Towards Energetic Circularity

greenhouse-supermarket-dwelling energy exchange

P.N. ten Caat - Jan ’18
Toward Energetic Circularity | P5 Presentation (provisional)

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Delft, 26.1.18

Welcome
Lidl & TU Delft?

Lidl goals: building stock and operational processes circular

Luuk Graamans & Andy v/d Dobbelsteen

02.2017 - 01-2018

Student thesis

Building related & operation/user related energy demand
Since the industrial revolution the world runs on fossil based energy

At the cost of global climate

More independence fossil fuel

Trias energetica: reduce, **reuse** & produce

Energy cascading

  Exergetic inefficiency
  Large scale
  Regional
How can we combine the energy flows of a supermarket and a greenhouse and connect them to the adjacent dwelling to reduce the cumulative environmental footprint of the three functions?

Research question
Research objective

General: reduce the CO₂ emission due to the **cumulative building related** energy demand

**lower** the building related energy demand

Design a **local**, small scale energy network

enable energy sharing, connect local supply & demand
General: reduce the CO$_2$ emission due to the building related energy demand

**lower** the building related energy demand

Design a **local**, small scale energy network

enable energy sharing, connect local supply & demand

new element: **Urban rooftop greenhouse**
1. Context
2. Circularity
3. Concept
4. Energy: supply & demand
5. Energy system
6. Balancing in the system
7. Urban Design
8. Conclusion
Context

Location, city block, components

part 1/8
Context | Lidl Helmersbuurt
Context | Potential components

- Appartment building A
  - 49 households

- Lidl supermarket
  - 49 households

- Appartment building B
  - 77 households
Context | Potential components

1. **Apartment building A**
   - 49 households

2. **Greenhouse B - 850 m²**

3. **Greenhouse B - 854 m²**

4. **Lidl supermarket**
   - 49 households

5. **Apartment building B**
   - 77 households
PV field
~800 m² GFS
Circularity, Energetic circularity, roadmap
circularity in the built environment

Linear economy: take-use-dispose

Circular economy: take-use-reuse

Linear economy -> circular economy

Materialistic circularity
  Goal: No more destruction of raw materials

Energetic circularity
  Goal: Indepedance from fossil based energy (autarkic)
example: supermarket

[1] CO$_2$ neutrality > compensation programs

[2] Energy neutrality > grey electricity = green electricity

[2.5] Energy neutrality 2.0 > including user/operation energy

[3] Fossil free > full disconnection from fossil fuels

[4] Energetic circularity > investment energy
**Circularity | Roadmap**

- **(1) co2 neutrality**
- **(2 & 2.5) energy neutrality**
- **(3) fossil freedom**
- **(4) energetic circularity**

- 
  - CO2 emission compensation
  - Fossil energy
  - Renewable energy generation
  - Annual netto grey energy usage
  - Retrospectively compensate for embodied energy
  - Total electricity demand

- 100%

- 0 > time
Achieving energetic circularity

Technically = solution is easy.

In practise = extremely hard (2018)
  Lack of space;
  Inefficient power generating installations;
  High temperature heating systems.

Practical objectives:
  Disconnection from gas network.
  Increase local energy generation
Local energy grid:

- Small scale;
- Short energy lines;
- Low temperatures; (industry = absent)
- Easy / cheap interventions. (existing environment)

Seek energetic potentials

Establish smart energetic connections

In this study:

- Lidl <> greenhouse energy exchange
- Greenhouse > Dwelling
- Lidl excess heat > System
**Fossil freedom = abandon gas**

Alternative heat source: rooftop greenhouse solar collector

Alternative heating system: heat pumps

Heat pumps

Minimal electric investment

Free heat source;
COP: the higher, the better;
Small temperature jumps.
Greenhouse solar collector = thermal energy

2 types:
  short term - warm water reservoir
  seasonal - underground energy storage

Underground energy storage:

  Underground water layers: aquifers;
  Cold & Warm storage: doublet system;
  Open source;
  Infiltration T = 25°C;
  Extraction T = ~8°C & ~16°C.

Most important:

**Balance**
assume: tomato production

Optimal greenhouse climate conditions:

Closed greenhouse
Hydroponic farming
Nutrient Film Technology
Temperature 18.5°C - 26.5°C
Relative humidity 75%
Root zone temperature 25°C
CO$_2$ concentration 1000PPM

Is this sustainable?
Concept: tomato production

Sustainable greenhouse climate conditions:

Closed greenhouse
Hydroponic farming
Nutrient Film Technology
Temperature 18.5°C–26.5°C
Relative humidity 75%
Root zone temperature 25°C
$\text{CO}_2$ concentration 1000 PPM

> Semi-closed greenhouse
> 15°C-30°C
> variable / ambient
> ambient

Better option.
2 greenhouses on their maximum size & $T_{\text{in}} = 15^\circ\text{C}-30^\circ\text{C}$

(U= 2.7W/m².K, STC=0.6, facade orientation reduction factors included)
**Condioned area** = 15.4m x 46m x 2.9m & $T_{IN} = 21^\circ C$

($U_{ROOF} = 0.17W/m^2$, $U_{FACADE} = 0.22W/m^2.K$, $U_{FLOOR} = 0.25W/m^2.K$, Inf. rate = 0.443m$^3$/s, Vent. rate = 0.1m$^3$/s, $q_{CUSTOMER} = 131W/person$)

Energy | Lidl energy balance
Energy | Dwelling heat demand

124 households & 810 m³ gas/hh

(230 m³ domestic water, 580 m³ space heating)
<table>
<thead>
<tr>
<th></th>
<th>Dwelling</th>
<th>Greenhouse</th>
<th>Supermarket</th>
</tr>
</thead>
<tbody>
<tr>
<td>Winter heating</td>
<td>- 700 MWh</td>
<td>- 316 MWh</td>
<td>-</td>
</tr>
<tr>
<td>Summer heating</td>
<td>- 282 MWh</td>
<td>- *</td>
<td>-</td>
</tr>
<tr>
<td>Winter cooling</td>
<td>-</td>
<td>-</td>
<td>+51 MWh</td>
</tr>
<tr>
<td>Summer cooling</td>
<td>-</td>
<td>+ 1104 MWh</td>
<td>+69 MWh</td>
</tr>
</tbody>
</table>

*Summer = April - September
Winter = Oktober - March
*short term energy demand excluded
Energy system

Energy circulation, summer system & winter system

part 5/8
Energy system | [1/7] The 3 components
Energy system | [2/7] The energy loop
Energy system |[3/7] Solar collector
separate heat pumps for domestic water and space heating

50°C

60°C

3.9

2.9

main heat exchanger

fresh water supply

27°C

19°C

11°C

Greenhouse heating demand: -58%
Supermarket cooling demand: -54%

Energy system |[4/7] The Lidl supermarket I
separate heat pumps for domestic water and space heating

main heat exchanger

fresh water supply

Energy system [5/7] The Lidl supermarket II
Energy system |[6/7] The greenhouse

- Separate heat pumps for domestic water and space heating
- Heating buffer 37,000L
- Main heat exchanger
- Fresh water supply
- +2 warm water reservoirs
- (de)humidifier

Temperature points:
- 30°C
- 19°C
- 11°C
- 35°C
- 25°C
- 20°C
- 18°C
- 21°C
- 16°C
- 11°C
- 8°C

Energy system diagram:
- Energy system diagram showing various temperature points and water flows within the greenhouse.
Separate heat pumps for domestic water and space heating

Fresh water supply

Heating buffer 37,000L

Main heat exchanger

National grid

Local PV

Separate heat pumps for domestic water and space heating

Energy system

Solar electricity

798 m² GFS, +96 MWh
**Summer system**

Main purpose: greenhouse cooling + provide heat for the apartments

Underground storage:
- Cold storage = extracted
- Warm storage = charged

**Winter system - System is reversed**

Main purpose: dwelling heating + greenhouse heating

Underground storage:
- Cold storage = charged
- Warm storage = extracted

Energy system | Summer system > winter system
Energy system | [1/3] Similarities
Energy system |[2/3] System is reversed!

- separate heat pumps for domestic water and space heating
- nutrient solution 6.000L
- local PV
- national grid
- fresh water supply
- main heat exchanger
- (de)humidifier
- cold source?
Energy system | [3/3] Cooling the system
Energy system  |  Summary

- Heat pumps
- Heat exchanger
- Supermarket
- Greenhouse
- Dwelling
- Heat storage
- Cold storage

Free heat source - solar energy
Free cold source - canal water
Balanced system

Part V

part 6/8
2 greenhouses on their maximum size
2 apartment building, 124 households in total
1 Lidl supermarket

Balance | Total heating/cooling demand - Individual components
Heating & cooling demand reduces:

(1) Supermarket <> Greenhouse heat exchange
(2) Heat pumps.

**Balance | Total heat demand - System integration**
Seasonal storage: energy surplus vs. energy demand

Total heat injected in storage
Total heat extracted from storage
Cumulative Storage
Cumulative Use

Remember: the first rule of underground thermal energy storage >>> Balance

Balance | Problem: unbalance
<table>
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<tr>
<td>Greenhouse A (North)</td>
<td></td>
</tr>
<tr>
<td>[10.8 \times 78.8m]</td>
<td></td>
</tr>
<tr>
<td>[T_{IN} = 15^\circ C - 30^\circ C]</td>
<td></td>
</tr>
<tr>
<td>Greenhouse B (South)</td>
<td></td>
</tr>
<tr>
<td>[8.0 \times 107m]</td>
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<td>Lidl Supermarket</td>
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<td>[15.4 \times 46m]</td>
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<tr>
<td>[T_{IN} = 21^\circ C]</td>
<td></td>
</tr>
<tr>
<td>Potential roof space</td>
<td></td>
</tr>
<tr>
<td>[798 \text{ m}^2 \text{ GFS}]</td>
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Many other parameters not mentioned

**Balance | Problem: unbalance, current core parameters**
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<tr>
<td>Greenhouse A (North)</td>
<td>Apartment building A</td>
</tr>
<tr>
<td>10.8 x 78.8m  [T_{IN} = 15°C - 30°C]</td>
<td>77 households</td>
</tr>
<tr>
<td>Greenhouse B (South)</td>
<td>Apartment building B</td>
</tr>
<tr>
<td>8.0 x 102m  [T_{IN} = 15°C - 30°C]</td>
<td>49 households</td>
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*Balance | Easy to obtain*
thermal energy injected = thermal energy extracted
Can we sustain the energy system by using only 1 greenhouse?

Half the investment cost;
Half the maintenance cost;
Less complicated logistics;
Less urban interference;
Half the water consumption.
2 options:

94 households, 810 m$^3$ gas/year/household

124 households, 619 m$^3$ gas/year/household

33% heat demand reduction by means of cheap & simple interventions

examples:

Smart thermostats / ventilation;
Place coated windows;
Insulation retention wall.
Greenhouses

Greenhouse A (North)
10.8 x 78.8m
\( T_{\text{in}} = 15^\circ\text{C} - 30^\circ\text{C} \)

Greenhouse B (South)
8.0 x 107m
\( T_{\text{in}} = 11^\circ\text{C} - 27^\circ\text{C} \)

Dwelling

Apartment building A
77 households
619 m3 gas/hh

Apartment building B
49 households
619 m3/hh

Supermarket

Lidl Supermarket
15.4 x 46m
\( T_{\text{in}} = 21^\circ\text{C} \)

PV system

Potential roof space
1649 m² GFS
Urban rooftop greenhouse agriculture
Urban rooftop greenhouse agriculture
Initial greenhouse design:

**thermal energy collector;**
food production;
marketing.

Greenhouse can be something else!

Prioritise social cohesion above direct profitability.

Make neighbourhood more attractive.

Alternative function? Social function!
The greenhouse as a social hub! A proposal
Conclusion

CO$_2$ emission cutback, discussion
1 Lidl supermarket
15 x 46m, $T_{IN} = 21^\circ C$

+ 

1 rooftop greenhouse
8 x 107m, $T_{in} = 11-27^\circ$

+ 

124 households
619m$^3$ gas/household connected according to energy model

60% cumulative CO2 reduction or 452 ton CO$_2$/year

Conclusion | CO$_2$ emission cutback
Conclusion | Natural compensation
187 acres

1 acre = 4.000 kg CO₂ uptake / year

Conclusion | Natural compensation - No intervention
Conclusion | Natural compensation - Local energy system
Conclusion | Points of Discussion

- High temperature heating system | inefficient
- Sustainability > Profitability | business model?
- 33% dwelling heat demand reduction | achievable in practise?
Thank you

Questions?
The photographs/illustrations used in the tabs are retrieved from the following sources [in order of appearance]:

Slide 1 & 66 - Presentation cover photo

Slide 9 - Context

Slide 15 - Circularity

Slide 20 - Concept

Slide 26 - Energy

Slide 31 - Energy system

Slide 45 - Balanced system

Slide 55 - Urban Design

Slide 60 - Conclusion

Slide 62,63,64 - Conclusion | Natural compensation
Satelite images by Google Earth

References