H2 Architecture
Hydrogen in Architecture

Design & Research

Graduation Thesis

Architectural Engineering
Lab 06

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Preface

The Architectural Engineering graduation studio has the focus of integrating research on an engineering level with architecture. The result of such an approach is to deliver architects with a better focus on engineering, which should lead to a higher level of integrated design.

The starting point of architecture designs in the Architectural Engineering Labs is a technological fascination. In my case the hydrogen technology is used to design a business and science center in Amsterdam north at the NDSM-terrain.

Prior to the graduation design, a small pavilion was designed based on hydrogen technology research in the first half of the Msc3 period. The second half of the Msc3 was used to do the most of the research and obtain a clear overview of the technological subject, design and research goals and methods in conjunction with a realistic planning for the Msc4 semester. In the Msc4 semester the research is applied to design my final architectural project.

This report describes the research of the potential of hydrogen technology in architecture but also the two architectural designs based on the technological fascination and research.

I would like to thank Jan Engels and Andy van den Dobbelsteen for their support during my graduation design and research period.

Bernard Aukema
Delft, 2012

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1 General

1.1 Problem statement and question

1.1.1 Introduction

Energy individualism in the society
Energy self-sufficiency buildings are rarely built because the generated energy does not always cover the energy demand of the building. Besides this, it is now more efficient to collectively generate energy for the society.

Storage
Another reason why buildings are rarely designed individually energy self-sufficient, is the fact that there are restrictive opportunities for energy saving. Energy could be stored in batteries that are in fact relatively efficient, but these required battery systems are very heavy and contain toxic metals.
Hydrogen can be a good energy storing solution, but the technology still has to be developed for the architectural practice, so there are no fully hydrogen powered projects built on such a public building scale.

Zero-energy is something different than energy self-sufficient.
Some projects are named zero-energy buildings, but they do not have to be energy self-sufficient. Zero energy buildings are often connected to the electrical grid. In the summer they deliver energy to the grid, and in the winter they use energy from the same grid. The overall energy balance is positive. These zero-energy buildings are not self-sufficient because they are not independent of their environment.

Integration architectonic design
A typical architectural problem is the fact that neither 'new' hydrogen technologies nor the renewable energy systems are often used in an architectural way, but just placed in, next to or upon the architecture as additional technologies.

1.1.2 Problem statements

1. Technological problem statement:
'Energy self-sufficient housing is rarely built, because there is no good individual energy storage solution.'

2. Architectonic problem statement:
'Energy technologies are often not optimally integrated with its architecture.'

1.1.3 Question

'What are the possibilities for hydrogen as an energy carrier in combination with renewable energy in buildings and how can both technologies be integrated as an architectonic aspect in the design?'

1.2 Relevance

Because the Amsterdam municipality wants to be progressive in the hydrogen technology, they want to profile the city with several projects. A hydrogen powered bus or a canal boat are two of the already realized examples. Besides this, the NDSM location will be energy neutral built, or at least that is one of the purposes. The NDSM site is now an energy experimental location. A Bio fuel and electric charging point is one of the examples.

'Energetica' was a museum about energy technology in Amsterdam until they closed in the year 2008. The exhibition is now located in the NEMO science center, but this center has a shortage of area for this 'old energy' exhibition. A new museum about the old and new energy technologies is one of the functions that can be realized at the energy focused NDSM site.

In the Netherlands a community named 'DutchHy' wants to stimulate the research and usage of the hydrogen technology. Because this is just a collaboration between several companies, research centers and cities, without a clear location, DutchHy can be combined in the design as a 'knowledge and research center' about the energy technologies used in the exhibition but also in the building design itself. This could be a research center and an expert panel connected to the museum.

Current buildings are energy dependent on their environment, and the energy generation for the society is barely visible. When we run out of the fossil fuels gradually, renewable energy technologies can and will become more and more visible in individual buildings.
The hydrogen technology can be a good solution for energy storage because it can be produced out of water and water is abundant on the surface of Earth. The production can be done with electrolysis, which is driven by renewable energy sources, such as solar and wind energy. There is no CO2 emission during the production and use of hydrogen. Because the storage is not so heavy as a battery system, and it contains no toxic metals, the hydrogen technology can become feasible for buildings.

1.3 Goal & Design assignment

The goal is to design an *energy self-sufficient building*. It will be an *exposition* in combination with a *hydrogen research center*. The exposition exhibition is about the innovative new energy technologies. The building itself demonstrates as much as possible these modern/futuristic energy systems.

Research focus
The focus of the building design will be on the applications and opportunities of *active* produced renewable energy and especially the hydrogen technology (Generation, storage and usage). The building should work as being a machine.

Architectural focus
The focus of the architectural design will be on the integration of the researched technologies in the design, in such a way that it is consistent with the used technologies. Besides this, the building must be interesting for the visitors of the exposition.

1.4 Timeline

The architectural design has to be driven by the technical research and the design proces comes with questions, which can be researched as a technological study.

Start Msc3 project - P1 exam - April 2011

- Discover the Buiksloterham + NDSM area
- Describe a fascination
- Start your technological research
- Design a pavilion, based on the technological research

P1 exam - P2 exam - June 2011

- Define location at the NDSM area
- Define the technological research and expand this specific technological knowledge
- Do market investigation in the researched technologies, especially the usage in architecture
- Define structuring ideas about the final building design, which will be designed in the Msc4 semester. The ideas will be based on the location, program, technological research and architecture.
- Finish in the learning plan

P2 exam - P3 exam - October 2011

- Start designing a building based on the technological research
- Finalize the technological research
- Define 'Technological capacity' needed in the building, and its dimensions and the translation to architecture
- Evaluate design variants and changes to optimize the design
- Evaluate the design with the design assignment in the learning plan
- Finalize the preliminary design drawings that are useful for the P3 exam

P3 exam - P4 exam - December 2011/January 2012

- Finalize the building design
- Evaluate the design with the design assignment in the learning plan
- Define conclusions about the design based on the technological research

P4 exam - P5 exam - Spring 2012

- Make a public presentation about the building design and technical research
- Finalize the graduation project

2 Design and program

2.1 Location

The NDSM site is now an old industrial area for the shipbuilding industry on the northern banks of the IJ-river in Amsterdam. Today the NDSM-warf has become a more cultural place where the warf offers facilities for a number of artistic disciplines and small crafts, called the cultural 'broedplaats' of Amsterdam.
Future urban plans want to maintain these activities in combination with living and working.

Fig. 1: W= Living, B = Broedplaats, H= Catering, R = Retail, O = Education, A = Offices

The circle represents the chosen location. Primary the location is chosen because of the character of the NDSM area and the environmental conditions. At the location is a lot of wind, and there are no obstuctions that could block the solar irradiance. Besides this, there is a fabulous view to the harbour and city of Amsterdam. Because of the location the building will be symbolic for its function: Hydrogen powered business and research center. The ferry boats sailing to the NDSM-quay, will sail around the location, so the energy developing character of the NDSM area will be emphasized. To strengthen this character at the entrance of the NDSM-harbor, a large wind turbine can be placed at the location of the red star.

2.2 Program

Primary functions
Research laboratory + offices
Conference possibilities
Auditorium

Secondary functions
Restaurant
Exposition and exhibition

General functions
Technical rooms
Parking
Toilets & Wardrobe etc.

2.3 Problems and restrictions

2.3.1 Problems - Architecture

- How to represent the hydrogen technology in the materialization?
- How do visitors enter the building?
- Routing through building
- Contradistinction old-new energy technology
- Integrating technology as an architectural way
- Experience of the energy for the visitors
- When is a building a machine?

2.3.2 Restrictions - Architecture

- Wind and sun directions
- Location. Buildings, streets, green, views
- Shape and sizes of renewable energy systems
- Physical properties of hydrogen
- General building regulation

2.3.3 Problems - Engineering

- How to store hydrogen in a good and save way?
- How to limit unnecessary energy losses?
- How to provide fresh water for the electrolyser?
- How to combine and express the technologies in architecture?
- How to integrate the technology in a building?
- How to let the building work/look like a machine

2.3.4 Restrictions - Engineering

- Now there is just a little research on hydrogen technology in buildings
- Physical properties of hydrogen
- Limited efficiency of renewable sources
- Environmental physical conditions
- Not all technologies are applicable in an architectural way

2.4 Solutions

- Study the materialization of industrial and hydrogen products in combination with their image.
- Study other museums and laboratories.
- Show a noticeable separation between different energy aspects.
- Use the location as much as possible for the energy experience.
- Discover the possible added value of the technology in architecture.

2.5 Precedents

Fig. 2: H2PIA - Peter Qvist Lorentsen

H2PIA

Architect Peter Qvist Lorentsen, principal of PQL Studio from Denmark, has been doing extensive research on hydrogen as an energy resource for architecture, and he wants to realize a hydrogen-powered city, H2PIA, in his country.

The projects should be hydrogen powered, but the hydrogen technology is not expressed. Only the renewable energy.

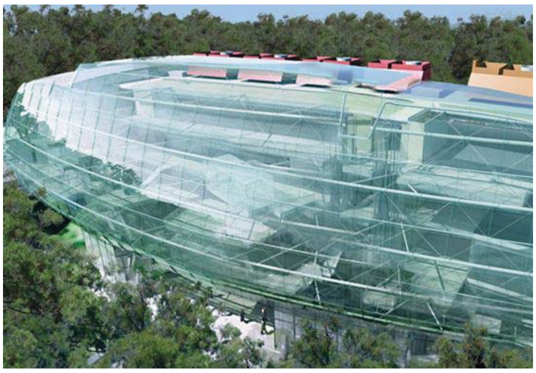


Fig. 3: Cox Architects - Zero-energy teaching and research building

Zero Energy + Solar Hydrogen

Eco Factor: Sustainable building powered by solar/hydrogen energy.

Zero Energy building + Transparent Solar panel. Energy is stored as hydrogen.

Technology is exposed (ducting etc.). The blob (glass volume) does express the gas and pressure

Fig. 4: Seymourpowell Aircruise Concept

Seymourpowell Aircruise Concept

The aircruise is a luxury travel experience, blending a fine hotel with the dreamlike quality and absolute freedom of flight.

Lift is provided by hydrogen, the lightest gas, and the clipper is powered by hydrogen fuel cells

New expression of the zeppelin. A huge volume is needed for lifting and uncompressed storage.

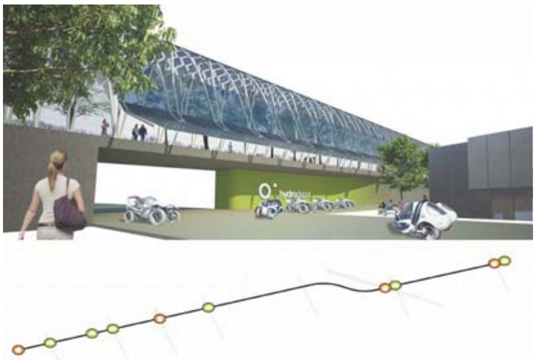


Fig. 5: Gensler - Hydrogenerator

Hydrogenerator

As it produces this much needed food and energy, the Hydrogenerator simultaneously releases oxygen as the by-product of photosynthesis and hydrogen production, a truly sustainable loop.

The excess hydrogen will be sold to alternative fuel vehicles at depots throughout the line.

Large surface is needed to provide enough energy. Opportunity: Roof is curved, solar panels can move to increase the yield?

Precedents

Fig. 6: Paul de Ruiter - Autarc

Autarc

The Autarc is a demonstration project for self-sufficient living.

- self-supplying
- environment friendly
- not connected to the power grid

Solar energy is transformed to hydrogen.
Critic: just a normal living boat, technology is not expressed.

Fig. 7: Serbia students - 2011 Skyscraper Competition

Hydra

The idea for the Hydra skyscraper is to harvest energy from lightning storms The power is produced through electrolysis and could be stored. Power plant that uses hydrogen as source of energy

Research is no clear study, but it is just a quite futuristic idea.

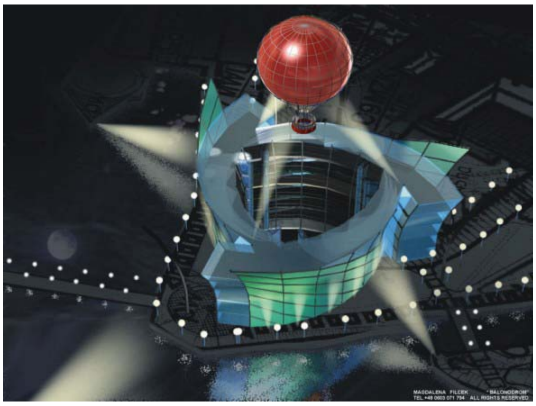


Fig. 8: Balonodrom Wroclaw - Balonodrom Project

Balonodrom Project

As the central feature of the building is a working helium filled passenger carrying observation balloon.

The balloon could also function as storage for hydrogen, and this can give a expressive form in architecture. Of course it also can be an attraction for people.

2.6 Inspirations

Fig. 9: Frank Ghery, Fisher Center for the Performing Arts

Fisher Center for the Performing Arts

Opportunities:
- *Big solar panel (rotate with sun?)*
- *Construction behind*
- *Could be adjustable with hydraulic systems*

Fig. 10: Eco Architecture

Sun Wall will produce 200 kw of energy

Opportunities:
- *Adjustable angle for optimal solar irradiance*
- *Lightness*
- *Wind flow bending for energy generation*
- *Connection with surrounding water.*

Fig. 11: Frank Ghery, Jerusalems Museum of Tolerance

Jerusalems Museum of Tolerance

Opportunities:
- *Moving parts*
- *Energy generating*
- *Energy expression*

Fig. 12: UnStudio, MoMema, Museum of Middle East Modern Art

UnStudio, Museum of Middle East Modern Art

Opportunities:
- *Routing visible as energy flows.*
- *Interesting daylight illumination*

Inspirations

Fig. 13: Herzog & De Meuron, Tenerife Expacio de las Artes

Tenerife Expacio de las Artes

Opportunities:
- *Clear routing and overview*
- *Looking where you walked before*
- *High ceiling*

Fig. 14: Energy City D-17, Doha Qatar

Energy City D-17, Doha Qatar

Opportunities:
- *Roof - moving/rotating solar panels?*
- *Right facade - Place a wind turbine in facade?*

Fig. 15: Richard Rogers & Renzo Piano, Centre Georges Pompidou, Paris

Centre Georges Pompidou

Opportunities:
- *Industrial architecture*
- *Even the routing is in a pipe, as a flow*

Fig. 16: Nicholas Grimshaw, Horno 3, Museo del Acero, Monterrey, Mexico

Horno 3

Opportunities:
- *Industrial architecture*
- *Historical integration*

Inspirations

Fig. 17: Triptyque, Pipe Light, So Paulo, Brazil

Pipe Light

Opportunities:
- *Do not hide the electrical connections*
- *Old & new integration*

Fig. 18: Underground tunnel

Underground Tunnel

Opportunities:
- *Old industry (coal, oil)*
- *Underground areas*
- *Curved ceilings*
- *Construction good visible*

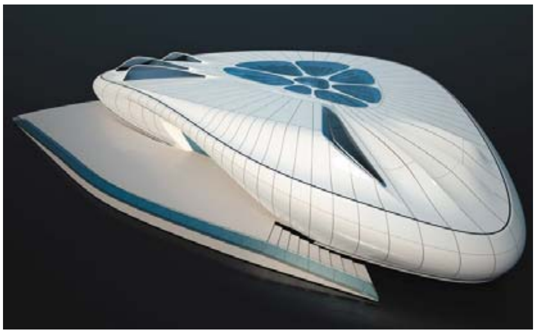


Fig. 19: Zaha Hadid, Chanel Contemporary Art Container

Mobile Art

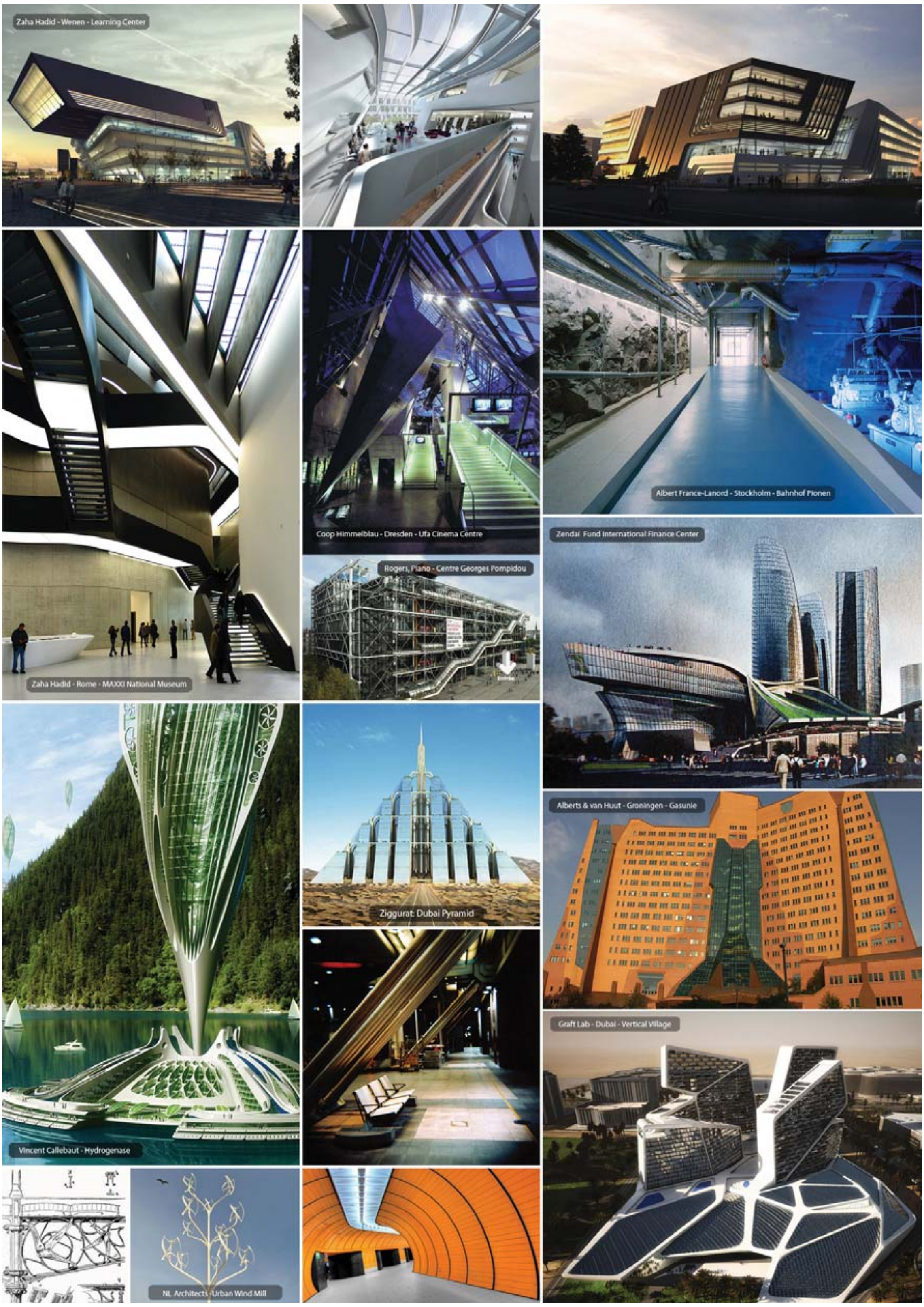
Opportunities:
- *Colors: white, blue, black*
- *Surface is curved and glossy: modern, wind flow?*
- *Transparent pillows instead of flat glass*

Fig. 20: BMW Hydrogen Motor

BMW Hydrogen Motor

Opportunities:
- *Colors: white, blue, black, brushed metal*
- *Transparent blue*
- *Aluminium colored blob-parts as buildings?*
- *Powerful image*

2.7 Moodboard



3 P1 Pavilion Design

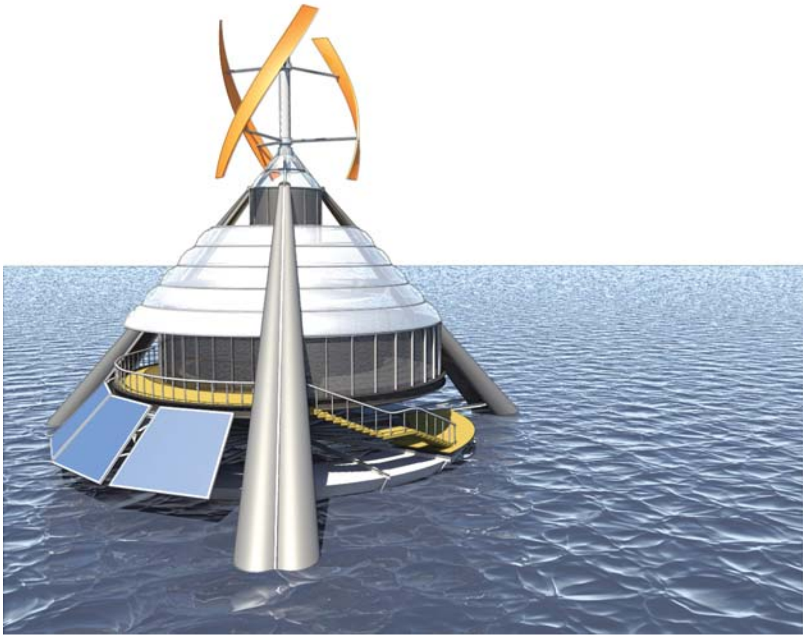


Fig. 22: Impression of the final design

3.1 Short introduction

The building consists roughly out of five parts:

1. A windturbine, that generates wind energy.
2. Solar panels (PV-cells). The building rotates with the sun direction and the panels can rotate with the angle of the sun for optimal yield.
3. Storage tanks, located in the 'legs' of the building. Hydrogen is generated with the energy from the solar panels and windturbine and will be compressed and stored inside, in the middle of the legs. The outer tanks are used for the floating stability of the pavilion.
4. A floater, at the water level. The building is visually seperated from this floater.
5. The building itself is suspended on the 3 legs of the building.

The next page will explain the design further into detail.
Appendix D includes more detailed design drawings.

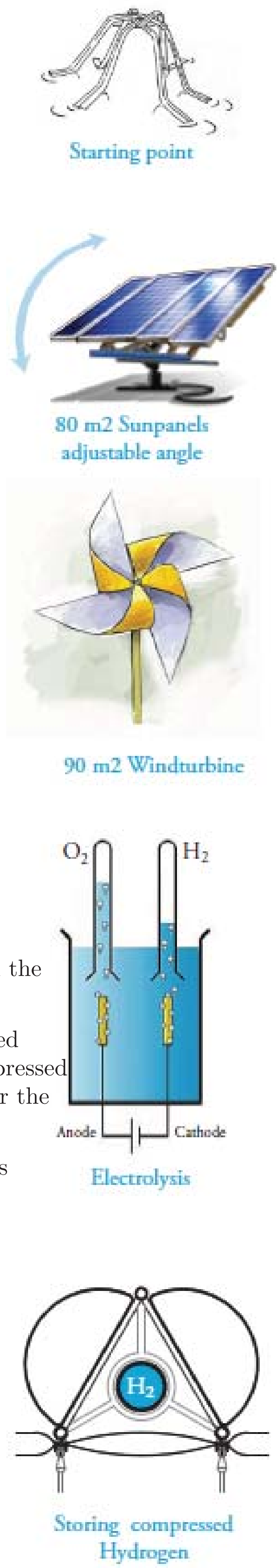


Fig. 21: Quick overview

3.2 Msc3 - Pavilion

A pavilion is designed with a focus on the energy autonomy, which is located in the IJ-river of Amsterdam.
There is chosen for a floating pavilion, which means that the building could easily turn. It can rotate with the sun, which increases the amount of energy that can be generated. Visitors will have a great view of the center of Amsterdam, the harbor and the new site, the Buiksloterham area.
It is a restaurant in combination with an exposition about energy potencies in architecture, mobility and the Buiksloterham area.

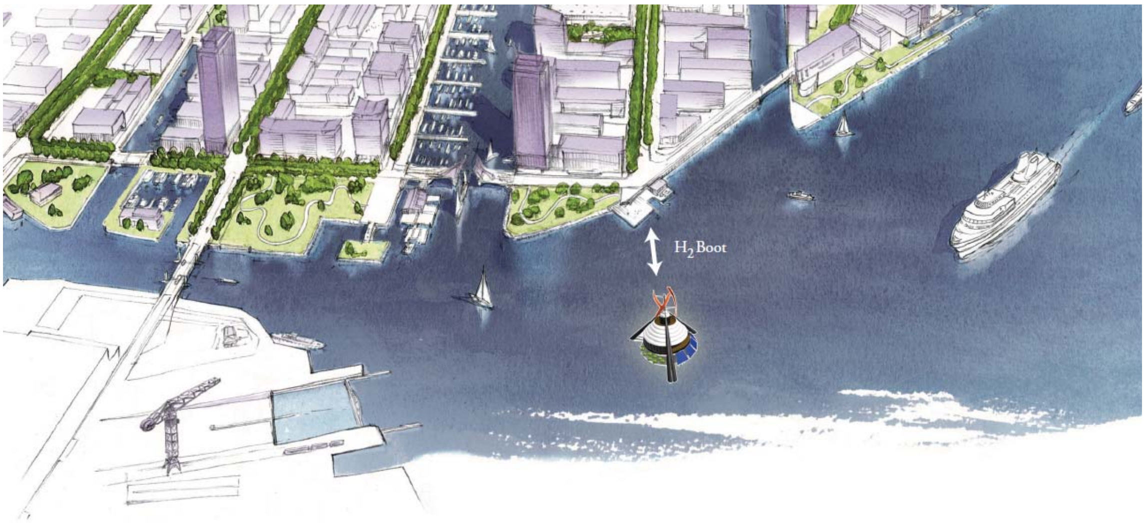


Fig. 23: Location, edited image

The research is roughly divided in to three aspects:

1. Generation of energy
2. Storage of energy
3. Use of energy

These three aspects are researched separately and all three have led to a feasibility study for the design project. Based on the research, design choices are made. The final design is summarized on the next page, with the aspects on which research has contributed.

3.2.1 Generation of energy

In the design, the research led to the use of solar panels and a wind turbine for energy generation. To make wind energy profitable, a very large flow area is required. Also solar energy requires a large surface. A quick comparison: 70 m2 of solar panels with an efficiency of 15 % generates about as much as a wind turbine of 120 m2. This is based on the weather in Amsterdam.
There is chosen for a Turby-type (improved version of the Darrieus-type) wind turbine. This wind turbine was chosen because it is very stable, has not so much vibrations compared to other wind turbines, has a good efficiency and also is consistent with the shape of the design. In addition, there is chosen for photovoltaic solar cells, which are mainly focused towards the sun. Furthermore, the angle of the sun panels is adaptable to the angle of the sun.
Finally the feasibility study has led to a building equipped with 80 m2 area of solar panels and with a 90m2 large wind turbine.

3.2.2 Storage of energy

The energy that is generated, is converted into hydrogen through electrolysis of water in the pavilion design. One advantage of electrolysis is that the energy is stored as a gas, and not in a heavy battery, which contains harmful toxic metals, which gets a lower quality over time. A disadvantage of hydrogen storage is that it requires a large volume. To solve this problem, the gas will be compressed, which has the effect that at higher pressures, a stronger tank is needed and that the compression to higher pressures costs more energy. So it is desirable to keep the pressure as low as possible. In the design the compression tanks are stored in the 'legs' of the building. The tanks are protected from the outside with air tanks that stabilize the building.

3.2.3 Use of energy

The usage is part of the design, but also of the feasibility study. There is chosen for a restaurant where can be cooked on hydrogen. This of course affects the amount of energy to be generated. Furthermore, the building is heated and lit. One important part of the energy consumption is the boat, powered on hydrogen, that brings people to the pavilion. Finally, the study shows that the boat and the cooking consume the most of the energy. The usage of electricity and heating/cooling is very low compared to other usages of the building.

Addition: as can be seen, a large part of the facade consists of air pillows. This is done to save weight, and to symbolize the storage of gas and pressure. The material of the pillows is the plastic EFTE.

'Ethylene tetrafluoroethylene, ETFE, a kind of plastic, was designed to have high corrosion resistance and strength over a wide temperature range. Technically ETFE is a polymer, and its systematic name is poly(ethylene-co-tetrafluoroethylene). ETFE has a very high melting temperature, excellent chemical, electrical and high energy radiation resistance properties.'[1]

[1] http://en.wikipedia.org/wiki/ETFE

4 P1 Research Pavilion

4.1 Floating

The following section will briefly explain the principle of floating. If you look to the difference between the density of air and hydrogen, hydrogen is much lighter. The question is whether hydrogen floats better than air. After this explanation there will be calculated what effects the floating has for the design.

4.1.1 Principle

Densities:
Air: 1,29 Kg/m3
Hydrogen: 0,09 Kg/m3
Oxygen: 1,29 Kg/m3
Water: 998 Kg/m3

Buoyancy (Floating rule of Archimedes)[2]
For floating the Archimedes principle is applied, called Buoyancy. *This concerns the amount of water that will be moved.* This is equal to the underwater volume, but then calculated with the density of water (Fa). So: Buoyancy = weight of displaced fluid.

Although hydrogen is 14 times lighter than air, it floats hardly better. However, the weight (Fp) of hydrogen + building is less than the weight of air + building, but this is negligible when you look to the total weight.

Example floating
Wood floats better than a piece of steel with the same volume because wood is lighter and steel is heavier than water. The wood is supported by the upward force of the displaced water (Fa). This upward force is not sufficient for steel, so the steel volume will sink.

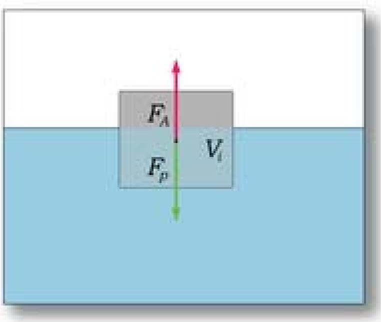


Fig. 24: Principle Archimedes, floating

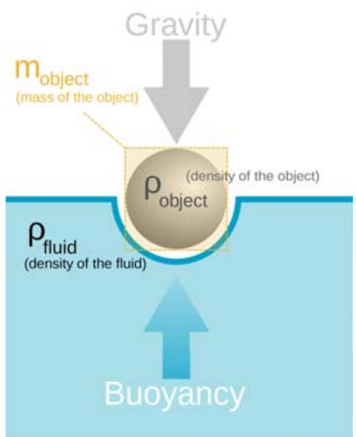


Fig. 25: Buoyancy

4.1.2 Calculation for the design

The pavilion design contains ± 450 m^2 floor area.
To calculate the weight of the total pavilion, is used 5 kN/m^2.
The minimal (Fa) counterforce, caused by the water displacement, must be 2250 kN. The density of water is 9,81 kN/m^3, so 230 m^3 of water must be displaced, to prevent the pavilion from sinking.

If the floating area is ± 180m^2, the thickness of the 'floater' must be 1,3m under water. In the design 2m will be used, to have a buffer.

[2] http://en.wikipedia.org/wiki/Buoyancy

4.2 Generating energy

The use of wind and solar energy is not always trustworthy. If it is not windy, less energy is generated, the same for sun-energy when the sun is not shining. Both systems have advantages and disadvantages. A major advantage of wind energy is that wind energy can also be produced at night. Solar energy can only be produced during the day. Furthermore, solar energy is very sensitive to the direction and angle of the sun. If the panels are not orrientated right, less energy will be generated.

Both ways are technically researched and integrated in the design. In the third week it started as a design concept for some sort of shape as in the pictures shown below. In the design the solar panels could complement with the wind turbine.

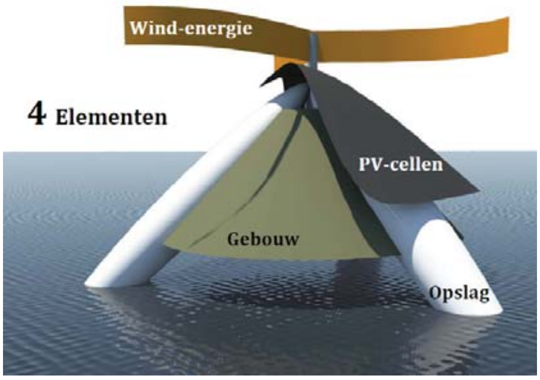


Fig. 26: Concept drawing

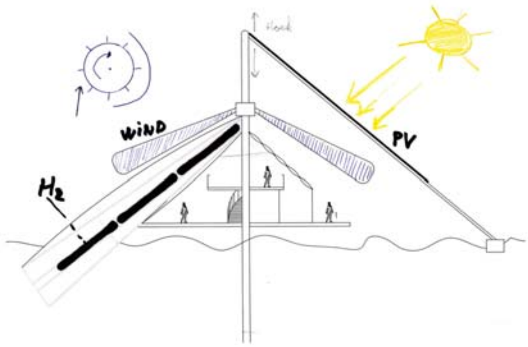


Fig. 27: Complementation. Sunpanels as windshield

4.2.1 Wind energy

As was just mentioned, wind is a 24 hours energy source, but not always present. It also depends on the type of wind turbine, the location, the windspeed and the size, which may affect the amount of generated energy. These aspects will be discussed in the research and design.

Different types

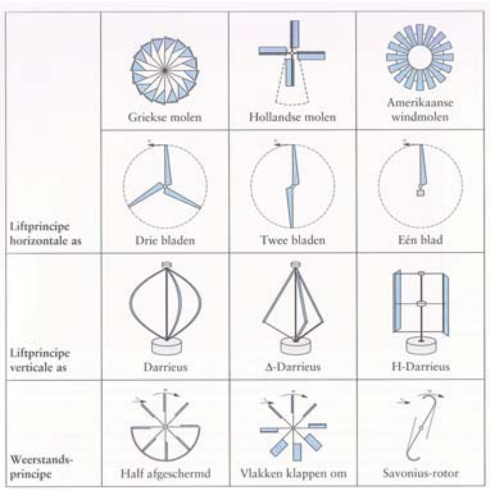


Fig. 28: Overview wind turbine types

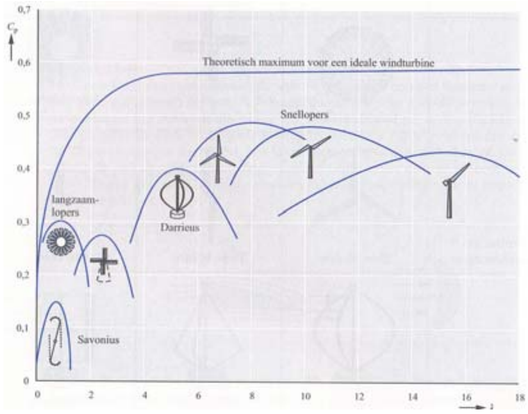


Fig. 29: Efficiency wind turbines

The pictures above[3] show how different wind turbines can look, and immediately give a clear picture of the efficiencies. Several types are considered, but finally there are two types studied. The Savonius-type and the Darrieus type.

There is a difference between horizontal and vertical-axis wind turbines. The horizontal orientated wind turbines are the most famous. The Dutch windmill is an example of this, but today the three-blade windturbines have reshaped the Dutch landscape. The disadvantage of these windmills is that they run very fast, and this will cause vibrations. This is not really desirable in buildings. The vertical wind turbines, the Darrieus like type, have the advantage that they are always directed correctly on the wind, and that there is no need to rotate into the right direction. Vertical-axis wind turbines use the lift principle and in theory could reach a 59 % efficiency (Betz optimum). This is the maximum amount of energy you can generate out of a certain flow surface.

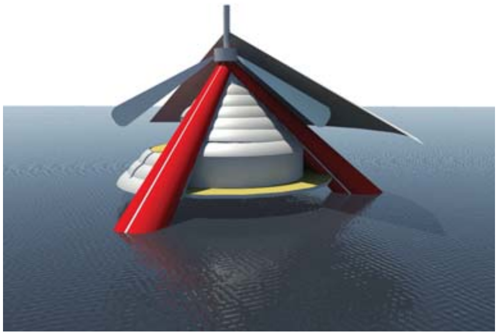


Fig. 30: Savonius type

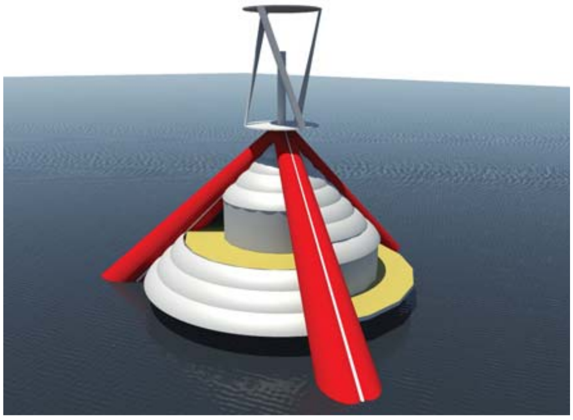


Fig. 31: Darrieus type

The two images above show the integration of a Savonius and a Darrrieus type wind turbine in the design. The shielded version, the Savonius rotor, is chosen primarily because it matched better with the design, but compared with the solar panels the production was very low. The windmill was protected by the "cape", on which solar cells are mounted. The cape worked as a half-shield so the windmill could rotate.
The second image is a Darrieus type. This type can not rotate around the building, because it must be placed on top of the building, full in the wind, to function properly.

[3] Ouwehand J., Toegepaste Energietechniek. Deel2: Duurzame energie: 162-162

Improved Darrieus = Turby

1. The blades have the same distance from the axis over the entire length
2. The blades have a helical shape

This leads to less vibrations, low noise and high efficiency in urban areas.

'Nadat het Turby team deze verklaring voor de nadelen van de Darrieus had gevonden was de richting waarin de ontwikkeling van een betere verticale as windturbine moest gaan duidelijk.

De afstand tussen blad en as moest over de hele bladlengte gelijk zijn zodat de invalshoek van de schijnbare wind overal gelijk zou zijn. Daarmee zou worden voorkomen dat de stroming om het blad turbulent werd (overtrek) met trillingen als gevolg en nergens bereikt het blad een zo hoge snelheid dat de voorwaartse component van de liftkracht nul wordt. Over de hele lengte ondervindt het blad een aandrijvende kracht. Het eenvoudigst zou zijn geweest de rechte balden parallel aan de as te nemen, maar tweemaal per omwenteling vindt een omslag van de windinvalshoek op het blad plaats. Om te voorkomen dat daardoor trillingen zouden ontstaan is ervoor gekozen de bladen over een kleine hoek te verdraaien naar een helix vorm. Om die bladen te kunnen maken met voldoende vormvastheid en sterkte moest de meest moderne technologie uit de kast worden gehaald. Alleen een constructie van koolstof-epoxy composite is daarvoor geschikt.

Tests hebben bewezen dat Turby trillingvrij, geluidsarm en met een hoog rendement functioneert. De schuinstaande bladen hebben een extra voordeel dat in de stedelijke omgeving goed van pas komt: daardoor kan Turby schuin van onder aanstromende wind benutten. Ook dat is met onderzoek aangetoond.' [4]

[4] http://www.turby.nl/05/03%20Content%20A.htm

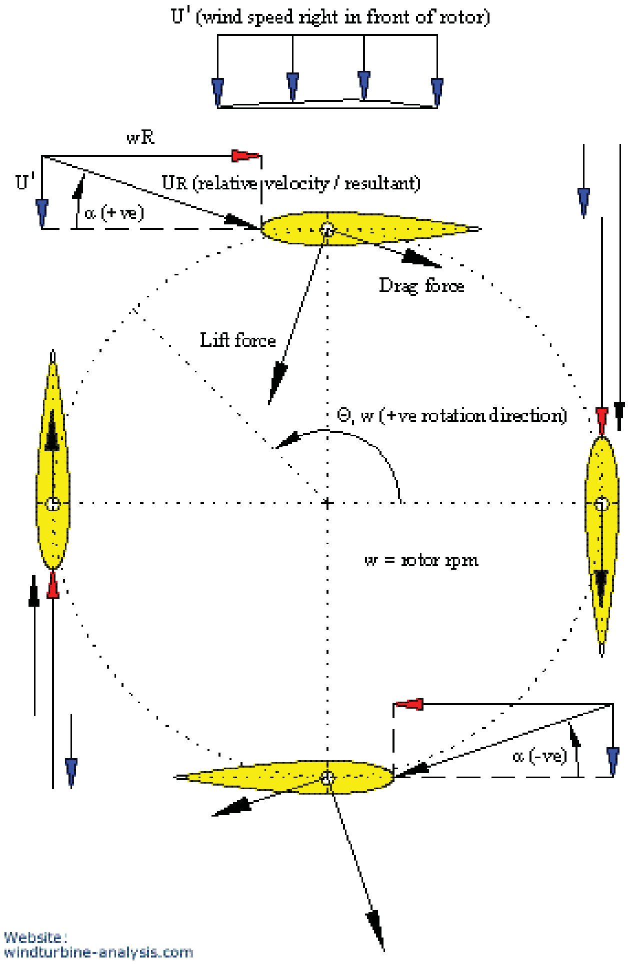


Fig. 32: Lift principle of the Darrieus vertical Axis wind turbine

Size and generation

The maximum amount of energy to get out of the wind is given with the formula:

$((0,5 * 1,225 * V^3 * A) * 24 * 60 * 60)/3600000$ (kWh) [5]

Where A is the flow area and V the wind speed. Because in the formula V is cubed, the wind speed is very decisive for the amount of energy generated. Some calculations can be seen in the next overview. In the final design a Turby-type wind turbine is chosen. This type has an efficiency of about 35 %, so to calculate energy generation of a Turby-type wind turbine, the formula must be multiplied by 0.35.

Surface	2 m/s	3 m/s	4,5 m/s	
A=5m2	0,21	0,69	2,34	kWh
A=10m2	0,41	1,39	4,69	kWh
A=20m2	0,82	2,78	9,38	kWh
A=30m2	1,23	4,17	14,07	kWh
A=50m2	2,06	6,95	23,44	kWh
A=100m2	4,12	13,89	46,88	kWh

Fig. 33: Effect of A and V on the amount of generated energy, for a Turby wind turbine.

[5]Ouwehand J., Toegepaste Energietechniek, Deel2: Duurzame Energie

In the final design A= 90 m2
Efficiency: 35%

Location and windspeed
The location of the design is the IJ-river in Amsterdam. The average windspeed is about 5,1 m/2 at Schiphol airport[6], but varies per month. In the next table the amount of generated wind energy is displayed, if the pavilion was placed at the airport.

Schiphol Airport

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Windspeed m/s	6,3	5,9	5,7	5,6	4,8	4,4	4,4	4,2	4,4	5,1	5,3	5,6
Kwh per day	115,8	95,1	85,7	57,9	51,2	39,4	39,4	34,3	39,4	61,4	68,9	81,2

Because the pavilion is not situated at Schiphol airport, but in an open urban area, the assumption is made to calculate with a 1 m/s lower wind speed. In the next table the amount of generated wind energy is displayed for the IJ-river as location:

IJ-river, Amsterdam

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Windspeed m/s	5,3	4,9	4,7	4,6	3,8	3,4	3,4	3,2	3,4	4,1	4,3	4,6
Kwh per day	68,9	54,5	48,0	29,6	25,4	18,2	18,2	15,2	18,2	31,9	36,8	45,0

As you can see this decrease in windspeed means almost a halving of the yield.

[6] http://www.klimaatatlas.nl/klimaatatlas.php

4.2.2 Solar Power

Besides wind energy, solar energy is integrated in the design as photovoltaic solar cells (PV-cells). Photovoltaic solar cells can produce electric voltages upon exposure to light.

Semiconductors

Photovoltaic solar cells make use of the semiconductor silicon. A semiconductor is a material that in terms of conductivity is between an isolator and a conductor. The conductivity depends on the environmental variables, such as temperature or the intensity of the light. The conductivity of a semiconductor can be regulated by adding some impurities through the crystal.

P-N Junction[7]

In a photovoltaic silicon solar cell there are two different layers with impurities. One layer with phosphor and one layer with boron as an addition to the silicon crystal. The layer with phosphor is called the ‘n-type’ and the boron layer the ‘p-type’. The layer with phosphor has too many electrons, and the boron layer has a shortage of electrons (‘holes’). This is because pure silicon has 4 electrons in the outer shell, phosphor 5 and boron 3.

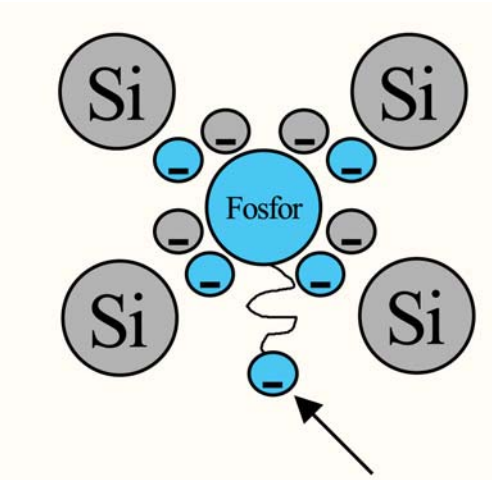


Fig. 34: N-type, phosphor

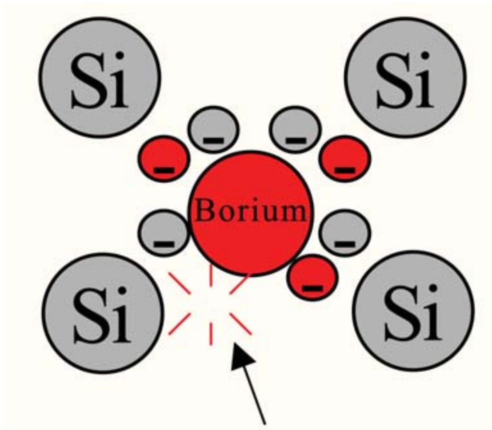


Fig. 35: P-type, boron

The region of the contact area of the two layers is called the p-n junction, where the positive silicon atoms are recombined with the negative silicon atoms. When photons hit the solar cell, freed electrons (-) attempt to unite with holes on the p-type layer. The p-n junction, a one-way road, only allows the electrons to move in one direction.[8]

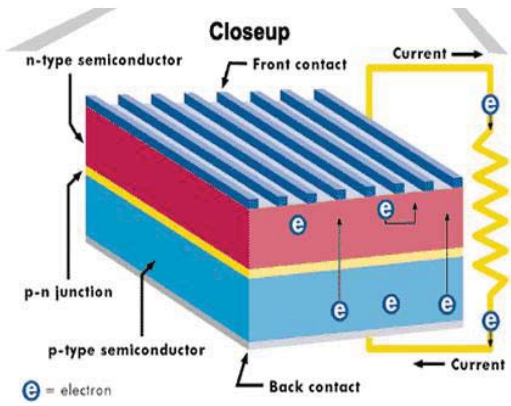


Fig. 36: Closeup of a silicium solar cell.

[7] http://www.ecn.nl/fileadmin/ecn/units/zon/docs/psp00068.pdf

[8] http://case-modding.nl/PWS%20De%20Zonnecel.doc

Different solar panels

There are different types of solar panels. Three types will be discussed. The monocrystalline, multicristalline and amorphous solar cells.

Mono-crystalline solar cells
These cells are produced using the expensive Czochralski process. The Czochralski process is a method of crystal growth used to obtain a material as one single crystal. The result is a cylinder, that will be sawed in pieces, the wafers. With these wafers, the suncells are assembled.

Multi-crystalline solar cells
Multi-crystalline cells are cheaper and easier to manufacture than mono-crystalline cells, but have been unable to reduce the cost of the solar power significantly, because they are less efficient. During the production, liquid silicon is cast and this will crystallize during the solidification. Therefore the texture is different than the mono-crystalline cells. Because the conductivity between the crystals is less, multi-crystalline solar cells are less efficient.

Amorphous solar cells
The cheapest solar cells are the thin film amorphous solar cells. This is because at very high temperatures, the solar cell are sprayed as only thin layers onto a backing material. Amorphous solar cells are cheaper, but their efficiency is less. An advantage is that amophous solar cells are flexible.

Fig. 37: Mono-crystalline

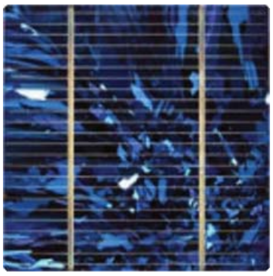


Fig. 38: Multi-crystalline

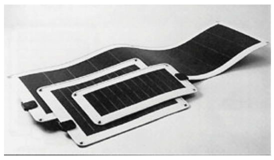


Fig. 39: amorphous

Type	Efficiency	WPEAK/m2
Mono-crystalline	18%	130
Multi-crystalline	16%	120
Amorphous	5%	50

Watt-peak (Wp) is a measure of the nominal power of a photovoltaic solar energy device under laboratory illumination conditions. This means an illumination of 1000 W/m2 and a temperature of 25 degrees Celsius.

[8]Source: Schnittich C., In Detail - Solar Architecturel: 164
[8]Source: http://www.sapa-solar.com/belgium/sapa-solar/index.html

Efficiency

For now we can say that we will calculate with a realistic efficiency of 15% for the solar cells. The illumination in The Netherlands is about 1000 W/m2. When we calculate the production of solar cells placed in the design, we will calculate with 80m2. This means that these panels can have a maximum capacity of 12 kW (80*1000*0,15).
The next table shows the solar energy production of the design. The amount of solar hours is based on the KNMI values (see Appendix A).

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar hours	2	3	4	6	7,1	6,8	7	6,3	4,6	3,5	2	1,6
Kwh per day	24	36	48	72	85,2	81,6	84	75,6	55,2	42	24	19

Angle sun

The table above is correct when the solar cells are focused correctly on the sun during the day. This can be done because the building can rotate on the water. In addition, the panels can adjust their angle to take the angle of the sun in account. This angle changes during the day and the entire year. In the summer, the solar panels are quite flatly orientated, and in the winter they are more vertical orientated. It could be that in the winter it is not profitable to rotate the panels, because that might cost more energy than panels produce themself.
The next table[9] shows the angle of the sun over the entire year.

Maand	Zon Hoek	Paneel Hoek	Paneel richten naar het
JAN	18	72	Zuiden
FEB	27	63	Zuiden
MAA	38	52	Zuiden
APR	50	40	Zuiden
MEI	58	32	Zuiden
JUN	61	29	Zuiden
JUL	58	32	Zuiden
AUG	50	40	Zuiden
SEP	38	52	Zuiden
OCT	26	64	Zuiden
NOV	18	72	Zuiden
DEC	15	75	Zuiden
Gemiddelde hoek			
Zonhoek 42°		Paneelhoek 48°	

Fig. 40: Angle of the sun

[9] http://users.telenet.be/annette-guy/zonP/zonHoek.htm

Integration in design

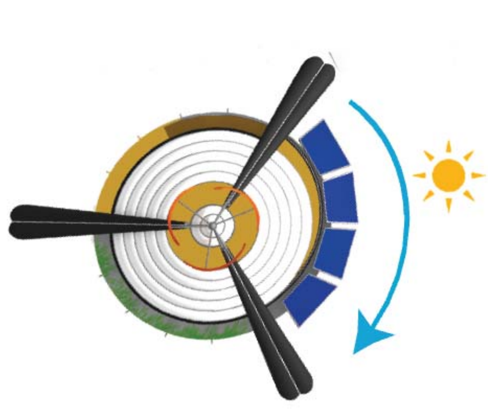


Fig. 41: Rotating with the sun

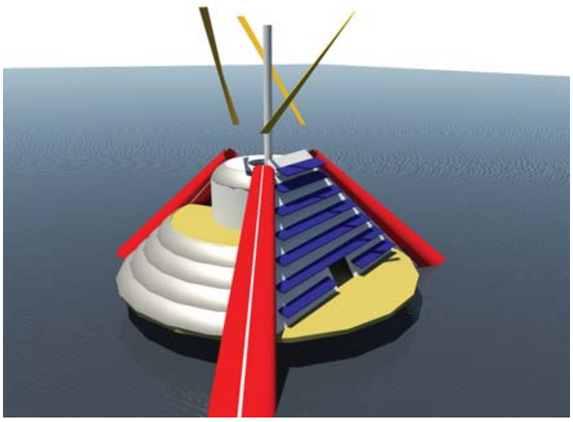


Fig. 42: Straight side, with panels

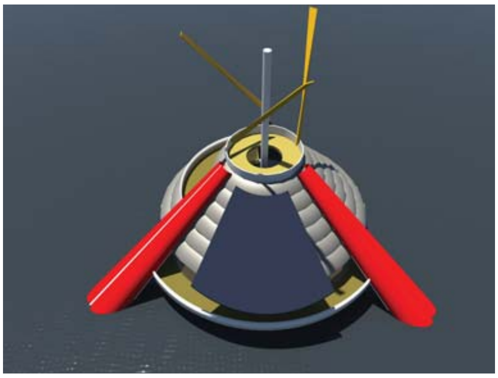


Fig. 43: Same shape as the building

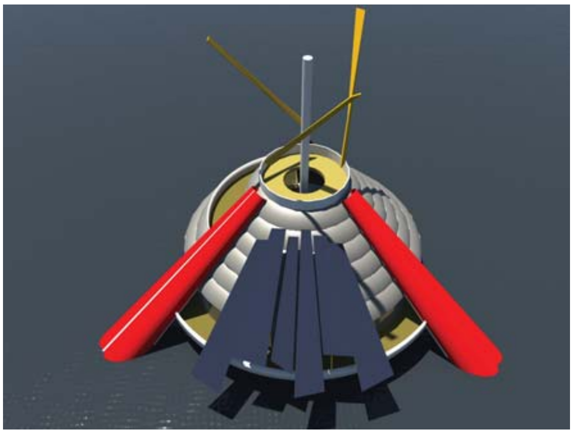


Fig. 44: Use she shape of sunrays

The images above clearly show that the building can rotate with the sun, and that initially it was important that the solar panels were orientated straight to the sun. The solar panels were attached to the building. As previously mentioned in the wind energy section, earlier in the design stage the building had a 'cape' of solar panels. An attempt was made to continue this in the lower two images. The shape of sunrays is used in the design, which would have been a creative interpretation of the solar panels.

Finally there is chosen for a compromise, where lower solar panels are placed above the water. Not all are exactly oriented to the sun (almost), but they can adjust their angle. The surface is less than in the other designs, but this is no problem according to the feasibility study.

Fig. 45: Adjustable solar angle

4.2.3 Conclusion

The energy production with wind energy is relatively stable over the entire year, but solar energy produces a lot more in the summer than in the winter. This energy will be saved as hydrogen so that it can be used in winter. The next section will deal with this part.

4.3 Hydrogen production

4.3.1 Advantages of hydrogen

1. Hydrogen can be produced out of water and water is abundant on the surface of Earth.
2. There is no CO2 emission during the production and use of hydrogen.
3. Dependence on the oil producing countries will decrease.
4. People can become energy self-sufficient.
5. Compared with batteries, no toxic metals are needed.
6. Hydrogen has a very high energy density of 120 MJ / kg compared with natural gas: 50 MJ / kg.

4.3.2 Disadvantages of hydrogen

1. Very explosive.
2. Under compression, a strong and heavy tank is needed.
3. Hydrogen contains 1/3rd of the heating value compared with natural gas. 10,8 MJ/m3 for hydrogen comprared with 36 MJ/m3 for methane.
4. Hydrogen takes a lot of space if you store it as a gas. It costs a lot of energy to liquify hydrogen, and make it more compact.

De grenswaarden waartussen een mengsel van waterstof en lucht ontvlambaar is, bestrijken een erg groot gebied: van 4 tot 75 vol %. Het ontvlambare venster bij methaan is veel kleiner: 4,4 tot 17,0 vol %. Bovendien is de benodigde ontstekingsenergie bij waterstof (0,02 mJ) meer dan een factor 10 kleiner dan bij methaan (0,29 mJ). [10]

4.3.3 Comparison with an battery system

To produce hydrogen using electrolysis, we need electricity. We assume that the two systems (hydrogen or battery) have the same electricity input. When charging a battery, 20% of the energy will be lost, so a battery system has an efficiency of roughly 80%.
The efficiency of electrolysis is between 50 and 90%. these values vary a lot, but we also assume that this process has an efficiency of 80%. It seems to have the same efficiency as a battery system. However, the energy is then converted into hydrogen rather than electricity. When using this hydrogen for cooking (burning with 100 %), the efficiency is still 80%, but when you convert the hydrogen back into electricity using a fuel cell (efficiency about 50%), the efficiency of the entire system is about 40%. So using hydrogen as an energy carrier does not always seem to be a good choice.

So, why choose for hydrogen?
The benefits are described above. Yet it seems the efficiency is not very high, and that the risks are great. Conversely, hydrogen is more environmentally friendly.
A major downside of battery systems on floating buildings is that they are very heavy. The table below shows what a battery weighs per kWh. This makes it a lot more attractive to use hydrogen as an energy carrier, especially when it concerns floating buildings.

Weight comparison [11]
Lead - 0,03 Kwh/Kg
Li-ion - 0,14 Kwh/kg
Lipo - 0,2 Kwh/kg
Hydrogen - 33,33 kwh/kg (without tank)

Volume-Mass comparisson (same amount of energy) [12]

Type	Volume	Mass
Benzine including tank	52 Liter	60 kg
Hydrogen, high pressure, including tank	300 Liter	400 kg
Lead battery	2000 Liter	3000 kg

[10] http://www.vswb.be/default.asp?WebpageId=17
[11] Hermans J., Energie survival gids: 180
[12] Hermans J., Energie survival gids: 179

4.3.4 Electrolysis

Electrolysis in chemistry is a process that separates elements when electricity runs through the medium. Reactions that take place are redox-reactions, which involves an oxidizer and a reducer. The strongest oxidizer will always react with the strongest reducer.
Oxidation of ions or neutral molecules occurs at the anode (+ side), and the reduction of ions or neutral molecules occurs at the cathode (- side).
There are roughly two types of electrolyzers that are often used. An alkaline or PEM electrolyzer.

1. Alkaline electrolyzer (60-90% efficiency)
The conductivity of pure water is very low, so no electrolysis reaction will occur. To improve the conductivity, an electrolyte must be added to the water. An electrolyte is any substance containing free ions that make the substance electrically conductive. The most typical electrolyte is an ionic solution, but molten electrolytes and solid electrolytes are also possible.
An often used electrolyte for water electrolysis is potassium hydroxide (KOH) 25%, so the conductivity of water is better. When water (H2O) is used as a medium, water will be split in hydrogen and oxygen. Hydrogen gas and OH- ions are released at the cathode-side and at the anode-side other OH- ions will form water and oxygen gas, as can be seen in the reactions.

Cathode: 4H20 + 4e- = 2H2 + 4 OH-
Anode: 4OH- = O2 + 2H2O + 4e-
Total: 2 x H2O = 2H2 + O2

In the reactions you can see that there is two times more hydrogen than oxygen formed. This will is also visible in the production of the amount of gasses.

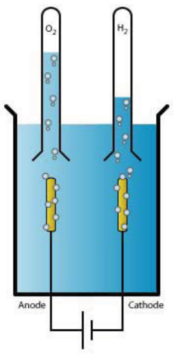


Fig. 46: Electrolysis

2. PEM electrolyzer (50-90% efficiency) A way to electrolyze water without a liquid electrolyte is by using a *polymer electrolyte membrane.*
A PEM electrolyzer, as the name says, contains a polymer membrane. That membrane is in fact the electrolyte, similar to the KOH in the alkaline electrolyzer. In the alkaline electrolyzer situation above, OH- ions are transmitted through the liquid electrolyte. In a PEM electrolyzer, H+ ions are used, and make use of a solid polymer membrane as electrolyte. It can directly split water without additions to the water.
A disadvantage of the PEM electrolyzer is that it uses platinum as a catalyst at the cathode side of the porous carbon electrodes. This makes it very expensive in comparison to an alkaline electrolyzer.
An advantage is that PEM electrolyzers can split pure water into hydrogen and oxygen. Another advantage is that the system is still operational under high pressure, so it is possible to produce pre-compressed hydrogen of 120-200 bar, unlike the alkaline electrolyzer that only works until 30 bar and needs additional energy to compress the gas further. Another advantage is the fact that PEM electrolyzer can be more compact, because of a higher current density, 1-2 A/cm2 compared to 0,4 A/cm2 for alkaline electrolyzers. PEM electrolyzers function very well with renewable energy systems where the amount of generated electricity varies greatly. Because of this, PEM electrolyzers seem to be a good choice in architecture, although there is a lot of experience with the cheaper alkaline electrolyzers.

[12] Spiegel C., Renewable Energy, Science Education Manual: 58

4.3.5 Water sources available for buildings

If you want to produce hydrogen gas out of water from the architectonic environment, we can state that this water will never be pure H2O. The best water could be rain water, but also that water should be purified or at least filtered. The same problems will occur with river- and seawater. Because of the pollution, the electrolyzers can become clogged. An option is to filter the water, using a semipermeable membrane, but that cost energy in the form of pressure.

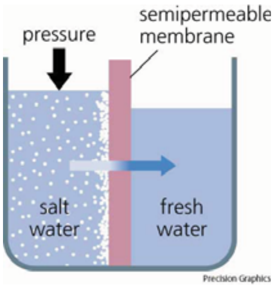


Fig. 47: Filter water

When using seawater for electrolysis, hydrogen will be produced at the cathode and chlorine at the anode. That presents a major environmental problem. Another problem is that a thin film of calcareous deposits will be formed at the cathode surface, mainly consisting of CaCO3 and Mg(OH)2.
Oxygen can be produced out of seawater when a coating is used over the conventional electrodes. Following this basic study, electrodes were prepared to specifically favor the evolution of oxygen from brine solutions. Unique manganese dioxide coatings are capable of evolving oxygen from seawater at 99% efficiency, and from saturated sodium chloride brine at 95% efficiency.

4.3.6 Urine as source for hydrogen production?

Another interesting development is the electrolysis of urine instead of water. Urea has four hydrogen atoms per molecule, less tightly bonded than the two hydrogen atoms in water molecules. Beside that there is less energy needed to electrolyze urea.[13]

'an electrolytic cell potential of only 0.37 V is thermodynamically required to electrolyze urea at standard conditions. This is significantly less than the 1.23 V required to electrolyze water theoretically generating 70 cheaper hydrogen. ...We have demonstrated that the technology is effective for both urea and urine.' [14]

This could be very interesting to integrate in architecture,but for the moment professor Botte from the Ohio university is still researching the electrolysis of urea and urine, so we have to wait for her final convincing results and technics.

[13]Piddock C., Liquid Gold, is urine the natural resource of tomorrow?
[14]http://nicksrealm.com/HHO/Library/urea_electrolysis.pdf

4.4 Usage

4.4.1 Function

A restaurant is placed in the pavilion. An exhibition is also part of the programme.
The design contains 8 restaurant tables and 10 seats at the bar.

4.4.2 Energy parts

1. Cooking

Cooking consumes gas. In order to make a first assumption for the amount of used gas, a normal household is checked. A normal household consumes 60-80 m3 of natural gas per year. Because this information is difficult to compare with a restaurant, the consumption of a single gasburner is also researched. The 'Essent horeca bespraartips' gave the answer that one gasburner uses 0,5 m3 gas per hour.[15]

Calculation

Assumption: 4 burners. 4 hours per day
1 burner per hour = 0,5 m3 natural gas

This consumes 2 m3 of natural gas per day, which is roughly in accordance with 6 m3 of hydrogen, because the heating value of hydrogen is 10,8 MJ/m3 compared with natural gas that has a heating value of 36 MJ/m3.
Because you need 4,8 kWh to produce 1 m3 of hydrogen, 6m3 is in accordance with 28,9 kWh.

2. Lighting

LED lightning: 3W/m2 [16]
Assumption 4 hours per day, 150 m2 of lightened surface = 1,8 kWh per day

3. Heating and Cooling

A normal household consumes about 1500 kWh per year. [17]
Using a heatpump, connected tot the river or suncollectors, a quarter[18] of the energy could be used. This is about 1 kWh per day.
Because the pavilion is bigger than an normal household, in the calculation will be used: 3 kWh per day.

4. Boat to the pavilion

People will be brought to the pavilion in small portions with a sloop that has a capacity of 5 kW[19]. When the boat will be used 2 hours a day, 25 kWh per day will be used. The calculation takes into acount that the hydrogen must be converted to electricity using a fuel cell, which has an efficiency of 40%.

5. Additional equipment

It is assumed that the pavilion has a large refrigerator of 200Watt. This is 4,8 kWh per day.

[15] http://www.essent.nl/content/zakelijk/besparen/energie bespaartips/horeca/index.html
[16] http://www.lighting.philips.nl/pwc_li/nl_nl/connect/Assets/downloads/online-documentatie/Brochure_leds_in_kantoren_NL.pdf
[17] Energie survial gids: 25
[18] http://www.techneco.nl/documents/download/90
[19] http://www.idtechnology.nl/?nr=158

Overview

Part	**Usage per day**
Cooking	28,8 kWh
Boat	25 kWh
Additional equipement	4,8 kWh
Heating/cooling	3 kWh
Lighting	1,8 kWh
Total	63,40 kWh

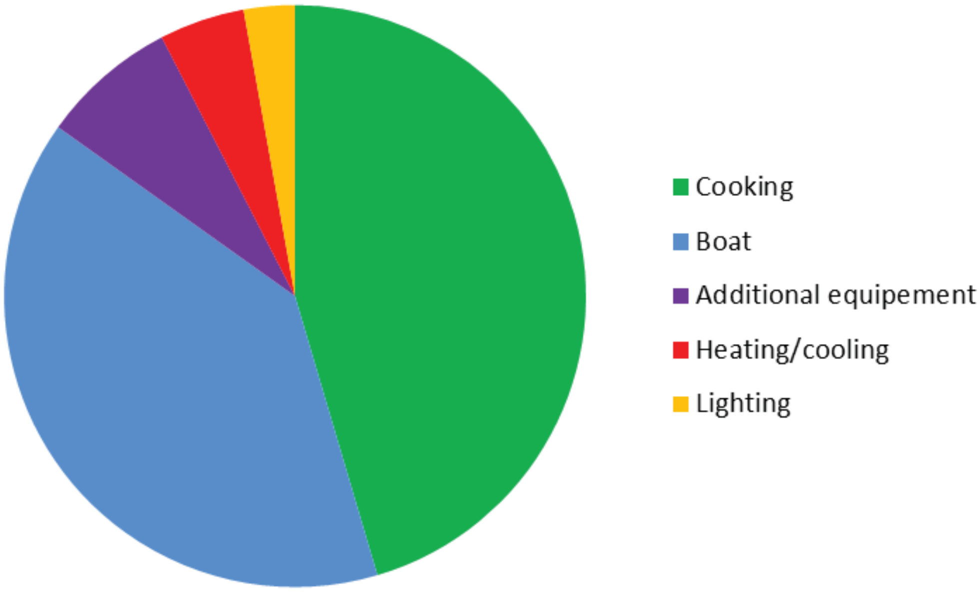


Fig. 48: Overview usage floating restaurant

Besides these uses per day, there is also the energy used to compress the hydrogen. The pressure will increase in the summer, because of a surplus of energy. Higher pressure also causes higher compression losses. This effect will be discussed in the next section.

4.4.3 Compression of hydrogen

If we want to store large amounts of hydrogen and want to save space, we need to compress the gas. If you are using a PEM electrolyzer, as previously discussed in the report, then it is not necessary to compress the hydrogen gas after the production, because a PEM electrolyzer can even produce under high pressure. When using the conventional alkaline electrolyzer, we will still have to compress the gas after the production. This compression takes extra energy. This section is about this amount of energy required to compress hydrogen. This is an extra energy usage of the building, and will be part of the feasibility study. Besides this the consequences for the pavilion project will be discussed.

$$W = [n/(n-1)]\, p_o\, V_o\, [(p_1/p_o)^{(n-1)/n} - 1] \qquad (1)$$

with	W	specific compression work	J/kg
	p_o	initial pressure	$Pa = N / m^2$
	p_1	final pressure	$Pa = N / m^2$
	V_o	initial specific volume	m^3/kg
	n	adiabatic coefficient, ratio of specific heats	

The compression work depends on the nature of the gas. This is illustrated by comparing hydrogen with helium and methane

H_2	$n = 1.41$	$V_o = 11.11\ m^3/kg$
He	$n = 1.66$	$V_o = 5.56\ m^3/kg$
CH_4	$n = 1.31$	$V_o = 1.39\ m^3/kg$

Fig. 49: Formula adiabatic compression

The formula above [20] describes adiabatic compression, which describes the compression of hydrogen the best. Before we start calculating it is important to note that a compressor and a compression engine are also involved, which have an efficiency of about 75 % each. This results in an efficiency of 0.56 % for the compression process.

Calculation

Question

How many energy does it take to compress 1 m3 of hydrogen gass from 1 to 100 bar?

Hydrogen values: n= 1,41 en V0= 11,11
1 bar = 100000 Pa
100 bar = 10000000 Pa

Following the formula , there is 10758711 J/kg needed.
The density of hydrogen gas is 0,09 Kg/m3. So for only 1 m3 hydrogen gas is needed: 968284 Joules.
1 KwH= 3600000 Joules
Theoretically 0,27 Kwh per m3 hydrogen gas is needed to compress the gas from 1 to 100 bar. Taking into account the efficiency of compression, this means: 0,48 KWh/m3 hydrogen gas.

[20] http://www.woodgas.com/hydrogen_economy.pdf

What are the consequences for the pavilion project?

In the design there are three 'legs' with approximately 3.8 m3 space each, so the total tank space in the pavilion is 11.4 m3.
The following diagram shows the pressure in the tanks and the energy per m3.

Volume	**Pressure**	Kwh/m3
68,4 m3	6 Bar	0,12
114 m3	10 Bar	0,16
228 m3	20 Bar	0,24
570 m3	50 Bar	0,36
1140 m3	100 Bar	0,48
2280 m3	200 Bar	0,62

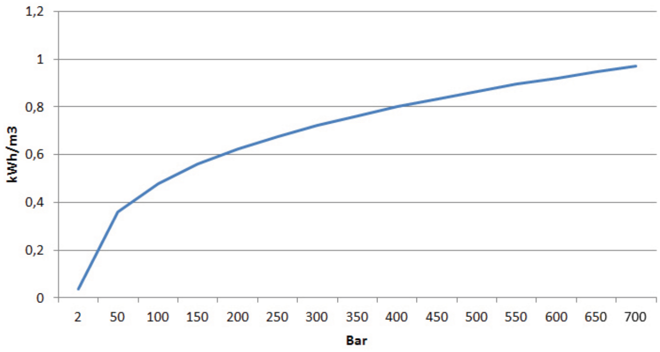


Fig. 50: Energy needed for the compression of hydrogen

Tank weight

The more the hydrogen is compressed, the stronger the tank must be. The chart below[21] shows the thickness of the tanks versus the pressure inside. Because the pressures in the pavilion will not be very high (maximum pressure will not exceed the 100 bar, later discussed), a maximum thickness of 0.02 meters is needed. It seems not to be so much, but 2 centimeters of solid steel is still heavy.
A 2 centimeter thick steel cylinder with a diameter of 350 mm (in the design) with a volume of 11,4 m3, has a lenght of approximatelly 30 meters. Now we can calculate the weight of the 1,38 m3 of solid steel. This is 1,36 * 7800 kg/m3 = 10585 kg. This is around 5 % of the total building weight. A Li-ion battery with similar capacity would be about three times as heavy.

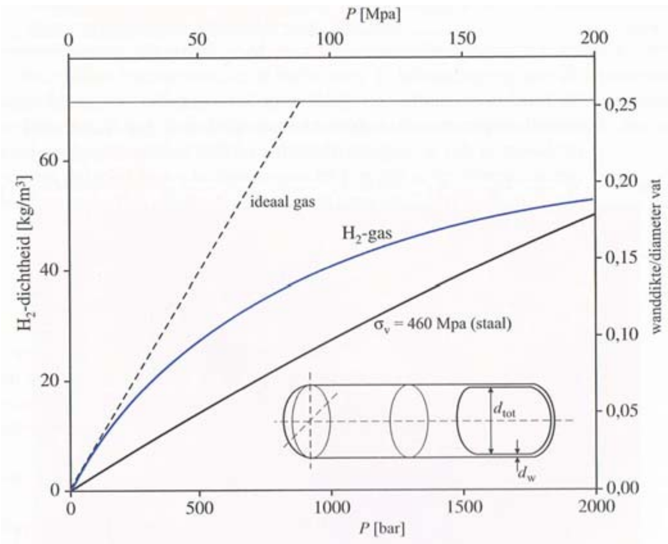


Fig. 51: Tickness tank

[21] Ouwehand J., Toegepaste Energietechniek, Deel2: Duurzame energie: 395

4.5 Feasibility

There is already described how the building can generate energy and how much it needs. This feasibility study examined the feasibility and how well we can deal as efficient as possible with the energy.
If it is feasible, it means that we still have energy left on an annual basis. Depending on the yields, it is possible that not every month of the year is self sufficient. The energy of the months with a surplus should be stored until other months with a shortage of energy need it. Probably in the summer solar energy production should be saved (in the form of compressed hydrogen gas) to provide the pavilion in the winter.

For the feasibility study an excel-sheet is made. The user can enter the surfaces of solar panels and wind-flow area. In addition, the duration per day and power of the boat, which sails to the pavilion, can be set.
Using the excel sheet, choices are made, and this feasibility study will be further discussed with the next values.

Design parameters

1. 80 m2 of sunpanels
2. 90 m2 flow area windturbine
3. 2 hours of sailing time (realistic total)
4. 5 kW electric boat motor

If a situation is feasible then there is energy left over a year. This energy can be pruned/harvested once a year, but it is also possible to do this in smaller quantities throughout the year. The advantage is that the pressure in the tanks remains lower, and therefore less compression energy is needed. The disadvantage is that a boat should come several times a year to the pavilion. This aspect is not included in the feasibility study.

4.5.1 Energy production overview

kWh

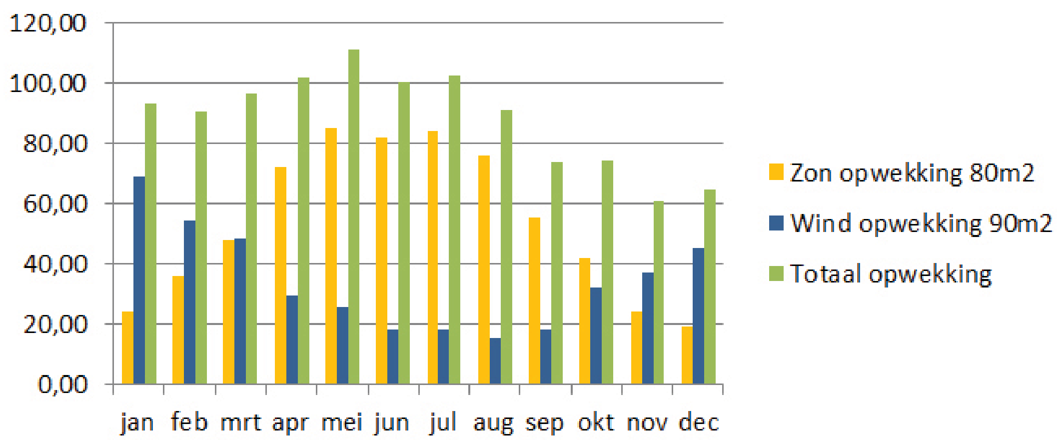


Fig. 52: Total energy production - overview

It is clear that most of the energy is produced in the summer. This is because of to the fact that the solar panels can generate over 4 times more energy than in the winter. Wind energy is relatively stable throughout the year, but it is clear that the summer is a little less windy than the winter.

4.5.2 Balance - Production - Usage

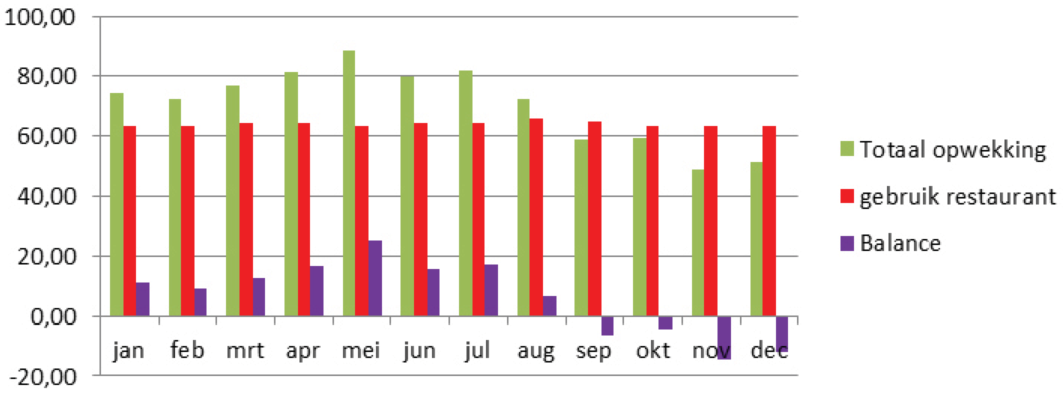


Fig. 53: Balance

In this balance diagram can be seen that the generated energy is more in the summer than in the winter. The energy consumption causes that in the months September until December there is not enough energy production for the month itself. Fortunately, the energy production in the summer is enough to cope with this problem. The overall balance is positive.
The energy consumption is quite stable but there is a slight variation. This is caused by the compression losses. In the months that the pressure is highest in the storage tanks, more energy will be used for the compression process.

Balance: + 2300 kWh
Maximum pressure: + 36 bar

Prune April: 5155 kWh = 2300 m3 H2
Prune over the year: 0 kWh = 0 m3 H2

4.5.3 Pressure in the tanks, over the year.

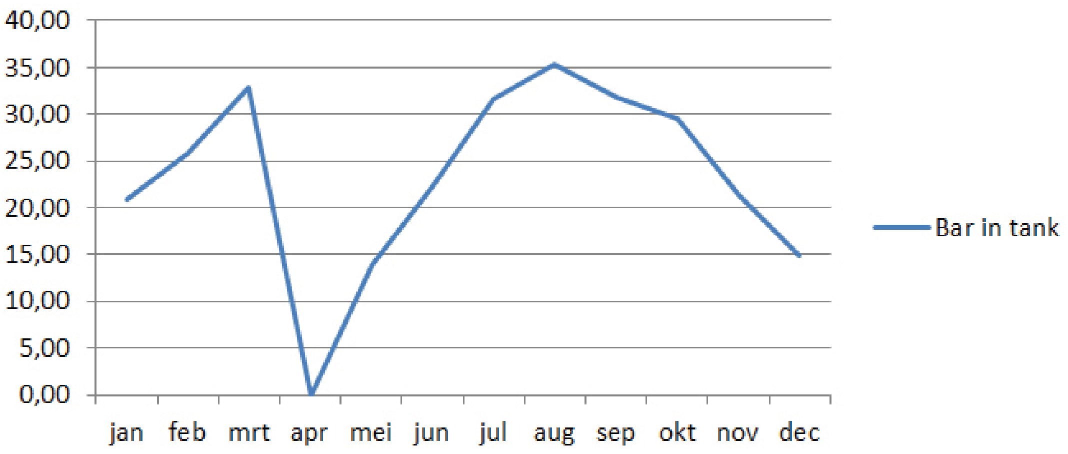


Fig. 54: Pressure in the tanks, prune in april

In April the surplus of the energy is pruned. Since then the energy balance is positive per month, and hydrogen gas will be saved. It is desirable that the pressure in the tanks is as low as possible. Firstly because of the explosion hazard but also because it takes less energy to compress hydrogen when the pressure is less. On the next page the effect of pruning over the year will be discussed.

4.5.4 Pruning over the year

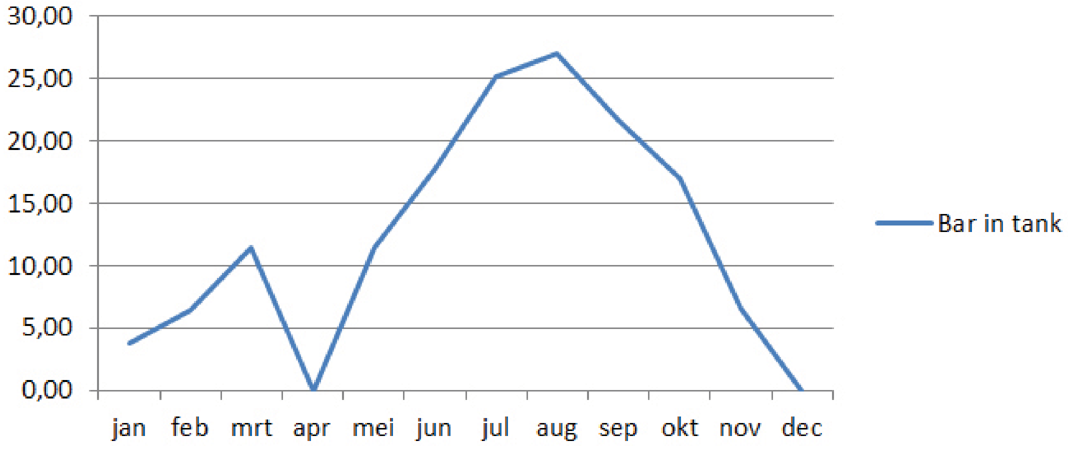


Fig. 55: Pressure in tank, pruning over the year

There is a clear difference between the chart where only the month April was used to prune, and the above chart, where is pruned several months a year. Again, the surplus of hydrogen gas is pruned in April. For the other months: if possible, prune 26 m3 (self defined). This leads to a lower pressure, so a higher energy efficiency. The maximum pressure is now around 27 bar in the summer. An other advantage is that the total pruning volume in April is less than before.

Balance: + 2393 kWh
Maximum pressure: + 27 bar

Prune April: 1146 kWh = 239 m3 H2
Prune over the year: 1248 kWh = 260 m3 H2 = 10 months

In ten of the eleven remaining months the rule is applied. It saves a lot of energy, what otherwise was wasted on unnecessary storage. The pruning over the year will also result in a lower weight of the tanks than previously calculated because the pressure is lower.

Reflection
Of course a 9 bar lower pressure is not very spectacular, but when the hydrogen production increases by enlarging the surface of the solar panels from 80 to 100 m2, pruning over the year can give a drop of 54 bar (from 87 tot 33 bar).

5 P2 - Building design startup

Although hydrogen is not always more efficient than a battery system, it has a lot of advantages, as described in the report. In combination with renewable energy it seems to be feasible in architecture. The challenge is applying these studies in architecture on a larger scale.

In the next project, hydrogen technologies and ways to generate renewable energy will be further investigated, in combination with a larger and final graduation project.

5.0.5 Ideas & specification

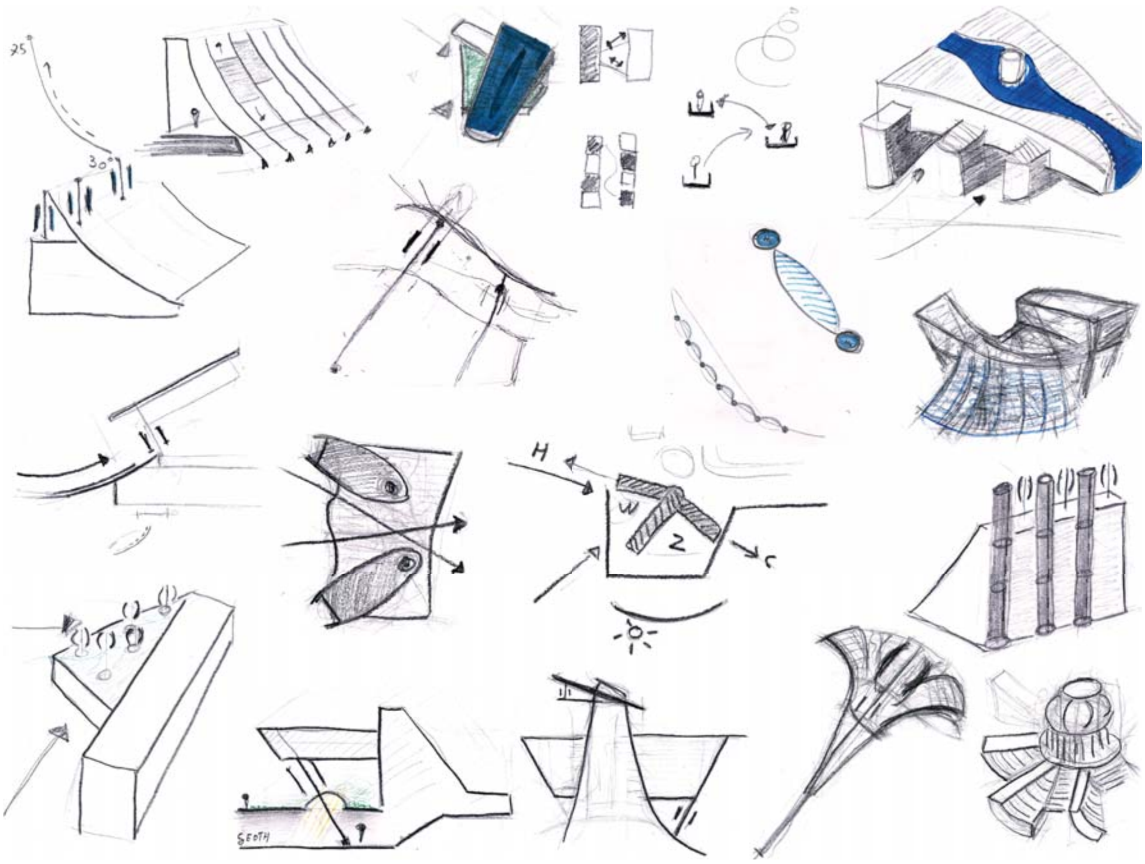


Fig. 56: Important sketches

Sketches and ideas

The sketches above are searching for the use of renewable energy at the location. There are also some basic principles shown, such as adjustable solar panels and building shapes to can guide the wind through the building or a turbine. Solar and wind adjustments can be translated in movements in the building.
The expression of movement or technology is expressed with the sketch right under.
The energy experience is part of the design, so the visual relations between spaces and technologies are important to research.
The hydrogen expression is an important aspect. The next page is about that expression and materialization.

Fig. 57: Examples of objects that could be the express the image of hydrogen

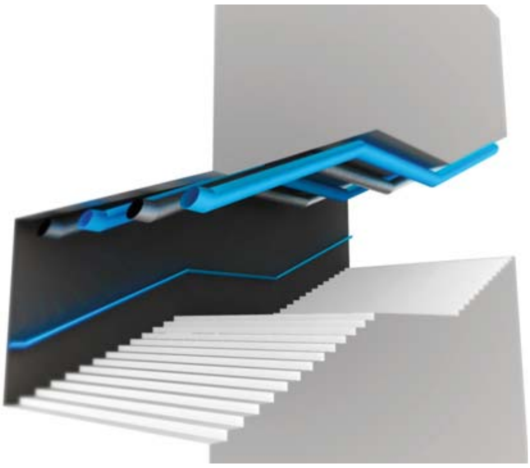


Fig. 58: Stairs and ducting, blue + aluminium

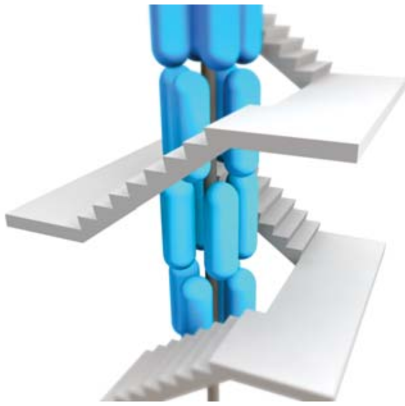


Fig. 59: Staircase, storage

Hydrogen materialization and expression
The materialization and expression should be more researched in the Msc4.

Now, as can be seen, my major idea about the image of hydrogen is blue, metallic, white, black, gray...So colors.
The other part is the kind of material. This could be metal, glossy plastic or at least a material with a curved shape.
The expression gas pressure is another aspect of the hydrogen storage.

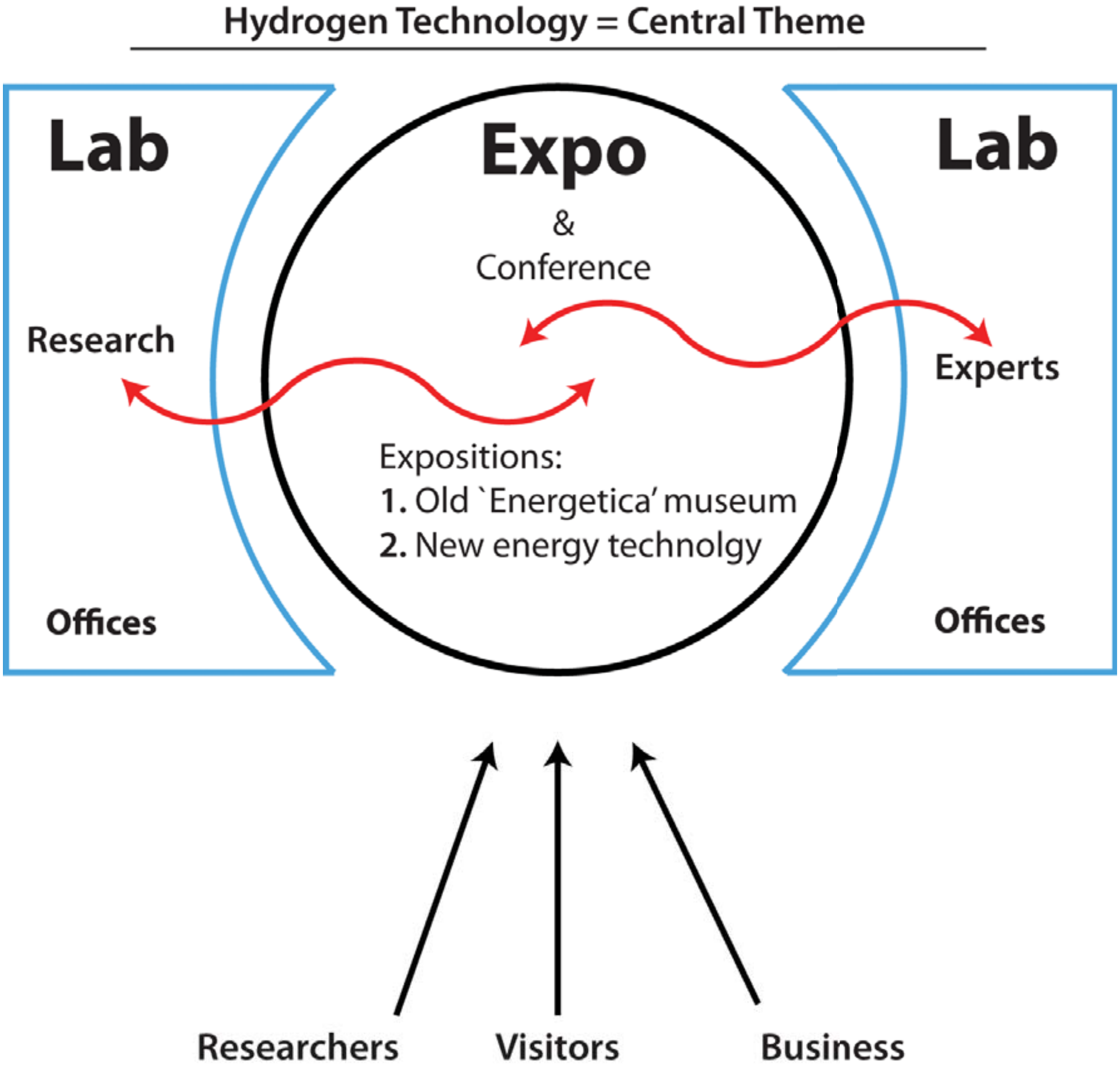


Fig. 60: Relations in building

Organisation
The exposition is about the old and new energy technologies. The main theme in the building is the hydrogen technology and society. The researchers, who are working in the laboratories can give visitors information about the expositions in the museum.

The business aspect is also important, to support Dutch hydrogen initiatives and give advice and information about the hydrogen technology. Therefore conference posibilities are necessary in the building design.

Building as a machine

Fig. 61: Combustion engine inside

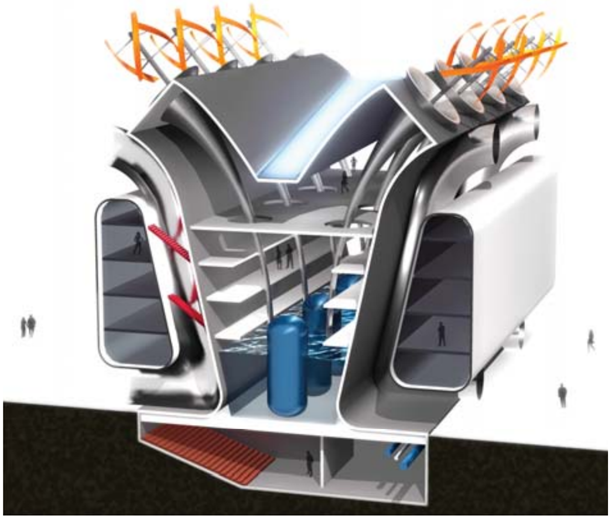


Fig. 62: Field of tension. Machine or building?

Field of tension - Machine or Building?

The image in figure 62 shows a building that looks in some ways like the inside of an engine. Exactly the word 'inside' is important in comparison with for instance the Centre Georges Pompidou, where the technology is mainly visible at the outside.
Technology will be part of the outside and inside experience of the visitors of the building.

Structuring

The building must work as a machine, but it must also demonstrate the hydrogen technology. These two aspects are important structuring aspects for the final graduation project.

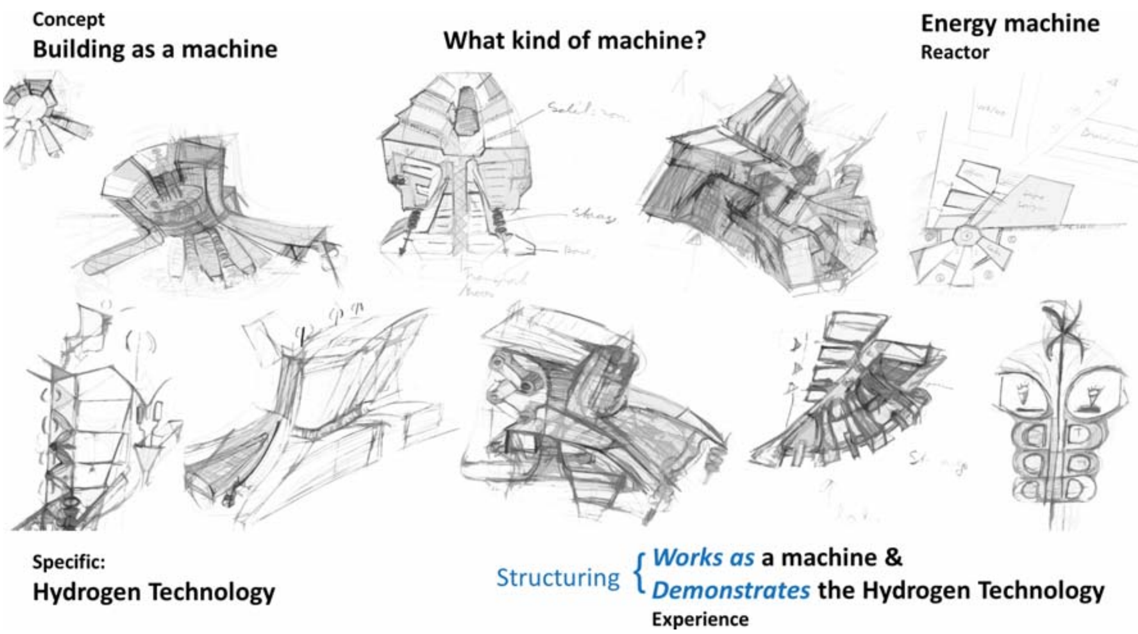


Fig. 63: Sketches, building as a machine?

6 P3 & P4 Advanced Research

The architectonic design will be based on the technological research. As mentioned before, the general question is:

'What are the possibilities for hydrogen as an energy carrier in combination with renewable energy in buildings and how can both technologies be integrated as an architectonic aspect in the design?'

The focus will be the active generation and storage of energy.

The technological research is about the energy technologies and especially the possibilities of the hydrogen technology combined with sustainable energy generation. Therefore already a start has been made with a research about solar and wind energy and a simple research about hydrogen technology in the quarter before the P1 exam. This has led to a feasibility study for a small floating restaurant pavilion. This feasibility study will also be done for the final graduating project, but better and more into detail.

6.1 Solar yield

External aspects can affect the yield of solar panels. Of course the location on the earth is important. Because the location of the design is given (Netherlands, Amsterdam), we will use this location.

The angle and orientation

The next table shows that the angle of the sun varies per month. Because the yield of the solar panels is the best when the panels are orientated perpendicular to the sun, the optimal angle for these panels varies per month too.

Maand	Zon Hoek	Paneel Hoek	Paneel richten naar het
JAN	18	72	Zuiden
FEB	27	63	Zuiden
MAA	38	52	Zuiden
APR	50	40	Zuiden
MEI	58	32	Zuiden
JUN	61	29	Zuiden
JUL	58	32	Zuiden
AUG	50	40	Zuiden
SEP	38	52	Zuiden
OCT	26	64	Zuiden
NOV	18	72	Zuiden
DEC	15	75	Zuiden
Gemiddelde hoek			
Zonhoek 42°		Paneelhoek 48°	

Fig. 64: Angle of the sun

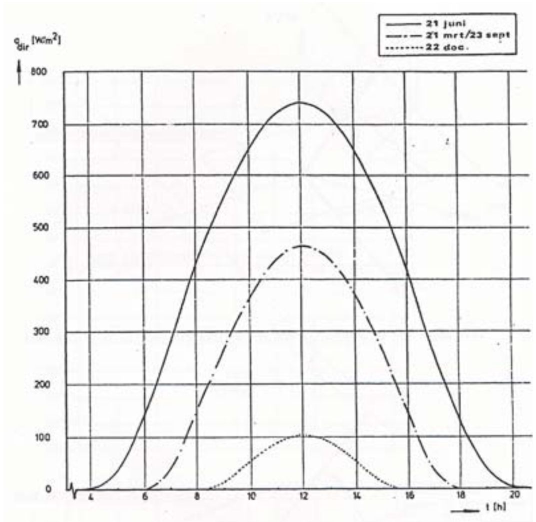


Fig. 65: Solar Intensity, Source: Bouwfysisch tabellarium, BK1500_a, 1987

Around 12:00 oclock the best orientation for fixed solar panels is south, but in the morning and afternoon, the angle is lower. The south orientation is also chosen because the intensity of the sun depends on the hour of the day, and at 12:00 oclock the maximum solar intensity is reached.
The average angle of 48 degrees is not the optimal angle for the solar panel because the solar intensity in the summer is higher than in the winter.

The optimal angle is 35-36 degrees, when the annual irradiation diagram below is observed:

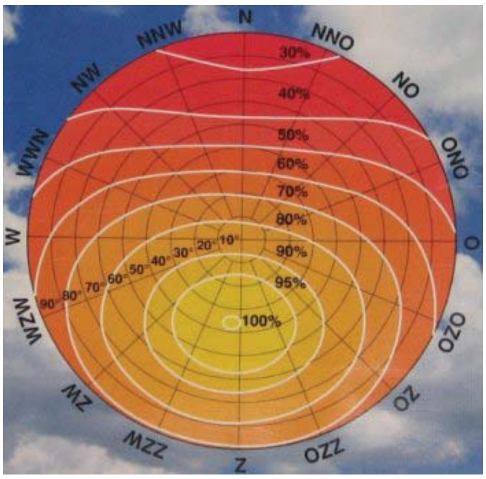


Fig. 66: Annual irradition diagram

Because an adaptive orientation system is expensive and often not profitable, at lot of projects make use of south fixed panels with an angle of 35-36 degrees, however such a system could give a 20% to 30% increase in yield.[22]

[22] http://www.allesoverzonnepanelen.nl/voorwaarden/dakhelling

36 degrees?
The annual irradiation diagram in figure 66 was developed by Ecofys using one called 'Test Reference Year'. Sidera[23] claims that this model is incorrect and that the best angle for solar panels in the Netherlands is 30 Degrees, south orientated, based on calculations with validated KNMI measurements.

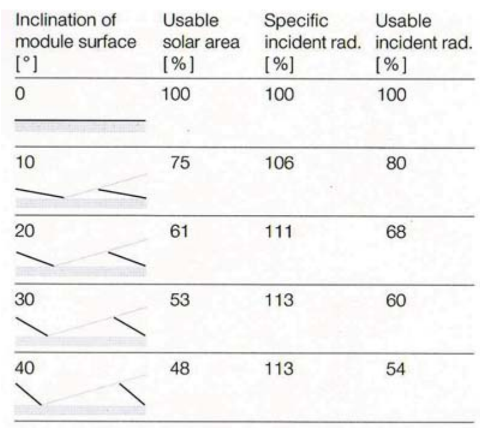
Full solar hours
To calculate the solar yield, the term 'full solar hours' will be used. This is not the time that the sun is shining during the day, but a normalized value which is in accordance with the time that there should be a solar irradiance of 1000 W/m2. More accurate calculations can be made with this data.

The values for the Netherlands:

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Solar hours	1	2	3	4	4,5	5	4,5	4	3	3	1	1

This means that one year contains approximately 1098 full solar hours. The market calculates with 1000 solar hours per year. So: 1000 solar hours per year with in irradiance of 1000 W/m2.

Shadow
However the best angle for fixed solar panels is 30 degrees orientated to the south, most installers mount solar panels at a flat roof in an angle of 25 degrees to the south. This is because otherwise panels can cast shadows on each other. With lower angled panels, the panels can be mounted with a shorter distance between each other. As the next picture[24] illustrates, the panels must be installed at considerable spaces, which reduces the electricity generating surface.



Inclination of module surface [°]	Usable solar area [%]	Specific incident rad. [%]	Usable incident rad. [%]
0	100	100	100
10	75	106	80
20	61	111	68
30	53	113	60
40	48	113	54

Fig. 67: Angles and placement solar panels

Conclusion
Best situations:
Monopitched roof: 30 degrees south orientated
Flat roof with angled solar panels: 25 degrees south orientated each

[23]http://www.siderea.nl/artikelen/hellingshoek2/hellingshoek2.html
[24]Hegger Energy manual: sustainable architecture

6.2 Energy usage of the design

Purpose of the calculation:
Energy self-sufficient building with solar panels with an operational time of 12 hours

Reference Museum 3000 m2 - Conference and exhibition pavilion, Osnabruck, Germany
Energy usage: 55 kWh/m2 per year (18 for electricity, 29 for heating, 8 for cooling)
This means 55/12/365 *1000= 12,56 Watt per m2 for one average day

Reference House 120 m2 Presentation Andy van den Dobbelsteen[25]
Energy usage: 6800 kWh per year = 56 kWh/m2
This means: 56/12/365*1000 = 12,79 Watt per m2 for one average day

Conclusions
-Energy needed = 13 Watt/m2 for one average day over the year.
-The energy usage of a normal household (24h) is approximately the same as a museum (12h).

6.3 Amount of solar panels needed

Irradiance: 1000 kWh/m2 per year
A solar panel with an efficiency of 15% can yield 150 kWh/m2 per year, but we will calculate with 120 kWh/m2, because the solar panels are not always correctly orientated.

Estimation energy usage of the design. 56 kWh/m2
Museum floor area = 9000 m2
This means 504000 kWh per year for the entire building.

Because of the transformation from electricity to hydrogen (6 kWh makes 1 m3 hydrogen) and from hydrogen to electricity (1 m3 hydrogen makes 3 kwh), we have to double the energy requirement: 1008000 kWh
1008000/120 m2 = 8400 m2 solar panels minimal needed.

Reflection
The amount of 8400 m2 solar panels is quite a lot, but fortunately, ***this calculation is not correct.*** The incorrect part of the calculation is the assumption that all the generated energy is converted into hydrogen and back into electricity again. The assumption that the heating and cooling energy is also provided by the stored hydrogen is also incorrect. During the production of hydrogen and electricity (electrolyzers and fuel cells) the half of the amount of energy is transformed into heat. This heat could be used in the building for heating.

Why this wrong calculation?
This was roughly the calculation I used for my P1 pavilion project. I want to show the difference between this 'old' and more advanced and efficient calculation (next pages).

[25] van den Dobbelsteen A., Sijmons, D. (2011), kWh/m2 introduction, Delft: Faculty of Architecture

6.4 Better integration of technology

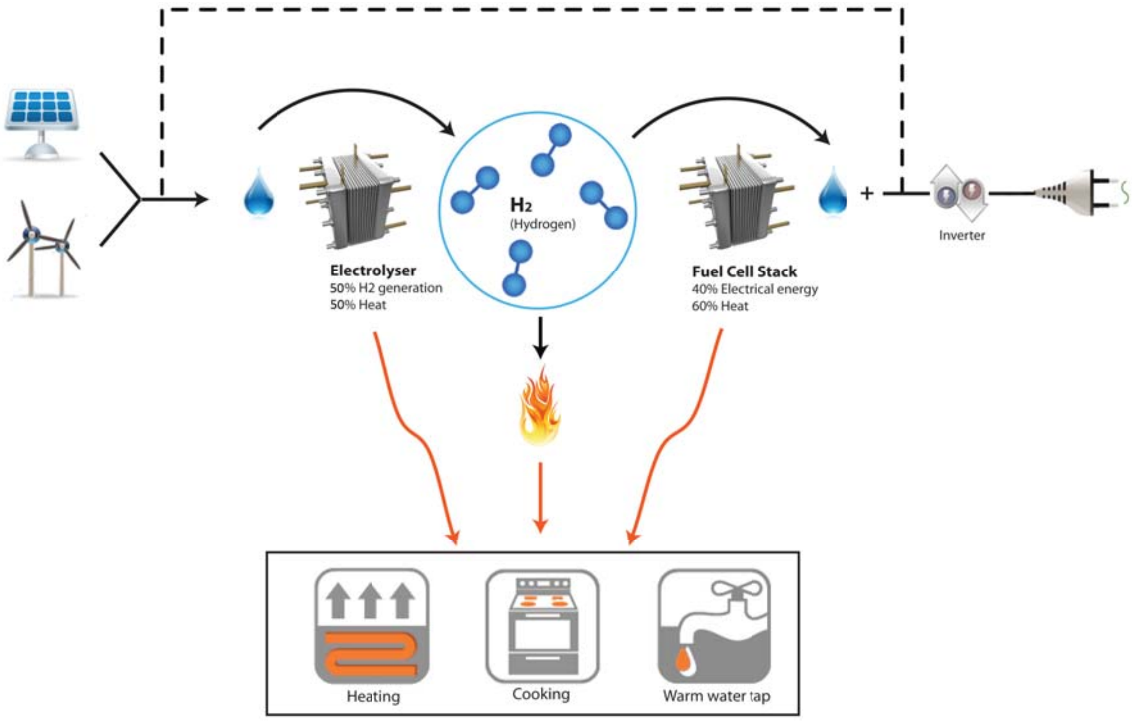


Fig. 68: Overview, hydrogen technology in a building

The biggest change in the applied technology is that the renewable generated electricity can be used directly by the building (dashed line). If there is a surplus of electrical energy in the summer, this surplus will be transformed into hydrogen. The hydrogen will be compressed to limit the volume.

The electrical energy demand is as much as possible provided by solar panels and wind turbines, and *if needed* (for instance in the winter or in the evening) the hydrogen storage is consumed by the fuel cells to provide more electricity. At the same time, the electrolyzer and fuel cell system can heat the building. This situation is better because now there are less unnecessary energy losses.

If there is too little heat produced by the electricity producing fuel cells(40%) in the winter, more heat will be produced by burning hydrogen gas directly.
Cooling in the summer will be done as much as possible with (semi-)natural ventilation and cooling with the water from the IJ-river and the soil.

Extra: Heat pump
The electrolysers produce 50% heat that is not desirable in the summer. This energy will be stored in a water basin and can be used in the winter for extra heating in combination with a heat pump. Cooling is provided by the same heat pump, but in the summer the soil and the IJ-river are the cooling sources.

The next page shows a schematic section with the mentioned installations.

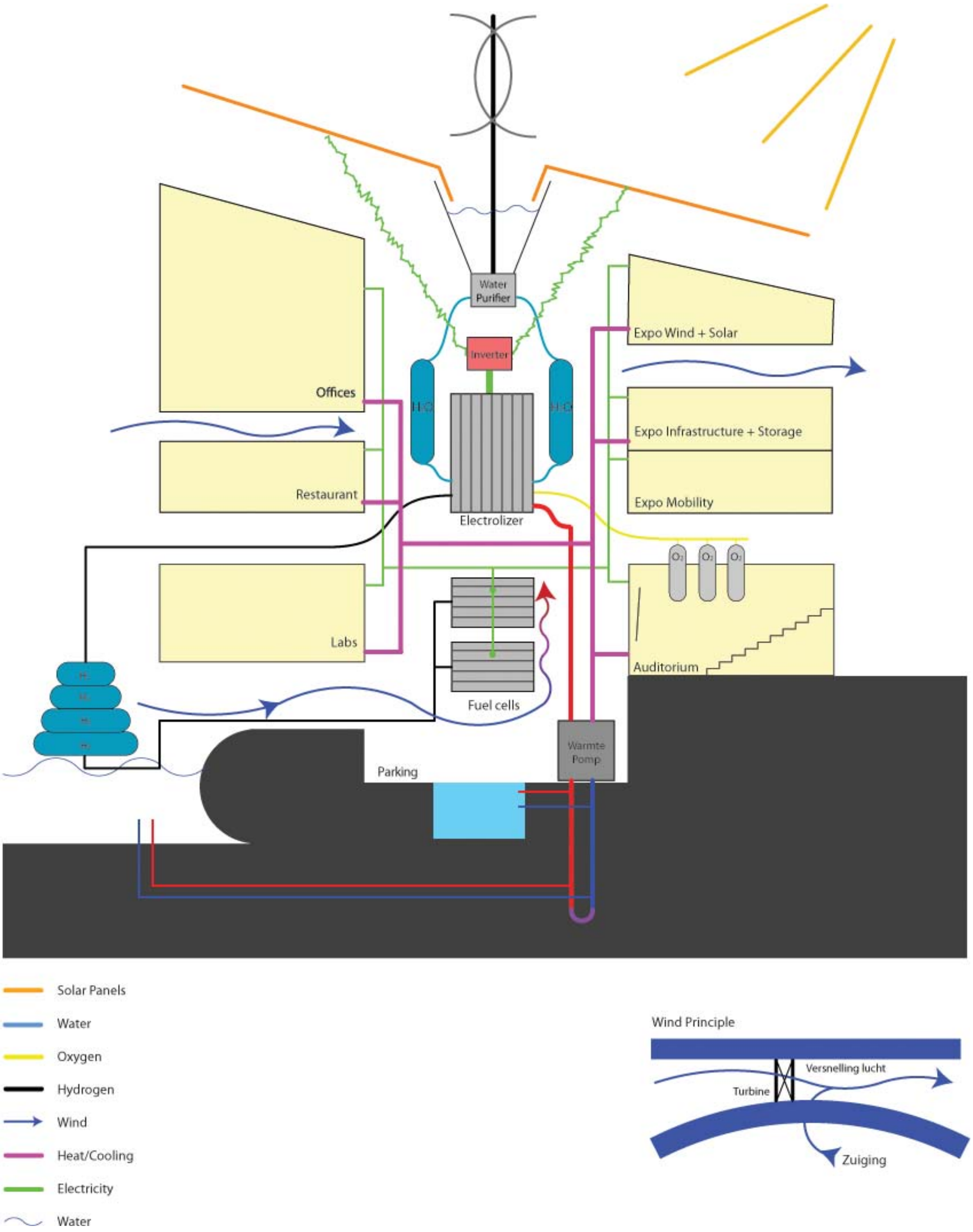


Fig. 69: Schematic building installation scheme, hydrogen technology

Water and solar energy are being harvested. After the water is purified, it will be transformed into hydrogen and oxygen by the electrolyzers. Hydrogen is stored outside (because of explosion danger) and a small part of the produced oxygen is stored inside the building. In the winter the fuel cells can transform the hydrogen back into electricity. Therefore a mixture of oxygen from the tanks and internal ventilation air is used. This air will warm up and can be transported as ventilation air. The heat from the electrolyzers will be stored in the basin, and can be used by the heat pump for heating the building in the winter.

6.5 Feasibility Simulation

This situation, sketched on the pages before, is simulated in Excel, to define the amount of solar panels and wind turbines needed to get the building energy-self-sufficient over the entire year. One of the conclusions for now is that the yield of wind energy is very low compared to the solar yield (in urban areas). This simulation explanation is only based on solar panels. The amount of turbine surface is set to zero.

The sheet below shows a feasible calculation for a building with 9000 m2 of floor area. Now only 2550 m2 solar panels are needed. In the 'old' calculations before (where all the generated energy was directly transformed into hydrogen) 8400 m2 of solar panels were needed to provide enough energy over the entire year. This is because of the bypass for direct energy usage (dashed line in image 68).

The calculation also gives an indication of which kind of electrolyzer and fuel cell should be used in the building design. An electrolyzer of maximum 30,9 kW and a fuel cell of maximum 17,2 kW are needed. Of course it is possible to use more separate machines to provide variable energy demands.

	jan	feb	mar	apr	may	jun	jul	aug	sep	oct	nov	dec
Heating Demand kWh	5315,0	4619,3	3414,4	2023,1	818,2	122,5	122,5	818,2	2023,1	3414,4	4619,3	5315,0
Cooling kWh (electrical)	22,5	150,5	372,1	627,9	849,5	977,5	977,5	849,5	627,9	372,1	150,5	22,5
Electricity kWh	13500,0	13500,0	13500,0	13500,0	13500,0	13500,0	13500,0	13500,0	13500,0	13500,0	13500,0	13500,0
Wind Kwh	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
Full solar hours per day	1,0	2,0	3,0	4,0	4,5	5,0	4,5	4,0	3,0	3,0	1,0	1,0
Yield 80% verlies (accu) kWh	7344,0	14688,0	22032,0	29376,0	33048,0	36720,0	33048,0	29376,0	22032,0	22032,0	7344,0	7344,0
Electr: Surplus/shortage energy kWh?	-6178,5	1037,5	8159,9	15248,1	18698,5	22242,5	18570,5	15026,5	7904,1	8159,9	-6306,5	-6178,5
TRANSFORMED into hydrogen kWh	0,0	518,8	4080,0	7624,0	9349,2	11121,3	9285,3	7513,2	3952,0	4080,0	0,0	0,0
Electrolyser kW needed	0,0	1,4	11,3	21,2	26,0	**30,9**	25,8	20,9	11,0	11,3	0,0	0,0
USED FROM STORAGE by Fuel Cell kWh	15446,3	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	15766,2	15446,3
Heat released kWh	3707,1	518,8	4080,0	7624,0	9349,2	11121,3	9285,3	7513,2	3952,0	4080,0	3783,9	3707,1
Shortage/surplus **Heat?** kWh	-1607,8	-4100,5	665,6	5600,9	8531,0	10998,7	9162,7	6695,0	1928,9	665,6	-835,4	-1607,8
Additional Heating **(USED FROM STORAGE)** kWh	1607,8	4100,5	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	835,4	1607,8
Fuel cell kW needed	17,2	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	17,5	**17,2**
Remaining stored H2 Kwh	0	0	4079,968	7624,03	9349,24	11121,27	9285,268	7513,236	3952,032	4079,968	0	0

Floorarea M2	**9000**
Heating/m2a	29
Cooling/m2a	8
Electricity /m2a	18
Efficiency Solar Panels	0,12
Burning hydrogen efficiency	1
Fuel Cell efficiency	0,4
Electrolyser efficiency	0,5
Building operating hours	12
Heat pump system? 1= yes, 0=no	1
COP Heating	8
COP Cooling	12
M2 solar panels	**2550**
M2 wind turbines	**0**
Feasible?	**Feasible!**

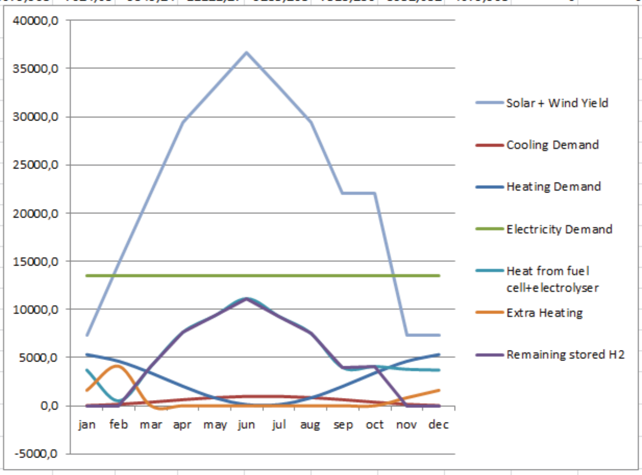


Fig. 70: Excel simulation

Note: This simulation is based on the use of multicristalline solar panels. When amorphous solar panels are used, there would be needed: 4400 m2 of solar panels when the energy is first stored in a battery system (that works as a buffer so the electrolyzer can have a lower capacity). When the solar panels are directly linked to (a better) electrolyzer, only 3500 m2 of amorphous solar panels would be needed.

6.5.1 Explanation simulation

1. Demands

The heating, cooling and electricity demands are based on a reference project, a museum, the conference and exhibition pavilion in Osnabruck, Germany. These values can be changed in the black data block in figure 70 (kWh per m2 per year). The values of the heating and cooling demands vary per month. This was simulated with the function *cos(2 * pi * x)+1*. The integral between 0 and 1 in this function is 1. Splitting this function into 12 months gives a curved distribution.
Cooling - Almost nothing (0,3%) in the winter, maximum in the summer (16,3%)
Heating - Almost nothing (0,3%) in the summer, maximum in the winter (16,3%)
Electricity - Same over the entire year.

2. Wind energy

The generated wind energy is calculated with the following formula:
$((0,5 * 1,225 * 5,3^3 * (m2windflowsurface)) * 24 * 60 * 60)/3600000 * 0,35 * 31 * 0,8.$

The first part is the maximum potential energy (kwh per day) in wind energy for a wind speed of 5,3 m/s (januari). 0,35 stands for the efficiency of the wind turbine. This is multiplied by 31 days. The last multiplication by 0,8 is used because of the efficiency of a temporary battery system.

3. Solar energy

The generated solar energy is calculated with the following formula:
$((((0,12 * 1000W/m2 * (fullsolarhours) * (m2solarpanels)) * 31)/1000)) * 0,8$

0,12 is the calculated efficiency of the solar panels. Full solar hours: converted amount of solar hours with an irradiance of 1000W/m2. 31 represent the amount of days in a month.

4. Check: enough electrical energy generated?

In the simulation the required amount of electrical energy is the basic electrical demand + the cooling demand.
If possible, electrical energy is used directly by the building. If there is a surplus of electrical energy, this will be transformed into hydrogen. Generally in the winter there is a shortage, and in the summer a surplus of energy. If there is a shortage, the fuel cells will transform hydrogen into electricity. If there is a surplus, the electrolyzers will transform water into hydrogen and oxygen.

5. Check: how much heat is generated?

Now the simulation can calculate when the fuel cells and electrolyzers have to be operational and what capacity they must have.
1. If there is an insufficient amount of electricity (electricity + cooling), the stored hydrogen will be used. 60% heat is the byproduct of the fuel cells. This heat can be used for heating.
Is there enough heat? If there is not, additional hydrogen must be burned.
2. If there is a surplus of electricity, this will be transformed into hydrogen and oxygen. The byproduct of the electrolyzers is 50% of heat. This heat is stored in a water basin, so the heat pump can use it in the winter period.

6. Heat pump Yes/No?

The simulation has the option to add a heat pump in the feasibility calculation. If the heat pump is activated, the heating and cooling demands are less than the original demands.
COP-heating via basin= 8. COP-heating via soil = 3[26]. COP-cooling via soil = 12.

7. Feasible situation?

Annual usage hydrogen = Fuel cell usage from tanks (= shortage electricity/ 0,4 efficiency) (kWh) + Additional burning for heating (shortage heat * 1,0(burning efficiency)) (kWh).
Annual generation of hydrogen = Rest energy from solar panels * 0,5 efficiency (kWh).

If the annual usage of hydrogen is less than the annual generation of hydrogen, the situation is feasible.

[26] http://www.techneco.nl/documents/download/197

Output per month

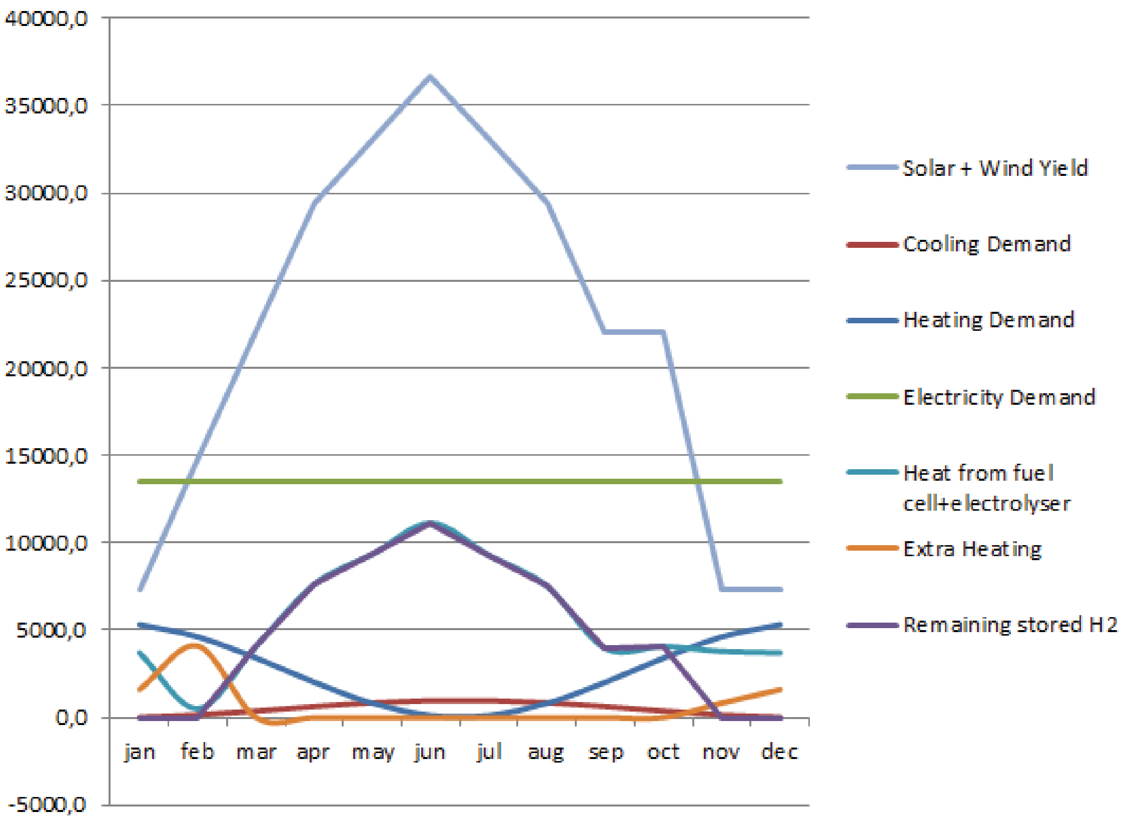


Fig. 71: Excel simulation, month diagram

The diagram in figure 71 shows the output of a feasible situation of a building with 9000 m2 floor area and 2550 m2 solar panels.
As can be seen, the maximum of generated electrical energy takes place in the summer. The heating and cooling demands have a curved distribution and the electrical demand is equal over the entire year as described before. Lets start in januari to explain the diagram. The heat from the fuel cells does not cover the total heating demand. Therefore additional hydrogen will be burned (orange line). In the summer no extra heating is required. Cooling is requirered, and is provided by the heat pump (COP of 12 in summer). In the summer the electrolyzers are producing hydrogen (50%) and heat (50%). Therefore these lines are equal in the summer period. In the winter, the fuel cells are producing heat (with another energy/heat-ratio (40/60%).

6.6 Market investigation

Market investigation is done to research the technology that would be available for the usage in buildings. The result of this investigation probably will be rectangular industrial machines, which you can place hidden in the basement of your building. Of course the integration of the technologies in architecture is an important aspect to focus on. A good question for this topic is how the technology could be expressed to give the building an additional architectonic value. This will become visible in the building design.
Market research is done for electrolyzer and fuel cell systems. Electrolyzers seem to have a smaller market than fuel cells, but there are some companies that deliver hydrogen generators and fuel cell systems with high capacities.

6.6.1 Fuel cell

The availability of fuel cells on the market is not a problem. Nedstack, a Dutch company delivers PEM fuel cells, water cooled, with a power range of 1 - 100 kW. After a good and clarifying phone conversation (Appendix C) it became clear that Nedstack was indeed a perfect manufacturer that could provide suitable fuel cells in the graduation building design.

Nedstack
PEM FUEL CELLS

Fig. 72: Nedstack fuel cell

6.6.2 Electrolyzer

Electrolysers seem to have a smaller market. There are just a few companies that deliver hydrogen generators with high capacities.
As calculated before, 3500 m2 of multicrystalline solar panels are needed for a self-sufficient museum with 9000 m2 floor area. According to the simulation we should need a 30,9 kW electrolyzer. I have to say that this value is calculated for 1 month where the *average* is 5 solar hours per day. When the sun is shining the whole day in the summer, this electrolyzer cannot handle this amount of energy. We could buy an electrolyzer with a better capacity, but there is chosen for a battery system, as a buffer, for such a situation. The electrolyzer can recover and catch up on less sunny days.

ITM-Power Sheffield, UK

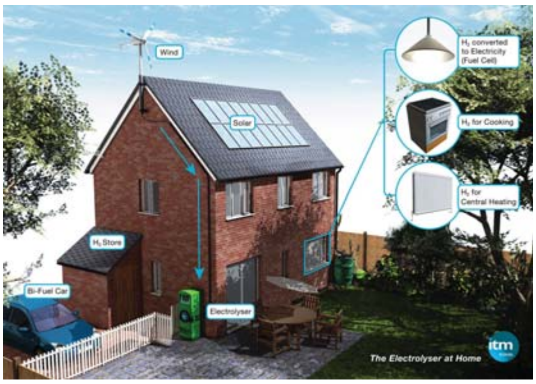


Fig. 73: ITM Power hydrogen at home concept

Fig. 74: ITM HPac

Because ITM-Power worked together with Ballast-Nedam at a home powered on hydrogen, the products of this company are researched. The biggest electrolyzer is the HPac, that has a power rating of 3,5 kW. So in the design we should need 9 of these Hpac's.

Fig. 75: Horizon Powerbox

Fig. 76: Angstrom HGH170000

Horzion Fuel Cell Technologies, Singapore & China
Although Horizon is specialized in fuel cells, they also sell hydrogen generators. Their hydrogen generators (Greenhub Powerbox) are only used as emergency power with a maximum of 1,8 kW.

Because ITM and Horizon do not seem to have the right electrolyzers of at least a power rating of 35 kW, other companies are researched. Of course it is possible to make use of more than 1 generator, so a situation with 3 generators of 12 kW is also an option.

Angstrom-advanced, Braintree, USA
This company does have an electrolyzer the HGH170000. The maximum input power is 65 kW. The electrolyzer is their biggest model and can produce around 10m3 hydrogen per hour.
Dimensions: 1200x900x1600 mm
Lifetime: 20-40 years

Proton energy systems, Wallingford, USA
Proton has hydrogen generators using PEM membranes with a very high production.
First, there is the H-serie. The biggest is the H6m model, that can produce 6m3 per hour.

In the summer, this would be insufficient but Proton has another serie, the C-serie, which contains models of 10 to 30 m3 hydrogen per hour.
Lifespan: designed for 20 year.

PROTON
THE LEADER IN ON SITE GAS GENERATION.

Fig. 77: Proton C model

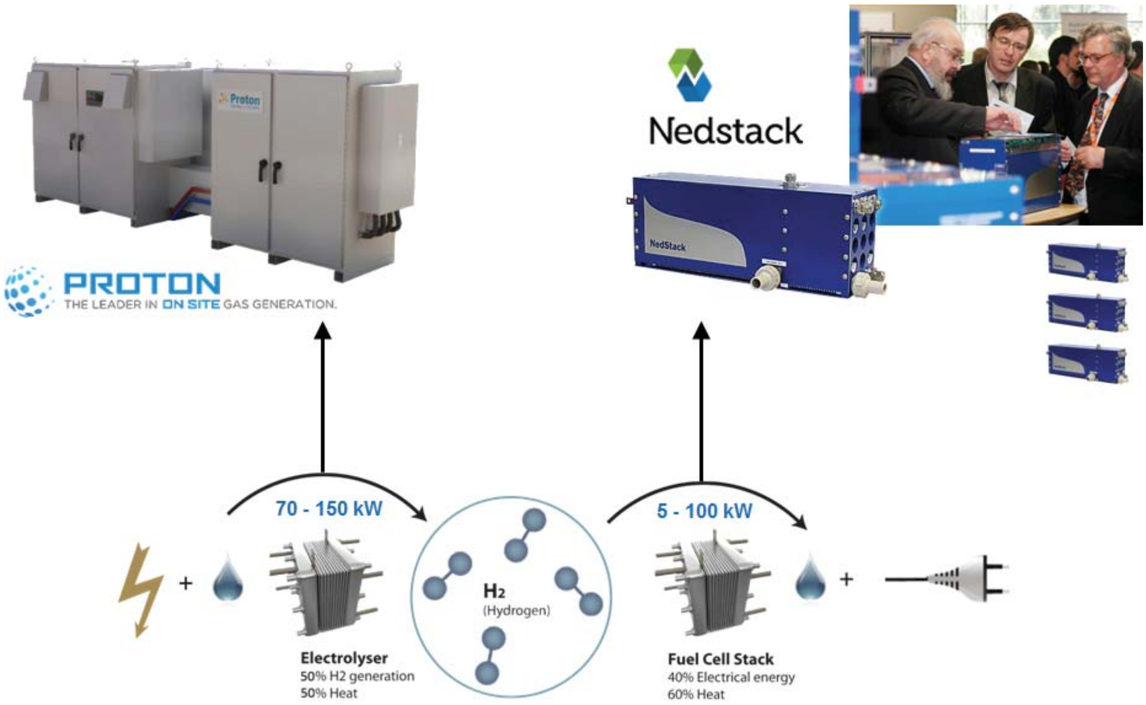


Fig. 78: Market research overview

6.7 Hydrogen to regulate solar irradiation

Another usage of hydrogen than just energy storage is that it can be used as a gas inside layered windows. The window will color blue if 2% of hydrogen is added, and will be transparent again when replaced with normal air. It is the inner coating of tungsten trioxide that turns blue when it comes into contact with hydrogen and loses its color if the cushions are filled with oxygen. So the passage of light and energy can easily be regulated.
When colored blue just 15% of the visual light will be transmitted and 12% of the energy will enter through the window.[27]

Fig. 79: Transparent

Fig. 80: Coloring blue

[27] Dr. Andreas Georg of Fraunhofer ISE, Gaschrome Membrankissensysteme

6.8 Rainwater collection

6.8.1 For electrolyzers

The average amount of rain per year: 779 mm per year. (see Appendix B)
Per square meter this is 0,779 m3 water.

According to the simulation, 30000 m3 hydrogen gas must be produced.
Goal: Calculate how much roof surface is needed for the production of 30000 m3 hydrogen gas.

Densities:
Hydrogen (H2): 0,09 Kg/m3
Water: 998 kg/m3

Molar Masses
H-atom: 1 grams per mol
O-atom: 16 grams per mol
Water-atom: 18 grams per mol

Mass-ratio H/O in water: 2/16 = 1/8

30000 m3 hydrogen = 2700 kg.
This is 1/9th of the weight of water.
2700 * 9 = 24300 kg water needed

Water per m2 per year
0,779 m3 = 777,4 kg water

Roof surface
24300/777,4 = minimal 31,4 m2 roof surface for water collection, used for the electrolyzers.

6.8.2 Water purification

Because the water, used for the electrolyzers, must be pure, the rainwater must be purified.
An industrial water purifier, using the reverse osmosis (semipermeable membrane) principle, consumes 0.75 kWh/m3[28]

Amount of water that will be purified: 0,779 * 31,4 = 25 m3 water.
Energy consumption = 0.75*25 = 18,75 kwh per year. This is negligible compared to the total amount of generated energy.

6.8.3 For toilet usage

Assumptions
10 Liter water per toilet visitation including washing hands.
150 toilet visitations per day, average.

Goal: Calculate how much roof surface is needed for 150 toilet visitations per day.

1500 Liter per day = 547,5 m3 per year

547,5/0,779= 703 m2 roof surface is needed for 150 toilet visitations per day.

[28] http://www.lenntech.com/systems/reverse-osmosis/ro/rosmosis.htm

6.8.4 Water storage in building

For toilet visitations and hydrogen generation only 725 m2 of the roof would be needed, but in the design roughly 2500 m2 of the roof will catch rain, and transport it into the building. Toilets can be flushed using this rainwater, which only needs to be pre-filtered [29]. The purified rainwater that will be used for the electrolysis will be stored near the electrolyzers in the top of the building. The remaining rainwater will be stored in two basins located at the ground floor. The spaces above these basins will work as the green 'lungs' of the building. This will be explained on the next page.

6.8.5 Heat storage

Heat capacity Water: 4186 Joules/Kg*K
Density water: 998 kg/m3
Roof surface that catches rain and brings inside: 2500 m2
0,779m3 water/m2 roof surface per year
2500 *0,779 = 2025,4 m3 water

Needed for toilets + electrolyzer = Around 600 m3
Water left for storage = 1425 m3 = 1422549 kg
Because of evaporation and rainwater flow losses there will be calculated with 1200000 kg.
To raise this amount of water 1 Kelvin 5023200000 Joules = 1395 kWh needed

Total heating energy from electrolyzer in summer: 57523 kWh.
The water would rise 41 degrees Celsius when electric energy would be applied.
However, the cooling temperature of the electrolyzer is maximum 50 degrees Celsius[30]. This will be the *'asymptote temperature'* for the water basin.

In the simulation an average source temperature of *35 degrees Celsius* is assumed. This results in a COP-value of 8 for the heat pump, when for heating an input temperature op 40 degrees is assumed. COP = Temp_warm/(Temp_warm - Temp_cold) = (40/(40-35))=8

Winter
In the winter the heat pump uses two sources. **1**. The basin (warm water from the electrolyzers (from summer)). **2**. The soil, average temperature: 11 degrees Celsius. Because in the winter the fuel cells are producing a lot of heat, this heat will be transferred to the basin. This will prevent that the basin will be exhausted as a heat source in the winter. If the heat input of the basin is not enough, the temperature of the basin will be complemented by additional heat from the direct combustion of hydrogen.

Summer
In the summer periods, the deep water of the IJ-river will be used as cooling source. If the river is too warm, the soil (11 degrees Celsius) can be used as a cooling source. Assumed is a minimal input temperature for floor cooling of 12 degrees, because of condensation (18 degrees Celsius at top surface of the floor) .
COP = Temp_warm/(Temp_warm - Temp_cold) = (12/(12-11))=12

[29] Creffier C., Waterwegwijzer voor architecten: 17
[30] http://www.protononsite.com/pdf/HOGEN_C.pdf

6.8.6 The green lungs

In the spaces, called the 'green lungs' of the building or the 'green zones', water is stored, plants are growing and the most important byproduct: Oxygen is generated in a natural way. Because the fuel cells are located between the 'lungs' this air will be used for generating electrical energy out of hydrogen (H2 from the tanks + O2 from the lungs/tanks = Energy + water vapor).

6.8.7 Hydrogenase

Micro-algae and cyanobacteria are naturally able to produce hydrogen[31]. But they will do this only in oxygen deficient environments[32]. If sufficient oxygen is present, the photosynthesis principle is running and sugar instead of hydrogen will be produced. This experimental way of generating hydrogen will be placed in the 'green zones', to strengthen the green character of the space.

Fig. 81: Experimental algae hydrogen production

[31] http://www.futurefarmers.com/survey/algae.php
[32] http://www.c2w.nl/hoe-je-algen-waterstof-laat-spuwen.131069.lynkx

6.9 Amorphous solar panels compared

Although amorphous solar cells have a lower yield (5-8%, compared to max 18% crystalline-silicon cells), they also have some advantages, especially for architectural purposes.

- Thin and lower weight - No additional structure required
- Flexible - Applicable on curved surfaces
- Easy to install without penetrations in the roof
- Uniform appearance

Economical

Amorphous silicon solar panels contain only about 1/300th[33] of the amount of active material compared to a crystalline-silicon cell. Because the silicon part is the most expensive element, the production costs are lower, but the costs per kWh are similar to crystalline-silicon cells. From an economical point of view the crystalline-silicon cells would be more attractive, because amorphous solar panels need approximately twice the amount of roof surface.

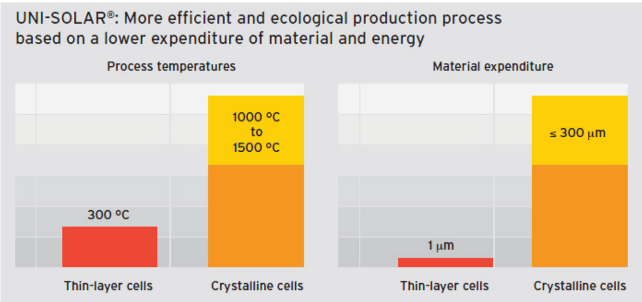


Fig. 82: Production amorphous solar cell

Efficiency

Amorphous silicon cells have a lower annual yield per m2, but they have a better annual yield in kWh/kWp. This means that the crystalline cells are less efficient per installed kWp. The reason of this is that amorphous cells can handle high temperatures, low light levels, and shading better. So crystalline solar cells are better in laboratory conditions, but the amorphous solar cells are more efficient (25%) per kWp in outdoor conditions.

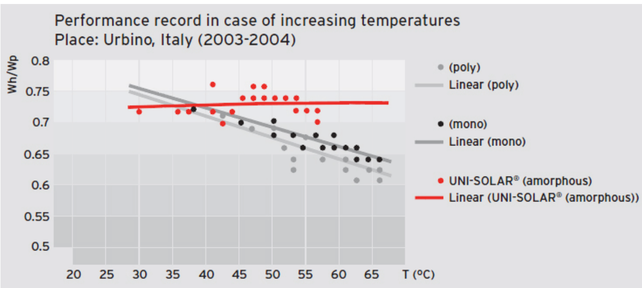


Fig. 83: Temperature influence

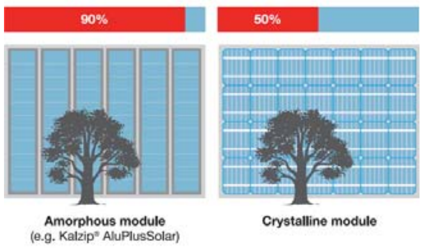


Fig. 84: Shadow compared

[33] http://www.aluform.de/viomatrix/imgs/PDFdownload/aluform_brochures_alu_solar_fotovoltaisch_zonneenergiesysteem.pdf

6.9.1 Roof integrated amorphous solar panels

Fig. 85: Uniform appearance, placed on roof, not integrated

Fig. 86: Solar facade elements

One of the advantages of amorphous solar panels is the uniform appearance. In figure 85 are the panels placed on a roof as non-flexible plates. In figure 86 amorphous solar panels are used as flat facade cladding.
Aluform (Germany) and Kalzip (international) have systems where amorphous solar cells are integrated in the roof[34]. The systems are almost the same: A folded aluminium cladding with integrated amorphous solar cells provided by the company Uni-Solar. As can be seen, it is possible to bend the panels. This flexibility is one of the reasons why Kalzip have chosen for amorphous solar panels.

Fig. 87: Kalzip integrated solar roof

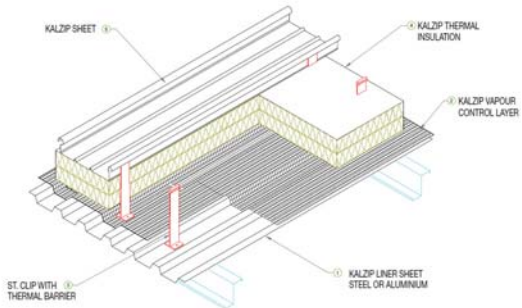


Fig. 88: Kalzip AluPlusSolar System

6.9.2 Triple Junction Technology

The Triple Junction Technology is used in the Uni-Solar amorphous solar panels to obtain a better overall yield. *'The exceptional Triple Junction Technology uses the blue, green and red parts of the sunlight in different layers of the solar cell.*
As a result a higher degree of efficiency is reached as with crystalline solar cells in case of minor solar radiation and of the diffuse light. Even in case of partly shadowing, electricity generation is still possible due to the cells interconnected via bypass diodes.' [35]

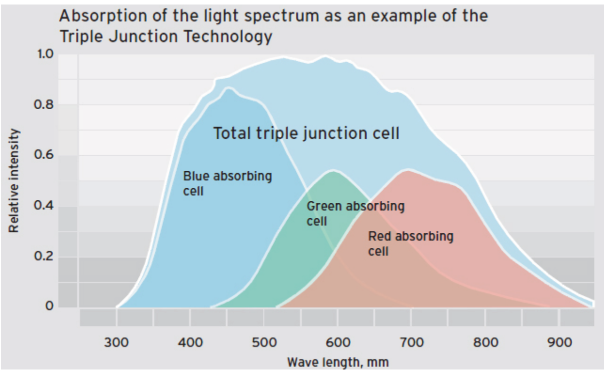


Fig. 89: Triple Junction Technology

[34] http://www.kalzip.com/PDF/uk/Kalzip-Solar-Systems.pdf
[35] http://www.aluform.de/viomatrix/imgs/PDFdownload/aluform_brochures_alu_solar_fotovoltaisch_zonneenergiesysteem.pdf

Efficiency
Kalzip claims in their brochure: *'In Germany, a 10 kWp solar system generates approx. 8000 kWh per year'* [36]
Using the simulation, the *theoretical maximum* annual yield in Amsterdam with 10 kWp would be approx. 10800 kWh, if all solar panels are ideally orientated. The information of Kalzip cannot be used because the exact location in Germany is not given. The yield for these the amorphous solar cells must be calculated.

The brochure of Uni-Solar of the PVL-144[37] comes with a flexible amorphous solar panel with a rated power of 144 Wp. The panel is assembled out of 22 triple junction amorphous silicon solar cells of 356 mm x 239 mm. So the *active* surface is 0,085 * 22 = 1,87 m2. Calculated, the solar cells of Uni-solar have a efficiency of 77 Wp/m2. This means that the amorphous solar panels have an efficiency of 7,7%. This value is quite high for amorphous solar panels.

Using the simulation it is possible to calculate the amount of square meters at the roof that would be needed needed for multi-crystalline compared to amorphous solar panels. The main question in this simualtion is: When is a hydrogen powered building design with 9000 m2 floor surface situation feasible (energy self-sufficient)?. It is calculated with a lower yield per square meter because of shadow and the fact that the panels are not all orientated optimally to the sun.

Multi-crystalline
- Theoretical maximum 150 W/m2 - Calculated with *120 W/m2* (80% fo 150Wp) = 12%
- Needed roof surface: **2550 m2**

Amorphous, Uni-solar
Theoretical maximum 77 W/m2 - Calculated with *69 W/m2* (90% of 77Wp) = = 6,9%
- Needed roof surface: **4400 m2**

Future perspective
In 2020 Uni-Solar expects that their amorphous solar panels can reach efficiencies of approximately 20%. In that case, the building design would be feasible with 1550 m2 of solar roof.

6.9.3 Conclusion

In theory the more expensive crystalline solar cells have a better annual yield per m2, but when there is for instance some shadow, amorphous cells could have a better annual yield in real outdoor conditions. Because of lower production prices and more environmental friendly production process, amorphous solar cells can be a better choice in a technological but also an architectural way.

Design decision
When amorphous solar panels are used in the design, the yield will be much lower than calculated, and the building will probably be not energy self-sufficient. Based on sustainable and architectonic considerations, amorphous solar panels can be a good option, although the energy self-sufficient goal in the design will certainly not be achieved *in 2012*.

[36] http://www.kalzip.com/PDF/uk/Kalzip-Solar-Systems.pdf
[37] http://www.uni-solar.com/wp-content/uploads/2010/05/PB_PVL-144_Technical_Data_Sheet_EN_AA5-3636-04.pdf

6.10 Ventilation

6.10.1 Global ventilation

Internal ventilation
Installations are placed in the basement of the building next to the fuel-cell-systems. These fuel cells are using hydrogen from the outdoor tanks and they extract oxygen from the indoor air that is blown through the fuel cells. This air will warm up. The fuel cells are located next to the 'green lungs' of the building, so the air intake has a relatively high oxygen level. Extra oxygen can be added in the air to obtain a more oxygen-controlled environment (for example the auditorium).
Because the fuel cells are mainly working in the winter periods, the warm air can be used for ventilation for the working places and common areas in the building and distribute the warm air with a good oxygen level.

Mechanical ventilation
Of course the building must be ventilated with fresh outdoor air. The problem of mechanical ventilation is the loss of energy. In the winter, heat is unnecessary disposed and in the summer it is difficult to keep the heat outside. To ventilate the building makes use of heat recovery using a twin-coil-system. The air supply is situated at a different place than the exhausted air outlet. Both places have heat exchangers that are connected to obtain a ventilation with a heat efficiency of 50 to 70% [38].

6.10.2 Office ventilation

The offices can be ventilated using mechanical ventilation, but also using (semi-)natural ventilation. To prevent energy losses, part of the facade is a heat exchanger itself. The fine-wire heat exchanger is a semi-natural ventilation system that is applied in offices and has an efficiency of approximately 95%[39]. It can have such a good efficiency because of the enormous surface of the heat exchanging fine mesh copper wire (15 kilometers of 0,1 diameter copper). The application of such a system in the building design is described later in the 'P4 Building Design' chapter.

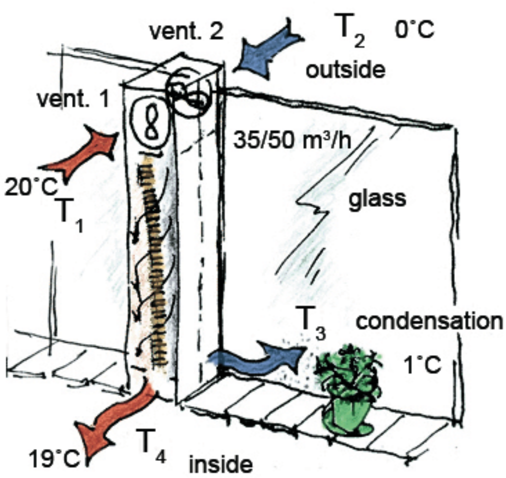


Fig. 90: Concept ventilation

Fig. 91: Breathing Window Prototype

6.10.3 Adiabatic heat exchanger improvement for summer situations

In my master1 course I did research on an improvement for heat exchangers in the summer. The system could blow cool air without active cooling. The trick was to humidify the waste air before it enters the heat exchanger. Because of the humidification, the temperature of the waste air will decrease. Now the heat exchanger can handle a larger difference in temperature. The principle is simulated and tested. Important sheets of this research are added in Appendix E.

[38] http://www.duurzaammkb.nl/tips/tip/439
[39] http://www.breathingwindow.org/telegraaf.gif

6.10.4 Ventilation with pure oxygen

The possibility to ventilate less in a building, when adding pure oxygen to maintain a normal oxygen level of 21%, is investigated. Ventilation with pure oxygen sounds very healthy, but it can be very dangerous.
When people are in a closed environment, they will finally die from suffocation. Most people would think this is due to the decreasing oxygen level, but it is the increasing CO2 level that kills the people. So when we want to ventilate a closed building it is important to keep the oxygen level high, but also prevent a high CO2 level. Closed environments like space stations or submarines are good examples of environments where the concentrations of the gases must be controlled. In these situations electrolysis is often used to generate oxygen. CO2 is bonded to other materials to control the CO2 level.

CO2 - Carbon dioxide

'Is co2 een gifgas? Het klinkt wat overspannen en het geldt ook niet direct voor de heersende natuurlijke concentratie van ongeveer 0,04%. Maar concentraties vanaf 4 a 5% worden in de literatuur wel degelijk levensbedreigend genoemd. Bij blootstelling aan een co2- concentratie van 10% treedt de dood binnen enkele minuten in.'[40]

'De lucht die wij inademen, bevat ca. 0,03 vol.% kooldioxide. Bij hogere concentraties kan CO2 schadelijk zijn voor de gezondheid. Bij 3-5 vol.% CO2 in de inademingslucht ontstaan hoofdpijn, storingen in de ademhaling en onpasselijkheid. Een concentratie van 8-10 vol.% kan leiden tot krampen, bewusteloosheid, ademstilstand en de dood. Het zuurstofgehalte in de ademlucht bedraagt daarbij nog wel ongeveer 19 vol.% en zou dus voldoende moeten zijn. De schadelijke fysiologische werking van dergelijke CO2-concentraties ontstaat dus niet als gevolg van zuurstofgebrek, maar door de directe werking van de kooldioxide.' [41]

O2 - Oxygen

Indien het normale percentage van 21% zuurstof met slechts een paar procent wordt overschreden, zullen de bekende verbrandingsprocessen ineens veel sneller verlopen, zodat ze onbeheersbaar worden. Materialen, die in normale lucht niet brandgevaarlijk zijn, kunnen dan plotseling heel intensief branden, ook bij een nog relatief lage verrijking. Zelfs vuurbestendige materialen verliezen soms (zeker bij hoge percentages zuurstof) die eigenschap en branden dan als een fakkel.
Ook de temperatuur en de snelheid waarmee verbranding plaatsvindt, is aanmerkelijk hoger dan we gewend zijn. Brandgevoelige materialen kunnen bij verhoogde temperatuur spontaan ontbranden. Kort gezegd: zuurstofconcentraties hoger dan 23% kunnen ronduit gevaarlijk zijn. [42]

Conclusion

It is important to let the CO2 level not exceed the value of 3 vol.%. Because the air we are used to contains 0,03 vol% CO2 there is a certain range. There could be less ventilated in the building that will cause a higher (but not dangerous) CO2 level while the oxygen level must be maintained at a maximum of 23%. For safety reasons it is important to control these systems very precisely! Therefore it is very difficult and expensive to integrate such a system in buildings as a whole, but it is possible to do it for some big rooms where the air can mix better. In the design the auditorium can be controlled by adding some oxygen-rich air and applying a lower ventilation rate.
The offices will be ventilated using (semi-)natural ventilation to preserve a good air quality.[43]

[40] http://www.klaarvooronderwater.nl/kvo/Kvo-107.pdf
[41] http://www.lindegasbenelux.com/international/web/lg/nl/likelghlnl30.nsf/docbyalias/beschikbare_documentatie_veiligheid_overige - Werken met kooldioxide
[42] http://www.lindegasbenelux.com/international/web/lg/nl/likelghlnl30.nsf/docbyalias/beschikbare_documentatie_veiligheid_overige - Werken met zuurstof
[43] Bauer M., Green Building - Guidebook for Sustainable Architecture:42

7 P4 Building Design

The building design in this report is explained right after the P4 presentation. It can be that some parts in the design drawings differ from drawings in the P5 graduation presentation.

7.1 Location NDSM-east

Amsterdam

Fig. 92: Map of Amsterdam and NDSM location.

Because the Amsterdam municipality wants to be progressive in the hydrogen technology, they want to profile the city with several projects. A hydrogen powered bus or a canal boat are two of the already realized examples. Besides this, the NDSM location will be energy neutral built, or at least that is one of the purposes. The NDSM site is now an energy experimental location. A Bio-fuel & electric charging point and the 'Gewoonboot' are some of the examples.

The location at the NDSM site is situated on a tongue of land that sticks into the river with a beautiful view to the city of Amsterdam and the industrial harbor. Beside these prominent spots, the crane on the NDSM site itself but also the view to the buiksloterham and houthaven area, are important.

NDSM, design location

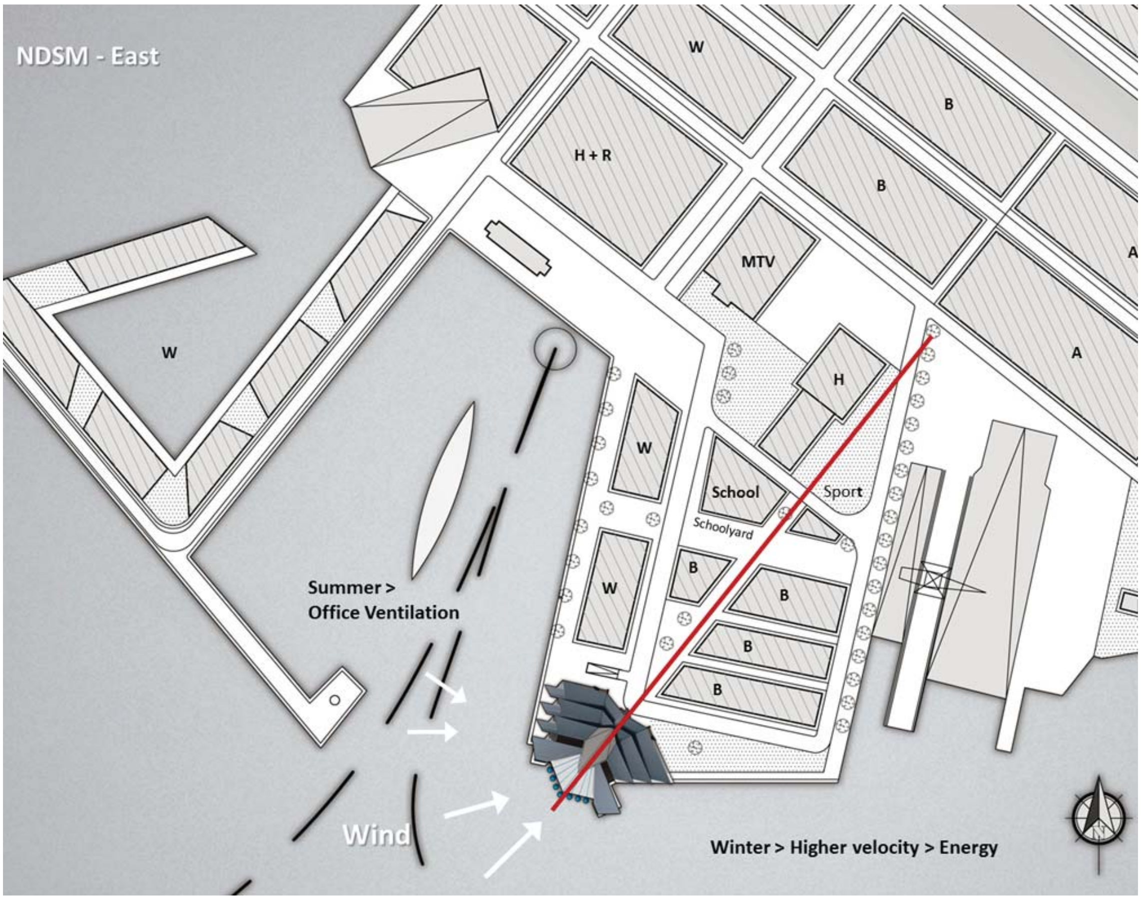


Fig. 93: NDSM area in more detail

Ferryboats are moving right next to building location and visitors can have a wonderful view over the IJ-river. The building is oriented to the sun but also on the dominant wind directions. The building works as a wind tunnel that leads the wind through a wind turbine in the center of the building. Because the powerful and dominant wind direction in the winter is southwest the wind tunnel is situated in that direction. Besides the southwest wind direction, the direction also can be found in the rest of the location (streets). In the summer, the dominant wind direction is west/northwest. This wind direction will be used for summer natural ventilation and cooling as described before (Fine-wire heat exchanger + Adiabatic cooling).

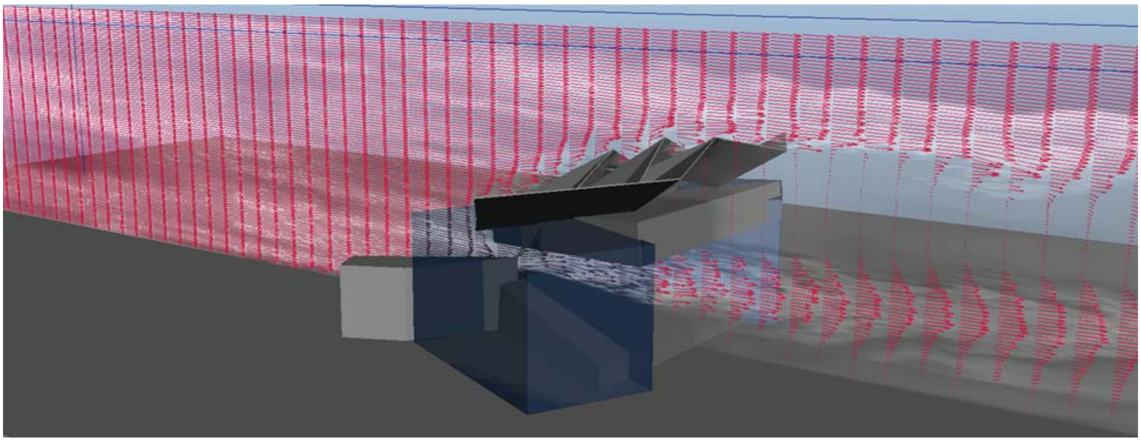


Fig. 94: Building concept shape simulated in a virtual wind tunnel

7.2 Preliminary models

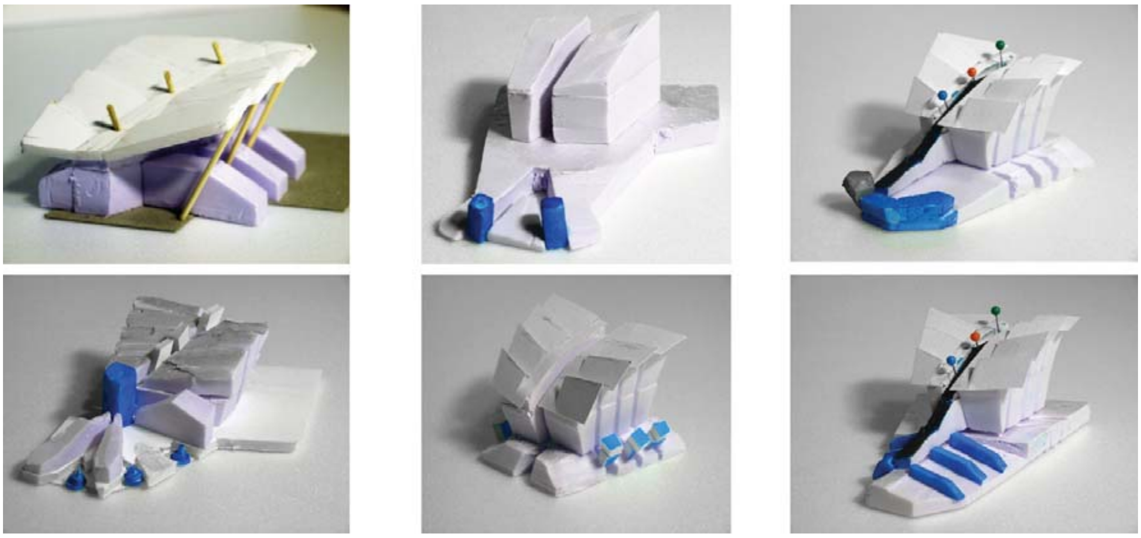


Fig. 95: Models, south west direction included

In the models above, the southwest direction is an important design aspect. Some wind turbines are be placed in the folded roof. The storage of hydrogen (blue parts) is also investigated in these models.

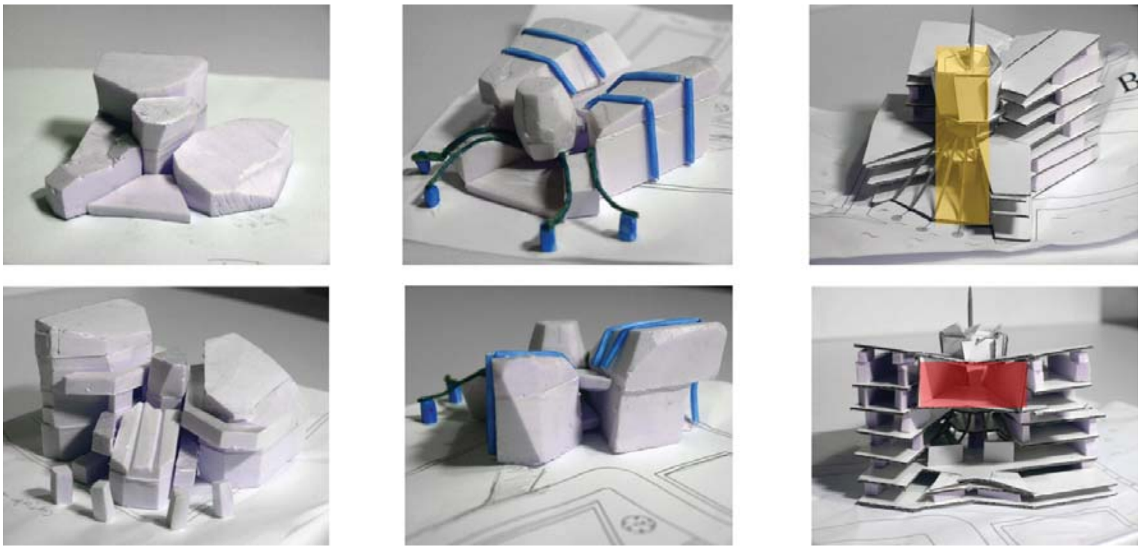


Fig. 96: Processes and Core structuring

In later models the hydrogen technology processes and important functions became structuring, while the southwest direction was still intact. In the last model de processes are situated in the yellow core. In the red part an auditorium is situated, which will be an important function for the hydrogen business convention center.

7.3 Building organisation

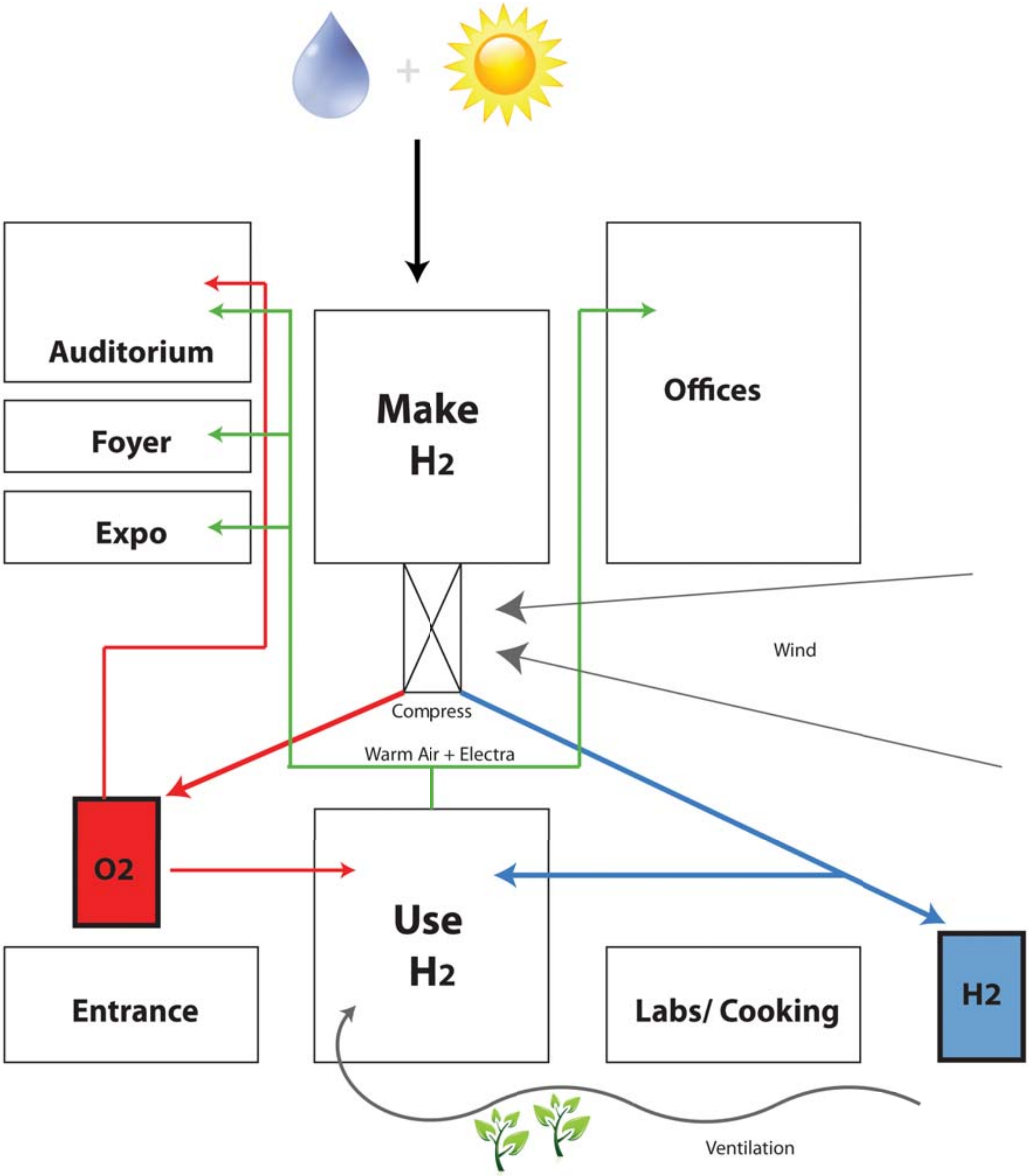


Fig. 97: Simplified building organisation

The scheme above shows the processes of the hydrogen technology. This scheme is in the first place structuring in a technological way for the global installations but it is also structuring in an architectural way that will become clear in the section on the next page.

There are two cores: 1. Make hydrogen and oxygen out of solar energy and rainwater. 2. Use hydrogen and oxygen to produce electricity. Wind energy will be used to compress the gases to their tanks and to purify the water (not in this scheme) before the electrolyzers split the water. The explosive hydrogen tanks are placed outside the building and the oxygen tanks are place in the entrance hall.

Because the 'Use H2' part, (the fuel cells) will be operational in the winter periods, this heat is used to heat the building. Also the air that is blown through the fuel cells warms up and can be used as warm ventilation air.

7.4 Section Auditorium / Entrance

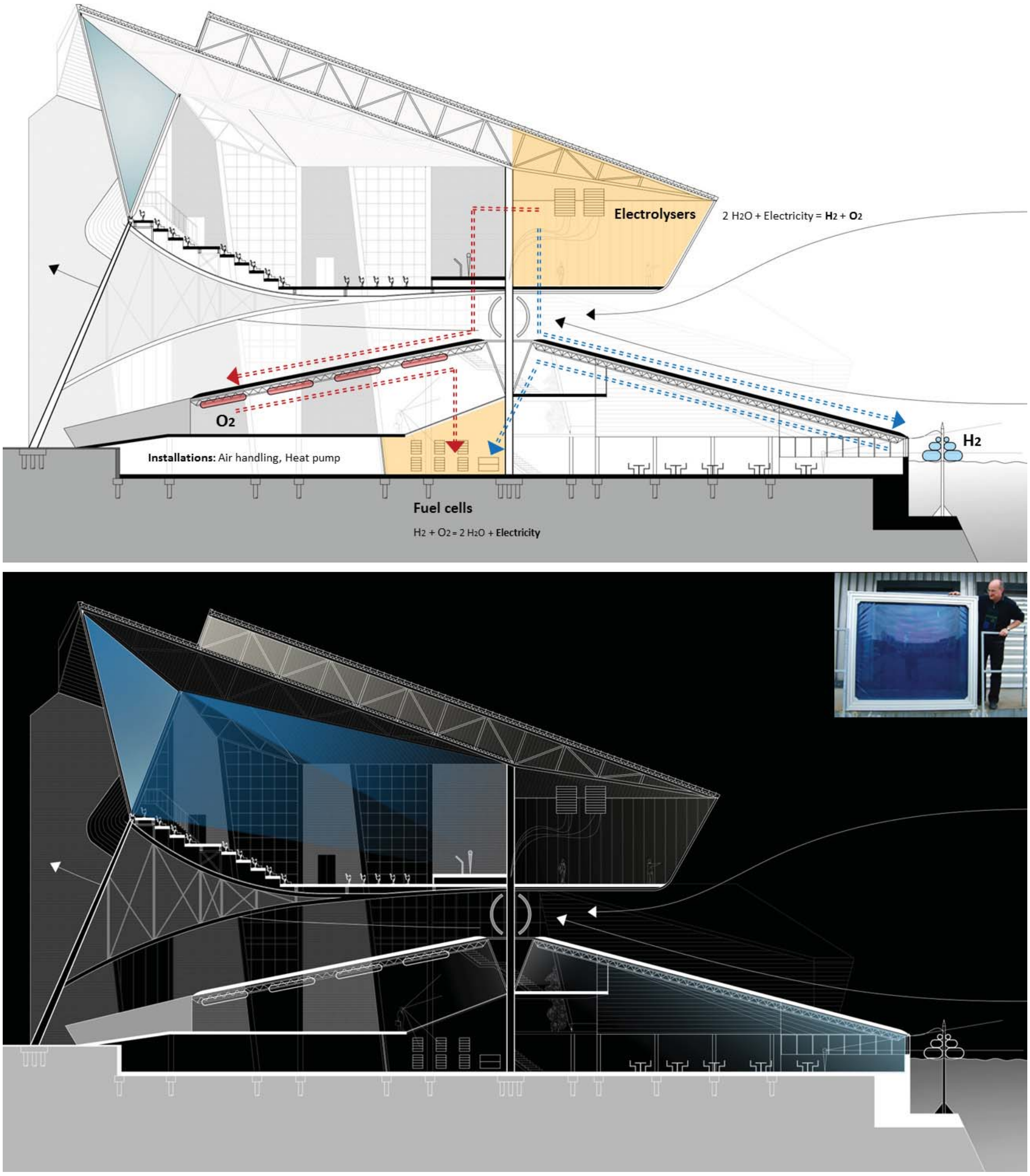


Fig. 98: Vertical Section Auditorium / Entrance

In the section above the structuring scheme of figure 97 is recognizable. The wind turbine is placed in the building's narrowest point. The hydrogen processing areas are yellow colored and the placements of the tanks are visible in the drawing. Important related installations (air handling/heating) are situated in the basement right under the entrance.

The dark section shows the effect of the windows in the darkened auditorium. Experimental windows with an inner coating of tungsten trioxide that turns blue when it comes into contact with hydrogen and loses its color if the cushions are filled with oxygen are used in the design. So the passage of light and energy can easily be regulated. Besides this, this contributes to the hydrogen experience.
When colored blue just 15% of the visual light will be transmitted and 12% of the energy will enter through the window.[44]

[44] Dr. Andreas Georg of Fraunhofer ISE, Gaschrome Membrankissensysteme

7.5 Detailed installation scheme

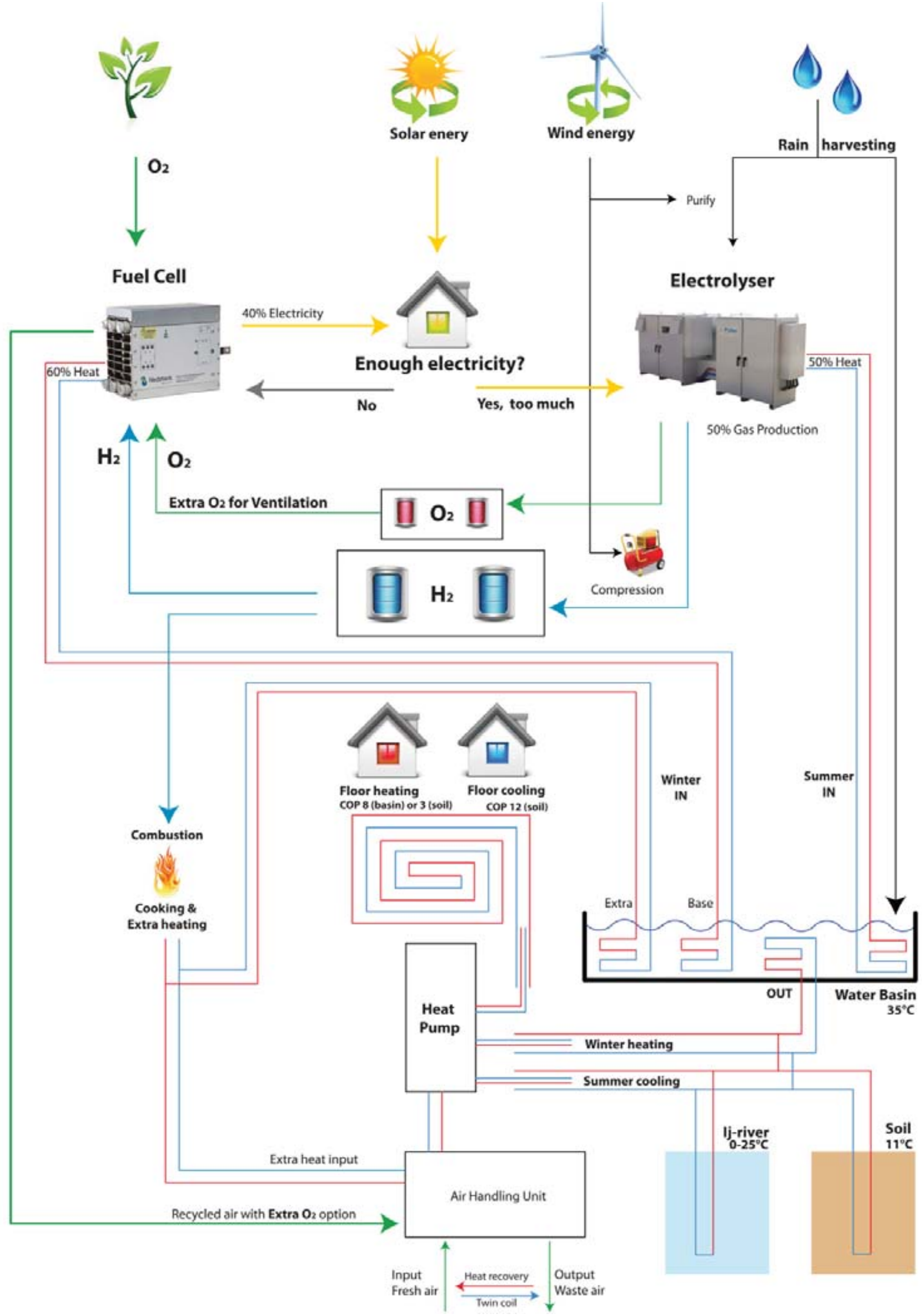


Fig. 99: Detailed installation scheme

The central question in this detailed installation scheme is 'Enough electricity?'. In fact this is the same question as in the feasibility simulation of hydrogen technology integrated in the building design. If there is not enough electricity generated by the solar panels (winter), hydrogen will be transformed into electricity. If there is too much electricity (summer), water will be split and hydrogen and oxygen will be stored in tanks. The situation is feasible when the tanks do not run out of hydrogen in the winter period.

To prevent too much energy losses, the heat of the fuel cells and electrolyzers are stored in the water mass of the basin. This is the main heat source for the heat-pump in the winter. If there is not enough heat produced, more heat can be obtained by the combustion of hydrogen.
In the summer periods, the deep water of the IJ-river will be used as cooling source. If the river is too warm, the soil can be used as a cooling source.

7.6 Sections Roof / Basin

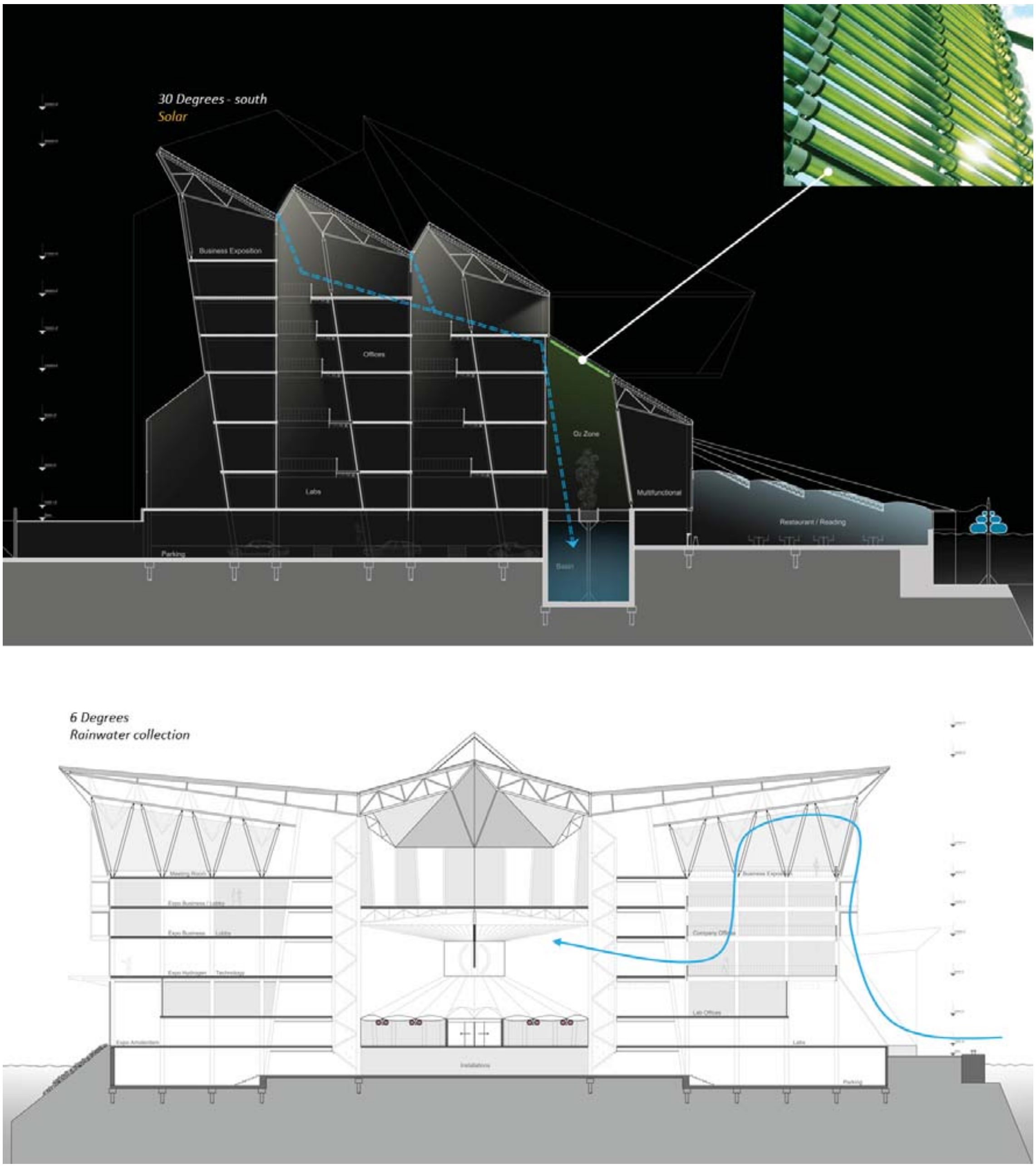


Fig. 100: Section Offices / Basin

In these sections, there can be seen that the roof is a 30 degrees south orientated saw-tooth roof. The roof has two functions catching solar energy and catching rainwater. The roof brings both to the upper core (make hydrogen).
-30 degrees south orientated to catch solar energy.
-6 degrees angle brings the rainwater to the gutters right above the transport-layers (marked with the trusses) in the building.

The water will be used to flush toilets. Just a little water will be purified so the electrolyzers can use it. The remaining part will be brought to the water basin placed in the basement. The produced heat from the electrolyzers and fuel cells will be stored in the basin.

The area above the basin is called the 'green lungs' of the building. Plants are growing and are producing oxygen. This more oxygen-rich air can be used by the fuel cells and will be part of the internal ventilation circulation hereafter. To strengthen the green experience, tubes with experimental hydrogen producing algae are placed right under the glass roof.

7.7 Layout Ground floor

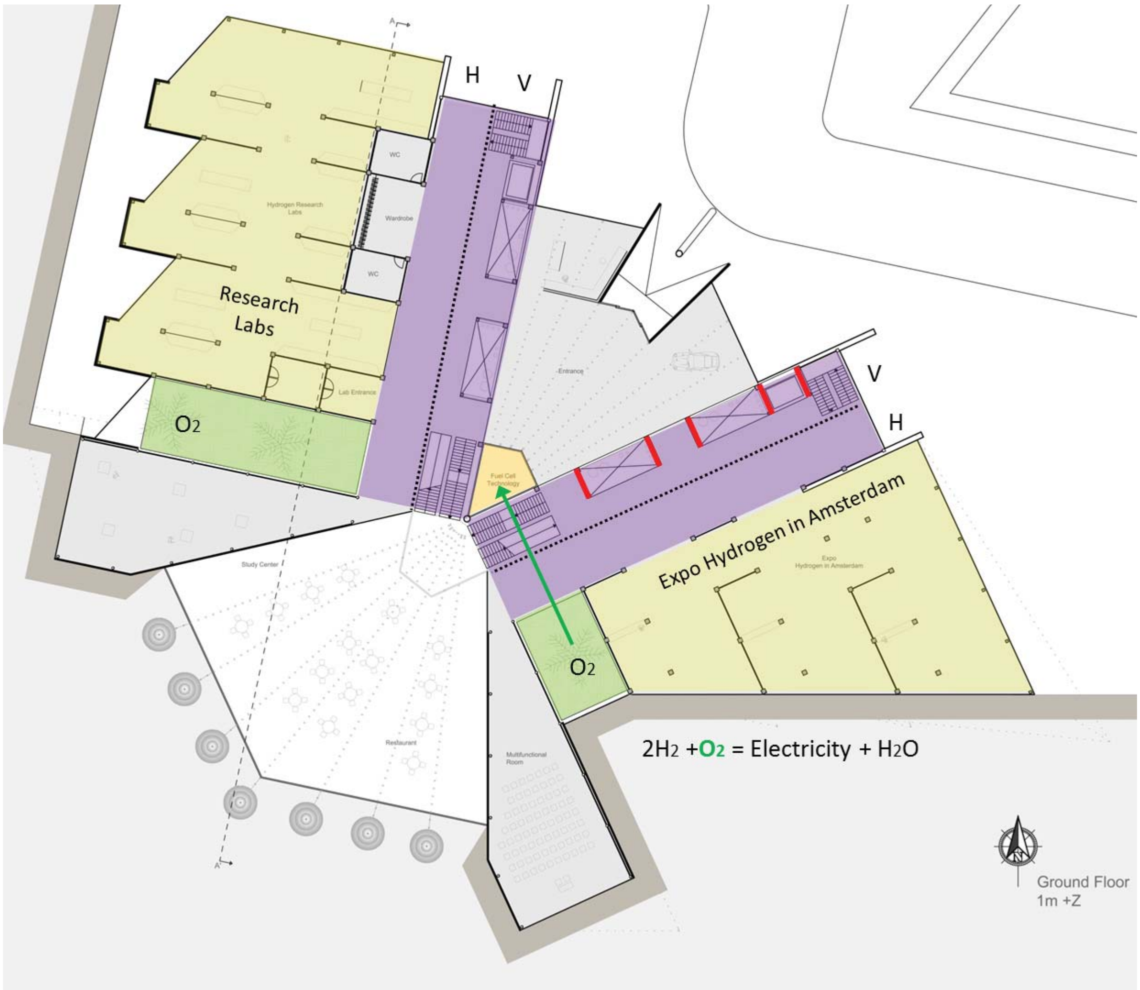


Fig. 101: Layout Ground Floor

The entrance is situated at the north side of the building, under the auditorium and wind tunnel outlet. Because of the overhanging auditorium the entrance hall is not a very natural-lit area. People will be attracted to the more lighted places. For instance the exposition about Amsterdam and the use of hydrogen technology in the city, overlooking the water towards the Amsterdam city center. At the west the laboratories are situated.

In the center the fuel cells are situated as a central hydrogen processing 'core'. People can look over the fuel cells, and when they look up, the rotating wind turbine is visible. The two gray 'mustache' rooms are multifunctional rooms for exhibitions or special events like a wedding. Between the two gray mustache parts a restaurant is situated that can be a study center during the day.
The green parts represent the 'green lungs' where plants are growing. Under these places the water basins for heat storage are situated.

The purple areas are called the 'transport layers'. These areas are designed for vertical and horizontal transport (people and installations). The shafts for vertical ducting transport are marked on both sides with trusses (red). These trusses are also used for structural reasons: the load of the auditorium.

7.8 Layout Fifth floor

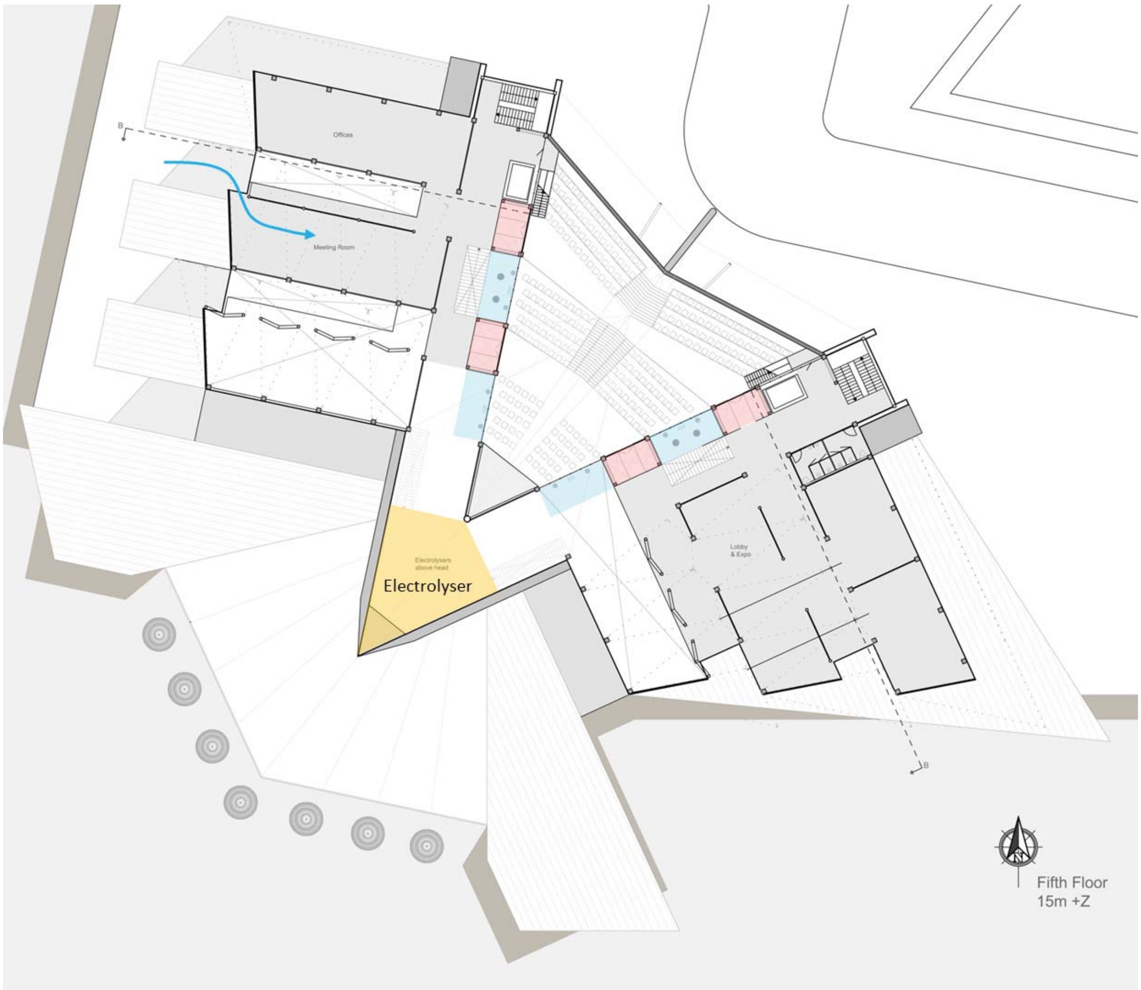


Fig. 102: Layout Fifth Floor

The electrolyzers are located on the 5th floor hanging at the roof structure above the head of people. This prominent place is chosen to show the hydrogen producing process but also the function of the roof: bring water and energy to the center of the roof where the electrolyzers are located.

The red areas represent the vertical shafts. The blue parts are the places where the rainwater is being processed: purified or temporary stored for toilet flushing.

The blue arrow at the west represents the natural office ventilation. Here the fine-wire heat exchanger and adiabatic cooling system are integrated in the facade, explained at the next page.

7.9 Office ventilation - Heat exchanger

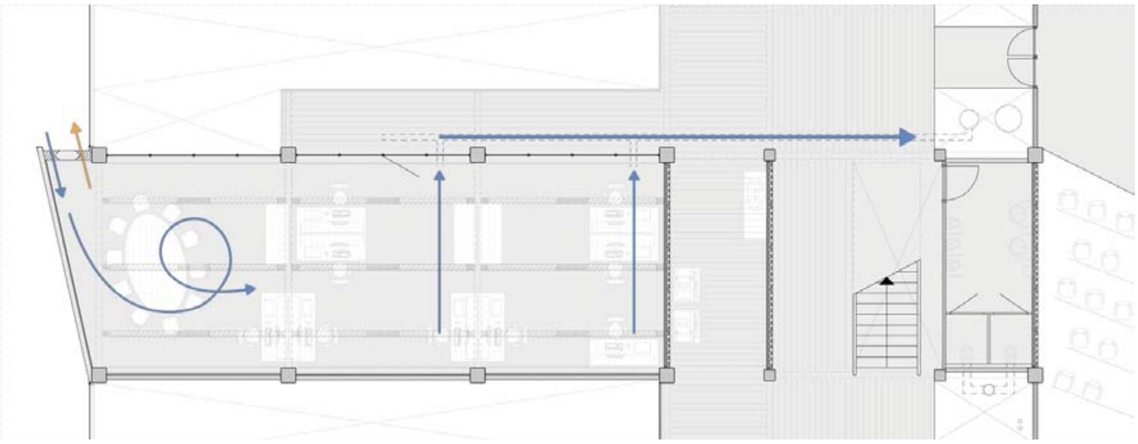


Fig. 103: Office Ventilation

Figure 103 shows an office in the west wing of the building. A part of the office space protrudes slightly beyond the building. In this small facade part, a heat exchanger is integrated. Because the office space has a length of 16 meters, the heat exchanger is not able to ventilate the entire office itself. Therefore the air in the office is slowly extracted by the ventilation system.

As described before, a high efficient heat exchanger will be used. The breathing window concept (figure 91), which works with a fine-wire heat exchanger, has a very high efficiency and it could be provided by Brink Climate Systems. Unfortunately Brink stopped the production of the Breathing Window. Another product is the Brink Advance ventilation Unit 104. Although it does not seem that Brink integrated a fine wire heat exchanger in it, the technical information[45] tells us that the plate heat exchanger has an efficiency of 90%. The Brink Advance or a similar product is integrated in the design as a facade element combined with adiabatic cooling addition (see Appendix E) for the summer periods.

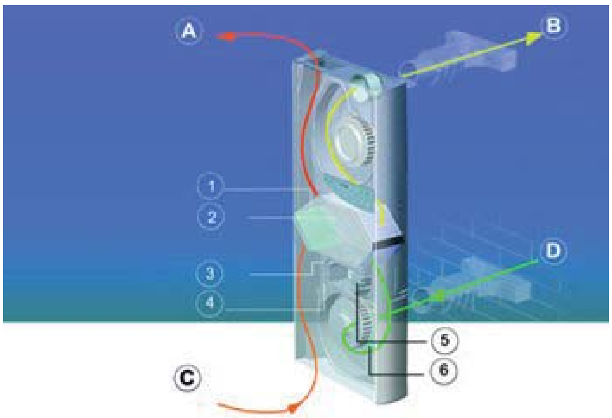
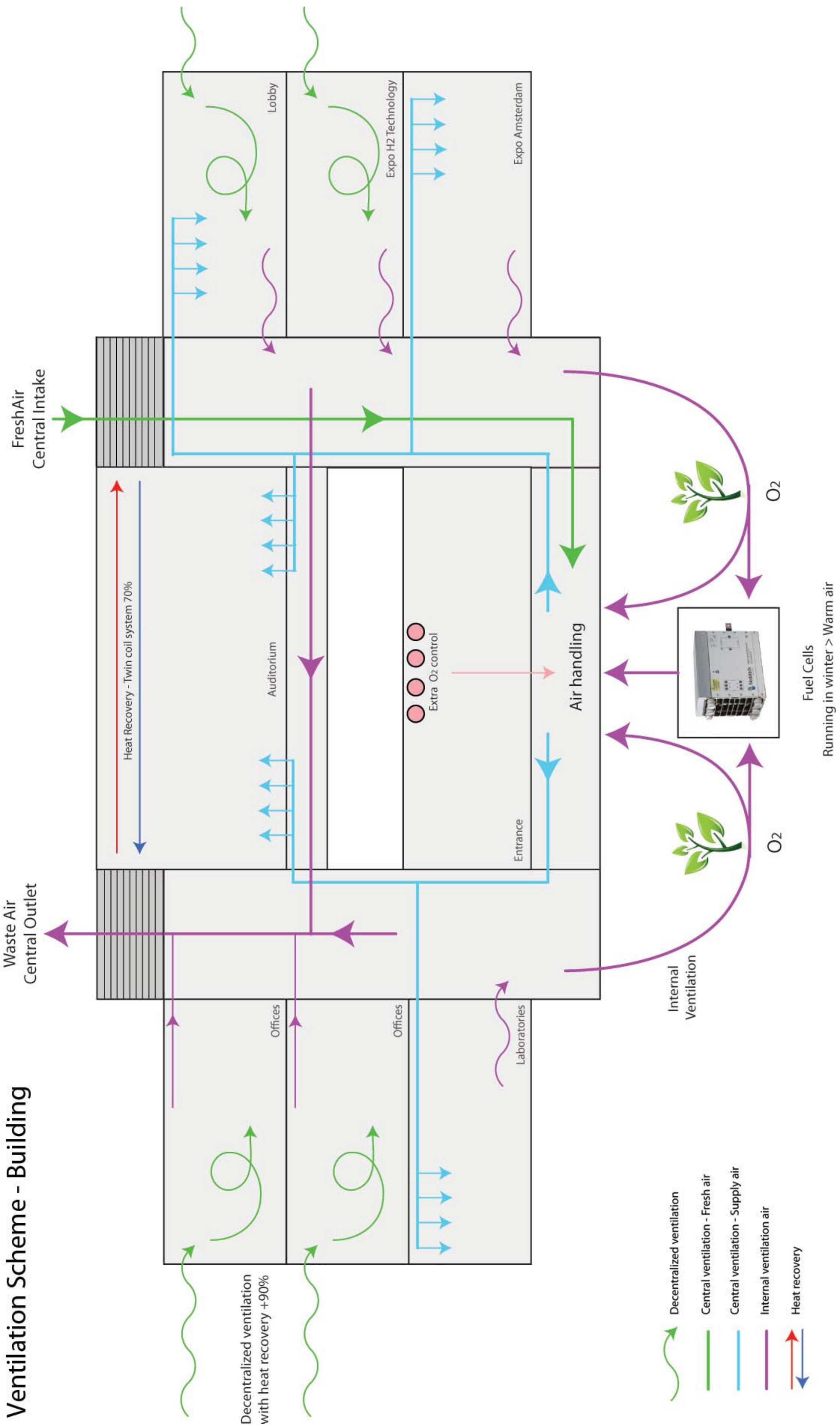


Fig. 104: Brink Advance Ventilation

The figure at the next page shows the ventilation system for the entire building. The office ventilation, as described before, is visible at the left side of the schematic section. The energy of the extracted waste air from the shafts wil be transfered to the fresh air inlet located at the other side of the building, using a twin-coil system. The air handling units are using fresh air but internal ventilation air, which flowed through the 'green lungs', as well. Fuel cells extract oxygen out of this more oxygen-rich interal ventilation air. The fuel cells are mainly running in the winter periods, what will warm up the internal ventilation air. The oxygen level for the mechanical ventilation is is adjustable.

[45] http://www.brinkclimatesystems.nl/Documentatie/Technische-gegevens-Advance.aspx


Ventilation Scheme - Building
FreshAir
Central Intake
Waste Air
Central Outlet
Lobby
Expo H2 Technology
Expo Amsterdam
Heat Recovery - Twin coil system 70%
Auditorium
Extra O2 control
Air handling
Entrance
Offices
Offices
Laboratories
O2
O2
Fuel Cells
Running in winter > Warm air
Internal
Ventilation
Decentralized ventilation
with heat recovery +90%
Decentralized ventilation
Central ventilation - Fresh air
Central ventilation - Supply air
Internal ventilation air
Heat recovery

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- Fraunhofer ISE, Valley, Germany
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- ITM-Power, Sheffield, United Kingdom
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7. http://www.kalzip.com/PDF/uk/Kalzip-Solar-Systems.pdf
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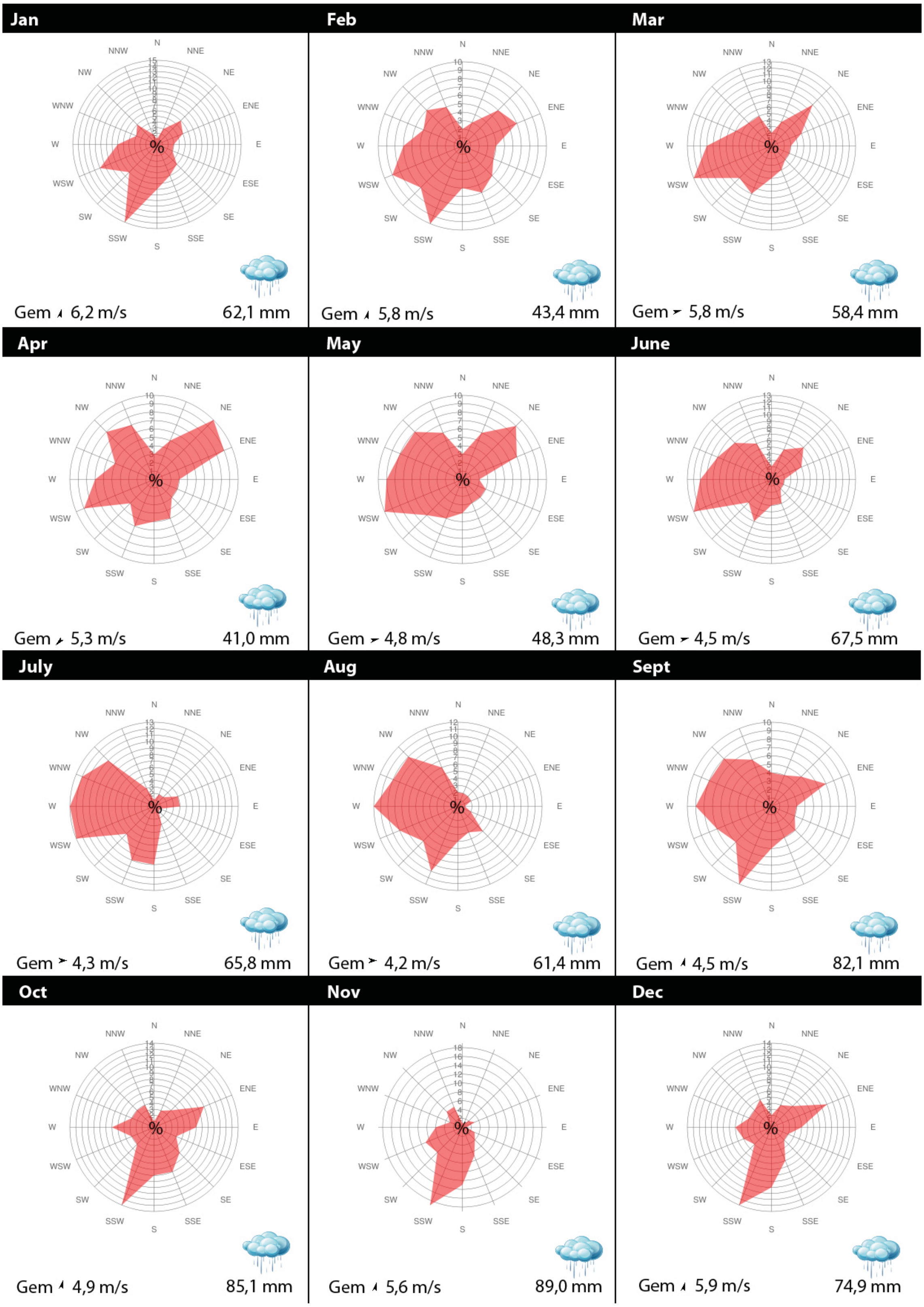
Appendices

Appendix A - KNMI Schiphol airport

Schiphol, langjarige gemiddelden, tijdvak 1981-2010

240	Temperatuur(°C)			Relatieve vochtig-heid %		Neerslag			Ver-dam-ping	Globale Straling	Zonneschijn		Lucht druk	Wind								
														Pot. wind	Gem. wind	Wind-vector		Aantal dagen met windkracht				
	gemiddeld	gemiddeld minimum	gemiddeld maximum	gemiddeld	12.00 UT	duur in uren	in % van de tijd	som in mm	som in mm	som in J/cm2	in uren	in % langst mogelijke duur	in hPa	snelheid in m/s	snelheid in m/s	snelheid in m/s	richting in graden	≥ 4 Bft	≥ 5 Bft	≥ 6 Bft	≥ 7 Bft	≥ 8 Bft
jan	3.4	0.8	5.8	88	86	69.8	9	66.6	8.6	7267	63.2	25	1016.3	6.4	6.3	2.8	223	25	17	10	4	1
feb	3.5	0.5	6.3	86	80	53.8	8	50.6	15.7	12867	87.5	31	1016.5	6.0	5.9	1.7	230	22	14	7	3	1
mrt	6.1	2.6	9.6	83	75	60.9	8	60.6	35.5	26700	126.3	34	1014.9	5.9	5.7	2.0	244	25	16	8	3	0
apr	9.1	4.6	13.5	78	65	41.3	6	40.9	62.2	42889	182.7	44	1014.3	5.2	5.0	0.5	295	24	13	4	0	0
mei	12.9	8.2	17.4	76	64	42.7	6	55.6	91.4	56968	221.9	45	1015.4	5.0	4.8	0.6	312	24	12	2	0	0
jun	15.4	10.8	19.7	78	67	42.8	6	66.0	96.5	57283	205.7	41	1016.2	4.7	4.4	1.6	280	22	9	2	0	.
jul	17.6	13.0	22.0	79	68	37.5	5	76.5	100.4	57049	217.0	43	1015.9	4.5	4.4	1.6	266	22	9	2	0	.
aug	17.5	12.8	22.1	80	66	37.4	5	85.9	83.8	47699	197.0	43	1015.4	4.4	4.2	1.4	260	21	9	2	0	.
sep	14.7	10.6	18.8	83	72	53.0	7	82.4	50.8	30686	139.4	37	1015.7	4.6	4.4	1.3	237	21	10	3	1	.
okt	11.0	7.5	14.5	86	78	63.8	9	89.6	27.8	18526	109.1	33	1014.3	5.3	5.1	2.0	205	23	13	5	1	0
nov	7.1	4.2	9.7	89	84	71.8	10	87.2	10.9	8147	61.7	23	1013.8	5.4	5.3	2.2	209	22	14	5	1	0
dec	4.0	1.5	6.4	90	87	70.0	9	76.3	6.4	5301	50.5	21	1015.1	5.8	5.6	2.1	217	23	15	7	2	0
winter	3.7	1.0	6.2	88	84	194.3	9	195.4	30.8	25442	201.6	26	1016.0	6.1	5.9	2.2	223	70	47	24	10	2
lente	9.4	5.2	13.5	79	68	144.9	7	157.1	189.2	126556	530.9	42	1014.9	5.4	5.2	0.9	265	73	40	14	4	1
zomer	16.8	12.2	21.3	79	67	117.9	5	228.5	280.2	161788	619.8	43	1015.8	4.5	4.3	1.5	269	66	27	5	1	.
herfst	10.9	7.4	14.4	86	78	188.6	9	259.1	89.5	57368	310.1	32	1014.6	5.1	4.9	1.8	214	66	36	13	3	0
jaar	10.2	6.4	13.8	83	74	648.6	7	838.2	591.0	371768	1662.0	37	1015.3	5.3	5.1	1.5	237	275	151	56	17	3

Appendix B - Overview wind and rain



Appendix C - Inquiries to Nedstack

Telefoongesprek met Siu Fai Au van Nedstack op 26 mei 2011

- Wat voor type brandstofcel denkt u dat in gebouwen het beste toepasbaar is? Zelf lijkt me de PEMFC variant de beste optie vanwege de bedrijftemperatuur.
Klopt, en deze is ook variabel waardoor het goed toepasbaar is bij een varierende vraag.

- Een PEM brandstofcel heeft een rendement van ongeveer 40%. Is de overige 60% warmte die gekoeld moet worden? Kan deze gebruikt worden in het gebouw voor verwarming?
Ja dit klopt maar een opmerking over het rendement: die kan oplopen tot 50%, als de bandstofcel een contant vermogen moet leveren. Het vermogen kan ook omhoog als je een grotere brandstofcel op een lager vermogen laat draaien.

- De PEM brandstofcel wordt met water gekoeld. Hoe is die koeling verwerkt in de brandstofcel? Door de brandstofcel stroomt H2 en O2 gas (of lucht), is er nog een extra kanaal voor dit water?
Ja er loopt door de brandstofcel een kanaal voor de koeling.

Ontsnapt het water, dat vrijkomt bij de reactie in de brandstofcel, als waterdamp, of kan dit weer opgevangen worden zodat het opnieuw omgezet kan worden in H2 door middel van een electrolyser?
Als je zou willen dan kan het worden opgevangen door middel van een condensor.

- Ik las op jullie website dat de brandstofcellen een levensduur van ongeveer 8000 uur hebben. Als ik uitga dat de brandstofcel 12 uur per dag gebruikt wordt in een gebouw, zou deze elke 2 jaar vervangen moeten worden. Klopt dit? Ter vergelijking: PEM electrolysers hebben een levensduur van 20 tot 40 jaar, volgens producenten.
De levensduur klopt, maar deze zal toenemen door ontwikkeling van de technologie. Het gaat hierbij trouwens niet om de gehele brandstofcel die vervangen dient te worden. Er is onderhoud nodig (het PEM membraam bijvoorbeeld) om de brandstofcel langere tijd in goede conditie te houden.

- Levert de brandstofcel een constant vermogen zodat er direct apparatuur op aan te sluiten is, of wordt de energie eerst tijdelijk opgeslagen in een accu als tussenstap?
Een brandstofcel levert wat er gevraagd wordt. Er is altijd een buffer, tenzij het maximale gevraagd wordt. Het is dus niet zo dat de brandstofcel een vast vermogen levert. Zolang er voldoende waterstof en zuurstof aanwezig zijn (buffer) kan de brandstofcel een variabele energiebehoefte leveren tot een maximaal vermogen.

- Zijn de PEM branstofcellen van Nedstack ook als electrolyser te gebruiken?
Nee, membraam, electrodes en opbouw zijn anders. De brandstofcellen van Nedstack zijn specifiek ontworpen om een zo hoog mogelijk rendement te leveren.

Een fuel cell stack. Hoe is deze precies opgebouwd? Gaat het kanaal er zigzaggend doorheen?
Ja, het plaatje wat je liet zien op je website[46] *was juist.*

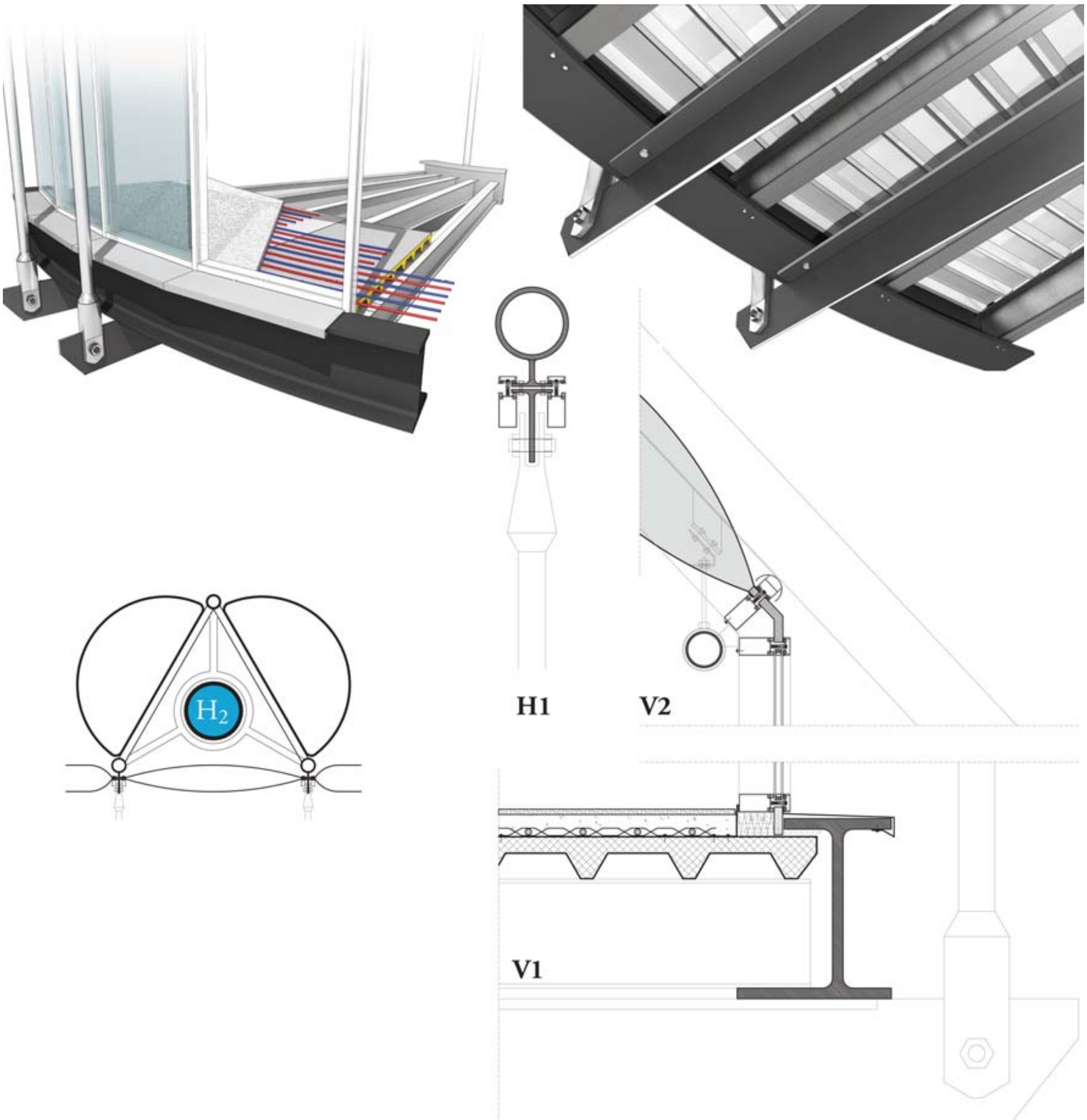
- Kent u bedrijven in Nederland die (grote) electrolysers leveren?
Nee, hier kan ik zo geen voorbeelden van noemen.

Opmerkingen schema: Wat mogelijk is, is dat de zonne- en windenergie in de energievraag voorzien. Zodra er meer gevraagd wordt, wordt er overgegaan op de brandstofcel. In de avond is wellicht de windturbine wel alleen voldoende.

Goede Tip! Ook toegepast (zie figuur 68 & 99).

[46] http://www.flyh2.com/Portals/0/images/content/disassembled-stack-mini.jpg

Appendix D - Final Design - Pavilion

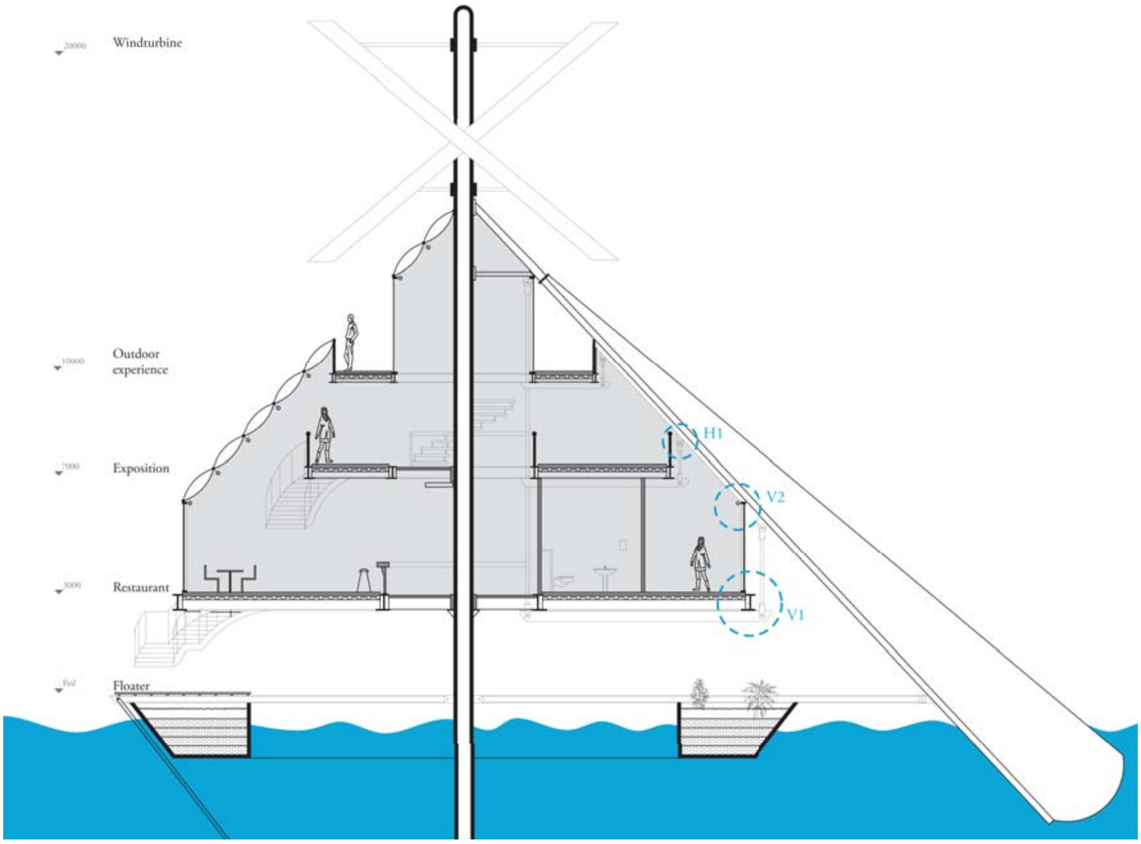


Detailing

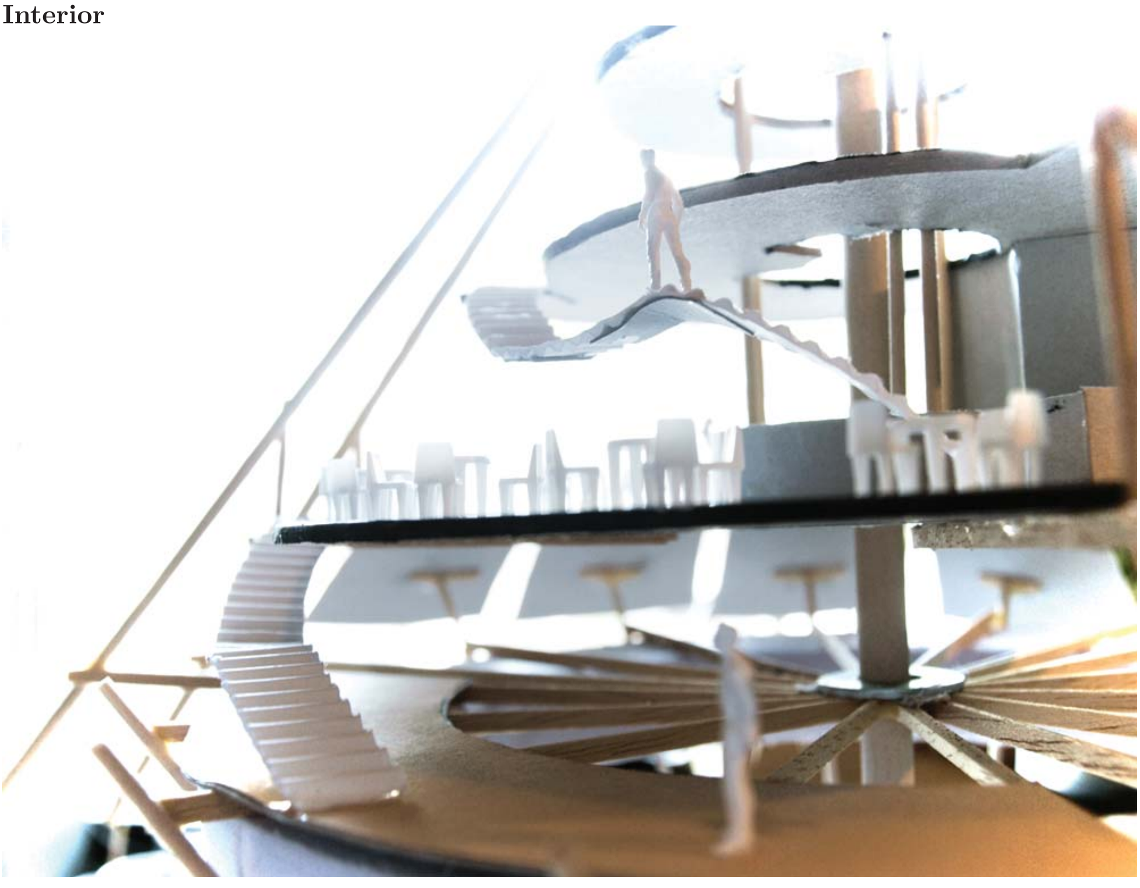
In the final design all parts are clearly to distinguish. There is a wind turbine, solar panels, storage tanks, a floater and a building.

The same principle is applied in the detailing. People can clearly see how the building is constructed, because most of the construction parts are visible, so their function becomes clear.

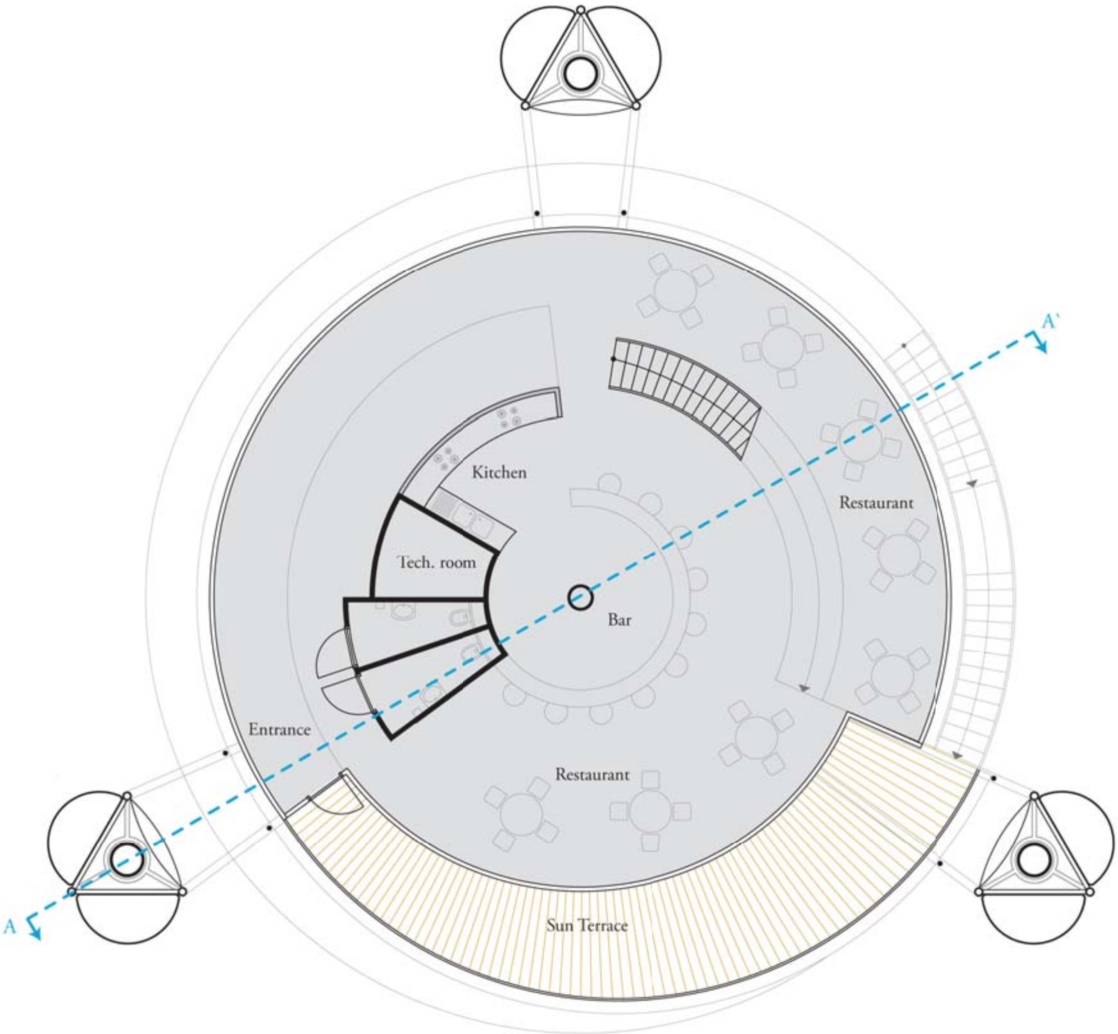
Section



Interior



Section



Routing and programme

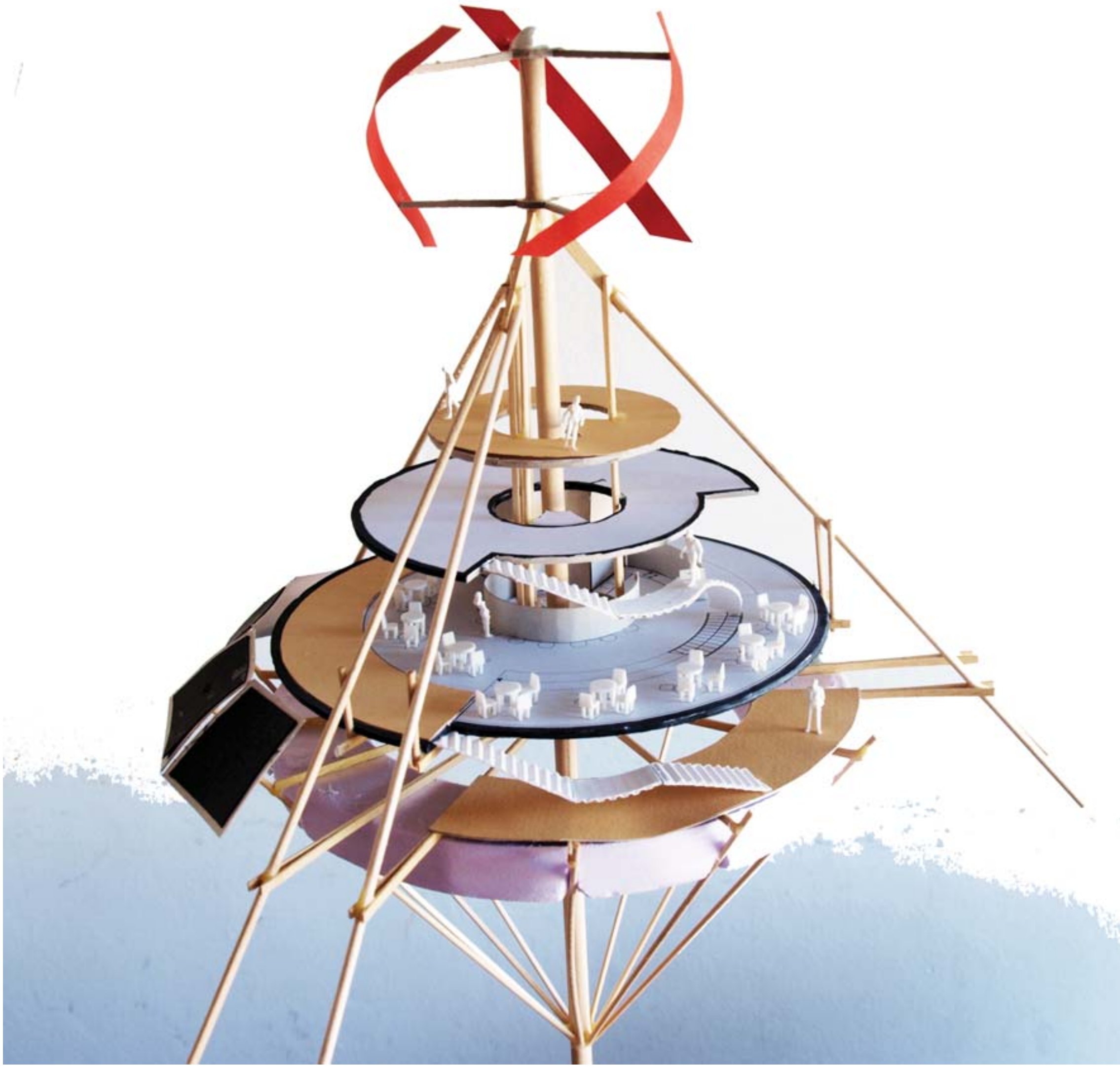
After arriving by boat (also hydrogen powered), you can walk up the outdoor stairs, followed by the sun terrace that leads you to the entrance.

Walking on, you see the kitchen, where pancakes are baked on hydrogen.You can sit around to bar, looking up to the rotating wind turbine on top of the building, or sit in the restaurant.

Walking up the stairs through the restaurant, you will reach the exposition floor, where an energy and sustainability exposition is situated.

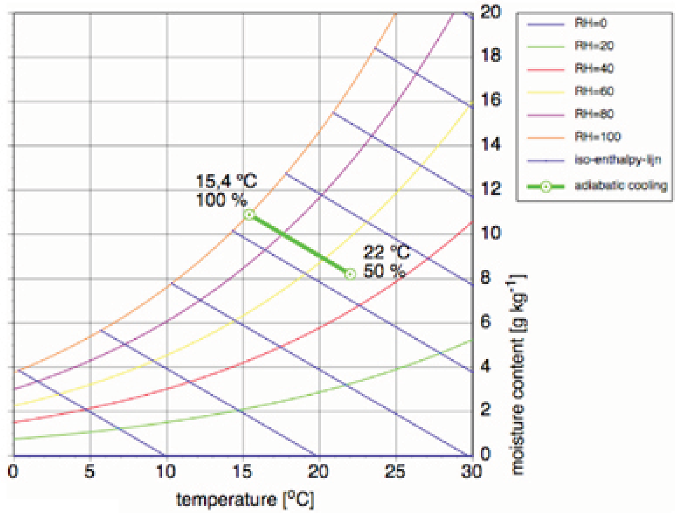
An option is to enter the outdoor top floor, and have a great 360 view over Amsterdam, the IJ-river and the Buiksloterham area, with the turbine wings above your head.

Model

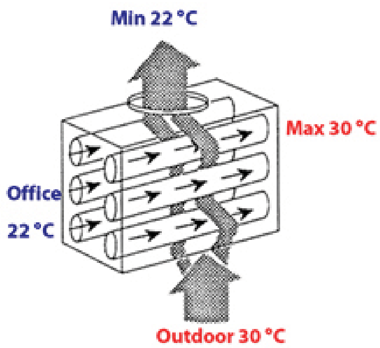


Appendix E - Adiabatic Cooling - Heat exchanger Msc1

De werking is gebaseerd op de verdamping van water. Bij de verdamping van water koelt de lucht af. In feite is het een energieoverdracht van temperatuur naar een hoger vochtgehalte. De energie van de temperatuur gaat dus zitten in een hoger vochtgehalte, en de temperatuur van de lucht daalt. De onderstaande grafiek geeft dit grafisch weer.

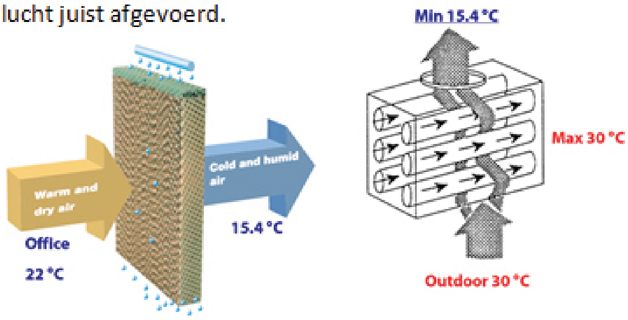


De onderstaande afbeelding laat een warmtewisselaar zien die een rendement van 100% levert. De lucht van buiten wordt volledig afgekoeld tot 22 graden, en de afgevoerde binnenlucht warmt op tot de buitentemperatuur. Dit is niet realistisch, maar dit is bedoeld om het principe te verduidelijken.

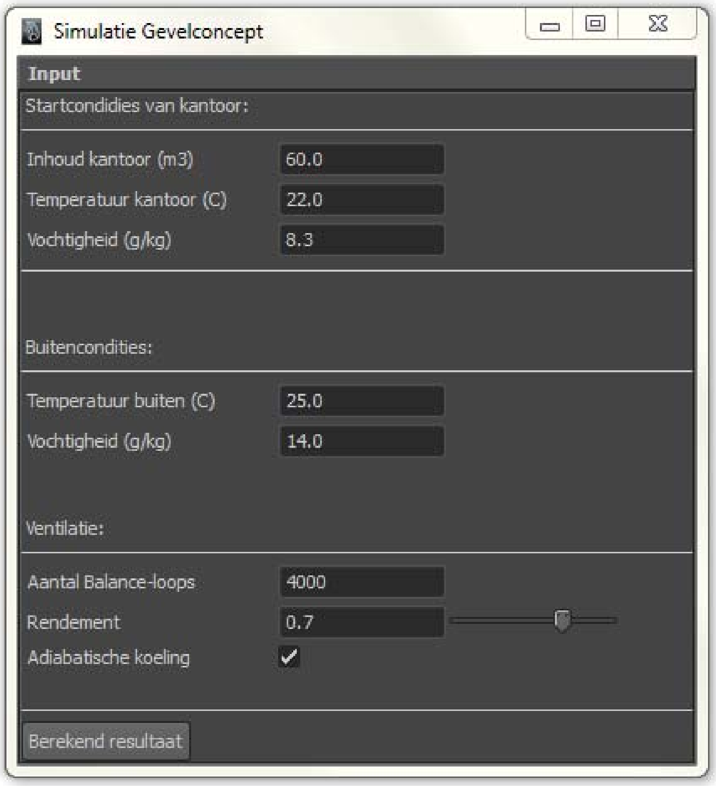


Indien we eerste de afgevoerde lucht bevochtigen, waardoor de temperatuur afneemt, en het daarna door de warmtewisselaar gestuurd wordt, zal met eenzelfde rendement van 100%, een lagere inblaastemperatuur worden verkregen. De deltaT is vergroot. Het rendement van het gehele systeem wordt nu 158%. Het systeem koelt.

Het systeem zou beter moeten presteren dan rechtstreekse bevochtiging van de ingeblazen lucht, omdat hierbij de vochtigheid in een vertrek veel sneller stijgt. In het onderstaande systeem wordt de bevochtigde lucht juist afgevoerd.



Computer simulation adiabatic ventilation



Measurement

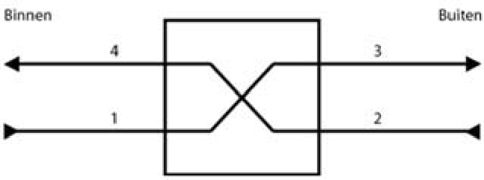
	Temperatuur (˚C)	Relatieve luchtvochtigheid (%)
Binnen (1)	17,0	34,5
Buiten (2)	36,9	14,8

	Temperatuur (˚C)	Relatieve luchtvochtigheid (%)
Na bevochtiging, voor WW	17,6	100
Inblaas (binnen) (4)	18,2	43,9
Uitblaas (buiten) (3)	21,1	42,9

Temperatuur verschillen (ΔT):
$\Delta T_{1\text{-}2} = 19{,}9$ ˚C
$\Delta T_{2\text{-}4} = 18{,}7$ ˚C

Rendementen (R):
Rendement $= \dfrac{T_2 - T_4}{T_2 - T_1}$

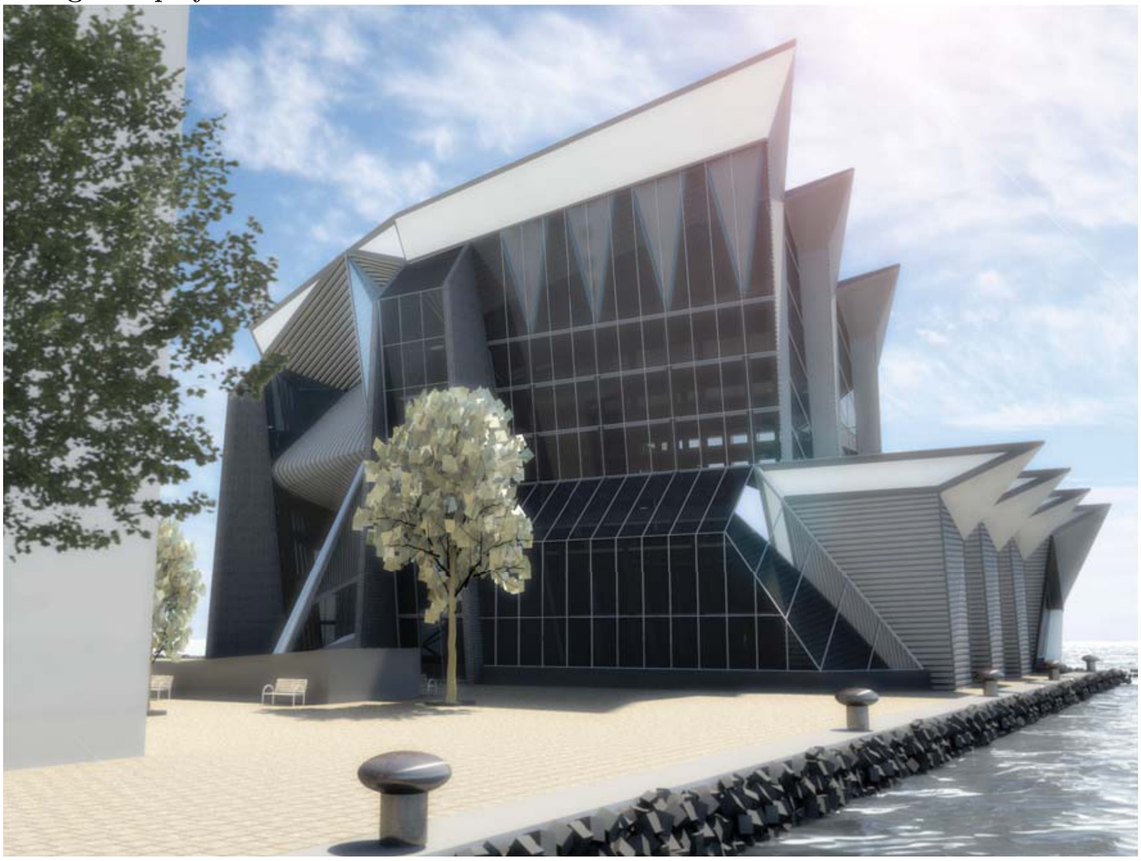
$R_{buiten\text{-}binnen} = \dfrac{36{,}9 - 18{,}2}{36{,}9 - 17{,}0} = 93{,}9\%$



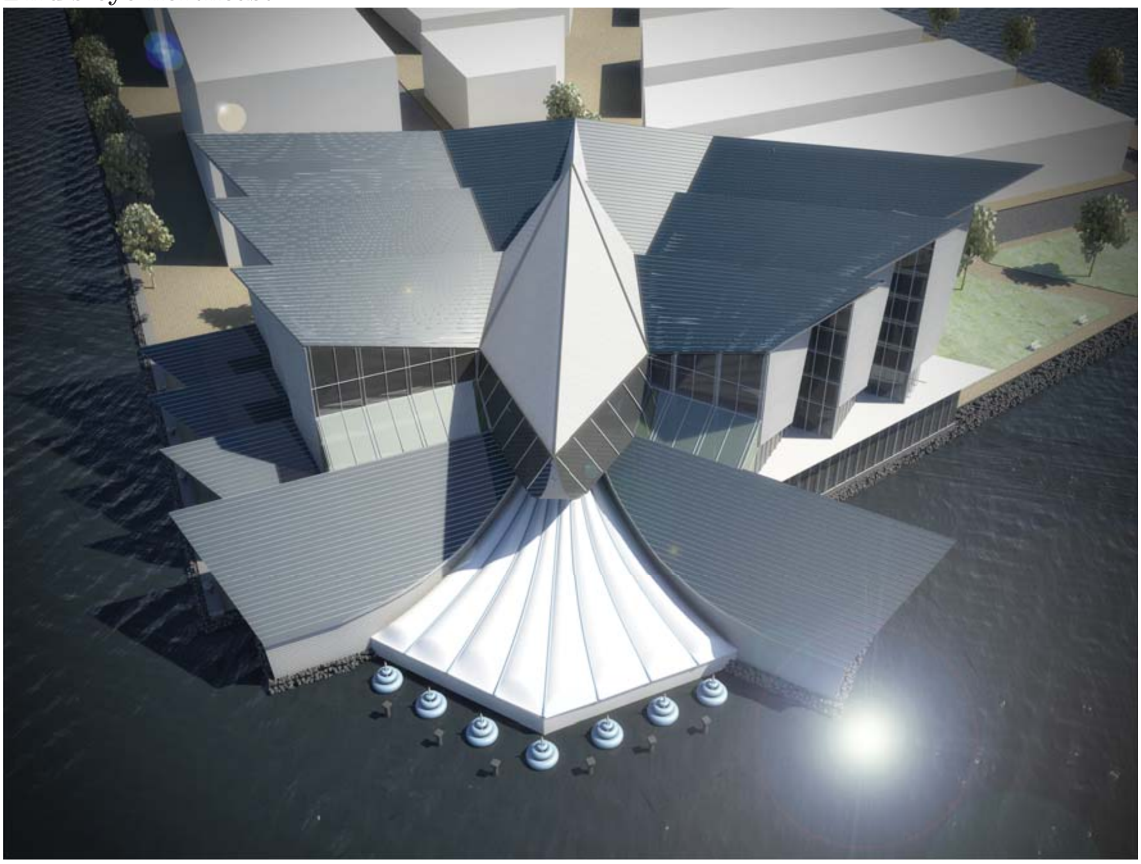
Zonder bevochtiging: 77,5%
Met bevochtiging: 93,9%

Appendix F - Impressions P5 presentation

Along the quay

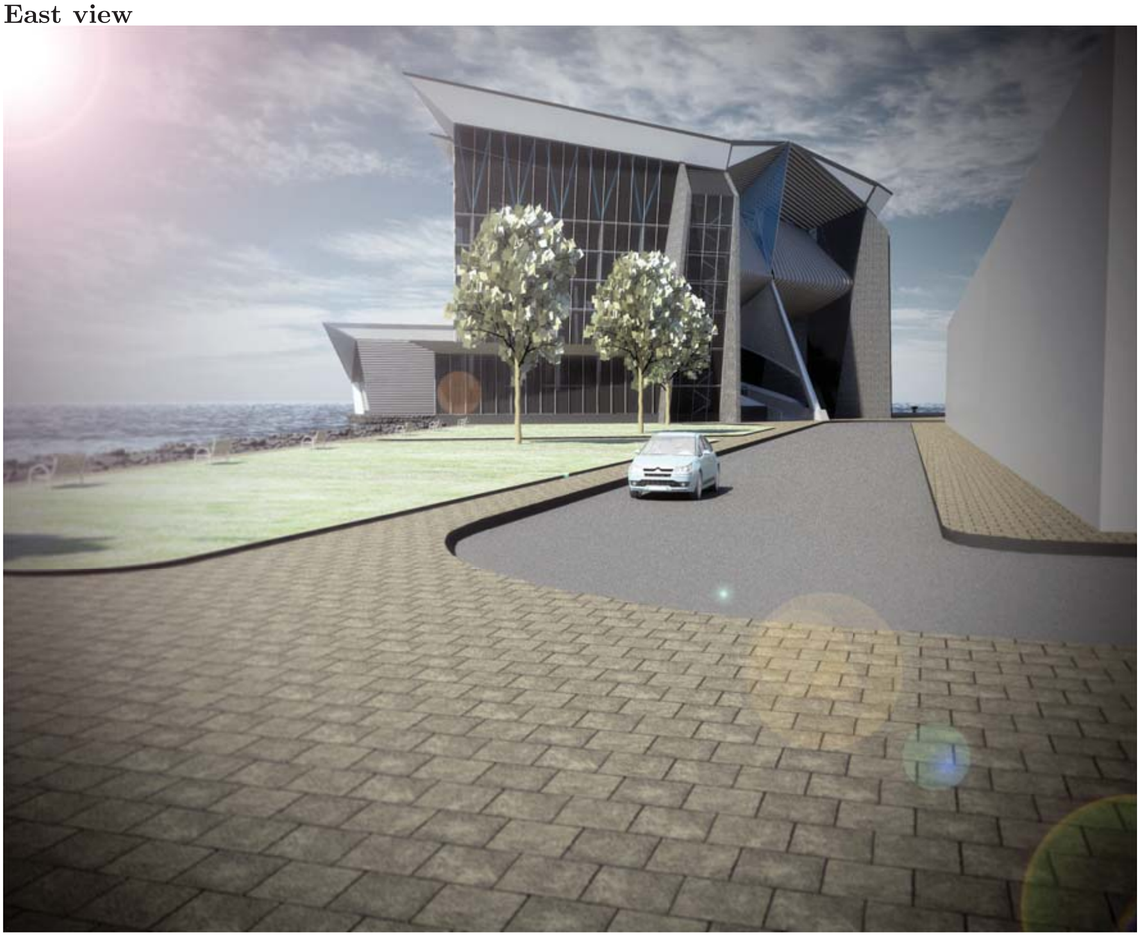


Bird's-eye northeast



Street view

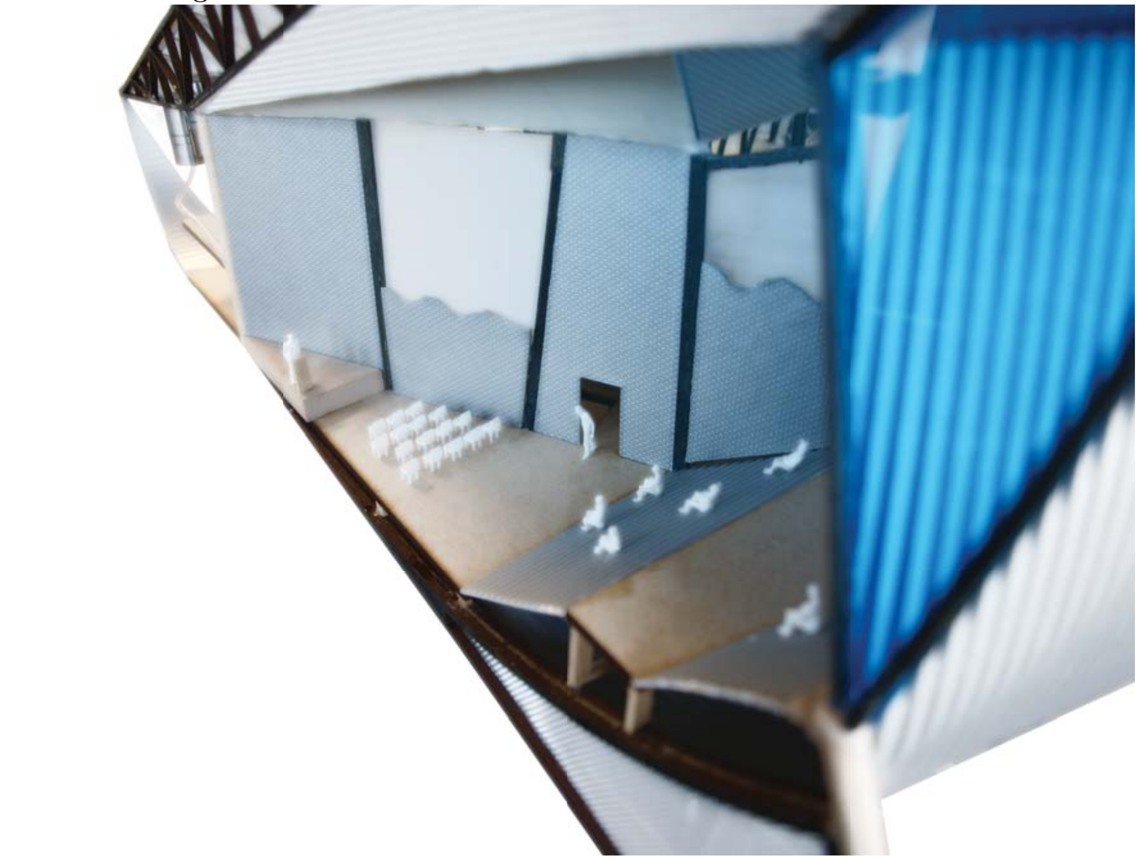
East view



Arriving by boat around the building

Arriving by boat around the building

Auditorium high



Entrance inside

Entrance outside