PERSONAL

Koen Fischer
4092236
Julianalaan 63b
2628BC Delft
0620629540
koenfischer@gmail.com

GRADUATION STUDIO

Architectural Engineering 2014/2015
Tjalling Homans & Leo Gommans

Frontpage photo: ‘On Top of the Dunes’ by Koen Fischer
Table of Contents

Abstract ...........................................................................5
1. Introduction .................................................................7
2. Methods .........................................................................9
3. Domestic Needs ............................................................10
   3.1 Energy .................................................................10
      3.1.1 Heat / Cold ..................................................10
      3.1.2 Electricity ...................................................10
   3.2 Water ........................................................................10
   3.3 Food .........................................................................11
4. Location Potentials ..........................................................12
   4.1 Sun .........................................................................12
      4.1.1 Energy .........................................................12
   4.2 Atmosphere ..............................................................13
   4.3 Water ........................................................................13
      4.3.1 Energy ............................................................13
      4.3.2 Water .............................................................14
      4.3.3 Food .................................................................14
   4.4 Earth .........................................................................14
      4.4.1 Energy ............................................................14
      4.4.2 Water .............................................................15
      4.4.3 Food .................................................................15
5. Instruments .......................................................................16
   5.1 Reduce .................................................................16
      5.1.1 Heat / Cold ..................................................16
      5.1.2 Electricity ...................................................16
      5.1.3 Water .............................................................16
      5.1.4 Food .................................................................16
   5.2 Reuse .................................................................16
      5.2.1 Heat / Cold ..................................................16
      5.2.2 Electricity ...................................................16
      5.2.3 Water .............................................................17
      5.2.4 Food .................................................................17
   5.3 Produce .................................................................17
      5.3.1 Heat / Cold ..................................................17
      5.3.2 Electricity ...................................................17
      5.3.3 Water .............................................................17
      5.3.4 Food .................................................................17
   5.4 Distribute ..............................................................18
      5.4.1 Heat / Cold ..................................................18
      5.4.2 Electricity ...................................................18
      5.4.3 Water .............................................................18
      5.4.4 Food .................................................................18
   5.5 Store .................................................................18
      5.5.1 Heat / Cold ..................................................18
      5.5.2 Electricity ...................................................18
      5.5.3 Water .............................................................18
      5.5.4 Food .................................................................18
6. Conclusion and Discussion ..................................................19
Bibliography ......................................................................21
Attachment A ...................................................................21
Attachment B ...................................................................21
Image 01: Initial research concept representation (Source: K. Fischer)
Abstract

The ecological footprint of all humans combined exceeds the available space on earth by a factor one and a half. This paper describes a research to find instruments to design a self sufficient dwelling in which the resources used to heat the rooms, power electrical equipment and feed the inhabitants are in balance with the resources planet earth can provide endlessly. This paper tries to find an answer to the question: “How can food, water, energy and waste flows be arranged and combined to create a closed circuit without the necessity of external inputs for a community in the coastal area of the Netherlands?”. To be able to answer the thematic research question as correctly and comprehensively as possible within the given time, the research is divided in three categories, each with their own subquestion. The first part describes the annual amounts of energy, water and food needed to sustain an average Dutch household and there impact on the ecological footprint. The second part describes the potentials for energy, water and food found in the dune area nearby Kijkduin in the Netherlands. The third part describes architectural and technical instruments to connect the needs from the first part to the available potentials in the second part. The result of this research is a toolkit of instruments which can be used during the design of a self sufficient dwelling. Only after a design is completed the actual benefits for the ecological footprint can be calculated.
Image 02: One and a half earths; our global ecological footprint (Source: Nasa, Altered by K. Fischer)
1. Introduction

This paper has been written in the context of the Architectural Engineering graduation studio within the faculty of Architecture from the Technical University Delft. Within this studio, students choose their own design project and a related research based on their technical fascination.

Described in this paper is the technical research related to the overall design question: “How can a permanent and self-sufficient cluster of dwellings in the fragile coastal area of the Netherlands be designed?” The leading question for this research is: “How can food, water, energy and waste flows be arranged and combined to create a closed circuit without the necessity of external inputs for a community in the coastal area of the Netherlands?”

According to the Living Planet Report 2014 written by the World Wide Fund for Nature our global Ecological Footprint (the amount of hectares Earth surface needed to supply the ecological goods, resources and services the world population uses) exceeds the available area by a factor of one and a half. The Ecological Footprint for the Dutch is even worse. The Dutch exceed the available area by three and a half. This means that if all 7 billion people on Earth were like the Dutch, three and a half Earths would be needed to provide everyone in their demands for energy, water and food.¹

With the growing number of people inhabiting planet Earth and the decrease of usable surface, the total amount of surface per person is decreasing every year. Today, while only 1.7 hectare is available per person, 2.6 hectares are used.² As mentioned above the Dutch use even more. A little bit more than 6gha is needed to satisfy the average Dutchman.³

This overuse is possible because all humans combined use Earths resources in a higher pace than they can replenish. Trees are cut down faster than new trees can mature, more fish are caught than the oceans can replenish and more carbon is emitted into the atmosphere than forests and oceans can absorb.⁴

To halt this exhaustion of planet Earth we should rethink the way we live, build, eat, drink, dispose waste, commute, et cetera. This paper describes the instruments to alter energy, water food and waste flows from linear systems to circular systems in houses. In an ideal circular system there is no waste and only sustainable resources are used to keep the system going.

The thematic research question is divided into three subquestions to get a good overview of the subject. The first subquestion: ‘What are the domestic needs for energy, water and food?’ is to show the consumption of an average Dutch household. This is what a house should be able to deliver to keep it at a comfortable temperature, power the electrical equipment’s and feed the inhabitants.

The answer to the second subquestion, ‘What are the location specific potentials for energy, water and food in Kijkduin?’ shows what potential and sustainable resources can be found in Kijkduin to feed a circular system.

The third and last subquestion, ‘What architectural and technical instruments can be used to combine the domestic needs with the location potentials?’

---

² gha stands for global hectare. The global hectare is normalized to the area-weighted average productivity of biologically productive land and water in a given year. Because different land types have different productivity, a global hectare of, for example, cropland, would occupy a smaller physical area than the much less biologically productive pasture land, as more pasture would be needed to provide the same biocapacity as one hectare of cropland. Because world bioproductivity varies slightly from year to year, the value of a gha may change slightly from year to year. http://www.footprintnetwork.org
is the connection between the previous two subquestions. The results of this research is a toolkit or catalog filled with architectural and technical instruments for reducing, reusing, producing, distribution and storing of energy, food and water. This toolkit will be used in the second part of the graduation studio which should result in the design of a self sufficient cluster of dwellings in the coastal area nearby Kijkduin in the Netherlands.

My proposal is one of the hopefully many solutions to change the current linear system into a circular system, where most of our waste can be used again or is not considered waste at all. This research is limited to find solutions for energy, water and food flows in a self sufficient cluster of dwellings located in Kijkduin, a small coastal town in the Netherlands. Waste is seen as loss in the three described flows. For example, heat leaving the chimney and water rinsing while flushing the toilet are seen as waste.
2. Methods

To be able to answer the thematic research question as correctly and completely as possible in the given time the research is divided in three subparts, each with their own subquestion. The following three chapters each describe the results for one of the subquestions. Each separate part of the research was done by a unique combination of research methods. Although many of the described results could be considered general results, all research has been done with a specific location and design strategy in mind: designing self-sufficient dwellings in the Dutch coastal area nearby Kijkduin.

The first chapter of the results, ‘Domestic Needs’, is mainly based on statistics provided online by the Dutch Central Statistics Office (CBR), the State Agency for Dutch entrepreneurs (RVO) and water supply companies were used. The found data is completed with facts and data found during literature research. For this research, only data concerning Dutch households is used. The aim for this part of the research was to find the needs for energy, water and food for an average Dutch household. The focus lies on how energy, water and food is used nowadays.

The second chapter, ‘Location Potentials’, is based on literature studies, statistics and online calculation tools. The research for this chapter is limited to sustainable resources. Sustainable resources are defined as resources that can be used endlessly without depleting the source. The aim for this part of the research was to find what the Kijkduin area has to offer in energy, water and food.

The third chapter, ‘Instruments’, is based on literature and case studies. The instruments introduced in this chapter are limited to function with sustainable resources and/or waste flows. The aim of this part of the research was to find the architectural and technical instruments that can be used to connect the needs section and potential part of the research. Each given instrument is a connection between a resource and the domestic needs. All the instruments can reduce, reuse, produce, distribute and/or store energy, water and/or food.
3. Domestic Needs

Everyone alive needs energy, water and food. Without these it would be impossible to live. There is a huge difference between what we need as a bare minimum to keep us alive and what we actually use in our daily life. The latter is not an issue for this research. This chapter will describe the average annual usage of energy, water and food of an average Dutch household. A typical household in the Netherlands in the year 2014 consists of 2.18 persons. For the past few years this number is declining.\(^5\)

All domestic needs contribute directly to the ecological footprint. Whether it is energy, water or food, everything humans need has to be produced, cleaned or dug up. In the end, this all relates to a certain amount of used Earth surface. Mines to dig for coal, oil fields to pump for oil, plants to purify water, fields to grow crops, forests to absorb the emitted carbon, et cetera.

3.1 Energy

The current usage of energy can be divided in to two subdivisions: heat and electricity. Currently, both are mostly generated with fossil fuels. Most households generate their own heat by burning natural gas. Electricity is mostly produced in large fossil fuel powered plants, a small part is generated by sustainable means.

3.1.1 Heat / Cold

Almost every building in the Netherlands is connected to the nationwide network of gas pipes. Gas is usually used for domestic heating, hot tap-water and cooking. A household uses a total of 1493 m\(^3\) natural gas per year.\(^6\) This equals to 14.631 kWh.\(^7\) As this number is an average, one can assume a modern, well insulated house uses less energy for heating and cooling. Heat and cold are combined in this chapter because to ‘produce’ cold it usually means heat has to be taken away which will cost energy. The 1493 m\(^3\) of natural gas used is accountable for 6,4% of the Dutch ecological footprint. This is 0,84gha per household.\(^8\)

3.1.2 Electricity

Electricity is used for lighting, electrical devices, gadgets, et cetera. An household uses a total of 3340 kWh\(^e\) per year.\(^9\) Again, this number is based on average devices, gadgets, et cetera. Every year newer, better and more efficient electrical devises are produced. For example an average refrigerator uses 400 kWh, a more economical model uses only 180 kWh. A closer look to the ratios between average and economical devises gives approximately a reduction of 50% in the used electrical energy.\(^10\) The 3341 kWh used is accountable for 4,6% of the Dutch ecological footprint. This is 0,6gha per household.\(^11\)

3.2 Water

The quality of Dutch tap water is very good and almost 100% of all households are connected to

---

\(^5\) [http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37296NED&D1=52,55&D2=0,10,20,30,40,50,(l-1)-l&VW=T](http://statline.cbs.nl/Statweb/publication/?DM=SLNL&PA=37296NED&D1=52,55&D2=0,10,20,30,40,50,(l-1)-l&VW=T)

\(^6\) [http://senternovem.databank.nl](http://senternovem.databank.nl)

\(^7\) 1 m\(^3\) a.e. = 9,8 kWh [Istaëls E.G., Stofberg F., EnergieVademecum (Boxtel 2010) p. 249]

\(^8\) This is based on: the emission of 0,056kg CO\(_2\) per generated MJ; 1 m\(^3\) of natural gas equals to 35,17 MJ; 1493m\(^3\) * 35,17 MJ * 0,056 kg/MJ = 2941kg CO\(_2\); According to the Living Planet Index a gha forest can absorb 3500 kg CO\(_2\) each year. 2.941 kg / 3500 kg/gha = 0,84 gha. sources: NEN, NPR 2917

Gommans, L., Gebiedsgerichte Energetische Systeemoptimalisatie (Delft 2012) p.69

Istaëls E.G., Stofberg F., EnergieVademecum (Boxtel 2010) p. 249

\(^9\) [http://senternovem.databank.nl](http://senternovem.databank.nl)

\(^10\) [Istaëls E.G., Stofberg F., EnergieVademecum (Boxtel 2010) p.230](http://senternovem.databank.nl)

\(^11\) This is based on: the emission of 0,0694kg CO\(_2\) per generated MJ; 1 kWh equals to 3,6 MJ; Energy losses of 61% between plant and user; (3341 kWh\(^e\) / 0,39) * 3,6 MJ * 0,0694 kg/MJ = 2140kg CO\(_2\). According to the Living Planet Index a gha forest can absorb 3500 kg CO\(_2\) each year. 2140 kg / 3500 kg/gha = 0,6 gha. sources: NEN, NPR 2917

Gommans, L., Gebiedsgerichte Energetische Systeemoptimalisatie (Delft 2012) p.69

Istaëls E.G., Stofberg F., EnergieVademecum (Boxtel 2010) p. 249
the nationwide water network. Tap water is mainly used to shower, flush the toilet, do the laundry and to cook with. A household uses 102 m³ water each year. Only 2.7 m³ a year is used for drinking and cooking. Only 1.6 m³ a year is actually used as drinking water. This roughly corresponds with drinking two liters of water per person per day. The 102 m³ of water used is accountable for 0.18% of the Dutch ecological footprint. This is 0.011 gha per household.

### 3.3 Food

How much and what a person needs to eat depends on its gender, size, age and activities. On average an adult man needs 2500 kilocalories each day and an adult woman 2000 kilocalories. This corresponds with 1100 grams each day and 402 kilograms each year for a man and 1010 grams each day or 369 kilogram each year for a woman. For an average household this makes 840 kilograms of food annually. It is important to have a diverse diet that can provide vitamins, minerals, carbohydrates, fat and oils in the right quantities.

To eat 2500 kilocalories one should eat 200 grams of fruit, 200 grams of vegetables, 250 grams of potatoes, rice, pasta or legume, 245 grams of bread, 30 grams of cheese, 450 ml of dairy products, 125 grams of meat, fish, poultry, eggs or meat substitutes, 15 grams of oily products and 35 grams of halvarine.

The table below shows food production conversion factors for energy, land and CO₂. Expressed in ecological footprint of a typical meal would be the equivalent of 0.63 gha per person or 1.39 gha per household. In perspective to the Dutch ecological footprint this is accountable for 10.5%.

#### Table 01: Food production conversion factors for energy, land and CO₂ (Source: Laorga, R., Sleane, R., FoodPrint Calculator Assumptions and data resources (2011))

<table>
<thead>
<tr>
<th>Food type</th>
<th>Energy M/Unit</th>
<th>Land ha/Unit</th>
<th>Water m³/unit</th>
<th>GHGs kg/ha/Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcohol beverages</td>
<td>6.18</td>
<td>0.000399</td>
<td>1.73</td>
<td>1.01</td>
</tr>
<tr>
<td>Dairy products</td>
<td>6.55</td>
<td>0.000323</td>
<td>2.47</td>
<td>1.08</td>
</tr>
<tr>
<td>Fish</td>
<td>72.73</td>
<td>0.000133</td>
<td>11.33</td>
<td>3.55</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>7.06</td>
<td>0.000067</td>
<td>7.12</td>
<td>1.13</td>
</tr>
<tr>
<td>Grains, starches &amp; derived</td>
<td>16.44</td>
<td>0.000337</td>
<td>2.21</td>
<td>3.83</td>
</tr>
<tr>
<td>Meat &amp; meat products (excl.</td>
<td>14.64</td>
<td>0.000383</td>
<td>2.69</td>
<td>4.93</td>
</tr>
<tr>
<td>Poultry meat &amp; products</td>
<td>34.29</td>
<td>0.000864</td>
<td>2.41</td>
<td>5.76</td>
</tr>
<tr>
<td>Eggs</td>
<td>21.04</td>
<td>0.000269</td>
<td>2.47</td>
<td>4.38</td>
</tr>
<tr>
<td>Vegetable and animal oils</td>
<td>81.05</td>
<td>0.000383</td>
<td>7.92</td>
<td>9.27</td>
</tr>
<tr>
<td>Other food products (incl.</td>
<td>21.01</td>
<td>0.000357</td>
<td>1.86</td>
<td>5.44</td>
</tr>
</tbody>
</table>

This is based on 200 grams of broccoli, 200 grams of apples, 250 grams of tomatoes, 30 grams of cheese, 450 milliliter of milk, 125 grams of beef, 15 grams of sunflower oil and 245 grams of bread and 35 grams of butter. This compares according to the dutch food centre (www.woedingscentrum to) 2500 kcal. This reference meal has been multiplied by 365.25 days and 2.18 people to see the estimation of the annual out come per household.

Laorga, R., Sleane, R., FoodPrint Calculator Assumptions and data resources (2011)
4. Location Potentials

This chapter describes the potentials for energy, water and food in and around Kijkduin and is categorized by resource. Kijkduin is a small coastal village within the municipality of Den Haag in the west of the Netherlands. The climate of this area is mainly dictated by the north sea.20

4.1 Sun

The sun is the direct and indirect source of almost all energy found on Earth and is the driving force behind many climatological and ecological processes happening on Earth. The sun has been radiating since the beginning of human history and will be radiating when all human life on Earth has been long gone. Therefore we can see the sun as an infinite energy source. The only limitation is the amount of solar energy reaching the surface of the Earth. This changes from place to place, day to day and from season to season.21

The apparent path of the sun changes from day to day due to Earths tilted rotation axis in relation to its path around the sun. During the summer the timespan between sunrise and sunset is longer and the sun rises to higher altitudes compared to the winter. The longest timespan between sunrise and sunset occurs on the 21st of June, when the Sun takes 16.5 hours from its rise in the North-East to its disappearance behind the horizon in the North-West.24 During its summer path through the sky the sun reaches its highest altitude of 61º around 13:45.25 26 The shortest timespan between sunrise and sunset occurs on the 21st of December, when the Sun takes 6 hours from its rise in the South-West to its disappearance behind the horizon in the South-West.27 During its winter path through the sky the sun reaches its highest altitude of 15º around 12:45.28 29

4.2 Atmosphere

The atmosphere surrounding planet Earth is an important condition for life on Earth. It is a protective layer which protects life on Earth from radioactive radiation, solar flares and extraterrestrial objects,

Graph 01: Apparent path of the sun during the year (source: K. Fischer)

4.1.1 Energy

Energy is the only thing we can harvest from the sun. The village of Kijkduin receives an annual amount of solar radiation of 1040 kWh per square meter. In a typical day in June this can be as much as 5 kWh for each square meter and for a typical day in December this can be as little as 0,5 kWh.22 These numbers are valid when measured horizontally. A 36º tilted surface could receives up to 15% more solar radiation. Solar radiation reaching the Earth consists of visible, ultraviolet and infrared light.23

20 http://www.klimaatinfo.nl/nederland/
21 Gommans, L., Gebiedsgerichte Energetische Systeemoptimalisatie (Delft 2012) p.35-36
such as meteoroids, on a collision course with our planet. An other vital aspect is the presence of oxygen in the atmosphere. This colourless and odourless gas is a byproduct of photosynthesis in plants but essential for almost everything else alive.

The most noticeable and most usable aspect of the atmosphere is the wind. Wind arises due to the rotation of the Earth and by differences in air pressure caused by temperature differences between two or more areas within the atmosphere. These temperature differences are the largest where sea and land meet each other. This makes coastal areas the most windy places. The table below shows the average monthly wind velocity at an altitude of 10m.

At an altitude of 60 - 100 meter an average wind velocity of 8.5 - 9.0 m/s is present in Kijkduin. To a certain extent, the wind velocity increases at higher altitudes.\textsuperscript{30} \textsuperscript{31}

<table>
<thead>
<tr>
<th>Month</th>
<th>Wind Velocity (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>&gt;6</td>
</tr>
<tr>
<td>February</td>
<td>5.5 - 6.0</td>
</tr>
<tr>
<td>March</td>
<td>5.0 - 5.5</td>
</tr>
<tr>
<td>April</td>
<td>5.0 - 5.5</td>
</tr>
<tr>
<td>May</td>
<td>4.5 - 5.0</td>
</tr>
<tr>
<td>June</td>
<td>4.0 - 4.5</td>
</tr>
<tr>
<td>July</td>
<td>4.0 - 4.5</td>
</tr>
<tr>
<td>August</td>
<td>4.0 - 4.5</td>
</tr>
<tr>
<td>September</td>
<td>4.0 - 4.5</td>
</tr>
<tr>
<td>Oktober</td>
<td>4.5 - 5.0</td>
</tr>
<tr>
<td>November</td>
<td>5.5 - 6.0</td>
</tr>
<tr>
<td>December</td>
<td>&gt;6</td>
</tr>
</tbody>
</table>

Table 02: Average wind speed at 10m above ground level (source: http://www.klimaatatlas.nl/klimaatatlas.php?wel=wind&ws=kaart&wom=Gemiddelde%20windsnelheid)

At an altitude of 60 - 100 meter an average wind velocity of 8.5 - 9.0 m/s is present in Kijkduin. Until certain extents the wind velocity increases at higher altitudes.\textsuperscript{32} \textsuperscript{33}

Graph 02: Average wind direction distribution in percentage (source: http://www.windfinder.com/wind-statistics/hoek_van_holland)

In the Netherlands there is no real prominents wind direction.\textsuperscript{34} However, strong winds are most of the time related to a wind to a south-west direction.\textsuperscript{35} The graph below shows the average wind direction distribution for the town of Hoek van Holland which is representative for Kijkduin.

### 4.3 Water

Water is omnipresent at Kijkduin and has two main appearances: salt water in the sea and fresh water as rain.

\textsuperscript{30} Gommans, L., Gebiedsgerichte Energetische Systeemoptimalisatie (Delft 2012) p.95
\textsuperscript{31} http://www.klimaatatlas.nl/klimaatatlas.php?wel=wind&ws=kaart&wom=Gemiddelde%20windsnelheid%20100%20m
\textsuperscript{32} Kristinsson, J., Integraal Ontwerpen (Boxtel 2002) p.65
\textsuperscript{33} http://www.klimaatatlas.nl/klimaatatlas.php?wel=wind&ws=kaart&wom=Gemiddelde%20windsnelheid%20100%20m
\textsuperscript{34} http://www.windfinder.com/windstatistics/hoek_van_holland
4.3.1 Energy
The sea can function as a heat or cold source. Sea water temperatures are relatively cold during the summer and relatively warm during the winter. Surface temperatures around 3°C can be found in February and surface temperatures around 20°C can be found in August. A few meters deeper temperatures are higher during the winter and colder during the summer. At a depth of five meters temperatures do not drop lower than 5°C. Energy can also be extracted from waves, tides and currents. At 7.5 kilometers of the coast waves have a potential energy of 5.5 kW/m1. At 30 kilometers of the coast waves have a potential energy of 10 kW/m1. Sea currents of 1 m/s can be found in the Dutch waters.

4.3.2 Water
Although not directly, sea water could be used as drinking water for a self sufficient community when the salt would be extracted.

Though the Dutch think it rains all the time in the Netherlands in fact it only rains for 7% of the time. However, the total rainfall is fairly evenly spread over the whole year. Although the second half of the year is a bit ‘wetter’ then the first half of the year. In total Kijkduin has an average rainfall of 925 to 950 mm each year. In perspective this means that every square meter receives a total of 950 liters of water every year. The table on the top right of this page shows the average monthly rainfall in Kijkduin.

Waste water from domestic use is rich in valuable nutrients. These nutrients can be used as food and fertilizers for plants and crops. Waste water can be divided in black water (toilet water) and grey water (all the remaining waste water). Black water is the most important source of nutrients. The table on the right shows the different nutrients and their ratio’s in domestic waste water.

<table>
<thead>
<tr>
<th>Month</th>
<th>Rainfall (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>January</td>
<td>70 - 75</td>
</tr>
<tr>
<td>February</td>
<td>50 - 55</td>
</tr>
<tr>
<td>March</td>
<td>60 - 65</td>
</tr>
<tr>
<td>April</td>
<td>40 - 45</td>
</tr>
<tr>
<td>May</td>
<td>60 - 65</td>
</tr>
<tr>
<td>June</td>
<td>60 - 65</td>
</tr>
<tr>
<td>July</td>
<td>70 - 75</td>
</tr>
<tr>
<td>August</td>
<td>85 - 90</td>
</tr>
<tr>
<td>September</td>
<td>90 - 95</td>
</tr>
<tr>
<td>Oktober</td>
<td>90 - 95</td>
</tr>
<tr>
<td>November</td>
<td>95 - 100</td>
</tr>
<tr>
<td>December</td>
<td>85 - 90</td>
</tr>
</tbody>
</table>

Table 04: Average rainfall (source: http://www.klimaatatlas.nl/klimaatatlasphp?wel=wind&ws=kaart&wom=Gemiddelde%20windsneleid)

<table>
<thead>
<tr>
<th>Annual</th>
<th>Grey water</th>
<th>Black water</th>
<th>Urine</th>
<th>Faeces</th>
</tr>
</thead>
<tbody>
<tr>
<td>(kg)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>N (nitrogen) 4-5</td>
<td>3%</td>
<td>97%</td>
<td>87%</td>
<td>10%</td>
</tr>
<tr>
<td>P (phosphor) 0,75</td>
<td>10%</td>
<td>90%</td>
<td>50%</td>
<td>40%</td>
</tr>
<tr>
<td>K (potassium) 1,8</td>
<td>34%</td>
<td>66%</td>
<td>65%</td>
<td>12%</td>
</tr>
<tr>
<td>COD 30</td>
<td>41%</td>
<td>59%</td>
<td>12%</td>
<td>47%</td>
</tr>
</tbody>
</table>

Table 05: Nutrients in waste water (source: Teeuw P.G., Luising A., Water Duurzaam in het Ontwerp (Boxtel 2005) p.40)

4.3.3 Food
The sea could also be a source of food. The sea is filled with uncountable species of fishes, seaweed and shellfish. Many of them can be eaten.

37 http://www.duurzaamdenhaaggids.nl
38 Gommans, L., Gebiedsgerichte Energetische Systeemoptimalisatie (Delft 2012) p.92-94
39 http://www.klimaatatlas.nl/klimaatatlas.php
40 Teeuw P.G., Luising A., Water Duurzaam in het Ontwerp (Boxtel 2005) p.40
4.4. Earth

Nearby Kijkduin one can find a lot of dunes. Most of these dunes are listed as nature reserves and therefore difficult places to develop buildings. Besides these surface restrictions the Earth has also some potential.

4.4.1 Energy

Our own planet is our second primary heat source besides the sun. Temperatures at the core of the planet equal those found on the surface of the sun. Unfortunately the core temperatures are not available for us. Temperatures available to us are found closer to the surface at a maximum of a few kilometers deep. The deeper you get, the more constant and higher the temperature will be. At a depth of 2 meters temperatures vary between 5ºC during the winter and 15ºC during the summer. Between 6 and 20 meters deep temperatures are constant 8 ºC to 10 ºC. Between 50 to 150 meters deep temperatures are constant between 12 ºC to 15 ºC. At these depths one can find most of the existing aquifers. Between 2 to 3 kilometers deep temperatures are constant 60 ºC to 100 ºC. Temperatures found at more than 5 kilometers deep exceed boiling temperatures.41

4.4.2 Water

Some water supply companies use the dunes to purify water. The dunes are used as a filter to extract bacteria and viruses from imported river water and rainwater. This process is only one step in the whole series of actions of purifying water.42

4.4.3. Food

The dunes are a harsh place for plants and trees due to strong winds and infertile soil. But still a few species can grow and produce edible goods. Rosehip, elderberry, daisies, hops and birch are some of the plants and trees, which can grow in the dunes.43

---

41 Yanovshitsinsky, V., Huijbers, K., Dobbelsteen, A. van den, Architectuur als Klimaatmachine (Amsterdam 2012) p. 53
42 https://www.dunea.nl/drinkwater/drinkwater-maken
43 http://eten-en-drinken.infonu.nl/dversen/64101-eten-uit-de-duinen.html
5. Instruments

For the instruments described in this chapter, a distinction is made between heating/cooling, electricity, water and food. Each of these categories are further divided in instruments to reduce, reuse, produce, distribute and store. The table below shows all possible combinations. The basic principles for each combination are described in this chapter, the actual instruments for each combination can be found in attachment A. All instruments are selected to be suitable for the location and the specific scale and goal: a cluster of 20 - 50 self sufficient dwellings in Kijkduin, Netherlands.

<table>
<thead>
<tr>
<th>Heating / Cooling</th>
<th>Electricity</th>
<th>Water</th>
<th>Food</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reduce</td>
<td>Reduce Heating / Cooling</td>
<td>Reduce Electricity</td>
<td>Reduce Water</td>
</tr>
<tr>
<td>Reuse</td>
<td>Reuse Heat / Cold</td>
<td>Reuse Electricity</td>
<td>Reuse Water</td>
</tr>
<tr>
<td>Produce</td>
<td>Produce Heat / Cold</td>
<td>Produce Electricity</td>
<td>Produce Water</td>
</tr>
<tr>
<td>Distribute</td>
<td>Distribute Heat / Cold</td>
<td>Distribute Electricity</td>
<td>Distribute Water</td>
</tr>
<tr>
<td>Storage</td>
<td>Store Heat / Cold</td>
<td>Store Electricity</td>
<td>Store Water</td>
</tr>
</tbody>
</table>

Table 06: Structure of chapter ‘Instruments’ (source: K. Fischer)

5.1 Reduce

Reducing the needs is the first step towards a self sufficient-dwelling. The less you need, the easier it is to find all the necessary resources locally.

5.1.1 Heat / Cold

For the reduction of the heat demand, a few principles can be used. The most important aspect for reducing the demands for heat and cold is to insolate the whole building. A different important aspect is passive usage of the sun. By designing a dwelling in such a way the sun only can enter the building when the heat is actually needed and is blocked when it would produce to much heat one can safe a lot of energy otherwise needed for heating and cooling the building. Orientation of the dwelling, the organization of rooms and adjusting window sizes appropriate to its facade are all possibilities for passive usage of solar energy.

5.1.2 Electricity

Architecturally wise it is difficult to reduce the electricity demands. Most of the devices using electricity are controlled and bought by the residents. If they would choose for electricity saving devices this could have a great impact on the total amount of used electricity. One aspect that can be improved by architecture is the amount of daylight that can enter the building. The more daylight enters a dwelling, the less the residents will be tempted to switch on the artificial lightning.

5.1.3 Water

Like electricity, in water usage architecture is not the decisive factor. It is mostly up to the users how much and how long they use the water. Besides being a responsible user one could install water saving devices in bathrooms and kitchens to pinch of the water stream.

5.1.4 Food

Also food depends on the residents. People might get more ‘aware’ of their food when the grow it themselves and will waste less food.

Image 07: Insulate to reduce heating (source: K. Fischer)
5.2 Reuse

Reusing is the second step towards a self-sufficient dwelling. The more reused, the less resources have to be extracted from the surroundings. Reusing is only possible when there are leftovers after the initial use of the resource.

5.2.1 Heat / Cold

Heat (or cold) can be directly reused by heat recovery. It is possible to recover heat in waste water or ventilation air and direct it back into the house. It is also possible to upgrade the heat via a heat pump to higher (or lower) temperatures.

Image 08: Heat recovery from waste water
(source: K. Fischer)

5.2.2 Electricity

There is no electrical waste. Most electrical devises transform electricity in labor, light and/or (waste)heat. The latter could be reused through the instruments written above.

5.2.3 Water

As can be read in the chapter 3.2, humans only need a few liters of clean water to drink and cook. The rest of the water leaves as waste. This waste water can be divided in black and grey water. Black water is what flushes away from a toilet, the rest of the waste water is called grey water. Grey water can easily be reused for washing, flushing or watering after purification.

The methods for purifying grey water can be divided based on their principle: organic, evaporation and filters. Organic purifiers use plants, bacteria or other living material to process the present contaminants. Evaporators use (solar) heat to evaporate the water leaving the contaminants behind. The damp is condensed to re-enter the system as water again. Filters are based on porous or fine meshed materials that collect the contaminants and let water pass.

Black water can be treated with the same methods as grey water but only after pre-treatment. The pre-treatment is necessary for the present solids and faeces. This can be done by settlement where the solid parts settle at the bottom of a tank or reservoir and relatively clean water can be extracted from the top. The solid leftovers can be treated as biomass.

5.2.4 Food

Left overs, cutting waste and non edible parts of food are ideal to reuse as biomass. In small quantities this biomass can be composted and used as fertilizer. In larger quantities this biomass can be used in a biomass fermenter to produce bio gas and fertilizer.

5.3 Produce

All resources needed after reducing and reusing have to be converted, produced or collected.

5.3.1 Heat / Cold

Historically, heat is the most important aspect for making a place livable. For the greater part of human history heat came from the sun, Earth and burning wood. Nowadays, we have a wide range of possibilities to heat our homes. The known principles can still be used albeit more sophisticated. Instead of wood, it is also possible to burn other (waste) bio mass and even bio gas extracted from biomass. With a greenhouse construction it is possible to concentrate heat from the sun. With a heat pump it is possible to upgrade heat extracted from the Earth, air, (sea) water or greenhouse.
5.3.2 Electricity

The sun and wind are two important components in producing electricity on site. Wind can make the wings of a wind mill go around, which in turn can drive a generator where rotating magnets create an alternating current in a coil of copper wire.

Photons traveling from the sun towards the Earth hitting a photovoltaic cell create a direct current.

Generators found in a wide variety fueled with biogas can produce both heat and/or electricity.

5.3.3 Water

Water is not actually produced but there are some instruments to generate or collect water. The most obvious one is collecting rainwater, but more water sources can be found. Water can be extracted from the ground and water vapour can be condensed. These tree sources provide relatively clean water which can be directly used on the condition that it is being used for non-consuming purposes.

A source that needs more treatment is the sea. After desalination the sea could provide a lot of usable water. Water can be desalinated by evaporation. Evaporators use (solar)heat to evaporate the water leaving behind the salt and other contaminants. Special filters and certain chemical es can also be used to desalinate sea water.

5.3.4 Food

If time and space would be unlimited, it would be possible for everyone to grow their own crops and keep some animals for dairy products and meat. In a domestic environment this isn’t the case but still there are some instruments to produce food in the neighborhoods of dwellings. Fruit trees and chickens in the garden, spices in the windowsill, fish in a pond but probably most usable would be a greenhouse where edible plants can grow all year long.

5.4 Distribute

Although not the most extensive part of this research distribution is a factor to take into account. Most of the times ‘things’ we used are not directly produced or stored at the place where we need them. Between those places there should be some sort of network to be able to transport heat, cold, electricity, water and/or food.

5.4.1 Heat / Cold

Heat or cold can be distributed via a medium that is often water or air. Methods to ‘deliver’ the heat to a room are based on radiation, conduction and the stack effect.

5.4.2 Electricity

Electricity can be distributed by electric conductive materials (primarily metals, most of the times insulated copper wire is used) or via induction (wireless).

5.4.3 Water

Water can be distributed via pipes, jerry cans, bottles or the like.

5.4.4 Food

The distribution of food within a community is not an issue for this paper.
5.5 Storage
When resources are produced but not needed they can be stored to use them at a time when they are needed but not produced.

5.5.1 Heat / Cold
The only way to store heat or cold is storing it in mass. The thermal capacity of this mass determines how much heat can be stored. Rules of thumb: the higher the density of a material, the higher the thermal capacity; the more mass, the more heat can be stored. Point of concern: heat and cold cannot be stored permanently. The stored energy will, depending on the storage material, sooner or later decay.

A distinction has to be made for phase changing materials. Like their names says, these materials change phase from solid to liquid whenever they absorb heat and change back from liquid to solid whenever they radiate heat. This ability makes this material absorb and radiate more energy than a ‘normal’ material

5.5.2 Electricity
There are a few possibilities for storing electricity. The easiest option -but environmentally less attractive- is chemical storage in a battery. Although research on environmentally friendly batteries continues, contemporary batteries are often based on poisonous or rare components.

Another option is to move mass up against gravity when the electricity is not needed and let gravity pull the mass back down to generate electricity when needed.

5.5.3 Water
Water for domestic use should be stored in a closed tank, reservoir or the like to prevent the water to get dirty. To prevent the water from being contaminated it is necessary to keep the water dark and cool.

5.5.4 Food
To store food for a longer period of time it needs to be in a dry, dark and cool place. Besides this there are many more non-architectural mostly traditional techniques to keep food from spoiling which do not fit in the scope of this research.
Many aspects have to be taken into account when designing a self-sufficient dwelling. This research provides an overview of some of these aspects. The question how to combine energy, water, food and waste flows to a self sufficient system without the necessity of external input is answered in three stages.

The first stage is about what amounts of energy, water and food an average Dutch household consumes annually. This part is very general and could be consulted when designing a dwelling no matter the location is. It has to be taken into account that the numbers given in this chapter are all averages.

The second stage describes the potentials of the locations. What does the location have to offer in energy, water and food. This part is very specific for the researched location and can hardly be used for other design projects.

The third and last part gives an overview of the instruments necessary for reducing, reusing, producing, distributing and storing energy, water and food. This part is also the connection between the first and second parts. All instruments are selected to be suitable for the location and the specific scale and goal. For now, this is a good reference for designing dwellings at the specific location. Many of the described instruments are more or less general and this research could be extended and made more general to act as a design guidance for different types of buildings regardless of the location.

The introduction of this research paper stated the overshoot of our ecological footprint. Chapter three “Domestic Needs” describes that heating is accountable for 6,4% of the ecological footprint, electric devices for 4,6%, water for 0,18% and food for 10,5%. This makes the influence factor of energy, water and food needed to sustain a Dutch dweller is accountable for 21,68% of the ecological footprint or 1,3gha in this case.

The proof, that the given architectural and technical instruments in this paper actually will lower the ecological footprint, is hard to give at this stage. Several setups of instruments should be used in a design to be able to calculate the influence of the separate instruments and the setups of instruments in total. However it is clear that this is not enough to reduce the Dutch ecological footprint to the available 1,7gha. It is however expected that the ecological footprint of a person living in one of the dwellings which will be designed in the second part of the graduation studio will have a smaller footprint than of someone who lives in a ‘traditional’ house.

If the aim is to reduce the footprint even more, materials should be taken into account as well. Although not mentioned in this research but a substantial part of the energy and resources used to build and use a building are embodied in the materials and thus contribute to the ecological footprint.

Furthermore there are numerous aspects which contribute to the ecological footprint but can not directly be influenced by the architect: The transport of people and goods (car, bus, airplane, et cetera), factories producing goods (many of our goods are produced in countries far away, which adds up to the ecological footprints of those countries but actually should be added up to ‘our’ footprint to be fair).

As a last remark, one should not forget the one who is using the building. In fact, a big responsibility lies in the hands of the user who can choose to use an energy saving fridge, accepts a lower indoor temperature or can turn off the television. Is a self sufficient dwelling only suitable for anyone who is educated on the subject?
Bibliography

Books
Israëls E.G., Stofberg F., EnergieVademecum (Boxtel 2010)
Gommans, L., Gebiedsgerichte Energetische Systeemoptimalisatie (Delft 2012)
Teeuw P.G., Luising A., Water Duurzaam in het Ontwerp (Boxtel 2005)
Yanovshtchinsky, V., Huijbers, K., Dobbelsteen, A. van den, Architectuur als Klimaatmachine (Amsterdam 2012)
Kristinsson, J., Integraal Ontwerpen (Boxtel 2002)

Reports
Laorga, R., Sleane, R., FoodPrint Calculator Assumptions and data resources (2011)
Vewin, Kerngegevens drinkwater 2010
NEN, NPR 2917

Websites
http://www.footprintnetwork.org
http://statline.cbs.nl
http://www.sciencespace.nl
http://senternovem.databank.nl
http://www.warmtepomp-info.nl
https://www.essent.nl
http://www.krmwtr-drinkkraanwater.nl
http://waterles.ditnet.nl
http://calculator.watervoetafdruk.be
http://www.voedingscentrum.nl
http://www.klimaatinfo.nl
http://suncalc.net
http://www.sunEarthtools.com
http://wetenschap.infonu.nl
http://www.klimaatatlas.nl
http://www.windfinder.com
http://www.duurzaamdenhaaggids.nl
https://www.dunea.nl
http://eten-en-drinken.infonu.nl
http://yumscrubblog.com

All websites rechecked on 03-01-2015
### Table 01: Food production conversion factors for energy, land and CO₂

(Source: Laorga, R., Sleane, R., *FoodPrint Calculator Assumptions and data resources* (2011)) a larger version printed in the attachment A.

<table>
<thead>
<tr>
<th>Food type</th>
<th>Energy MJ/unit</th>
<th>Land ha/unit</th>
<th>Water m³/unit</th>
<th>GHGs kgCO₂e/unit</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alcoholic beverages</td>
<td>5.18</td>
<td>0.000098</td>
<td>1.73</td>
<td>1.01</td>
<td>kg</td>
</tr>
<tr>
<td>Dairy products</td>
<td>6.55</td>
<td>0.000123</td>
<td>2.42</td>
<td>1.08</td>
<td>kg</td>
</tr>
<tr>
<td>Fish</td>
<td>72.73</td>
<td></td>
<td>1.13</td>
<td>3.55</td>
<td>kg</td>
</tr>
<tr>
<td>Fruit and vegetables</td>
<td>7.06</td>
<td>0.000067</td>
<td>2.12</td>
<td>1.38</td>
<td>kg</td>
</tr>
<tr>
<td>Grain, starches &amp; derived products</td>
<td>16.44</td>
<td>0.000173</td>
<td>2.1</td>
<td>0.92</td>
<td>kg</td>
</tr>
<tr>
<td>Meat &amp; meat products (excl. poultry)</td>
<td>78.82</td>
<td>0.001352</td>
<td>6.54</td>
<td>10.96</td>
<td>kg</td>
</tr>
<tr>
<td>Poultry meat &amp; products</td>
<td>34.29</td>
<td>0.00064</td>
<td>2.41</td>
<td>5.76</td>
<td>kg</td>
</tr>
<tr>
<td>Eggs</td>
<td>26.04</td>
<td>0.000569</td>
<td>2.47</td>
<td>4.3</td>
<td>kg</td>
</tr>
<tr>
<td>Vegetable and animal oils and fats</td>
<td>33.15</td>
<td>0.002621</td>
<td>7.2</td>
<td>0.97</td>
<td>kg</td>
</tr>
<tr>
<td>Other food products (incl. sugar)</td>
<td>23.01</td>
<td>0.000157</td>
<td>1.86</td>
<td>5.44</td>
<td>kg</td>
</tr>
</tbody>
</table>

Attachment B is referred to in chapter 3.3 “Food”.
Attachment B

Attachment B is referred to in chapter 5 “Instruments”. This is a visual representation of the actual architectural and technical instruments found during the research.