim N(10000, 1000^2) & pakchoi \\ output\_8 \sim N(15000, 1500^2) & cabbage\ plants \end{cases} \quad \text{(Formula 3)}$$

According to the Distribution Law of the normal distribution of random variables, if the building has only one floor, then regardless of how the annual operating costs change, the average years of recycling costs is 11.5 years. The substitution calculation can get the 68.3 percent confidence to recover the cost between 10.5-12.9 years, there is 95.4 percent confidence to recover the cost between 9.6 and 14.5 years. If the climate is suitable and technical management is good, the cost may be recovered in 10 years. And if the technical management and climate situation are poor, the cost will also be recovered in 15 years. If the average value and fluctuation range of production are changed in the actual situation, the value of the parameters in the model can be adjusted and recalculated.

After recovering the cost, we can choose to grow (2 *0.0667) hectares of cucumbers, tomatoes, potatoes, bokchoy, and cabbage steadily each year. The average income is about 947,000 RMB ($148000). There is 68.3 percent certainty that the annual income is between 825,000 and 1,041,000 RMB ($129,000-$163,000). There is 95.4 percent certainty that the income will range between 757,000 and 1136,000 RMB ($118,000-$177,500) per year.

We can also select cucumbers, tomatoes, peppers, carrots, potatoes, Chinese cabbage, Chinese cabbage, cabbage, and cabbage. Each of the nine high-yield and high-demand vegetables grows 0.0667 hectares for each variety, and the remaining land can be allocated on its own, which can achieve an average annual stable profit of 592,000 RMB ($92,500). Even if the remaining land is not cultivated, there is 68.3 percent certainty that makes an annual income of 533,000-651,000 RMB ($83,000-$102,000), with 95.4 percent of the determination to make annual income about 474,000-710,000 RMB ($74,000-$110,000).

Additionally, If the building has three floors then regardless of how the annual operating costs change, the average years of recycling costs would be 9 years, the substitution calculation can get 68.3 percent certainty to recover the cost between 8.2-10 years, there is a 95.4 percent certainty to recover the cost between 7.5 and 11.3 years. And the annual income of planting vegetables is three times that of the original strategy where the building has only one floor. If the building has ten floors, then we can assume the cost of the whole building is about 120 million RMB ($18.75 million). Then the whole building can provide more than (10*10*0.0667) hectares of planting space. The building can plant all

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kinds of vegetation to meet the demand of the university. The calculation method is the same as above.

4. Discussion

Universities have multiple sources of income through research, industry involvement, investment, government grants and others. This is one of the major reasons of why universities can implement new technologies such as vertical farming for their students and staff. The increasing population will also increase the demand-supply chain of food systems. This can be managed by installing vertical farming.

Introducing vertical farms in university campuses will not only save money and resources but also facilitate multiple streams of income. Research labs can be established in these farm buildings where people from national and international institutions can be brought in for new innovations and technologies. These farms will able to supply specific foods according to specific seasons. Additionally, universities can monitor the production and usage in real time and make decisions could benefit the society. This will start an incredible chain of advanced research and development in the field of sustainability, science, social science, business, materials, agriculture, mathematics and other interdisciplinary domains. The universities can set an example of taking bold initiative which would bring them fame and they can attract resources. In the educational industry, profits may not be focused on short-term gains rather than pushing boundaries for students and faculty with having financially benefited in the long term.

Construction of vertical farming can save labour, packaging, logistics costs. Logistics have direct and indirect impacts on the environment. The use of plastic sheets, styrofoam and others are non-biodegradable. Also using fossil fuels in vehicles have a direct impact on the air pollution and depletion of natural resources. The produce from vertical farming is free from any harmful chemicals and is more healthy than traditional farming. Furthermore, this system produces the least waste which is highly beneficial. The vertical farming building can serve as a teaching space for the students all over the world and can inspire other institutions in getting involved in advanced urban agriculture. For the general production of plants, the students can be considered as a key element. Training and part/ full-time employment can motivate them to get involved in the process. This will enable to create a strong sense of community belongingness. Whenever there is an excess production, the vegetation can be donated or sold at a reasonable price to people outside of the university. The building can be built through best sustainable practices and the operational energy can be harnessed from renewable sources such as solar, wind and hydropower. Finally, there can be multiple opportunities for bringing in financial resources from research labs, innovations in technology, governmental capitalizations and others.

5. Conclusions

The concept of introducing vertical farming can be a strong tool used in the built environment for fighting climate change and global warming. As per the study conducted on various scenarios, a vertical farm can break even economically in 10-20 years and could alleviate the stress on the environment. Additionally, the stress on fertile land all over the world can be reduced to great extent when industries start becoming self-sustainable. The technology has been sporadic in nature

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throughout the countries which makes it difficult to recognize its true value. Furthermore, enterprises who have initiated vertical farming have not been completely transparent which results in less awareness among industries, and the application on a large scale is not evident. The quality of all aspects of technologies in vertical farms are also important because it relates to the ability of these to achieve sustainable development and achieve cost recovery and profitability. However, in the vertical farm environment, the yield and fluctuation of crops are still unclear, and further practical experiments and conclusions are needed. For using vertical farming on a pragmatic undertaking, there should more research focused on industrial scale, location-based climate analysis, financial models scoring lower breakeven time and higher profit margins. There can be federal and state incentives to push this idea among the citizens. We believe that vertical farming and sustainable urban agriculture has tremendous potential in recovering from social and planetary issues.

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Appendix A

The vegetable and fruit consumption by HUST (Huazhong University of Science and Technology) in 2016 as per the data collected is shown in the following tables.

Vegetables	Amount(kg)	Price in USD（RMB 6.45：1）
Sea mushroom	6.2	11.05
Mushroom(capped)	3583	8474.57
Mushroom	11611.45	32763.87
Mongolia mushroom	166.5	331.32
Babysbreath	25	48.06
Nostoc commune	346.2	1011.91
Straight cucumber	83195.45	51366.13
Towel gourd	29708.6	19212.58

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Bitter gourd	21099.9	14339.96
Wax gourd	60530.9	25939.09
Pumpkin	31886.6	16043.10
Horredcucumbern	31780.1	20914.94
Tomato	156396.1	107086.70
Cherry tomato	33856.6	15101.83
Opo squash	11521.5	7025.43
Eggplant	57386	34925.47
Eggplant king	34979.5	40608.17
Pimenton	127100.05	95853.45
Cayenne pepper	26811.85	33270.69
Wuhu pepper	16064	15812.03
Hangzhou-pepper	15437.95	15458.42
Green bean	68904.2	82643.19
Fresh corn	18540.6	33702.60
Fresh lotus root	11073.1	17297.94
Net onion	28949	23002.34
Cutted lettuce	19264.9	15381.63
Head of lettuce	29397.5	39637.13
Chinese cabbage	105107.7	56670.61
Pakchoi	86014.5	54379.11
Cabbage plants	85700.4	67020.45
Cabbage sprouts	44027	21018.60
Red Brassica campestris	11023	17477.43
Cabbage	157831	78485.54
Rain-water food	11264.7	7121.88
Romaine	16230.45	21568.87
Lactuca sativa	19153.45	16276.58
Spinaciaoleracea	18078.5	21057.89
Caraway	8265.1	13830.48
Cauliflower	36706.85	37887.78
Broccoli	5	6.98

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Crowndaisy chrysanthemum	979	948.22
Garlic puree	10765.1	23546.61
The head of garlic	7425	17041.48
Garlic (white)	2104.75	6275.46
Garlic (red)	6613.5	5291.50
Shallot	19372.75	30343.24
Green Chinese onion	16840.25	21484.47
Sweet rice bean	4307.9	5944.23
Shanghai celery cabbage	4465.5	5831.64
Red rice pepper	383.9	1111.26
Purple potato	2453.8	4757.58
Chinese chestnut	2247.7	16243.45
Broccoli	32316.5	41619.14
Parsley	14.3	71.63
White radish	57378.7	25007.83
Carrot	81530.15	51415.07
Green tangerine radish	2	0.54
Dasheen	15365.2	9786.70
Chinese yam	24441.8	61294.12
Big potato	118039.9	67528.17
Big potato fresh	295895.9	253434.75
Sweet potato	26252	21668.22
Lotus Root	75351.15	117068.76
Mud artemisia	1365.5	1683.61
Net mud artemisia	1593.7	5651.79
Mung bean sprout	28355	15352.95
Soybean sprouts	16380	8106.16
Chinese chives	42861.3	31248.33
Blanched garlic leaves	3152.6	7245.57
Garlic bolt	16023.6	25991.50
New garlic sprout	15154.82	17432.36
Celeriac	6007.4	4948.68
Fine celery	12224.15	13308.09
Celery	8510.95	6982.33
Onion	13563.3	9178.45
Fresh ginger	15883.85	17861.98
Galanga	11.5	45.58
Chrysanthemum	309	725.46
Cloud ear	250	426.36
Oyster mushroom	9302.5	12093.28
Enokitake Mushroom	9226.5	15582.62

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Pleurotus Mushroom	10263.55	24677.47
Agrocybecylindracea	2610.3	6143.31
King oyster mushroom（big）	17950.25	29551.17
King oyster mushroom small	142.4	160.67
Baby cabbage 1.1~1.3	2751	4555.61
Baby cabbage	75.6	134.57
Raw corn	1655.6	3071.96
Water chestnuts	12	30.70
Cantonese cabbage	8034.8	15609.87
Fresh water caltrop kernel	788.9	2970.47
Fresh cicada douban	7105.45	23338.08
Cantonese leaf lettuce	21970.5	37636.45
Fresh pea	2338	11555.00
Fresh soya beans	10534.2	31713.67
Special green hang pepper	6549.4	11121.74
Shearing beans	2393	4606.80
Mini-cucumber	1622.1	3810.56
Snow peas	4053	13151.95
Purple cabbage	568.8	501.10
Red hang pepper	2193.73	4097.24
Hotbed chives	2355	6124.09

No.	Fruits	Amount(kg)	Price (RMB)	Price (USD)
1	honey-dew melon	4132	26731.08	4144.353488
2	Seedless watermelon	49824.3	318248.79	49340.89767
3	pawpaw	331.85	3445.29	534.1534884
4	Fuji Crystal apple	38327.5	30233.34	4687.339535
5	pineapple	7246.6	46421.04	7197.060465
6	banana	472	2781.72	431.2744186
7	mango	1863.61	38927.74	6035.308527
8	kiwi berry	1506.4	22385.34	3470.595349
9	Crown pear	3481.65	22312.4	3459.286822
10	lemon	247.63	5087	788.6821705
11	Watermelon with seed	635.2	698.44	108.2852713
12	calamondin orange	95.3	1383.51	214.4976744
	TOTAL	**108164.04**	**518655.69**	**80411.7349**

DAILY CONSUMPTION STATISTICS (NO. OF PEOPLE) (2017.11.1-2017.11.30)

No.	Canteen name	Breakfast	Lunch	Dinner	Total
1	BAIPIN	92	1105	1147	2344
2	BAIHUI	804	617	598	2019
3	XIYI	2368	4905	4333	11606
4	XIER	422	1218	859	2499
5	LINFENGWAN	31	291	294	616
6	BAIJING	2009	2821	2299	7129
7	YUYUAN	968	1015	1093	3076
8	JIJINGLOU	1875	1667	1529	5071
9	JIXIAN	1444	1723	1449	4616
10	JIEDAIZHONGXIN	69	34	20	123
11	QINGZHEN	230	678	450	1358
12	DONGYI	3405	5364	4001	12770
13	DONGER	404	560	493	1457
14	DONGSAN	607	1109	1111	2827
15	XUEYI	0	2026	1009	3035
16	XUEER	119	159	56	334
17	QIQIN	1049	1051	670	2770
18	TONGQIN	1198	2490	1912	5600
19	DINGXIANG	326	1032	246	1604
20	XINGLIN	0	277	199	476
21	ZIJIN	4983	4695	4356	14034
22	YUNYUAN	837	734	794	2365
23	DONGJIAOGONG	793	4147	3296	8236
24	DONGYUAN	24033	39718	32214	95965

Daily Consumption Statistics in the canteens-provided by Information of Data Centre and Technology