The Opportunity of Building Integrated Agriculture in Bangkok

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Abstract

This paper reviews existing urban farms and studies the opportunity to integrate agriculture into the high rise building in city of Bangkok. The consumption behaviors of 300 consumers aged between 26-36 years old who work in city of Bangkok are collected with questionnaires. The design methodology is applied in two high rise buildings and the payback period of the farm projects in the proposed buildings are analyzed. The result shows consumers who have healthy life styles prefer consuming fresh fruits and vegetables together with meats but do not like growing plants for consuming by themselves. Two mixed-used residential buildings with supermarket integrated vegetables farms are designed in two locations of Bangkok. The farm products are found adequate for residences and for selling. The payback period of the agricultural farms are within five years.

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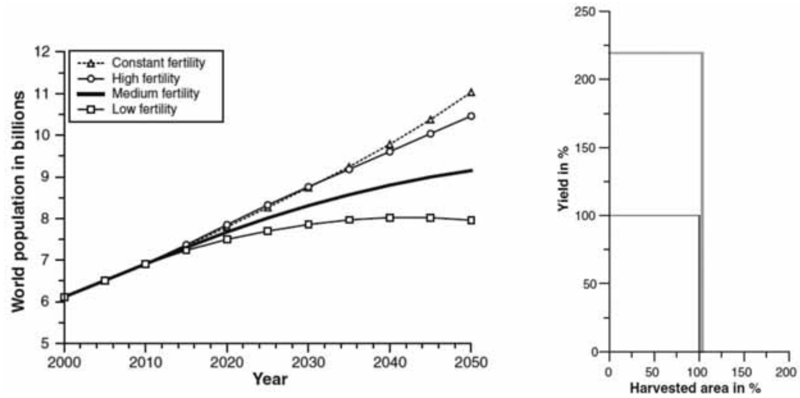
1. Introduction

The current crisis in food production, consumption and the effect of nutrition on health is generally known. The main cause of the food problem is the growing of world population while food production area is the same or slightly increased (Figure 1) (Germer et al., 2011, pp. 237-251). The yield of food crops can be calculated from food crop production per area times the planting area. The increase of food nowadays comes from adding workers, increasing the use of natural and synthetic fertilizers and genetic improvement in the area. Food crops yield per area of the world increased by 120% from breeding, laboring and chemical pesticides (Figure 1). This is called intensive food production or intensive farming. The intensive farming affects the quality of the output, consumer health and ecosystems.

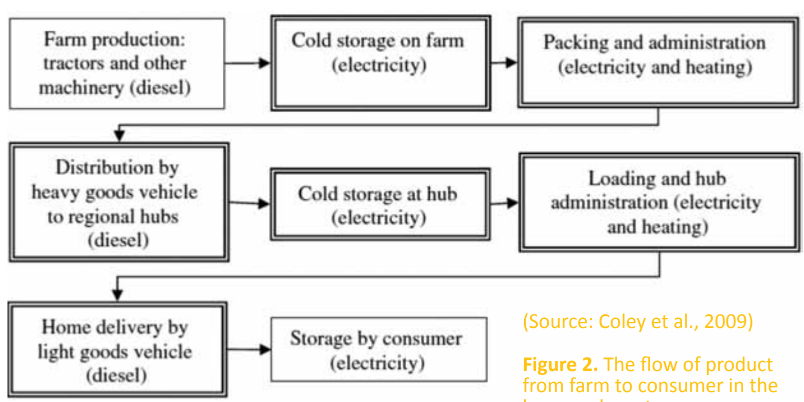
In addition to food production activities, human consumption is also associated with the activities of food distributing and food trading. These activities effect the fossil energy consumption, food nutrition depletion and multiplication of food price. Sources of fresh food, dried food, frozen food, beverage and packaging of processed products come from both within the country and outside the country. Food storage and transportation require electric energy and oil. Hence, food prices increases. Also, keeping fresh food refrigerated decreases food nutrition value. The concept of delivering fresh food from farm directly to consumers is a way out. This concept is likely to help reduce energy consumption and preserve t food nutrition. Figure 2 shows the process of shipping food production from the large-scale manufacturer. Figure 3 shows the process of delivery from producer to small-scale consumer. It can be seen that the small-scale system has less steps and use less energy. The less energy was found for the transportation of distance between the farm and consumer of less than 6.7 km. Otherwise, the small scale system would produce as large greenhouse gas as the found in the large-scale system. (Coley et al., 2009)



(a) (b)

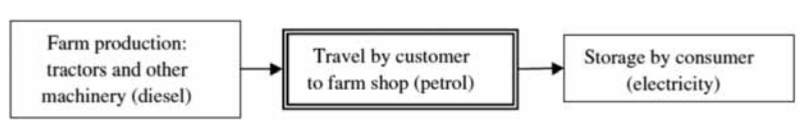
(Source: Germer et al., 2011, pp. 237-251).

Figure 1. Forecasts show that the population of the world increases by the level of fertility (a), while harvested area increased by only 11% in 2011 but the yield per area of cultivated food crop of the world increased by 120% from intensification.



(Source: Coley et al., 2009)

Figure 2. The flow of product from farm to consumer in the large-scale system.



(Source: Coley et al., 2009)

Figure 3. The flow of product from farm to consumer in the small-scale system.

In cities where space is limited, building integrated with agriculture could be an opportunity to moderate food problems such as food production, transportation, nutrition depletion and price. Typically, people in cities rely on food from the markets, supermarkets, retailers, convenience stores in the neighborhoods (Borradaile et al., 2009). The chain stores usually sell processed food and food preserved for several days. Consumption of processed food leads to insufficient nutrients and lack of fibers from vegetables. A study shows nutritional status of Thailand changes with the number of retail stores during 1991-2010. The result shows that the number of Thai females with overweight is direct proportional to the number of retail stores (Kelly et al., 2010, pp. 4-7) According to a study by Department of Health of Thailand, it is found that Thai people aged 15 years and over Thailand having fresh fruits and vegetables of 76-179 grams per day. This amount of fruit and vegetable intake is not enough to prevent serious diseases and strengthen the body recommended by the World Health Organization, which recommends fresh fruits and vegetables 400 g/day (Saleepan, 2014).

It can be seen that the food production system, transportation and distribution, are currently impacting both the ecosystem and consumption behaviors and directly effect on lives of consumers. An accessible fresh food at stores and food harvesting at residential buildings locating in cities is a viable answer which has been interested by architects for years. The successful example of urban farm has been found in Singapore (Lim, 2012). There are several projects of agriculture integrated with old buildings in other countries. In this paper, existing urban farms (Architecture and Food, 2014; Gotham Greens, 2014) and a few initiate projects are reviewed. The opportunity of agriculture integrated with new buildings in the city of Bangkok is shown by design and economic aspects.

2. Existing urban farms

Currently, companies in UK and US construct new buildings integrated with agriculture and retrofit old buildings for commercial agriculture. Their projects employed rooftop farms and vertical farms in the terraces of commercial and residential buildings. Architecture and Food (A & F) in UK founded by architect Oscar Rodriguez renovated old buildings and constructed new buildings for agriculture. Procedures started from the signing of the cooperation between the building owners and the company. A & F studied the feasibility of projects and business plans, designed and developed a construction plan and then began to construct and transferred to the owner. For the new building, designer co-operated since the beginning of the project. The greenhouse vegetable farms were registered as a company that sold a particular product in a community (hyperlocal).

Figure 4. Old residential building retrofitted to growing vegetables on the roof.

A & F has retrofitted and added agricultural farm in five old buildings and there have been five new buildings in progress. This included residential, residential and shops, restaurants and office buildings (Figure 4 and 5). A & F projects conducted agricultural building on the roof and terrace. All projects used organic fertilizer (compost) from sewage and waste from the residence and harvest rainwater in underground tanks. Products included various types of vegetables.

Gotham Green, a company in New York City owned three vegetable farms on roof of old buildings. Hydroponics vegetables were grown on the top of building and a supermarket at the ground floor of the building sold vegetables and healthy food to customer in community (Figure 6). Solar cells installed on the roof of the parking lot and combined heat and power plant (CHP) produced energy to operate farm and supermarket.

(Source: Architecture and Food, 2014)

Figure 5. Roof farm on new building, London Victorian terraced house

(Source: Gotham Green, 2014)

Figure 6. Green Point supermarket of Gotham Green Company.

(Source: Lim, 2012)

Figure 7. Vertical vegetable farm in Singapore.

A vertical farm in Singapore operated officially for the first time in October 2012 on an area about five football fields in the region Lim Chu Kang. The farm was a property of Sky Greens who also owned a patent of water circulating system for its vertical farm. Plants were grown in plots arranged in layers in the aluminum framed tower of 6 m high (Figure 7). There were 2,000 towers for the total investment of 28 million dollars. The yield was 10 times more than typical growing system. The produced vegetables were sold at lower price than those imported vegetables from Indonesia, but fresh because they were local food.

In Africa, Asia, Eastern Europe, Latin America, urban vegetable farming was a career for the low income people who live in city. It did not help solving the problem of poverty due to the planting area and the technology were very limited (Zezza &Tasciotti, 2010, pp. 265-273). The importance of urban farming were likely to get high quality nutrients directly from the plantation and reduced cost down. It was reported that growing vegetables in schools help increase consuming of vegetables, fruits, in children who did not like vegetables and fruit by 135% (Yoder et al., 2014, pp. 341-349). In Thailand, hydroponics farms have been found in framed house covered with nest.

3. Methodology

This paper surveys a sample of 300 people in the two sites about their behaviors in consuming food and purchasing food. Two sites are included in this study, a site at Krungthonburi road of 9,184 m^2 and a site at Sukumvit soi 105 of 7,324 m^2. The two sites are examined for their development potential. Site analysis is conducted according to City Planning and Development Law 2013. For the site in Krungthonburi road, a residential building with agriculture using artificial lighting is designed. For the site in Sukumvit 105, a residential building with agriculture using natural lighting is designed. In the building with agriculture using natural lighting, a program computer called Ecotect simulates solar hours on the building façades. Food crop are cultivated and grew on the façade gaining solar 4- 5 hours per day.

4. Results and Discussions

4.1 Survey on fruit and vegetable consumption

The results from survey of target group of 300 people aged between 26-36 years old are summarized in Figure 8. The average number of population in these sites are 85,500 people. Taking into account the confidence level of 95% and confidence interval of 5-6%, the number of sample size of 300 is derived from the sample size calculator (Creative Research Systems, 2012). Overall, the target group are the new generation who like keeping healthy by having vegetables and fruits and meat in high amount. 60% of them have fruits and vegetables every day. For the question of how often a person having clean food, 68% reply that they have clean food a few times in one week or in one month. The clean food in the questionnaire are whole grains, unrefined food, and food with cut out fat, sugar and salt. There are only 17% of people in sampling grows vegetable for eating. These answer shows, in terms of customer, that there is an opportunity for building with integrated vegetable farm in Bangkok.

Figure 8 also shows the results of survey on purchasing food and the opinion in growing vegetable farm. The target group are typical office workers who like dining out in restaurant. They prefer buying food in the supermarket because of convenience and availability of supermarket in city. There are 66% of people like to have growing vegetable at home. 30% have no idea about growing vegetable because they hesitate to spend time and cost on growing food crops.

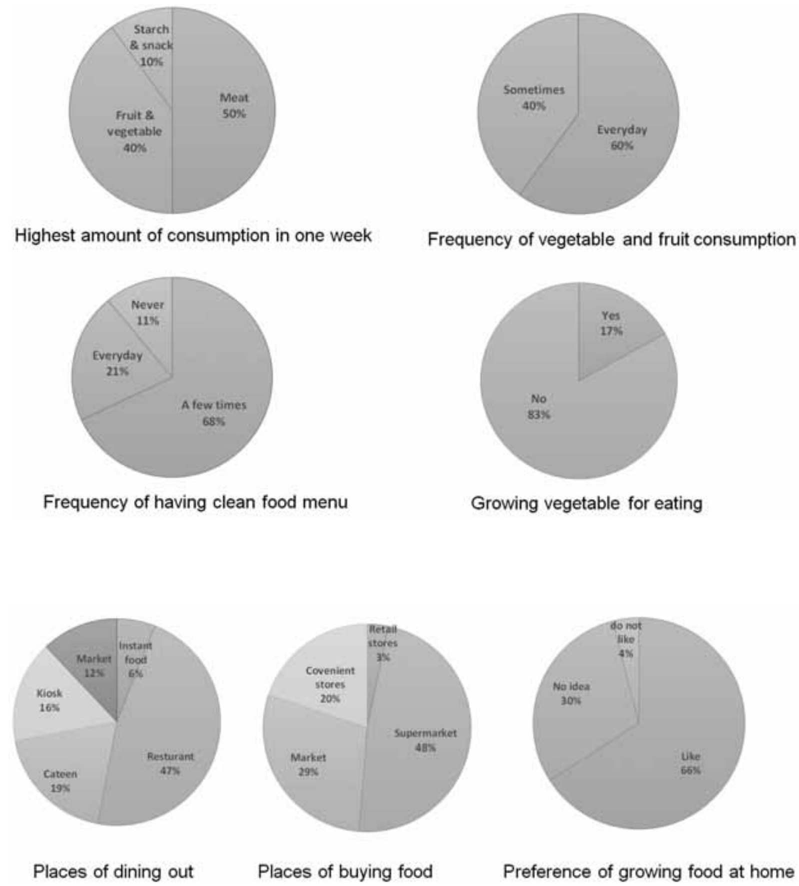


Figure 8. Results of survey on purchasing food and the preference of growing vegetable farm.

4.2 Site survey and analysis

4.2.1 Site #1: Krungthonburi road

Figure 9a shows the location of site on Krungthonburi road. The total area of this site is 9,184 m^2, locating 200 m from Krungthonburi BTS station. The north of this site faces Krungthonburi road and the south faces canal named Klong Tonsai. Neighborhoods are composed of

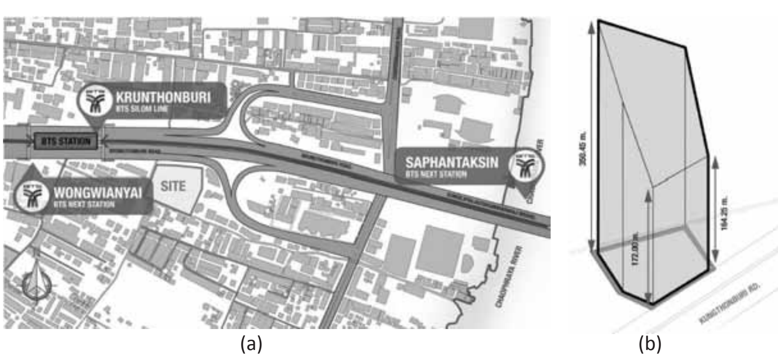


Figure 9. a) Location of site on Krungthonburi road b) the maximum height of a building in site #1.

residential houses, row houses, office and condominium. The site can be accessed by bus (number 76, 84), BTS sky train (Krungthonburi station), and private cars. Situated in Klongsan District, site #1 is considered in high density residential area. According to City Planning and Development Law, this land could be constructed with floor to area ratio (FAR) of 6:1. With offset distance from the canal and main road of 2 m and for a fire truck of 6 m, the maximum height of the building could be 350.45 m as shown in Figure 9b (Royal Thai government gazette, 1979).

4.2.2 Site #2: Sukumvit Soi 105

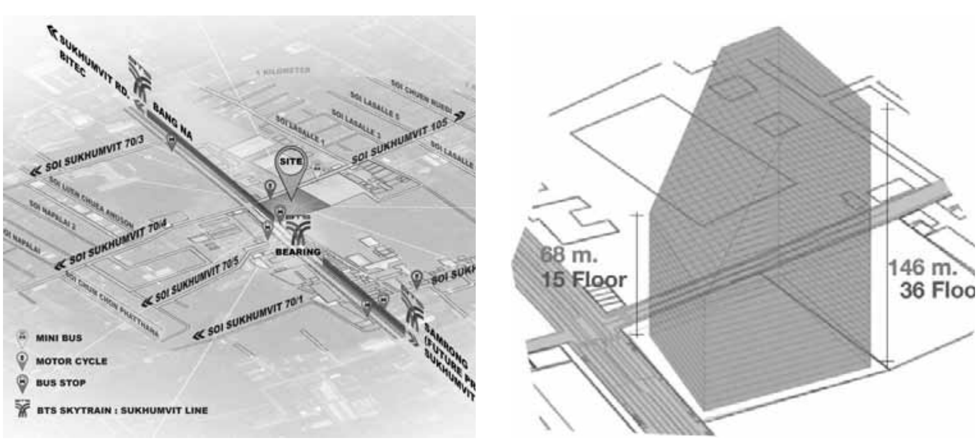
Figure 10a shows the location of site on Sukumvit Soi 105. The total area of this site is 7,324 m^2, locating 50 m from Bearing BTS station. Neighborhoods composed of residential houses, row houses, office and condominium. The site can be accessed by bus, BTS sky train, motorcycle, and private cars. Situated in Bangna District. Site #2 is considered in medium density residential area. According to City Planning and Development Law, this land could be constructed with floor to area ratio (FAR) of 5:1. With offset distance from public road of 2 m and for a fire truck of 6 m, the maximum height of the building could be 146 m as shown in Figure 10b (Royal Thai government gazette, 1979).

4.3 Building integrated with agriculture using LED light

4.3.1 Building design

The designed project is a high rise condominium (50 floors) with hydroponic core in the elevator hall. The installed light-emitting diode (LED) bulbs give light of purple color so that the hydroponic core is in purple or deep pink color. The pink-color core can also be seen from outside in the nighttime as shown in Figure 11. Residences in this condominium can take views of vertical indoor farm through glass elevators as shown in Figure 12. The vertical void are continuous from 4^{th} - 50^{th} floor which are arranged in different forms as shown in Figure 13.

The first floor to third floor of this building is a food center and a supermarket where hydroponics vegetables, fruits and clean food are sold to customers. The customers are population in neighborhoods. Hydroponics fruits and vegetables are also given to the condominium residences for free under a limit of 400 grams per occupants per day. This minimum amount of fruit and vegetable consumption per person help prevent diseases such as cardiovascular disease and certain cancers (World Health Organization, 2014).



(a) (b)

Figure 10. a) Location of site on Sukumvit Soi 105 b) the maximum height of a building in site #2.

Figure 11. Picture of building integrated with agriculture using LED light.

Figure 12. Agricultural area in the lift core.

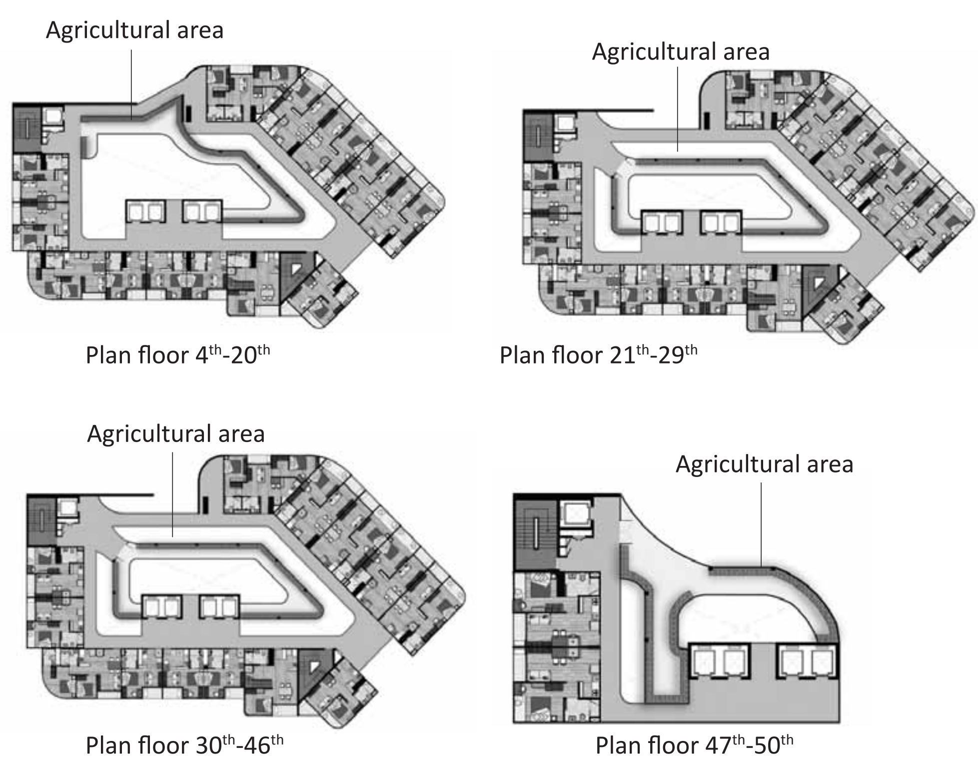


Figure 13. Building floor plans show residential units and agricultural area.

4.3.2 Techniques and calculation of cultivation area

The vertical farm in this project uses hydroponics system with LED light bulbs. Growing crops under the controlled light wave length increases the productivity. This technology has been widely applied in Japan and US (Clive, 2015). The blue and red light waves are necessary for growing of food crops, but the blue light is a high energy light wave that would cause macular degeneration in residence and workers in the area. To reduce the blue light penetrate to human eyes, a row of lightbulbs in each floor providing white light is required between the human and the growing plots. The total cultivation area is computed from the recommended quantity of fresh fruits and vegetables consuming, i.e. 400 grams per day per person. The total number of residence of the condominium is 1,053 persons and the customers is 700 persons. The shortest period of harvesting hydroponics vegetables is 45 days, hence, a person need 18 kg of vegetables in 45 days. Since the productivity per cultivating area is 4.0 kg/m^2, area required for cultivation per person is (18 kg/person)/(4.0 kg/m^2) = 4.5 m^2/person. This project serves 1,053 residences in condominium of person and 700 people in the nearby community. Therefore, the total required cultivation area is (4.5 m^2/person) x (1,753 person) = 7,889 m^2. A cultivation tower composes of 5 layers, thus the designed agricultural area in the building is (7,889 m^2)/5 = 1,578 m^2.

4.3.3 Economic analysis

The land cost in this study is high since the location is in a large city. The land cost for this project is around 735 million Baht. The total cost including land cost, land development cost, construction cost, tax and miscellaneous is around 2,893 million baht. The 531 residential units in condominium consisting of studio type, one and two bed room types, and duplex room type have total value of 3,362 million baht. The price per square meter of the residential unit is 130,000 baht which is the price of upper class condominium in the district. The income of the legal entity of condominium obtains from rental area in the food center and selling fruits, vegetables and products in the supermarket. The analysis of cash inflow and outflow for condominium are complicated and it is omitted from this paper. Only the preliminary economic analysis of the vertical hydroponics farm is shown here.

Table 1 show functions and area in the vertical hydroponics farm in this project. The total area of farm including circulation is 2,789 m^2.

Function	Number of users (person)	Area per person (m^2)	Total area (m^2)
Cultivation area			1,600
Product storage			325
Product checking	5	5	25
Workshop	50	1.1	55
Cleaning and packaging	20	7	140
Total activity area			**2,145**
Circulation 30%			**644**
Total farm area			**2,789**

Table 1. Functions and areas of the indoor farm.

Description	No. unit	Area (m^2)	Price/m^2	Total (baht)
Farm building		2,789	22,630	63,091,440
LED light	4,242		1,150	4,878,300
Farm equipment			5,000	40,425,000
			Total capital cost	**108,395,740**

Table 2. Capital cost of the indoor farm project.

Description	No. unit	Price/unit (baht)	Total price/ month (baht)	Total/year (baht)
Labor salary	8 persons	12,000	96,000	1,152,000
Manager salary	2 persons	20,000	40,000	480,000
Liquid fertilizer		76	51,025	612,300
Water		1.97	1,327	15,924
Electricity		1.98	479,153	5,749,836
Seeds		35	2,949	35,388
		Total operation cost	**670,634**	**8,047,608**

Table 3. Operation cost of the indoor farm project.

Description	No. unit	Price/unit (baht)	Total price/ month (baht)	Total/year (baht)
Sell vegetables	3,345	373	1,247,685	14,972,220
Public amenities fee	27,415	40	1,096,600	13,159,200
		Total revenue	**2,344,285**	**28,131,420**

Table 4. Total revenue of the indoor farm project.

The capital cost consists of construction of farm tower, the LED light bulbs and equipment such as controller, water pumping and mixing chamber. The total investment cost is 108,395,740 baht. The operation cost is based on the labor cost, fertilizer, electricity, water and seed. The total operation cost is 8,047,608 baht annually. The total revenue per year from selling fruits and vegetables and public amenities fee is 28,131,420 baht. Therefore the payback period is computed from Investment cost/revenue = (108,395,740 + 8,047,608)/ (28,131,420) = 4.13 year. Therefore, the indoor farm is an interesting project and has opportunity to invest.

Figure 14. Picture of building integrated with agriculture using daylight.

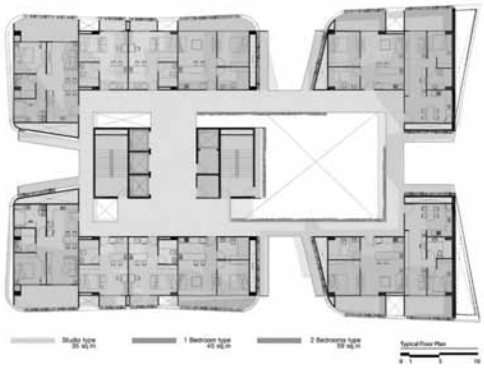


Figure 15. Floor plans of residential units on 6th-30th floor.

4.4 Building integrated with agriculture using daylight

4.4.1 Building design

The designed project is a high rise condominium of 30 floors with hydroponic plant cultivation in the terrace of residential rooms and in the corridor. The room owners can grow their own vegetables at the room terrace. The fruits and vegetables planted in the corridor are for sell in the supermarket. As seen from the outside in Figure 14, it is looked like four buildings. Actually, this is a building with four external voids connected inside with an opened corridor. The external voids allow daylight to penetrate into the corridor. Therefore, the corridor area is also available for plant cultivation.

There are total of 100 residential units in this building starting from 6th floor. The floor plan of residential units is shown in Figure 15. In each floor, there are 4 units of studio room type, 6 units of one bed room type and 2 units of 2 bedroom type. The opened corridor in each floor are depicted in elevation as shown in Figure 16.

4.4.2 Techniques

In this project, the maximum agricultural area depends on room space and façade design. To grow food crops like cabbage, kale, red oak, lettuce, etc., crops should receive solar radiation at least 5 hours daily. The terraces of residential rooms already obtain more than 5 hours of solar gain per day. The oblique façades designed as shown in Figure 15 allow maximum solar radiation incident on the corridors of 6th-30th floor. The oblique façades are obtained from simulation results of the Ecotect computer program.

To find appropriate angles of façade, six schematic designs of corridors shown in Figure 17 are simulated together with rearranging salable room areas. Scheme #5 and #6 give similar profits from the salable area, but Scheme #6 have smaller elevator core. This provide higher solar radiation in the corridor in the Scheme #6 compare to

Figure 16. Front elevation and left side elevation.

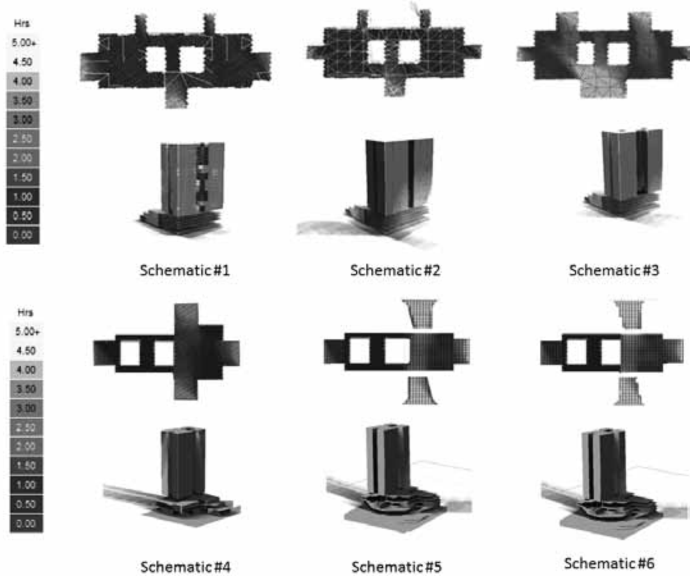


Figure 17. Design development of building with solar hour varying from 0-5 hours on the corridor.

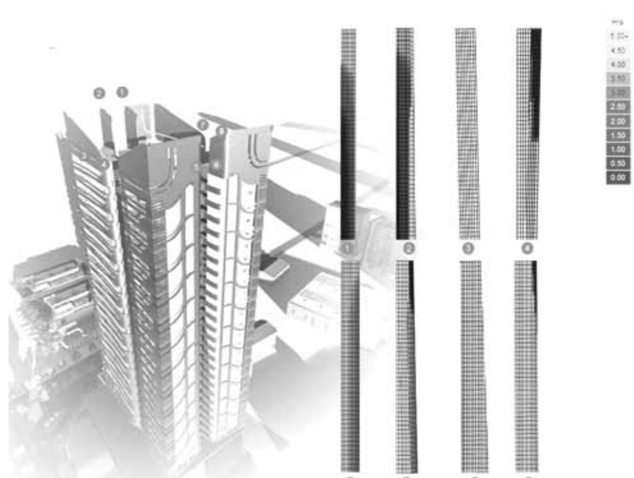


Figure 18. Solar hours on the façade of corridors.

Scheme #5. Therefore, Scheme #6 is chosen since it provides both feasible profit of salable area and highest solar hour on the corridor.

The availability of solar on the top floors are higher than those on the lower floor. From the results, there are parts of façade area receiving no solar radiation (Figure 18). Thus, the available agricultural area for commercial is calculated from the total area of facades receiving solar of 4-5 hours (Figure 19). From Figure 19, the total agricultural area is 9,450 m^2.

The hydroponics system is applied in this project. To grow food crops, plants need not only sufficient solar radiation per day but also protection from too high wind and too high temperature. The planting modules with wind and sun protection are designed so that they can be attached to the circulation wall (Figure 20).

4.4.3 Economic analysis

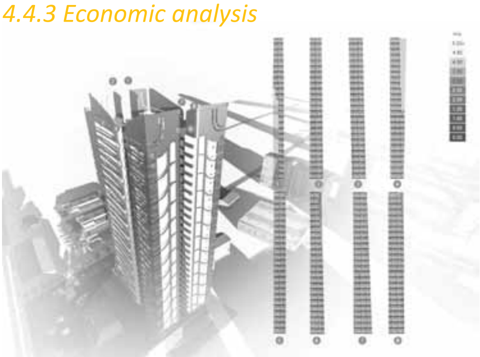


Figure 19. Agricultural area on the façade of corridors.

The land cost for this project is around 670 million baht. The price per square meter of the residential unit is 89,000 baht which is the price of middle class condominium in the district. The price per square meter in this project is lower than the previous project because building in this project is quite typical consisting of 30 floors and no glass lifts. For the farm project, the capital cost, annual operation cost and annual revenue are calculated based on the computed results of previous project with assumptions as follows:

1. The planting area in this project is 9,450 m^2. The farm building cost of 22,630 bath/m^2 was given for a tower of 5 planting layers. Therefore, the total cost of farm building is calculated from the area of (9,450/5) + 30% for circulation area = 1,890 + (1,890 x 0.3) = 2,457 m^2.
2. Farm equipment cost is 50% lower than that of indoor farm using LED. The capital cost of hydroponics system using daylight is 61,744,410 baht show in Table 5
3. For operating cost, electricity is used for driving water pumps and auxiliary devices. The total price per month is assumed 50% lower than the indoor farm using LED. Other items in operating cost are assumed unchanged as shown in Table 6.
4. Since daylight is available only in the daytime, the productivity in this project could be less than the previous project by 50%. The number of units of vegetable for selling is then 50% reduction.

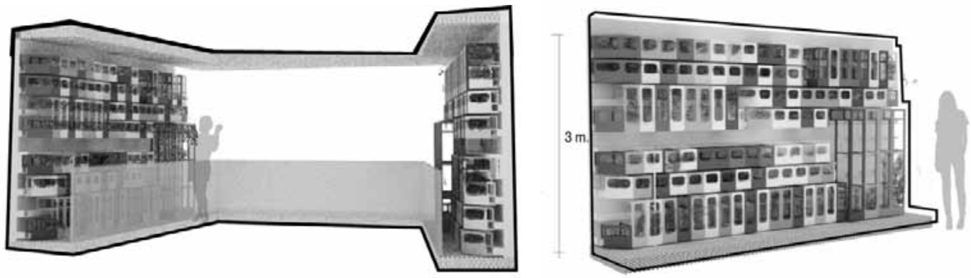


Figure 20. Planting modules attached to the wall.

5. The public amenities are calculated from (total salable area) x (amenities fee per m²). In this project the total salable area is 13,175 m² and amenities fee is 40 baht per m². The total revenue is shown in Table

7. Therefore, the payback period for hydroponic system using daylight is (61,744,410+2,769,974)/ 15,307,332 = 4.21 years. The hydroponic system using daylight contributes less income, required less capital and operating cost than the indoor farm using LED. The payback period of both systems are less than 5 years.

5. Conclusions

Currently, no high rise integrated with agriculture physically exist. However, there are roof top farms on the low-rise commercial and residential buildings. From survey, consumers who have healthy life styles shows the demand of consuming fresh fruits and vegetables together with meats. The consumers hesitate of growing plants by themselves, but they like dining in restaurants and shopping in convenient places such as supermarkets. The idea of growing and selling fruits and vegetables from residential buildings locating in city of Bangkok is investigated in two studied projects.

The mixed-used residential buildings with supermarket are proposed here. The typical technique of growing food crop without soil called hydroponics is applied in the agricultural farm in the buildings. The indoor farm using artificial lights and vertical farm using daylight in the proposed projects can produce sufficient food for residences and for selling. Consider only the farm investment cost and operating cost, selling farm products in supermarket paybacks within five years. Therefore, farm project in the high rise building is viable. However, the price per square meter of the residential unit are high due to high land cost in the city. This leads to the limitation in application to new buildings and targets to those with high incomes. However, this study does not consider the potential of retrofitting old buildings. The results of this study would be apply to cities in tropical climate with similar land, construction and labor cost as Bangkok.

Description	No. unit	Area (m²)	Price/m²	Total (baht)
Farm building		2,457	22,630	55,601,910
Farm equipment			2,500	6,142,500
			Total capital cost	61,744,410

Table 5. Capital cost of hydroponic system using daylight.

Description	No. unit	Price/unit (baht)	Total price/ month (baht)	Total/year (baht)
Labor salary	8 persons	12,000	96,000	1,152,000
Manager salary	2 persons	20,000	40,000	480,000
Liquid fertilizer		76	51,025	612,300
Water		1.97	1,327	15,924
Electricity		1.98	239,577	474,362
Seeds		35	2,949	35,388
		Total operation cost	**430,878**	**2,769,974**

Table 6. Operation cost of hydroponic system using daylight.

Description	No. unit	Price/unit (baht)	Total price/ month (baht)	Total/year (baht)
Sell vegetables	2,007	373	748,611	8,983,332
Public amenities fee	13,175	40	527,000	6,324,000
		Total revenue	**1,275,611**	**15,307,332**

Table 7. Total revenue of hydroponic system using daylight.

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