R E I N H A R D   P R O P H I T I U S

P2 - Research report

Wind driven architecture

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Preface

This report is written for the master track Architectural Engineering at the Tu Delft. This report is the start for an architectural design which has to be made in the harbor area of Scheveningen. There are two parts in this report. The first one is a literature study of how to design architecture with wind. The second part consist of a study of rotating Architecture. The reason to do this study is due to the multi directional behavior of wind in Scheveningen. This reason will be explained in the report. Both parts will be supported with analyze from build architecture and example calculations. The gained knowledge will be the under layer for the design in Msc4.

I hope that you will enjoy reading this report.

Reinhard Prophitius, 2012, Delft

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Introduction

Fascination

'My fascination is to use natural resources in a sustainable way.'

In this broad fascination there are two words that need further explanation. First there is the question which resources are natural. With the natural resources I mean the sustainable sources sun, earth, wind, water. Within this field all kind of subdivisions are included like for instance pressure provided by wind or water.

The second is the question what a sustainable way is. Nowadays sustainability is a hype. Lot of things don't deserve to be called sustainable but it happen. Durable and sustainable are both used under the name of sustainability without explanation. Something sustainable doesn't have to be durable. In this way sustainable isn't sustainable for nature.

The most authoritative definition is the definition formed by the UN in their report 'our common future'. (Brundtland 1987) This report described how we can create a sustainable society in this world. The definition is:

> 'Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.'

This definition contains two important concept. The first is the concept of needs, especial the needs of the most poor world inhabitants should be given top priority. The constant growing world population has to able to fulfill their needs. The second is the limitation of the environmental ability's to fulfill this for future generations.

Seen this definition we don't have to forget the most common and dangerous misconception which is perfectly worded by A.A. Bartlett: (Bartlett 1994)

> 'We see that sustainability often is uses to describe a lot of different activities which are ecological valuable but has nothing to do with sustainability.'

Design input

In this semester we have to make a design in the harbor area of Scheveningen. This design location has a great impact on the design and also on how the natural sources are present.

Of all natural sources wind is the most prominent natural source available. In the chapter *general knowledge* the characteristics of the wind in Scheveningen will be explained further. In the design the use of wind will be the leading focus point.

Relevance

In the explanation of the fascination the importance of building in a sustainable way is already explained. One of the skills of future architects also is to be able to design in a sustainable way. In 2020 the new buildings have to be energy neutral. To acquire this using the local available sources to generate and diminish energy demand will be a useful skill.

Figure 1: Research sustainable area's Europe

Looking at the research of AMO a great opportunity of green energy production in Europe is wind energy. (OMA No date) Especially the east coast of the North Sea is suitable. The whole coast of the Netherlands is laying here and the location of this design is right at this sea side.

Beside energy generation there is another feature of wind where we use wind for. Ventilation is of growing importance cause we bring more polluting devises in our buildings and the openings for natural ventilation are diminishing for creating better isolation. This two features have resulted in a large ventilation marked with large mechanisms to regulate ventilation. This is a very expensive and non-sustainable progression in building sciences. Beside this we see that older buildings have problems with good ventilation. The national government have written out a regulation of improving ventilation of schools cause the bad ventilation was degrading the learning of the scholars.

Research question

> *'How can we use the natural source wind in the build environment in a sustainable way?'*

Part A - Wind

General knowledge

Summary

There are a few parameters if it comes to designing with wind. First of all the two properties of the wind itself. Its direction and its velocity. These are given facts. By shaping objects this can be tuned or played with. The second parameter is the location where the wind is flowing. The roughness of the terrain guide or block the wind. How rougher the terrain is how more difficult the use of wind become. For the artifact the same parameters are present. Due to positioning and geometry the wind can be guided and used or blocked and ignored.

Location factors

Wind is no more than moving air particles. They travel from a high pressure area to a low pressure area. This areas are created by the combination of the sun and the rotation of the earth around the sun. Under a specific velocity the wind is also uncompressible which means that the amount of particles per volume can't alter. The particles will be moving from a high pressure to a low pressure area for creating an equilibrium. The higher the pressure area is the higher the wind velocity becomes. (Ghiaus 2005)

Wind direction

If we look at the wind data of The Hague (Scheveningen is part of The Hague) we can create a wind rose. The wind rose of The Hague let us see that the wind most of the time is coming from south to west. This means that most of the time wind is coming from sea where it encounter almost no disturbances.

Wind velocity

The KNMI site state that the average of Scheveningen is slightly more 7m/s. This value is relative high. This is an average of almost no wind to more than 10 m/s.

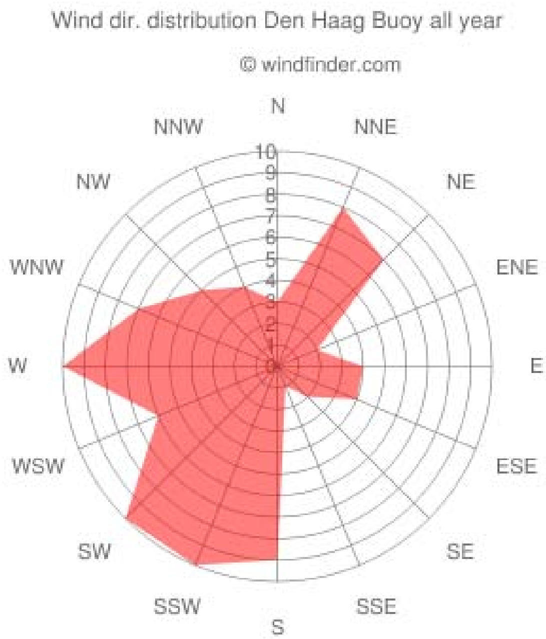

Figure 2: Wind rose the Hague measured near Scheveningen (e.g. 2011)

> The combination of these two factors are the main reason to make wind mill parks in sea and at the seashore. Here there is not much geometry to disturb the wind flow. On land there is way too much geometry which create hugh area of turbulence. There have to made a remark here. In turbine parks on sea the windmill in front of another will create such a disturbance in the airflow that the efficiency of the second mill will drop with more than 34 percent. In this light we can see that a wind park is way less profitable than one good positioned windmill. (e.g. 2011)

Beside energy production is wind also a refreshing source. Available wind can be used for natural ventilation. In urban areas the disturbance is so much that ventilating a building in a complete natural way is very difficult. There where the velocity is high enough natural ventilation is possible. (Ghiaus 2005).

Designing parameters

To design with wind there are two mean topics which are leading. The wind behavior and the shaping of the surrounding. This two topics can both be divided in two parameters. The first in the *velocity* and the *direction* and the second in *geometry and positioning* and *terrain roughness.*

Wind velocity and wind direction

It is obvious that with a changing wind velocity the parameters for designing are also changing. Changing velocity's generate changing wind loads and changing velocity's also change. This differences are created by different pressure differences as described in the beginning of this chapter.
If we include a changing direction of the wind the difficulty of designing with wind will become even more difficult. Especially if we know that by increasing height wind velocity and direction can differs very much. Sometimes even 180 degree. This behavior of wind has a great impact on the wind load on the building and the negative turbulences that it creates.
By shaping the building to control the direction and velocity of the wind around and through the building a great benefit can be obtained in structural, building physical and economical way. How to do this is described in the chapter Aerodynamics. Another precondition for analyzing and designing this benefits is the terrain roughness.

Terrain roughness

The biggest player in predicting the behavior of wind is the terrain roughness. In a complete empty space the wind shall be travel homogenously from the high to the low pressure area but when it meets obstacles the direction and velocity will alter.
If wind for example move through mountains the gabs between mountains will force the wind with a higher velocity through this gab and the wind that hit the mountains will be deflected over and around the mountain.
This deflected wind will create suction and turbulence on the lee side of the mountain.

Figure 3: Wind flow over Mountains

Another example is a tree. Wind that hit to a tree will be partly deflected from the tree and partly travel through the branches and leaves. The second part will be deflected so much that there will be lot of turbulences created at the other side of the tree. Cause this happens there is no suction area at the this side generated by the deflected wind. This is the reason that vegetation is a very good solution for creating wind protection in a windy area. (Bussel van 2008)
With a combination of these two examples we can describe a build environment. A lot of closed objects and perforated objects deflecting the wind creating suction and windy areas and diminish or increase the wind velocity in changing directions. Due to this feature the geometry and positioning of a buildings is very important.

Geometry and positioning

Like described in the paragraph before the build environment have a great impact on the wind behavior. Looking in the picture beside we can see the difference of positioning the geometry blocking or guiding the wind.
In the picture above there will be large suction areas created where the wind load diverse a lot in direction and force on the building façade which require a large bearing structure. If the same geometry is rotated the suction areas and there impacts change a lot. This shaping and positioning works in 3d which means in every directions horizontal, vertical and everything in between.

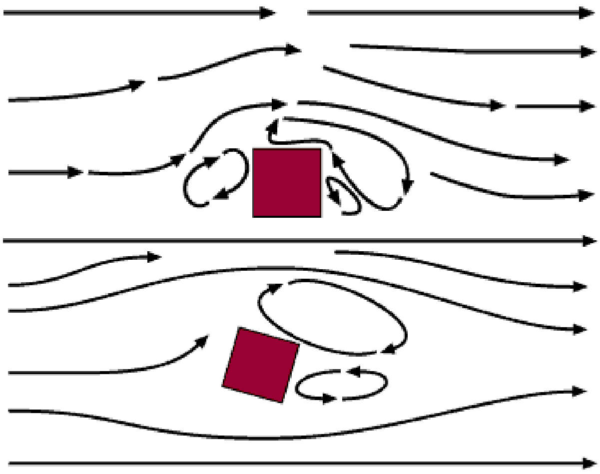

Figure 4: Consequences for wind flow in particular placing buildings.

Relation to Scheveningen

As seen in the wind rose of The Hague (figure 2) the behavior of the wind is multidirectional. If we look at the wind roses for every month in Appendix 1 we can see that the multi directionality is every month. The main direction is the direction from south to west.

> There has to be made a remark. Cause the wind rose is made of data from a buoy on sea, the direction of the wind align the shore will be bended to a south west wind a bit at beach level. The reason is the roughness of our dikes which is a straight barrier for the wind. This will bend the wind along and over the dikes.

Besides the multi directionality the wind velocity is also very high. Especially in some months. An average of 7 m/s means that this location is one of the windiest places in Europe.
The combination of the average wind velocity and the average wind direction from see makes Scheveningen a perfect spot to gain maximal profit out of the wind.

Energy production

To generate energy out of wind with a wind incorporated turbines we first need to know the behavior of the different turbines. If we incorporate the behavior of wind described in the previous chapter we can make some statements of the possibilities of generating energy with turbine incorporated turbines on a particular location.

Turbines

There are two different turbine types. The horizontal axed wind turbine and the vertical axed wind turbine. In short the HAWT and the VAWT. (See picture 5) The difference is the way the axes is placed in comparison to the wind direction. By the HAWT the axes is placed aligned to the wind direction and by the VAHT perpendicular. (Think about an ancient watermill as a VAHT). Most of the time the first one (HAWT) is used because it can translate the wind into rotating energy more effectively. If we look at the VAHT it isn't use much in wind farms cause the rotors are too close to the ground to generate the amount of energy the HAWT does. (Bussel van 2008)

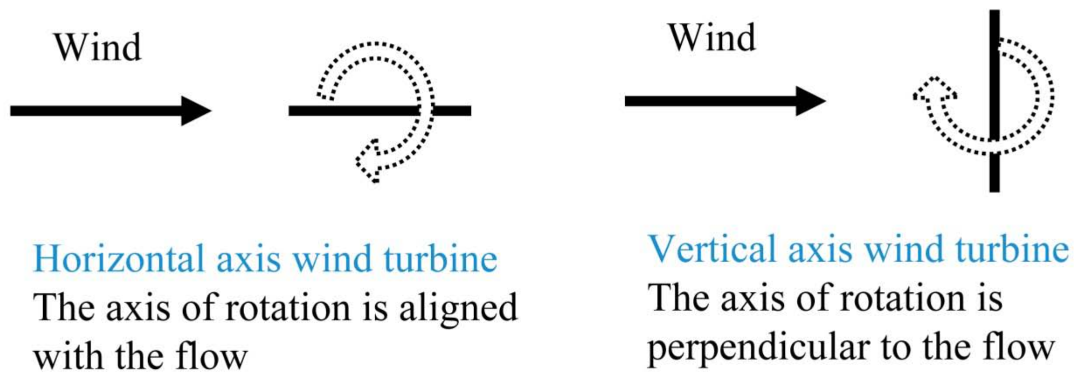

Figure 5: Difference between VAWT and HAWT

There are however advantages of a VAHT.
- The generator, gearbox etc. may be placed on the ground and a tower may not be needed for the machine.
- There is no need for a yaw mechanism to turn the rotor against the wind.

The disadvantage of a VAHT are:
- Wind speeds are very low close to ground level, where the lower part of the rotor is placed.
- The overall efficiency of the vertical axis machines is much lower.
- The machine is not self-starting.

When it comes to a building with a incorporated turbine, the most important factor for choosing the optimal turbine type is knowing how the wind is flowing in an specific area or around a specific building.

Geometry

The most well-known windmills are those on a pole. Big turbine parks on land or sea state that they generate large quantities of energy. There are however also turbines incorporated in a building. In this way the building itself is a part of the windmill.
By incorporate a wind turbine in a building the geometry become very important. This create opportunities and threats for the energy generation. Lot of people will state that it is better and more effective to place a turbine in open space on a pole but this isn't through. If a building can catch a non-disturbed wind and guide a large area of this wind through a gab with wind turbines the wind velocity will increase before encounter the turbine. The shaping becomes very important. In this way the same design tool become the opportunity and the treat.

If we want to make calculations of the wind energy production we need to know more about wind flows and its behavior of wind on a geometry. To gather knowledge to make a good calculation we need to study in the field of the aerodynamics.

Aerodynamics

Before learning about the wind flows around buildings it is important to look at the wind behavior in the build environment. Due to the wind speeds the wind around the building is almost always incompressible. This means the wind speeds will not be exceed 0,3 Mach from where the wind will be show compressible behavior. Due to this fact the continuity equation for steady fluid flow is a basic rule. In this rule the air density is always the same and if the area doubles at one side the wind speed halve at the other side.

$\boldsymbol{\rho_1 * A_1 * v_1 = \rho_2 * A_2 * v_2}$

$\rho_1 = \rho_2$ = air density (kg/m^3)
$A_1 = A_2$ = Area (m^2)
$v_1 = v_2$ = wind velocity (m/s)

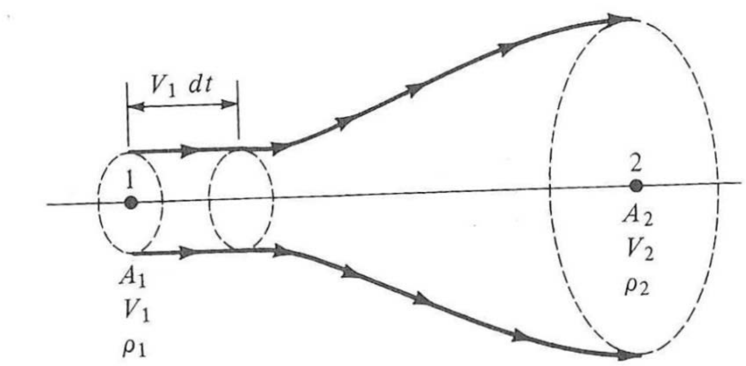

Figure 6: The continuity equation

Knowing this we need to state that every object generates friction on a surface. This area of friction is called the boundary layer. The wind speed on the surface (a) is 0 and the wind speed on the other side of the boundary layer (b) is the average wind speed. The boundary layer of a aero plane wing is showed in the picture below. (Anderson 2005)

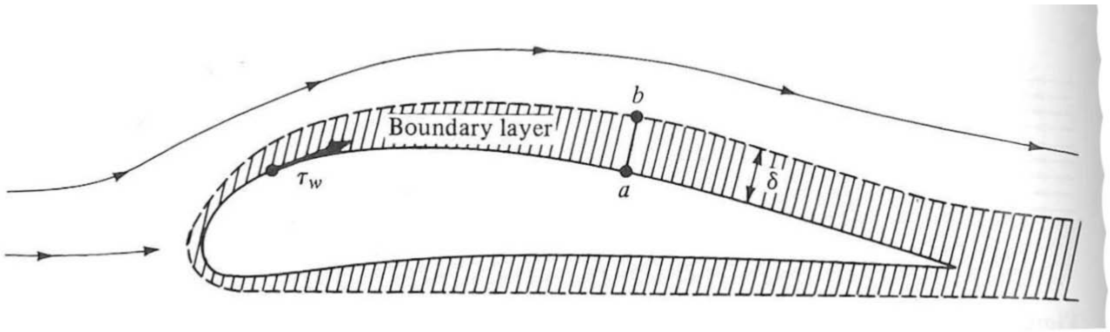

Figure7: Boundary layer around a shape

The layer isn't on real scale. Cause the angle of attack is perpendicular to the wing shape the boundary layer is just a few mm thick. This is direct the most important factor of the boundary layer. Thickness. A geometry shaped for wind guidance can create a huge boundary area if the angle of attack is high. The other factors are a long surface line and the wind velocity. If they increase the thickness of the boundary area will increase. The thickness of the boundary layer can be calculated with the following formula:

$$\delta = 5{,}2 * x / \sqrt{(Re_x)}$$

δ = Boundary layer thickness (mm)
x = Distance over shape (mm)
Re_x = Reynolds number

in this formula Re is the Reynolds number. This number can be calculated with the following formula:

$$Rex = (\rho * v * x) / \mu$$

ρ = air density (kg/m^3)
v = wind velocity (m/s)
x = Distance over shape (mm)
μ = absolute viscosity coefficient (Pa s)

In this formula μ is the absolute viscosity coefficient and ρ and v are the air density and the wind speed above the boundary layer. (in the laminar air flow)
If this boundary layer becomes thicker the shear forces on the surface will increase. This can lead to flow separation. This wind separation is a negative effect for the overall wind flow. This separation will lead to turbulent air flow which not only is the noise that wind creates on a surface but also not useful for generating energy out of wind.
The factors that lead to a quick separation from the geometric body are, a high wind velocity, a long surface, a high angle of attack and the geometric body itself. In the following picture some wind flows around standard geometric bodies are presented.

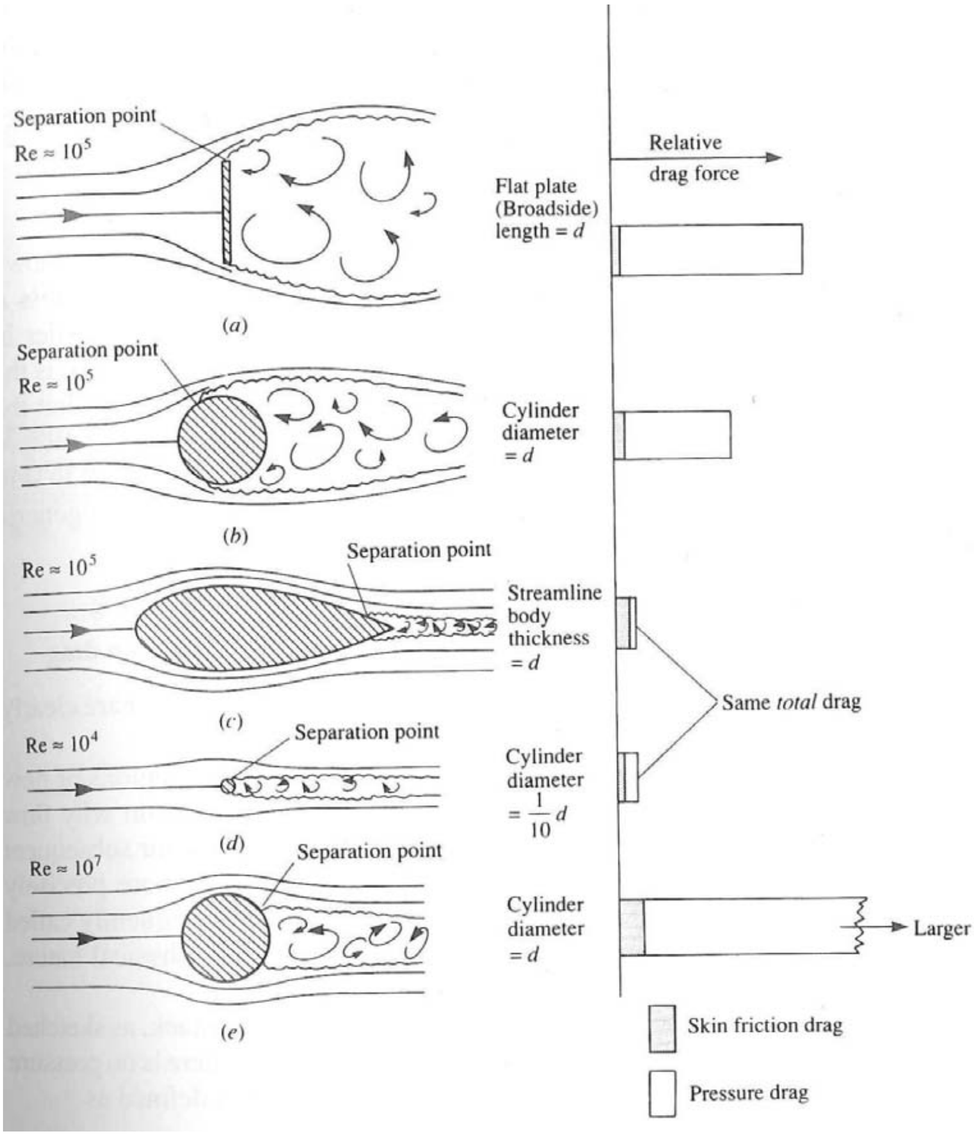

Figure8: Separation points of different shapes

In this picture we can see the importance of the wind speed. If the wind speed becomes higher the Reynolds number becomes lower. A lower Reynolds number means a higher drag force which means a quicker point of separation. Also the shape is of great importance. If it follows the flow of the wind the separation point will be laying further on the surface.

Then there is the behavior of the wind in the boundary layer itself. There the wind flow can be laminar or turbulent. This has a great impact on the point wind seperation and the boundary layer thickness. This is although too difficult for this report. The conclusion which have to be mentioned is that although a turbulent airflow in the boundary layer will generate a thicker boundary layer, it also prevent the wind longer to seperate from the surface. This seems to contradict with the statement that a thicker boundary layer will lead to a quicker wind separation. This isn't true. It is due to the behavior of a turbulent and a laminar flow which lead to the difference. If we only look to the turbulent flow the earlier statement is again through. A thicker boundary layer increase the change of separation. See picture on the next page. (Anderson 2005)

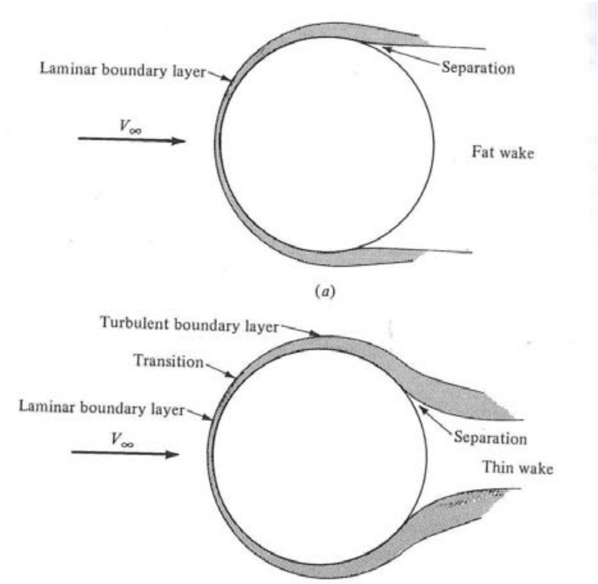

Figure9: Separation point by laminar (above) or turbulent (below) boundary layer

With this knowledge a designer is possible to understand the wind flow over a geometry and design a geometry for maximal guiding wind without creating large areas of turbulence. If we now place a turbine in a laminar air flow the profit will be maximal. The formula to calculate the amount of energy is:

$$P = 1/2\rho * A * v^3$$

P = power (W)
ρ = Air density (kg/m^3)
A = Swept area (m2)
v = wind velocity (m/s

In this formula we can see the importance of a high wind velocity. If we for example double the radius of the swept area of the windmill the A will be 2^2 is 4 times higher which lead to a 4 times higher energy production. If we somehow doubles the wind velocity it will lead to a $2^3 = 8$ times higher energy production. This doubling of the wind velocity can be done with a shape of the terrain or with a well created / designed shape.

> A remark has to be made for the actual energy production of a wind turbine. The law of Betz learns us that wind turbines can attract (16/27) of the energy out of the wind.

Besides this the wind velocity also increase in height on a curtain terrain with its own roughness. This new wind velocity can be calculated with the following formula:

$$v_h = v_{10} * \log(h/z) / \log(10/z)$$

v_h = wind velocity on specific height (m/s)
h = Height (m)
v_{10} = wind velocity on a height of 10 meter (m/s)
z = Roughness of the terrain

Example

How much swept area of a wind turbine is necessary to generate the amount of energy needed for 10000 m² hotel?

Before calculating the amount needed we need to know the site, the form of the building and the need of 1 m² hotel. Let's put our example building in Scheveningen which gives us an average wind speed of 7 m/s through whole year. The building is a building with a gab wherein the HAWT wind turbine is placed. The ratio of the area of wind the building grab and area of the gab is 2 to 1. 1 m² hotel needs 200 kWh every year.

If we place the building to the most favorable wind direction we can extract energy out of the wind for an estimated 4 months. (the rest of the time the wind is blowing out of another direction. Another effect is that the average wind speed will increase to 9 m/s for this specific wind direction. (for estimation the wind roses of appendix 1 are used.)

Due to the reduction of area of wind flow the wind speed will double. So the wind speed become 18 m/s (65 km/h).
The needed energy is 200 * 10000 = 2.000.000 kWh is a year. This equals a production of 230kW every hour.

Formula

$P = 1/2\rho * A * v^3$

P = power (W)	= 230.000 W
ρ = Rho (kg/m³)	= 1,29 kg/m³
A = Swept area (m2)	
v = wind velocity (m/s)	= 18

In this case we need (230.000 / ((16/27) * 1/2 * 1,29 * 18³) **104 m²** swept area. Cause the production needs to be done in one third of a year the production and thereby the swept area has to be tippled. 312 m². This equals a wind turbine with a diameter of 20 meter

If we now look at a rotating building which track the wind direction so it will always generate the maximal energy we need other need (230.000 / ((16/27) * 1/2 * 1,29 * 14³) **220 m²** swept area. This equals a wind turbine with a diameter of 17 meter.

> This is a example calculation with a big misconception in it. If the average wind velocity is taken it means for example half a year 9 m/s and half a year 5 m/s. Combined makes this an average of 7 m/s. In the formula for wind energy the wind velocity is to the third. If we now want to take the average of half a year 9^3 and 5^3 the average lays higher than 7m/s The actual theoretical wind energy will be higher so the swept area to gain this energy will be lower than calculated.

Case study ZED project

General

Architect	Group 2
Building site	London
Completion year	Not, Case study
Function	Office space, Wind generating
Characterize:	The whole building is designed to make optimal use of wind.
Sources:	(Hamer No date) (Systems 1996) (Hagen 2008)

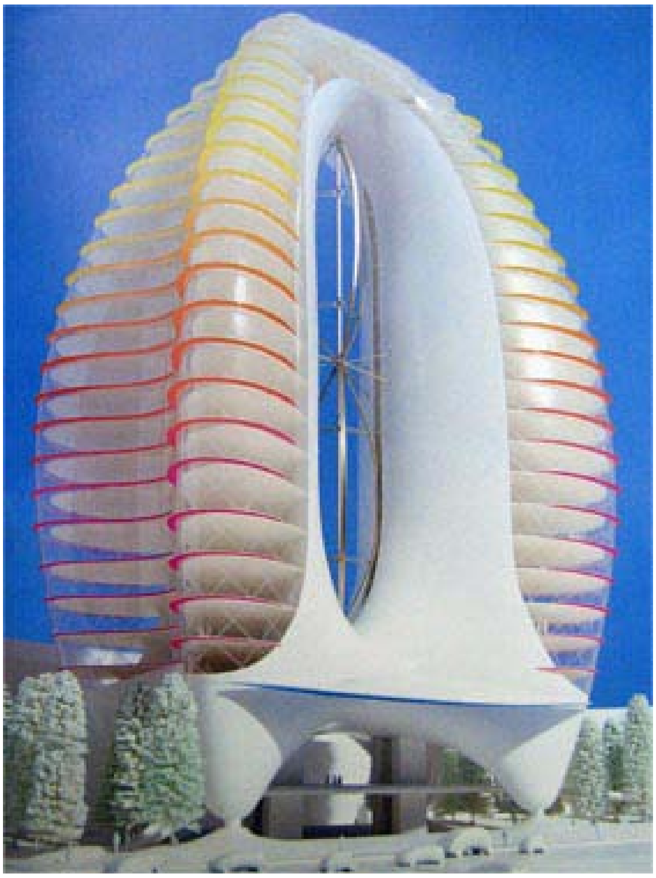

Figure 10: ZED project

Description building

The ZED project is a project in London whit the intention to design a building which generate the most amount energy as possible using a building attached turbine. Furthermore the building is also designed to have as less negative wind effects (sound and suction) on the building as possible. The only negative issue is that the project never is realized.

How is the shape formed?

The building is shaped that the wind flows on a higher level are directed through the gab in the building. In this gab a VAWT (Vertical Axed Wind Turbine). This is done cause the wind in London is multidirectional. In precious chapters you can read why this type of turbine is the best option in this case.

The building uses two boomerang like shapes not only to deflect as much wind as possible through the ventilator but also to direct the flow across the facades. At the leeside of the building the wind doesn't abruptly flow away from the building forming a great suction effect on the building but the wind flow through the turbine and across the facades are brought back to each other as much as possible before leaving the building.

Seeing the picture of the building we see also solar panels. (red shapes) attached to the building at the floor slap height. This generate not only the energy used in the building but also deflect wind from the façade itself. Due to the creation of turbulences the pressure on the façade is greatly reduced. The same principle is used in the new DUO building in Groningen. Due to this measure the windows can be opened. In figure 11 the principle of the DUO building is showed.

Wind will deflected away from the building by the lamella like addition to the floor slaps.

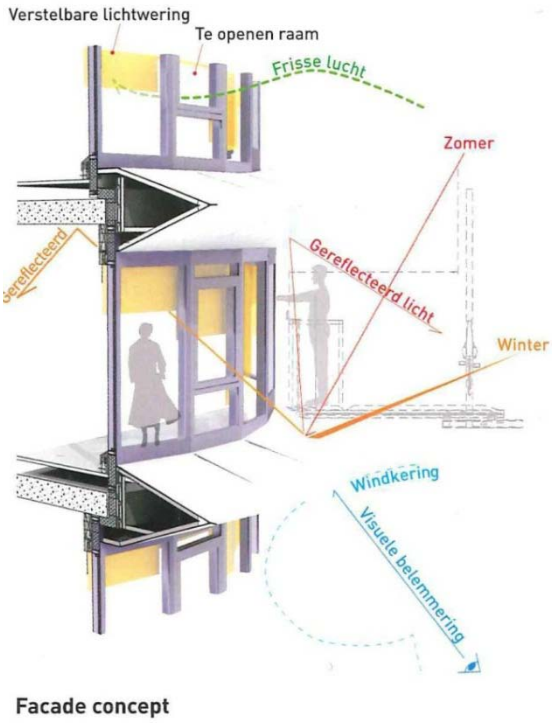

Figure 11: Concept of DUO

What is used for generating the 'perfect flow'

To make the optimal shape for the ZED project they mostly used a wind flow software program because the wind is very unpredictable on a small scale. They researched the wind flow under different wind directions and concluded that the double boomerang shape was the best shape to direct the wind under the conditions they would it. High velocity through the gab with the turbine, less acoustic and suction effect on the other facades.

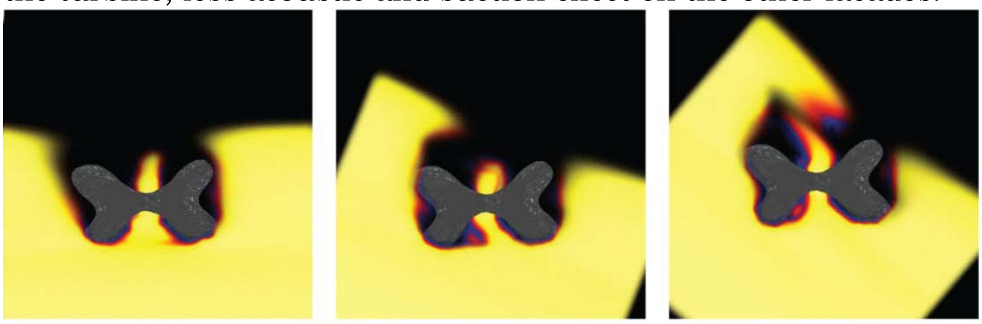

Figure 12: Shaping ZED building 0, 20 and 40 degrees

What is used to make it happen?

In the floor plan of the ZED project is seen that a lamella structure is placed with solar cells to not only generate energy but also deflect the wind of the building with the positive effect of the decreasing of wind suction on the building and less acoustic inconvenience. This was not possible to do within the gab of the turbine. Here the load and acoustic was higher and would lead to disturbance. To make sure the people on the working area didn't experience this negative effects of the turbine created gab al services were placed against this side of the building. Another positive effect of placing these functions here is that sunlight is not entering so deep into the building to reach this area.

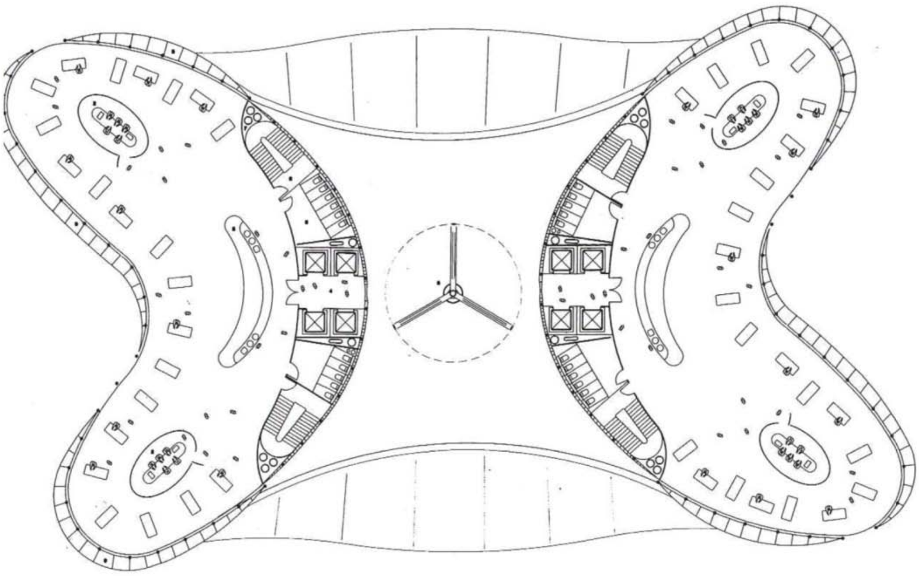

Figure 13: Floor plan ZED project

Conclusion

Due to the double boomerang shape and not one flattened façade the wind will flow across and through the building with minimizing the acoustic and structural load to the limit. Due to placing a lamella structure at the building facades the wind will deflected even more from the façade minimizing the negative effects of wind on a building. By placing all service area to the turbine side of the boomerang shape the noise and wind load of the turbine doesn't disturb the working people. This service area works as a acoustic isolation layer and structural core.

Relations to Scheveningen

When it comes to production of energy wind velocity, direction and shape of surrounding and building is important. Looking at Scheveningen the wind velocity is high and the terrain roughness most of the time is low. This means that the potential of energy production is high. The difficulty is to cope with the multi directionality of the wind.
This can be concurred by rotating turbines. However the shaping of the surrounding has also a large influence to the energy potential. This means by a building incorporated turbine that the shape also has to rotate with the wind direction. A rotating building with a incorporated turbine is here the best solution. This is also the reason for the extended research into the domain of rotating architecture in part B.
In the formula's of wind energy and aerodynamics the wind velocity isn't only an important factor it's also a leading factor. As seen in the example calculation a doubling of the wind velocity has more influence than the doubling of the swept rotation of a turbine. This means that the effort to shape a building for wind velocity increasing pays back more than enlarging.

Natural ventilation

One of the most disturbing phenomenon in the human and global world is the extreme urbanization. Was the population in the big cities were in 1950 globally 200 million people in 2000 it was already 3 billion and in 2025 the estimate 5 billion people are living in big cities. This generates lot of environmental economical social en energy problems.
Urbanization increase energy consumption and production of pollutants. The last years air-conditioning has created an energy consumption peek and due to the great poverty class 2 billion people has to use biomass as fuel which resulting in even more indoor pollution .
The solution could be natural ventilation. Even simple components of natural ventilation can result in a better indoor climate, a reduction in energy consumption and overall a better way of live.
The role of ventilation is mainly to dilute and evacuate the contaminants produced indoor (To maintain a good air quality). It also can help regulate thermal comfort by exchange heat and regulate the humidity. Thereby occupants of buildings are more tolerant than in controlled spaces.
(Ghiaus 2005)

Strategies

Wind variant induces single sided ventilation

Wind has a mean and a fluctuating component that may vary over the opening and produce a pumping effect. When $T_i > T_o$ then due to buoyancy the cold air will flow into the room at the bottom part of the opening and the hot air will leave the room in the upper part. When $T_i < T_o$ then the hot air exit and the fresh air entrance is the other way around. When $T_i = T_o$ then there will not be any exchange. From this point of view we may conclude that when the difference in temperature is higher more exchange is present.

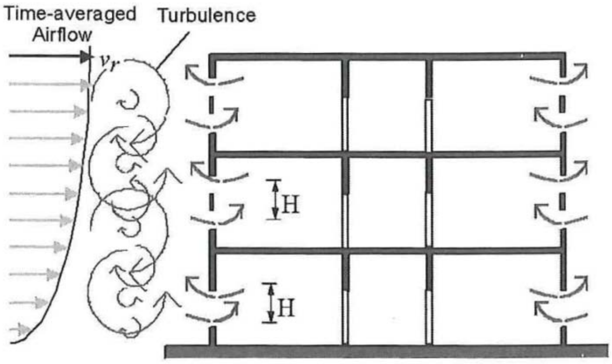

Figure 14: Concept single sided ventilation

To use this method the window has to have an area of 1/20 of the area of the floor. The window has to be 1,5 meter high in a room with a height of 2,7m. This type of ventilation does not work properly when the room has more depth than 2,5m and isn't a good solution for cooling during warm periods. (Ghiaus 2005)

The formula of the air changes per hour ACH is

$$\mathbf{ACH = (3600/V) * V_{fr}}$$

$$\mathbf{V_{fr} = 1/2 * A_w * ((c_1 * v_r^2) + (c_2 * H * \Delta T) + c_3)^{1/2}}$$

V = volume of room (m^3)
V_{fr} = flow rate (m/s)
A_w = effective area of opening window (m^2)
c1, c2 c3 = dimensionless coefficient (0.001, 0.0035, 0.01)
v_r = wind velocity (m/s)
H = height of the window opening (m)
ΔT = temperature difference (K)

From this formula we can see that the effective area of the window and the window height are the main design tools for natural ventilation with a window. The wind velocity and the temperature difference are the main constrains of nature when determine if natural ventilation with to opening windows is useful.

Wind driven cross ventilation

Cross ventilation works aligned with the wind direction. The wind will create a positive pressure at the windward side and a negative pressure at the leeward side of the building. This will lead to a ventilation flow through the building from the windward to the leeward side.

The ventilation is very dependent on the wind direction and velocity. Due to this this type of ventilation will be working well in open land sides but way less in urban areas where the wind velocity is much lower and the direction more diverse. Another negative affect of this type of ventilation is that it spread pollutants through the building. (Ghiaus 2005)

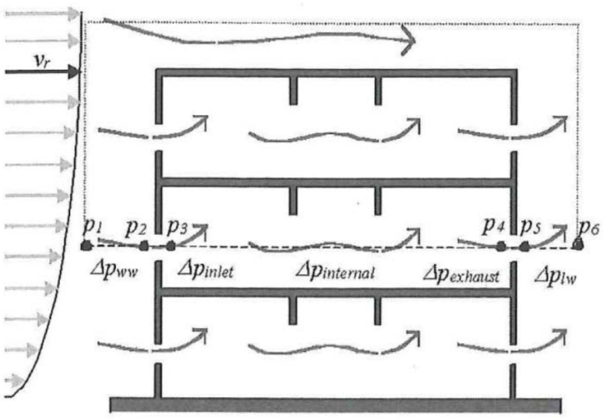

Figure 15: Concept crossing ventilation

The formula of pressure difference on both sides is:

$$\Delta \mathbf{p_w} = \mathbf{p_{ww}} - \mathbf{p_{wl}} = ((\mathbf{C_{p\text{-}ww}} - \mathbf{C_{p\text{-}lw}}) * (\rho * \mathbf{v_r}^2) / 2)$$

$C_{p\text{-}ww}$ = wind pressure coefficient wind side (mostly +0,5)
$C_{p\text{-}wl}$ = wind pressure coefficient lee side (mostly -0,5)
ρ = density of air (kg/m^3)
v_r = wind velocity (m/s)

This is only if the wind direction is in ideal direction (so perpendicular to the façade). Beside this the wind pressure coefficients are difficult to calculate precise and they will differ a lot in time.

<u>Example</u>

In an area with a wind velocity the ideal scheme will have a pressure difference of 9.6 Pa which is small relative to typical fan driven pressure differences. To generate same ventilation rates the natural ventilation system has to have a small resistance relative to a mechanical ventilation system

Buoyancy driven stack ventilation

This ventilation types relies on the difference of warm humid air and dry cold air. Warm and humid air is lighter and while indoor air is often warmer than outside it tent to leave the building through upper openings. This air is replaced by cold air entering through the lower openings.

The upper openings should be as large and as high as possible so that the natural pressure level would be as high as possible. The openings should also be placed at the low pressure, leeside, of the façade so that the wind and stack pressure working in the same direction. If the principle is used in a tall building the upper floors will have a lower pressure to drive natural wind flow than the lower floors. It has a complicated system behavior due to the unpredictability in wind force and direction. (Ghiaus 2005)

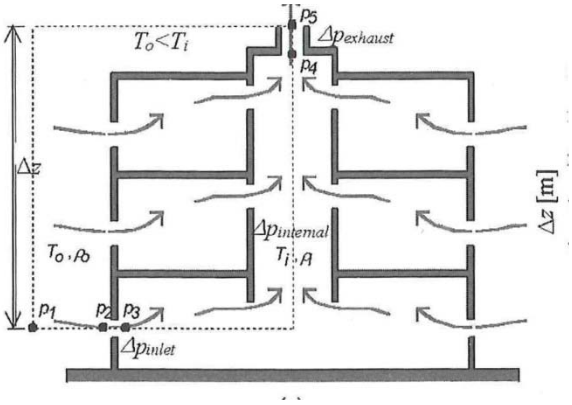

Figure 16: Concept Buoyancy driven stack ventilation

The formula of calculating the pressure difference which generate the draft in the stack is:

$$\Delta p_s = (p_o - p_i) * g * \Delta z = ((352,6/t_o) - (352,6 / T_i) * g * \Delta z)$$

p_s = stack pressure (Pa)
p_o = pressure outside (Pa)
p_i = pressure inside (Pa)
T_o = outside temperature (K)
T_i = inside temperature (K)
g = Gravitational force (kg/m^3)
Δz =height of inlet and stack outlet (m)

In this formula we see that the height of the stack is very important for the working of stack ventilation. This is the only design impact which create a greater stack pressure and by this a greater wind draft. We also see that the temperature difference has a great impact, so in summer the outside temperature will be almost the same as inside. In this case there has to be a design implementation which will generate a temperature difference to sustain the natural ventilation.

Combined Wind and buoyancy driven ventilation

To make the buoyancy driven type better the stack opening can be changed so the wind direction will always maximize the pressure induced by wind. This can be done by introducing operable louvers and rotating cowls. What always has to be considered is that the rooms on the leeside of the ventilation scheme experience the lowest driving pressure so lower ventilation rates. (Ghiaus 2005)

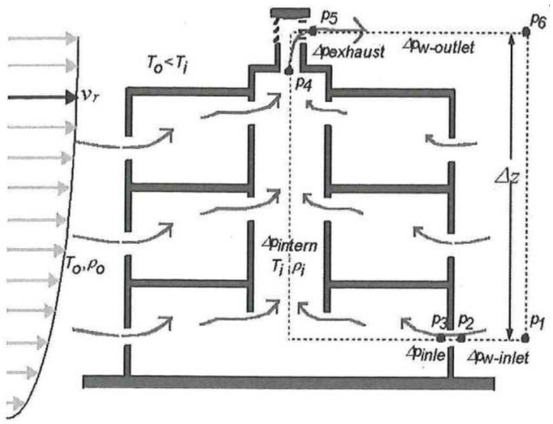

Figure 17: Concept buoyancy and wind driven ventilation

If both methods are combined also the formulas will be combined. The formula will become:

$$\Delta \mathbf{p} = ((352{,}6/to) - (352{,}6\ /\ Ti) * g * \Delta z) + ((C_{p\text{-}ww} - C_{p\text{-}lw}) * (\rho * v_r^2)\ /\ 2)$$

Δp = pressure difference (Pa)
To = outside temperature (K)
Ti = inside temperature (K)
g = Gravitational force (kg/m3)
Δz =height of inlet and stack outlet (m)
$C_{p\text{-}ww}$ = wind pressure coefficient wind side (mostly +0,5)
$C_{p\text{-}wl}$ = wind pressure coefficient lee side (mostly -0,5)
ρ = density of air (kg/m^3)
v_r = wind velocity (m/s)

The calculation is more difficult but the both strategies are helping each other to generate a greater natural ventilation when good designed. In this case especially the different sites of lee warts and wind warts side are important. Lee warts pressure differences tent to be smaller than wind warts sides. To overcome this the inlet has to be greater than the wind wart side or else the ventilation in the lee warts rooms is less. By multidirectional wind this is a great objective to overcome.

Combination of fundamental strategies

It is also possible to use more strategies together to get the best ventilation. It depends on the function, dimensions and usage of the room to choose which is best in ways of ventilation and costs. There are also differ optimal use of the strategies so one can compensate the minima of the other. (Ghiaus 2005)

In this way there has to be extra concentration to make the strategies improve each other and not disturb each other.

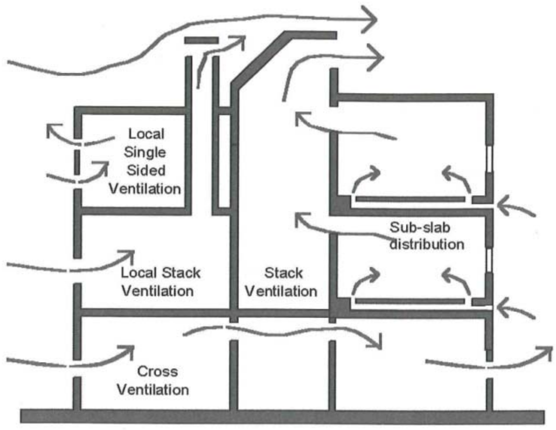

Figure 18: Conbination of fundamentals

Balanced stack ventilation

This strategy is based on middle eastern strategy. If in the inlet stack the air temperature can be maintained close to the outside air temperature and the outlet stack will be much warmer than outside, than there will be a natural ventilation flow. This principle is working very good in a climate with a single wind direction and therefore is less suitable for urban sites. (Ghiaus 2005)

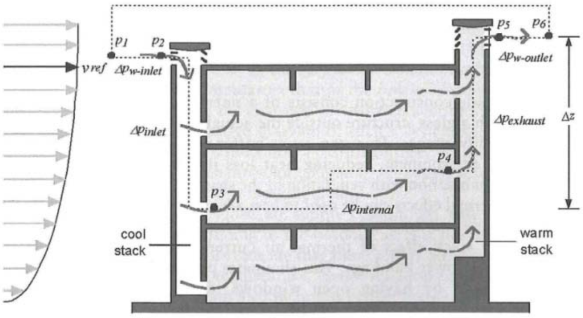

Figure 19: Concept balanced stack ventilation

Passive evaporative cooling (Adiabatic)

An improvement of the balanced stack ventilation consists in adding evaporative cooling to the supply stack. This more than doubles the bouncy pressure while at the same time provide adiabatic cooling. (Ghiaus 2005)

The formula which can be used is the same as the formula used by balanced stack ventilation:

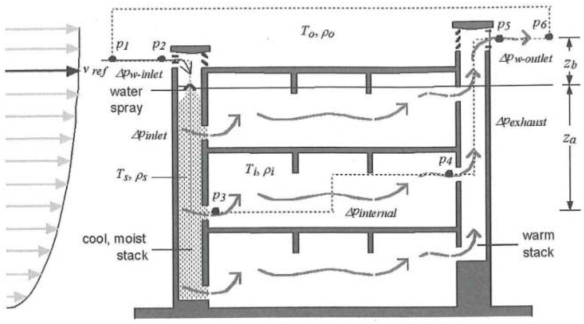

Figure 20: Concept passive evaporative cooling

$$\Delta p_s = [(\rho_o * z_b) + (\rho_s * z_a) - \rho i * (za + zb)] * g$$

Δp_s = pressure difference (Pa)
ρ_o = density of air outside (kg/m^3)
z_b = height room exhaust above moist column (m)
ρ_s = density of air moist stack (kg/m^3)
z_a = height room inlet room exhaust (m)
ρ_i = density of air inside (kg/m^3)
g = Gravitational force (kg/m3)

Example
To show how it work we will fill in this formula. We take an inside temperature of 25 degrees Celsius and a humidity of 20 per cent relative humidity. The outside temperature is 28 degree Celsius and a humidity of 60 per cent RH. With a moist stack we get a pressure difference of (((1,18 * 0) + (1,21 * 10) – (1,15 * (0 +10))) * 9,81) = 6,4 Pa.
Without evaporative cooling the z_a and z_b exchange their value so the stack pressure will be (((1,18 * 10) + (1,21 * 0) – (1,15 * (10 +0))) * 9,81) = 2,9 Pa.
In this representative example evaporative cooling more than doubles the buoyancy pressure difference or stack pressure.

Double skin façade

Double skin facades offer several advantages. It creates a buffer zone, it reduces heat loss in winter and heat gain in summer, in combination with ventilation of the space between the two facades the passive thermal effect can be used to best advantage, windows can safely be used to draw natural ventilation, the stack effect in taller buildings offers more advantages over lower ones, it eliminates the wind pressure differentials around the building and it can be used for solar assisted stack ventilation. The great negative effect is that there has to be two facades instead of one which requires lot of material. (Ghiaus 2005)

Solar assisted ventilation

Heating the exhaust stack duct increase the pressure differential and increase the flow of air and thereby the natural ventilation. This is very applicable in urban sides because it diminish the effect of the wind velocity in urban areas. It can be used for ventilating and for heating. (using it in double skin facades or Tromble walls it need a minimal gap of 50 to 100 mm) (Ghiaus 2005)

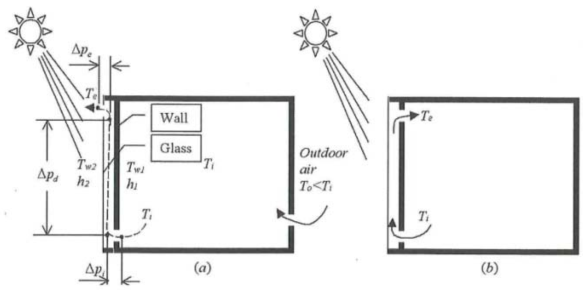

Figure 21: Concept solar assisted ventilation

To calculate the stack pressure and thereby the natural ventilation velocity we use the formula:

Δps = po * To * [(1/Te) – (1/Ti)] * g * Δz

ps = Stack pressure (Pa)
po = Pressure outside (Pa)
To = Temperature outside (K)
Te = Exhaust temperature (K)
Ti = Inlet temperature (K)
g = gravitational force (kg/m3)
Δz = height of inlet and stack outlet (m)

Again the formula shows that the temperature difference is leading to generate a high stack pressure and with this higher pressure we create a higher draft through the shaft.

Fan assisted natural ventilation

If there are rooms or conditions which interrupt the natural ventilation there could be installed some additional vents which ensure this natural ventilation. The meaning of this fans is to insure the air in and out let if pressure or temperature differences are to low. (Ghiaus 2005)

Biomimicry of the Termite mould

Another strategy of ventilate a building is the mimicking of termite moulds. This moulds are a ongoing research field and architects are trying to incorporate the results to make a sustainable ventilation system. To make it not too complicated we only have to know that the ventilation in a Termite mould works with due to under pressure. Due to the shape and the canal systems in the mould the wind will be sucked out of the hole. The termites than make sure that there will be openings in the lower part of the mould where the fresh air will be sucked in. The termites themselves exchange the Co2 and O2 for the refreshing of the nest of the mould.

In Appendix B you can read the two leading theories of the working of the termite mould.

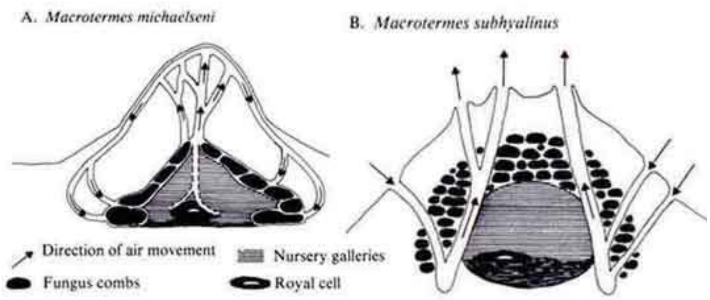

Figure 22: Working of a termite mount (Deon, 2007)

Example

How much fresh air has to be let in every hour in a room for 75 people?

If all people are there and knowing that one human needs 40 m3/h fresh air we can calculate the maximal mound of fresh air needed every hour. This makes a ventilation rate of (75 * 40) is 3000m3 every hour.

What are the dimensions of the air shafts.

If we know that the maximum air velocity in vertical shafts are 10m/s and in horizontal shafts 4m/s we choose for horizontal shafts. This with the reason that this will generate the biggest dimensions. If we divide the minimal ventilation rate in case that the room is full per second by the maximum speed we know the minimum shaft dimensions.

0.833 / 4 = 0,20833m2

This means that the air supply will be done through a shaft of ,21m2. This is a round shaft with the **radius of 260 mm**.

If we make an exhaust directly on a chimney. The average speed of exhaust will be the same as the wind velocity. This means 7m/s in Scheveningen. This can be done with a round shaft with the radius of (0,833 / 7) **200mm**

<u>Remark:</u>

- This example only shows the air needed for breath.
- This is also to global because if everybody is in one space this space already needs this dimension.
- There are rooms which requires more ventilation because of its function

Specific devises

There are a lot of tools which can be used to create a natural ventilation system. In buildings all these devises can be used to create one working natural ventilation system cause every devise have their own strengths and weaknesses. There are also devises who are working with the input of a computer. This makes the whole system less natural but more reliable especially in strongly changing wind conditions. In the list below the strengths and weaknesses are written down of the most used devises used for natural ventilation.

Operable windows

Operable windows are often used to control natural ventilation. It gives a large airflow rate needed to evacuate pollutants generated by short activity such as cooking, smoking or painting. It isn't a device which insure a small and continues controlled airflow rate and doesn't protect against rain, dust, insects and burglary.

Louvers

If there is need for a large and continues airflow than ventilation louvers are well suited. It protects against rain, dust, insects and burglary. Air Vent inc. have a rule of the trump for designing with large spaces and ventilation of it. They use the formula: (e.g. 2012)

$$A_{floor} / 150 = 1/2A_{inlet} + 1/2A_{exhaust}$$

A_{floor} = floor space area (m^2)
Ainlet = needed inlet area (m^2)
$A_{exhaust}$ = needed exhaust area (m^2)

Vents

There are a lot of vents available. There are some that has to controlled by hand or which are controlled by pressure difference or a sensor which measures the air quality (most of the time the air humidity). This vents are suitable to generate a small continuously air inlet.

Stack ducts

Stack ducts have long be used to either introduce outdoor air or extract vitiated air from rooms. The stack affect could be enhanced by the use of wind catchers or fans. It is recommendable to use different stacks for each room to prevent against pollutant or fire exchange.

Wind catchers

The wind catcher is a devise which, through louvers or fans, direct the wind in or outwards of the building. It depends on the direction the wind blows. It uses the pressure differences and is a great improvement of the stack duct.

Chimneys

A chimney is a natural exhaust. This increase the outlet ventilation rate and the thermal effect and usually need a large area.

Double skin facades

Double skin facades are used for the reasons of, protecting indoor environment of noise, protect shading devises from rain and wind, allow safe natural ventilation and passive night cooling and renovate the building skin whiteout perturbing occupants.

Case study Cultural Center Tjibaou

General

Architect	Renzo Piano
Building site	New Caledonia
Completion year	1998
Function	Cultural center and Museum for native Kanak people
Characterize:	Using local material, use way of building native inhabitants, use of natural source.
Sources:	(Piano 2008) (Silloway 2004)

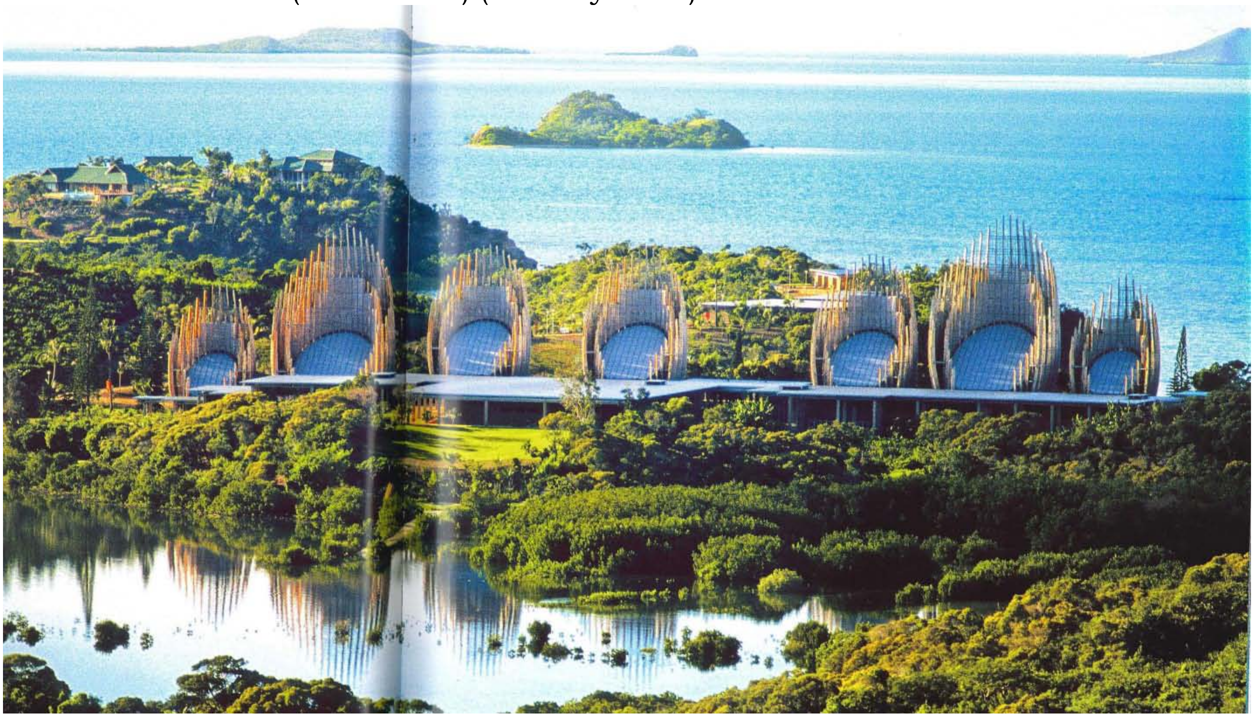

Figure 23: Cultural Center in Tjibaou

Description building

The cultural center is built in a natural environment on New Caledonia. The architecture used is coming from the native people who lived in the surrounding. The shell like structures are placed with their back to the most common wind direction. In this structure the main ventilation is regulated on a natural principle.

How does the natural ventilation work in this building?

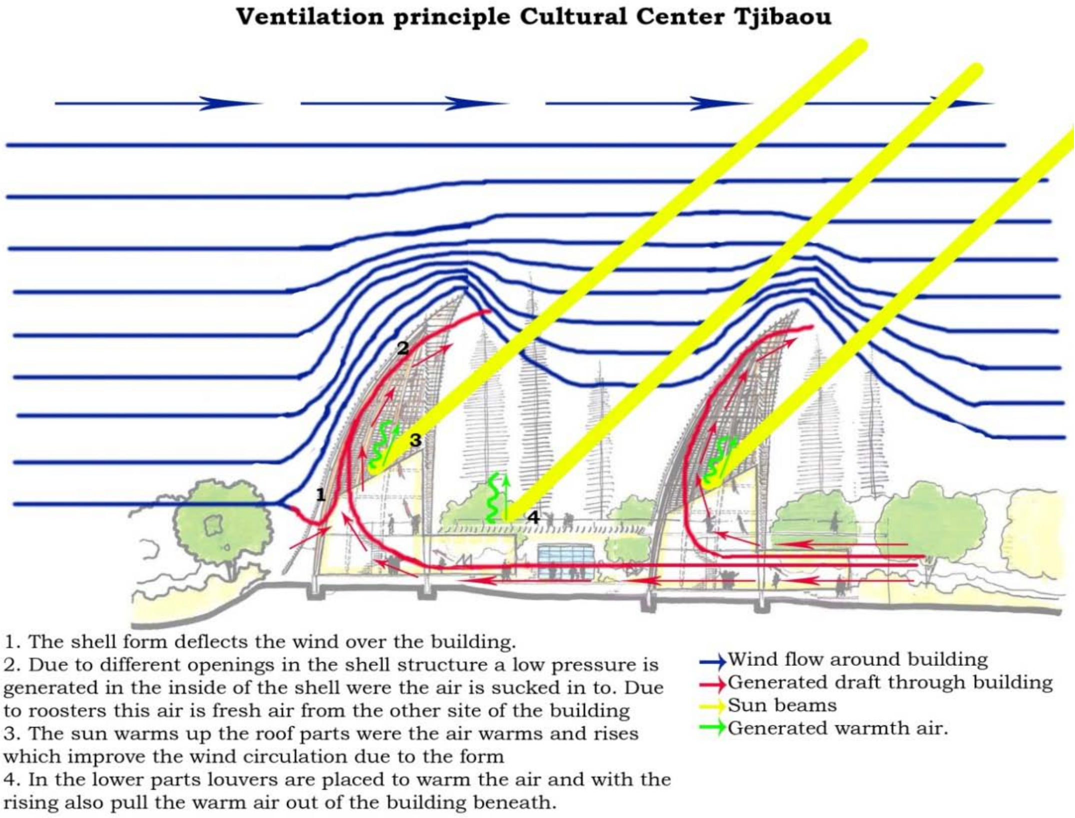

Figure 24: Ventilation concept of Tjibaou center

The main principle of natural ventilation consist in three parts. The first is the wind directing over the building which generate suction on the building. The shell like structure is a double façade system. The inner wall is the thermal insolating and bearing façade. Behind it there is the controlled room. The second skin is a façade build with wooden slats. All over the second skin the dimension of the gabs between the slates are different. This have a huge effect on the wind flow. Where the percentage open and close is high the wind can flow in or out the room in between the skins. Coming closer to the edge the percentage become higher. In this was turbulences are created which diminish the acoustic pressure on the façade and between the skins. It also decrease the load on the structure. There where the created draft has to be large the percentage of gabs are practically nothing. In this way the wind will flow through the skins across the façade generating pressure at the bottom where air is sucked in to the space between the skins and generating under pressure at the position of the exhaust roosters where the used are practically is sucked out of the building. (See figure 33 for a picture board of the second skin façade.)

The second part is the sun. This sun warm the lamella structure above the roof and the inner part of the shell form. This lamella structure prevent the warming of the actual roof. The warm air in between will be sucked out this space due to the sucking effect of the first part described above. This draft will draw the warmed air out of the underlying space.

This suction on many parts in the building lead to the third part. Due to this flow and pressure working a flow of fresh air is created form the other site of the building. Here the whole façade could be used as rooster to led fresh air form under the threes and above the water in to the building.

How to regulate the ventilation?

The picture bellow show us the openings of the roosters during different wind velocities. The roosters are completely open if the wind has a velocity lower than 3 m/s. Some roosters will close automatically with the change of wind velocity. This will ensure that the wind velocity inside the building isn't disturbing and the amount of ventilation is secured. Beside this there is no other installation used in this building.

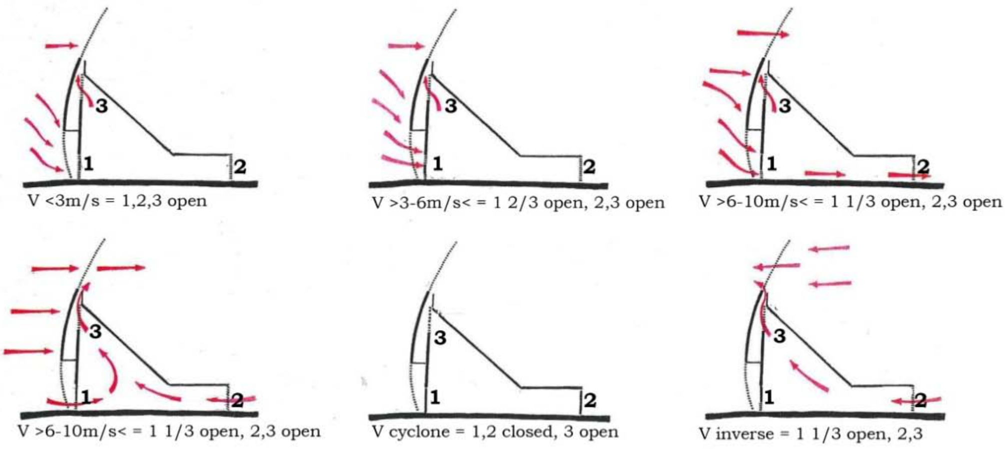

Figure 25: Ventilation with other velocities.

Conclusion

Due to the form and the teamwork with the sun there is created a drafts across the building and over the building which suck the wind out of the building. By the pressure differences created newly and fresh air is entering the building at the other side. The wind velocity control the inlet and exhaust roosters to create the natural ventilation needed inside the building.

Case study Government Center Ypenburg

General

Architect	EGM architecten
Building site	Ypenburg
Completion year	2007
Function	office for governement
Characterize:	Sustainable building with natural ventilation
Sources:	(Leeuw de n.d.)

Figure 26: Government center Ypenburg

Description building

The government center of Ypenburg is standing across a highway. The building consist of office space without separating walls. The floors are designed to be one large room. The building has a large air exhaust shaft with the most characteristic part of the building on top of it. The 'fool'. This aerodynamic shaped exhaust always rotate in the wind direction.

How does the ventilation works in this building?

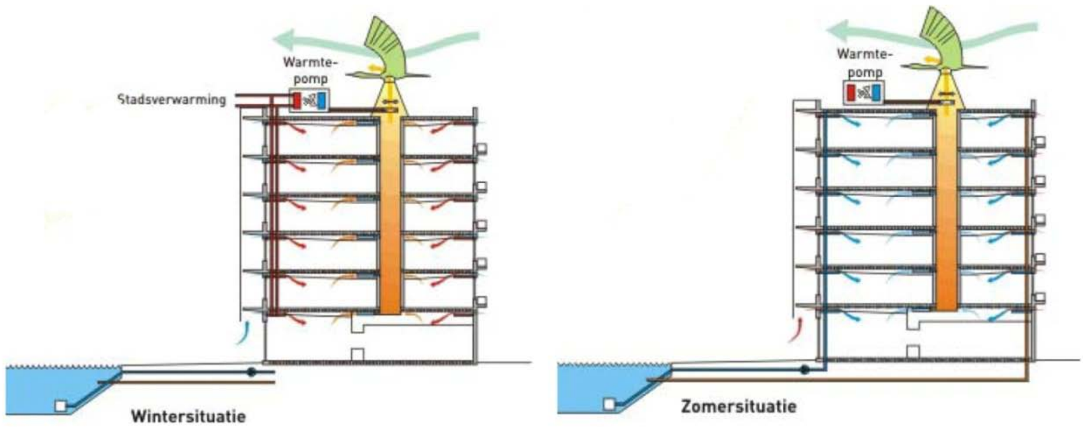

Figure 27: concept of ventilation in winter and summer

The ventilation principle works like a large chimney system like structure. The 'fool' is always in the perfect direction to generate an air draft out of the building. The used air in the working spaces, which all are attached to this shaft, will be sucked out of the building by this principle. At the other side of the spaces the air will mechanically sucked in o the building. This air flows over a radiation panel which warm or cool the space to the wishes of the user before it enters the room. Below the 'fool' a ventilator is placed to generate the flow of air if the velocity of the wind is too low. The only two places in the building with a mechanically regulated ventilation are the canteen and the place of the arrested persons.
At the side of the highway a second skin façade is placed so the windows can be opened without directly let the highway air with a high CO2 concentration will enter the building. This has to be a lamella structure according the fire regulations.

What is used to make it happen?

To make natural ventilation happen and without diminishing the wishes of the users there are a lot parts designed to help or generate the natural ventilation. Following the wind we enter the building through roosters with a CO^2 detection devise. This has to be done because the building is standing across a highway. The air inlet is mechanically regulated which partly contradict with the wish to ventilate completely in a natural way.
After entering the building radiation panels regulate the temperature of the inside air. In this way the user can regulate its own climate in the office space.
Due to chimney effect the air leave the space in a big air shaft which lead the used air out of the building. This shaft has a dimension of 2,5 meter in diameter.
On top of the building there is the 'fool'. Almost all of the time the aerodynamic shaped air exhaust, which give the option to rotate to the optimal stand, natural ventilation is enough. For moments the wind velocity is to low or practical none a ventilator placed under the 'fool' will generate the wind suction in the shaft. A wind sensor on the 'fool' regulates this ventilator. This fool is also structural too heavy to let it rotate on its own. A motor also connected to the wind sensor will rotate the fool in the perfect direction

Conclusion

Due to the aerodynamically shaped air exhaust the chimney effect works optimal in an area with multidirectional wind. This is the reason **85%** of the time the building can be natural ventilated. A negative effect is the location of the building. Because it is standing next to a highway the air inlet has to be mechanically regulated to make sure the air let in to the building doesn't have a level of co2 which is too high. Due to this ventilation principle the sound disturbance is much lower than conventional mechanical ventilation.

Summary

Natural ventilation

Due to the velocity at Scheveningen natural ventilation is a good solution. Most of the time a low velocity means a lot of adding in order to make ventilation work. In Scheveningen this is less the problem. An issue is the air quality. It is very salty and this isn't good for a lot of materials and is also not desirable for the occupants.
The order of types is from top to bottom the best applicable solution to the least applicable system. Beneath the table a summary of advantages and disadvantages is stated.

Ventilation type	**Scale**		**Benefits**			**Costs**			**Location**	
	Room ventilation	Building ventilation	Effectivity	Flexibility	Equaly distributed	Material	Mintainance	Polutant distribution		
wind and buoyanvy driven ventilation	+	++	++	++	-	+	0	0	++	
Buoyany driven ventilation	+	++	+	+	-	+	0	0	+	
Solar assisted stack ventilation	+	++	++	+	+	++	+	0	++	
Double skin façade	+	++	+++	+	+	+++	++	0	+	
Passive evaporative cooling	-	++	++	-	+	++	+	-	-	**
Balanced stak ventilation	-	++		-	+	++	+	-	-	**
Induced single sided window	++	--	+	-	-	--	0	0	-	*
wind driven cross ventilation	+	+	+	-	+	-	0	--	-	**
Bio Mimic	0	+	+	++	+	++	+++	-	--	

* Not effective cause unfiltered sea air isn't desirable and has lot of salt in it which can inflict damage on indoor materials

** Has lot of salt in it which can inflict damage on indoor materials and drive pollutants through building.

Table 1: Summary and pros and cons of natural ventilation concepts

Buoyancy and wind driven ventilation

Advantage

Take double advantage of the high wind velocity and works with multidirectional winds

Disadvantage

There has to be a input regulation to be sure that ventilation on wind and lee side are enough.

Buoyancy driven ventilation

Advantage

Works with multidirectional winds and is most used natural ventilation system

Disadvantage

Doesn't work evenly good on different levels.

Solar assisted ventilation (double skin façade)

Advantage

Not only make the zone between outside and tempered room whereby a graduate transition take place but also protect against sans and wind disturbance

Disadvantage

There is a lot material needed.

Evaporative stack ventilation

Advantage

Higher bouncy force is created so higher ventilation rate and even make use of evaporative cooling

Disadvantage

The system doesn't work even good in al wind directions and it needs a lot of material.

Balanced stack ventilation

Advantage

Very effective in hot climates and on hot seasons in tempered climates

Disadvantage

The system doesn't work even good in al wind directions and it needs a lot of material.

To opening windows

Advantage

High ventilation rate and manual very handy

Disadvantage

Not easy to implement in a controlled system and doesn't work if window is too small or room is too deep.

Wind driven cross ventilation

Advantage

Separate ventilation on every floor

Disadvantage

Transport pollutants through over floor and doesn't work properly with wind in a variable wind direction.

Bio mimic

Advantage

Excellent maintenance of air quality

Disadvantage

Needs constant tuning and a lot of controlling.

For using the natural ventilation correctly the main objective is to control the temperature difference which create the draft. In winter the difference is naturally there. In summer the ventilation have to be helped in order to work properly. This can be done in an aerodynamic or a temperature increasing design input.

Relations to Scheveningen

Natural ventilation is generated in the same way as wind itself but then directed and through a building. Like wind, ventilation can be produced by introducing a pressure difference. This can be done by using temperature difference or using the wind and lee side of wind around a building. In Scheveningen the wind velocity is high with a great opportunity to generate a pressure difference with a windy outside and a wind low inside. Let the wind flow draw the wind out of the building which generate a under pressure which then draw wind in on lee side of the building.
The same principle can be reached by using height. (stack ventilation) The point of interest is then the multi directional wind. From every direction there has to be enough suction through the stack. The sun intensity can be of good help in this case. If it comes to ventilation, the multi directionality of the wind also is the factor that has to be dealt with.

Conclusion

The research question of this report was find the answer to the research question:

'How can we use the natural source wind in the build environment in a sustainable way?'

General

Wind is locally very unpredictable natural phenomena with multidisciplinary opportunities in architecture. In principle it is easy to predict and to handle but in detail and reality handling and designing with wind, due to its unpredictability on local scale, is very difficult.

Wind energy

Wind energy is a free available energy and it will not deplete. This makes it one of the best sustainable sources in our world. The local unpredictability and behavior of wind makes it difficult to generate power efficiently.
Guided by the terrain roughness, wind velocity and wind direction there are two turbines that are most effective. The horizontal and the vertical axed turbines. Both have their own benefits.
In the case of the design in Scheveningen the multidirectional wind requires a turbine which generate energy of all directions. This means that a VAHT is most suitable but a rotating HAWT is also possible.

Natural ventilation

Like every aspect of the wind it is the local requirements and local characteristics of wind which result in most suitable ventilation techniques. The high average wind speed and undisturbed path (most of the time) of the wind makes Scheveningen a place where complete natural ventilation is possible and suitable. It is the shape and height of the design which result in the best ventilation scheme.

Part B - Rotating Architecture

Introduction

Due to the wind conditions of Scheveningen (see wind rose of fig 2) an additional research is required. A research of rotation architecture with the aim on a complete structure that rotate. This study has the aim to investigate the possible ways of rotation which already is used in architecture and the reason to let architecture rotate. The underlying question is how to make a structure rotate on an effective way in Scheveningen to track the wind.

History of rotating architecture

Rotation in Architecture in the early ages.

Many people think that rotating architecture is something from the last decades but there are stories of rotating dining rooms out of the roman empire. There are unfortunately no real examples left which could prove this stories. From then on there were lot of mighty emperors who would like to make rotating rooms like the Persian king Chosroes who build a throne room in the seventh century with a rotating throne in the middle. For doing this they used a lot animals who let the column with a statue and the throne rotate. Three hundred years later Abd ar Rahman III made a domed room with rotating walls.

The reason to build rotating architecture was to impress visitors and the mechanisms it requires where enormous or animal labor was needed. The first real rotating mechanisms to let complete structures rotate where windmills.

These industrial buildings had to be able to rotate to the wind direction to be most useful. The history of this mills go back way further than the emperors who wants to impress visitors. The first mills where build in the Byzantium realms but it needed much muscular power and where not so productive.

The invention of the using of the momentum of spinning wheels made the mill develop in the miles we know. To make optimal use the first post mills where build around a central wooden post which could rotate the building to the optimal wind direction. First with muscle power and further on with gear wheel constructions. This industrial machines where very important for developing whole countries to the point motors came to replace them.

Nowadays we know wind turbines which are made to generate energy but there the only rotating parts are the ‘spinning wheels’ to generate electricity. This isn’t architecture anymore but the main concept of rotating a building around a central ax.

In the renaissance the rotating building was a way to express superiority. Military driven we can see the first complete rotating structure. The turret. A building that can rotate to be able to shoot at the enemy and saving expensive cannons (figure 24) This building rotated due to gear wheel around a central rotating point.

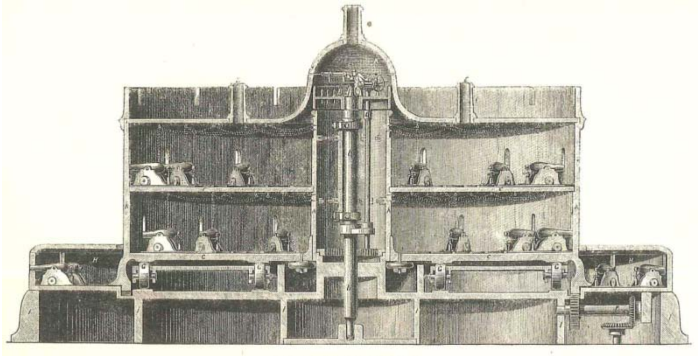

Figure 27: First rotating stucture; Turred

From this point rotating theater stages rotating summerhouses and even rotating jails where developed with mechanisms like the mechanism on the next figure. A rotating column driven by muscular or engine power.

Figure 28: Rotating mechanism of a rotating jail

Early nineteen century

Due to technological inventions in the early nineteen century the whole concept of rotating architecture get a boost. The rotating car turntable and theater stages where become common and due to the power of the engines even complete houses where placed on a turntable to rotate. In houses not only rotating car turntables where popular but also functions like a kitchen became popular. Because it was possible.

From this turntable like rotation to rotate complete objects the development of rotating towers appeared. There was a fixed volume with in the middle a round tube where the stairs and tubing and pipes where placed. On the roof and around this tube the rotating volumes were attached. First with the turntable principle but later the functions where placed on roller bearing and clamed around the central tube. (see case study)

This rotating buildings where build on high places to generate 360 degree views or to rotate with the sun. The climax in the early nineteen century was the proposition of a rotating building of Norman Bel Geddes for a rotating restaurant for the 1933 Progress Exposition in Chicago, but it is never build.

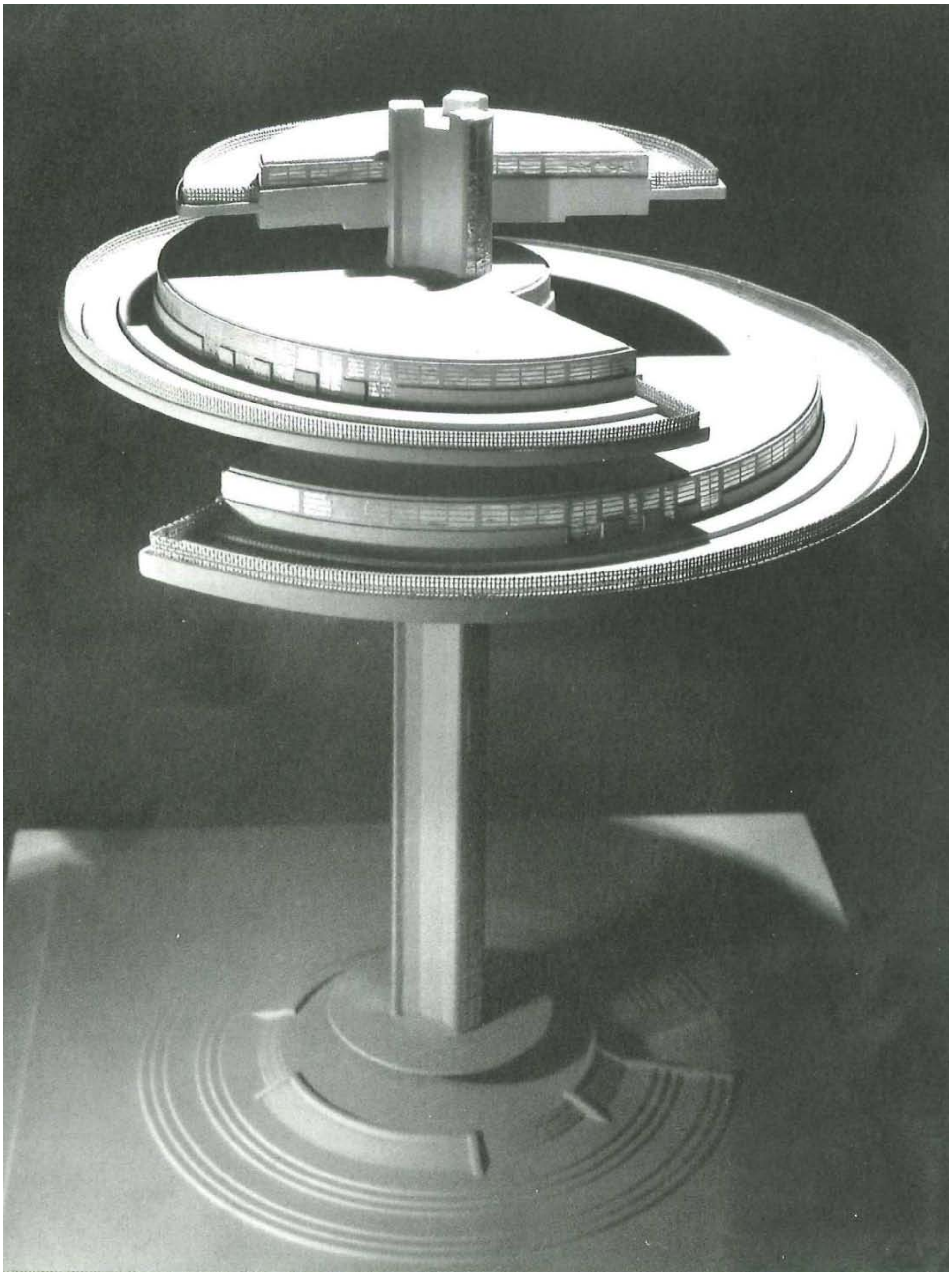

Figure 29: Rotating building of Norman Bel Geddes

Postwar rotating design

The rotating idée of Norman Bel Geddes of a rotating bar/restaurant high from the ground was a hot topic after the war. A lot hotels where topped with a rotating restaurant where of the whole restaurant rotated or only the floors. Not only hotels but also on tv towers rotating volumes are placed in the top of the tower to generate panoramic views.

Postwar rotating residence

In the residence architecture we see a sort like evolution due to the power of engines. The turntables of inside functions become larger and even more functions are placed on top of it to make better use of the usable space, like in rotor Haus prototype interior.

On the other hand there are buildings build which can rotate with the sun to get most profit from the sun like the heliotrope house which rotate complete from the foundation. This house only cannot rotate more than 360 degrees.

Other buildings would be able to rotate complete for more than 360 degree like the Everingham rotating house. Al tubing and pipes is located in the middle with the ability to rotate around one another so the building can rotate further after 360 degrees.

The rotating history in Architecture now is coming in the time of rotating high-rise. Complete high rise buildings which can rotate complete like Suite Vollard or even every story individually like David Fishers dynamic architecture tower Figure 29. (Randl 2008)

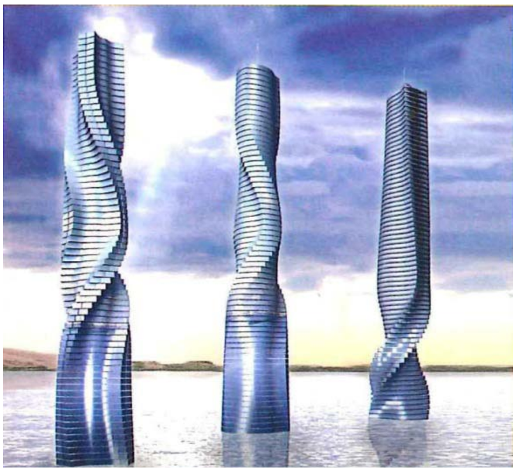

Figure 30: left Suite Follard, right Fishers dynamic architectural tower

From the beginning we can divide a few rotating mechanisms all coming from the rotating turntable.
(Randl 2008)

Technique behind rotational architecture

Turntable

The father of the rotating mechanism is the turntable. It consist of a rotating point a plateau and outer support with wheels. If the span of the two supports is large sometimes another set of wheels is placed in between.
There are two ways to let the plateau rotate. First the wheels of the outer support can be rotated by a motor which let the plateau rotate or the rotating point can rotate. Most of the times a gear wheel system is then used to generate the rotation out of the power of a motor.

Clamping cantilever

In this case the rotating volume is attached on a rotating ax (most of the times the vertical traffic element of a building). If the central ax is not rotating the volume is attached on this volume with roller bearing. This also can be motor driven wheels which generate the volume. Because most of the times the rotating ax is round and the volume that rotates is completely around this ax there will not be a momentum. If this is not the case the rotating ax has to be able to handle the momentum.

If the central ax rotate with the building the rotating system is lookalike on the turntable. The difference is that the rotating point is bigger and there are no support structures. This means that the rotating object has to be stiff to handle all the forces and the rotating point has to be able to handle momentum forces.

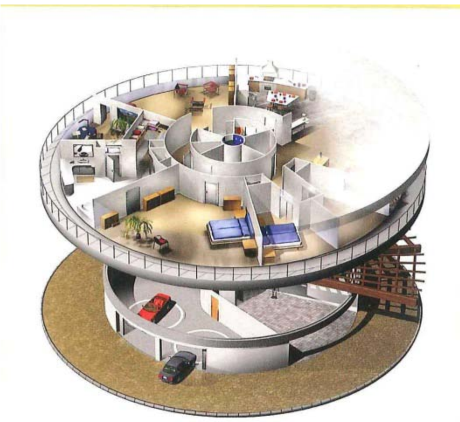

Figure 31: Clamped rotating construction of Johnstone . house

Suspension

In this case the rotating volume is attached on a rotating ax (most of the times the vertical traffic element of a building). If the central ax is not rotating the volume is attached on this volume with roller bearing. This also can be motorized.

Devices needed to make rotational architecture

Gear wheel

This gear wheel are inventions out of industry and are used to generate motion and give the motion through on other gear wheel to de or increase the power or alter direction

Chains

Also chains are used for generate motion. Most of the time in combination with gear wheel. A motor often drive a gear wheel in motion and the chain let a gear wheel move on a other place. So chains are used to transfer the movement quickly from one place to another.

Wheels and rails

Wheels are used for move an object. Think about cars. If wheels are attached to rails the movement is fixed and the object can a preset motion. Think about trains. If an object like a building Is attached to circular rails it can be called a rotating building

Roller bearing

This elements are mainly used to create a load bearing connection of a fixed object with a rotating object. This invention made it possible to make rotating architecture.

Case study Heliotrope house

General

Architect	Rolf Disch
Building site	Freiburg
Completion year	1994
Function	Resident
Characterize:	It rotate with the sun so that it always in the optimal orientation
Sources:	(Jolly 2011)

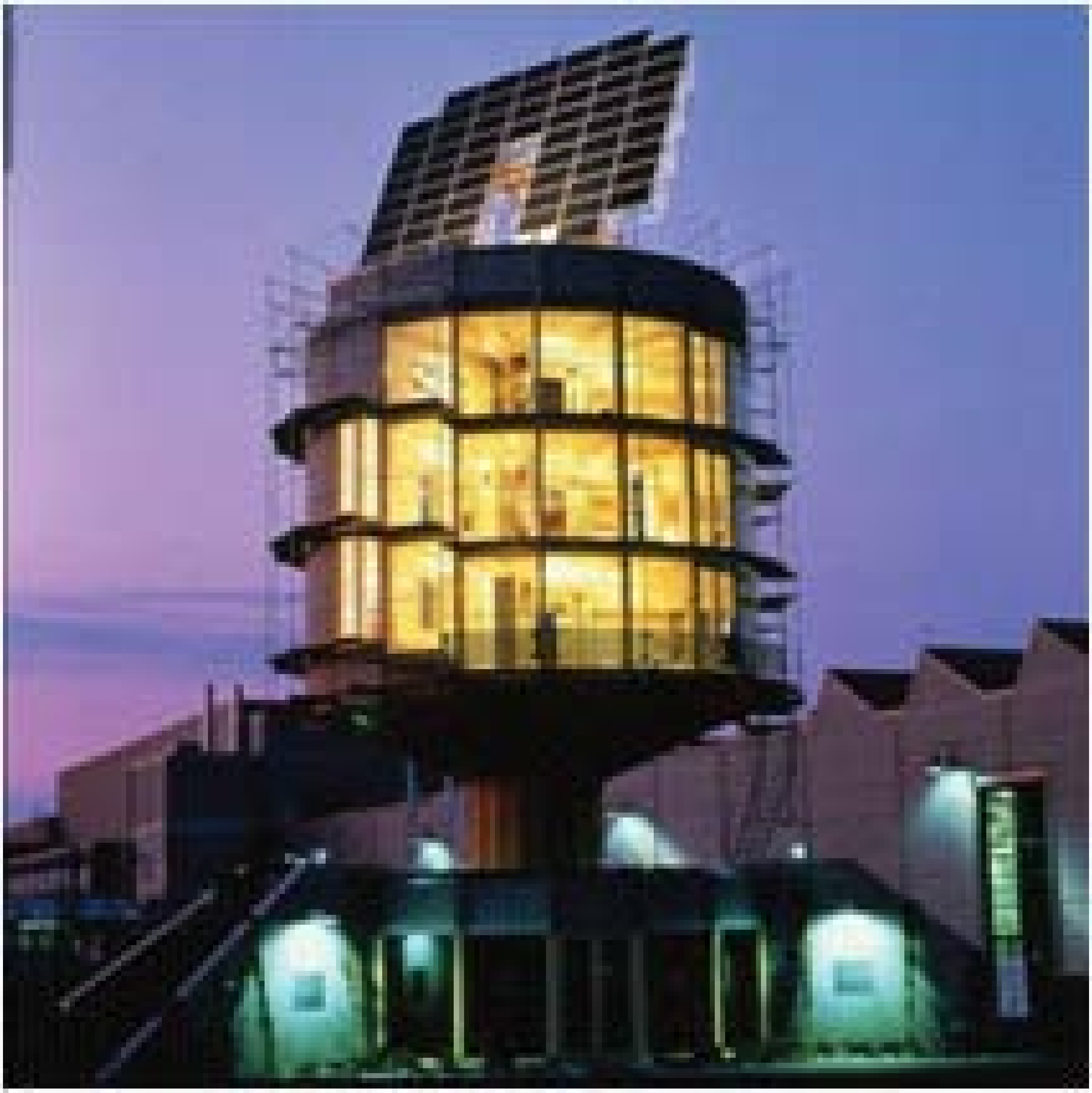

Figure 32: Heliotrope house

Description building

The Heliotrope building is a self sustainable building which generate more energy than it needs. Due to the ability to rotate, the sun cells on the roof the cells can continually generate the maximal amount of energy. By placing the functions in the volume minimizing their energy need, the total consumption is reduced.

Which part is rotating?

The whole building above the foundation is rotating. The central column is placed on a foundation which can deal with a large momentum and the massive round column is placed on top of this foundation. The construction of the house itself is made of the light weight material wood and the vertical distribution of people, piping and wiring is located within the central column.

Figure 33: The foundation and central column of the Heliotrope structure

Why does the building rotate?

The reason of rotation is to track the sun so the sun cells on the roof can reach the optimal energy production. This is the only reason why this building can rotate.

How does the building rotate?

The rotation of this building is provided by a small motor which actuate a gear wheel. This gearwheel makes the building gradually rotate so the sun can be tracked optimally. In night time the building rotates back to the starting point so the piping and wiring will not be damaged.

Figure 34: The motor and resident structure of the Heliotrope house

Conclusion

This building doesn’t have a genius rotating mechanism but a small and economic system which rotate a central column with a load that is as low as possible. Due to this the efficiency of the energy production is greatly improved.

Case study structures rotating buildings

General

Architect	Angelo Invernizzi
Building site	Marcellice
Completion year	1935
Function	residence
Characterize:	make the dream come trough to make a building that was able to following the motion of the sun
Sources:	(Randl 2008) (e 2011) (e 2012)

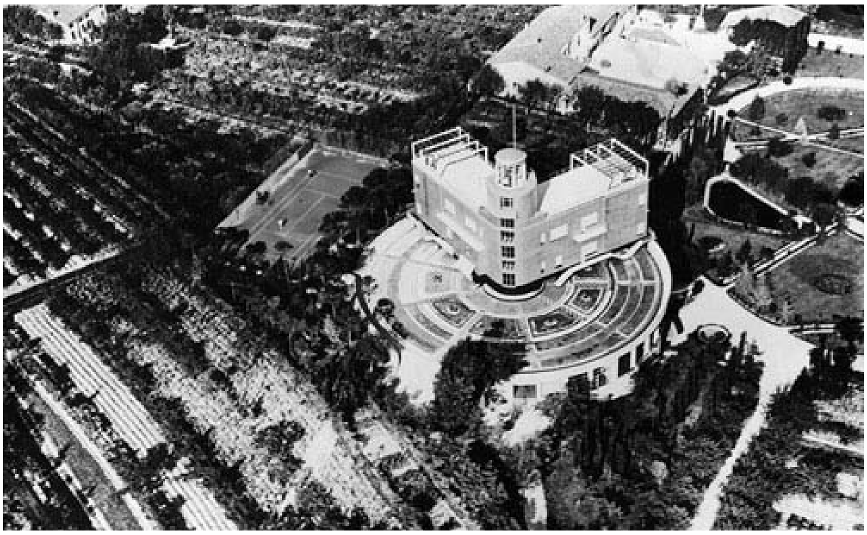

Figure 35: Air picture of the Girasole house

Description building

This building as seen in the picture above is build on a roof of a circular volume. This is in fact a lifted rotating tableau where on top a resident is build. The v shape of the building creates a outer space which due to the rotation is always on the sunny site.

How does the building rotate?

If we now look at the 3 dimensional cross section of the building we see that the central column which is the rotating part runs through the lower volume to the foundation. By doing this the vertical transport could be easily placed there and the building gained stability. The residence itself is placed on a tableau with three rings of wheels beneath the tableau to carry the load. In the pictures below you can see how big the rotating devise on the bottom of the foundation are and how big the wheels of the supporting structure are.

Figure 36: Rotating mechanism

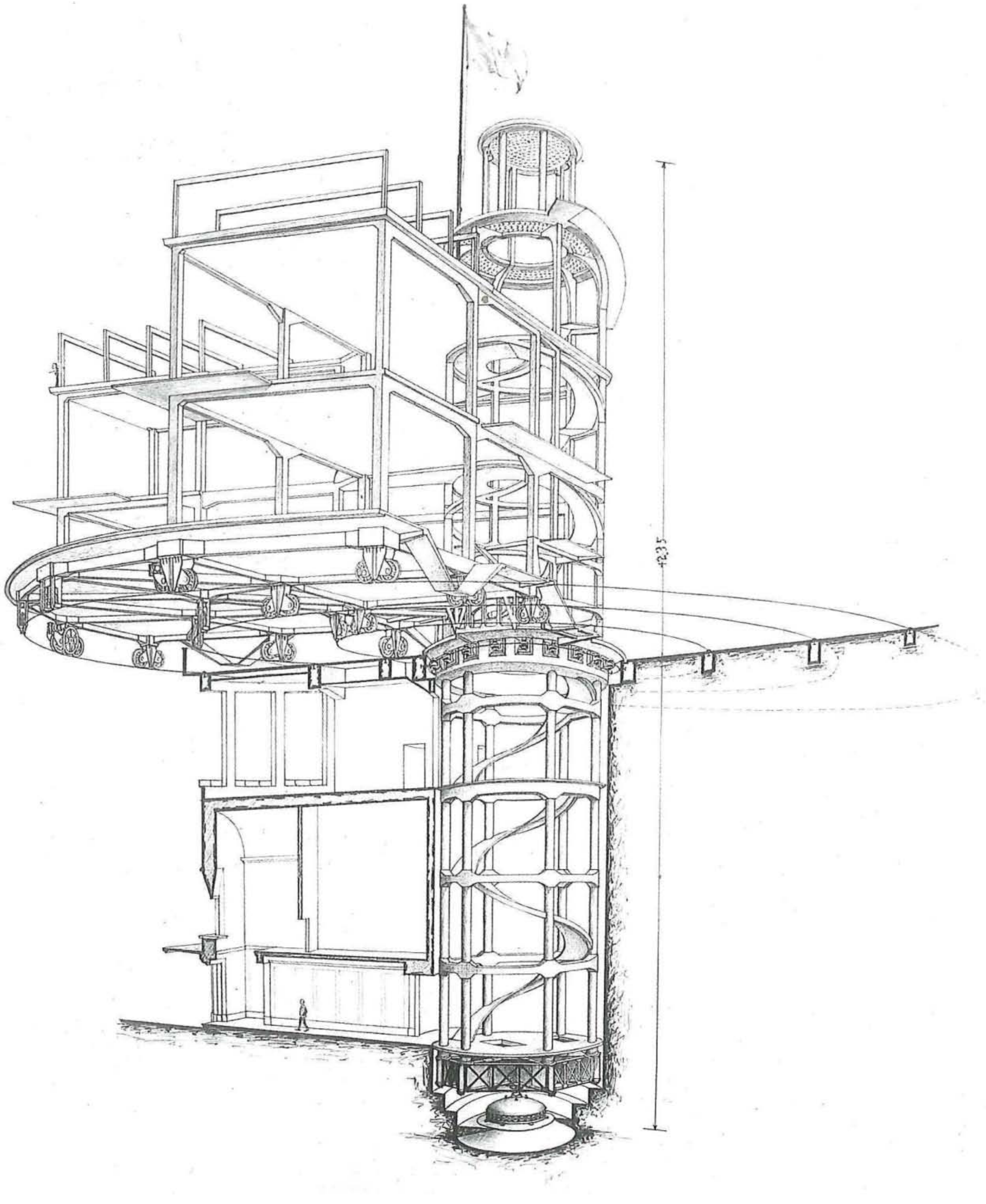

Figure 37: Rotating mechanism of villa Girasole house

Everingham rotating house

The Everingham rotating house is build with the same mechanism. A large rotating tableau with a building on top of it. The reason is to track the sun and to generate a changing view. In Great Britain the Everingham rotating house is located which is a house of 160 ton and has the same energy consumption of an average washing machine.

Figure 38: Everingham house in Great Britain

There is just one more building that needs our attention because it claims that it can rotate further than 360 degrees due to its smart Swivel. It is the Johnstone house out o America.

Johnstone house patented Swivel

The picture below show the swivel of the Johnstone house. You can see that every instalation runs through one casing which can rotate. This means that the electrial wiring runes trough the gaspipe and water pipes. This without leaking and it has proved that it works. Due to technical possibilities it is possible. All piping inside is flexible but because it is patented there are now drawings or pictures of the crossection.

Figure39: Swivel of the Johnstone house

Summery

Rotating Architecture

The history of rotating history is a history of making use of new possibilities due to technical progress. More than ever the reason, ‘because it is possible’ is the foundation to make buildings larger rotations. With the invention of the motor bigger and heavier parts where able to rotate to complete buildings. The gained value is, (1) a panoramic 360 degree view, (2) following the path of the sun to gain maximal profit out of the sun or (3) multiple use of space.

Rotating mechanisms

There are three main rotating mechanisms which are, (1) turntable, (2) clamping cantilever and (3) suspension. In all types there is a central rotating ax most of the time a tube with every vertical movement in it. If possible a cantilever is reduced or lifted with wheels over rails or roller bearings. If not the structure has to be light so the centre column can handle the momentum. If a cantilever is the case the cantilever on one side is mirrored on the other side to make an equilibrium in the centre of the load bearing structure.

Problems to solve

The first problem to solve is the problem of vertical transportation. In the rotating architecture nowadays the vertical transportation is the static core where everything is rotating around or the vertical transportation is located in the rotating point. In the last case the entrance to the vertical transportation (first step of the stairs) is rotating with the rotation of the building.

The second problem to solve are the running of the installations. As everybody knows are the services water sewer and electricity coming from a fixed point into the building. If rotating around a point the installations doesn’t have to rotate against each other. Especially if a rotation of more than 360 degree is needed. Without inventions like the patented swivel from the Johnstone house this wouldn’t be possible if there are more than 2 installations have to rotate with the rotation.

Conclusion

The reason to use rotation architecture is to make use of other qualities. The most applicable is the following the track of the sun or generating panoramic views from one point.
The principles used are the principles which are used in attraction parks. There is the suspension like a giant's stride, there is the rotating plateau like a merry go round, the screw mechanism like a watch-tower and if a more difficult or eccentric rotation is needed the rails like a roller coaster are used. These methods are sufficient to make complete buildings rotate. The difficulty is the rotation limit. A long time there it wasn't possible to lat a building rotate further than 360 degrees because the limitations of the installations. The contractor of the Johnstone house which was a pipefitter himself designed a swivel which should do the trick.

Relations to Scheveningen

Seen by the diversity of places where rotating architecture is placed the side isn't of big influence to the possibilities of rotating. The wind forces will be higher than in lot of other places and that makes a suspension less suitable but with the technical knowledge today is everything possible. Still we can see that the most used rotation devise is the turntable cause this can cope best with forces.

Evaluation

I'm very pleased and content with the stuff I learned investigating this issue. The issue space was broad and many things where in investigation. It has triggers me to deepen myself not only in the stuff I had to investigate but also the meaning and definition of sustainability in architecture. The thing I'm not completely content with is the report. My written English isn't very good and due to my own organization I had a lot of unorganized information which makes it difficult to write all important issues organized in this report. If I read the text there is a lot which could be added with the remark if it will clarify the context. Especially some deepening issues.
If someone want to investigate the possibilities of using water and wind in a sustainable way I recommend to read the books I have red in progress of investigating my objective in this report. If someone is as interested in sustainable design as me I recommend to look and analyses very thorough and don't forget the remark of Bartlett

> 'We see that sustainability often is uses to describe a lot of different activities which are ecological valuable but has nothing to do with sustainability.'

It is like Winston Churchill said:

> *'First we shape our buildings then our buildings shape us.'*

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Appendix A – Wind roses of The Hague

The data for the wind roses of The Hague are taken from a buoy in the sea by Scheveningen. Most of the time wind data from Hoek van Holland is used but this measurements are taken from a point in between the roughness of that site. I use the data from the buoy to have the most suitable data for a building that is placed in front of the roughness of the terrain. Especially if the wind is coming from sea what is the case most of the times.

First the wind roses of every month. In this rose the main direction and speed is displayed. Seen this roses the wind direction is more multi directional than in the average wind rose. The wind roses are presented on the next page

The wind rose with the average of the whole year is the wind rose used as design input.

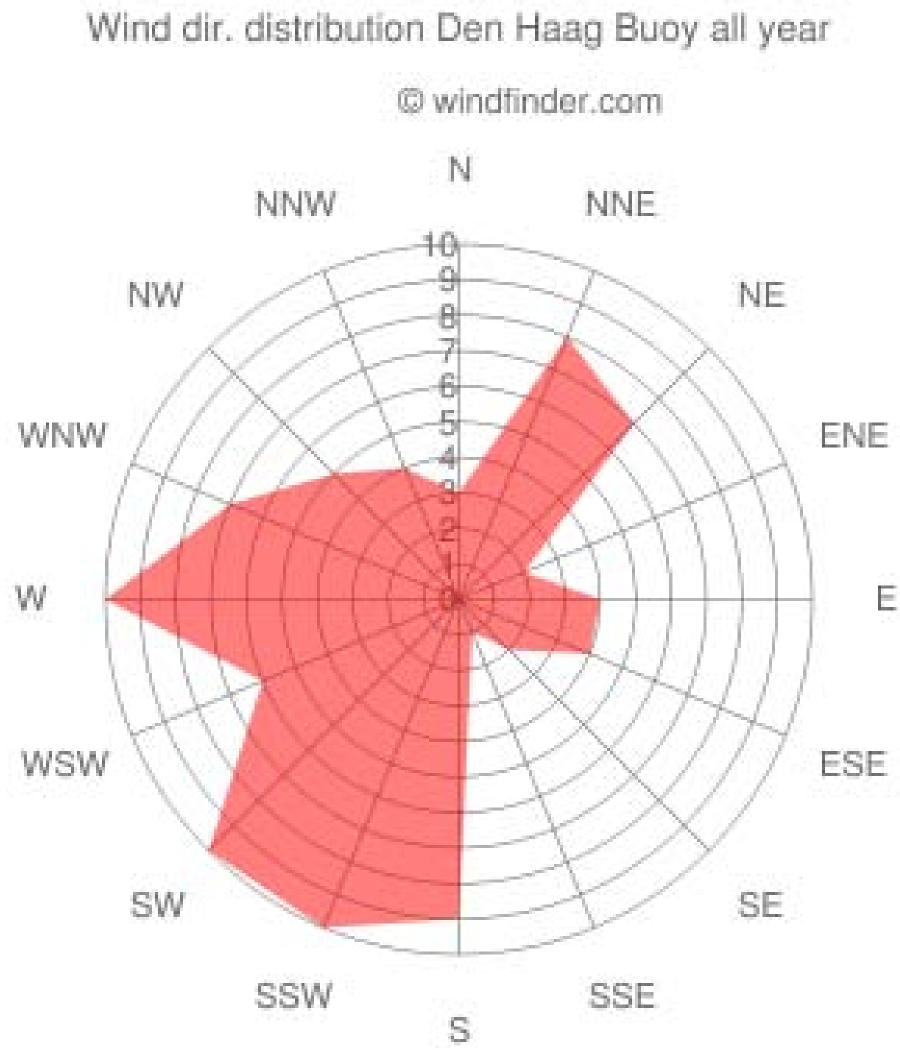

Figure 1: Wind rose average wind of the buoy of The Hague

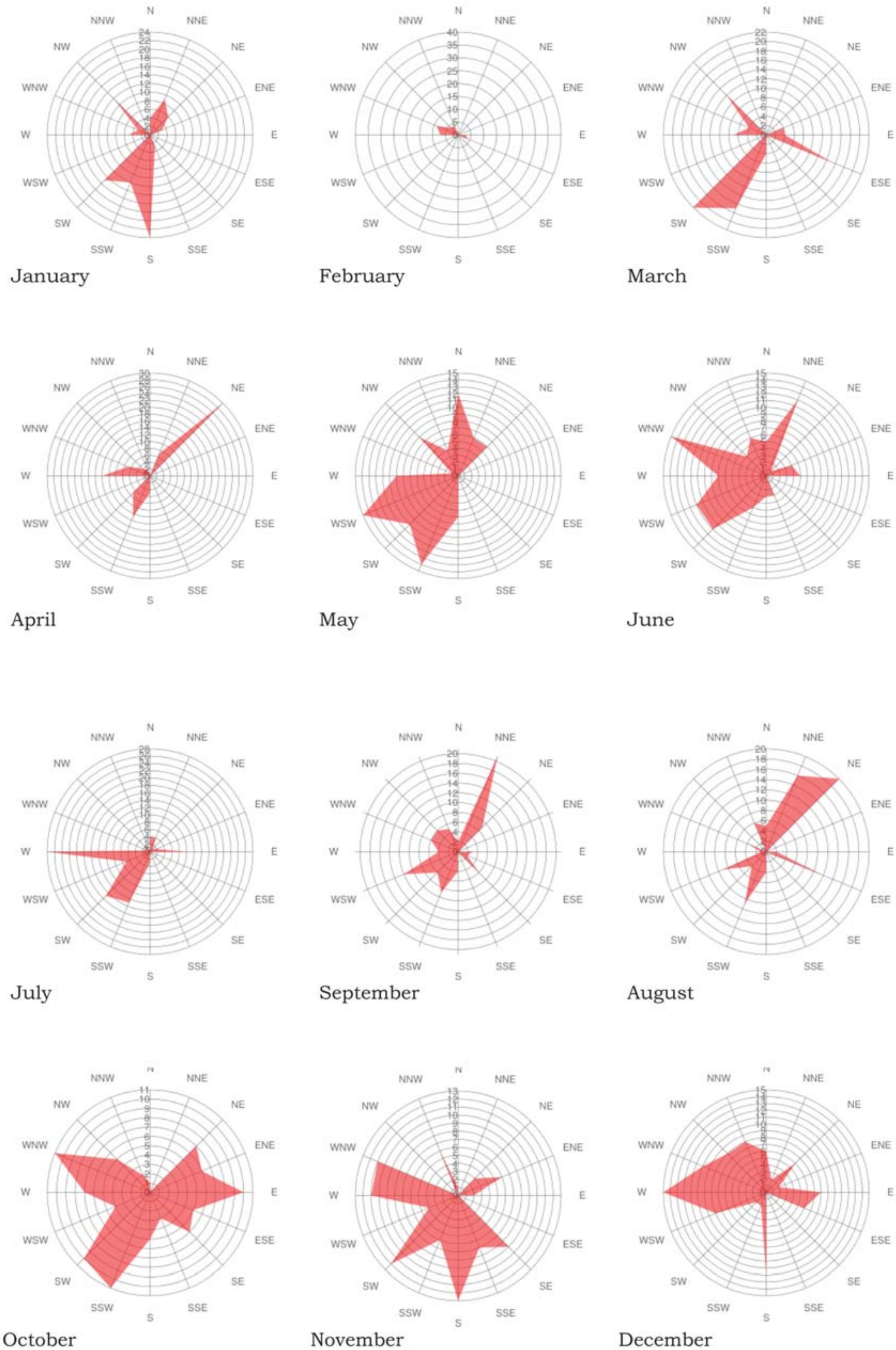

Figure 2: Wind rose of every month

Appendix B - Bio mimicry termite mounds

A special topic in natural ventilation is the bio mimicry of the termite mounds. Due to the cry of designing more sustainable architects look more to copy nature. For ventilation the termite mound is a world spread reference but there are different outcomes on studies in how the ventilation in the mound happens.

Mount for ventilation and temperature regulation

Termites build gigantic mounds inside of which they farm a fungus that is their primary food source. The fungus must be kept at exactly 87 degrees F, while the temperatures outside can differ more than 70 degrees F during night and day. The termites achieve this remarkable feat by constantly opening and closing a series of heating and cooling vents throughout the mound over the course of the day. With a system of carefully adjusted convection currents, air is sucked in at the lower part of the mound, down into enclosures with muddy walls, and up through a channel to the peak of the termite mound. The industrious termites constantly dig new vents and plug up old ones in order to regulate the temperature. (Deon 2007) (Tsui 2008) The East gate Centre in Harare is designed whit this principle and is further explained in case study 6.3.

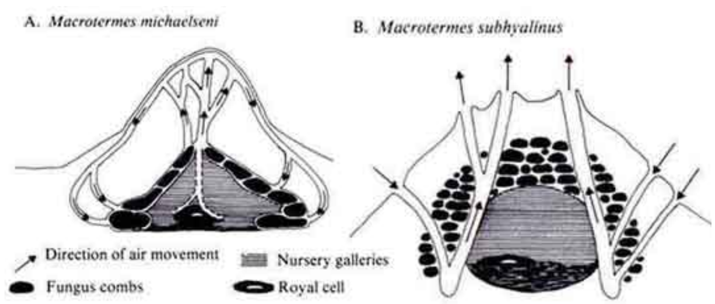

Figure 1: Working of a termite mount (Deon, 2007)

The earliest model of the function of the termite mound comes from Maritn Luscher in which the mound is a venue for metabolism driven circulation of air. The colony generates the heat which generate enough buoyancy to the nest air to loft it up into the mound and to drive it eventually to the mound's porous surface. There the spent air is refreshed as heat water vapor and respiratory gases exchange with the atmosphere across the porous walls. The higher density of the refresh air than forced it downward into open spaces below the nest and eventually through the nest again. This mechanism works in mounds without obvious vents or closed mounds.
In open mounds the stack effect is working. A large chimney vent is exposed to higher wind velocities than the openings closer to ground. A venture flow then refresh the air into the mound through the ground level openings, then trough the nest and out of the chimney. (Turner 2008)

Mount for ventilation and gas exchange

There is one problem in the old explanation of the termite mounds. There is no evidence that termites regulate the nest temperature with ventilation. There is more evidence that they do not do this. The nests are embedded into the ground soil and if the temperature is measured for a year the conclusion is that the ground heat is the regulator of temperature and not the ventilation.

There is surprisingly even no evidence that support the claim that there mound ventilation means nest ventilation, whether the ventilation is driven by wind or by heat. In new measurements with tracer gases indicate that air in the mound is almost never driven into the nest. This signifies that mechanisms beside ventilation must be involved in mediating the mound's function, respiratory gas exchange.

This new way of how the termite mound works can be conclude that a termite mound is a functional analogue of a human long. Like in the long, in termite mounds multiple layers of subsidiary function are involved in the global function of colony gas exchange. The functional complexity is the reason why earlier models for termite mound failed.

A long is described as a multi-phase gas exchanger where ventilation is one phase which operates in the upper airways. Here the gas exchange is dominated by forced convection driven by respiratory muscles. In the aveoli and aveolar ducts gas exchange is dominated by diffusion cause there is no bulk flow of air. In between these phases is an extensive region of the long which includes the fine bronchi, where neither forced convection nor diffusion dominates flux. This region in the overall control of long function.

Termite colonies have a similar function organization. The ultimate diffusion phase is located in the termites themselves. They are mobile aveoli. The termites are embedded within the nest which comprises numerous galleries separated by thin walls that are perforated by a few large pores (2-3mm). The nest is embedded in a larger reticulum of large diameter tunnels that permeate the mound. The connection between the nest galleries and this reticulum is by a chimney. The reticulum of subterranean tunnels envelops the nest appears to connect to the nest at its base. The air movement in the nest and the subterranean tunnels are dominated by natural convection powered by metabolism that is concentrated within the nest. The reticulum extends to the mound surface to encompass a web of vertically biased surface conduits. These ultimately open to many small egress tunnels that project to the surface and serve as zones of mound porosity. In the surface conduits and egress tunnels, air movement is strongly driven by wind. As in lugs, the colony respiratory function is dominated by a mixed phase regime that is sandwiched between the subterranean structures and the upper parts and peripheral air spaces of the mound.

Pendelluft ventilation is also an aspect what a mound has analogue to a long. In the mixed regime region of the longs weakly driven bulk flows of air between alveolar ducts and between the fine bronchi enhances gas exchange. In termite mounds this pendelluft ventilation is driven by an interaction of buoyancy forces, generated by the colony's heat production, slow transients in turbulent wind energy that penetrate to the lower chimney and subterranean tunnels and the rapid transients that drive flows in the superficial tunnels. Depending on the wind speed direction and the distribution of surface porosity this can impart a downward or an upward pressure on the peripheral parts of the mixed regime phase.

Another analogue can be made whit the so called high frequency ventilation (HFV). This is a respiratory therapy which imposes miniscule volume changes on the long in a much higher frequency. (10 times faster.) This enhance the diffusion and pendelluft ventilation. This can also occur in termite mounds by particular bandwidths of the frequency spectrum of turbulent wind. Large caliber long tunnels in termite mounds can extend up to 2m in length. These resonates strongly at frequencies of 20-30Hz. This is in the range of the bandwidths of the frequency spectrum of turbulent wind which is between 1-100Hz. This resonation of air into the tunnels can be seen as a HFV which could promote gas exchange without large bulk flows of air through the nest. The conclusion is that transient winds at the upper end of the frequency spectrum could do work in the shorter superficial tunnels while lower frequency transients do work in the deeper and longer tunnels.

Termites tightly regulate the nest water balance, which is often undermined by percolation of groundwater in the nest following rains. At the same time termites can regulate oxygen and CO2 very well. Termites accomplish this actively transporting water to the superficial parts of the mound in wet soil, where it is deposited around the egress tunnels. Because it is precisely these regions that should be ventilated most strongly by rapid wind transient, evaporation can be enhanced without increasing respiratory gas flux.
(Turner 2008)

How buildings can be like longs

If building facades will change outside oxygen with inside carbon dioxide then there are very specific filters needed. These are on the marked for an external mechanical long. This ECMO uses polymer filters which like a long change the oxygen and carbon dioxide by concentration differences. The downside is that if there is no high concentration level the change will not happen this makes it only useful for complete closed structures like bunkers or facilities under ground. (Rodrigue-Cruz 2011)

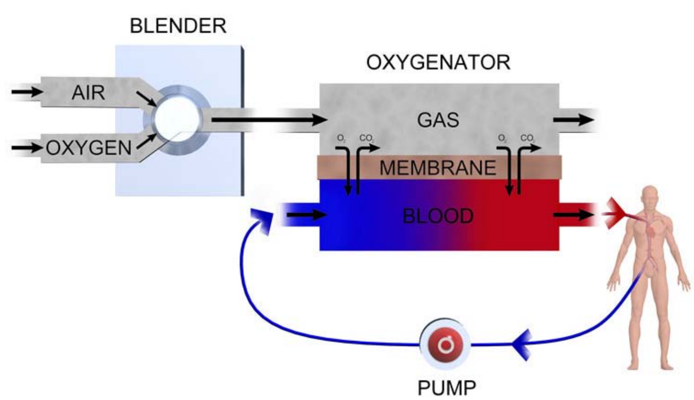

Figure 2: Principle working external long