FARMHAL
High-efficient material flow in a building integrated agriculture system based on existing building stocks, theory and application

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Content

Introduction

Housing shortage, wasted vacant buildings and sustainable food production are part of the various issues that populated cities are facing nowadays. Living and farming used to be a common mode of human's life while modern urban populations are generally away from the production of food that is consumed on a daily base. The separation of farm and live is determined by the high land value of urban space and modern industrialized food production based on vast rural area. It is an inevitable result of urbanization but also brings the concern of food safety and the estrangement between food and citizens. At the same time, vacant buildings with insufficient physical performance are considered a waste of urban space in contrast with the severe housing shortage in big cities such as Amsterdam.

Responding to the issues above, researches and practices have been done in the realm of building integrated agriculture (BIA) which combines high-performance indoor farming with the building environment in one synergetic system. BIA uses spared building space such as rooftop for farming, together with the complementary material exchanges between farm and building, to realize the maximum of resources utilization. In addition, introducing farming in the building environment also contributes to a better psychological health of residents as well as agricultural education to the public.

The design of a building integrated agriculture system is complicated which includes architectural design, microclimate control, indoor agriculture, food management, human behavior, etc. Among various knowledge required, the complementary material flow between the building environment and the indoor farming is one of the key perspectives.

Material flows in building environments are diverse according to the functions. Among various building types, the dwelling is with one of the most rigid demands in the cities and occupies approximately 55% of energy consumption in architecture. Thus the combination of farm and dwelling could be a promising energy-saving solution to be applied widely in the urban area. Meanwhile, based on existing studies, BIA has a great potential in improving the performance of existing buildings stocks as a renovation option.

In this paper, the study focuses on the potential material exchanges between indoor farms and existing buildings which is or will be developed for residential use. Based on the material flow, an architectural model, Farmhal[1], is proposed as an example of possible interventions. Further on, a workflow is constructed for the assessment of existing buildings which could be suitable for the proposed intervention. The assessment includes the renovation requirements, future energy reduction, investment and earnings based on computer simulations, business plan and local factors.

In addition, the study of material flow in building environment is closely related to the heat and air-fluid which requires specialized physical knowledge for accurate simulation and calculation. In this study, figures are collected through the analysis of existing researches and cases instead of original scientific examinations.

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[1] In this paper, Farmhal is referring to the building integrated agriculture solution proposed for building renovation

1. Typical Material Flows in Dwellings and Urban Farms

1.1-Model Description

Prior to the study of potential material flows between dwellings and farms, housing and farming are two different programs which require diverse resources. In this section, the study focuses on the inputs and outputs of typical dwellings and greenhouse farms respectively. The material flows in dwellings and farms in real life are various while it is still possible to be summarized in a synthetic model. To quantify each parameter and establish a comparable standard for two programs, several conditions are given for quantitative calculations.

Hypothetical models of a greenhouse farm and a dwelling are set with the same area of 1000 square meters with different heights according to the common situations. Apart from the, local factors such as rainfall, solar irradiance, average living space, average food consumption are based on the data of the Amsterdam region. (In this paper, all quantified calculations are based on the conditions in the model description.)

	Floor Height/m	Area/m²	Floor	Location
Farm	5	1000	1	Amsterdam, NL
Dwelling	3			

Table 1

The yield of a greenhouse can be extremely diverse according to the cultivating techniques and crops. Considering the high land value and food demand in urban area, in this study the farm is prescribed as a vertical farming system which is with high yield-to-area ratio and low material cost. In most vertical farms, leafy green is the major product due to its low space occupation, high economic and freshness value. A quantified material flow of the farm is based on the data collected from a constructed indoor vertical farm, *SkyGreens* in Singapore[2]. Though the weather of Singapore is very different from Amsterdam, where the model is hypothetically located, the data availability is relatively comprehensive compared to case references in the Netherlands. Since indoor farming is a controlled-environment agriculture technology, the climate impact on the yield and the water usage is little while the energy consumption for climate control varies according to the weather.

In this paper, the quantified material flow in the farm and the dwelling only works as a brief model for preliminary research. Specific calculations need to be done for further study in future.

1.2-Respective Material Flows in Indoor Vertical Farming and Dwelling

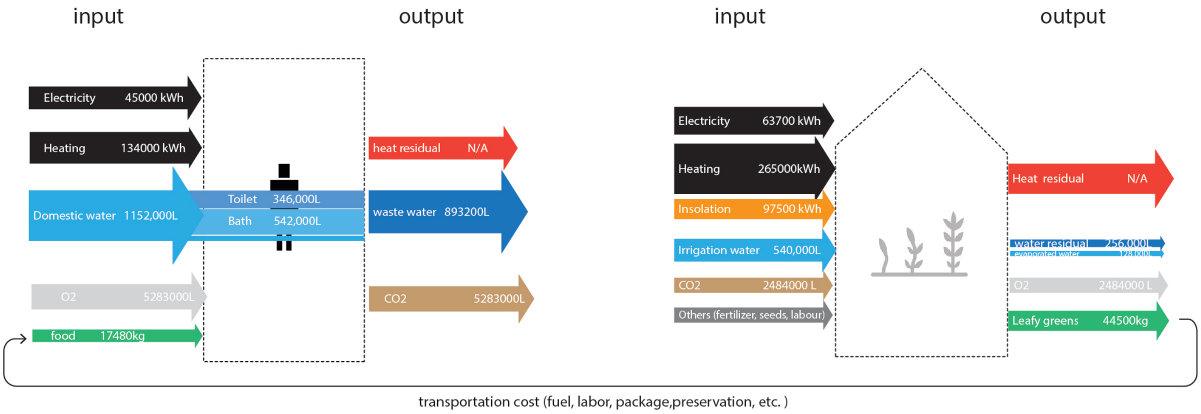

Figure 1. Existing material flow in the dwelling (left) and the greenhouse farm (right)

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2 https://www.skygreens.com/

Based on pre-set conditions, material flows in the farm and the dwelling are calculated, including water, energy, heat, air, food and solid waste. The graph above shows the input and output materials in the hypothetical models.

Among the listed categories, residual heat is the figure which is not applicable to be quantified at this stage. Residual heat exists in the ventilated air and heat loss through the external wall. It is related to various factors that require professional simulations based on specific building models.

In a comparison of material flows in two building environments above, many categories play major occupancies in both while the quantities are diverse. In the dwelling, water consumption reaches a tremendously 1152,000 liters followed by energy for heating of 134,000 kWh. The water consumption is mainly composed of flushing water for toilets and hot water for shower. In the farm, the heating cost is 265,000kWh, double amount of the dwelling's. And the irrigation water usage is less, 640,000 liters. Considering the fact that dwellings in urban area are commonly multi-floors, the heating energy cost for an apartment could be way higher than a same size farm in real life. In terms of air, residents in the dwelling require fresh air with 5283,000 liters oxygen and produce 5283,000 liters CO_2, while plants need 2484,000 liters of CO_2 and emit 2484,000 liters oxygen.

In summary, many material flows are overlapping or complementary in the farm and the dwelling. The potential behind the integration of two systems is positive while the quantitative calculation is crucial when measuring the feasibility under specific situations.

2. Existing studies and practices on building integrated agriculture system

2.1 Building integrated agriculture system

Studies on the material exchange between the building and the indoor farming have already been conducted in the profession of agriculture, represented by the concept of BIA (building integrated agriculture). BIA was first used to describe a complementary farm and building system by Ted Caplow in *Building-integrated greenhouse systems for low energy cooling*[3]. Based on model simulations, Ted concluded that the combination of a building and a hydroponic greenhouse could yield net energy savings compared to conventional air conditioning and green roofs.

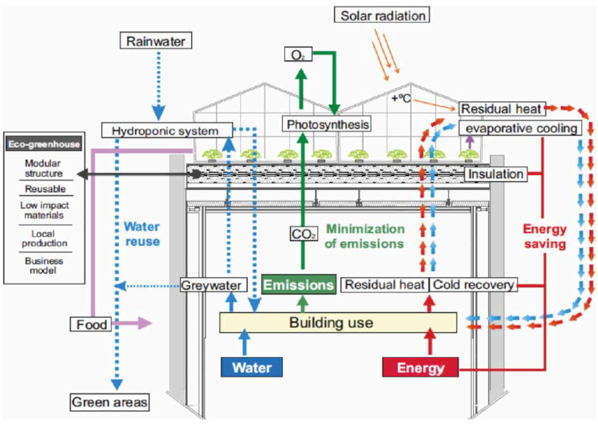

Figure 2*. Conceptualization and material flow of an IRTG system, source in the footnote

[3] Ted Caplow , *Building-integrated greenhouse systems for low energy cooling* , 2nd PALENC Conference and 28th AIVC Conference on Building Low Energy Cooling and Advanced Ventilation Technologies in the 21st Century, September 2007, Crete island, Greece

[*] Figure2. Ileana Cerón-Palma , Esther Sanyé-Mengual , Jordi Oliver-Solà , Juan-Ignacio Montero & Joan Rieradevall (2012) Barriers and Opportunities Regarding the Implementation of Rooftop Eco.Greenhouses (RTEG) in Mediterranean Cities of Europe, Journal of Urban Technology

Typically, a BIA system is realized by adding a rooftop greenhouses on buildings, named RTEG(rooftop eco greenhouse) or iRTG(integrated rooftop greenhouse). Technologies employed in a BIA system include rainwater collection, recirculating hydroponics, evaporation cooling, waste heat recovery from building HVAC system, etc. Overall, the major concerns in a BIA system are circulating use of water, residual heat recovery, passive cooling, O_2 and CO_2 exchange.

2.2 Case study

The strategy of BIA has been applied in practices prior to the proposal of the concept. The following two cases revealed how BIA works in the building environment from agricultural and architectural perspectives.

The Vinegar Factory, New York, USA[4]

Figure 3. The Vinegar Factory, Left: outside the factory, from www.ryerson.ca;
Right: basic material exchange between the rooftop farm and the market

The 1800 m^2 rooftop greenhouse of the Vinegar Factory in New York is one of the earliest commercial BIA projects. While the greenhouse looks resemble to many urban rooftop farms, the determinant distinction of a BIA farm is whether material exchanges exist between the farm and the building beneath. In the Vinegar Factory, residual heat produced from the pastry ovens is harvested and delivered into the greenhouse to maintain the ideal temperature for farming. Since the Vinegar Factory is functioned a marketplace, food produced in the farm is directly sold or reprocessed in the same building, which result in less environmental impact in both the production and selling process.

Glazen Aeres Hogeschool, Dronten, NL [5]

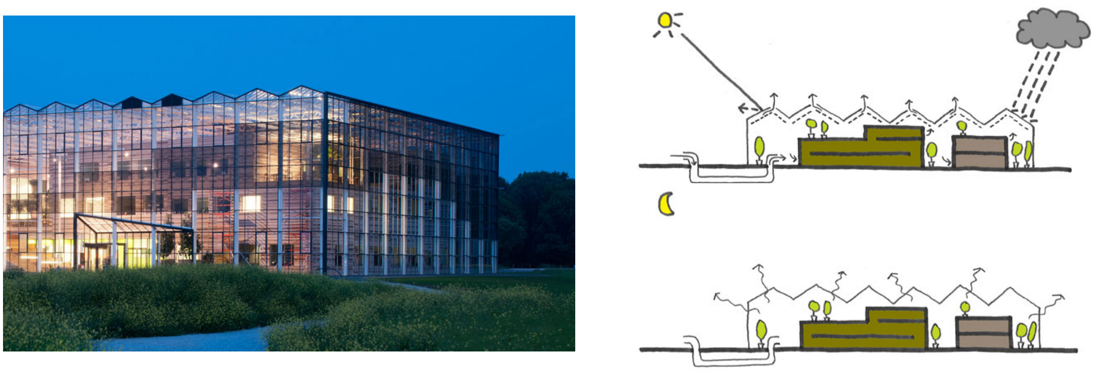

Figure 4. Glazen Aeres Hogeschool, Left: outside the building, from www.ryerson.ca;
Right: Air and heat flow in the building, day and night

[4] The Vinegar Factory, New York, http://www.elizabar.com/The-Vinegar-Factory.aspx
[5] Glazen Aeres Hogeschool, Dronten, NL, https://www.bdgarchitecten.nl/projecten/cah/

Though Glasses Aeres Hogeschool in Dronten is not an agriculture integrated project, it conducts many principles that BIA system promotes. The building is composed of an interior building and a transparent envelope which works similar to a greenhouse. The buffering zone between rooms and greenhouse envelope enables hot air to flow from the bottom to the top, forming a passive cooling ventilation system with openings on the roof. Plants in the buffering zone also purify and cool down the interior air through photosynthesis and evapotranspiration. Similar to a double-skin faced, air in the buffering zone partially plays as a heat reservation medium. In this case, interior walls do not need to be fully insulated to satisfy the desired thermal performance which saves building materials and enables flexible room configurations in future.

The two cases above utilize the material exchange in different environments with diverse approaches. However, neither of the cases have taken full advantage the potential material flows of an building integrated agriculture system. In the next chapter, an intervention proposal is made based on existing studies and practices to explore a high-efficient BIA model.

3. Intervention proposal and new material flow

3.1 Farmhal, greenhouse envelope and rooftop farming

In conventional rooftop farms, the greenhouse performs as a separated environment from the building beneath. Though materials such as residual heat and water are harvested and transported between the building and the greenhouse, the process relies on mechanical equipment which consumes extra energy to run. At the same time, while the greenhouse contributes to a better thermal performance of the rooftop, building facades are out of protection and have to rely on self-insulation. It could be a problem when the added greenhouse is on an old building with poor insulation, that the benefit of a BIA system can be little compared to the existing high energy cost.

In order to make the most of complementary material flow in a BIA system as well as optimize overall building performance of existing stocks, a model is proposed as an integration of precedent practices. As is shown in the diagram below, a conventional rooftop greenhouse is expanded into an envelope that covers the entire building. While the envelope works as a weather boundary for the indoor farming, it also creates a buffering zone where air could naturally flow with little mechanical control. Material exchanges in this model can be categorized into three, water, heat & air, others. These categories work in diverse ways and are also closely related to each other.

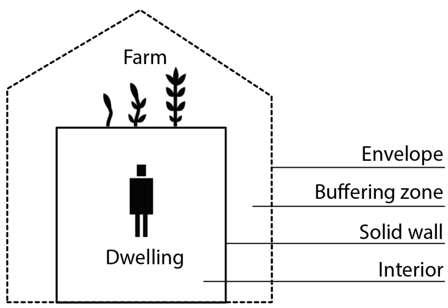

Figure 5
Conceptualization of a Farmhal system and definitions

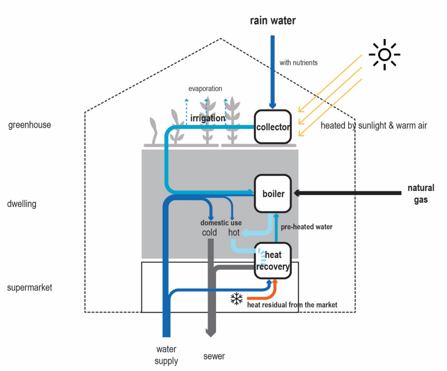

Figure 6
Water flow in the Farmhal

Water
The water flow starts with rainwater collection. Studies have shown that plants have a preference for weak acid water (pH5.5-6.5) which makes rainwater(average pH5.6) a better irrigation source compared to tap water (average pH7). Also, many economic crops, such as tomato and spinach, are with better growth when irrigated by warm water range from 15 to 25 ℃[6]. So the rainwater will be collected in the rooftop tank and pre-heated by the sunlight and indoor air before being used for irrigation. In the previous calculation, the amount of rainwater is abundant enough to satisfy the irrigation demand with some surplus in the case of Amsterdam, approximately 766,000 liters per year. Around 20%[7] of the irrigated water will be evaporated into the air with a cooling effect. Besides, another 7%[6] will be absorbed by the crops and 40%[6] remains as the reusable water. Filtered and cleaned by the plants, the remaining 40% water residual could be used for toilet flush in the dwelling which occupies 28%[8] of domestic water usage.

Heat & Air
Heat, which exists in various mediums such as air and water, flows in a complex way in the building environment according to room configurations, walls, openings, etc. Generally, since the warmer air tends to move upwards, heat is gathered in the greenhouse before being released to the exterior. The table below shows different temperature demands in the building environment. Since heat transfers from the high to the low, residual heat from high-temperature medium could be utilized by others with lower temperature demand.

	irrigation water	shower water	heating water	dwelling summer	dwelling winter	farm, day	farm, night
temperature/ °C	15-25	38-40	40-60	23-26	20-24	25-30	15-25

Table 2. Temperature requirmentss in the dwelling and the greenhouse farm

In summer, cooling and ventilation are the major concerns. During the daytime, air in the buffering zone is heated by the sunlight and prevent the solar irradiance from reaching the interior directly. With openings on the roof and the bottom facade, a natural air movement is formulated, bringing cool fresh air from the ground floor up to the rooftop farm. Heat ventilated from the dwelling is also gathered through the air lifting and transported to planting area. In the evening, heat stored by the solid wall during the daytime is released to the buffering zone which provides extra heating for the farm.

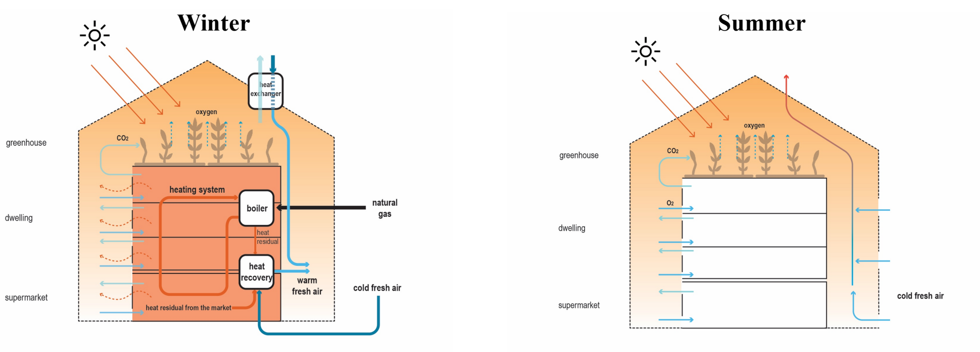

Figure 7. Heat and air flow in the Farmhal, left: winter heating mode, right: summer cooling mode

6 R.J. Worrall, The effect of irrigation water temperature on the generation and growth of plants, ActaHortic.1978.79.16
7 Toyoki Kozai, Genhua Niu, Michiko Takagaki, Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production, p70, figure 4.4, Academic Press, 2 Oct 2015
8 Dutch Drink water statistics 2015, Vewin, Association of Dutch Water Companies

In winter, when heating becomes the main task, natural ventilation continues inside in the greenhouse envelop while the air exchange with the exterior is controlled mechanically. First, interior air is heated by the heating system and released to the buffering zone through natural or mechanical ventilation. During the daytime, while the sunlight keeps heating the buffering zone, ventilated air from the interior also contributes to the warming of the rooftop farm. At the same time, the heated buffering zone works similar to a double-skin façade by providing a sealed cavity，which reduces the interior heat loss. In terms of air flow with the exterior, a heat exchanger is installed on the roof to preheat the cold fresh air with warm air indoor. Then preheated air will be further heated by travelling through the dwelling and be released to the buffering zone on the ground floor.

Extra heat could also be obtained from the shower drain using a heat recovery system. Drain water from the shower is around 32 degrees which contain enough energy to preheat the cold fresh air in the winter or rainwater for irrigation.

Other than heat, important gases such as O_2 and CO_2 are also part of the air flow. For indoor farming, a proper CO_2 level is essential in the growth of crops. Conventionally, CO_2 is produced by CHP[9] installations using natural gas as the energy source. In the Farmhal model, CO_2 produced by the residents works as a supplement for the farm's CO_2 supply through the ventilation. At the same time, fresh oxygen generated by plants' photosynthesis also contribute to a better air quality of the entire building.

-Others (solar power and ground floor market)
During the summer, less heat from the sunlight is wanted while the visible light is in need for rooftop farming. Advanced transparent solar cell TLSC[10] has been invented to capture only infrared and ultraviolet ray, where most heat is embodied in the sunlight, for electricity generation. By applying TLSC in the envelope roof, electricity will be generated for night time farm lighting, heat is blocked from entering the indoor environment and visible spectrum is retained for lighting.

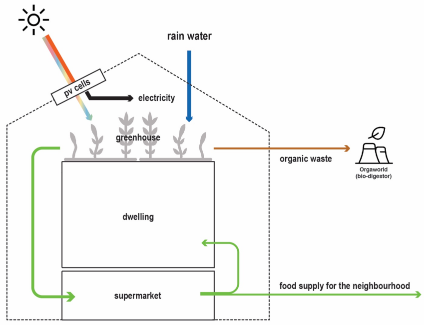

Figure 8. Other possible flows

In addition, by combining the dwelling with a food market in the ground floor, vegetables produced in the rooftop farm could be sold directly in place. Thus a mental connection between the farm and the residents is built and the cost of food transportation is reduced. Residual heat from the market could also be integrated into the heat recovery system of the entire building.

[9] combined heat and power, https://en.wikipedia.org/wiki/Cogeneration
[10] transparent luminescent solar concentrator

3.2 New material flow in proposed BIA model

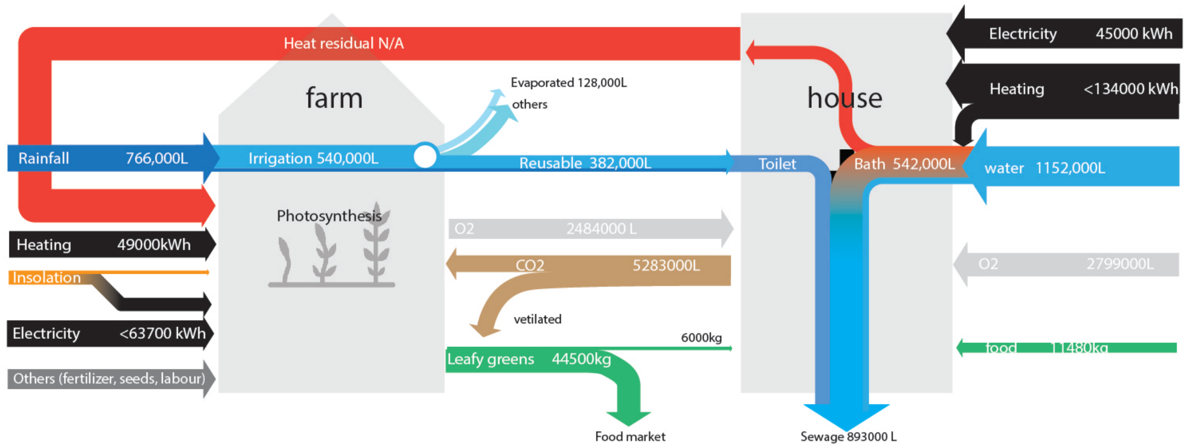

Figure 9. New material flow in the Farmhal system,
(*residual heat requires energy simulation to quantify, 'others' subdivisions see footnote 7, base conditions see chapter 1)

Based on the proposed Farmhal model, a new quantified material flow (figure 9) is made using the same condition settings in chapter 1. In the table above, heating residual is titled as not applicable. The calculation of heat waste that could be recycled relies on the scientific simulation of specific building models. In order to quantitatively indicate how beneficial a Farmhal model could be, data is borrowed from a similar precedent as a comparison.

The ICTA-ICP building in Barcelona is an office and farm combined project which employs the same strategy of the Farmhal model. Researchers from The Autonomous University of Barcelona conducted a detailed simulation on the thermal physical performance of the building. The conclusion shows that 'integrated nature of the iRTG resulted in 341.93 kWh/m2/yr of heating energy being 'recycled' from the rest of ICTA building; this is within 139–444 kWh/m2/yr of the reported power requirements for heated Mediterranean greenhouses.'[11] The study indicates that in the case of the ICTA-ICP building, a 4 stories office building with a central atrium, the heating demand of the rooftop farm can be fully satisfied by the residual heat from the associated building. Thus a rough conversion can be made based on this study that in the Farmhal model, approximately 85000 kWh residual heat could be recycled from the dwelling for the farm.

The graph below shows the reduction of the water, heating and gas consumption in the new flow compared to the existing consumption of the dwelling and the farm in total. In the cities, residential

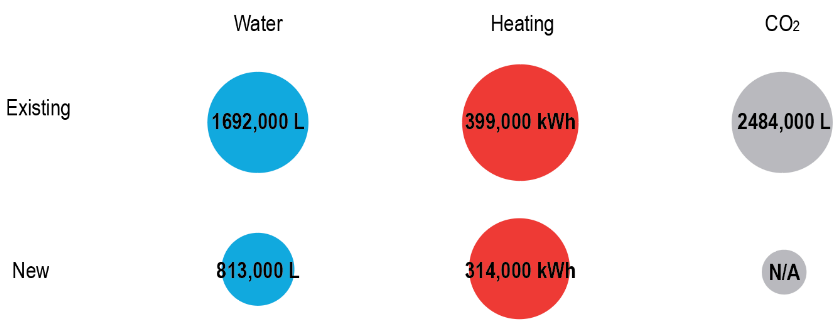

Figure 10. Water, heating and CO2 consumption comparison between the existing and the new flow
(*existing data is not sufficient enough to quantify the CO2 supply in the new flow, but a reduced amount is certain)

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[11] Ana Nadal, Integrated rooftop greenhouses: An energy and environmental assessment in the Mediterranean context, Applied Energy 187 (2017) 338–351

buildings are commonly multi-story, the heating and CO_2 compensation from the dwelling for the farm could be multiplied according to the story number.
Outside the boundary of the envelope, overall environmental impact reflects the flow of a BIA model in a broader context. A research has been done on the ICTA-ICP building in terms of the economic and environmental impact of a rooftop greenhouse farm by Esther Sanyé-Mengual[12]. The research concludes that compared to conventional greenhouses in the rural area, a rooftop farm in an IRTG system is with higher economic cost and environmental impact in the construction level while the impact of the production process is 31-42% less with 21% cheaper cost. Also, products from a rooftop urban farm is with 20% higher economic value than the average level.

4. A workflow for building selection and decision making

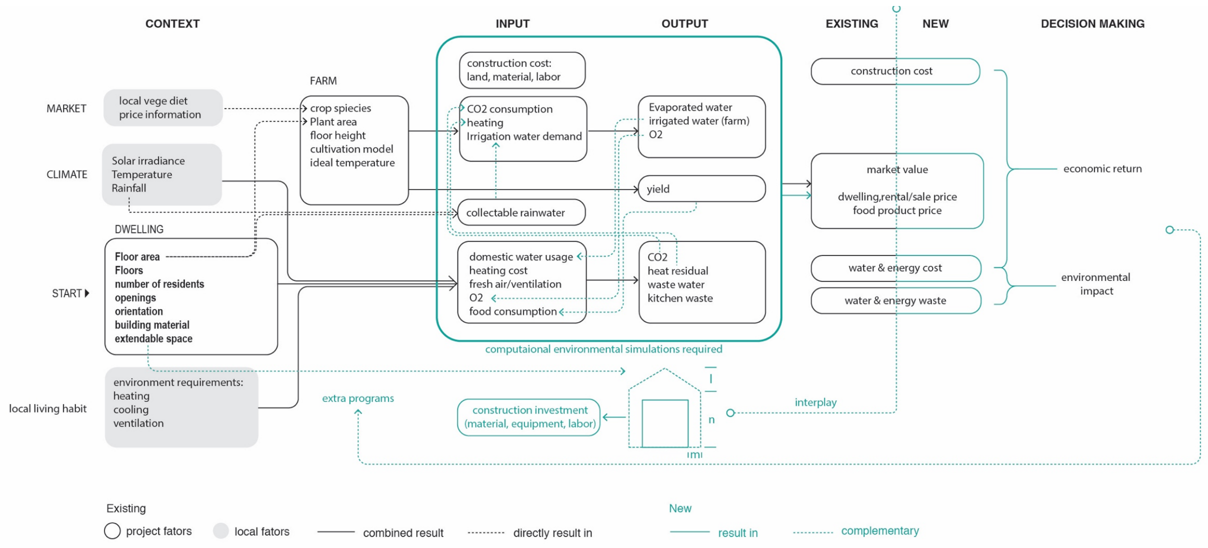


Figure 11. Workflow of a Farmhal project development

In practice, the application of a Farmhal model requires consideration of various factors. Apart from the material saving, initiation investment, future economic benefits are all important in the development of a BIA project. In this chapter, a workflow is formulated to organize the concerned factors for building selections and decision makings. The workflow is roughly divided into three sections, context study, existing and future flow analysis, comparison and decision making.

Starting with the context, when an existing building is selected or several candidate ones are available, data needs to be collected about the buildings and the surroundings. First, besides architectural information such as facade materials and openings, the local climate and living habits are essential in estimating the energy consumption under existing flow. In terms of the rooftop farm, production efficiency is affected by the roof area and the orientation. In current cases, most commercial rooftop farms are larger than 1000m^2 to obtain higher production efficiency. The ideal orientation of a greenhouse varies due to the location. In northern Europe, an east-to-west manner is preferred for plants to catch the sunlight during the daytime all year round. The selection of crop species depends on the cultivation technique and local food market. Leafy greens such as lettuce and spinach with high economic value, short growth cycle and less space occupation are most common in urban vertical farms.

Based on the context study, models of the dwelling and the farm are formulated for material flow analysis. Calculations will be conducted to estimate the resource consumption, waste production and

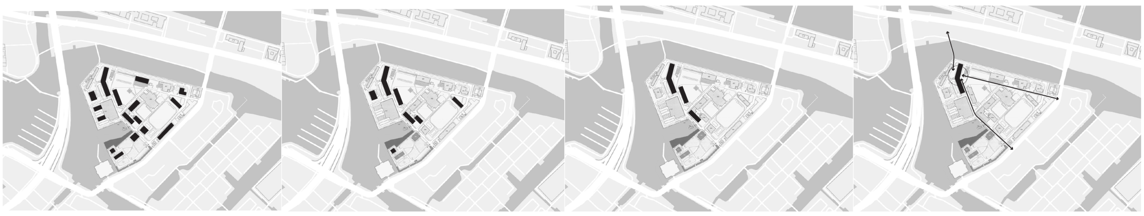
12 Esther Sanyé-Mengual, An environmental and economic life cycle assessment of rooftop greenhouse (RTG) implementation in Barcelona, Spain. Assessing new forms of urban agriculture from the greenhouse structure to the final product level, Int J Life Cycle Assess (2015)

market value of the dwelling and the food production respectively. Then based on existing conditions, same assessment is applied to a renovated model. Materials and sizes of the greenhouse envelope need to be specified for the set-up of the new model. Size of the envelope is influenced by multiple conditions, including the extendable surrounding space, desired building performance, and user spatial experience. In order to articulate the heat and air flux in the BIA model, computational environmental simulations are required in this step. In addition, the shape of the envelope is not a fixed matter. It forms an interplay relationship with the simulation result. When the result is not ideal enough, the greenhouse envelope alters for better performances.

After the renovation model is settled, a comparison between the existing and the new flows follows from the perspectives of the economic return and the environmental impact. Compared to the existing building, the rental and selling price would correspondingly increase due to the renovation. Locally produced food is also generally sold at a higher price than the average level. In addition to the increased income, reduction of resource consumption with associated expense saving also contributes to the new money flow. In terms of environmental impact, apart from the resource saving, waste produced from the system is also part of the concern. Based on the economic return and environmental impact, decisions could be made for building selection, design development and future business plan. Extra programs such as marketplace or restaurant could also be added to optimize the updated flow.

5. An application in the context of Marineterrein, Amsterdam

The Marineterrein area in Amsterdam is a triangular island in the city center with many vacant buildings waiting to be occupied. In order to target the building for future intervention, the assessment starts with the 'context' part, looking at existing conditions that fit the preferences of a Farmhal.



Linear shape | east-west orientation | area>1000m2 | key circulation node

Figure 12. Building selection, filtering conditions

First, a Farmhal requires a flat roof and relatively small depth for the residential purpose. In terms of orientation, in Amsterdam, where solar irradiance is between 900-1000 kWh/m^2, an east to west orientation is most ideal for capturing more sunlight for photosynthesis and ensuring enough daylighting for both sides of the dwelling. In commercial rooftop farms, the production efficiency is positively correlated with the planting area. A roof area more than 1000m^2 is preferred for a commercial urban farm. Finally, the target building No.026 is determined due to its key location in a circulation node of the surrounding and a roof area of 2275m^2. According to the floor plans, the target building was a 4 stories residential apartment with 54 studios of 32m^2 each.

Regarding the crop selection, among various vegetables, leafy greens in the Dutch market are with rapidly increasing consumer prices while the producer prices have not[13], which it a high-profit crop type. In addition, according to the report *Food consumption in the Netherlands and its determinants*[14], a Dutch citizen consumes 45kg of vegetables per year on average.

[13] Frank Bunte, Pricing of food products, p15, Project code 40871 LEI Wageningen UR, The Hague

[14] M. Geurts, Food consumption in the Netherlands and its determinants, RIVM Report 2016-0195, National Institute for Public Health and the Environment, University of Florida

Based on the conditions above and other local factors, a rough material flow in the target building before and after the intervention is calculated and illustrated in the graphic below.

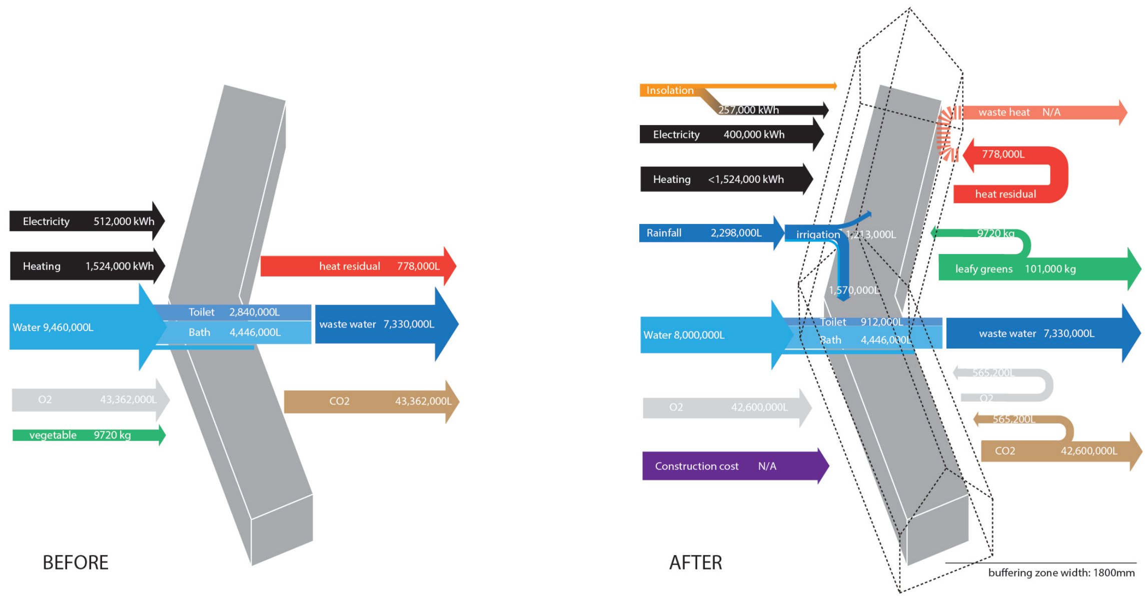


Figure 13. Preliminary material flow calculation, left: existing flow, right: flow after intervention

The preliminary flow assumption reveals that after the intervention, material inputs are all less than the existing situation while the profitable outputs increases. Residual heat and CO_2 from the dwelling are able to fully satisfy the corresponding demands of the farm. Reusable water from the rainwater and the farm could replace 56% of flushing water usage while the amount of oxygen produced by the plant is little compared to the demand of the residents. Overall, the dwelling benefits the farm more than the other way around. At the same time, the greenhouse envelope has the potential in reducing the energy cost of the attached building with the cavity between two facades, which works similar to a double-skin façade system. However, no conclusion can be settled without further computational simulation on the overall energy performance of the specific project.

Conclusion

Based on theoretical calculations and current researches, complementary material flow in a Farmhal model works high-efficiently between the dwelling and the farm. It is able to reduce a considerable amount of resource consumption as well as enhance the performance of existing building. The farm and live mode also contributes to better economic values of agriculture and housing as commercial activities.

However, in actual application, the performance of a Farmhal depends on the simulation results based on a specific building block in the associated local environment. In this study, the scientific calculation is not covered and will be further explored in the future design project.

Appendix 1. Parameters used in the general flow calculation, chapter 1

		liter	mm	m2	m	kg	kWh	ppl	μmol mol	source
rainfall, amsterdam			766 [1]						1	http://www.amsterdam.climatemps.com/precipitation.php
roof area				1000						
rainwater		766000								
irrigation water/kg		12 [2]								Khoo Hong Meng, SKY URBAN SOLUTIONSVERTICAL FARMING – AN URBAN AGRICULTURE SOLUTION
irrigation water consumption		533333								
reusable water rate	0.40									Toyoki Kozai, Genhua Niu, Michiko Takagaki, Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production, p70, figure 4.4, Academic Press, 2 Oct 2015
evaporation rate	20%									see 8
rainwater for domestic use		446000								
water for toilet		345789								
domestic water consumption		1152632								
yield/yr						44444				see 6
farm floor height					5					
vege consumption/capita kg						45 [3]				http://www.rivm.nl/bibliotheek/rapporten/2016-0195.pdf
vege consumption						1184				
food consumption at home						17482				
kitchen waste						2401				
waste water	93kg/cap/day	893289								
ppl be feeded								988		
farm electricity consumption/1000m2							63709 [4]			see 6
solar irradiance/m2/yr amsterdam							975 [5]			http://www.eborx.com/download/en/data/European-Solar-Irradiation-kWh-m2.pdf
annual solar insolation							975000			
CO2 concentration for better photosynthesis									800-1000 [6]	see 8
ambient CO2 concentration									400 [7]	http://www.plant-phenotyping-network.eu/lw_resource/datapool/_items/item_198/co2_handout.pdf
CO2 supply for farming(romaine)	1/10 of crop weight	2484444 [8]				4444				http://www.lessco2.es/pdfs/noticias/ponencia_cisc_ingles.pdf
CO2 production by human transpiration/capita/day	5% [9]	550 [10]				0.70				https://health.howstuffworks.com/human-body/systems/respiratory/question98.htm
O2 produced by photosynthesis		2484444								6CO2 + 6H2O -——> C6H12O6 + 6O2
total co2 production, residents		5282895								
human O2 consumption/capita/day	5% [11]	550 [12]								https://en.wikipedia.org/wiki/Breathing
residents number	26									
floors	1									
living area/capita NL				38 [13]						http://www.entranze.enerdata.eu/
housing electricity consumption							45000			
dwelling floor numbers	1									
housing heating consumption(gas)							134000			
greenhouse heating	38 kwh/m2						38000			http://edis.ifas.ufl.edu/aa212
material saving in the new flow										
water consumption reduction		879123								
heat recycled from the dwelling							85000			Building-integrated rooftop greenhouses: An energy and environmentalassessment in the mediterranean context, Applied Energy 187 (2017) 338–351
electricity compensation							112983			http://photovoltaic-software.com/
CO2 compensation		5282895								
O2 compensation		2484444								
vegetable production/year						44444				
ppt to be feed	988									

Appendix 2. Parameters used in the flow calculation of building No.026, chapter 5

		liter	mm	m2	m	kg	kWh	ppl	µmol mol	source
rainfall, amsterdam			766 [1]						1	http://www.amsterdam.climatemps.com/precipitation.php
roof area				2275						
rainwater		2298000								
irrigation water/kg		12 [2]								Khoo Hong Meng, SKY URBAN SOLUTIONSVERTICAL FARMING – AN URBAN AGRICULTURE SOLUTION
irrigation water consumption		728000								
reusable water rate	0.40									Toyoki Kozai, Genhua Niu, Michiko Takagaki, Plant Factory: An Indoor Vertical Farming System for Efficient Quality Food Production, p70, figure 4.4, Academic Press, 2 Oct 2015
evaporation rate	20%									see 8
rainwater for domestic use		1861200								
water for toilet		2838240								
domestic water consumption		9460800								
yield/yr						60667				see 6
farm floor height					3					
vege consumption/capita kg						45 [3]				http://www.rivm.nl/bibliotheek/rapporten/2016-0195.pdf
vege consumption						9720				
food consumption at home						143489				
kitchen waste						19710				
waste water	93kg/cap/day	7332120								
ppl be feeded								1348		
farm electricity consumption/1000m2							63709 [4]			see 6
solar irradiance/m2/yr amsterdam							975 [5]			http://www.eborx.com/download/en/data/European-Solar-Irradiation-kWh-m2.pdf
annual solar insolation							2218125			
CO2 concentration for better photosynthesis									800-1000 [6]	see 8
ambient CO2 concentration									400 [7]	http://www.plant-phenotyping-network.eu/lw_resource/datapool/_items/item_198/co2_handout.pdf
CO2 supply for farming(romaine)	1/10 of crop weight	3391267 [8]				6067				http://www.lessco2.es/pdfs/noticias/ponencia_cisc_ingles.pdf
CO2 production by human transpiration/capita/day	5% [9]	550 [10]				0.70				https://health.howstuffworks.com/human-body/systems/respiratory/question98.htm
O2 produced by photosynthesis		3391267								6CO2 + 6H2O ------> C6H12O6 + 6O2
total co2 production, residents		43362000								
human O2 consumption/capita/day	5% [11]	550 [12]								https://en.wikipedia.org/wiki/Breathing
residents number	216									
floors	5									
living area/capita NL				38 [13]						http://www.entranze.enerdata.eu/
housing electricity consumption							511875			
dwelling floor numbers	5									
housing heating consumption(gas)							1524250			
greenhouse heating	38 kwh/m2						86450			http://edis.ifas.ufl.edu/aa212
material saving in the new flow										
water consumption reduction		3566240								
heat recycled from the dwelling							85000			Building-integrated rooftop greenhouses: An energy and environmental assessment in the mediterranean context, Applied Energy 187 (2017) 338–351
electricity compensation							112983			http://photovoltaic-software.com/
CO2 compensation		43362000								
O2 compensation		3391267								
vegetable production/year						60667				
ppt to be feed	1348									

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