BIOTECTURE VILLAGE
Thematic research paper

Abstract

To reduce the environmental impact of built environment, a circular approach needs to be implemented on all levels. Resources often travel great distances to their consumers, which leads to an inefficient and wasteful supply chain. Thus, by moving to localized production of all resources needed to sustain a small village can be greatly reduced. This research intends to explore the possibilities of a self-sufficient village applying known technologies to all energy and material flows. Achieving full autarky is therefore a key aspect of the plan. The demands of water, food and energy will be researched and from this a quantified plan will emerge that can serve as design guidelines. The village will be placed in the Dutch sub-urban context of Parkstad, which is known for population decline and changing demographics. This region will be presented by IBA as a regional incubator of sustainable innovations by the year 2020. It is therefore essential to attract people of all age groups to seize this opportunity and collaborate for a sustainable and diverse living environment.

Colophon

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1. Introduction

The area around the municipality of Heerlen is struggling with high vacancy rates, shrinkage and changing demographics. In order to mediate this trend, IBA-Parkstad was established to search for innovative solutions that would sustainably benefit the region and its identity. Along themes of “recycle city”, “energy city” and “flexible city” changes will be made to reinvigorate public space, green landscape and urban neighbourhoods. These changes will need to ensure a sustainable and attractive future for the region and its municipalities. In the spirit of this, I want to explore innovative housing solutions and permaculture, which can enable a local independence of resources while adding spatial quality to the surrounding. As the need for reducing architecture’s carbon footprint has been growing in the past decades, the relevance of circular design and closing material flows has been proven. Resources nowadays travel great distances to their destinations, often leading to losses along the way. Therefore, the challenge of today is to locally organize sustainable food, energy, water and waste flows. This leads to the following questions:

Thematic research question:

How can the flows of food, energy, water and waste be locally organized and incorporated in the design of an autarkic eco-village that exemplifies sustainable living in Parkstad?

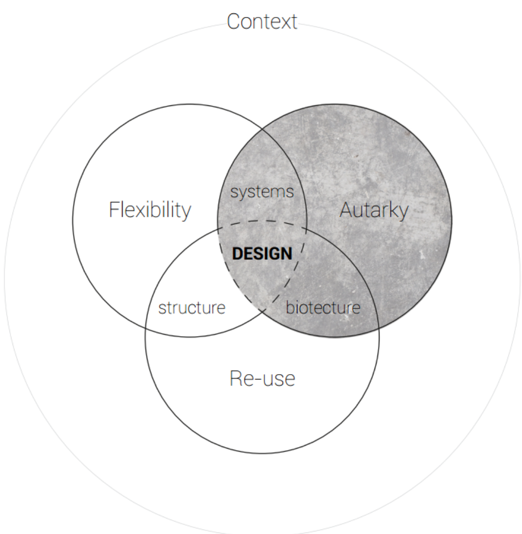
Sub-questions:

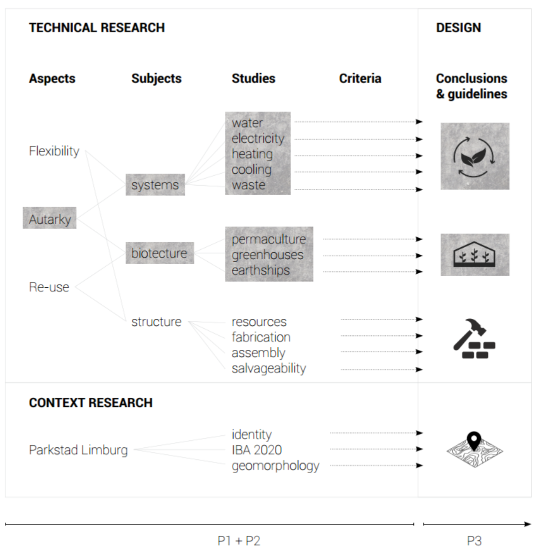
- To what extent can earthship biotecture aid to the autarky of housing in The Netherlands?
- How much surface area is required to produce enough food and water for the village?
- How much energy can be generated with waste flows and can this power the village?

2. Methodology

This research is mainly informed by literature and case studies. IBA-Parkstad documents have provided background information about the projected urban developments. E-mail correspondence with permaculture enthusiasts and lectures were used to assess the need of such lifestyle in the region. Existing research literature and case studies about earthship biotecture was used to examine its potential in the local climate and what parts of its design principles are of use during the design process. Research about closed greenhouses as energy producers has been used as well. Consequently, case studies about the use of anaerobic (biogas) digestion in conjunction with a Combined Heat and Power system (e.g. Zonneterp Greenhouse Village) have been used to quantify a general approach for the eco-village. With this collected information material flow analyses can be made and each flow can be quantified using spreadsheet calculations.

Chapter 3 will provide information about the locational context. Assumptions about future housing needs and locational climatological data will inform the creation of a program of requirements. From this program, a conceptual design for the eco-village emerges. Thereafter, chapter 4 will explore the concept of autarky according to earthship biotecture, greenhouses and permaculture according to the data from chapter 3. This will also include systems of autarky of relevance and what their spatial implications (in m^2) may be for the design phase.



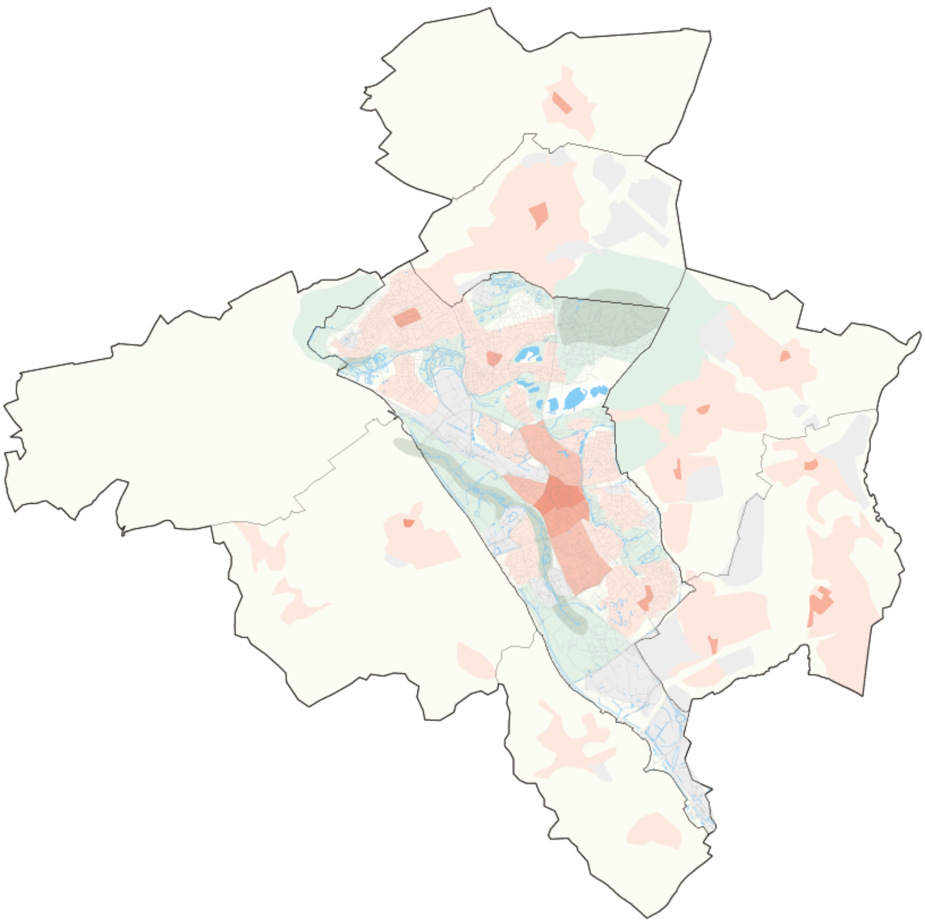


3. Context: Parkstad

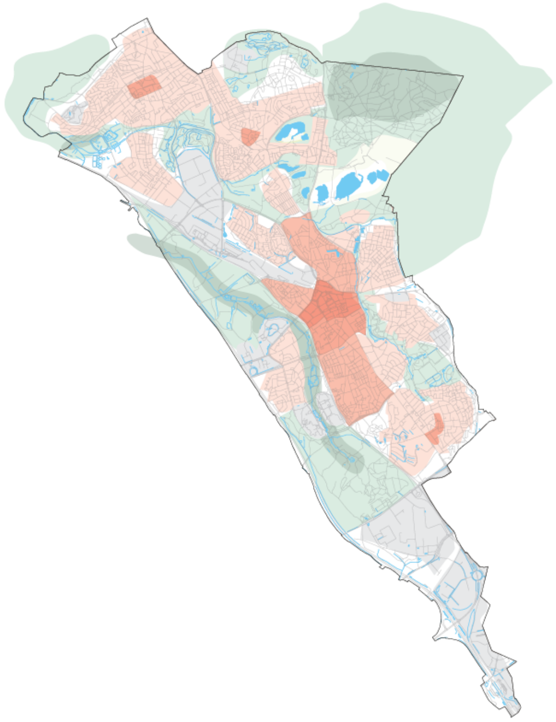
Parkstad is a 255.000-people region that consists of eight collaborating municipalities in South-eastern Limburg, the largest and most central of which is Heerlen. Parkstad used to be a major energy producer for The Netherlands due to its coal mining industry, but was not able to economically adjust after its industrial decline. This has left the region with relatively high unemployment rates and a shrinking population. However, the region has grown rapidly in a hotspot for leisure, tourism and nature recreation. The region's rather unique heathland hills and stream valleys are considered of great national value. High sea levels during the Miocene deposited sand, silt and clay sediments which led to raised plateaus and unique vegetation. The Brunssummerheide nature reserve lies on one of these plateaus and is regarded as the largest natural heathland of its surroundings, attracting many recreational visitors.

Besides leisure and recreation, the regional focus has also shifted towards entrepreneurship due to the availability of low-cost office spaces. These attract young start-up talent to settle in Parkstad. Moreover, with the introduction of IBA, Parkstad seeks to provide an open campus dedicated to the search, application and production of renewable energy. IBA-Parkstad revolves around three themes; recycling, flexibility and energy. By the year 2020, IBA-Parkstad aims to present innovative projects that aid to a more sustainable future. Initiatives like Avantis, Solland Solar and M3 Recyclepark are an example of this development. Consequently, the region will be in the international spotlight more than ever.

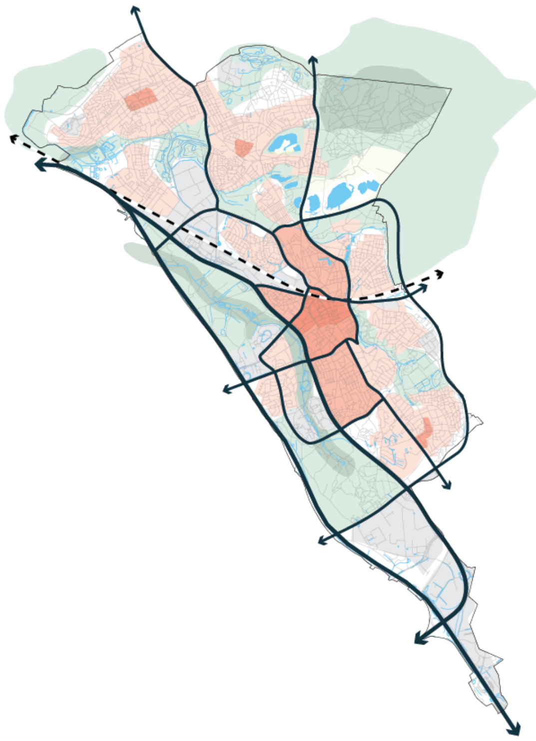
In order to prevent further population decline, Parkstad needs to become an attractive stage for starters and families, while also prepare for an increasingly ageing population. This will have to be done according to the three themes IBA has urged. Therefore, my proposal is to exemplify sustainable living by introducing an eco-village which can house various age groups in local off-grid autarky. Ideally, the village will produce enough energy to power a visitor centre. This village will prove that housing can be energy producers, instead of consumers. As a result, an attractive and sustainable place to live can be created to reinvigorate a shrinking region.



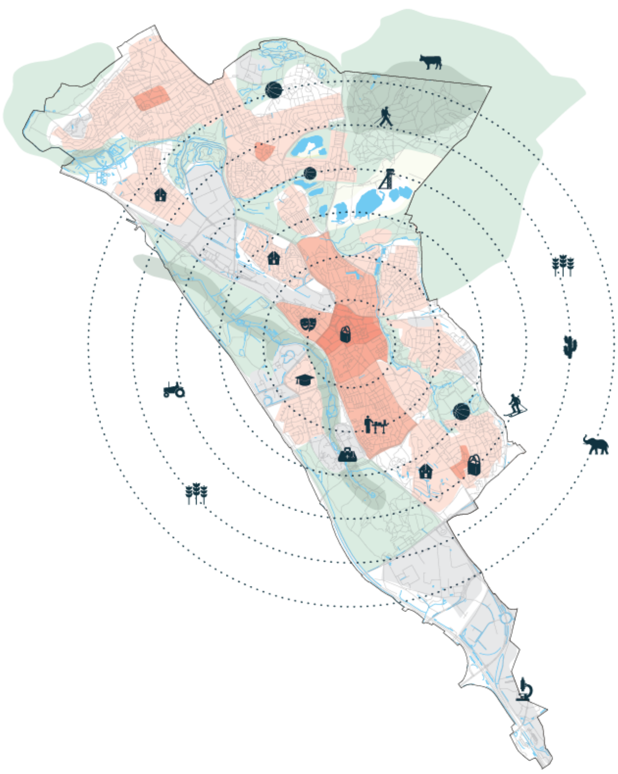
3.1 Heerlen



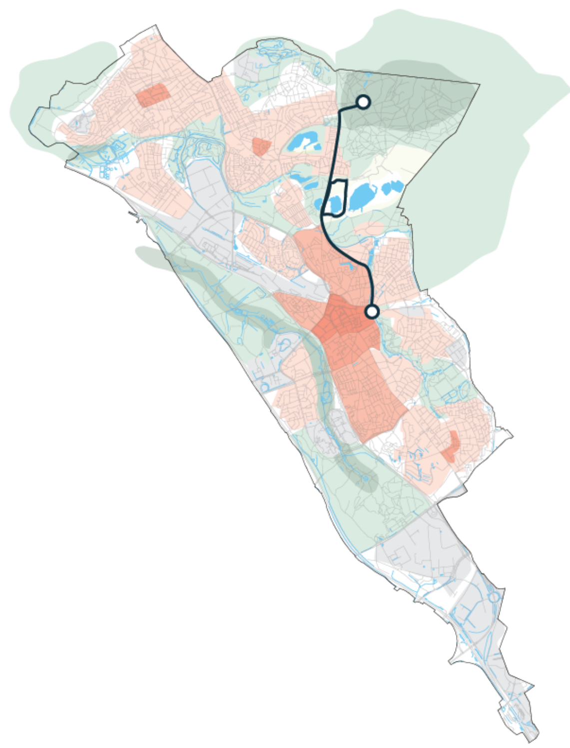
1. Municipality of Heerlen



2. Infrastructure in and around Heerlen



3. Facilities and places of interest in Heerlen

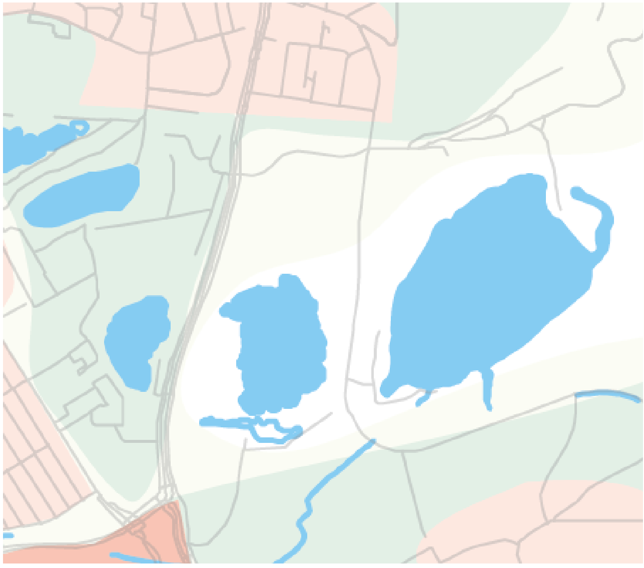


4. Location between city center and recreational nature area of Brunssummerheide

3.2 Location Beaujean East Sand Quarry

700m * 300m, surface around 22 Hectares.

Situated on a sand deposit layer 40 to 60m deep.

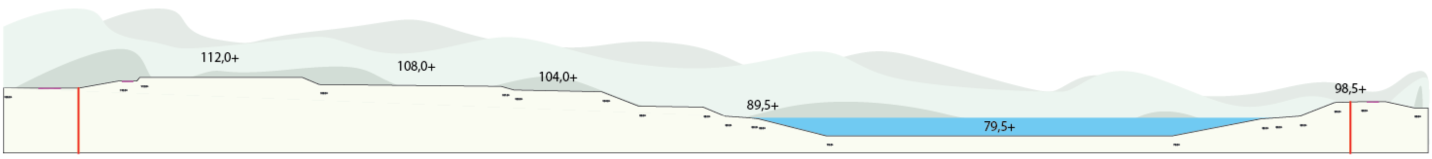


Beaujean East Sand Quarry plot. Housing destination plan is being approved by the Municipality. The Sibelco Quarry to the East of the plot is planned to be restructured to a recreational area.

3.2.1 Eco-village situation

The sandy layer in the soil of the plot is an underground that is very well suited for buildings without foundations. Movable structures and modular types of building are therefore possible on this terrain. The sand itself is high-quality silver sand which is used for the manufacturing of glass and other silica-containing materials. Local production of building materials can therefore be an option.

The natural slope of the chosen location also provides an excellent viewpoint of the Parkstad area and solar irradiance from the South without obstacles for all projected houses. The body of water on the south side of the area marks where groundwater has come to the surface.



3.2.2 Locational properties

Temperature in (long-term yearly average)

Yearly average	10,1 °C		
Summer average:	17,0 °C	Daily maximum:	21,9 °C
Winter average:	3,4 °C	Daily minimum:	0,5 °C

Summery days[1]: 26
Tropical days[2]: 4

Icy days[3]: 8
Frost days[4]: 58

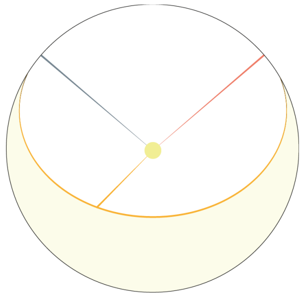
Degree days[5]: 2884

1. Maximum temperature 25 °C or more.
2. Maximum temperature 30 °C or more.
3. Temperature not more than 0 °C.
4. Minimum temperature below 0 °C.
5. Measure of heating or cooling consumption.

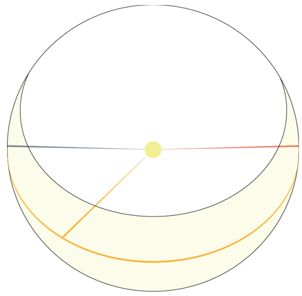
Precipitation (long-term yearly average)

Rainfall: 887 mm
Rainy days: 131
Snowy days: 25
Dry days: 122
Misty days: 63

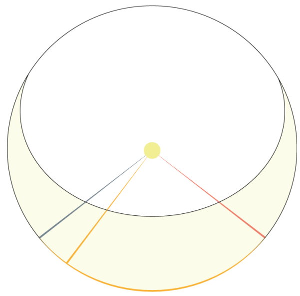
Evaporation: 559 mm
Relative humidity: 82%



Summer



Fall/Spring



Winter

("CBS StatLine - Klimaatgegevens; De Bilt temperatuur, neerslag en zonneschijn 1800-2014," 2015)

Sunshine

Sun hours: 1602
Days without sun: 61

	Sunrise	Solar noon	Sunset	Solar angle
Summer solstice	08:37	12:35	16:33	61,5°
Spring/fall equinox	06:37	14:44	18:51	38,1°
Winter solstice	05:23	13:39	21:55	14,5°

("SunCalc sun position and sunlight phases calculator," n.d.)

Maastricht average solar irradiance figures, measured onto a solar panel set at a 24° angle (winter optimal).

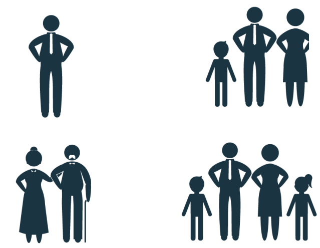
	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec
Solar Irradiance (kWh/m^2/day)	1,47	2,23	2,88	3,44	3,88	3,83	3,82	3,86	3,19	2,47	1,64	1,19

("Solar Irradiance Calculator," n.d.)

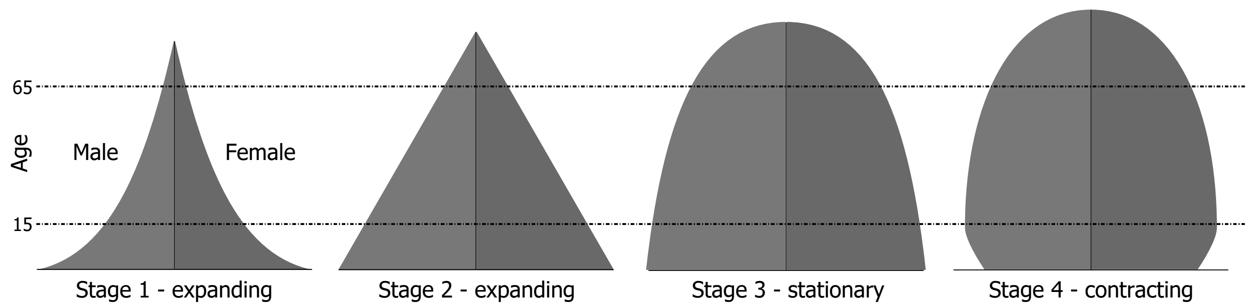
3.3 Program of requirements

One of the objectives of the eco-village is to counter shrinkage by attracting young people and families to the region. At the same time, enough housing options should be provided for the ageing population. The human life cycle needs to be represented in the eco-village. Therefore, the following program can be proposed:

Household type	Amount	# of people	Bedrooms	Bathrooms	Surface
Starter	5	1	1	1	80
Family 1	5	3	3	2	120
Family 2	5	4	4	2	140
Elderly	5	2	2	1	110



The choice for 50% family housing, 25% starters and 25% elderly is made based upon a stationary population pyramid. This means that the proportions of population in the stationary scheme would ensure that the population would at least not further age.



Different types of population distribution pyramids. Source: ("Ideal Population Pyramid," n.d.).

To be able to function in autarky, the eco-village ensemble will need supporting facilities to enable the production of food, energy and water. Important is that the users would not have to radically adjust their lifestyles when moving into the eco-village. Not everyone wants to be a farmer, or refresh their composting toilet on a weekly basis. This will serve as a guideline when choosing systems and technologies used for the households.

In addition to the houses, the eco-village will comprise:

1. Farming greenhouses
2. Aquaponic greenhouses
3. Energy station
4. Waste recycling facility
5. Livestock petting zoo
6. Orchard and seasonal garden
7. Visitor centre with café (max. 500m^2)

Technical requirements:

EPC of ≤ 2

Rc-value of ≥ 3,5 W/m^{2}K. All structures should be at least within "Passivehouse" requirements of 15kWh/m^2 heating/cooling.

4. Autarky

The Netherlands are the world's second largest food exporting economy with $79 billion generated annually. Thanks to the high-value production of Dutch vegetables (tomatoes, chillies, capsicum) and live plants (flowers), less expensive foods can in turn be imported from producing countries like China and Thailand. This global food market enables a small country like The Netherlands to thrive, but at the cost of non-renewable resources. Production and transportation of food is energy-intensive and often wasteful, for 32% of all food is wasted in the supply chain (Soethoudt, Vollebregt, & van der Burgh, 2016). Even more problematic than food is the production and transport of energy. Due to the large distance energy (in the form of heat and electricity) needs to travel from source to recipient and the inefficient design of common energy production facilities, only 34% of the available energy is actually usable (Vanderstadt, 2007). These rapidly depleting resources that are being wasted release toxins into the environment, polluting large portions of soil, water and air. Climate change, ocean acidification and soil degradation are all direct consequences of pollutants released by human activity and may result in massive loss of plant, animal and eventually human life. This means that the efficiency of producing food and energy can be drastically increased by moving the source closer to the recipients. Therefore, local autarky can be an effective way to reduce the impact of built environment and eventually lead to zero-impact built environment. According to Ronald Rovers (2011), local autarky can be reached by closing life cycles in the urban metabolism. Essentially, closing life cycles increases efficiency of renewable resources, while re-using non-renewable resources as much as possible. Using this approach, local autarky on all levels can be achieved. Rovers' closed cycle theory is based on these four principles (Rovers, 2011, pp. 5–6):

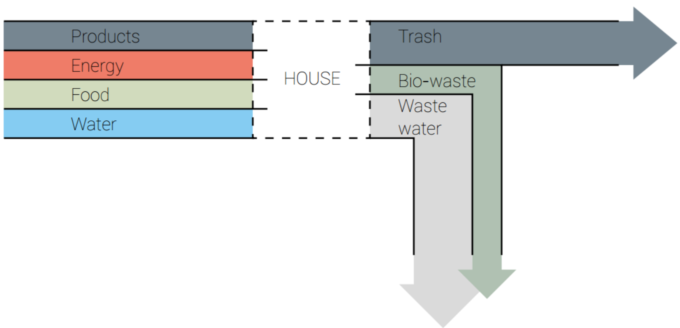
1. Close the cycle
Resources and energy that go into the cycle should be equalled in quality and quantity by what comes out of the cycle.

2. Reduce the volume
Reducing the demand for resources by preventing waste and by increasing resource efficiency.

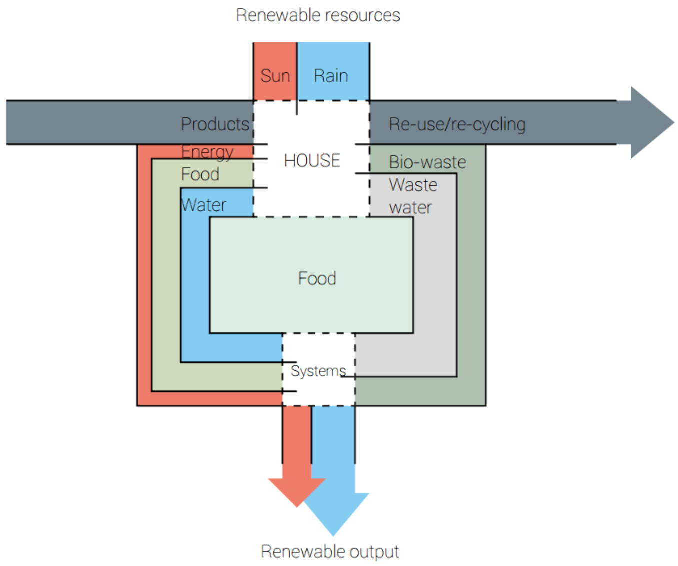
3. Reduce speed
Extending component's lifetimes benefits the replenishment rate of resources.

4. Reduce the energy that drives the cycle
By re-using products, the energy input for the process to its final condition is minimized.

The focus throughout this research will be closing the cycle (1) and reducing the volume (2).



Open life cycle flow diagram of a house.
One-way movement of resources and loss of embodied energy.



Closed life cycle flow diagram of a house. Systems for local autarky enable a circular movement of resources. External products are not taken into account.

4.1 Earthships

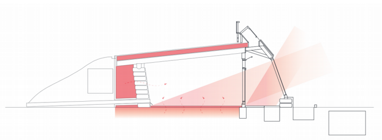
This housing type was developed and pioneered by Michael Reynolds in the 1970's as an incarnation of sustainable living in autarky. In essence, a conventional earthship is a self-sufficient passive solar home made mostly of natural and recycled materials. Essentially, an earthship should be able to maintain a comfortable indoor temperature, produce its own electricity, collect its own potable water supply and manage its own waste (Kruis & Heun, 2007).There are many iterations of the earthship, which depend on local climate, geophysical properties and construction method. The most commonly used one though is the Global Model Earthship (GME), which will be the archetypical earthship used as a reference in this research.

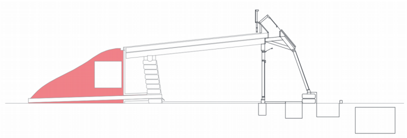
In a typical GME the north, west and east exterior walls are built with car tires, each packed with around 136 kg of rammed earth and stacked like masonry to a height of 2.4m (Reynolds, 1990). These walls should provide structural support and thermal mass to the building. The south side (assuming it's location is in the Northern Hemisphere) is made of a glass façade, tilted at an angle to optimally transmit solar radiation. Usually there is a sunroom conservatory that buffers the incoming sunlight and temperature. This sunroom can also be used to naturally ventilate the building.

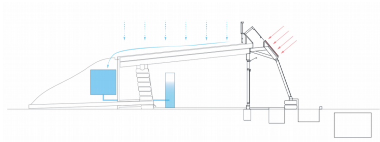
Because a GME is an off-grid building, it needs to harvest water from precipitation. Most earthships use precipitation for their entire water supply, which is minimized by re-circulating grey water in a semi-biological treatment process using filters and botanical cells (Reynolds, 2012). This water is then used to flush the toilets with. Various filtration methods can be used to obtain potable water from rainwater.

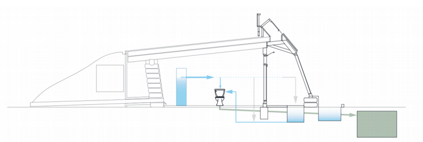
With optimal climate conditions, a GME should maintain a comfortable indoor temperature throughout the entire year without using any active acclimatization systems. However, this is not the case in The Netherlands. In colder, wetter climates there will still be a heat demand comparable to that of a passive house (15kWh/m^2). Also, there is a high chance of overheating in summer periods (M. H. P. Freney, Soebarto, & Williamson, 2013), implying the need for additional acclimatization systems. Another research mentioned the fact that the earth berm's thermal mass storage is not effective in Dutch climate like it can be in the arid climate of the Arizona desert. An earth berm wall should therefore be considered purely insulative (van der Gun, 2010). However, adding thermal mass to the interior can have positive effects on the stability of the indoor temperature and the heat load during winter periods (M. Freney, Soebarto, & Williamson, 2012).

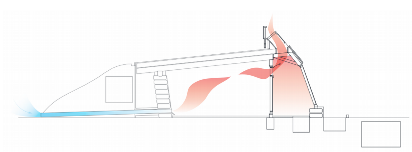
With this knowledge, it is safe to assume that a traditional GME cannot effectively be implemented as a viable housing option in Parkstad. However, some of its design principles have been proven to work and can provide insight for increasing resource efficiency and closing cycle flows. These principles will serve as guidelines for achieving local autarky during the design assignment following this research.

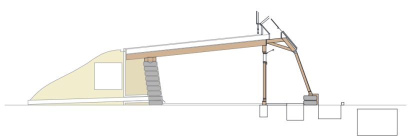

1. Solar radiation for seasonal heat storage.


2. Earth berm wall to add thermal mass.


3. Local (solar) electricity & water harvesting


4. Contained sewage & greywater treatment.


5. Sunroom conservatory for food & ventilation.


6. Built with natural and recycled materials.

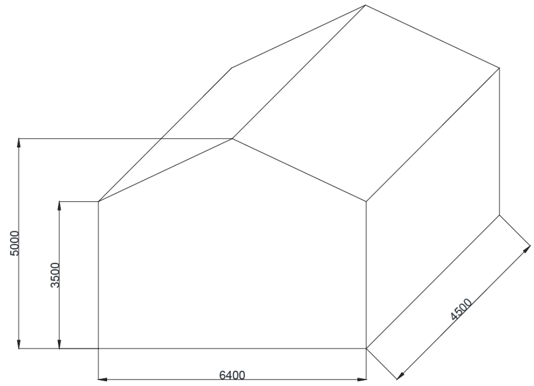
Answer to sub-question 1

Earthship biotecture (in Heerlen) can inform the following design principles of the Parkstad eco-village:

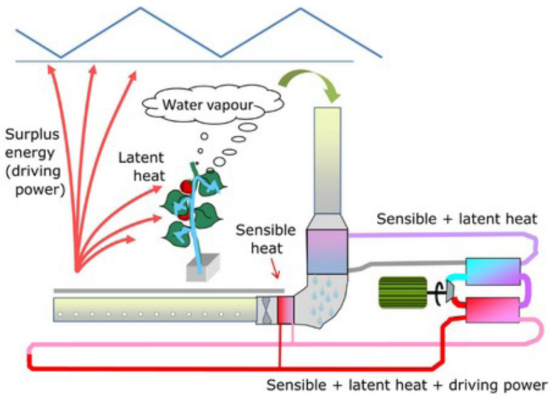
Solar electricity, rainwater harvesting, grey water re-circulation, earth berm for insulation, high mass interior, attached/integrated greenhouse.

4.2 Greenhouse

Besides food, greenhouses produce energy. Solar radiation creates a surplus of heat which usually is moved into the environment by ventilation. Using this energy to supply nearby heat demand may significantly contribute to local autarky. This can be done by closing this energy cycle by re-using greenhouse heat with a heat exchanger in combination with heat storage. A 'Closed Greenhouse' is an example of a such a set-up. This greenhouse set-up comprises long term heat storage in aquifers, heat exchangers and air distribution system, which were combined into a complete production system (Opdam, Schoonderbeek, Heller, & de Gelder, 2005). According to Jon Kristinsson, the basic type of heating and cooling from this aquifer is radiation heating supplemented with fine-wire air heating (Kristinsson, 2006). This fine wire air heat exchangers can also provide ventilation, as the air vents need to be closed in order to regulate the inside temperature. Under laboratory conditions and with a co-generator for heat, CO2 and power production, an electrical heat pump, heat delivery to additional greenhouses at 40 °C and a cooling water temperature of 8 °C, a closed greenhouse module of 6,4*4,5*5m (l*w*h) is expected to generate up to 800MJ year round (Campen, Bakker, & de Zwart, 2006). Raising CO_2 from 500 to 1000 ppm yields roughly a 20% larger crop. This CO_2 may be extracted elsewhere in the local cycle; for example biogas, which consists 33% out of CO_2 (and 66% methane, CH_4). Also, due to the fact that the greenhouse is closed there are fewer troublesome insects and the fact that 85% relative humidity is maintained does not cause any problems (Kristinsson, 2006, p. 4).

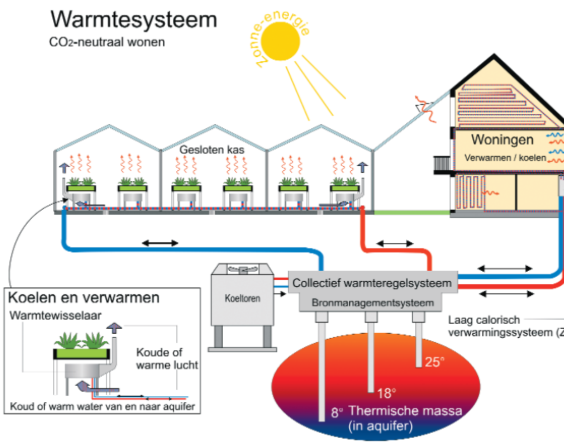


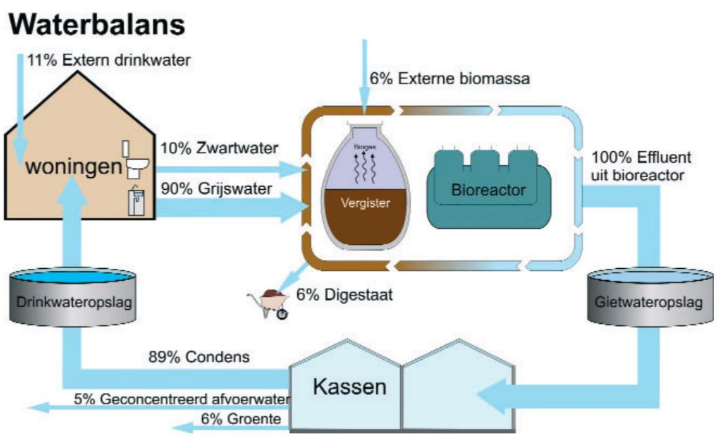
'Closed Greenhouse' energy production:
&27,8MJ/m^2 or 7,7kWh/m^2 energy production.



Heat extraction from inside the greenhouse (Wortmann Kruseman, 2005).

How much greenhouse is needed per person? Assuming a total vegetable growth area of 11m^2 per person with the use of aquaponics (own calculations) and a 75% ratio of growth area / technical area & access, the approximated necessary surface per person would be 11/0,75= 14,7m^2. For the whole village that results in 14,7*50= 733,3m^2 greenhouse, which can supply 733,3*27,8= 20.370MJ or 5658kWh of heat energy if a Closed Greenhouse system is used. A Closed Greenhouse can also reduce the external water demand by 89%, as it re-uses condensation from the greenhouses.





Energy extraction and re-use of water through greenhouse condensation in the Zonneterp (Wortmann & Kruseman, 2005).

4.3 Permaculture

Permaculture is design system for creating sustainable human environments applying functional design based on ecological principles and systems. In the case of local autarky, the concept of permaculture can be exploited following these 3 principles:

1. Decentralized renewable resources
2. Integrated agriculture with multiple yields
3. Perpetual life cycles of mutual benefit

Because of environmental parameters, permaculture will look and function differently depending on altitude or latitude. Also, its productivity, reliability and resilience depend on the diversity and availability of local resources. Therefore, a controlled environment like aquaponics may provide an efficient way of producing food. Aquaponics is the combined culture of fish and plants in recirculating symbiotic systems. Nutrients, which are excreted directly by the fish or generated by the microbial breakdown of organic wastes, are absorbed by plants cultured hydroponically (Rakocy, Bailey, Shultz, & Thoman, 2004). The treated water then flows back to the fish tank. The advantages of using aquaponics are a reduction of land use by 98% and water use by 90% (Effekt, 2015). The system does consume energy to function; around 56kWh/kg crops and 159kWh/kg fish (Love, Uhl, & Genello, 2015). Of this energy demand 43,8% is electricity and 56,2% is heat. However, this particular system uses tilapia, which requires water to be heated to grow and live comfortably. The electric heating of water (especially in colder months) required the majority of the energy during the research, leading to high kWh needs per kilo. A fish that does not require heating is the African Catfish (*Clarias gariepinus*). This species is also very resilient to water compositions, fluctuations in temperature and bacteria (Vos, 2015). Without the heating, the energy demand is only required for lighting and the water pumps. The energy demands are therefore reduced to 5,1kWh/kg crops and 16,7kWh/kg fish. Aquaponics can be used to combine the vegetables and non-egg protein demand. As mentioned in the previous paragraph, a growth area of 11m^2 per person is required to supply the yearly intake of vegetables. This 11m^2 system requires 29,5m^3 water for replenishment per year to function continuously.

Annual food consumption per person: *(average minimum amount)*	110kg	vegetables
	73kg	vitamins (fruits)
	61,5kg	protein (meat/fish/nuts)
	11,5kg	eggs
	37kg	dairy (milk/cheese/yoghurt)
	219kg	carbohydrates (bread/pasta/rice/cereal)

Average annual food consumption: 2,6kg/day/person
Average annual kitchen waste: 0,25kg/day

Source: “Flowcalc_v0.1” data sheet (Superuse Studios, n.d.).

To provide the whole village (50 people) with vegetables and fish using an aquaponic system, the following values can be calculated:

Vegetables: 110*5,1*50= 28.021kWh electricity.

Fish: 61,5*16,7*50= 51.233,3kWh electricity.

Water: 29,5*50= 1476,5m^3 (1.476.481,3L per year).

Surface area: (11*50)/0,75= 733m^2 aquaponic greenhouse.

Dimensioning the needed space to provide the eco-village with the rest of the essential nutrients can be done according the following calculations:

Fruits:

25m^2 per person on average for apple and pear trees (20m^2 for apples and 32m^2 for pears). This means (20*50)/2 = 500m^2 apple trees and (32*50)/2= 800m^2 pear trees in total.

Dairy:

A cow produces 6350kg of milk per year ("JAARSTATISTIEKEN Archives," n.d.). 37*50=1850, 6350/1850= 3,43. This means that 4 cows should be able to provide all the needed milk to provide all the needed dairy.

Eggs:

An average chicken lays around 250 eggs/year. With an average consumption of 192 eggs/year/person, there will be (192*50)/250= 39 chickens needed.

Carbohydrates:

These can be divided 50% into potatoes, 37,5% Super Dwarf Wheat and 12,7% legumes. Growing wheat and legumes at a 3:1 ratio provides all essential amino-acids people need. Also, the legumes provide nitrates to the soil that the wheat needs. Combining the two crops therefore keeps the soil rich in nutrients.

Potatoes:

Average yield of 50.000kg/Ha and 45% of the weight is edible. 5*0,45=2,25kg/m^2. With 3 harvests per year 2,25*3= 6,75kg/m^2. The entire village needs (219/2)*50= 5475kg of potatoes per year, so 5475/6,75= 811,1m^2.

Super Dwarf Wheat:

Average yield of 40.000kg/Ha and 33% of the weight is edible. 4*0,33= 1,32kg/m^2. With 3,8 harvests per year 1,32*3,8= 5,0kg/m^2. The entire village needs (219*0,375)*50= 4106,3kg of wheat per year, so 4106,3/5= 818,6m^2.

Legumes:

Average edible yield of 7538kg/Ha, 3 harvests. 0,7538*3= 2,3kg/m^2. The entire village needs (219*0,125)*50= 1368,8kg of legumes per year, so 1368,8/2,3= 605,3m^2.

Conclusion

With a Closed Greenhouse system crop size can increase up to 20% (because of the added CO_2), so this can be reduced from the needed surface area, leading to the following needed areas:

1 Aquaponic greenhouse of 733*0.8= 587m^2
1 Potato greenhouse of 812*0,8= 649m^2
1 combined Super Dwarf Wheat and legumes greenhouse of 1424*0,8= 1140m^2

In conjunction with fine-wire heat exchangers the Closed Greenhouses can provide (587+649+1140=2376)*27,8= 66.052,8MJ of thermal energy, which can be stored in a collective heat aquifer.

Also, the village will need:

A combined 1300m^2 orchard with apples and pears, 4 cows (4*10= 40m^2) and 39 chickens (39/5= 9,8m^2), assuming 10m^2 per cow and 4 chickens per m^2.

4.4 Water

4.4.1 Domestic water demand

Harvesting potable water from rain is a method that requires no location-bound interventions like excavations or drilling. According to current meteorological data the yearly average precipitation in Heerlen is 887mm/m^2/y, which equals 887L/m^2/year. To assess the possibility of providing all the water the eco-village with filtered rainwater, first it needs to be known how much water average households use on a daily basis. These numbers serve as a quantification of potable water consumption without needing the users to drastically adapt their lifestyle.

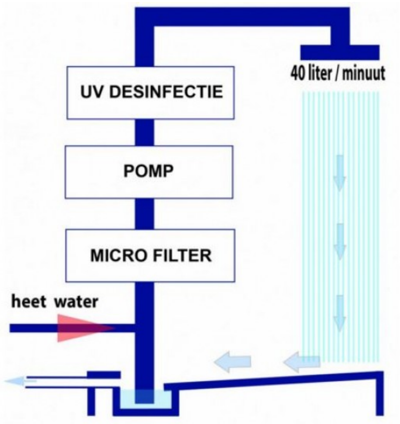
Toepassing	1-pers.	2-pers.	3-pers.	4-pers	5+
Bad	0,4	1,4	2,7	3,4	3,2
Douche	54,2	48,9	53,9	49,7	51,4
Wastafel	5,5	5,2	5,4	4,7	5,5
Toiletspoeling	33,7	39,0	31,4	31,0	28,5
Kleding wassen, hand	1,3	2,6	0,8	0,6	0,6
Kleding wassen, machine	16,3	16,7	12,7	12,4	9,4
Afwassen, hand	6,4	5,2	2,0	1,5	1,2
Afwassen, machine	1,2	2,1	2,0	2,6	1,7
Voedselbereiding	1,4	1,4	0,8	0,6	0,8
Koffie/thee	0,9	0,6	0,6	0,4	0,5
Water drinken	0,6	0,4	0,3	0,3	0,4
Overig	4,6	4,5	3,0	1,7	3,1
Totaal	**126,5**	**128,0**	**115,6**	**108,7**	**106,4**

Average household water usage statistics over the year 2013 (Geudens, 2015, p. 24)

What immediately strikes is the large water consumption of toilet use and showering, which make up respectively 27% and 43% of the total potable water use. By implementing water saving techniques however, these amounts can be greatly reduced. Toilet water use can be reduced by the use of various types of toilet systems. With a separation toilet system average toilet water use per person can be reduced to 5,5L (a 82,2% reduction). Also, by separating the urine valuable Nitrates can be collected efficiently (Swart, 2008). This can then be used for the enrichment of soil.

Toilet type	L flush type	L/day/person
Traditional	9/9	57,5
Modern	6/6	38,4
Modern with division	3/6	24,7
Broyeur	3/3	19,2
Gustavsberg	2/4	16,4
Separation	**0/4**	**5,5**
Vacuum	1/1	5,5
Composting	0/0	0

Water consumption according to toilet type (Swart, 2008).

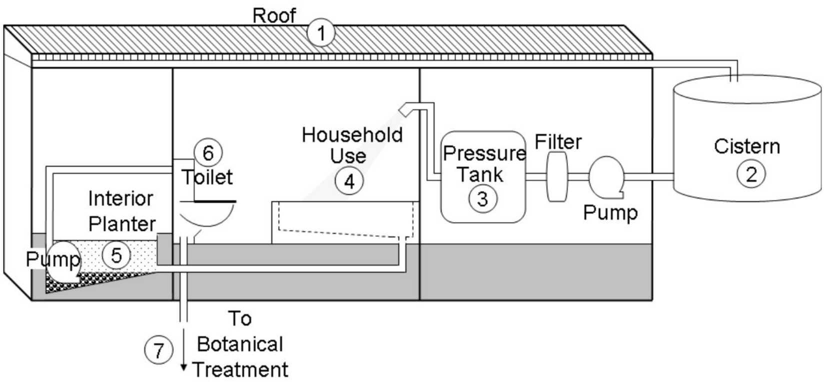


Upfall shower mechanism (Upfall Shower, n.d.)

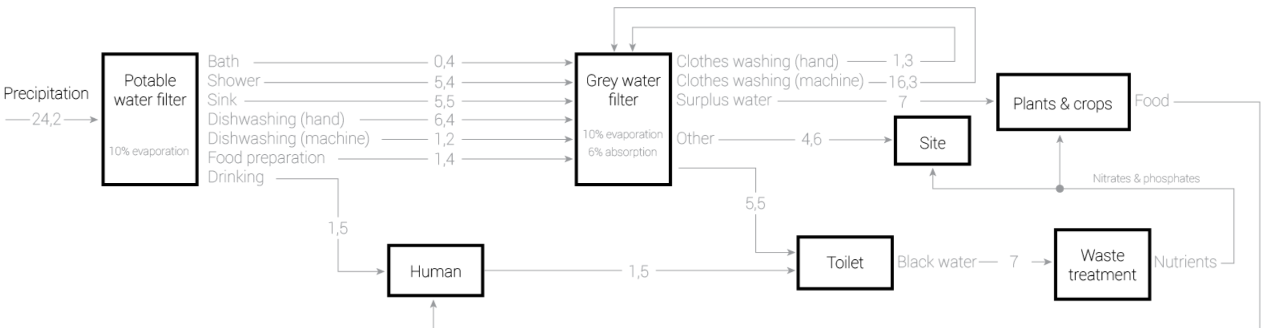
Reducing the shower water consumption can be done with the use of an ‘Upfall shower’. The Upfall shower is a system which reduces water use by 90% by re-circulating shower water through a micro filter and UVdisinfection. Using a separation toilet and an Upfall shower reduces the potable water consumption of a 1-person household with 61% (own calculations).

	1 person	2 people	3 people	4 people
L/day/person	49,4	51,2	40,7	38,1
Potable water	21,8	21,2	19,2	18,5
Grey water	27,5	30	21,5	19,6
L/year	8855,3	17.199,2	23.363,8	29.983,0

However, not all consumed water needs to be potable. In the case of using a biological grey water recuperation system like the one used in a GME, the water flows for washing clothes and flushing toilets can use grey water. Assuming a 10% overall evaporation rate and 6% plant absorption rate during the various harvesting and filtration processes, the following flow scheme can be made.



Biological grey water re-circulation system in a GME (Kruis & Heun, 2007, p. 4).



Material flow scheme of water in a 1 person household (own illustration).

In a 1-person household there is an average surplus of 7L grey water per day, which can be further directed to plants, crops or a reed bed filter. Using this grey water flow system it can be calculated how much rain catching surface the houses in the eco-village need.

	1 person	2 people	3 people	4 people
Needed m^2	10,0	19,4	26,3	33,8
Total households	49,9	97,0	131,7	169,0

These needs amount to a total need for rainwater of 397,0m^3/year and 447,6m^2 of rainwater catching surface. However, this water can also be harvested individually per house, as the required surfaces are less than the expected footprint of the houses.

4.4.2 Food production water demand

	L/day	L/kg/year	Amount	Needed L/y
Cows	115		4	168015,0
Chickens	0,25		39	3561,2
Potatoes		287	5475 kg	1.571.325
Apples		922	1825 kg	1.682.650
Pears		822	1825 kg	1.500.150
Super Dwarf Wheat		100	4106,3 kg	419.630
Legumes		350	1368,8kg	479.080
Aquaponics				1.476.481,3
Total livestock				171.576,2
			Surface needed	**193,4m^2**
Total crops				3.937.516,3
			Closed Greenhouse (89% reduction)	433.126,8
			Surface needed	**488,3m^2**
Total surface				**757,5m^2**
			Total L/year/person	13.437,8

Crops and water demand. Source: (Mekonnen & Hoekstra, 2011).

The total required amount of surface to harvest rainwater to supply all food flows is 757,5m2.

The total required greenhouse area for this food production was, according to last paragraph, 2376m^2. This means that the roof area of all implemented greenhouses should be able to provide all the needed rainwater for food production, but for the entire domestic supply as well. If this water is stored effectively, it can be saved for times of extreme drought.

Answer to sub-question 2

The entire eco-village will need a total of 1350m^2 of orchard and livestock space. Also, it will need a total of 2376m^2 of greenhouses to supply all needed food.

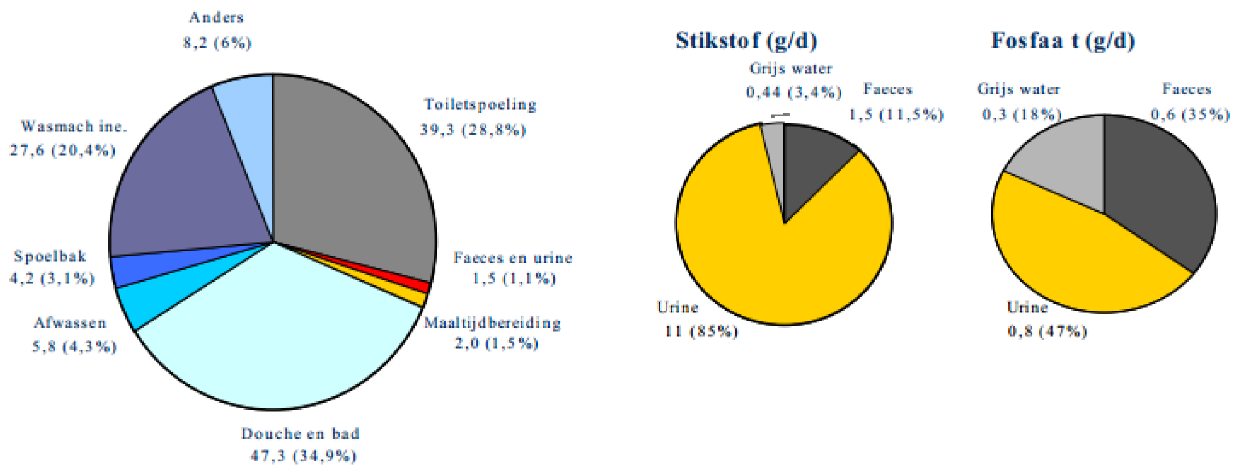
The total rainwater catching surface demand is 447,6m^2+757,5m^2= 1205,1m^2. The domestic use water is assumed to be harvested by the houses individually, but could also be collected using the surface area of the food production greenhouses.

4.5 Waste

Referring back to the first principle of autarky, resources and energy that go into the cycle should be equalled in quality and quantity by what comes out of the cycle. This means that to achieve local autarky the waste flows need to be further treated until they become usable resources (like water and energy).

4.5.1 Fertilizer extraction

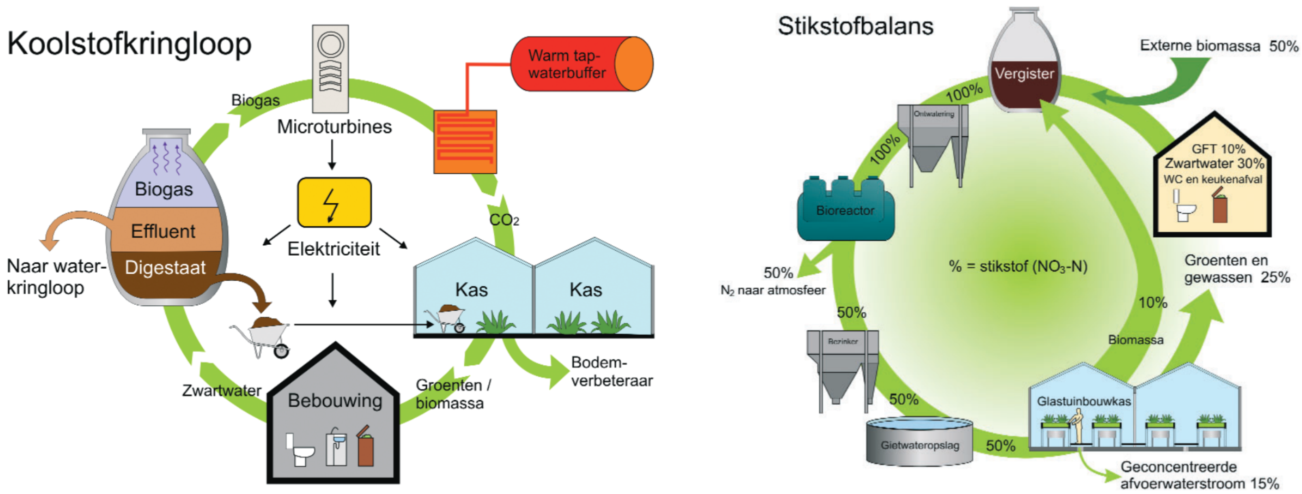
Urine is extremely rich in N (usually as urea, $CO(NH_2)_2$), P (as phosphates, PO^{3}_{-4}) and K (Potassium). Even though the amount of urine is just 1% of the total average household waste water, it accounts for 85% of all Nitrogen and 47% of all phosphor measured in waste water (Swart, 2008). Because of this urine is regarded as a highly concentrated waste flow. The N, P and K can be extracted to make fertilizer for the crops, which means extracting the nutrients from a concentrated source like urine is more efficient than to extract it from general black water. Therefore, the choice for separating toilets has a positive effect on the flow cycle.



Volume of daily household sewer water in L/d and the percentage of Nitrogen and Phosphate in black water in grams/day (Swart, 2008, p. 21).

4.5.2 Biogas digestion

All waste flows which contain volatile solids (excreted organic material) can be funnelled into a biogas digester system, which usually is a process of anaerobic digestion. In conjunction with a Combined Heat and Power system (CHP), a biogas digester can supply biogas to fuel a gas turbine for heat and electricity. In the Zonneterp Greenhouse Village this system has been theoretically elaborated on a village scale, leading to the following diagrams:



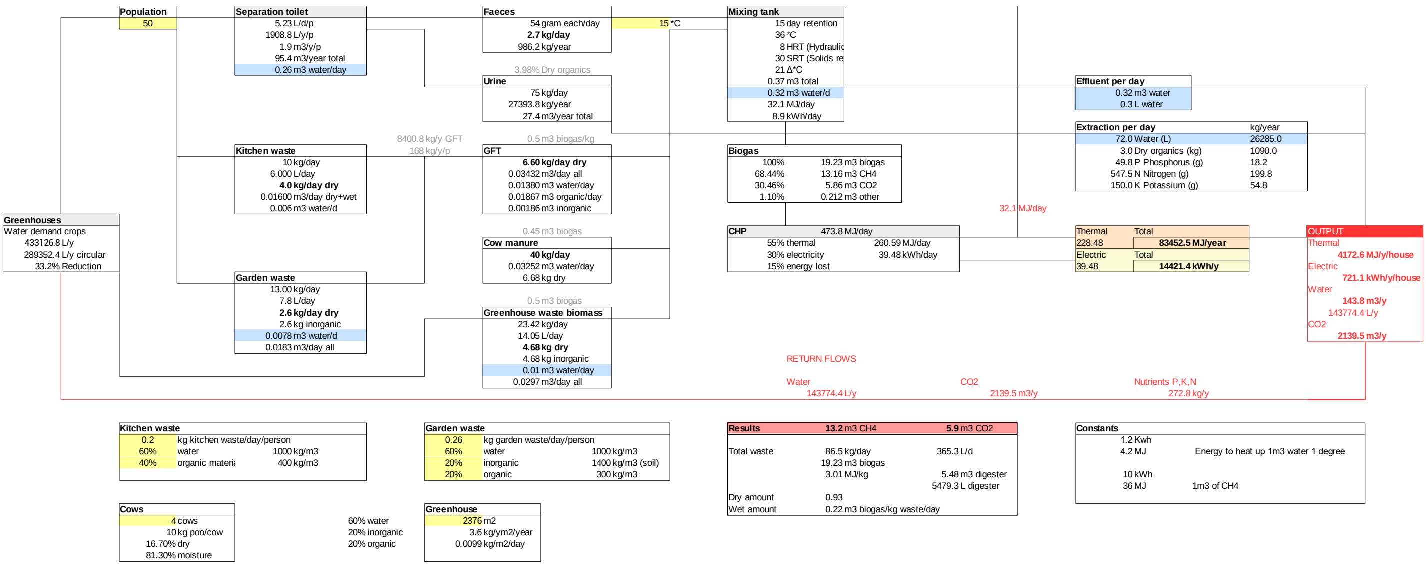
Biogas digestion process, outputs and nutrient cycles in the Zonneterp Greenhouse Village (Wortmann & Kruseman, 2005, p. 31,36).

In order to quantify the energy potential of the village waste flows, each waste type needs to be categorized according to dry weight to water ratio and how much m^3 of biogas can be yielded per kg dry waste material. The biogas that is referred to in this research contains 68,44% CH_4 (methane), 30,46% CO_2 and 1,1% of other (Superuse Studios, n.d.). In the following table all waste flows from the village are categorized accordingly:

Waste type	Weight (kg/day)	Water (%)	Organic (%)	Dry weight (kg)	m^3 biogas/kg
Faeces	6	55%	45%	2,7	0,45
Urine	75	96%	4%	3	n.a.
Cow manure	40,0	81,3	16,7	6,7	0,45
Garden waste	13,0	60%	20%	2,6	0,5
Kitchen waste	10	60%	40%	4,0	0,5
Greenhouse waste biomass	31,2	60%	20%	6,2	0,5

Waste flows that can be processed by anaerobic digestion. Values for whole village. Sources: (Afvalbeheer, 2009), (Banks, 2009).

Taking into account all previously collected data about the village food and water needs, all waste flows can be combined in the following scheme:



The output flows are:

143,8m^3 water
83,5GJ thermal energy
14,4GWh electrical energy
2140m^3 CO_2
25,2kg Dry compost
272,8kg Soil-enriching nutrients P, K, N

Conclusions: External biomass can be added to increase the energy output of the digester.

Answer to sub-question 3

With a centralized biogas digestion system (5,5m^3 digester), the eco-village waste flows can generate up to 85,5GJ of thermal energy and 14,4GWh of electrical energy. This energy can then be used to supply the heat demand of the greenhouses, homes and possibly a visitor centre on the site. The electrical energy can be distributed similarly, but is clearly a fraction of the quantity of thermal energy. Therefore, it is very probable that the individual houses will need additional solar panels to supply enough electrical energy to function. This will depend on the electrical power consumption of each household.

4.6 Energy

4.6.1 Electricity

Solar power could be a reliable source of electricity, but its usable output is determined by seasonal fluctuations. Winters are most challenging due to short days and low solar intensity. Therefore, to achieve local electric autarky should analyse monthly solar radiation data and compare it with current technological possibilities. From the table it is visible that December is the darkest and least effective month with only 5,0 kWh/m^2 of effective generation. That would mean that for a house to function in December, it needs twice to three times more solar panels than during spring or summer. Therefore, using electricity generated from the CHP (14,4GWh) could be used to supply the electrical demand of the houses in winter. With the expected supply of 721,1kWh/y/house (leaving greenhouse and aquaponics energy consumption out of the equation), and measures to reduce the household electrical demands, it can be assumed that the CHP can supply electrical demand during 3 (darkest) months; November, December and January. Therefore, it may be realistic to dimension the solar panel surface to February instead. Surplus electricity during summer months could be used to charge electric cars.

		kWh/m2/d	*kWh/m2/d*	*kWh/m2/d*	*kWh/m2/month*	*Wp/m2/month* 16%	*Wp/m2/month* 85%
Days	**Month**	**year round**	**winter optimal**	**adjustable**	**Monthly total**	**Panel efficiency**	**Usable electricity**
31	jan	1.44	1.47	1.47	45.6	7.3	6.2
28.25	feb	2.23	2.23	2.24	63.0	10.1	8.6
31	mar	3.02	2.88	3.02	89.3	14.3	12.1
30	apr	3.77	3.44	3.95	103.2	16.5	14.0
31	may	4.41	3.88	4.77	120.3	19.2	16.4
30	jun	4.35	3.83	5.08	114.9	18.4	15.6
31	jul	4.38	3.82	4.8	118.4	18.9	16.1
31	aug	4.29	3.86	4.59	119.7	19.1	16.3
30	sep	3.39	3.19	3.39	95.7	15.3	13.0
31	oct	2.5	2.47	2.51	76.6	12.3	10.4
30	nov	1.61	1.64	1.64	49.2	7.9	6.7
31	dec	1.16	1.19	1.19	36.9	5.9	5.0
					kWh/m2/y	*Wp/m2/y*	*kWh/m2/y*
365.25			**Total**		**1032.7**	**165.2**	**140.4**

Household	*Size (m2)*	*kWh/y*	*kWh/m2/y*	*kWh/month*	*m2 December*
1 person	80	2420	30.3	201.7	40.2
2 people	110	2920	26.5	243.3	48.5
3 people	120	3420	28.5	285.0	56.8
4 people	140	3920	28.0	326.7	65.1

Electric demands per household and effective kWh accumulation with solar panels on a winter-optimal angle (24°)

Storing energy collected during the day for use by night can nowadays be done with a Tesla powerwall system. One powerwall unit of 13,5kWh provides a continuous power of 5 kW (7 kW peak power) and can be used in conjunction with up to 8 other powerwalls (Tesla, n.d.).

4.6.2 Heat

As mentioned in paragraph 4.1, the passive house regulations permit an annual heating load of 15kWh/m^2/y. This means that if the houses are designed correctly with knowledge gained from the analysis of earthship housing, the houses would have the following maximum heat loads:

Household	*Size (m2)*	*kWh/year*	*MJ/year*	*MJ/year – CHP*	*Extra heating (kWh/y)*
1 person	80	1200	4320	147	40.8
2 people	110	1650	5940	1767	490.8
3 people	120	1800	6480	2307	640.8
4 people	140	2100	7560	3387	940.8

This table shows that the current CHP system would not provide enough heat energy to supply all households. This can be solved by either reducing the heat demand or adding biomass to the digester.

5 Conclusion

To reduce the environmental impact of built environment we need to produce more locally. Closing the energy cycle reducing the volume means that our output needs to equal our input in quality and quantity. The energy volume can be lowered by using these techniques adopted from earthship biotecture:

Solar electricity	*independence from grid*
Rainwater harvesting	*independence from grid*
Grey water re-circulation	*lowers water demand*
Earth berm for insulation	*lowers heat demand directly*
High thermal mass interior	*lowers heat demand over time*
Attached/integrated greenhouse buffer	*lowers heat demand directly*

Using a Closed Greenhouse can greatly reduce the needed water input by 89%, while increasing crop size by 20% with the additional CO_2 that is supplied to the plants. This type of greenhouse also can extract surplus heat energy and store it for use in colder periods (27,8MJ/m^2).

To supply the eco-village with enough food, permaculture principles can be applied. An example of this is aquaponic greenhouse, of which the village would need 733m^2 to supply the village with enough fish and leaf vegetables. Moreover, a potato greenhouse of 649m^2 and a combined Super Dwarf Wheat and legumes greenhouse of 1140m^2, a combined 1300m^2 orchard with apples and pears, 4 cows on 40m^2 and 39 chickens on 10m^2 are needed. This food production needs 671.890L water per year to function.

All domestic water uses can be minimized by using water minimizing systems like an Upfall shower, separation toilet and grey water re-circulation. The toilet is especially useful, as it separates the concentrated urine stream to a separate container, which eases the extraction of N,K and P. The total water need is 397,0m^3/year, which can be harvested individually per roof.

Using biogas digestion waste flows like unused biological plant matter and faeces can be converted into thermal energy, electrical energy, dry compost, H_2O, CH_4 and CO_2. As all of these can be used as a resource for other components in the cycle, circularity is achieved.

The energy that is needed to heat and power the houses is more than the output of the digester, which means solar panels need to be used. These panels have different output rates per month, leading to outputs which are three times less in winter than in summer. Dimensioning the panel quantity on winter months will therefore be an expensive strategy, so the electrical output of the biogas digester will have to be used in the three darkest months (November, December and January).

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