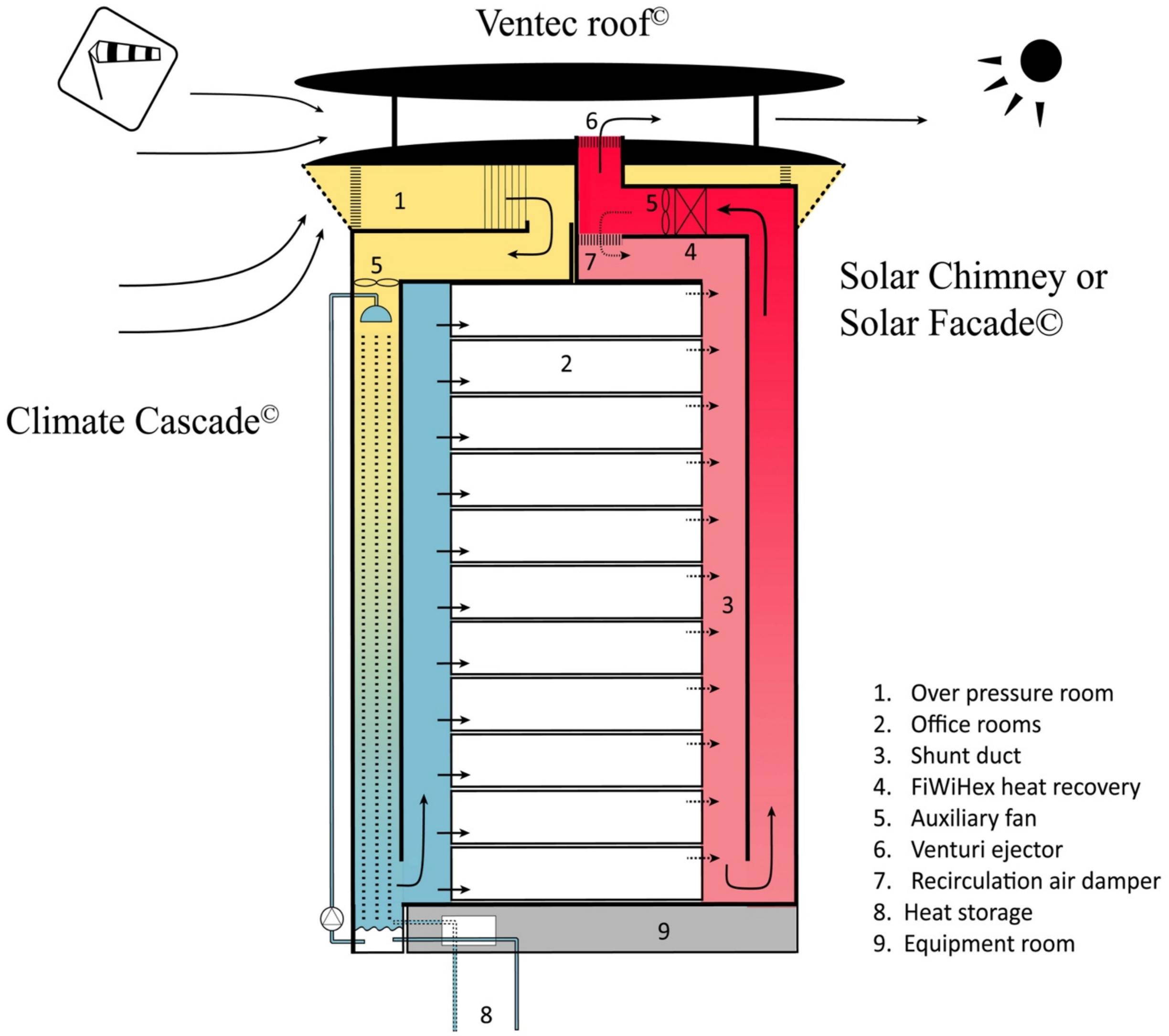
Earth, Wind & Fire learning module

2024



In a sustainable world, people, the environment, and the economy are in balance, ensuring that we do not deplete the Earth. Sustainable development means using the Earth in such a way that future generations can also enjoy it. One of the major factors negatively impacting the environment is the use of fossil fuels. It is clear that the heating, cooling, and ventilation of buildings currently have a significant impact. The current climate technology can barely keep up with the ever-increasing sustainability ambitions within the Dutch context.

It is time for change. The Earth, Wind & Fire concept, developed by B. Bronsema, responds to these rising ambitions. It draws on centuries-old techniques and harnesses natural, non-fossil forces such as wind, sun, and gravity.

The emergence of the Earth, Wind & Fire concept is a result of a conflict between climate technology and architecture. The artistic, intuitive, and creative architect stands in direct opposition to the rational and logical climate technician.
With the development of the Earth, Wind & Fire concept, B. Bronsema has found a balance between the two disciplines.

Unfortunately, the Earth, Wind & Fire concept has not yet achieved the recognition it deserves. This learning bundle aims to enhance the general awareness and basic knowledge of the Earth, Wind & Fire concept among building professionals.

On the left side of the screen, see the table of contents, where clicking provides direct access to the various chapters.

The material includes information modules, references, and images. All these links are listed in the right column, media, on the screen.

Thomas Krcevinac,

Den Haag, September 2024

1. Climate-responsive design

Over the centuries, in regions with a warm climate, the use of natural forces for ventilation became increasingly common. However, with the advent of the Industrial Revolution, climate control machines were developed, and natural ventilation techniques gradually became obsolete.

Since the dawn of architecture, designers have taken environmental factors that affect a design into account: They considered solar exposure when orienting facades; window reveals ensured that windows were largely shaded; mass was added to the construction to absorb more heat, and with the help of smart natural ventilation, a comfortable indoor climate was created.

In this way, architects took responsibility for the indoor climate in their designs. Thought was also given to how residents could influence the indoor climate themselves through windows, shading, or a courtyard.

The emergence of climate technology around the end of the 19th century granted architects immense design freedom. Over the course of the 20th century, architects and climate engineers gradually grew apart. The art of designing within the context of lighting, ventilation, cooling, and heating was largely lost. Slowly, building physics split off from architecture and became its own "forgotten" discipline. Air conditioning provided solutions to all the environmental factors of the time.

This invention addressed almost all issues related to the indoor climate. No longer were heavy constructions and small windows the norm; instead, lightweight structures such as steel were used and it became possible to create large windows on the south facade.

This shift was particularly noticeable in commercial buildings. It was no longer the norm to use small windows to block out solar heat in the summer and to utilize stored solar heat in heavy constructions during the winter. New construction methods allowed architects to create fully glazed facades. While this was fantastic for admitting daylight, it was a disaster for cooling and heating.

Figure 1 Bauhaus in Dessau

A building was no longer responsible for its own indoor environment. That became the task of climate control machines such as the air conditioner and the ventilation system.

Modernism, the architectural movement associated with the Bauhaus, paid much attention to the user experience. The French architect Le Corbusier compared a house to a machine, but unfortunately, not as a climate machine, rather as a living machine. Here, the architecture of the house dictates the lifestyle of the user through the specific placement of different spaces and their corresponding functions.

Nevertheless, in some of his designs, particularly affordable residential towers, Le Corbusier took solar exposure into account. By omitting certain window sections in the facade, shade was created. Le Corbusier had learned to use sunshade in fully glazed facades after earlier large overheating problems in the Salvation Army Hostel in Paris (1933), which had to be renovated.

Figure 2 Unité d'Habitation with passive sunshade

The "sustainable" aspect of a design became the domain of building physics and installation technology, while it is architecture that can have the greatest impact on a sustainable design.

This worked well for a while, until the energy crisis began in the 1980s. The climate control machines that had previously run at full capacity became too expensive to keep on all day. Soon, the first insulation measures were implemented to save energy.

Unfortunately, too little attention was given to ventilation. Not long after, users of these buildings began experiencing symptoms such as dizziness, dry eyes, sore throat, fatigue, concentration problems, and tiredness. Eventually, the World Health Organization investigated these symptoms and linked them to ventilation issues. It was found that up to 30% of new and renovated buildings worldwide were associated with these symptoms. These symptoms became known as Sick Building Syndrome and were caused by inadequate ventilation.

About 100 years later, natural air conditioning is making its comeback, in the form of the Earth, Wind & Fire concept.

The name Earth, Wind & Fire symbolizes the energy of the earth, wind, and sun. Notably, water is absent from this list of natural elements. Water is essential to the concept but serves as a medium. The elements "Earth, Wind & Fire" function as energy sources.

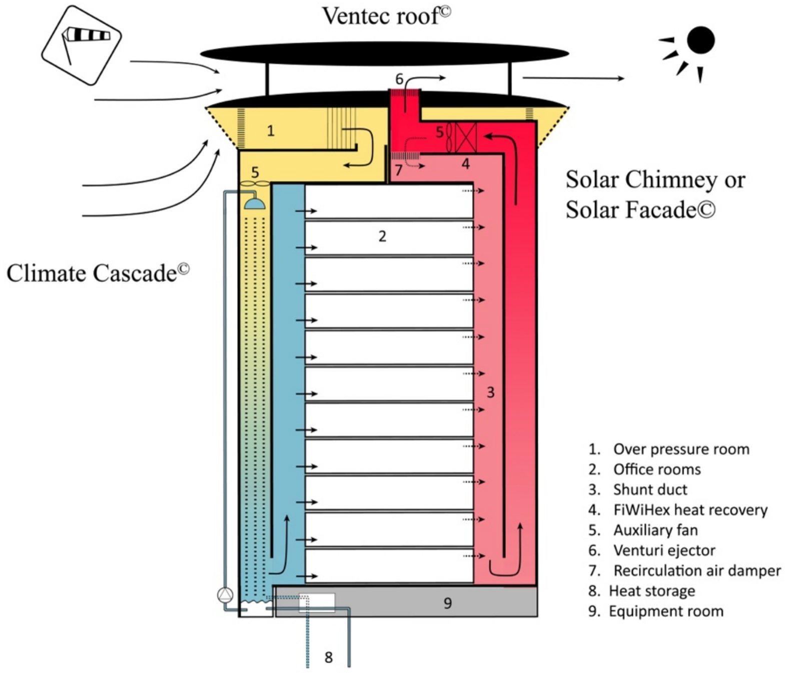
The concept aims to bring architects and climate engineers closer together once again.

The Earth, Wind & Fire concept introduces three key components. These components—the Ventec roof, the Climate Cascade, and the Solar Chimney—are integrally involved in the design of a building and thus become part of the architecture. A building should be designed as a climate machine.

B. Bronsema states in his dissertation: A building should be designed as a climate machine. "Climate technology is no longer subordinate to architecture; it IS architecture."

2. Anatomy of the Concept

The three elements: Earth, Wind & Fire are represented by three components: the Ventec roof, the Climate Cascade, and the Solar Chimney. These systems were developed separately and can be implemented independently. However, together they form the comprehensive Earth, Wind & Fire system.
In this section, the three concepts are succinctly introduced. The concepts are further elaborated in the informational modules: I01, I02, & I03.



Ventec Roof
By utilizing positive wind pressures, the Ventec roof supplies ventilation air to the building. Negative wind pressures pull the used ventilation air out of the building. The extraction of air is achieved through a narrowing that creates the Venturi effect. This occurs in the Venturi ejector. (6)
The fresh ventilation air is supplied to the pressurized chamber. (1). From the pressurized chamber, with the possible assistance of an auxiliary fan (5), the supply air is directed into the Climate Cascade.
See informational module I01 Ventec Roof – see appendix 1

Climate Cascade
In the Climate Cascade, ventilation air is accelerated, cooled or heated, and dried or humidified through a spray system. Cooling or heating is facilitated by the temperature of the droplets. Droplets at approximately 13 degrees cool the warm outside air in the summer and heat the cold air in the winter.

The Climate Cascade is essentially a gravity-activated heat exchanger.
Residual heat is extracted at the bottom of the Climate Cascade and stored in an Aquifer Thermal Energy Storage (ATES) system (8). The fresh ventilation air is distributed over the occupied spaces through a supply shaft (2).

See informational module I02 Climate Cascade – see appendix 2

Solar Chimney
In the Solar Chimney, ventilation air is heated. The heated ventilation air rises, effectively pulling the ventilation air through the Shunt channel (3) out of the occupied spaces. At the top of the Solar Chimney, solar heat is transferred to circulating water and stored in the ground.

See informational module I03 Solar Chimney – see appendix 3

3. Application

Most commercial buildings and new residential constructions use a central mechanical system for air handling. This air handling is carried out using an air handling unit. These installations, depending on the function of a building, are often quite large. Therefore, a separate technical room is usually created for climate control systems. To allow for the intake of clean air, the technical room is typically located on the top floor.

The Earth, Wind & Fire concept replaces this mechanical system. The Solar Chimney, Climate Cascade, and Ventec Roof work together as a comprehensive system.

When an Earth, Wind & Fire concept is chosen, the architect is responsible for developing the building as a climate machine. This responsibility provides the architect with more design freedom because there is less need to accommodate current climate control technology. The Ventec Roof eliminates the need for a specific technical room.

In addition to new construction projects, the Earth, Wind & Fire concept is also applicable in major renovations. Existing facades can be converted into Solar Chimneys, and vertical ventilation shafts can be used as Climate Cascades.

Since the Earth, Wind & Fire concept derives its "energy" from the natural forces of wind and sun, the built environment surrounding the project location is very important. The Solar Chimney and Ventec Roof can perform optimally when a building is minimally obstructed by surrounding buildings.
The operation of the Ventec Roof is highly dependent on the height difference between surrounding buildings. For optimal performance, the wind must have free access around the Ventec Roof.

When considering the application of the Earth, Wind & Fire concept, the amount of solar radiation on a facade is a critical factor. The operation of the Solar Chimney is entirely dependent on the sun shining on the chimney. If the Solar Chimney’s sun exposure is blocked by surrounding buildings, the chimney will need to be heated mechanically, resulting in high energy consumption. Therefore, it is recommended to conduct a sun study for densely built environments.

4. Design principles

The Earth, Wind & Fire concept is typically designed based on the project's requirements specification. In a requirements specification, there are often demands related to the project's sustainability ambitions and the desired amount of ventilation. The Earth, Wind & Fire concept is currently only applied when traditional ventilation methods cannot meet the sustainability ambitions. When choosing to apply the Earth, Wind & Fire concept, it is essential that the architect is aware of the considerations involved. The consultancy firm ABT has established several design principles for this purpose.

Principles
The key design principles are:
- Orientation of the Solar Chimney on sun-exposed facade surfaces;
- Preferably position the Climate Cascade and Solar Chimney close to each other and as integrated into or adjacent to the building as possible;
- The height of the Ventec Roof should be suitable for free wind flow from all directions;
- Technical room at the base for ATES facilities, spray pump, heat exchanger, heat pump system (in the case of water/water), transport pumps for the heat network, and connection to the air distribution system in the crawl space;
- Technical room at the top for auxiliary fans, heat exchanger, heat recovery, heat pump system (in the case of air/water), and connection to the Venturi ejector in the roof.

Design Criteria
- The Climate Cascade is sized based on 80% of the maximum required ventilation capacity;
- In buildings higher than 12 stories, it is necessary to use a Climate Cascade every 6 stories due to the pumping power required to supply the droplet system in the Climate Cascade;
- The Solar Chimney is sized based on thermal and energy needs;
- The Solar Chimney performs better when it is oversized;
- The Solar Chimney has a minimum depth of 650 mm to allow for maintenance;
- Using a lightweight construction for the Solar Chimney is 10% more efficient than a heavy construction. Note: This relates to the function of a building. Offices typically do not require heating at night. Because a heavy construction releases heat more slowly, this residual heat is lost;
- Choose glass with a high g-value to achieve maximum solar gain;
- Choose glass with a low u-value to minimize heat loss to the outside air.

5. Available Literature with references

(Bron: EWFlab.nl)

Earth, Wind & Fire
Dissertation Ben Bronsema, TU Delft, 7 juni 2013 (Dutch)

Earth, Wind & Fire – 1, (English)
Earth, Wind & Fire – 2, (English)

HANDBOEK EWF versie november 2023 (Dutch)
The Handbook provides a description of the EWF concept and offers guidelines for design and calculations.

Articles

Rotterdams universiteitsgebouw wordt 'klimaatmachine' dankzij baanbrekend ventilatiesysteem

Studeren in een boomhut – Bouwwereld 2023-3

"Drive" – Wat drijft de huidige ingenieur? – De Ingenieur (jan. 2023)

"Vol inzetten op natuurlijke klimatisering van hoogbouwwoningen", door Yvette Watson

Tweede gebouw met EWF geopend!

Research

Lessen uit de monitoring van BREEZE, nu Four Elements Hotel. Het eerste EWF – Gebouw
Hotel Breeze – monitoring prestatie EWF systeem
Ben Bronsema - Green Building Engineering

Earth, Wind & Fire in gestapelde woningbouw
A study on the added value and feasibility of the EWF concept compared to a conventional ventilation system in multi-story residential buildings in an urban environment. Bronsema Consult / ABT Engineering in Building Technology, February 24, 2020.

Earth, Wind & Fire – Design manual
Graduation project Peter Swier, June 11th, 2015 (English)

Video's

Het Earth Wind & Fire concept in een eerder ontwerp van hotel breeze

Hotel Breeze in Amsterdam | Eerste energieneutraal hotel ter wereld

Earth, Wind & Fire concept: Langeveld Building- Campus Woudestein

Ben Bronsema 75jr: promoveert op Earth, Wind & Fire

Onderzoeker Ben Bronsema promoveert op Earth, Wind & Fire

Air conditioning with wind, sun and water: Ben Bronsema at TEDxDelft

Case studies

Hotel Breeze Amsterdam

Langeveld Building Rotterdam

Appendix 1. The Ventec Roof
Appendix 2. Climate cascade
Appendix 3. Solar chimney

Ventec roof

Kennisbank Klimapedia
Author: Thomas Krcevinac

The concept of utilizing natural forces to ventilate a building has long been established.
One of the earliest forms of 'natural cooling' can be traced back to the 13th century BC. The Egyptians used palm trees as wind catchers – see Figure 3 – to ventilate and cool buildings.

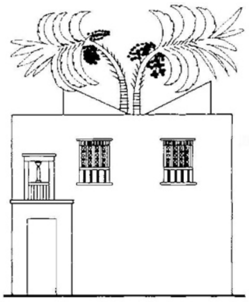


Figure 3 Palm tree as windcatcher

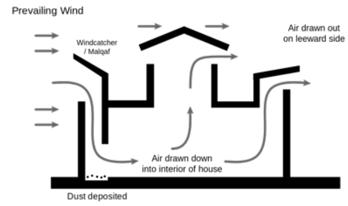


Figure 4 Schematic representation of the functioning of a malqaf

The use of a palm tree as a wind catcher for ventilation evolved into a 'malqaf.' The malqaf became a part of Islamic architecture and spread across the Middle East, India, North Africa, and Spain.

In Iran, the wind catcher, now called a Badgir, was further optimized by utilizing both wind direction and solar heat. As the wind flows past the Badgir – see Figure 4 – the hot and polluted air is directed outside, while cooler air is drawn inside.
At the base of the wind catcher, often near the entrance of a building, there is a water reservoir. The warm, dry air drawn in from outside is cooled and humidified in this way.

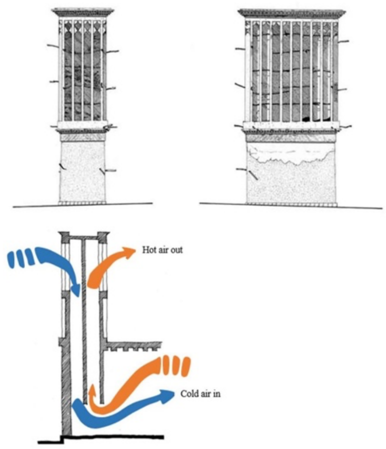


Figure 5 Principle of a Badgir

Modern Wind Catcher: The Ventec Roof

The Ventec Roof derives its name from the Latin words "Vent" and "Tect," meaning Wind and Roof. The name also refers to Ventilation & Technology.

The principle of the Ventec Roof (B. Bronsema 2012) is similar to that of the Badgir. Positive wind pressure supplies fresh air to the Climate Cascade, while negative wind pressure extracts the polluted air through the Solar Chimney—see Figure 6.

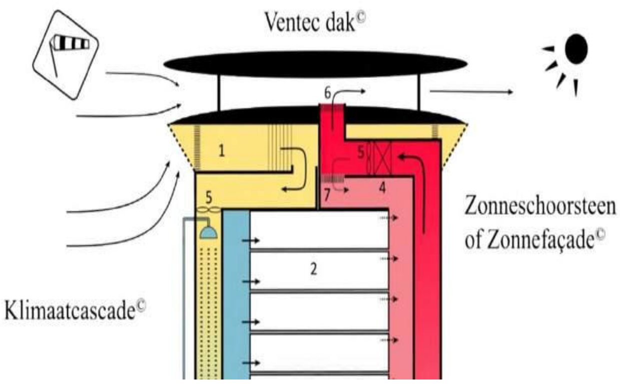
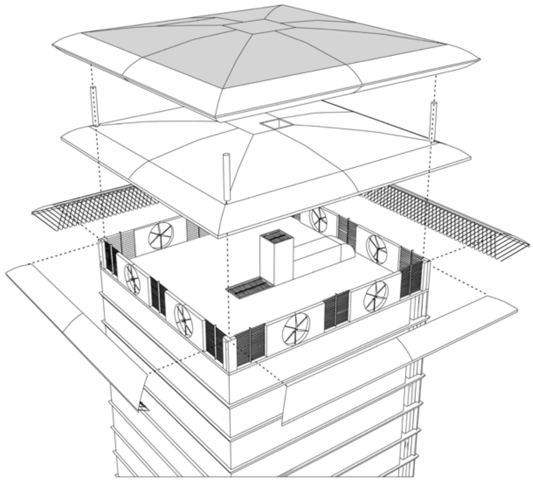


Figure 6 Principle of the Earth, Wind & Fire concept

Components



The structure of the Ventec Roof, as shown here, illustrates the various components. The views of the Ventec Roof are identical, as it must function in all wind directions.

Venturi-ejector (1)

As previously described, the Ventec Roof utilizes negative wind pressures to exhaust polluted air through the Solar Chimney. This extraction occurs in the Venturi ejector.

The Venturi ejector employs a Venturi: a narrowing in a flow channel. Because the same volume of air must pass through a smaller channel, its speed increases. This increase in speed results in a pressure drop. Due to this pressure drop, polluted ventilation air can be drawn out through an opening in the Venturi.

A horizontal separation (2) between the Venturi ejector and the overpressure space ensures that the supply and exhaust air do not mix.

Overpressure chamber (2)

Fresh air is supplied to the building through the overpressure chamber. The outside air enters the overpressure chamber via automated air valves (4).

Since the chamber must always remain under positive pressure, it is essential that all air valves can open and close. The air valves automatically open on the windward side and close on the leeward side. The supply air flows through the overpressure chamber, passes through a filter to block debris and insects, and then continues to the Climate Cascade.

The Earth, Wind & Fire concept was conceived as an energy-neutral ventilation system. The Ventec Roof enables the generation of energy for water pumps and auxiliary fans using solar and wind power.

Energy generation

For solar energy generation, a thin PV film (6) has been applied as the roofing material of the Ventec Roof.

By equipping the Ventec Roof with wind turbines (5), the wind is harnessed to its full potential. During the development of the Ventec Roof, research was conducted on the use of wind turbines. The performance of these turbines is highly dependent on the building's height, the urban environment, and the project location.

Disappointing performance results of the wind turbines have led to a significant decline in interest in this development.

Currently, the wind turbines do not achieve the desired outcomes, but when that changes, incorporating wind turbines into the Ventec Roof will be a step closer to achieving energy neutrality.

Dimensions

The dimensions of the Ventec Roof depend on the size of the overpressure chamber, which in turn is determined by the building's total ventilation capacity.

The overpressure chamber can be sized using the formula for the area of a duct.

$$A = q_v / v \qquad (m^2)$$

Where v (average wind speed) = 3.6 m/s and the louver height is 1.0 m.

Since the supply of outside air is dependent on wind direction and is optimal when it flows perpendicular to the louver, the louver length is doubled as a rule of thumb. During the development of the Ventec Roof, it was assumed that, depending on the prevailing wind direction, half of the louvers in the overpressure chamber would be closed, making only half of the air louvers usable. Therefore, the louver length must be twice as long. The wind will rarely strike the surface at a perfect right angle but rather at an angle. The required surface areas to meet a certain ventilation capacity are presented in Table 1.

Ventilatiecapaciteit	*m3/h*	*20.000*	*30.000*	*40.000*	*50.000*	*60.000*	*70.000*	*80.000*	*90.000*	*100.000*
Aanzuigsnelheid	m/s	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Roosteroppervlak	m2	5,56	8,33	11,11	13,89	16,67	19,44	22,22	25,00	27,78
Roosterhoogte H	m	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0	1,0
Roosterlengte	m	5,56	8,33	11,11	13,89	16,67	19,44	22,22	25,00	27,78
*Roosterlengte*2*	m	11,11	16,67	22,22	27,78	33,33	38,89	44,44	50,00	55,56
Maat A	m	3,33	4,08	4,71	5,27	5,77	6,24	6,67	7,07	7,45
*Voetafdruk A*A*	m2	11,11	16,67	22,22	27,78	33,33	38,89	44,44	50,00	55,56

Table 1 General Sizing of Overpressure Chamber and Ventec Roof - EWF Handbook November

Architecture

The Ventec Roof challenges architects to design a distinctive crown for the building. Apart from the required louver area and footprint, the architect has complete design freedom.

The Ventec Roof as a crown is emblematic of the Earth, Wind & Fire concept.
The crown offers an opportunity to convey sustainability. Therefore, it is desirable that the Ventec Roof is not concealed but rather stands out.

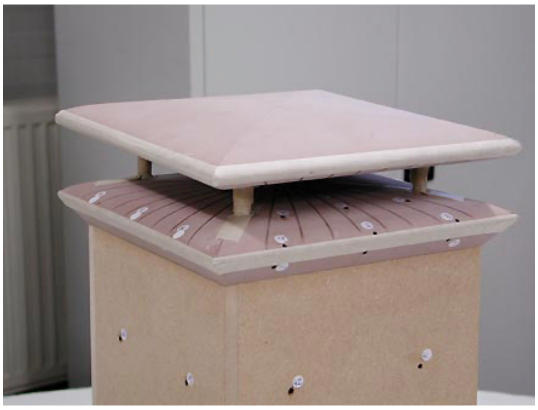


Figure 1 Test model of the Ventec roof

Figure 2 Ventec roof on top of the Langeveld Building

The Climate Cascade

Kennisbank Klimapedia
Author: Thomas Krcevinac

Introduction

The Climate Cascade utilizes gravity (Earth) for the drying, humidifying, cooling, and heating of ventilation air. Within the Climate Cascade, air can be transported without the use of fans, and cooling or heating occurs with high efficiency in terms of both cooling and heating factors.

The "Earth" theme represents not only gravity but also the mass of the earth itself. This mass can be used as a source or storage for thermal energy – see the section on Thermal Energy Storage.

Air handling unit

In most commercial buildings, the heart of traditional ventilation systems is the air handling unit. This central ventilation system supplies fresh air and exhausts polluted air.

In an air handling unit, several processes occur: the supply air is filtered, heated or cooled, humidified or dried, and heat recovery from the exhaust air is employed. Modern air handling units also utilize a heat exchanger that extracts heat from the exhaust air and transfers it to the supply air. Since the supply air must pass through multiple components of the air handling unit, large fans are required – see Figure 9. This ventilation capacity results in high energy consumption.

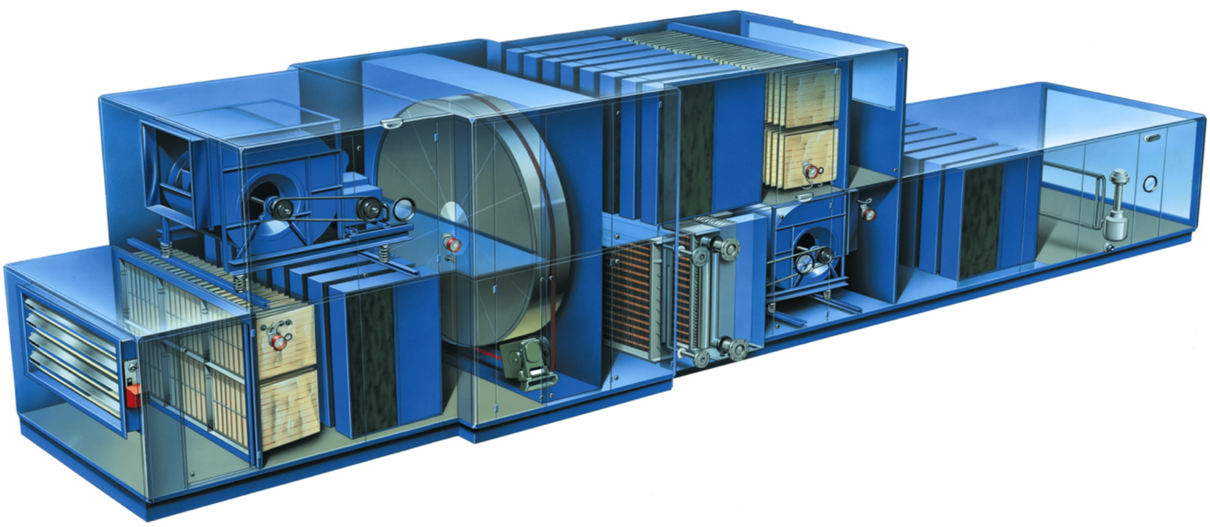


Figure 9 Cross-section of an air handling unit

Climate Cascade as Air Handling Unit

In the Earth, Wind & Fire concept, the Climate Cascade replaces the air handling unit as the core of the ventilation system.

The Ventec Roof supports the gravity-activated droplet cascade by supplying fresh ventilation air. To ensure continuous ventilation, an axial fan is installed at the top of the Climate Cascade. This fan can be activated if the Ventec Roof does not supply sufficient ventilation air, such as during calm wind conditions.

The droplet cascade accelerates the ventilation air to a certain speed, which results in a specific pressure increase. This pressure buildup allows the ventilation air to flow through the building.

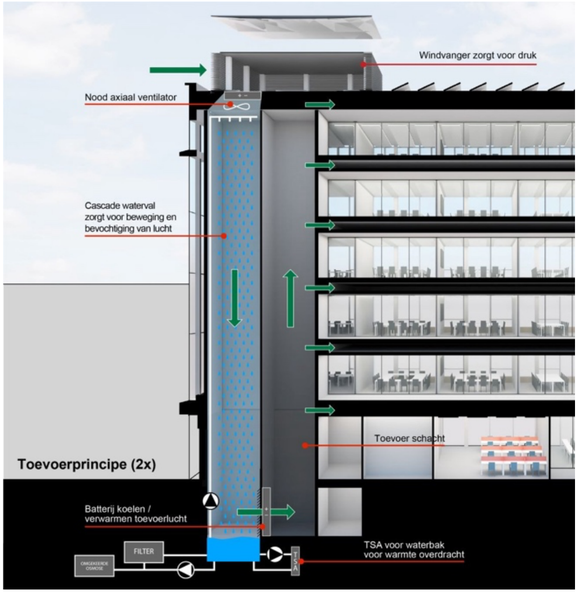


Figure 10 Schematic cross-section of the supply principle. Image: Paul de Ruiter architects

Similar to a traditional air handling unit, the Climate Cascade adjusts the ventilation air by cooling or heating, drying or humidifying, and filtering it as needed..

Waterfall

The gravity-activated waterfall – see Figure 11– possesses multiple properties. To cool or heat ventilation air as needed, the waterfall functions as a heat exchanger.

The falling water droplets, at approximately 13°C, act as a heat exchanger with a large heat exchange surface area. This surface area is the combined area of all the falling water droplets.

Figure 11 Gravity-activated waterfall system in the Climate Cascade. Photography: Eric Fecken

What makes the Climate Cascade unique as a heat exchanger is its ability to scale the heat exchange surface area. In traditional heat exchangers, this surface area is fixed, but by turning the sprayers on or off, the surface area can be increased or decreased. This allows for the adjustment of ventilation capacity and the temperature gradient of the droplets while maintaining consistent cooling performance.

During the summer months, the falling water droplets provide cooling, and during the heating season, they heat the ventilation air. If the pressure generated by the Ventec Roof is insufficient to provide the required overpressure, auxiliary fans are activated. These auxiliary fans are axial fans – see Figure 12 – allowing air to pass through without pressure loss when the fans are not operating

Auxiliary fans

When the pressure generated by the Ventec Roof is insufficient to provide the necessary overpressure, auxiliary fans are activated. These auxiliary fans are axial fans – see Figure 16 – allowing air to pass through without pressure loss when the fans are not in operation.

Figure 12 Auxiliary fans

Air cooling

To maintain a comfortable indoor climate, cooling during the summer months is desirable. The warm (humid) outside air contains a high percentage of water vapor.

As the outside air enters the Climate Cascade via the Ventec Roof, the water vapor begins to condense. The heat released during the condensation of moisture from the air is transferred to the falling water droplets. These droplets then transfer the heat to the thermal energy storage, where it is stored for use during the winter months.

A favorable side effect of condensing moisture from the ventilation air is the drying of the air.

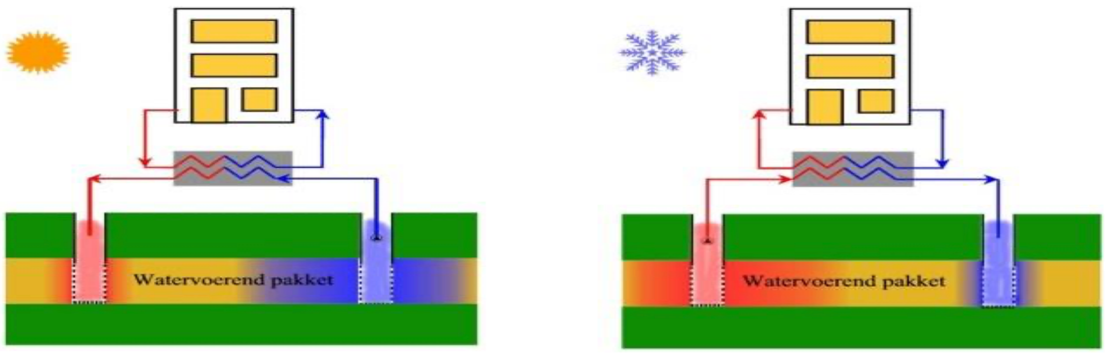
Thermal Energy Storage

On particularly warm summer days or cold winter days, the ventilation air passing through the waterfall may not reach the desired indoor temperature.

Since there is typically a demand for heating in winter and potentially a need for cooling in summer, it is beneficial to use seasonal thermal energy storage. This approach reduces the need for generating heat or cooling (in total) at the time of demand using (fossil) energy sources – see Klimapedia.nl: Thermal Energy Storage in the Ground.

On such days, the ventilation air may need to be further cooled or heated using a thermal energy storage system (TES) – see Figure 13. This installation is located at the base of the Climate Cascade – Figure 10.

In winter, in addition to the heat from ground storage, heat from the Solar Chimney is also utilized.



.

Figure 13 Principle: Heat and cold storage Source: Stichting Kennisbank Bouwfysica: Klimaatinstallaties "Koeling"

Architecture

The Climate Cascade is typically constructed from concrete, but alternative materials are also possible. The interior surface must be finished smoothly. Architecturally, the inner wall of the Climate Cascade functions as an exterior wall that is continuously exposed to water. Therefore, the interior of the Climate Cascade must be finished with a waterproof coating. This coating should have mold-resistant, odorless, washable, and anti-adhesive properties.

Insulating an indoor Climate Cascade is not necessary.

Bottlenecks

The Climate Cascade is regarded as the core of the concept. Should this "core" fail to function for any reason, the entire ventilation system will cease to operate effectively.

It is therefore essential that the Climate Cascade is easily accessible for maintenance and inspections. Given that the Climate Cascade essentially functions as a ventilation duct, maintenance and inspection are primarily required for the spray system. In the "Four Elements" hotel, a collapsible work platform has been installed at the top of the Climate Cascade to facilitate these tasks.

Sizing

The surface area of the Climate Cascade and supply shaft can be determined by the air velocity and the total ventilation flow rate—refer to the formula below.

$$(2) \qquad A = q_v / v \qquad (m^2)$$

Research by Ben Bronsema indicates that the Climate Cascade performs optimally at air velocities between 3.5 $m.s^{-1}$ and 4.5 $m.s^{-1}$. For buildings with more than 8 floors, it is recommended to implement multiple Climate Cascades. This is due to the exponential increase in pump power required as the length of the water pipeline increases.

The air velocity decreases as the ventilation air flows from the Climate Cascade through the heat exchanger into the supply shaft. In the supply shaft, air velocities between 1.5 $m.s^{-1}$ and 2.5 $m.s^{-1}$ are maintained. Therefore, the surface area of the supply shaft must be larger than that of the Climate Cascade.

Calculation Example
Total ventilation flow rate: 30,000 m^3/h
Air velocity: 3.5 $m.s^{-1}$
Calculate the surface area of a square Climate Cascade and determine the width and depth:
A=qv/V A=30,000/ 3.5 = 2.38 m2

Given that A=D×B, so D =1.54 m and B=1.54 m

The Solar Chimney

Kennisbank Klimapedia
Author: Thomas Krcevinac

The sun, an inexhaustible source of energy, is often blocked as much as possible in commercial building construction. Stringent insulation regulations, which buildings are required to comply with, frequently result in solar heat entering the building needing to be mechanically cooled. All of this residual heat is wasted, and additional energy is required to power the cooling systems.

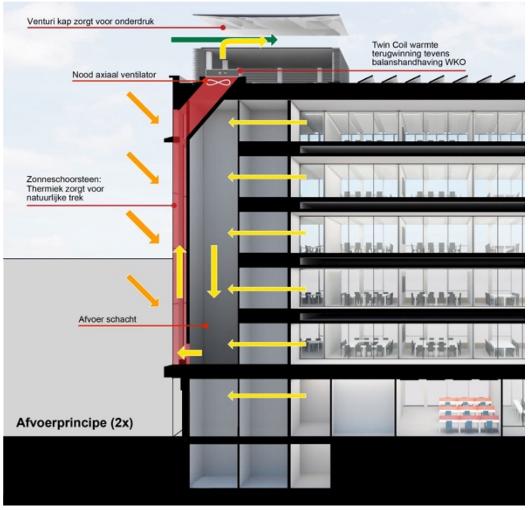


Figure 14 Schematic representation of the drainage principle.
Image: Paul de Ruiter architects

Exhaust

The solar chimney utilizes solar heat to stimulate natural draft. This draft essentially draws the used ventilation air out of the building.
The Ventec roof assists the solar chimney in exhausting the ventilation air by creating a vacuum effect – see Figure 14.

Similar to the Climate Cascade, auxiliary fans ensure that the necessary air exhaust is maintained under all weather conditions.

Heat Exchanger

The solar chimney acts as a heat exchanger, where the walls heated by the sun transfer heat to the air. The function of the building influences the composition of these walls.

Behind the glass wall, there is an absorber. This layer serves as additional heat storage. This could, for instance, be an aluminum plate or even a solar panel.

Heat Recovery

The used ventilation air is extracted via the exhaust shaft, which is connected at the base to the solar chimney. It is crucial that this solar chimney is oriented towards the south. The solar chimney is constructed from insulated glass. The sun heats the air inside the chimney, causing it to rise and create a draft at the bottom, effectively acting as an exhaust fan. The Ventec roof functions like a wing, aiding in extracting the used air from the building.

At the top of the solar chimney, the heat from the building, as well as the solar heat in the chimney, is recovered using a heat recovery system (HRV). The collected heat is stored in an aquifer thermal energy storage (ATES) system. Depending on the season, this heat is used to either warm or cool the ventilation air:

- Winter season: The heat is transferred to a heat exchanger in the air supply, pre-warming the cold ventilation air.
- Mid-season: The heat is distributed between the heat exchanger in the air supply and the water in the spray system. The heated water is then used as a heat source for the heat pumps.
- Summer season: The heated water from the ATES is used as a heat source for the heat pumps and, if necessary, for hot tap water. Any excess heat is returned to the ground to restore the energy balance.

Night Ventilation – Residential Buildings

Ventilation in residential buildings operates continuously, day and night. In many cases, residents are absent during the day, and ventilation demand typically increases in the late afternoon when occupants return home, just as solar heat decreases. To release the solar heat accumulated during the day at night, the solar chimney is equipped with a Trombe wall – see Figure 15. This heat is used to facilitate night ventilation.

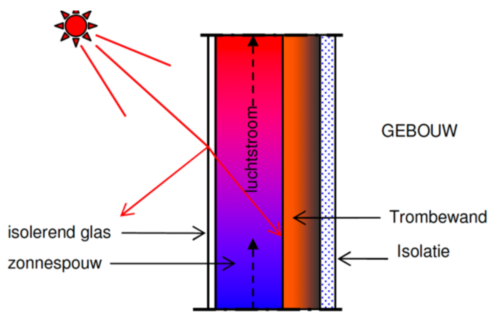


Figure 15 Heavy construction – Trombe wall

Night Ventilation – Commercial Buildings

In commercial buildings, the ventilation system is predominantly used during the day. When occupancy levels are high, it is often desirable to maintain ventilation for a certain period after use. In such cases, night ventilation is not necessary. If a solar chimney is equipped with a Trombe wall in this context, it would result in unnecessary ventilation.

To prevent this waste of heat, commercial buildings typically opt for a lightweight wall. Excess residual heat is transferred to thermal storage via an absorber.

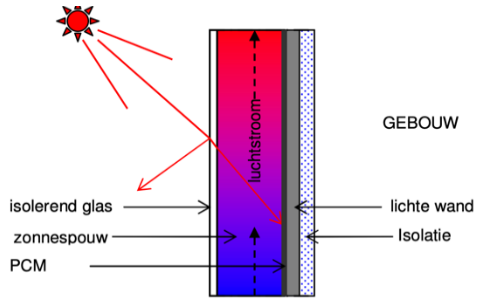


Figure 16 Light construction – PCM al absorber

In certain cases, night ventilation is desirable. In these situations, a layer of phase change material (PCM) is applied to the lightweight wall – see Figure 16. This layer releases the stored heat at a later time.

If night ventilation is not required, a metal plate can be installed on the rear wall – see Figure 17. This plate absorbs heat and immediately releases it into the air. The residual heat is extracted at the top of the solar chimney via a heat exchanger.

Figure 18 illustrates how photovoltaic (PV) cells can be used as the front surface of the solar chimney. A significant portion of the captured solar radiation is converted into heat. However, the efficiency of PV cells decreases as temperatures rise. This variant was not further investigated in the dissertation of B. Bronsema.

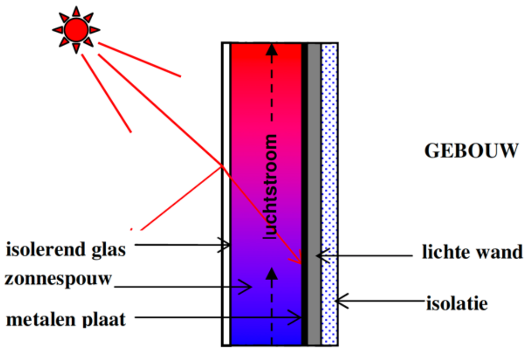


Figure 17 Light construction – Metal plate as absorber

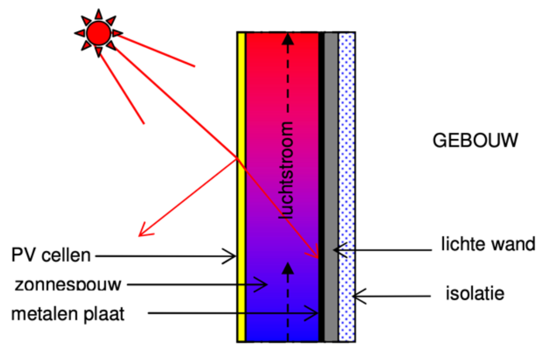


Figure 18 Light construction – With PV cells

Energy generation

When the solar chimney is equipped with PV panels, it also contributes to renewable energy production. However, due to the relatively low energy yield, it is important to prioritize more efficient energy generation methods on the roof and façades. Given that the use of PV panels is not yet circular, it is crucial to limit their application. This aligns with the underlying philosophy of the Earth, Wind & Fire concept.

Reducing a building's energy consumption through the Earth, Wind & Fire concept is more sustainable than compensating for energy use with non-circular PV panels.

Figure 19 demonstrates how PV panels function as absorbers behind insulated glass, in what is referred to as the solar chimney 2.0. One of the issues that arises with the PV solar chimney 2.0 is that during times of low sun angle, the rear wall of the solar chimney is partially shaded, as shown in Figure 20. This reduces the effective surface area of the PV panels and consequently decreases energy production.

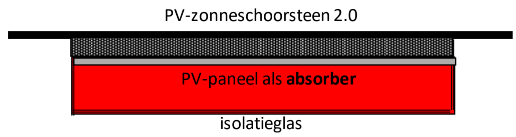


Figure 19 Schematic cross-section: solar chimney with solar panel

Given the relatively low output of PV panels in a solar chimney, particularly in comparison to roof-mounted PV panels, it can be concluded that the solar chimney 2.0 is not a viable solution for buildings where the required energy can be entirely generated by PV panels on the roof.

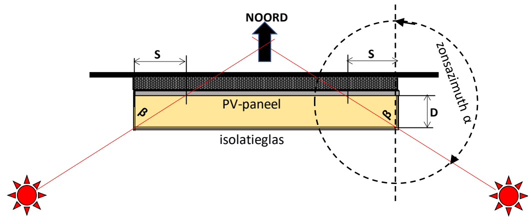


Figure 20 Schematic cross-section: shadow

Urban Environment

The performance of the solar chimney is influenced by its surroundings and building-specific characteristics, such as the number of floors, shape, energy demand, and ventilation capacity.

The optimal orientation of the solar chimney lies between southeast and southwest. To harness solar heat throughout the day, it is possible to implement multiple solar chimneys. A solar chimney does not necessarily need to be integrated into the façade; it can also be designed as a conservatory.
While the Climate Cascade is primarily sized based on aerodynamic performance, the solar chimney is sized based on energy performance. This is because solar heat significantly contributes to a building's energy consumption.

If the location lacks sufficient solar radiation for a traditional solar chimney, the use of a "hidden solar chimney" variant is a viable alternative.

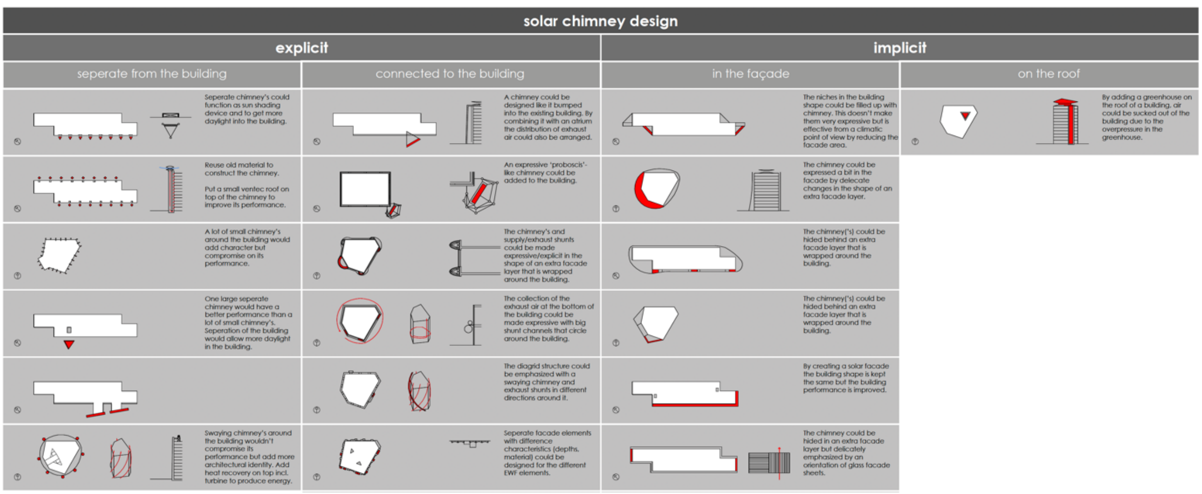


Figure 21 Different design variations of the Solar Chimney. Source: Earth, Wind & Fire - Design manual

Variant: The Hidden Solar Chimney

A hidden solar chimney is an internal shaft where thermal draft is generated by heating the air at the bottom of the chimney. This heat is supplied by PVT panels on the roof. See Figure 22.

This version of the solar chimney offers a solution where a traditional solar chimney is not feasible due to architectural constraints or when buildings have heritage status. The hidden solar chimney can often be integrated into an existing shaft.

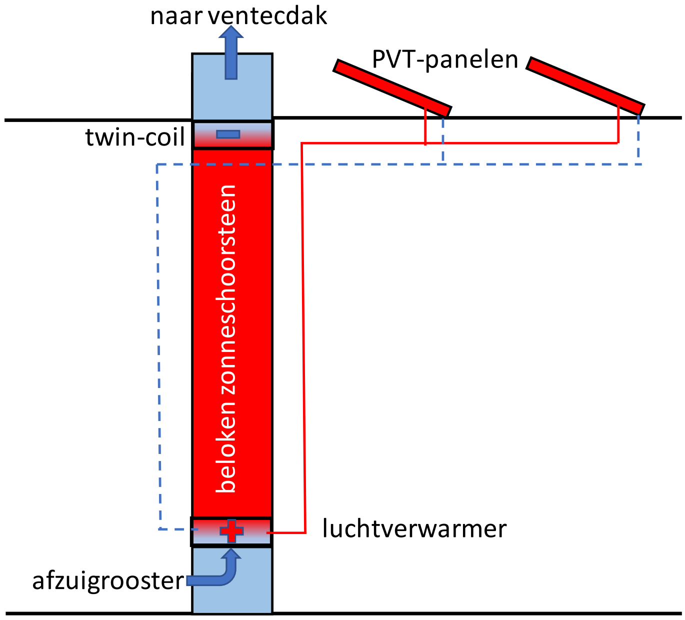


Figure 22 The hidden solar chimney

Glass facade

For optimal performance, the glass should be selected according to the following criteria:

- The highest possible g-value for maximum solar transmission.
- The lowest possible U-value for minimal heat loss to the outside air.

To ensure the optimal functioning of the solar chimney, it is essential that the glass wall remains clean. To prevent contamination, a glass coating has been applied. This coating is anticorrosive and dirt-repellent, contributing to performance retention and reducing the maintenance required to clean the solar chimney. An example of such a coating is the sustainably biodegradable Vindico PV+ coating. This coating has anti-reflective properties, which increase light transmission by up to 5%.

Materialization

The solar chimney primarily consists of glass. The larger the glass surface, the better the solar chimney functions. A clear example is the Langeveld building, where the solar chimney is prominently visible beneath the Ventec roofs.

Figure 22 Langeveld Building Rotterdam

Sizing

The solar chimney operates most efficiently at an airspeed between 1.0 m/s and 1.5 m/s. Only when the solar chimney reaches a height of 8 or more stories can airspeeds up to 2 m/s be used. As the shunt channel must remain in balance with the solar chimney, it operates at the same airspeed.

	Minimum ($m.s^{-1}$)	Maximum ($m.s^{-1}$)
Climate cascade	3,5	4,5
Supply shaft	1,5	2,5
Solar Chimney	1,0	1,5
Solar Chimney n>8	1,0	2,0
Shunt shaft	1	1,5 (n>8 (2,0))

The solar chimney must be accessible for maintenance and cleaning, and therefore requires a minimum depth of 650 mm, in accordance with occupational health and safety regulations.

Calculation example
The total amount of ventilation air to be extracted is 30,000 m³/h.
Air velocity: 1.3 m/s.
To calculate the surface area of the solar chimney, we use the formula:
A= qv/v Thus:
A= 30.000/1,3 = <u>6,41 m^2</u>
Given that A = B*D, where B is the width and D is the depth, with D = 0.650
we can determine B as follows:
B = A/D = 6.41/0.650 = 9.86 m

Therefore, a suitable width for the solar chimney is approximately 10 meters.