URBAN SYMBIOTIC GREENHOUSE

An integrated approach to improve building performance

P5 presentation 31.10.2022

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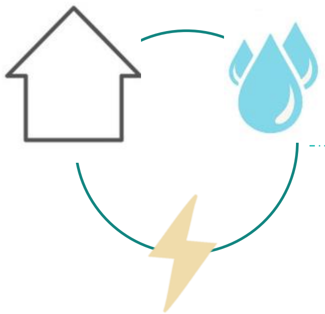
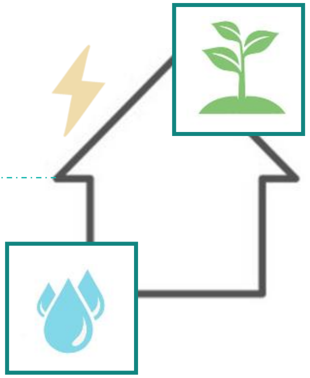
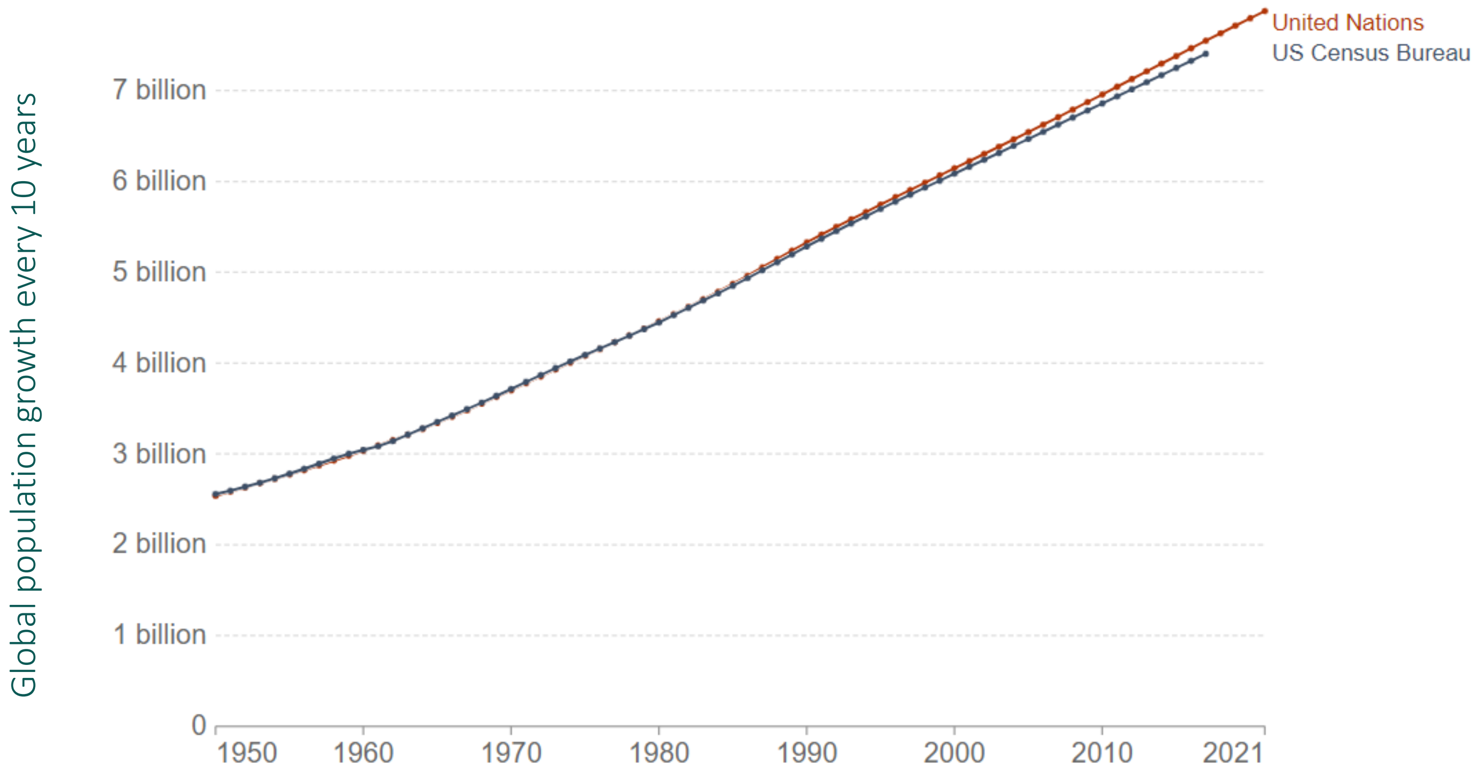




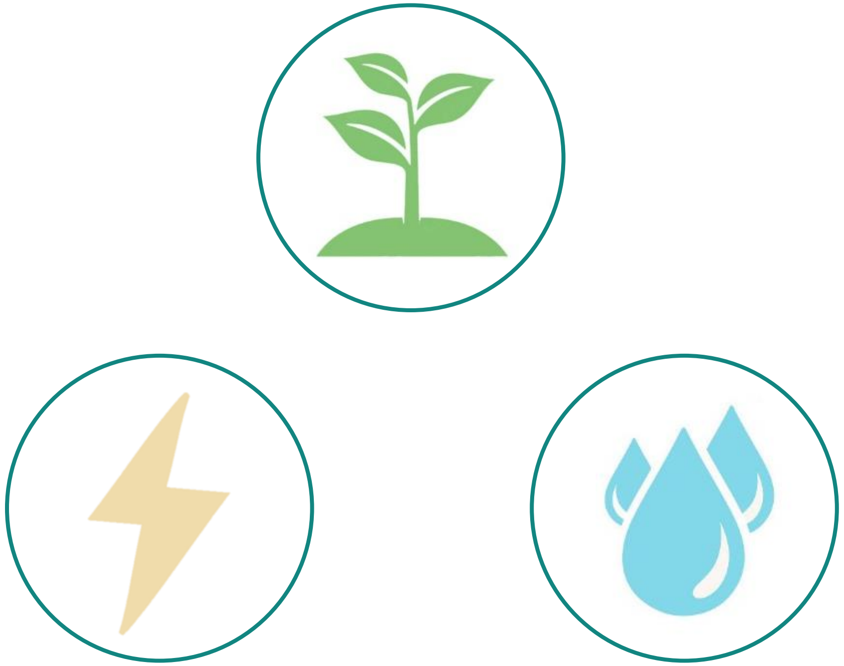
POPULATION GROWTH



9.7 billion Global population by 2050

6.3 billion Urban population by 2050

As population grows



Demand for food, energy and fresh water increases

RESOURCE SUPPLY

Conventional Agriculture

Energy supply

Water supply

RESOURCE FLOW

Energy, Water, Materials

Emissions to soil, water & air

Resource flows in Urban context

Current scenario

PROBLEM STATEMENT

The growing global population has led to an increased demand for food, energy and resources such as fresh water, land, soil, etc. Conventional and modern agricultural techniques are being used to satisfy the increasing food demands, however in doing so, **the energy consumption and resource use is also increasing, leading to high waste flows and rapid resource depletion.**

HOW DO WE TACKLE THIS PROBLEM?

Urban Agriculture – a possible solution?

“Renaissance of urban agriculture in the world’s wealthy, northern cities as new technologies like hydroponics, with their significantly higher yields and water recycling ratio per square metre, offers the promise of competing with traditional agriculture.”

Goldstein et al. (2016)

Benefits outweighed by the energy inputs and inefficient use of production outputs?

DUTCH ENERGY TRANSITION PLAN

low carbon energy systems

sustainable sources

reduce greenhouse gas emissions (GHG)

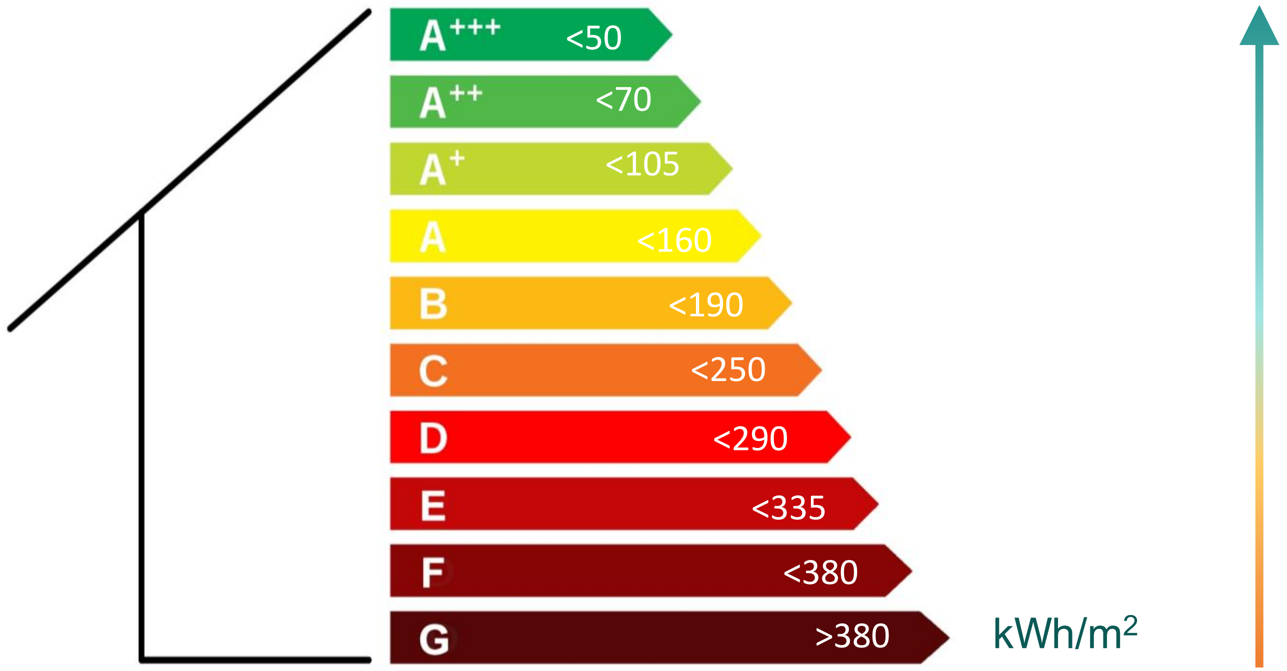
95% lower by 2050 compared to 1990

100% electricity from renewables

by 2050

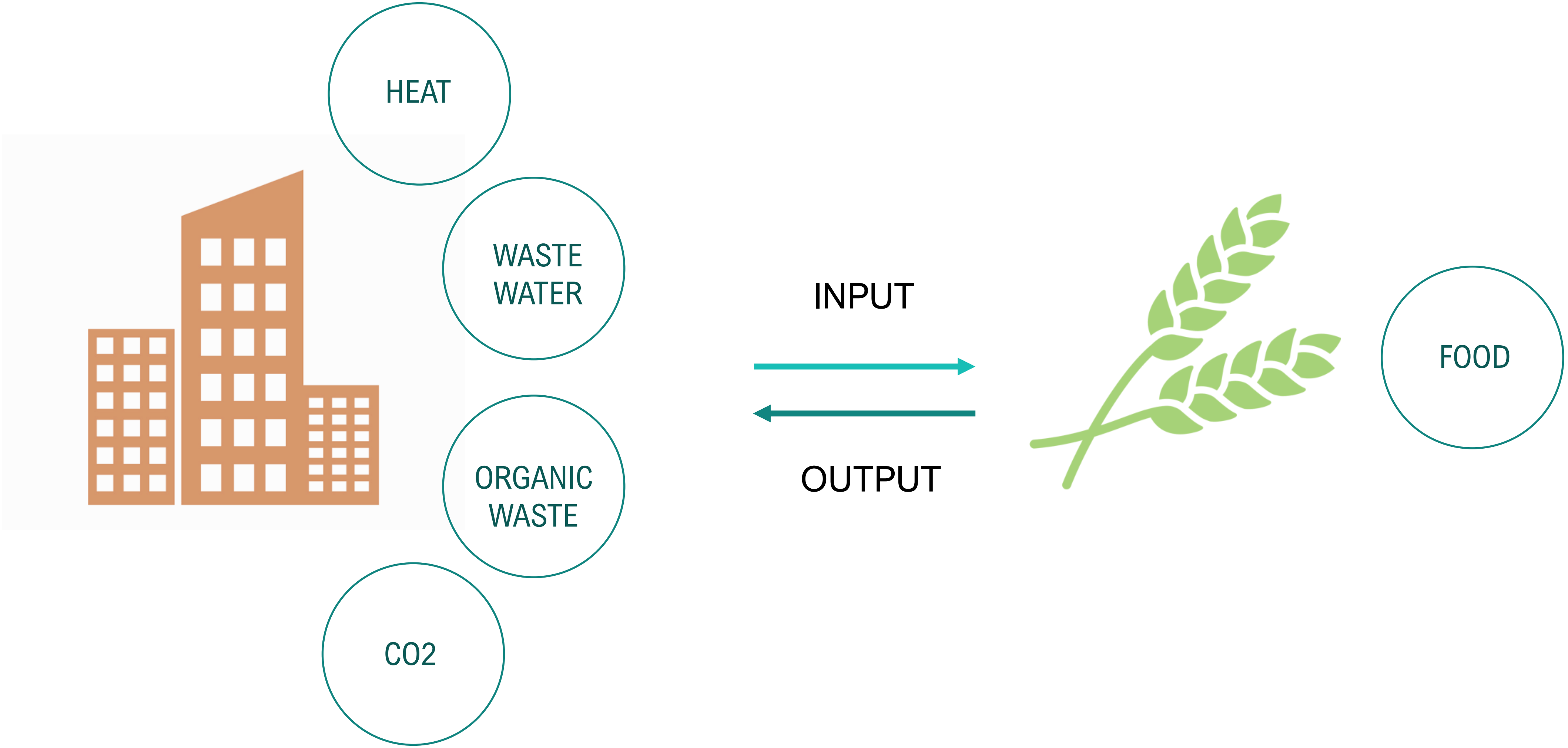
https://www.government.nl/topics/renewable-energy/central-government-encourages-sustainable-energy

ENERGY LABEL FOR RESIDENTIAL BUILDINGS



POTENTIAL SOLUTION

ENERGY SYNERGY



RESEARCH QUESTION

How can **modular greenhouse units** be designed and integrated in buildings in an urban context, **to utilize available waste resources** in exchange for **food production** while reducing primary resources of the building, where possible?

1 Energy IN/OUT

How can the symbiotic greenhouse unit utilize the existing energy waste flows from the building and in turn convert it to valuable crop produce?

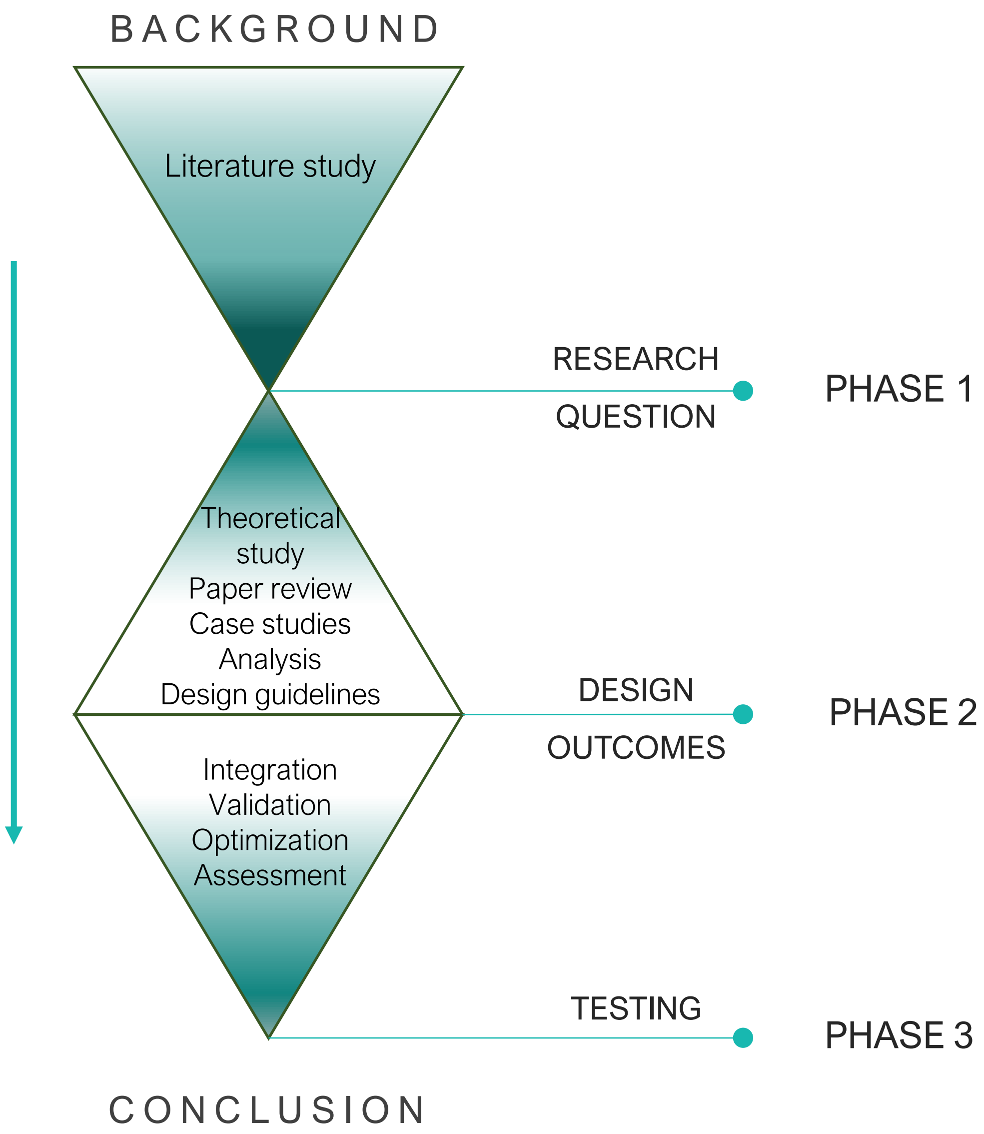
2 Efficiency

What are the reductions in primary energy resources of the building, wherever possible, caused by the co-symbiotic units?

3 Buildability

How can the symbiotic greenhouse be made modular and circular in terms of its buildability to achieve flexibility in construction and adaptation?

RESEARCH METHOD & FRAMEWORK



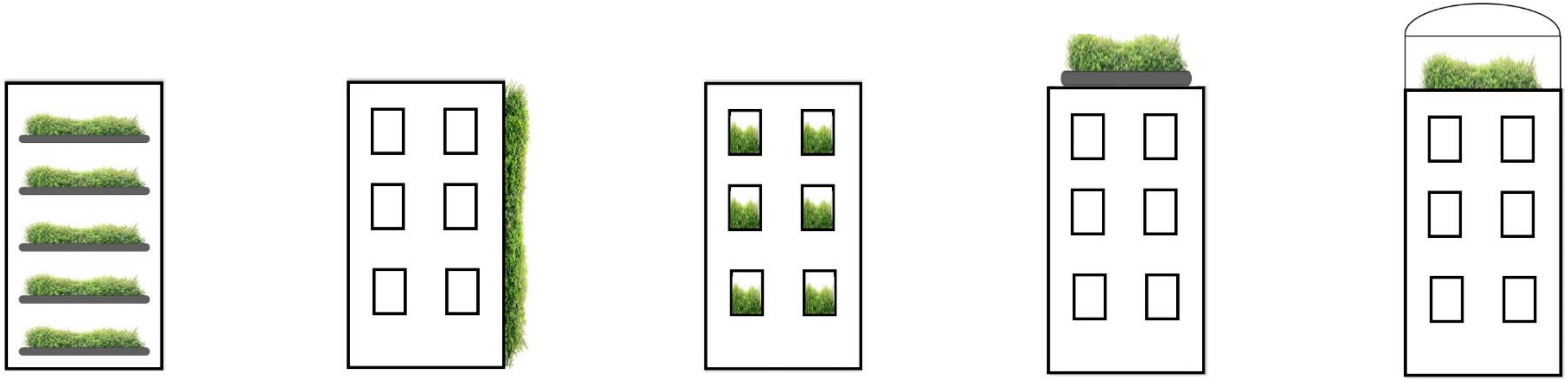
Energy calculations on excel

SANKEY diagram

DESIGN of modular GH unit

LITERATURE REVIEW : URBAN AGRICULTURE

BUILDING INTEGRATED AGRICULTURE (BIA)



Vertical farming or Sky farming

Edible walls & balconies

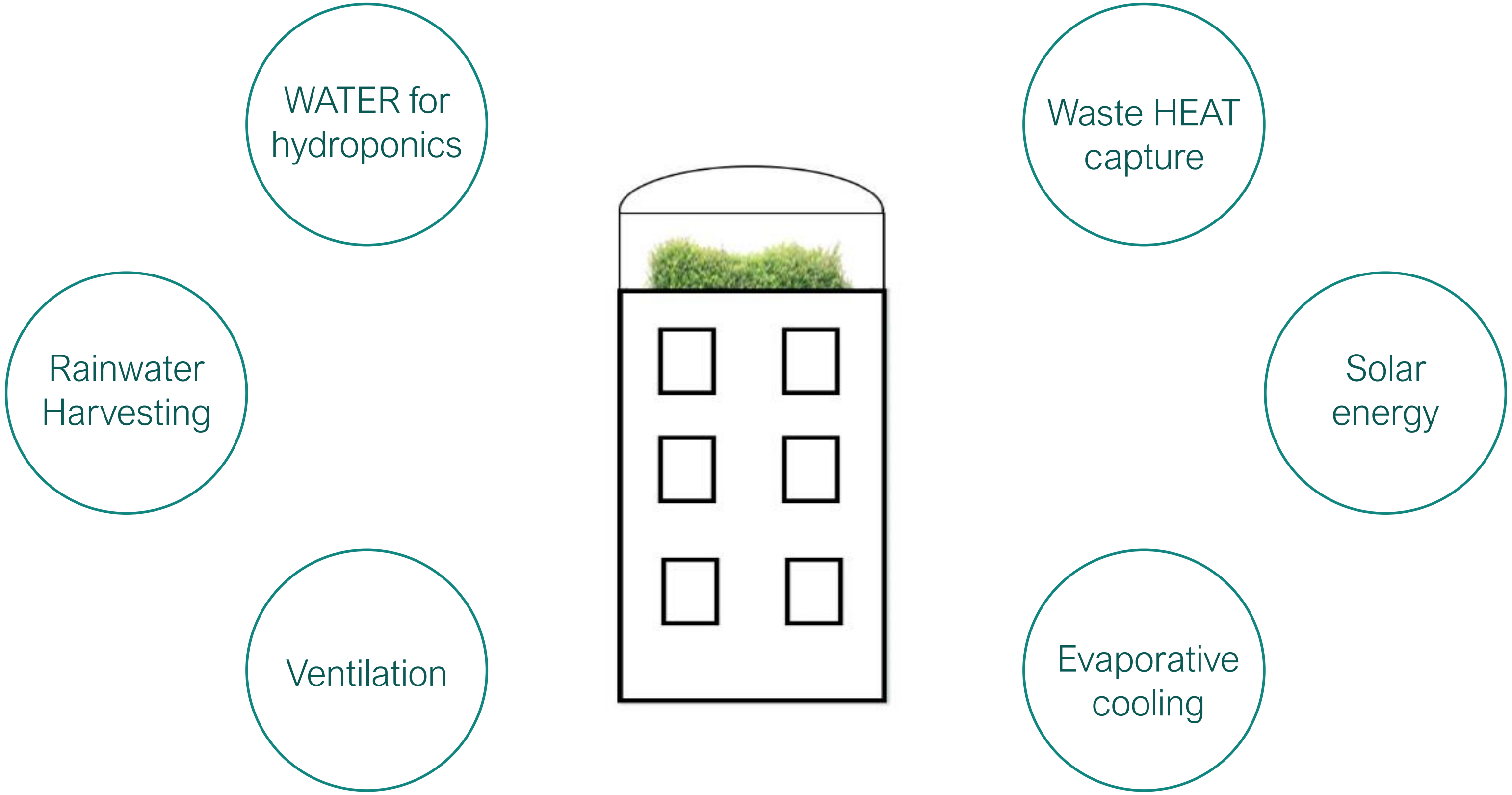
Indoor farming

Open air rooftop farming

Greenhouse rooftop farming

TYPES OF BIA

ENERGY FEED for BIA



GREENHOUSE
ROOFTOP FARMING

D. Gould, T. Caplow, (2012) 8 - Building-integrated agriculture: a new approach to food production, Metropolitan sustainability

URBAN FARMING TECHNIQUES – SOIL BASED

RAISED BEDS IN URBAN SPACES

- Lack of flexibility
- High levels of evaporation
- Lack of space in urban areas

ROOFTOP GARDENS

- Heavy loads
- Difficult on existing buildings
- Water leakage, structural damage

URBAN FARMING TECHNIQUES – WATER BASED

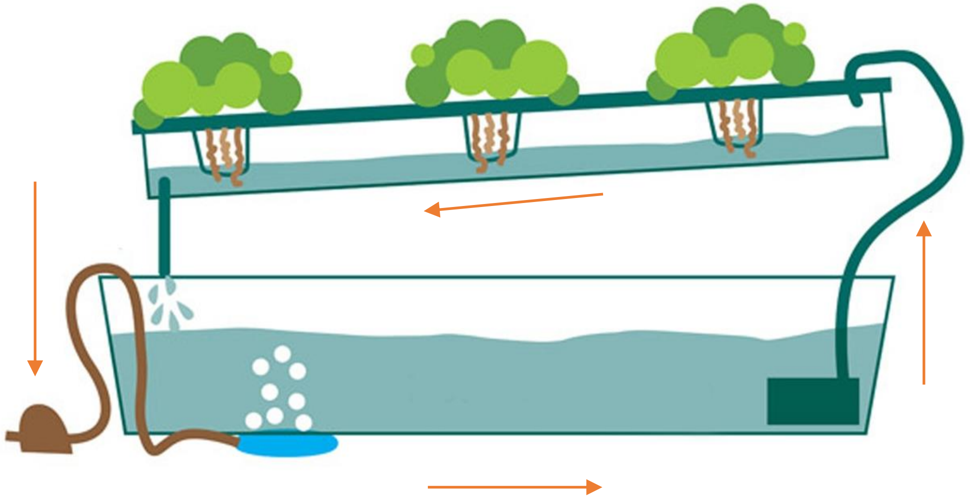
DEEP FLOW TECHNIQUE

EBB & FLOW TECHNIQUE

AEROPONICS

AQUAPONICS

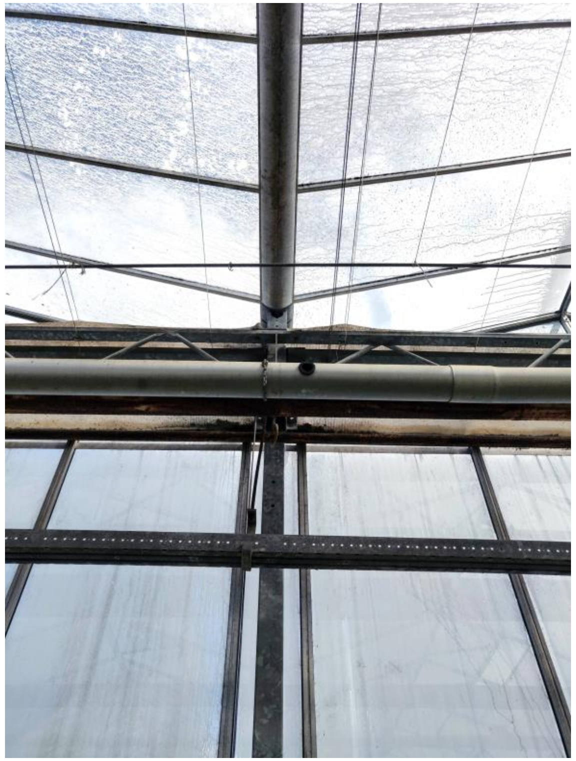
NUTRIENT FILM TECHNIQUE

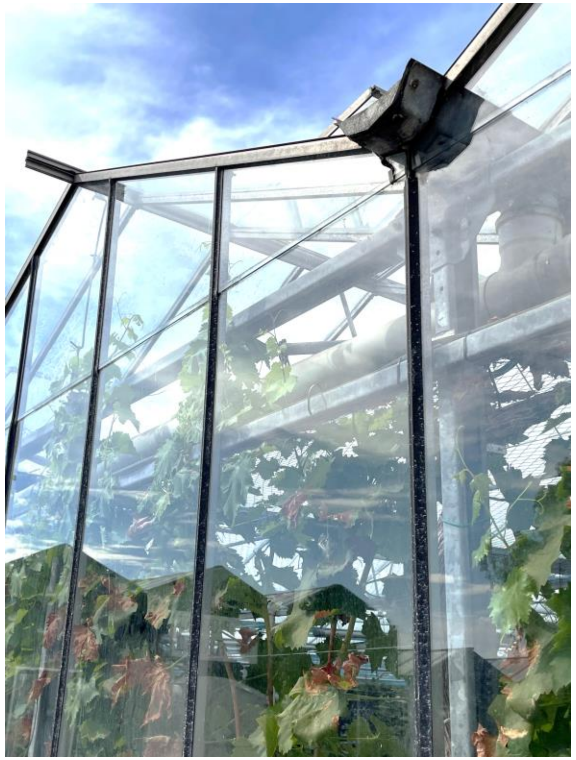


- Less water & nutrients needed
- Less volume, easy treatment
- Modular, expandable
- Recirculation of water

GREENHOUSE VISIT

GREENHOUSE VISIT

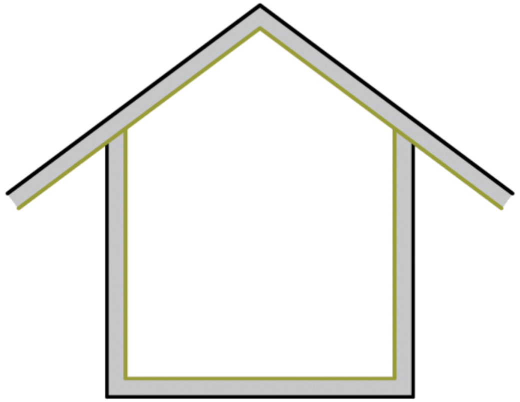




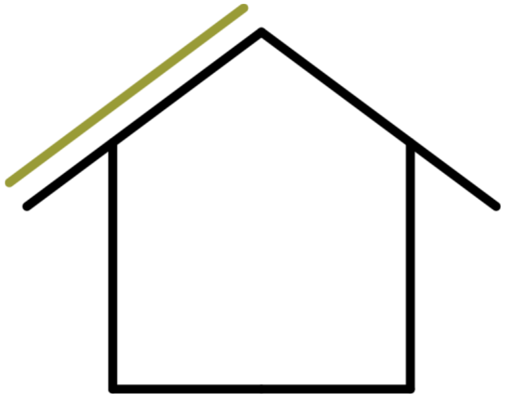
LITERATURE REVIEW : BUILDING PERFORMANCE

BUILDING PERFORMANCE

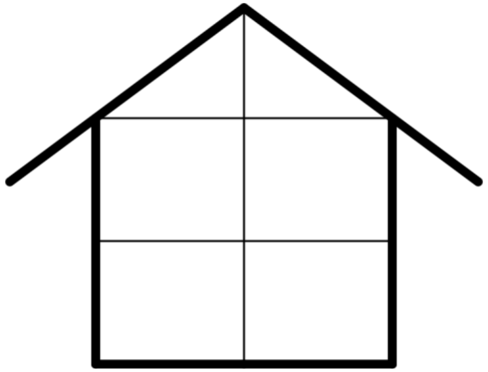
FACTORS DECIDING ENERGY LABEL



Insulation



Installations
(e.g. solar panels)



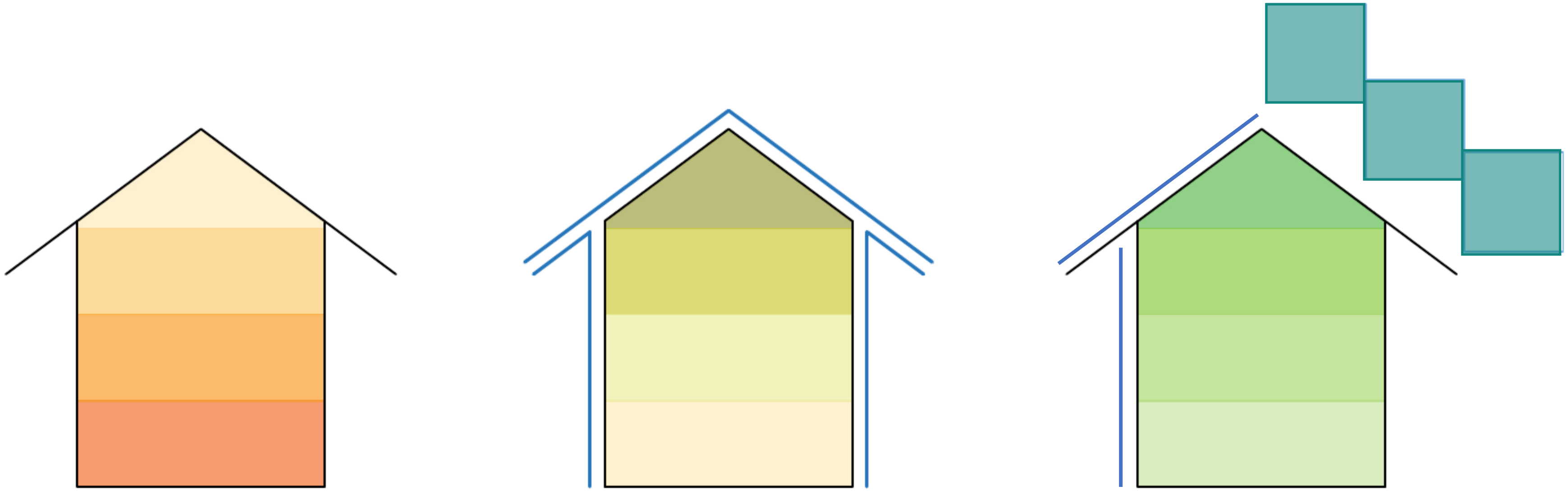
Compactness

IMPROVEMENT STRATEGIES ADVISED BY THE GOVT.

Home improvement options (mileu central/https://www.verbeterjehuis.nl/)

DESIGN VISION & PROJECT CASES

No improvements | **Renovation & remodelling** | **Part Renovation + Greenhouse modules**



High energy demands
Poor building performance

Energy efficient
Costly & time consuming

Less energy demands
Efficient building performance
Quick & flexible

DESIGN GOAL

Improved energy performance

Grow own food

Energy resources produced **BY** and **FOR** the bldg.

Vacant spaces utilized

A

PROJECT CASE 01

- Residential apartment
- Rotterdam
- **2005 – 2006**
- 63 m^2 – 138 m^2 units

Street view of the building (Funda, 2022)

A

Energy Label

++	Gas boiler	Mech. exhaust
insulation	*heating*	*ventilation*

Electric	/
cooking	*renewables*

- Dutch family home
- Rotterdam
- **1914**
- 174 m^2

Street view of the building (Huispedia, n.d.)

F

Energy Label

--

insulation

Gas boiler

heating

Mech. exhaust

ventilation

Electric

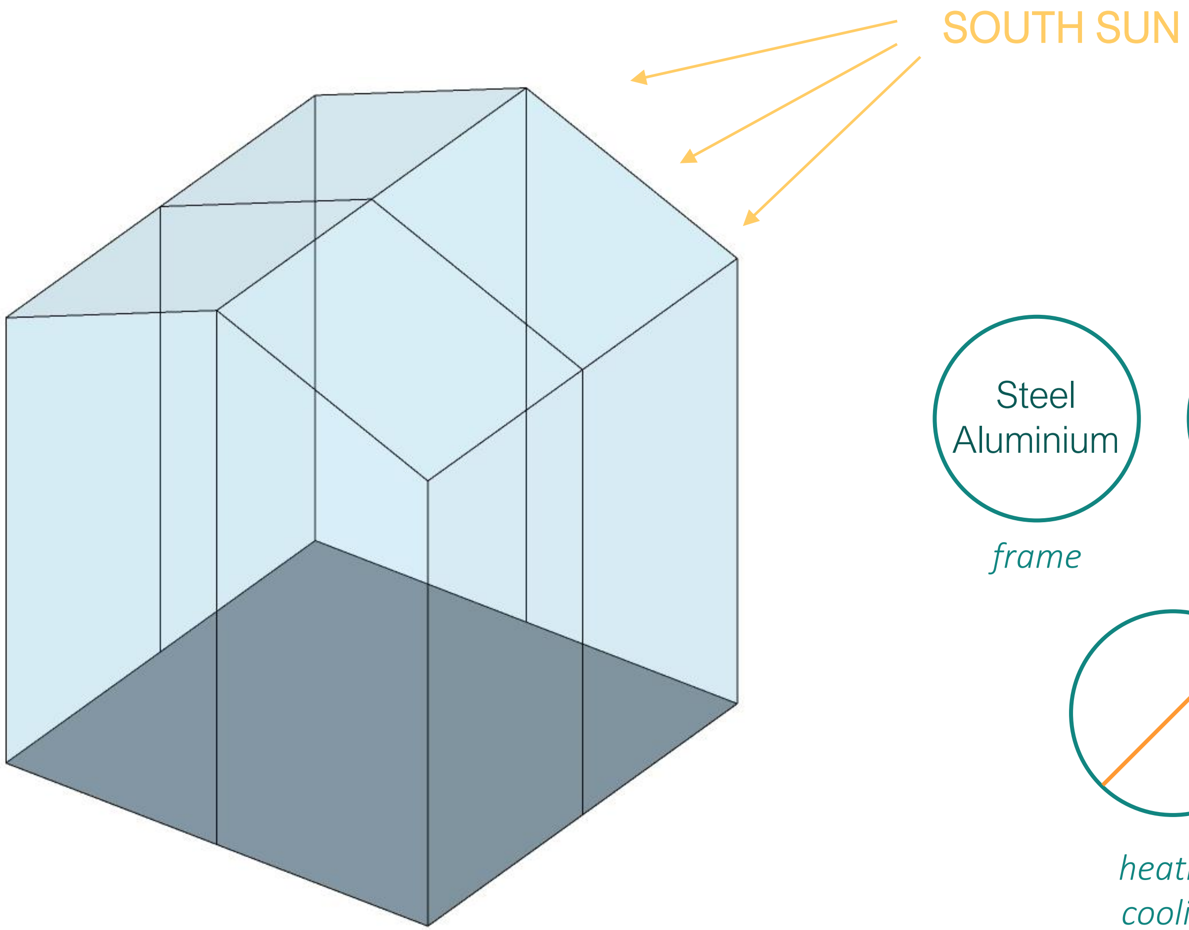
cooking

renewables

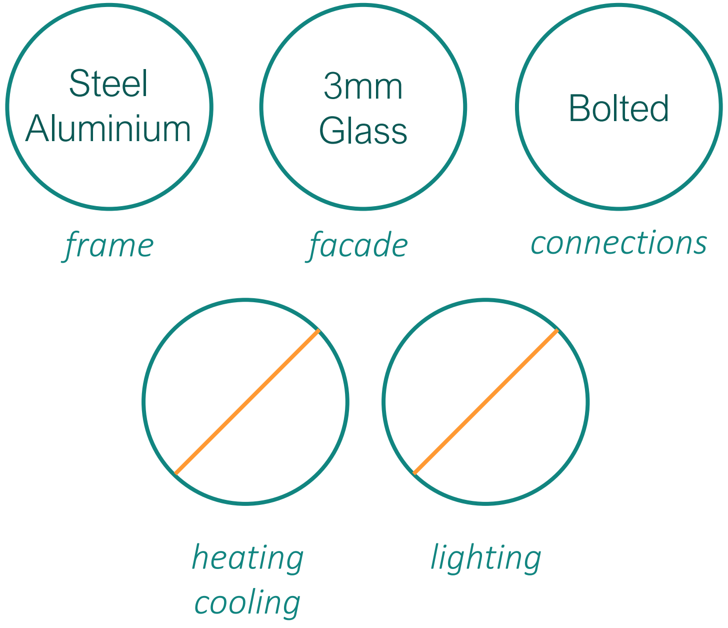
NEIGHBORHOOD

Aerial view of the neighbourhood (earth.google.com)

MODULAR GREENHOUSE CONCEPT



- A- frame, even span
- Rooftop & Facade
- 6.25 m^2



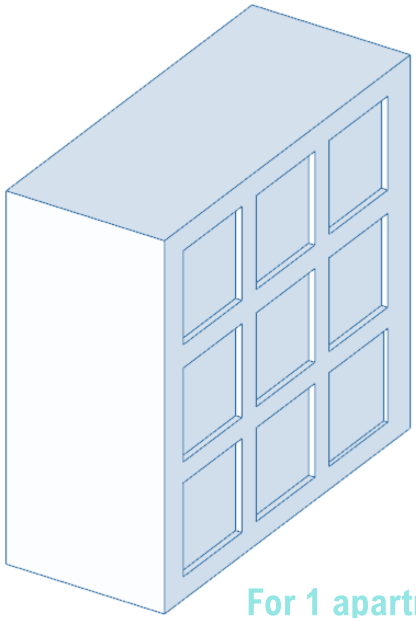
MATERIAL & ENERGY RELATIONSHIP

BUILDING ENERGY & RESOURCE DEMAND - INPUTS

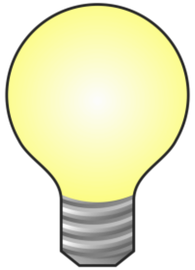
DEMANDS		APARTMENT	DUTCH HOUSE
ELECTRICITY	Appliances Cooking	2500 kWh	4500 kWh
HEATING (NATURAL GAS)	Space Heating (NG)	117 kWh/m^2 (8950 kWh)	335 kWh/m^2 (58160 kWh)
HOT WATER	Direct Hot Water supply	2240 kWh	4480 kWh
FRESH WATER	Tap Water Bathrooms, Others	97674 L/year	195348 L/year
FOOD	Vegetables & Fruits Others	1700 kg/year	3400 kg/year
OXYGEN	Ventilation Breathing	756 L O_2/day	1512 L O_2/day

BUILDING WASTE FLOWS - OUTPUTS

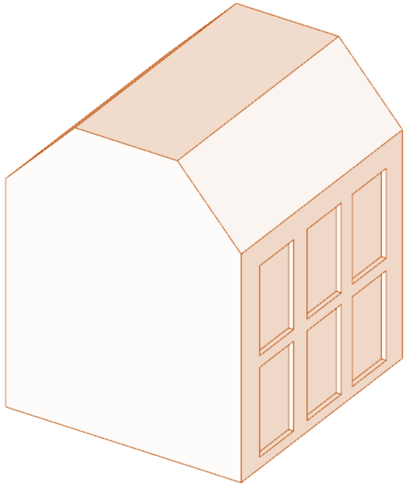
HEAT LOSS FROM BUILDING



For 1 apartment



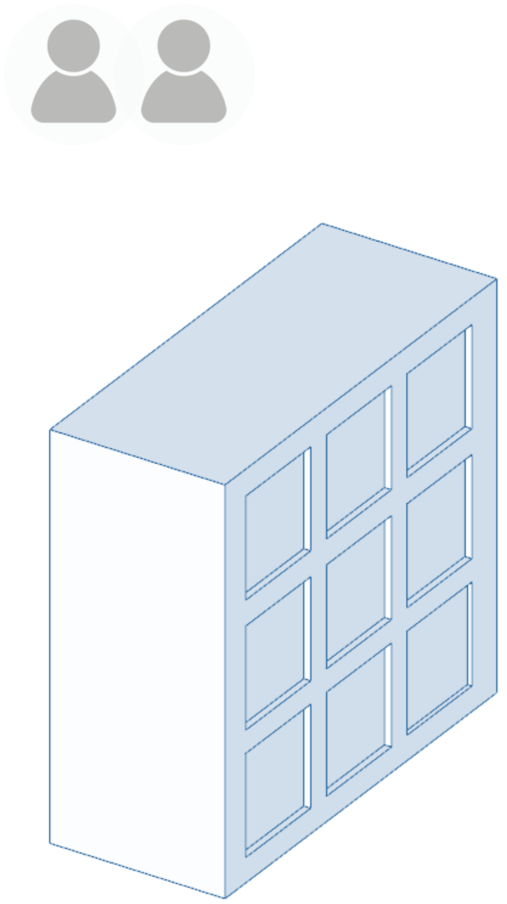
1kWh = 100 hours light bulb



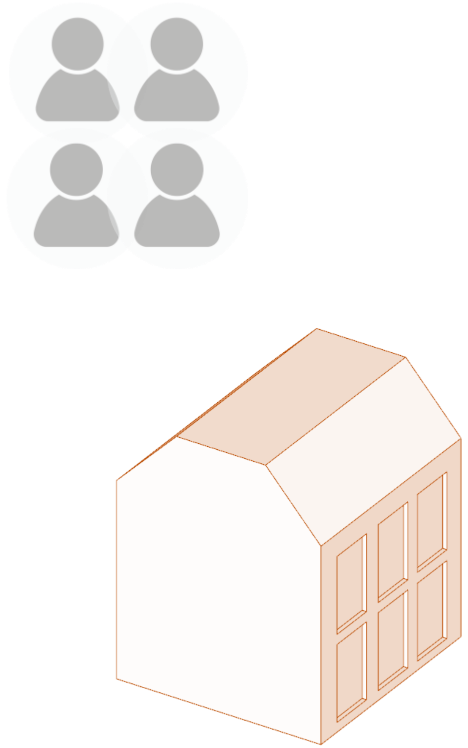
ROOF	WINDOW	WALL	VENTILATION
1.42 kWh/day	8.92 kWh/day	1.57 kWh/day	1.17 kWh/day

ROOF	WINDOW	WALL	VENTILATION
2.06 kWh/day	2.22 kWh/day	negligible	3.10 kWh/day

BUILDING WASTE FLOWS - OUTPUTS

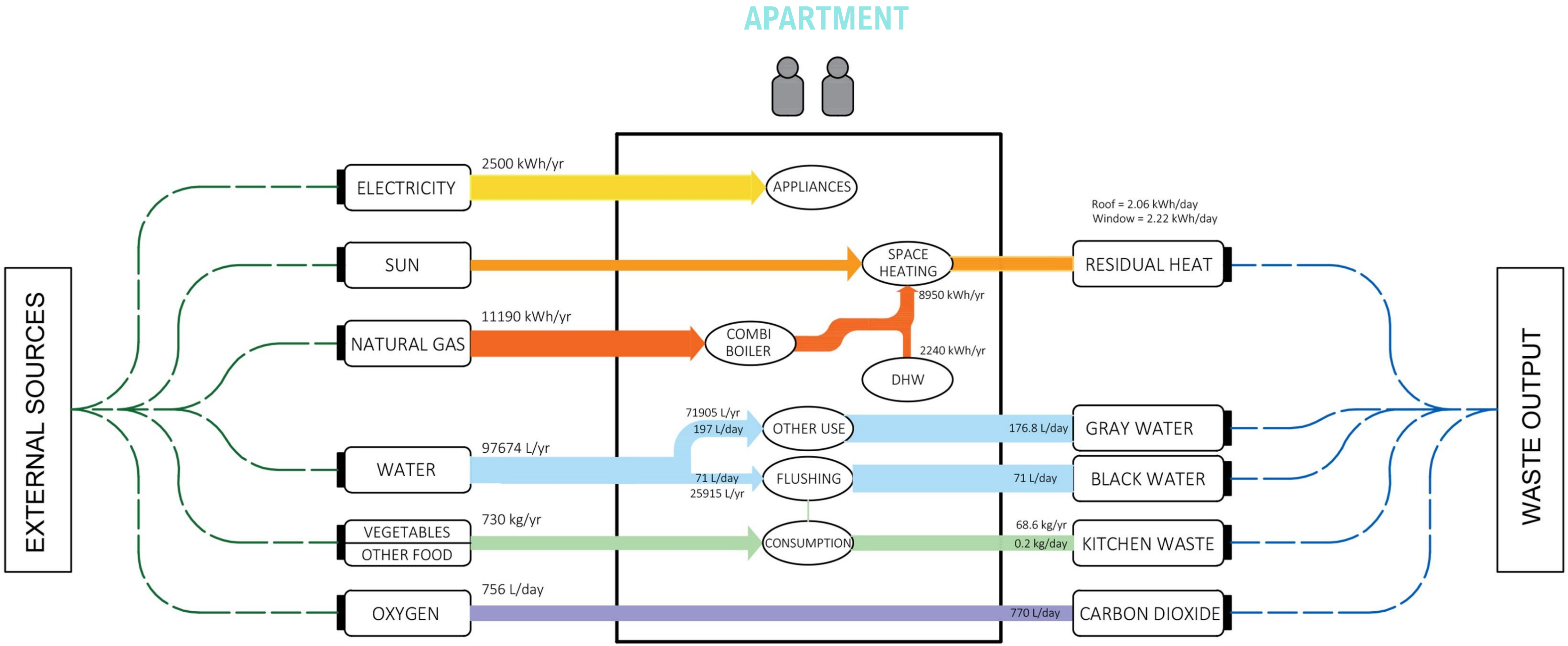


- Grey water: 175 litres/day
- Black water: 70 litres/day
- Kitchen waste: 0.2 kg/day
- CO_2: 450 litres/day

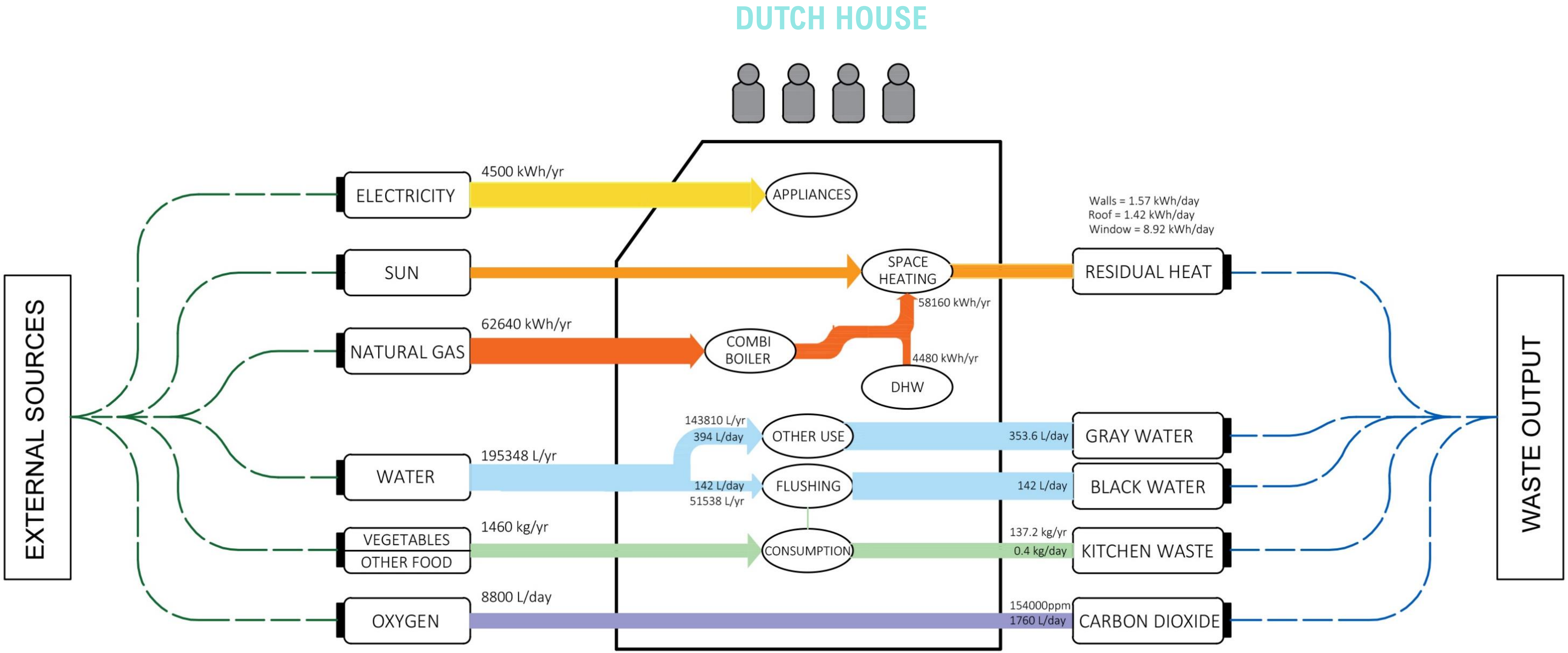


- Grey water: 354 litres/day
- Black water: 140 litres/day
- Kitchen waste: 0.4 litres/day
- CO_2: 900 litres/day

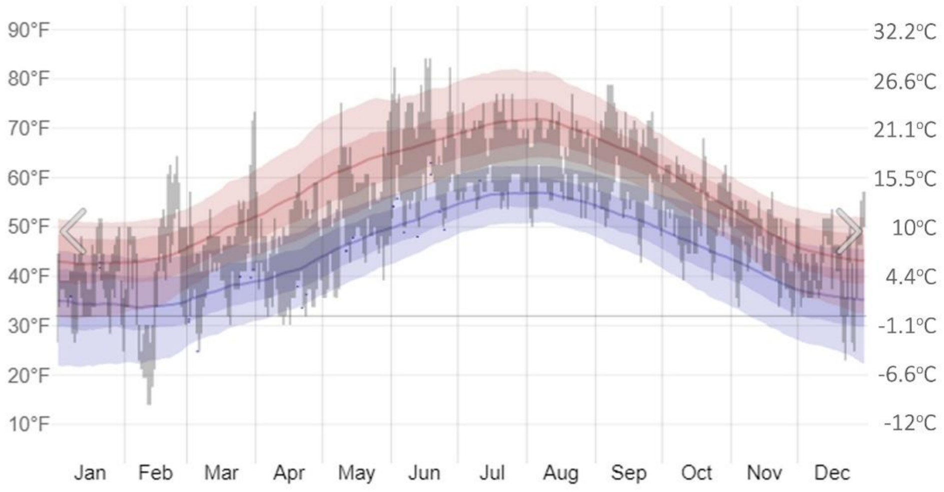
MATERIAL & ENERGY FLOW DIAGRAM



MATERIAL & ENERGY FLOW DIAGRAM



OUTSIDE TEMP



Rotterdam yearly temperature 2021 (WeatherSpark.com)

January – March

WINTER
5ºC

April – June

SPRING
15ºC

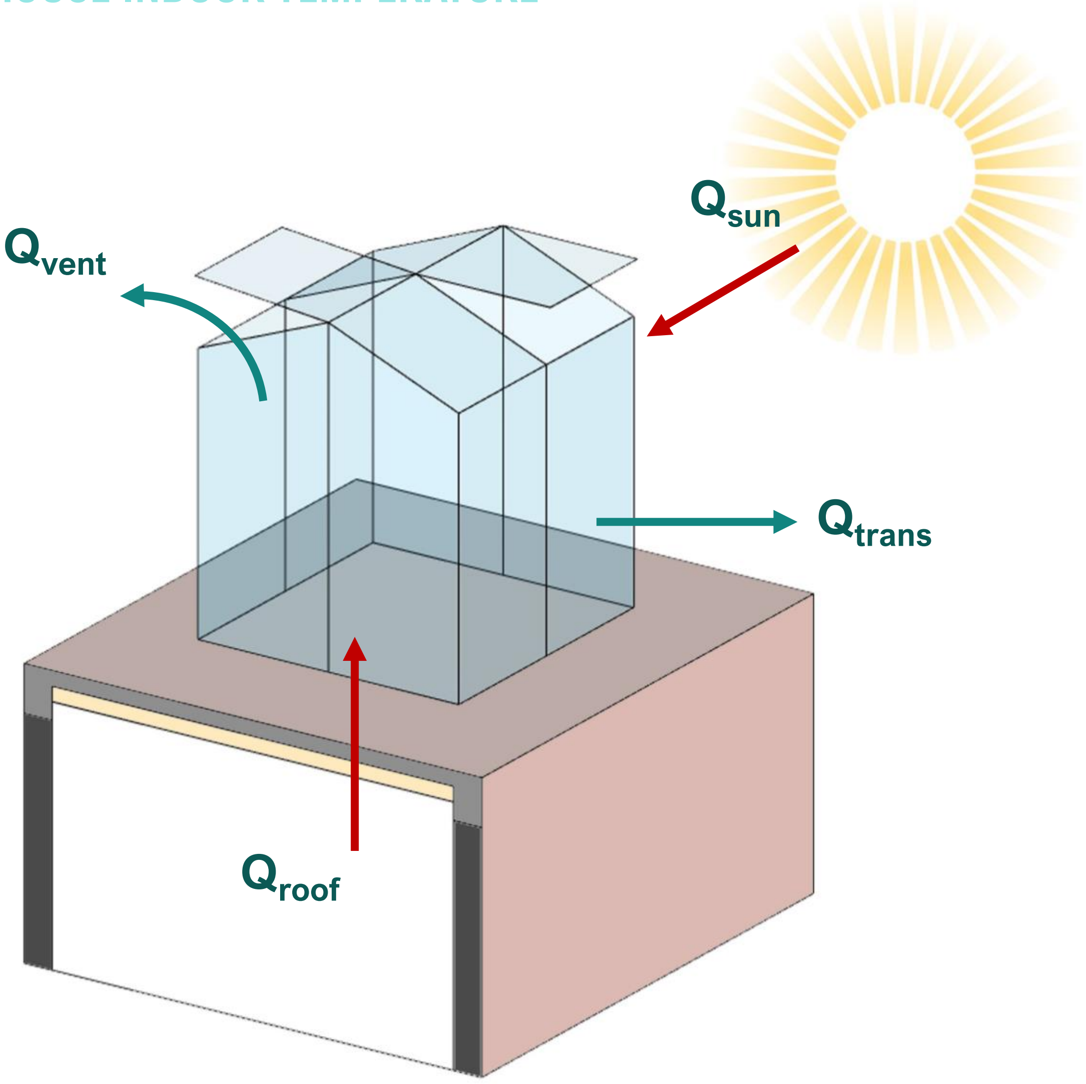
July – September

SUMMER
25ºC

October – December

AUTUMN
10ºC

GREENHOUSE INDOOR TEMPERATURE



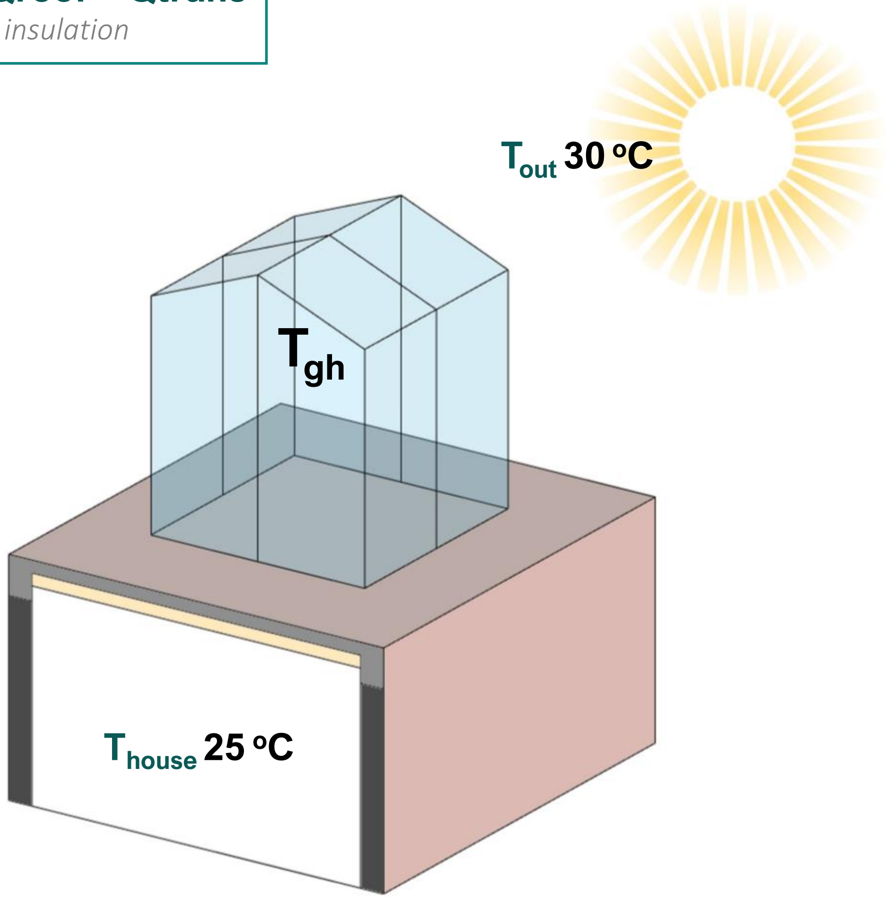
$$Q_{vent} + Q_{trans} = Q_{sun} + Q_{roof}$$

Energy balance equation

GREENHOUSE ENERGY CALCULATIONS

INDOOR TEMPERATURE – SUMMER (windows closed)

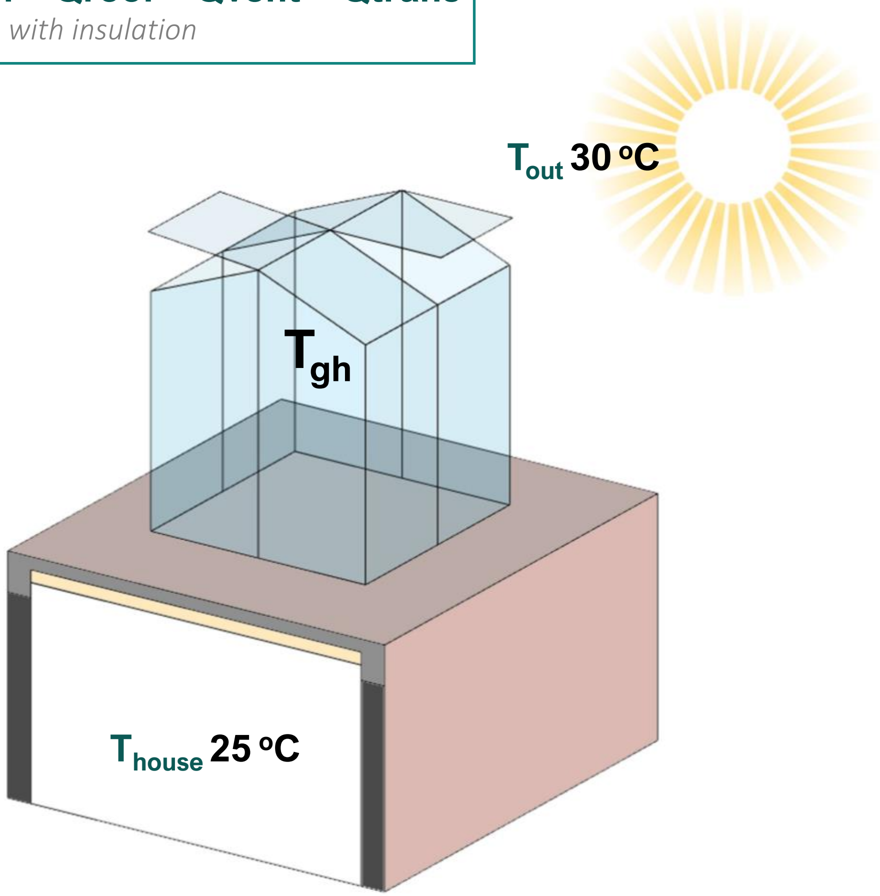
Qsun + Qroof = Qtrans
with insulation



T_{gh} = 42°C to 46°C

INDOOR TEMPERATURE – SUMMER (windows open)

Qsun + Qroof = Qvent + Qtrans
with insulation

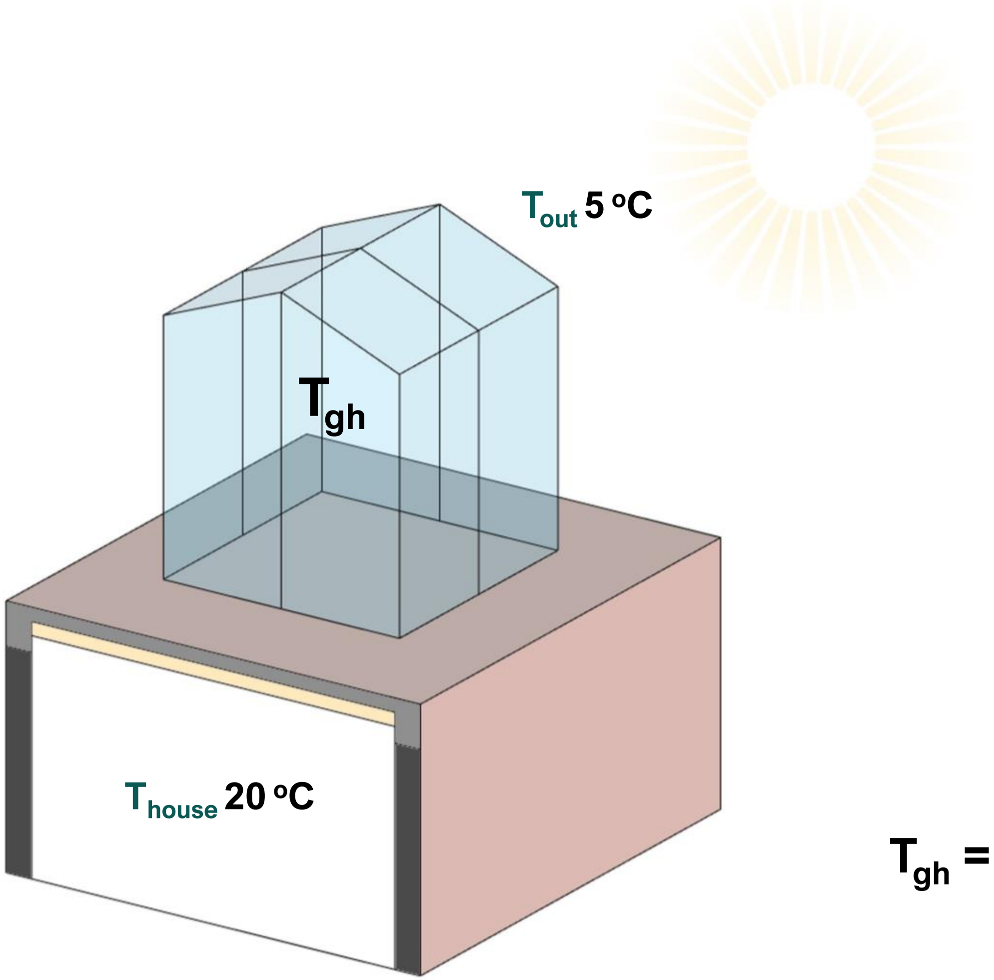


T_{gh} = 39 °C to 42°C

GREENHOUSE ENERGY CALCULATIONS

INDOOR TEMPERATURE – WINTER (windows closed)

Qsun + Qroof = Qtrans
with insulation



T_{gh} = 9°C to 15°C

CROP PLANNING

WARM WEATHER

21-26 ^{o}C
2 months

21-27 ^{o}C
2.5 months

24-30 ^{o}C
2.5 months

COLD WEATHER

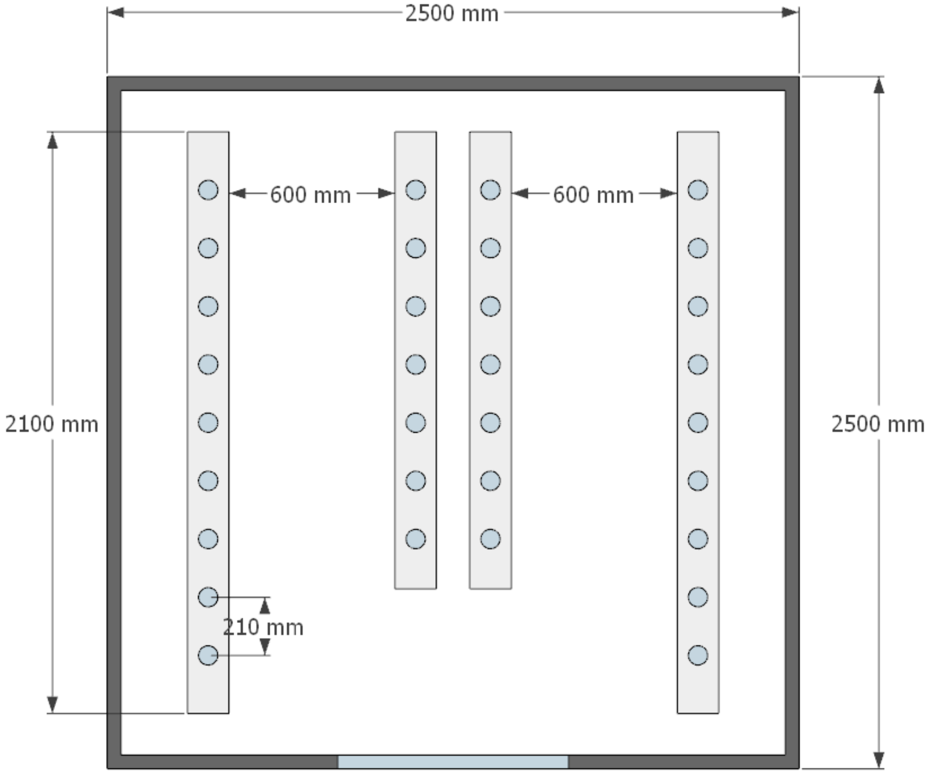
15-20 ^{o}C
1.5 months

10-21 ^{o}C
1.5 months

5-18 ^{o}C
1.5 months

GREENHOUSE DEMANDS

WATER, CO2 & ELECTRICITY



HYDROPONIC PLANTS LAYOUT

9 plants each

9 L per plant

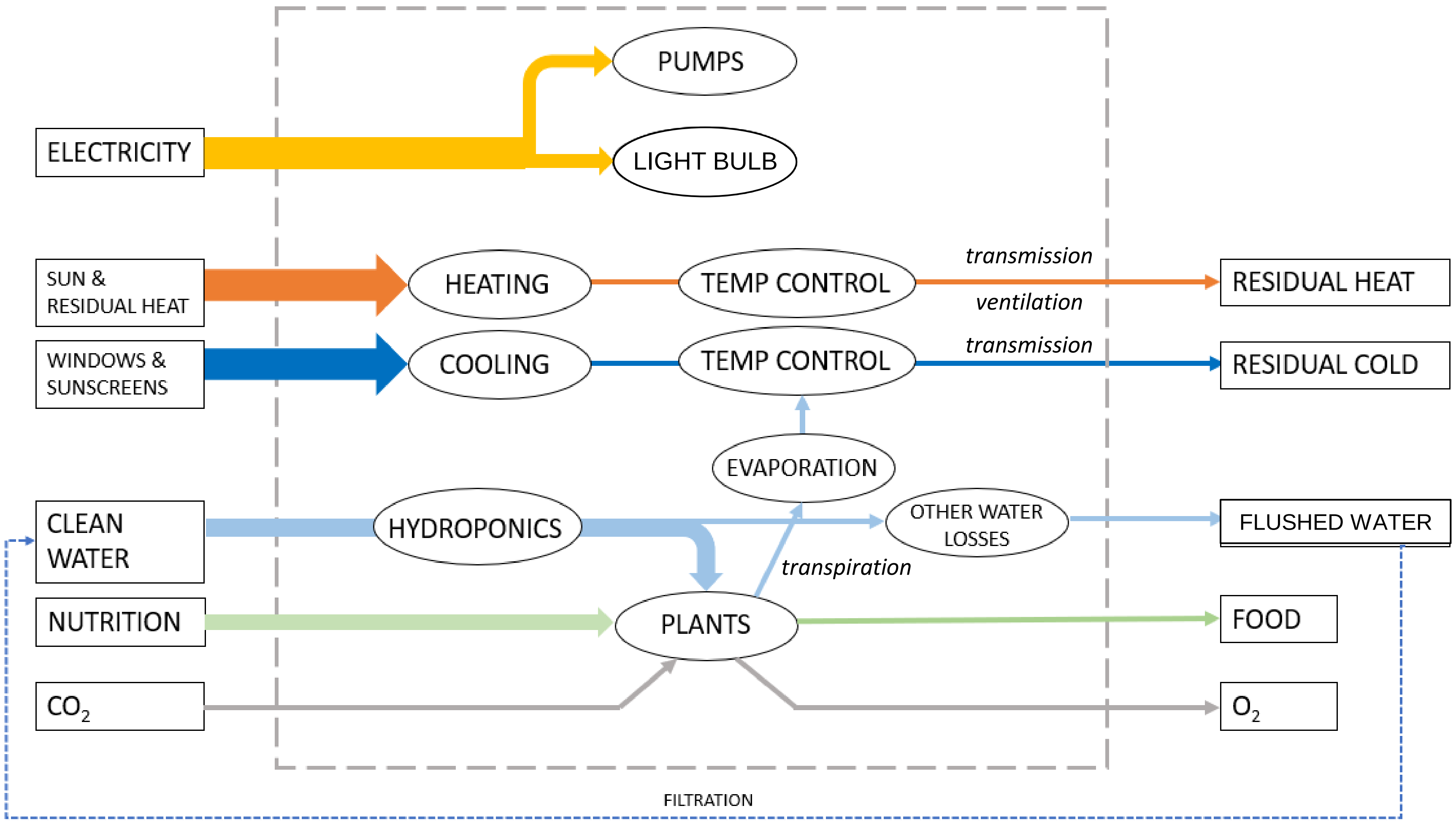
4 L per plant

14 plants each

9 L per plant

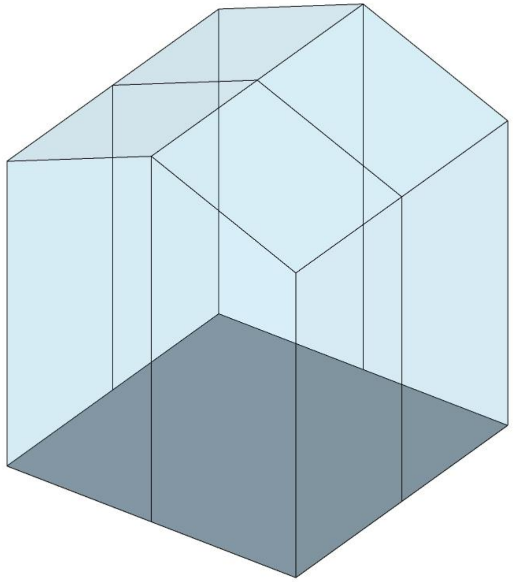
WATER DEMAND	**200 to 300 L** approx. per 2 weeks
CO2 DEMAND	**800 to 1000 ppm**
ELECTRICITY DEMAND	**50kWh/yr (pump and light bulb)**

GREENHOUSE MATERIAL & ENERGY FLOW DIAGRAM



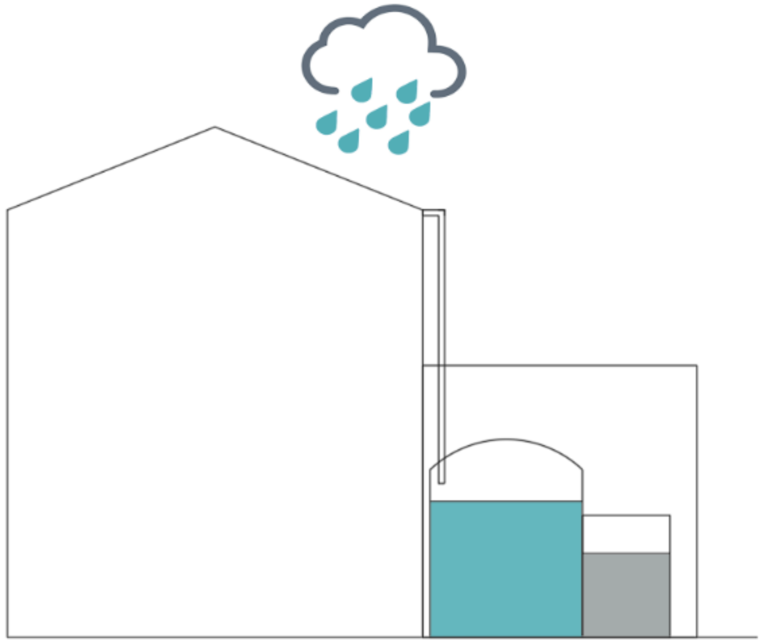
MODULE YIELDS & PRODUCTION

HYDROPONIC GREENHOUSE MODULE



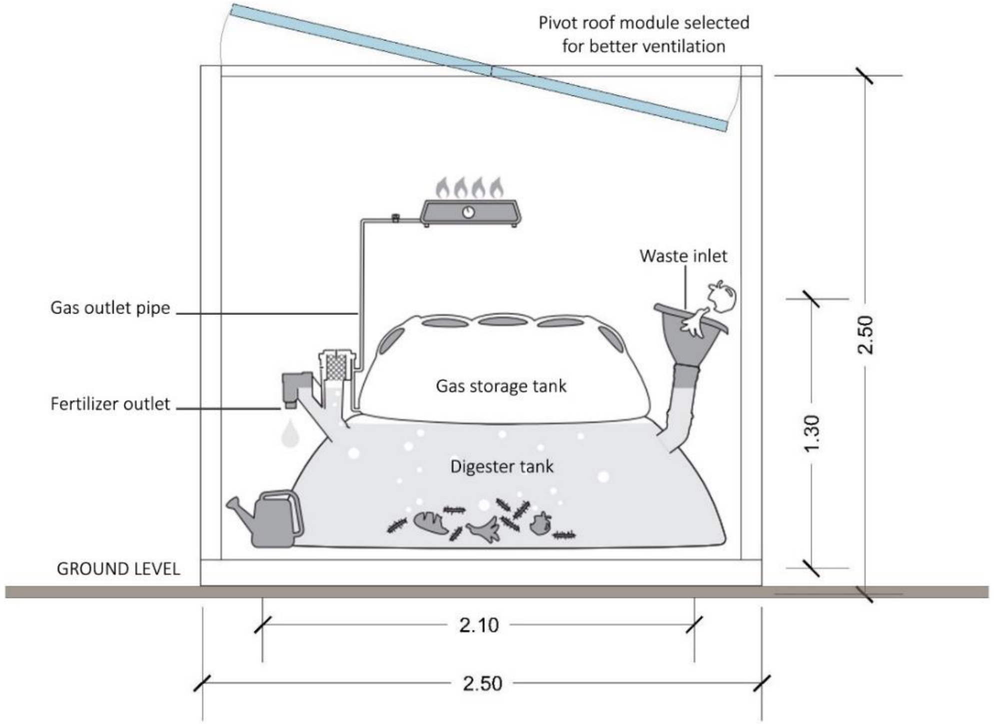
- **Tomato: 72kgs**
- **Cucumber: 324kgs**
- **Paprika: 28kgs**
- **Lettuce: 11kgs**
- **Beetroot: 5kgs**
- **Spinach: 9kgs**

RAINWATER HARVESTING & GRAYWATER FILTRATION MODULE



- **APARTMENT:** 2 apartments **1 tank & 1 filtration unit**
- **DUTCH HOUSE: 1 tank & 1 filtration unit**

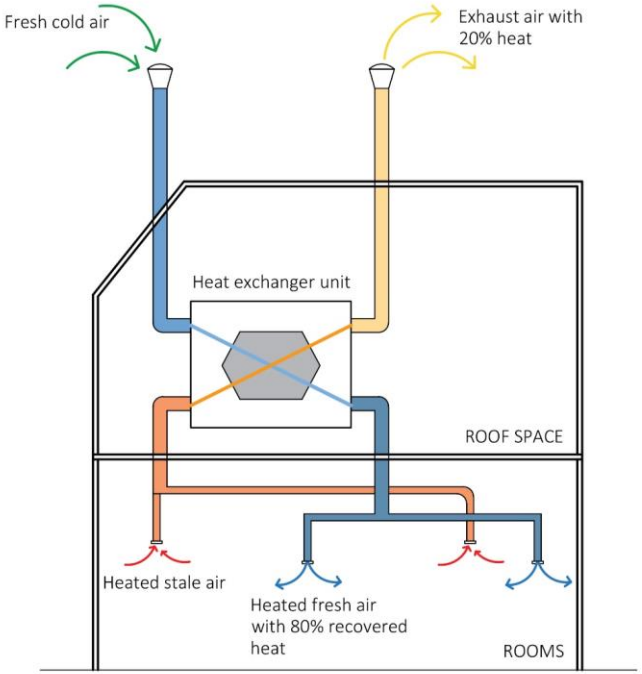
ANAEROBIC DIGESTOR MODULE



up to 2 hours on single flame burner/day

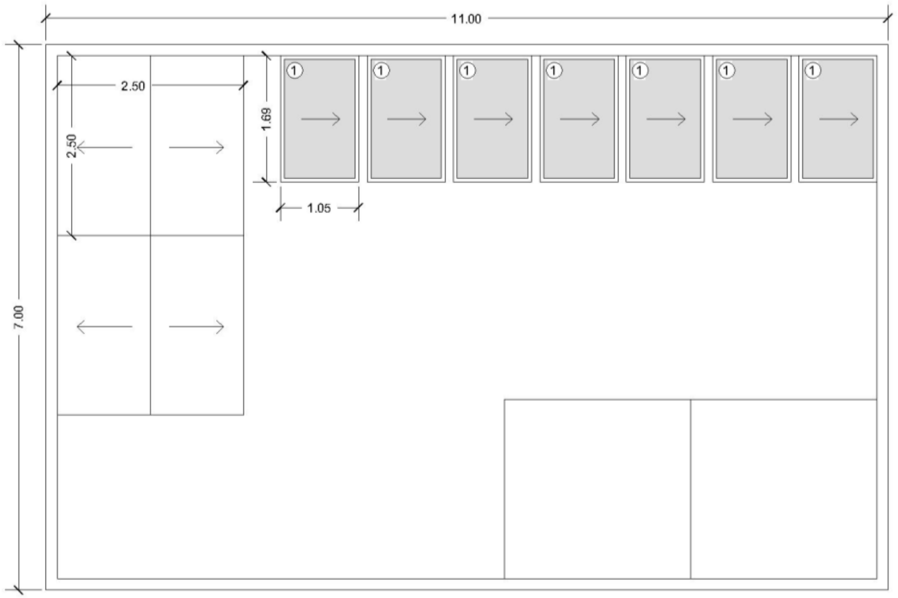
- **APARTMENT:** **0.2L fertilizer** per day
- **DUTCH HOUSE:** **0.4L fertilizer** per day

VENTILATION HEAT EXCHANGER

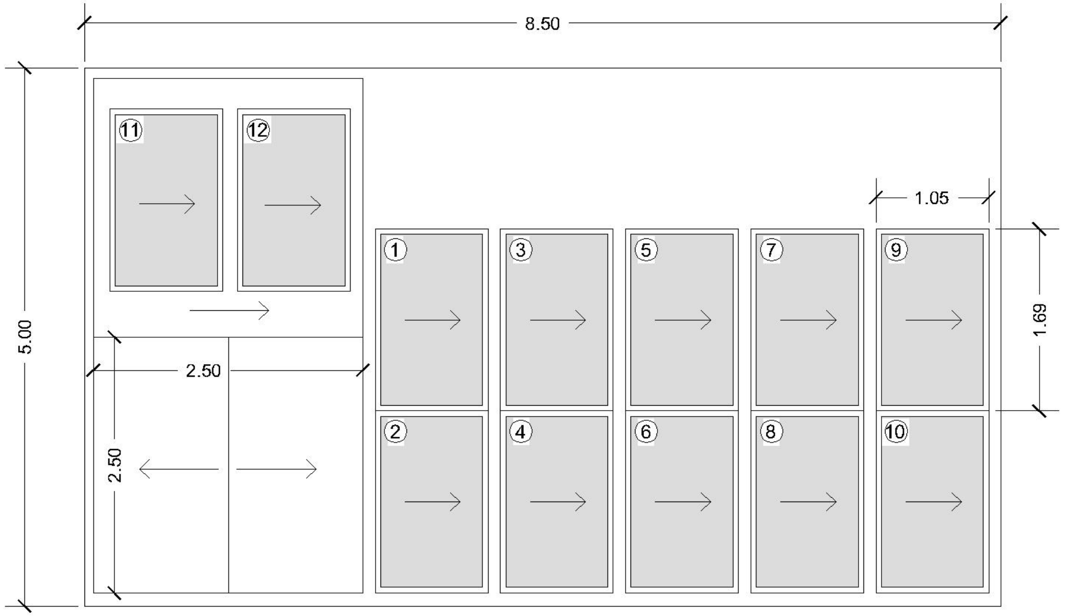


- **APARTMENT:** **2.48 kWh/day** heat recovered
- **DUTCH HOUSE:** **0.94 kWh/day** heat recovered

SOLAR PANELS



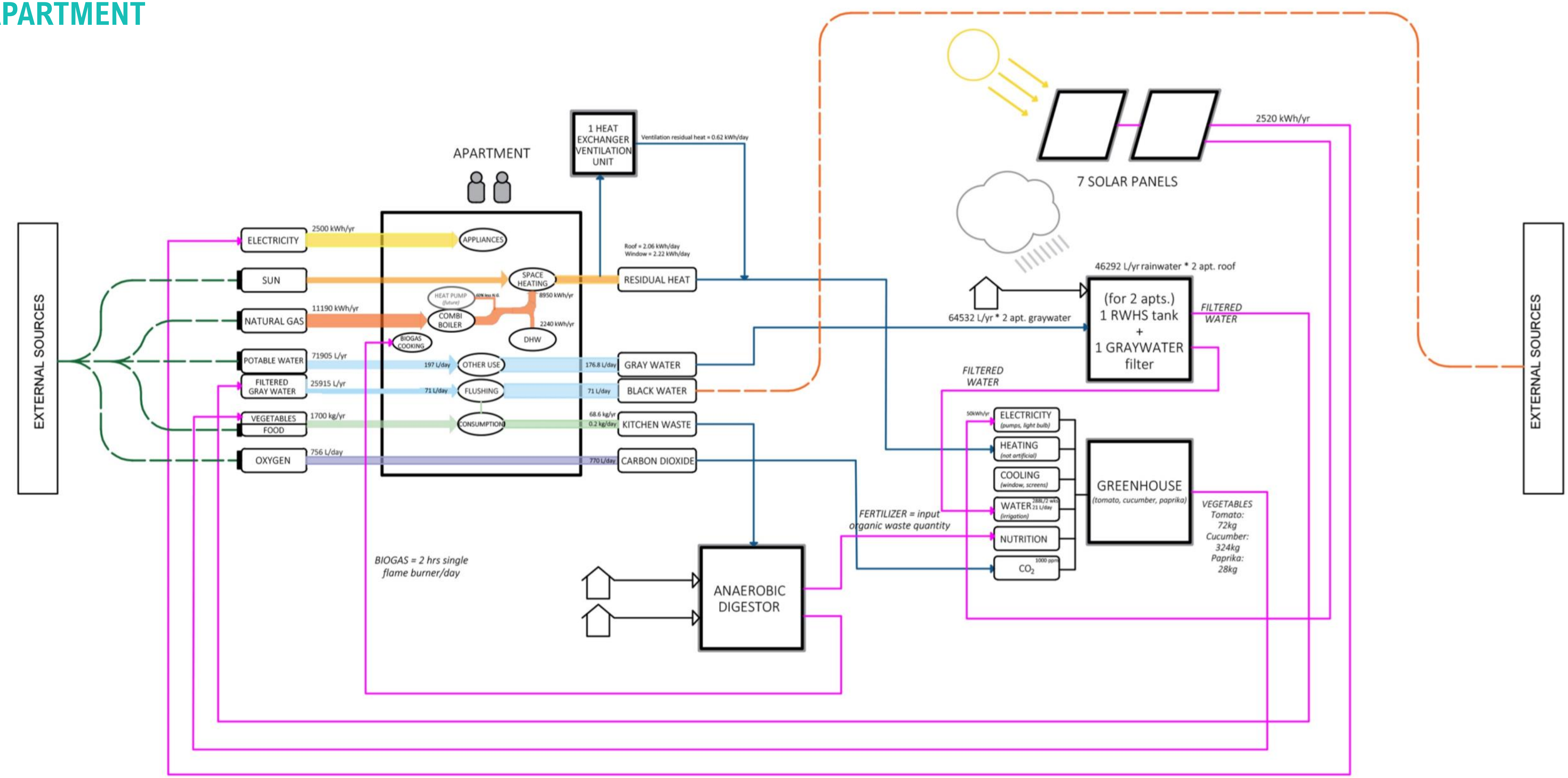
APARTMENT
7 panels : 2520kWh electricity



DUTCH HOUSE
12 panels : 4320kWh electricity

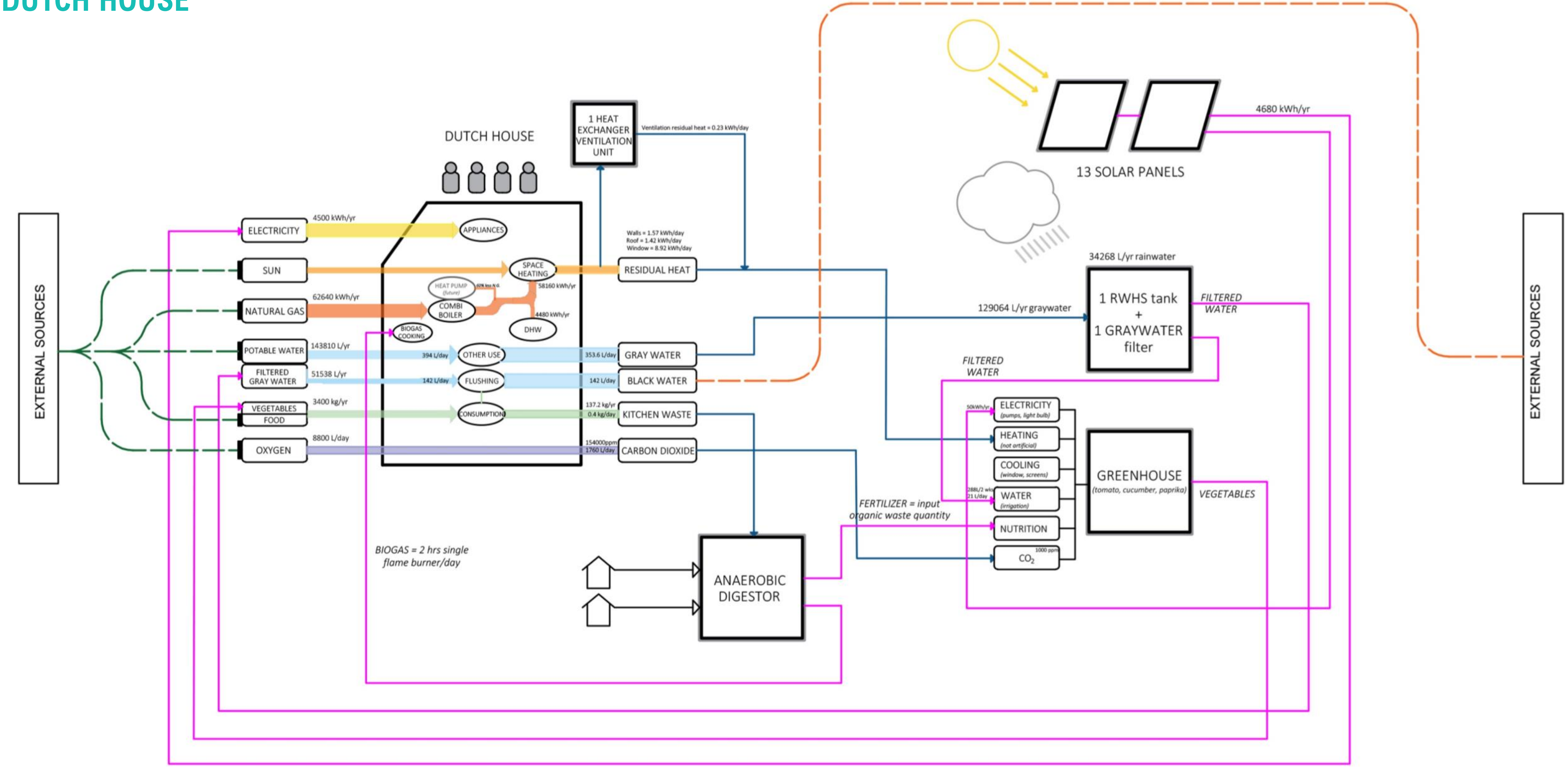
CO-SYMBIOTIC MATERIAL & ENERGY FLOW DIAGRAM

APARTMENT



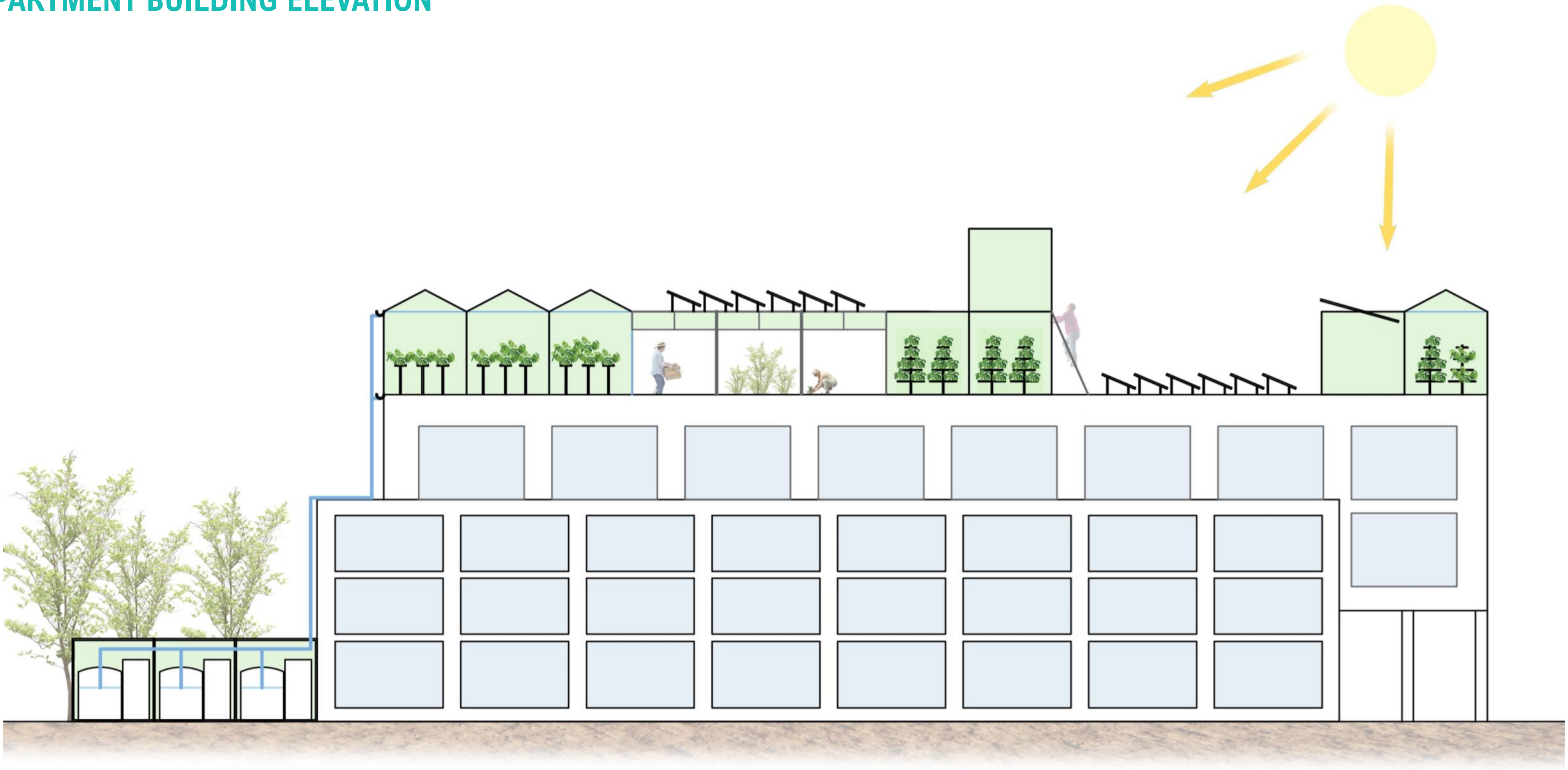
CO-SYMBIOTIC MATERIAL & ENERGY FLOW DIAGRAM

DUTCH HOUSE

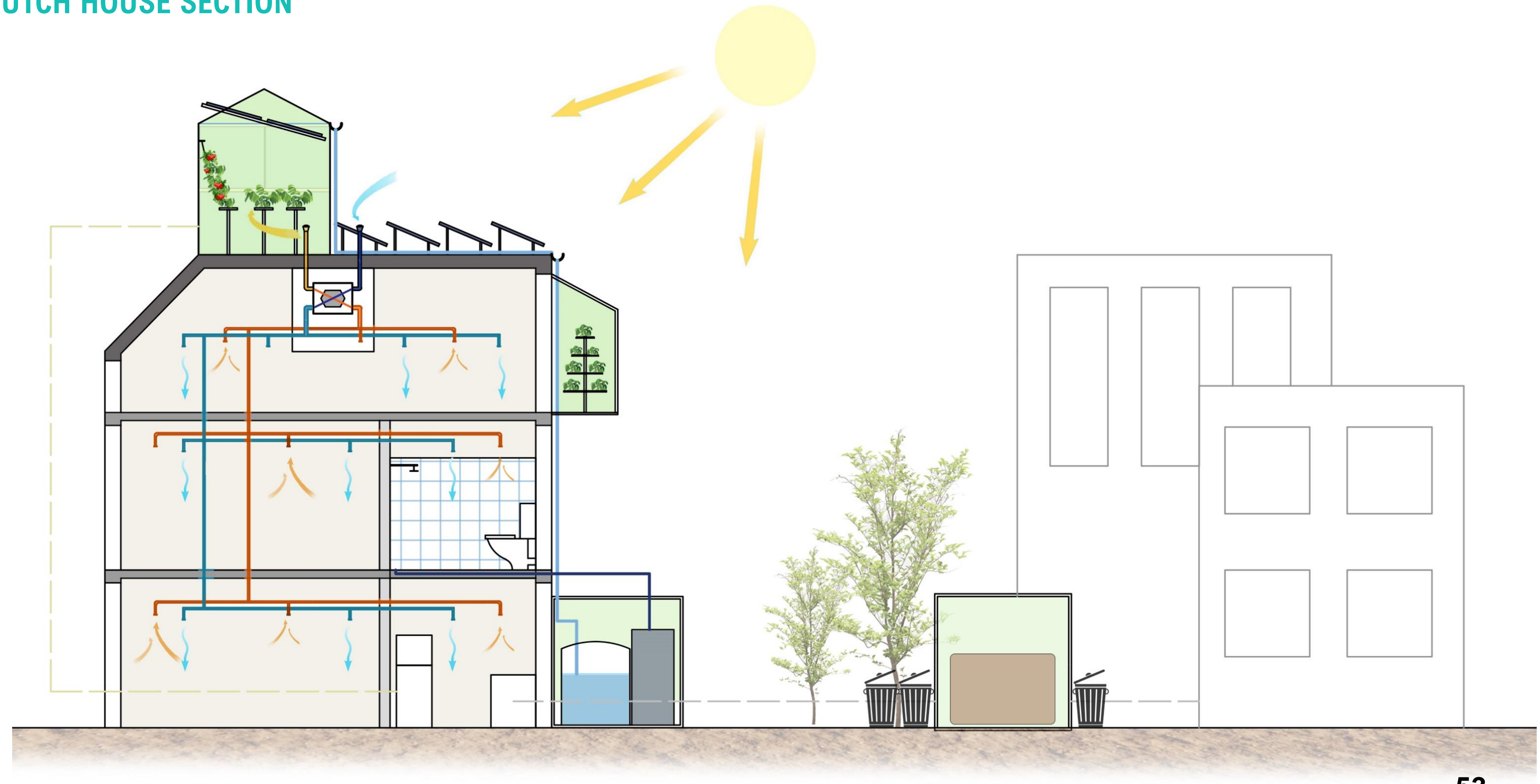


MODULE DESIGN

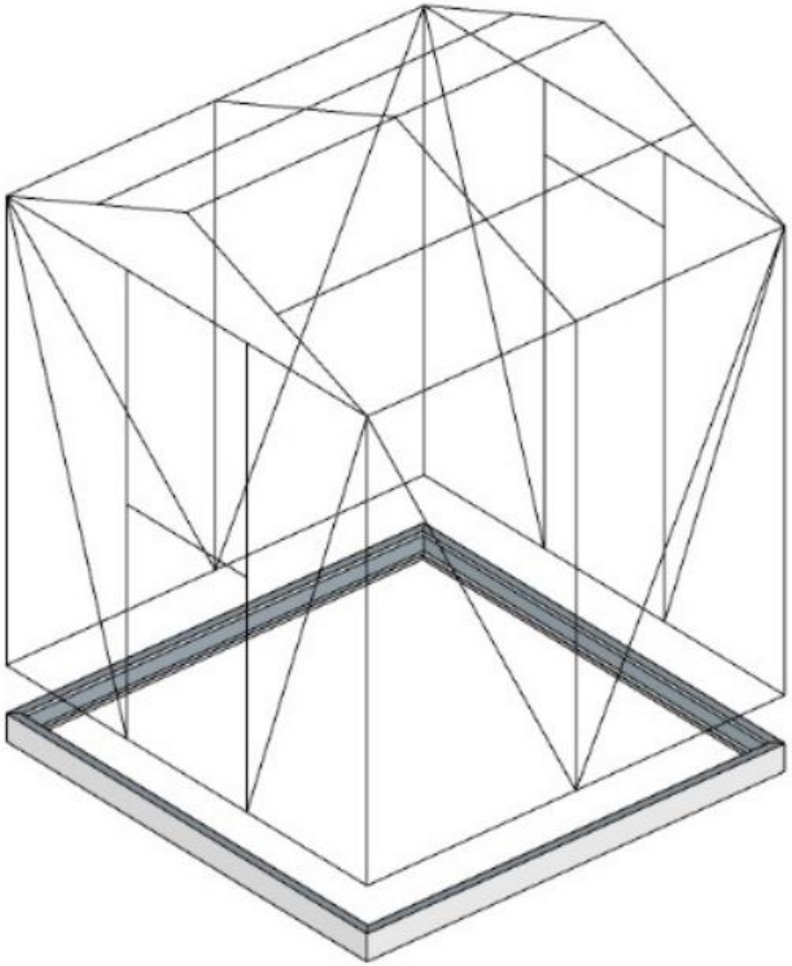
APARTMENT BUILDING ELEVATION



DUTCH HOUSE SECTION

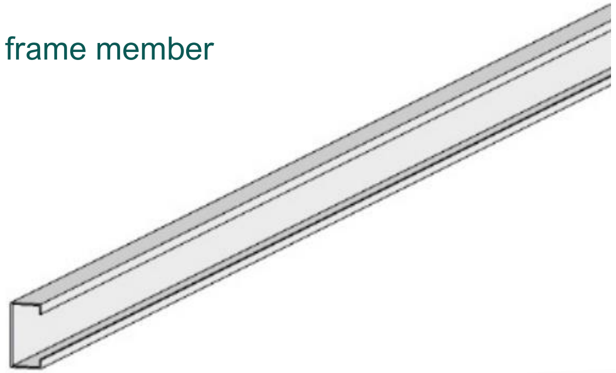


STRUCTURAL DESIGN

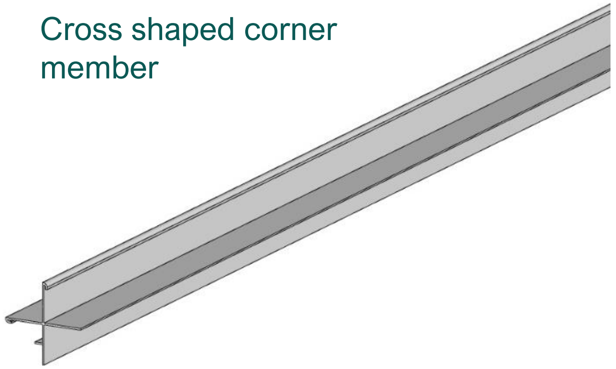


PARTS FROM DEMOLISHED GREENHOUSE IN NL

C – steel frame member

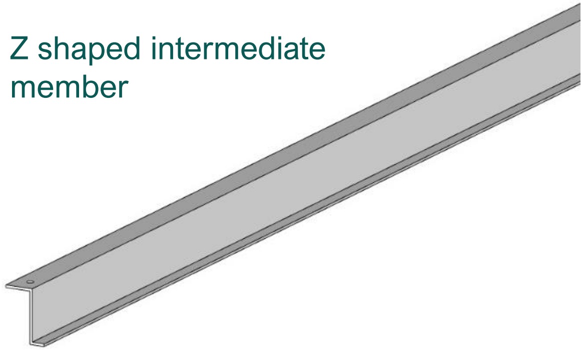


Cross shaped corner member

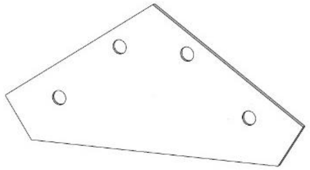


T – shaped structural member

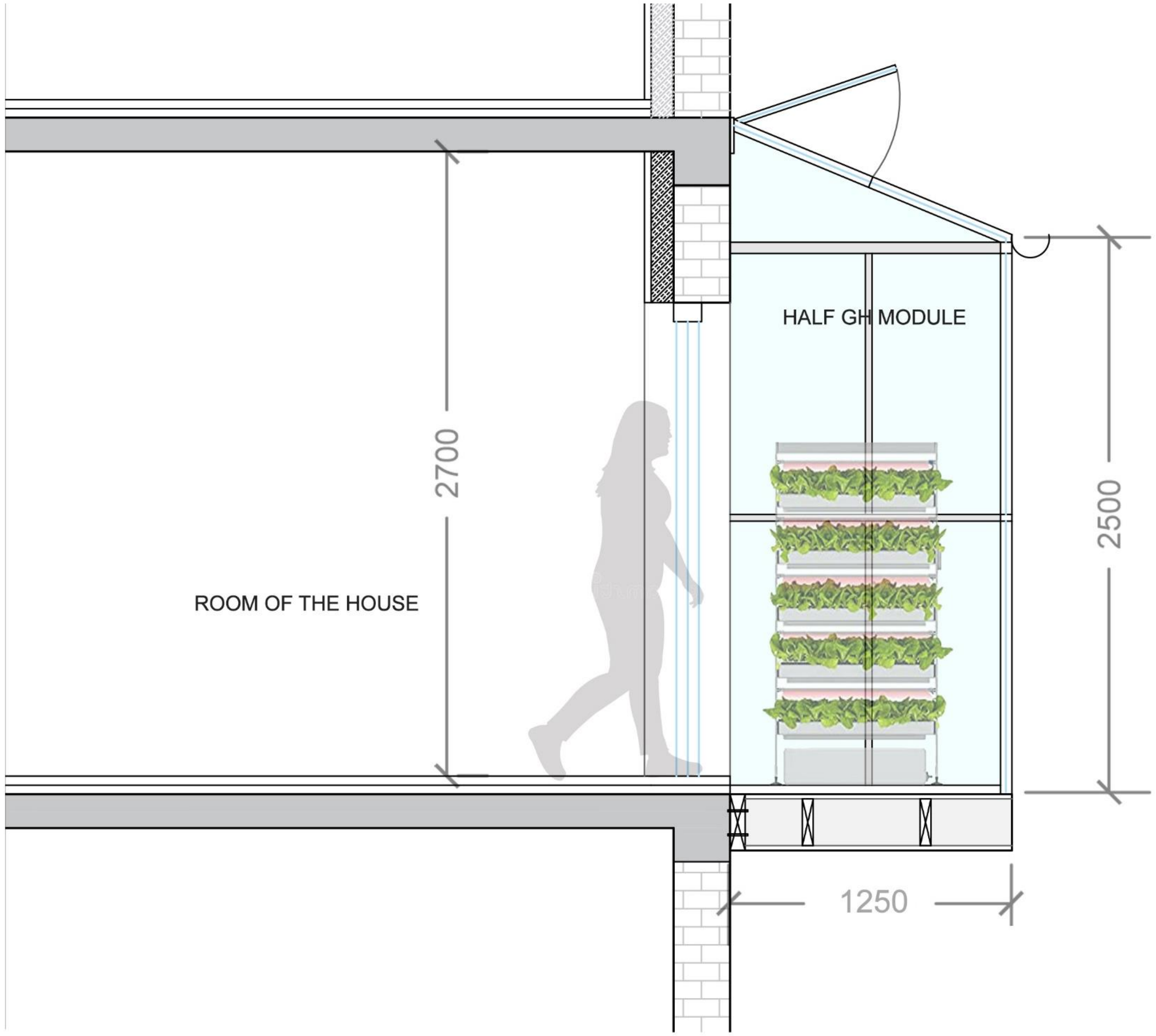
Z shaped intermediate member



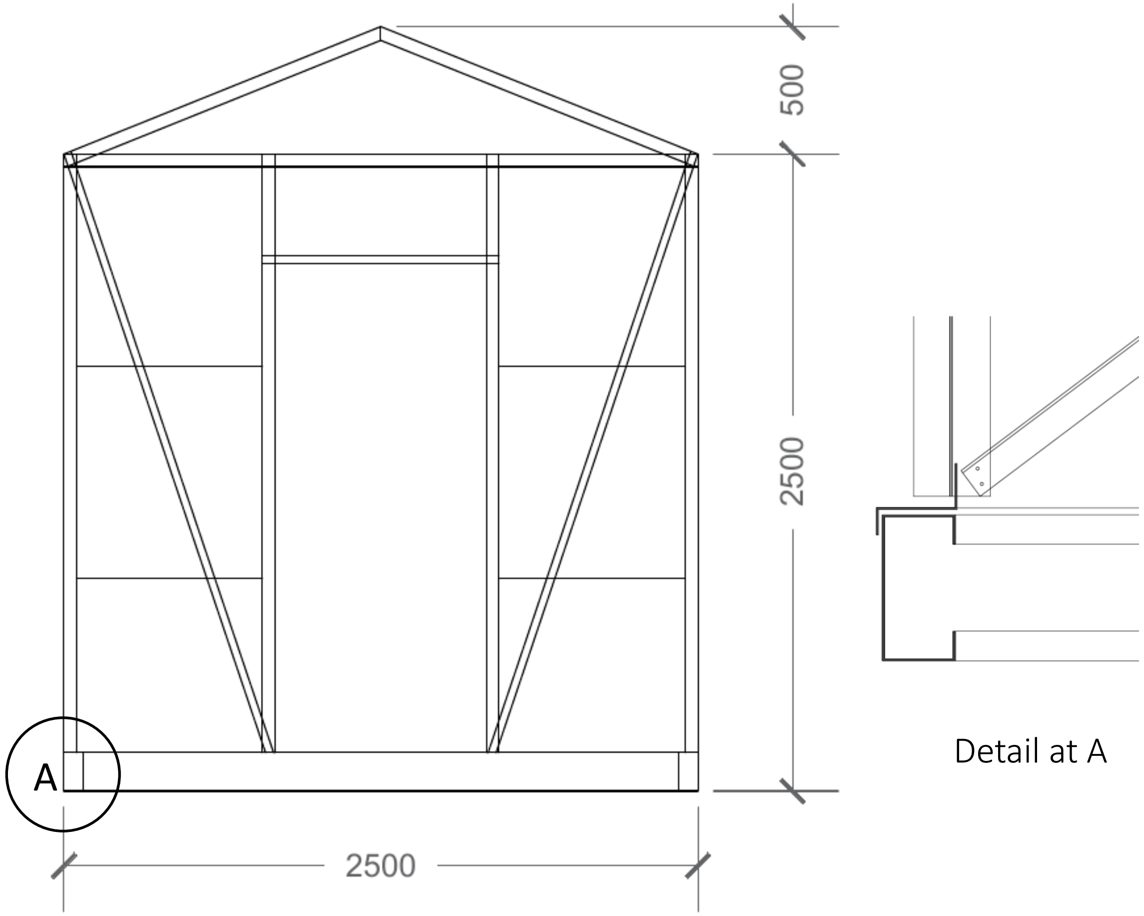
Connection plate



STRUCTURAL DESIGN

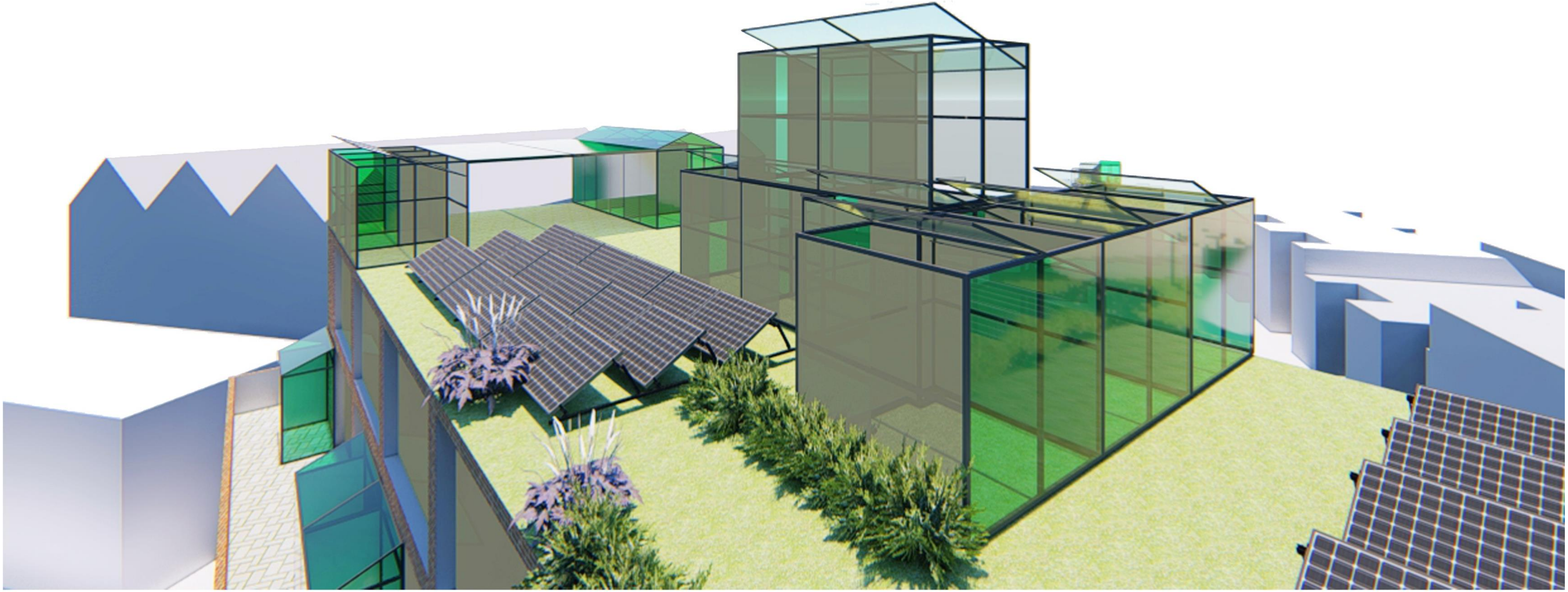


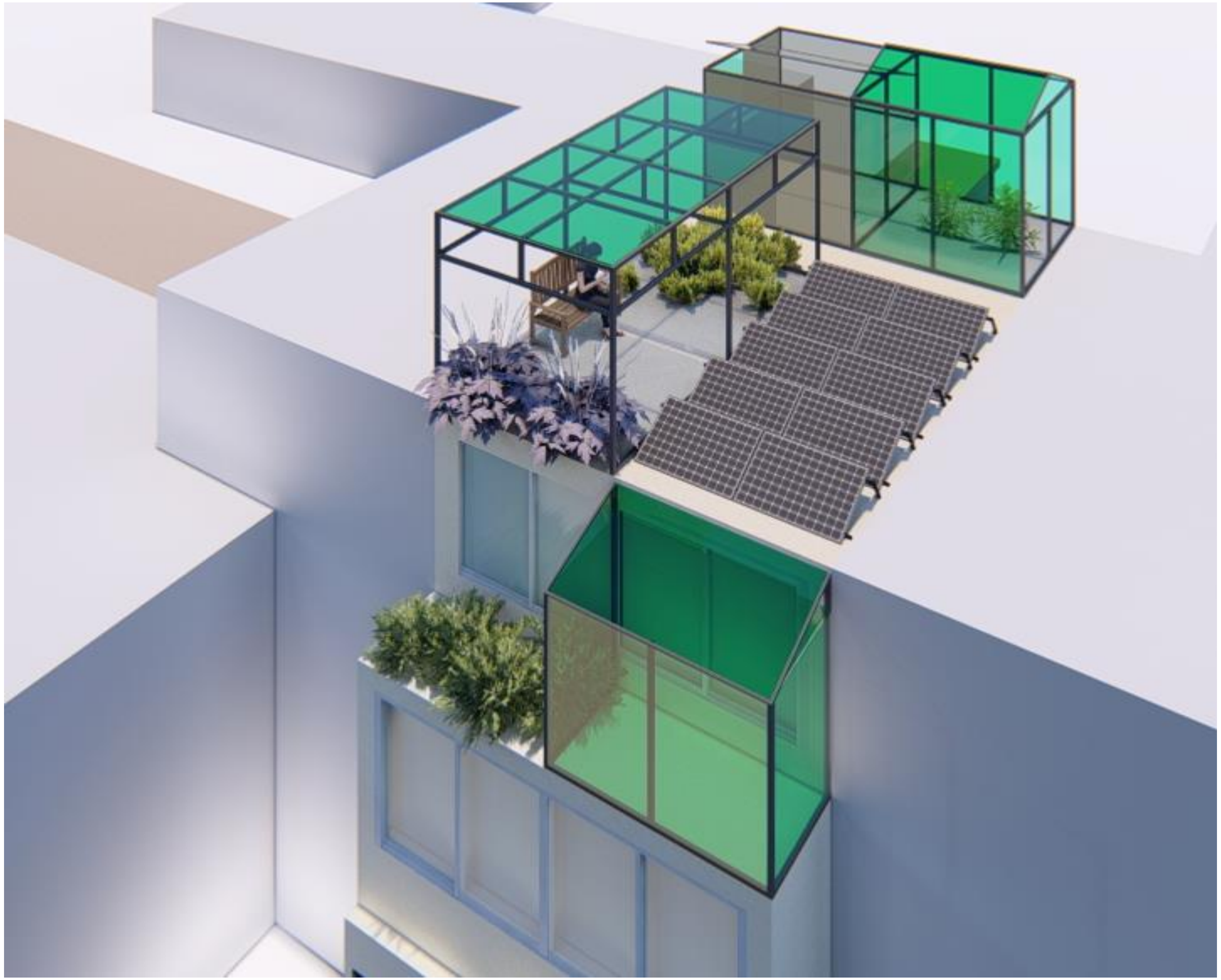
SIDE ELEVATION OF HALF MODULE



FRONT ELEVATION OF FULL MODULE

VISUALIZATION

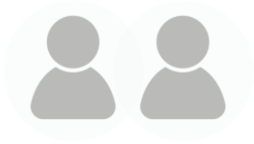




EVALUATION

DEMAND vs GENERATION

APARTMENT BUILDING



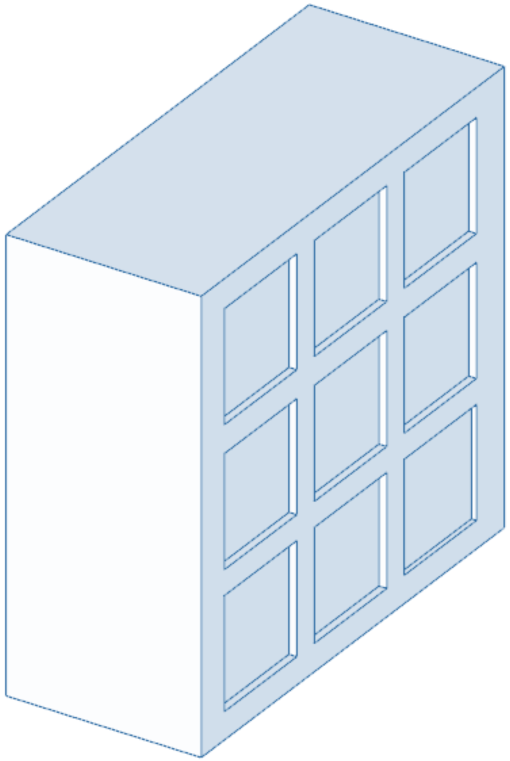
DEMAND without GH

2500kWh
electricity

1.17kWh
heat loss

45361L
non-potable water

70kg
vegetables



SUPPLY after GH

2520kWh
electricity

0.62kWh
heat loss

110824L
non-potable water

450kg
vegetables

$120kWh/m^2$ A → $70kWh/m^2$ A++

DEMAND vs GENERATION

DUTCH HOUSE

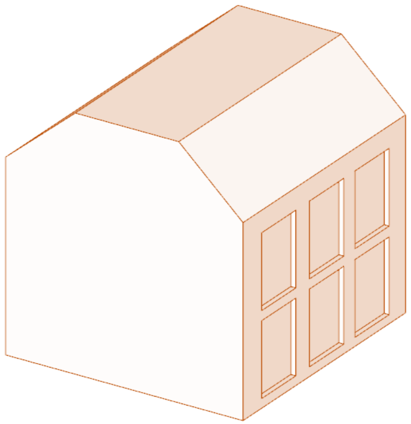
DEMAND without GH

4500kWh
electricity

3.10kWh
heat loss

85730L
non-potable water

140kg
vegetables



SUPPLY after GH

4320kWh
electricity

0.23kWh
heat loss

163113L
non-potable water

450kg
vegetables

360kWh/m^2 F → 230kWh/m^2 C

INDOOR CONDITIONS & YEILD

GREENHOUSE

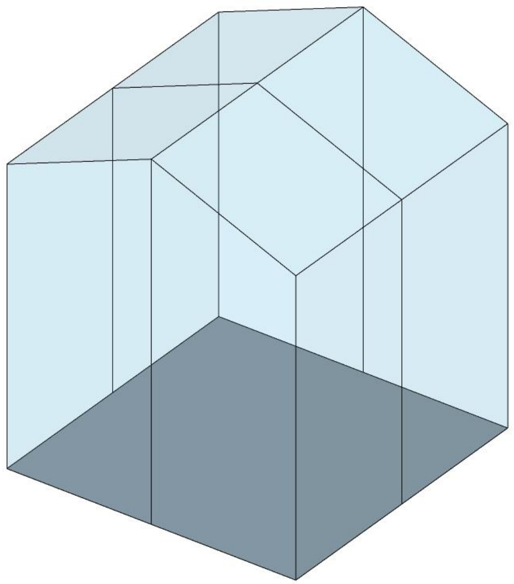
TEMP INSIDE GH

WINTER
9 - 15

SPRING
19 - 25

SUMMER
39 - 42

AUTUMN
14 - 24



SEASON FOR CROP

21 - 26
Tomato SPRING

15 - 20
Lettuce AUTUMN

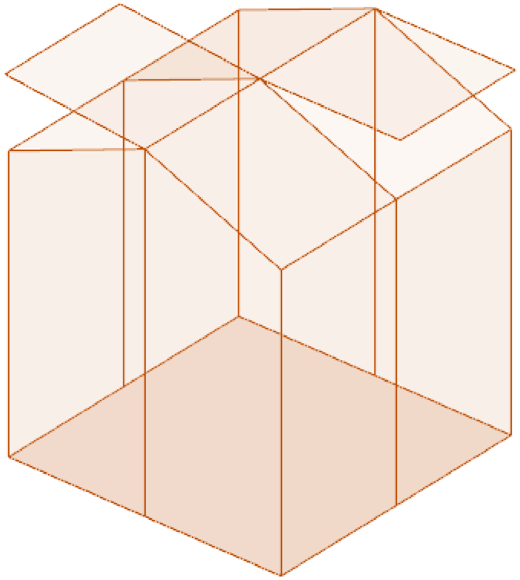
21 - 27
Paprika SPRING

10 - 21
Beetroot AUTUMN

24 - 30
Cucumber

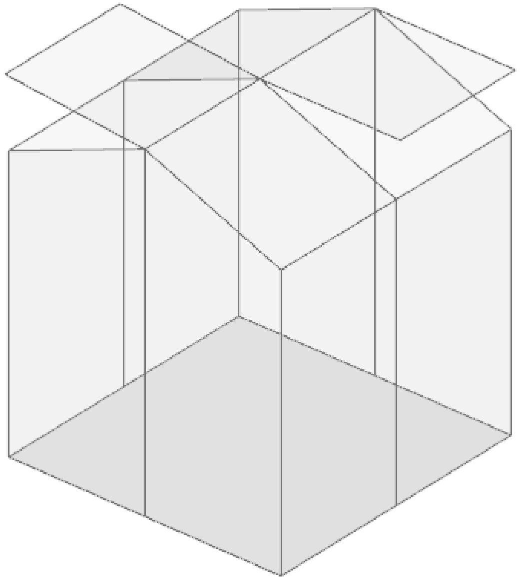
5 - 18
Spinach WINTER

SUMMER



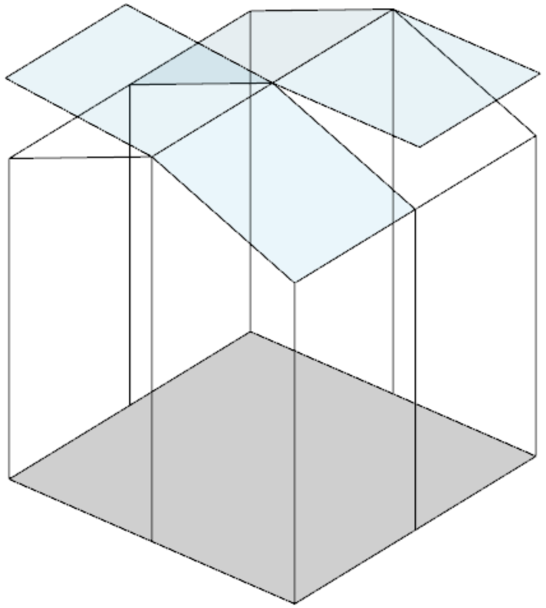
Windows open
No sun-shading

39 – 42°C



Windows open
Sun-shading or screens
(20% SHGC)

30 - 32°C

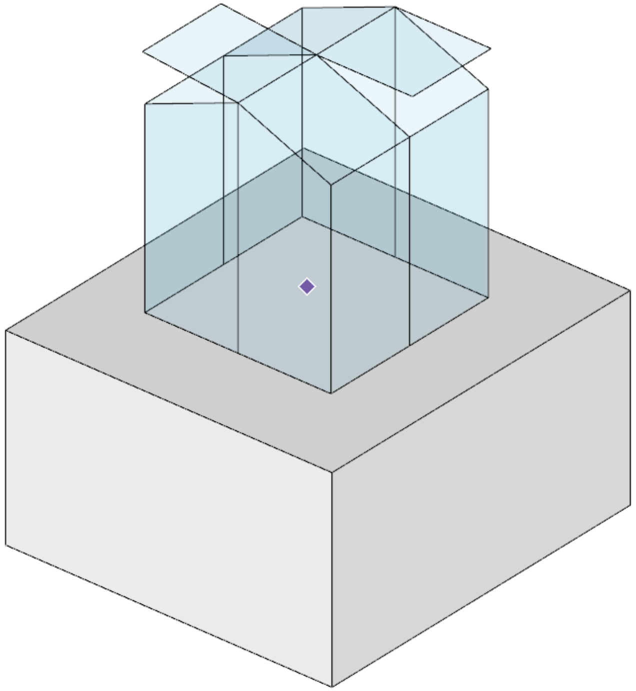


Windows open
No enclosure on sides

Slightly cooler than outside temp

GREENHOUSE BENEFITS FOR BUILDING

- Extra insulation
- Preventing solar heat gain inside house during summer
- Cooling effect by plants



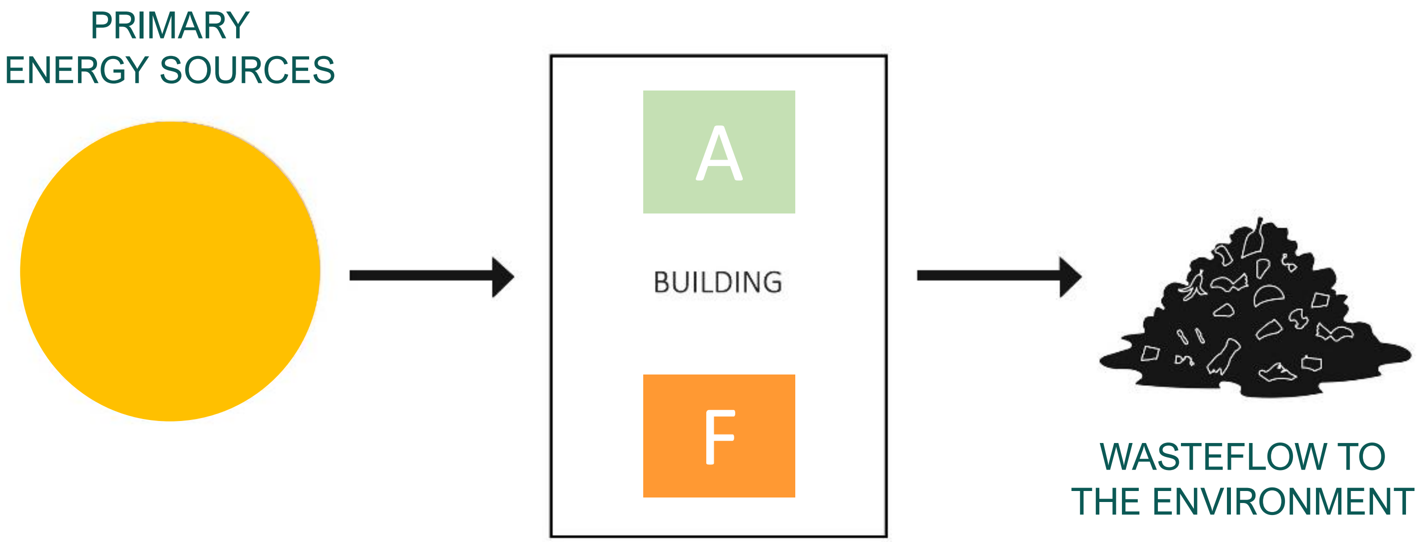
- Grey water filtered & used for plants
- Rainwater from roof collected

- Extra insulation
- Preventing heat loss from house during winter
- Residual heat from house used in GH

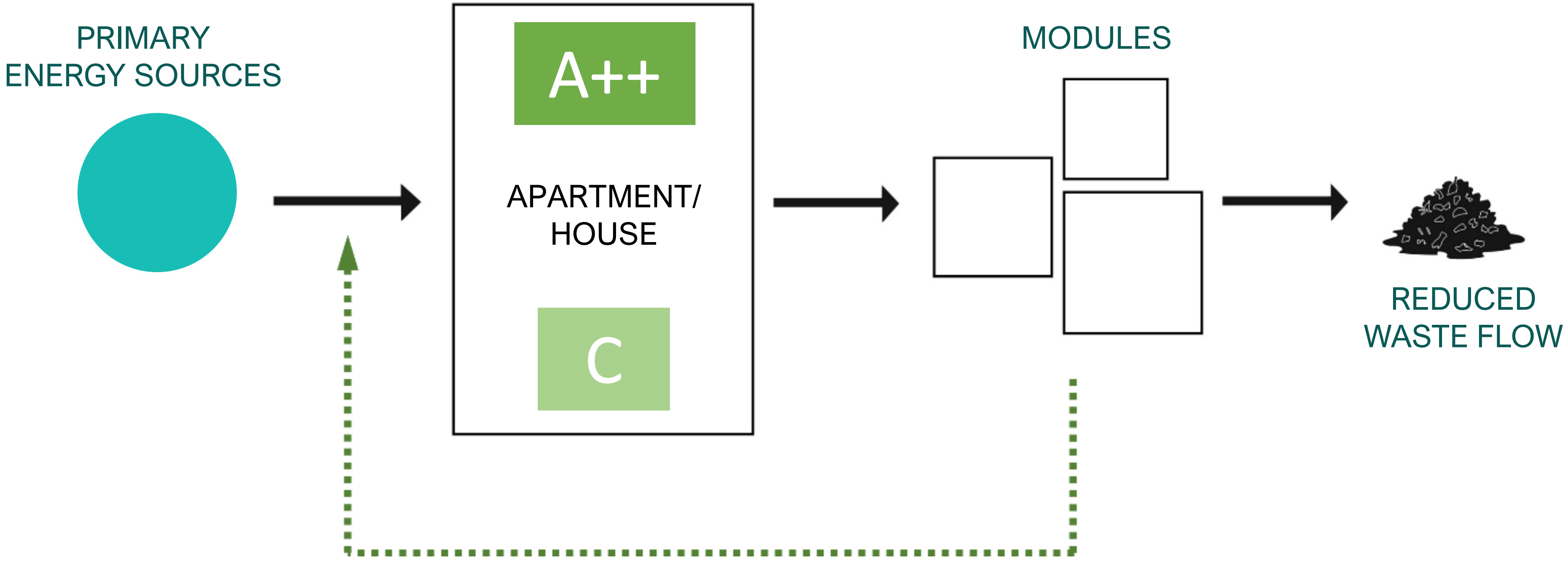
- CO_2 from house circulated in GH from crop growth

CONCLUSION

BEFORE


PRIMARY
ENERGY SOURCES
A
BUILDING
F
WASTEFLOW TO
THE ENVIRONMENT

AFTER


PRIMARY
ENERGY SOURCES
A++
APARTMENT/
HOUSE
C
MODULES
REDUCED
WASTE FLOW

THANK YOU