Improvement of office environment

Material flow in a farming-integrated office system

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Content

Abstract

Offices consume a lot of energy in the Netherland. In addition to the low energy efficiency, the office environment, and working style cause health problems. This research focuses on the farming-integrate office system and the flows in it, involving food, air, water, electricity, and heat. Taking Marineterrein as the site and use environmental database of Amsterdam, this paper proposed a suitable farming integrated office in Marineterrein and could act as a guideline for other offices to integrate farming in other cities.

Key words

Flow, BIA, Office, Urban farm, Energy, System

Introduction

Most full time workers in the Netherlands spend 7-8 hours per day in the office working and activities happening in office became an essential part of daily life. Usually, office building is highly modernized, using mechanical facilities such as HVAC to meet the requirement of temperature and fresh air and using computer to improve working efficiency. In this way, people inside an office is kept sitting in front of computer screen, movement in the closed space are limited into printing and eating in the restaurant. Even though this kind of working environment improve working efficiency, limited activities lead to health problems, such as low back disorder.[1] When people calling for healthy lifestyle, they ask for healthy work style at the same time.

Meanwhile, technical facilities lead to huge energy consumption in office buildings. From the government report last year, we found that for non-residential buildings, 30% of the national energy consumption comes from offices in Netherland[2].

In order to promote a healthier work style while improving the energy efficiency in old buildings, using an urban farming integration system could be a choice. Greenery could provide fresh air inside buildings and an integrated farm could provide space and potential for activities for office workers, a combination system could help increase energy efficiency.

Responding to the issues above, building integrated agriculture (BIA) was introduced by Ted Caplow. The BIA is a method which combines high-performance indoor farming with building environment into one integrated system. In order to design a BIA system, architectural design, system control, microclimate design and human behavior should be take into account simultaneously. The main issue in the BIA system is material flow, which determines the direction and form for energy-performance optimization, and this will influence final design ideas and architectural forms.

In this paper, the study focuses on the potential optimized material flows of indoor farms and existing buildings and the future integrated material flow system based on analysis on existing case

[1] Marras, W. S. (2000). Occupational low back disorder causation and control. *Ergonomics*, *43*(7), 880-902.
[2] ING Economics Department (2013). Saving Energy in the Netherlands- New EU Directive takes on Energy Efficiency

studies, data collection and the site situation.

1. Typical material flows in office and urban farm

Office and farm are two different programs which require diverse resources. In order to make it easy to make comparison, we need to find a standard for the two systems. The input and output of offices and farms varies in accordance to design and place. In this paper, the study focuses on typical farms and offices, identifying the main inputs and outputs are electricity, water, heat and air, and using an additional material flow of food which is related to the research as a supplement.

In order to establish a standard system for the research of office integrated farm, a controlled environment is being established. The standard area for both office and farm is 1000 square meters. Due to the standard office area in Amsterdam, 1000 square meters office will accommodate 41.67 people working inside[3]. Apart from area standard, local factors such as solar irradiance, quantity of rain water the food consumption data will be based on Amsterdam region as well.

Farming activities and energy consumption differs based on typology, location, climate and technology. Since Marineterrein is located in the center of Amsterdam, where land price is high and space is limited, this study focuses on vertical farming, due to its high yield-to-area ratio and relatively lowest material cost.[4] Due to lunch healthy food requirement and vertical farming space need, in the design we select leafy vegetables as main crops. The data in the farm research part is gathered mainly from the case study *skygreens* in Singapore, which is a vertical indoor farm[5]. Even though the climate is different to Amsterdam, where the graduation project will be located, the data of irrigation and electricity system could still be put in use. The indoor farming mostly relies on indoor climate, which is under computer control, so the outdoor climate has limited impact on where vertical farming located.

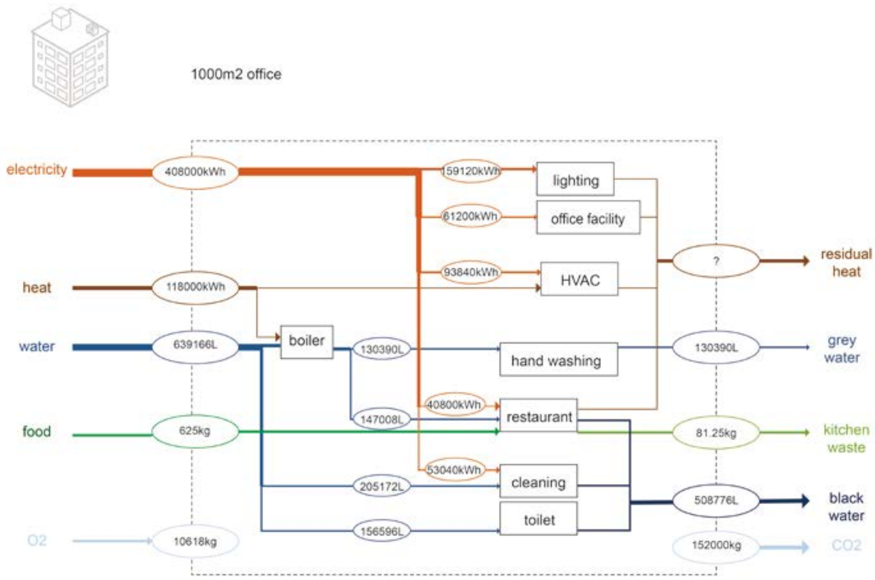

Figure 1. Existing material flow in the farm system

(typical vertical farm)

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[3] Voss, J. (2000). Revisiting office space Standards. *Grand Rapids, MI: Haworth*, 1-6.

[4] Martellozzo, F., Landry, J. S., Plouffe, D., Seufert, V., Rowhani, P., & Ramankutty, N. (2014). Urban agriculture: a global analysis of the space constraint to meet urban vegetable demand. *Environmental Research Letters*, *9*(6), 064025.

[5] https://www.skygreens.com/

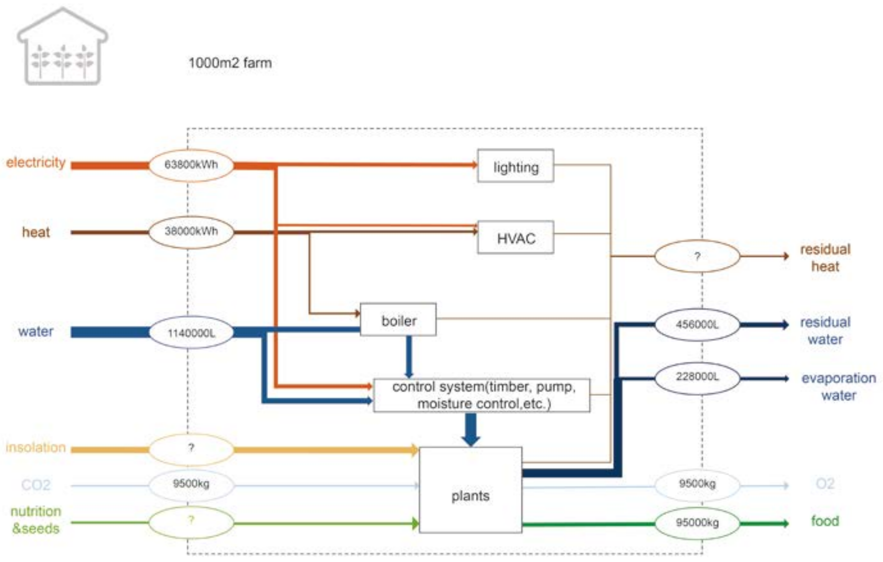

Figure 2. Existing material flow in the office system

The graph above shows the input and output material flows based on a given standard situation, and the main flows such as electricity, heat, water, air and food are calculated.

Even though farms and offices requires various facilities, only the main facilities and activities which relate to the program will be paid attention to. In farming system, the main components are facilities and the vegetables inside. Facilities include lighting, HVAC system, boiler, the temperature and irrigation control system. All of water, electricity, heat and CO_2 consumption and residual material such as residual water and O_2 are related to vegetable yield. While in offices, the electricity, heat and water consumption and residual material are mainly based on office area, the O_2 input relates to the number of people inside while the total output of CO_2 will add facility produced CO_2 on people's production together.

Among the listed categories, some data are not applicable to be qualified, such as residual heat and kitchen waste. Residual heat exists in the ventilated air and heat loss through wall, it varies due to different kinds of insulation material. But in the future circulation system, after the model has been decided we can approximately know the heat exchange between inside and outside. Kitchen waste mainly comes from food waste, which limits to the food consumption combining with farm vegetable production in the system. Since food waste is not the main topic and it has limited interaction on the whole system, limited attention would be paid in the project.

2. Existing studies on building integrated agriculture system

2.1 Building integrated agriculture system

The BIA (building-integrated agriculture system) is a way which introduces hydroponic greenhouse with a building. The concept was first referred by Ted Caplow in the paper *building-integrated greenhouse systems for low energy cooling* in 2007 Passive and Low Energy Cooling Conference in

Greece.[6] The techniques applies in the BIA system including HVAC (heating-ventilation-air condition system), rain water collection and hydroponic irrigation, waste heat reuse and the use of renewable energy, etc.

2.2 Case studies

Based on the BIA theory and technique development, there are some case studies that reveals how agriculture can be integrated with building.

Lufa Farms, Montreal, Canada

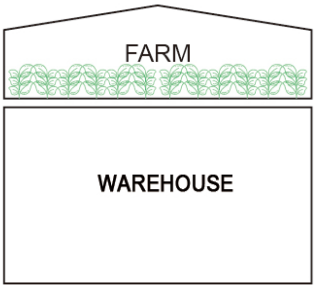

Figure 3. Typology of Lufa Farms

Figure 4. Lufa farm

Source: www.concretegarden.ca

The earliest way to realize BIA is to add a rooftop farm on buildings, which has the examples of Lufa Farms. This rooftop farm has 5850m^2 area, laying on top of an old Montreal warehouse. Using hydroponic technique, tomatoes, variety of leafy vegetables and eggplants grow inside the farm. The main design intention of rooftop production of Lufa Farms is based on the situation of farmland shortage and the need of local food production. As one of the earliest BIA example, Lufa Farms uses recycling water and sustainable energy to meet their slogan *'making cities more sustainable'*.[7]

Aeres Hogeschool, Dronten, The Netherlands

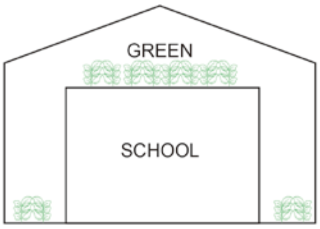

Figure 5. Typology of Aeres Hogeschool

Figure 6. Aeres Hogeschool

Source: www.dearchitect.nl

The project Aeres Hogeschool is an agricultural college. Even though in this project, the greens

[6] Caplow, T., & Nelkin, J. (2007). Building-integrated greenhouse systems for low energy cooling. In *2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century* (Vol. 1, pp. 172-176).

[7] https://montreal.lufa.com/en/

grows inside are trees for landscape decoration, the design meet ideas which BIA system promotes. In this project, architecture, sustainability and technology are integrated in a natural way. Compare to other sustainable buildings, using the integrated method can increase energy efficiency and decrease energy consumption without too much mechanical system. The space between 'greenhouse envelope' and the building inside functions as a buffer zone. In this space, outside air is generated and heated by sunlight, enables air ventilated through bottom to top. The zone also functions as a double-skin, with the plants inside purifying the interior air and at the same time benefiting from heat reservation of double-skin facade. The buffer zone is designed as a public space with stairs where students and teachers meet each other, providing a space for informal education such as debates and spontaneous discussions.

Urban Farming Office, Ho Chi Minh City, Vietnam

Figure 7. Typology of Urban Farming Office

Figure 8. Urban Farming Office
Source: www.votrongnghia.com/projects/urban-farming-office

The urban farming office designed by VTN architects is not a typical form of BIA system. The 1386 m^2 project is using simple modularized planter boxes, hanging on concrete structure and steel supporting frame. The boxes are replaceable and the kind of plants inside boxes is depend on the intensity of the sunlight. Edible plants are selected to provide 1.1 tons of food each year[8]. In this project, rain water is collected for irrigation. Water evaporation cools hot air and the openings of the building enhance cross ventilation.

Pasona Urban Farm, Tokyo, Japan

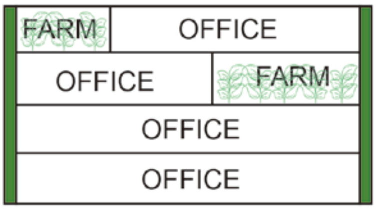

Figure 9. Typology of Pasona Urban Farm

Figure 10. Pasona Urban Farm
Source: www. inhabitat.com

The Pasona company did a renovation on a 50-year-old building in downtown Tokyo and made it

[8] www.votrongnghia.com/projects/urban-farming-office

into a combination of urban farm and eco office. Crops in the building grows in a hydroponic way throughout the entire building and this includes façade, public space, conference rooms and even ceiling. Varies crops grow under control system and office workers inside participate in the maintenance and harvest of crops. The BIA system promote ventilation and office air quality, improving energy efficiency and provide healthy food for employees.

The four cases above summarized typical kinds of BIA system. Even though each of them has their advantages, simply taking a type as my design draft is inappropriate. Based on these case studies, a new intervention will be created to fit my design in Marineterrein.

3. Intervention proposal and a new material flow

In traditional BIA system, the earliest example such as Lufa Farms only focus on farm itself and the energy flow in the system mainly focus on farm. While cases such as Pasona want to make a totally integrated system, the system mostly relies on mechanical way which consumes extra energy. Based on the BIA system case studies, extra electricity consumption is created by LED for crop growth. Extra water consumption is due to irrigation. And heat provided for farm and offices separately is unnecessary.

Based on the material flow model of 1000m^2 offices and farms, this research seeks to optimize the existing BIA system so as to fit the requirement of my graduation project.

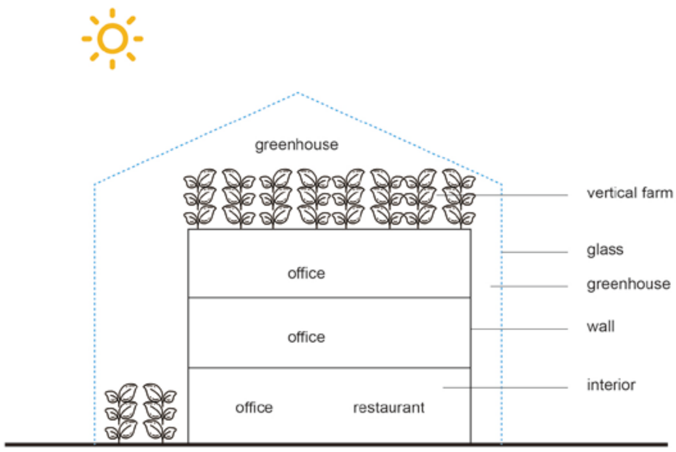

Figure 11. Typology and function

As the diagram shows above, I selected typology of Aeres Hogeschool as starting design draft. The greenhouse looks like an envelope which wraps around the office inside. Using limited mechanical system, office and farm can integrated as a whole which benefit each other. The main materials flow exchange between farm and office can be identified as water, air and others.

Water

In order to reduce water consumption in the system, studies of irrigation water was first take into consideration. As compared to traditional agriculture farming, hydroponic farming will allow a reduction of 12 Liter when a kilograms crop grows.[9] Meanwhile, studies shows that crops prefer acid water which pH varies from 5.5-6.5. (Appendix 2) So the rainwater (average pH 5.6) is suitable for irrigation in this way. When rainwater is collected, after physical purification, the water quality will be suitable for irrigation.[10] Around 20% of the irrigated water will evaporate and 40% of the irrigated water remains reusable.[11]

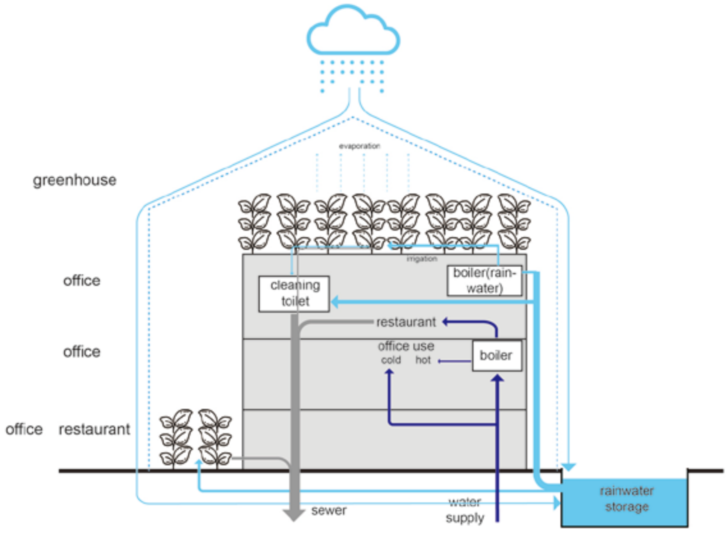

Figure 12. Water flow

When it comes to office water consumption, water usage can be divided into cleaning, toilet, hand washing and restaurant usage. Only non-potable water quality is limited into drinking water which need tap water while others could use purified rainwater. The ratio of restaurant water usage among total water consumption is 23%.[12]

Considering the situation above, the purified rain water will be separated for both irrigation and office use. The reusable water from irrigation could also be used in the office. In order to make a balance between the two water consumption, the ratio of farming area and office will be decided later on.

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[9] Khoo Hong Meng, Sky Urban Solutions: Vertical Farming, An Urban Agriculture Solution, Nanyang Technoprenuership Center

[10] Schröder, F. G., & Lieth, J. H. (2002). Irrigation control in hydroponics. *Hydroponic production of vegetables and ornamentals*, 263-298.

[11] Kozai, T., Niu, G., & Takagaki, M. (Eds.). (2015). *Plant factory: an indoor vertical farming system for efficient quality food production*. Academic Press.

[12] Zadeh, S., Lombardi, R., Hunt, D., & Rogers, C. (2012). Greywater Recycling Systems in Urban Mixed-Use Regeneration Areas: Economic Analysis and Water Saving Potential. In *Second World Sustainability Forum* (pp. 1-18).

Air

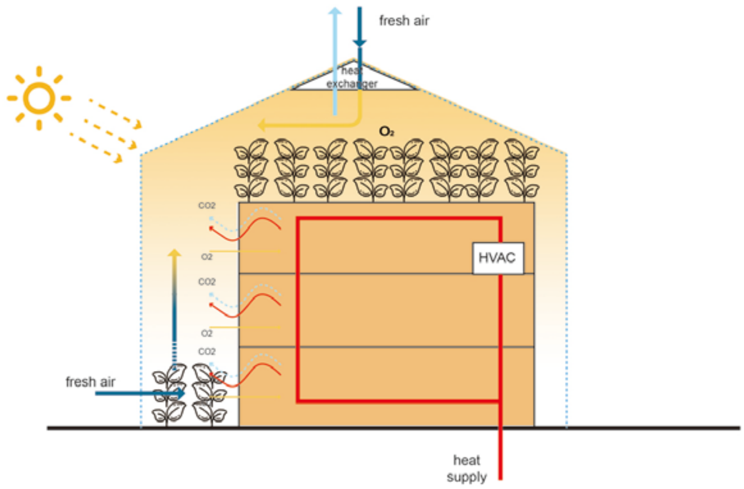


Figure 13.Air and heat flow, winter

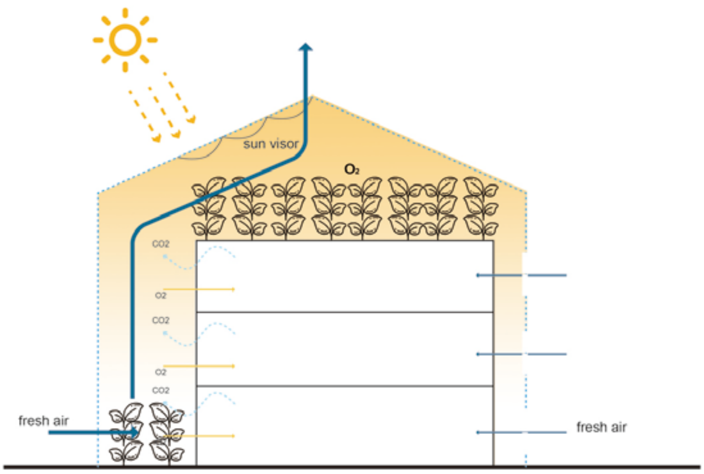


Figure 14.Air and heat flow,summer

The buffer zone between office and farm functions as a thick double-skin façade. The façade will reduce heat exchange between inside building and outside air.

In winter, heating is the main task. Cold air from outside will be heated by sunlight and heating system, then move upwards and ventilated to outside by heat exchanger. The mechanical heat exchanger on rooftop will preheat cold air from outside using heat air inside. The HVAC system would help control farm area temperature. Due to natural ventilation, the temperature of ground and rooftop varies by 2° which allowing the growth of different kinds of vegetables. The average temperature in the greenhouse will be maintained at 18° (Appendix 2). According to United States Pharmacopeia--National Formulary, the most suitable room temperature for human is 20-25°. Compare to traditional office heating, the preheated air in the greenhouse only needs to be heated by around 5° to meet human requirement. In this way, heat consumption will be reduced in the integrated system.

In summer, fresh cold air come into the building and after getting heated by sunlight, it will move upwards before being released to the surroundings through rooftop opening of the greenhouse. Natural ventilation will be enhanced in this way. Sun visors will be used in order to prevent too much sunlight.

In both summer and winter, openings from the office will allow the CO_2 produced by office workers and office facilities to be used for vegetable growth in greenhouse. Meanwhile, the O_2 produced by plant photosynthesis contribute to a better indoor air quality in offices.

Others

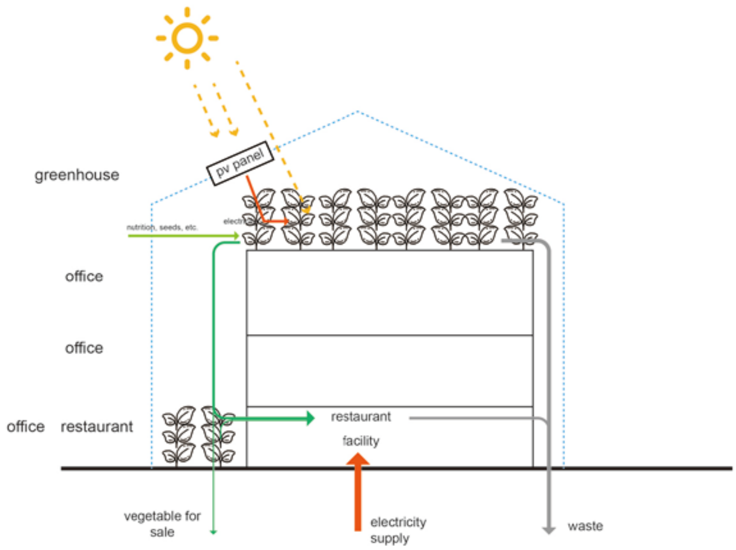


Figure 15. Other flow

Putting PV panels on rooftop could provide extra electricity for the whole building. The vegetables produced in the farm will meet daily need of employees of offices while the extra vegetables will sell to restaurant nearby.

4. Architectural design

Considering of office shortage situation in Amsterdam and surrounding environment analysis, the most suitable size of office is 2400m^2, containing 100 office workers inside. Based on the 1000m^2 standard area flow calculation and analysis of the ideal typology of my design, the farm area will be 800m^2-1000 m^2. In order to make it easy to calculate, the area of farm is set as 860 m^2 and the whole land area will be 2300m^2. The below diagram shows the existing flow of 2400m^2 office and 860m^2 shows based on the Marineterrein situation.

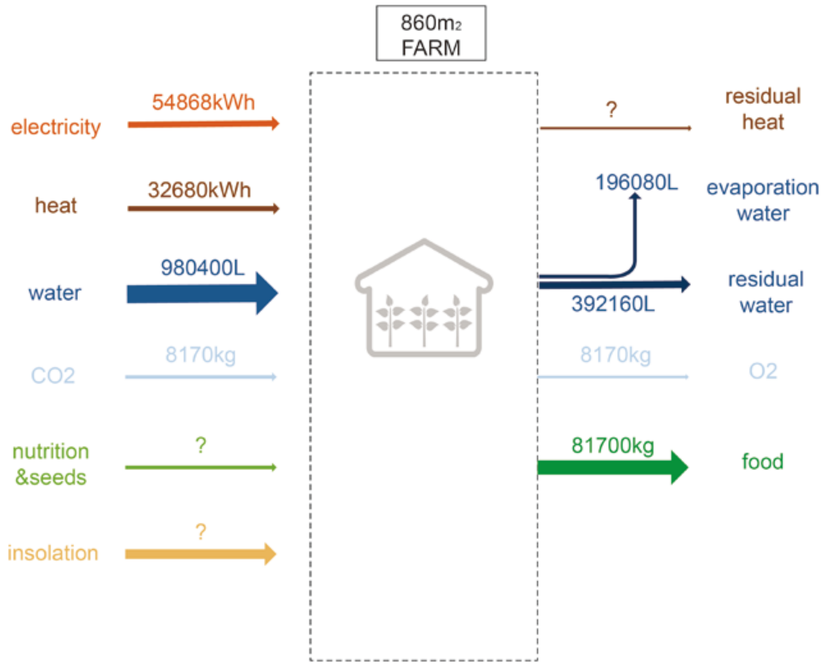


Figure 16.Flow based on Amsterdam situation, farm

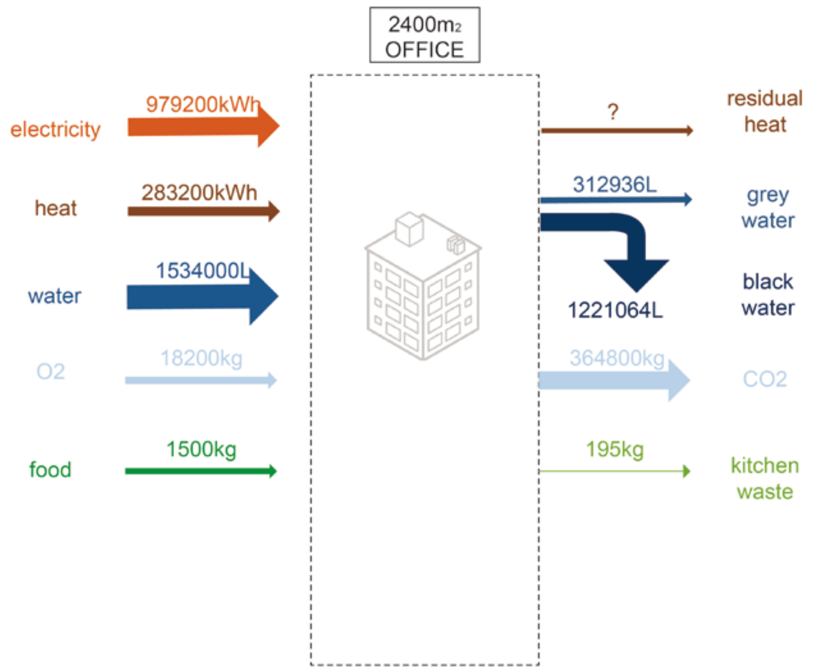


Figure 17.Flow based on Amsterdam situation,office

4.1 New ideal material flow model

The diagram below shows the ideal flow of the future farm integrated office system, using the same environmental condition as chapter 1. In this ideal flow, all electricity supply will be produced by PV panels. Tap water will only be used in restaurant and drinking while purified rain water will be used for irrigation and other activities such as toilet, cleaning and hand washing in office. Average temperature in farm is 18° and the average temperature in office is 23°.

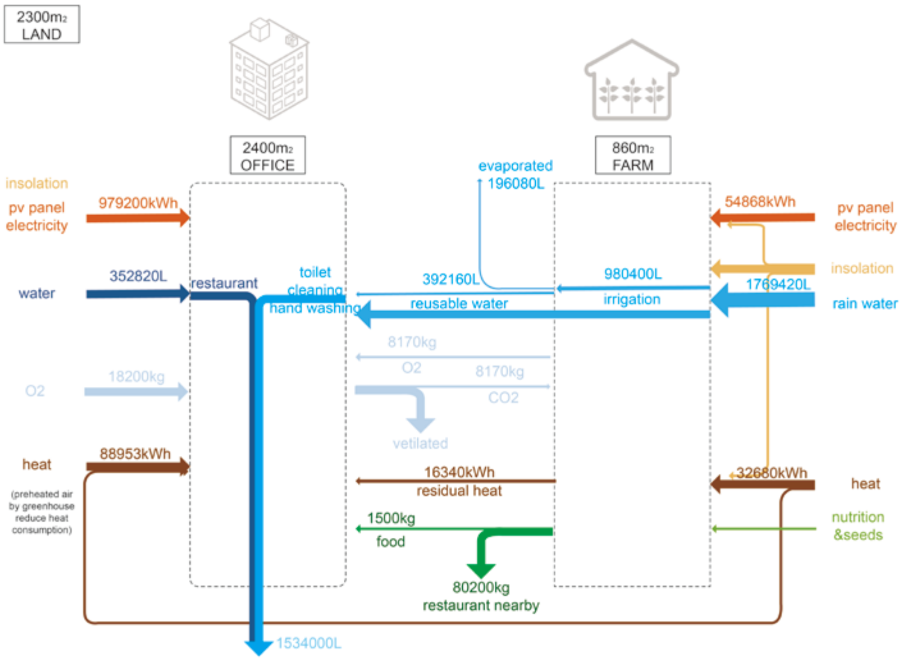
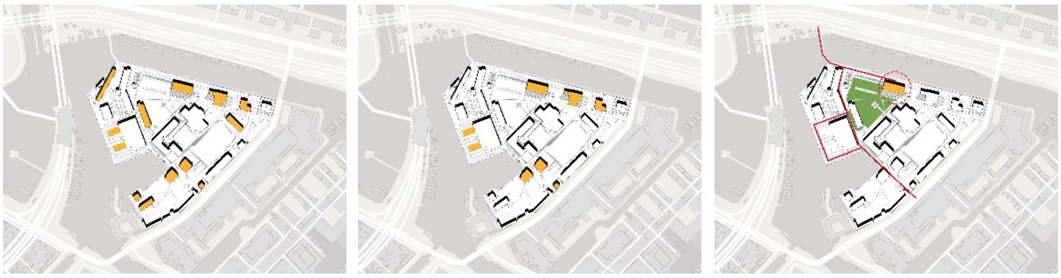


Figure 18. Ideal flow in the combination system

4.2 In the context of Marineterrein, Amsterdam

The Marineterrein area is an 'island' in the east side of center of Amsterdam. The site was used by Dutch Royal Navy. From 2015, the Navy is leaving the area progressively and that it will have a public function for the city.[13] The river surround Marineterrein are is now facing with water pollution problem. The main reason is in rain season, too much runoff would spread to overloaded sewage discharge pipe and the mixed sewage would spread to the surrounding water. Also, many vacant buildings in Marineterrein need to be renovated and occupied later on. In order to develop my project based on building renovation, the selected building should meet specific requirements in terms of area, orientation and easy to reach.

[13] https://www.marineterrein.nl



Step1. Area<2400m^2 step 2. South facing building   step3.Easy to reach & south vacant area

Figure 19. Building selection process

The first requirement is area. The inside office area is decided as 2400m^2 so the target building should be around or less than 2400m^2 . In the next design step, extra area could be added on existing buildings. Otherwise, the only way to meet area requirement is demolishing extra area on existing building, which will lead to unnecessary waste.

The next step to start design is vegetable selection. Considering that most of employees only have lunch at office, so vegetables which could be mixed into salad is preferred. Meanwhile, cultivation techniques and the growth speed should be taken into account. Cucumber, tomato, lettuce, kale and strawberry are 5 of the most suitable hydroponically grown crops, in terms of their requirements of temperature, moisture and irrigation, which is easy to be satisfied in Marineterrein area in Amsterdam (Appendix 2).

The orientation of selected building is crucial. The ideal orientation of the existing building is south facing. It is preferred that the south part of the building is vacant so that the sunlight in greenhouse would not be interfered by other buildings or trees. For an office building, the accessibility from station and main roads is also important.

Finally, the target building is No.040. The building is a 1 floor truck parking garage with total area of 1300m^2. The orientation of the building is almost south facing and the south of the building is a park. It is close to a bridge which connect to Amsterdam central station.

Based on the selected building and other conditions, a rough flow of material future is calculated in the diagram below.

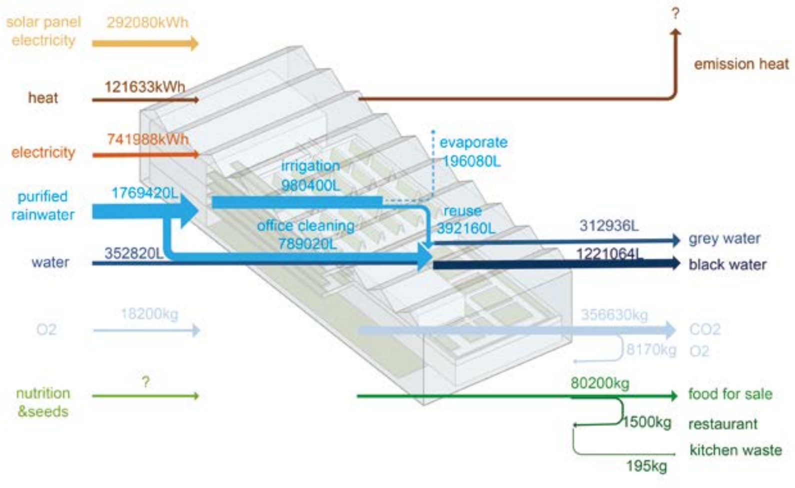


Figure 20. Future flow in design project

The average sunlight hours In Amsterdam is 1662 hours per year.[14] Each PV panel could produce 0.29kWh/piece per hour[15] and the size of PV panel is 1.65m^2.[16] In order to meet electricity requirement, the system need 3540m^2 area for PV panel, which is hard to achieve. Hence, for the design project in Marineterrein, the electricity production system will be modified. According to the rooftop area of selected building and the conceptual design tentative, the possible area for PV panel is 1000m^2, which will produce sufficient electricity to meet all of the farm electricity requirements and a part of office electricity use.

5. Conclusion

Designers are trying many ways to provide better office environment. In the trend of design a sustainable building, people are struggling with techniques to improve energy efficiency. The farm-integrate office system is one of the attempt that meet the two requirement.

When compare the energy usage in the independent office and farm model and the farming-integrated office model, the energy efficiency increased a lot in using renewable energy combined with recycling technology. At the same time, by collecting rainwater in rainy days, especially in the rain season, rainwater could be stored in the tank and then be used for irrigation and office cleaning. In this way, the surface runoff will be reduced so as to deal with water pollution in Marineterrein area. This farming-integrated office system also provide more activities in the office and promote a healthier workstyle. In a word, integrate farming into office is beneficial for food, water, electricity, heat, and air.

[14] https://www.currentresults.com/Weather/Netherlands/sunshine-annual-average.php
[15] https://news.energysage.com/what-is-the-power-output-of-a-solar-panel/
[16] https://www.solarpowerrocks.com/solar-basics/how-much-electricity-does-a-solar-panel-produce/

The humidity and temperature of the indoor vertical farming are under computer control. This determines farming would not be affected by the outside climate. So the farming-integrate office prototype will be not only suitable for Marineterrein area in Amsterdam but could also be suitable for office needs in other cities around the world according to the local circumstance.

Appendix 1. Parameters used in flow calculation in Chapter 1

	L	mm	m2	m	kg	kWh	ppl			source
ppl							100			
rainfall,amsterdam		766mm/m2								http://www.amsterdam.climatemps.com/precipitation.php
area			2300m2							
reusable water rate(farm)									40%	Toyoki Kozai, Genhua Niu, Michiko Takagaki, Plant Factory: An Indoor Vertical Farming System for Efficient Quality
evaporation rate(farm)									20%	Food Production, p70, figure 4.4, Academic Press, 2 Oct 2015
rain water collection	1225600L									
office water consumption	59L/ppl/working day									water use in your business, advice&tips for saving water, *south staffs water*
farm water concumption	12L/kg									Sky urban solutions vertical farming-an urban agriculture solution, *Khoo Hong Meng*
water use ratio in office										Greywater Recycling Systems in Urban Mixed-Use Regeneration Areas: Economic Analysis and Water Saving Potential, *Sara Zadeh, Rachel Lombardi, Dexter Hunt and Christopher Rogers*
office area in ams/ppl			24m2							Revisiting Office Space Standards, *Judy Voss*
office electricity use						408kWh/m2				Energy consumption guide 19 ,best practice programme
farm electricity consumption						63.8kWh/m2				R.J. Worrall, The effect of irrigation water temperature on the generation and growth of plants, ActaHortic.1978.79.16
sunshine amsterdam/yr									1662hrs	https://www.currentresults.com/Weather/Netherlands/sunshine-annual-average.php
solar panel size			1.65m2							https://www.solarpowerrocks.com/solar-basics/how-much-electricity-does-a-solar-panel-produce/
solar panel electricity production						0.29kWh/piece				https://news.energysage.com/what-is-the-power-output-of-a-solar-panel/
vegetable consumption/ppl					45kg/yr					Food consumption in the Netherlands and its determinants,Background report to 'What's on our plate? Safe, healthy and sustainable diets in the Netherlands.'
vegetable general production					95kg/m2					Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics
CO2 production in					152kg/m2					Energy consumption guide 19 ,best practice programme
o2 consumption/ppl					0.7kg					How many pounds of oxygen do we 'eat'each day? *Joseph Engelberg*
o2 produced by photosynthesis									1/10 of crop weight	6CO2+6H2O=C6H12O6+6O2
co2 consumed by photosynthesis									1/10 of crop weight	http://www.lessco2.es/pdfs/noticias/ponencia_cisc_ingles.pdf
office heat						118kWh/m2				SenterNovem
farm heat consumption						38kWh/m2				Comparison of Energy Needed to Heat Greenhouses and Insulated Frame Buildings Used in Aquaculture1, *P. A. Fowler, R. A. Bucklin, C. D. Baird, F. A. Chapman, and C. A. Watson*
suitable temperature for human									15-25℃	

Appendix 2. Parameters of vegetable in design project

vegetable grow	production	light	temperature	harvest time	moisture	PH		
cucumber	11.1kg per plant	sunlight>8h	18℃-27℃	35day	moderate humidity	5.5-6.0	Cucumbers benefit from CO2 enrichment	https://luv2garden.com/hydroponic_cucumbers.html
strawberry	54,000 pounds of strawberries per acre	sunlight>6h	18℃-24℃	12 months corping	low humidity	5.5-6.0	bees ?	https://luv2garden.com/hydroponic_strawberries.html https://www.greentechmedia.com/articles/read/the-farm-of-the-future-will-grow-plants-vertically-and-hydroponically#gs.u4GobVA
tomato	70 to 90 kg/m2/y	8-10h	18℃-25℃	11 month corping	50%-70%	5.8-6.3	Bumblebees	https://ag.purdue.edu/hla/fruitveg/Presentations/Hydroponic%20Tomato%20Production%20in%20Soilless%20Culture_February%2013_%202018_Petrus%20Langenhoven.pdf https://www.greenandvibrant.com/grow-hydroponic-tomatoes
lettuce	leefy vegetable	10-14h	16℃-18℃	45-55days	60%-70%	5.5-6.5	LEED	Vertical farming increases lettuce yield per unit area compared to conventional horizontal hydroponics http://www.nosoilsolutions.com/how-to-grow-hydroponic-lettuce/
kale	leefy vegetable	6-10h	4℃-18℃	20-30days(baby) 60-80days(mature)	50%-70%	5.5-6.5		https://luv2garden.com/hydroponic_kale.html https://gpnmag.com/article/growing-hydroponic-leafy-greens/

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[1] Marras, W. S. (2000). Occupational low back disorder causation and control. *Ergonomics*, *43*(7), 880-902.

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