A Zero Energy terminal building
for Amsterdam Airport Schiphol

Climate Design and Sustainability
Prof.dr.ir. Andy van den Dobbelsteent
first mentor

Structural Design
Ir. Joris Smits
second mentor
Zero Energy is the future of the built environment.

- Why do we need Zero Energy Buildings?
- When is a building energy neutral?
- How are ZEBs planned, built and evaluated?
- When are they profitable and how do we make them attractive to the market?
CARBON CYCLE

Annual man-made CO₂ emissions and partitioning
RISKS OF GHG EMISSIONS-RELATED GLOBAL WARMING

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Loss of wildlife

Air pollution

Extreme weather events and rising sea level
DEPLETION OF RESOURCES

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World energy supply by fuel

A society based on consumption

Why does economy play a substantial role?
How is humanity going to cover its huge needs?

GLOBALIZATION, OR RISE OF NEW ECONOMIES

CHEAP FOSSIL FUELS
CHEAP GOODS
CHEAP PRODUCTION

CREATION OF A HUGE NEED
THE CONSUMER SOCIETY

GLOBALIZATION, OR RISE OF NEW ECONOMIES

DEPLETION OF RESOURCES

CHEAP GOODS
CHEAP PRODUCTION

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GLOBALIZATION, OR RISE OF NEW ECONOMIES

CHEAP FOSSIL FUELS
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CREATION OF A HUGE NEED
THE CONSUMER SOCIETY

GLOBALIZATION, OR RISE OF NEW ECONOMIES

Other*

Other**

Natural gas
Biofuels and waste*
Coal/peat
Electricity
Oil

0 2 000 4 000 6 000 8 000 10 000 12 000 14 000

World energy supply by fuel

Oil reserves are running out, oil price is rising because of demand. Future emission taxes will make it even more expensive.

Natural gas and coal can't take over oil's share. They are too polluting and future emission taxes will make them sensibily more expensive.

ALL (?) COUNTRIES WILL NEED MORE ENERGY.
THE TIME TO INVEST IN RENEWABLE ENERGIES IS NOW.

How do we produce the future % of renewables?
How do we offset fossil fuels?
Energy efficiency and CO₂ trends: large fall in CO₂ emissions per unit of GDP (CO₂ intensity) decreased faster than in the Netherlands.

Losses in energy conversion are more noticeable between 2000 and 2009, reflecting increased pace than primary energy intensity. That trend, which was even more pronounced in the Netherlands, is higher than the EU average (by 8 percent).

Total energy consumption per unit of GDP (primary energy intensity), measured at purchasing power parity, is only slightly higher than total energy intensity over the period 1990-2009 due to fuel substitutions of coal by biomass in the primary energy mix.

In the framework of its Clean and Efficient Program, the country aims to double its wind power production capacity, try set the target of achieving 20 percent of renewables in power generation by 2020. Moreover, the Netherlands aims to double its wind power production capacity, mainly driven by the development of gas-combined cycle facilities.

The efficiency of the power sector has increased significantly, mainly driven by the development of gas-combined cycle facilities.

The share of natural gas in electricity production is growing rapidly and in 2009 represented about 60 percent of the overall power generation, which is expected to dominate power generation in the future.

In order to qualify for government aid, the “green” electricity must be produced in the Netherlands. This can be achieved directly, or by buying green certificates. Since 2002, the green certificates can be used to buy electricity produced from renewables.

The share of nuclear power, which is exempted from the environmental tax abroad, however, the new law on renewables specifies that in order to qualify for government aid, the “green” electricity must be produced in the Netherlands.
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BUILT EXAMPLES

NREL Headquarters, 2010.
Colorado

WWF Headquarters, 2006.
The Netherlands

In Europe, all new buildings will have to be Energy Neutral by 2020.
All public buildings by 2018.

United Kingdom
ESSENTIAL CONCEPTS

ZEB definition

energy used = energy produced

Set peer building benchmark

1. Avoid energy demand
2. Reuse waste flows
3. Generate renewable energy

New Steps Strategy

Benchmark strategies

1. Reduce energy demand
2. Reuse waste flows
3. Generate renewable energy

If a building cannot achieve zero energy, it may be possible to achieve it on a community scale. The global water cycle works this way. A closed loop system may appear as linear in/out when examined on a small scale.

Site Energy [kWh]

Total energy used, from all energy sources, as measured on site (electricity meter or utility bill).

Source Energy [kWh]

Total energy used, from all energy sources, as measured at the power plant (includes transport losses).

Site Energy x Source Energy factor

1.04 for T&D electricity in the NL (Enerdata, 2011)

ESSENTIAL CONCEPTS

Coefficient Of Performance

Ratio of energy out to energy in.

Energy Use Intensity [kWh/m²]

Total annual building energy use by gross building area, indicator of buildings performance, comparison tool for projects with similar use in the same climate area. 108 for the NL, 100 for EU average (Enerdata, 2011)

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Better Airport Regions research project

“[…] enhanced reciprocity between the airport and its surrounding metropolitan region can facilitate a transformation path towards more sustainable, better airport regions.”

“…The project starts from a joint perspective on essential flows (energy, water, materials, food and mobility), urban development and spatial quality […]”

Also, as yet there is no existing ZEB airport terminal.
REDESIGNING THE “PIER A” EXPANSION

new satellite ZEB terminal VS planned expansion (2014)

- less aircraft fuel
- more efficient timing
- future-proof

- even longer way to Polderbaan
- is it really the best strategy?
An aircraft driving on the ground emits 46x more CO₂ than during take off. The average time needed to drive to and from the Polderbaan is 40 minutes.

Considering the price of fuel and of energy, when would a new terminal that solves these issues pay back for the investment?

\[
( \frac{€}{m^2} \text{ Pier A} + \frac{€}{kWh \text{ per year}} + \frac{€}{liter kerosene \text{ per year}} + \frac{€}{CO_2 \text{ per tonne per year}} ) - ( \frac{€}{m^2} \text{ ZEB} - \frac{€}{kWh \text{ per year}} ) = 13.5 \text{ projected payback years}
\]
LOCATION AND CONNECTION

5 min.
ENERGY USE

INFLUENCING FACTORS

PROGRAM
facade area
floor area
volume
people density

CLIMATE
temperature
sunlight
humidity
wind
ground

MITIGATING STRATEGIES

BUILDING TECHNOLOGY
massing, thermal zoning
materials
passive systems
use of waste flows

THERMAL LOADS

BUILDING PHYSICS
transmission
solar radiation
infiltration
ventilation
int. heat gain

TOTAL ENERGY CONSUMPTION

heating
cooling
ventilation

FEEDBACK
value >60%
better than base?
NO

SUCCESS!
METHODOLOGY

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TEMPERATURES

Graph generated with Autodesk Weather Tool using a weather data file from http://apps1.eere.energy.gov
WEATHER DATA

Ground temperatures

Direct, diffuse and global radiation

Solar geometry

Sky cover
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PSYCHROMETRIC CHART

DESIGN STRATEGIES: JANUARY through DECEMBER

2.7%  1 Comfort(54 hrs)
3.3%  2 Sun Shading of Windows(207 hrs)
3 High Thermal Mass(0 hrs)
4 High Thermal Mass Night Heating(0 hrs)
5 Direct Evaporative Cooling(0 hrs)
6 Trombe Wall Preheating Cooling(0 hrs)
1.0%  7 Natural Ventilation Cooling(154 hrs)
8 Fan Forced Ventilation Cooling(0 hrs)
30.1%  9 Internal Heat Gain(2634 hrs)
10 Passive Solar Direct Gain Low Mass(0 hrs)
9.2%  11 Passive Direct Gain High Mass(895 hrs)
9.4%  12 Wind Protection of Outdoor Spaces(625 hrs)
13 Humidification Only(0 hrs)
14 Dehumidification Only(0 hrs)
15 Cooling, add Dehumidification if needed(952 hrs)
69.5%  16 Heating, add Humidification if needed(5259 hrs)
99.5%  Comfortable Hours using Selected Strategies
(8712 out of 8760 hrs)

SUPERINSULATED ENVELOPE
- transmissions
- solar radiation
- internal heat gain
Avoid energy demand

DESIGN
Building envelope: keep it simple, direct, use technology selectively, cost effective integrated solutions
too many layers/technologies = overly complex, difficult to build, prone to problems, difficult to maintain

1
Start thinking about balancing out /f_lows - maybe switch off heating when plug loads are at peak?
Balance point: outside air temperature at which the building does not need heating nor cooling
climate / building program / massing / envelope design can be tuned to meet a wider range

transmission + solar radiation + infiltration + ventilation + internal heat gain = peak load for heat gain or heat loss [kWh/m²]

thermal resistance R-value = 1/[W/m² K°]
transmittance U-value = 1/R = [kWh/m² K°]

Q = U-value x Area x Temp. difference [kWh/m²]

superinsulate
thermal mass
earth coupling

VENTILATION
occupants + lighting + equipment

internal thermal loads  skin thermal loads

lighting power density

ventilation

plug load density

conduction

radiation

infiltration
SHAPE EXPLORATION

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**SHAPE EXPLORATION**

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Shape</th>
<th>Total MJ/sm/yr</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rectangular</td>
<td>742</td>
<td>little space for gates</td>
</tr>
<tr>
<td>2</td>
<td>Round</td>
<td>760</td>
<td>difficult to expand</td>
</tr>
<tr>
<td>3</td>
<td>Square</td>
<td>774</td>
<td>boring</td>
</tr>
<tr>
<td>4</td>
<td>Round with atrium</td>
<td>797</td>
<td>panoramic view on the whole of Schipol</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- enclosed atrium used as indoor garden</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>- has climatic and non-climatic advantages</td>
</tr>
<tr>
<td>5</td>
<td>Rectangular</td>
<td>800</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>Rectangular with atrium</td>
<td>807</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Rectangular</td>
<td>808</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Square with atrium</td>
<td>817</td>
<td></td>
</tr>
<tr>
<td>9</td>
<td>Rectangular</td>
<td>844</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Round with atrium</td>
<td>850</td>
<td></td>
</tr>
<tr>
<td>11</td>
<td>Round</td>
<td>858</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Rectangular with atrium</td>
<td>861</td>
<td></td>
</tr>
</tbody>
</table>
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01. PEER BUILDING BASELINE to 02. SHAPE AND ORIENTATION

- **kWh/sm/yr**
  - 234 to 220
  - reduction from baseline: -6%
  - reduction from previous tot.consumption: -6%
  - reduction from previous heating and cooling load: -18%
03. THERMAL INSULATION

- MOTIVATION
- DESIGN PREPARATION
  - Why Zero Energy Buildings
  - What does Zero Energy mean
  - Selected study case
- SITE
  - Location
  - Climatic aspects, influence and potential
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**Thermal Energy Distribution**
- Heating
- Hot Water
- Electricity
- Cooling and Ventilation
- Lighting
- Misc. Equipment

**Energy Consumption**
- kWh/sqm/yr: 193
- Reduction from baseline: -18%
- Reduction from previous total consumption: -12%
- Reduction from previous heating load: -25%

**Thermal Insulation Table**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>1 1,25 cm Gipskartonplatte</td>
<td>0,250</td>
<td>0,250</td>
<td>-10,0</td>
<td>0,0</td>
<td>18,6</td>
<td>19,3</td>
</tr>
<tr>
<td>2 5 cm Weichfaserplatte</td>
<td>0,039</td>
<td>1,282</td>
<td>-8,4</td>
<td>19,0</td>
<td>7,5</td>
<td>0,3</td>
</tr>
<tr>
<td>3 1,25 cm AGEPAN OSB/3 PUR</td>
<td>0,130</td>
<td>0,096</td>
<td>-10,0</td>
<td>11,9</td>
<td>7,9</td>
<td>0,3</td>
</tr>
<tr>
<td>4 16 cm Gutex Thermowall</td>
<td>0,042</td>
<td>3,810</td>
<td>-9,3</td>
<td>11,4</td>
<td>22,8</td>
<td>0,0</td>
</tr>
<tr>
<td>5 Hinterlüftung (40 mm)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Temperature Chart**

- Temperature variation: -10°C to 20°C
- Temperature amplitude damping: 31.3
- Phase shift: 15.5h
- TA-Damping: 31.3

**Energy Reduction**

- kWh/sqm/yr: 193
- Reduction from baseline: -18%
- Reduction from previous total consumption: -12%
- Reduction from previous heating load: -25%

**U-Value Calculation**

- U = 0.204 W/m²K

**Hvac System**

- Heating
- Hot Water
- Electricity
- Cooling and Ventilation
- Lighting
- Misc. Equipment

**Graphs and Diagrams**

- Energy consumption chart
- Thermal insulation materials
- Temperature variation chart
- U-Value calculation

**Notes**

- U-wert.net All data without warranty
- Savings from previous heating load
- Savings from previous total consumption
**04. IMPROVED GLAZING**

- **kWh/sm/yr**
  - 169

  - Reduction from baseline: -28%
  - Reduction from previous total consumption: -12%
  - Reduction from previous heating load: -30%

- Double-leaf facade
  - U-value: 0.35

- Triple glazing with outer pane

- Non-metal insulated frame
**05. AVOID OVERHEATING**

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- **Reduction from baseline**: -32%
- **Reduction from total consumption**: -5%
- **Reduction from previous cooling load**: -60%

---

**Facade: overhang**

- **Return**
- **Inclination**

**Roof: not ventilated**

- **Green roof**
- **Ventilated roof**

---

**Graph**

- kWh/m²/yr
  - **160**

- Reduction from previous to total consumption: -5%
- Reduction from baseline: -32%

---

**Thermal energy**

- Heating
- Hot water
- Lighting
- Cooling and ventilation
- Miscellaneous equipment

---

**Facade angles**

- Overhang
- Return
- Inclination

- 30°
- 25°
- 23°
- 25-30°
- 30°
- 36°
06. SUNSHADE

Sunshade: external if none: g-value 0.8

internal 0.35

in-cavity 0.15

KWh/sm/yr
155

reduction from baseline
-34%

reduction from previous tot. consumption
-3%

reduction from previous cooling load
-70%

thermal energy
heating
hot water
electricity
cooling and ventilation
lighting
misc. equipment

kWh/sm/yr
155
07. NATURAL VENTILATION

- thermal energy
- heating
- hot water
- electricity
- cooling and ventilation
- lighting
- misc. equipment

- Reduction from baseline: -41%
- Reduction from previous total consumption: -12%
- Reduction from previous ventilation load: -70%

Temperate to hot days, summer nights
08. HEAT RECOVERY

**MOTIVATION**

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**PLANS AND DETAILS**

5.0

**CONCLUSION/REFLECTION**

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**HEAT RECOVERY**

- **Thermal energy**
  - Heating
  - Hot water
  - Electricity
  - Cooling and ventilation
  - Lighting
  - Misc. equipment

- **Reduction from baseline**
  - 51%

- **Reduction from previous total consumption**
  - 16%

- **Reduction from previous heating load**
  - 65%

---

**Temperate to cold days**

---

**Diagram:**
- Double glazed skylights
- Exhaust outlets with heat recovery
- Double glazed greenhouse
- Ground coupled air pre-heating
- Components in contact with the ground
- Vertical annexes, overhang and ventilation spaces
- In-cavity blinds
- Double glazing plus outer pane
- Double facade with air filter
- Roof slab to underheated space
09. LIGHTING CONCEPT

- kWh/m²/yr
  - 101
  - Reduction from baseline: -57%
  - Reduction from previous total consumption: -12%
  - Reduction from previous lighting load: -40%
ON SITE ELECTRICITY
GENERATION

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ON SITE ELECTRICITY GENERATION

adaptation integration addition

1. PEER BUILDING
2. SHAPE AND ORIENTATION -6%
3. THERMAL INSULATION -12%
4. INSULATED GLAZING -12%
5. AVOID OVERHEATING -5%
6. SUNSHADE -3%
7. NATURAL VENTILATION -12%
8. HEAT RECOVERY -16%
9. LIGHTING CONCEPT -12%
10. OCCUPANCY/DAYLIGHT -12%

PLUG-LOADS

234 kWh/sm
87 kWh/sm

thermal energy
heating 282 000 kWh
hot water 128 000 kWh

electricity 1 817 600 kWh
cooling and ventilation
lighting
misc. equipment

1 200 000kWh solar cells
725 000kWh PV panels

ventilation lighting misc. equipment

1 817 600 kWh +15% annual electricity yield & consumption
SOUTH ELEVATION
MOTIVATION

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SKIN CLIMATE CONCEPT
INTERSEASON

- electricity
- thermal energy
- rainwater
- sunlight

- tilt- or sliding triple pane windows
- heat exchangers
- pre-warmed fresh air
- cavity façade
SKIN CLIMATE CONCEPT
HOT SEASON

- electricity
- thermal energy
- rainwater
- sunlight
- tilt-or sliding triple pane windows
- heat exchangers
- increased flow rate
- cavity façade
SKIN CLIMATE CONCEPT
COLD SEASON

- electricity
- thermal energy
- rainwater
- sunlight
- tilt- or sliding triple pane windows
- heat exchangers
- cavity façade
ASSEMBLY

- folded aluminum deck e.g. Kalzip system
- skylight
- vapour barrier
- 26cm insulation
- thermally decoupled clips
- structural steel deck

- skylight truss
- secondary steel profile
- primary structure twin glulam beams
- steel connection node
- timber clad steel façade mega-truss
- flooring assembly structural steel deck
- secondary structure steel trusses

- integrated building services
- interior triple glazing
- with retractable shading
- intermediate façade-bearing truss
- ventilated cavity
- external single glazing

- aluminum gutter
- steel supporting brackets
- perforated aluminum cladding
- finishings panels

- flooring assembly concrete
- 26cm insulation
6.0 CONCLUSION AND REFLECTION

- Energy efficiency is not a matter of technology but of planning.
- Stakeholders are not motivated enough to put energy efficiency as a priority, and knowledge of the topic is still fragmentary.
- Choices related to architecture and to energy efficiency can integrate each other perfectly, the level of creativity and originality that this methodology creates is outstanding.
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Thank you