Natural Ventilation in Buildings

–architectural concepts, consequences and possibilities

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Natural ventilation in buildings relies on wind and thermal buoyancy as driving forces. Humankind has used these driving forces throughout history to create the desired thermal environment and to transport away undesired contaminants. The technique we take advantage of to control and adjust our indoor climate has grown ever more sophisticated. This technique has in the 20th century been dominated by mechanical ventilation and air conditioning. These technologies have developed into systems of great complexity with an increasing number of components, need for space, and use of energy. Despite this, many of the mechanical systems do not manage to deliver the desired indoor climate. Because of this contradiction, the focus has again been put on simpler, more robust, and less energy consuming solutions.

The driving pressures derived from wind and thermal buoyancy are low compared to those produced by fans in mechanical ventilation systems. It is therefore necessary to minimise the resistance in the airflow path through the building. Thus, the building itself, with its envelope, rooms, corridors, and stairways, rather than the ducts familiar from mechanical ventilation systems, is used as air path. A natural ventilation concept is therefore highly integrated in the building body and will consequently have influence on building design and architecture.

This paper examines the relationship between building design and the utilisation of natural ventilation in office and school buildings in Northern Europe. The main objectives of the work have been to identify and investigate the architectural consequences and the architectural possibilities of natural ventilation. Case studies and interviews with architects and HVAC consultants have been the most central “research instruments” in achieving this. The case buildings studied are the GSW Headquarters in Germany (solar chimney/double facade), the B&O Headquarters in Denmark and the Mediå Primary School in Norway (sunspace). The most important findings are that:

- **Utilisation of natural ventilation in buildings has architectural consequences as well as possibilities.**
- **Natural ventilation primarily affects the facades, the roof/silhouette, and the layout and organisation of the interior spaces.**
- **The ventilation principle applied (single-sided, cross- or stack ventilation) together with the nature of the supply and extract paths, i.e. whether they are local or central, are of key importance for the architectural consequences and possibilities.**
- **Designing a naturally ventilated building is more difficult than designing a similar but mechanically ventilated building. An interdisciplinary approach from the initial stages of design is mandatory for achieving successful natural ventilation concepts.**

Principles and elements of natural ventilation

The principles of natural ventilation in buildings are relatively few and straightforward, relying on wind, thermal buoyancy, or both as driving forces. There is, however, a whole range of subtle and sophisticated ways to take advantage of the natural driving forces to promote the ventilation principles. This is exemplified in a number of both new and old buildings that utilise natural driving forces for ventilation.

The utilisation of natural ventilation in modern buildings is almost without exception done in conjunction with a mechanical driving force that assist the natural forces in periods when they do not suffice. The combination of natural and mechanical driving forces is most commonly referred to as *hybrid*[1] or *mixed mode*[2] ventilation in the literature. We have, however, decided to use the term *natural ventilation* in this paper, even if auxiliary fans are installed in the buildings we deal with. The reason for this is that our focus is on the "natural part" of the ventilation system, and the consequences and possibilities this part has for the architecture.

Figure 1 *Wind and thermal buoyancy, here illustrated with the wind blowing in a tree (left) and a glider ascending attributable to thermal buoyancy (right), are the two natural "engines" that can be utilised to drive air in, through and out of buildings.*

We use three essential aspects of natural ventilation to describe and classify various concepts. The first aspect is the *natural force* utilised to drive the ventilation. The driving force can be wind, buoyancy or a combination of both (Figure 1). The second aspect is the *ventilation principle* used to exploit the natural driving forces to ventilate a space. This can be done by single-sided ventilation, cross ventilation, or stack ventilation (Figure 2).

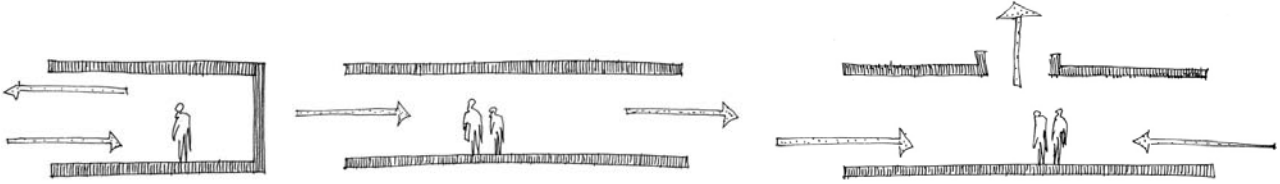

Figure 2 *Sketches illustrating the three ventilation principles, from left to right; single-sided ventilation, cross-ventilation and stack ventilation. As a rule of thumb, single sided ventilation is effective to a depth of about 2 – 2.5 times the floor to ceiling height, cross ventilation is effective up to 5 times the floor to ceiling height and stack ventilation is effective across a width of 5 times the floor to ceiling height from the inlet to where the air is exhausted*[3]*.*

The third aspect is the *characteristic ventilation element* used to realise and/or enhance the natural ventilation principles. These elements are characteristic for natural ventilation, and distinguish natural ventilation concepts from other ventilation concepts. However, natural ventilation can be realised without the use of dedicated ventilation elements. The building itself then doubles as a ventilation element. With such a building integrated element we understand that the building as a result of its design is capable of harnessing the natural driving forces and of directing the ventilation air through its spaces without the need for dedicated ventilation elements. In this sense, a building integrated ventilation element is really not an element, but rather the absence of one. As the “ventilation system” and the occupants share the same spaces (rooms, corridors, stairwells et cetera), and windows and doors are utilised as part of the air-paths as well, the most characteristic feature of a building integrated element is that the building appears not to have a ventilation system at all. The main advantage with a building integrated element is that the ventilation system represents no additional use of space in the building. Ductworks, ventilation plants, and related components are avoided. The B&O Headquarters building is a good example of this approach.

Most naturally ventilated buildings do, however, make use of dedicated ventilation elements to harness the natural driving forces and to support the airflow through the building. An overview over the various elements, together with the ventilation principle the various elements is most likely to be associated with, is provided in *Table1*.

Characteristic element	**Ventilation principle**	**Supply or exhaust**
Wind scoop	Cross and stack	Supply
Wind tower	Cross and stack	Extract
Chimney	Cross and stack	Extract
Double facade	Cross, stack and single-sided	Supply and extract
Atrium	Cross, stack and single-sided	Supply and extract
Ventilation chamber	Cross and stack	Supply and extract
Embedded duct	Cross and stack	Supply
Ventilation opening in the facade	Cross, stack and single-sided	Supply and extract

***Table 1** The relation between characteristic ventilation elements and ventilation principles. The table also shows whether the individual element is used in the extract or in the supply end of the air-path. Some characteristic elements can be used both as extract and supply.*

In addition to the principles and elements above, the nature of the supply and exhaust paths is crucial to the architectural consequences and possibilities associated with a natural ventilation concept. With supply and exhaust paths we understand the air path the ventilation air travels between the outside and the occupied spaces inside a building, i.e. not the airflow path within the occupied zones. The supply and exhaust paths can be divided into two categories: local and central.

A central supply path means that one or several occupied zones are serviced by the same path. The ventilation air can be given different treatments along this path. It can be filtered, heated and cooled, and fans can be installed to surmount pressure drops in the airflow path. Thus, one single filter unit, one single heat exchanger, and one single fan can service the entire supply airflow. A central exhaust path means that used air from one or several occupied zones is collected and exhausted at the same point. When both supply and exhaust paths are central, heat recovery is easier to implement. An embedded duct and an atrium are examples of central supply paths. A staircase that serves as a stack is a central exhaust path.

As opposed to central supply and exhaust paths, local supply and exhaust paths have no distribution system associated with them. The air is taken into and exhausted out of an occupied space directly through openings in the building envelope. Openable windows and hatches in the façade are examples of local supply and exhaust paths.

Architectural consequences of natural ventilation

Three case buildings have been investigated: two office buildings (the GSW Headquarters and the B&O Headquarters) and one school building (the Mediå primary school). Their respective design teams (architect and HVAC/energy consultant) were also interviewed. In addition to the three case study buildings, a number of other buildings were also investigated, but in those cases in less detail.

GSW Headquarters

***Figure 2** The Gemeinnützige Siedlungs- und Wohnungsbaugesellschaft (GSW) Headquarters, (1999) in Berlin, Germany was designed by Sauerbruch Hutton Architects and Arup (HVAC/energy consultant). The 22 story tall building is characterised by a double facade towards the west that utilises solar energy to boost the thermal bouyancy in the cavity, which in turn suck air out of the building. Fresh air is provided through a myriad of ventilation inlets in the east facade. The plan of the highrise is narrow (11.5-15 m) to facilitate utilisation of daylight and natural ventilation*[4, 5, 6].

B&O Headquarters

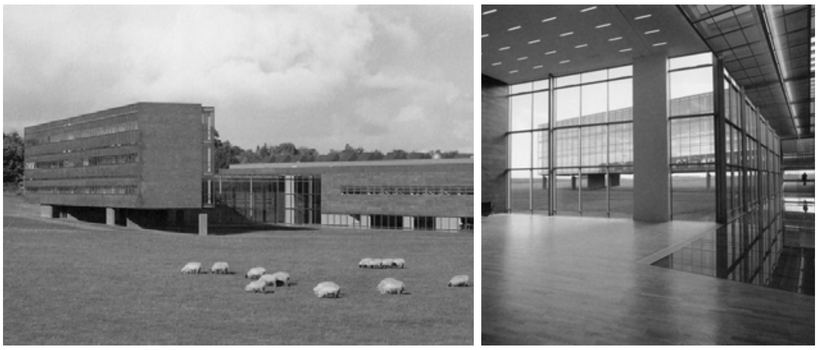

***Figure 3** The Bang & Olufsen (B&O) Headquarters, (1998) in Struer, Denmark was designed by KHR AS Architects and Birch & Krogboe AS (HVAC/energy consultant). The naturally ventilated southern office wing is characterised by being elevated as well as having an extremely light appearance from the court (made possible by the absence of suspended ceilings and ducts familiar to mechanical ventilation systems). The north facade of this wing also has a band of narrow openable windows in front of each floor slab serving as ventilation inlets. The interior spaces are used as airpath. Two stairwells are used as extract chimneys. The ventilation concept is totaly integrated in the building structure, the building appears not to have a ventilation system at all*[7, 8, 9].

Mediå School

***Figure 4** The Mediå Primary School, (1998) in Grong, Norway was designed by Letnes Architects AS and VVS Planconsult AS (HVAC/energy consultants). The school is characterised with an exhaust chimney and a combined sunspace/extract chamber on the roof. The sunspace provides the classrooms with extra daylight, increases the thermal buoyancy and enhances the efficiency of the recovered heat from the exhaust air. An embedded duct connected with an inlet tower provides fresh air into the interiors*[10, 11].

A natural ventilated building must be designed to get air in and out as well as to support a natural airflow through the interiors. The main architectural consequences are in short:

- Ventilation openings for inlet(s) and outlet(s) in the building envelope
- An internal layout, both in plan and section, that provide a low pressure drop air path from the inlet(s) to the outlet(s).

To elaborate on these two points, we have used a "checklist of architectural aspects" to structure the architectural consequences of natural ventilation in the three case buildings. The checklist consists of the following points: Site, Orientation and shape, Plan, Section, Façade, Ventilation elements, and Interior spaces.

Site

A natural ventilation concept is based on the characteristics and potentials of the site. The most dominating driving force on the site (wind or buoyancy) is selected and utilised as effectively as possible. The ventilation concept is thus designed for the primary driving force (buoyancy in the case of Mediå School) or for both wind and buoyancy (like in the GSW Headquarters). The climatic conditions on the site also influence the design of the natural ventilation concept. Cold climates favour central ventilation inlets and outlets, as that is advantageous with regard to heat recovery and pre-heating of the ventilation air (e.g. Mediå Primary School). Local inlets and outlets may be applied in temperate climates (e.g. GSW and B&O Headquarters) where the risk of draught is lower. The investigation on the three case-study buildings indicated that their urban/rural response (to neighbouring buildings, streets/roads, the building typology at the site and so forth) and laws and regulations governed the design of their natural ventilation concepts to a great degree, especially in the initial design stages.

Orientation and shape

The orientation and overall shape of buildings utilising natural ventilation is less influenced/dictated by the natural ventilation concept than initially expected. Considerations related to the urban context and laws and regulations decided the orientation of the buildings to a far greater extent than did considerations to the natural ventilation concept.

Furthermore, the buildings investigated in this study show that the form of naturally ventilated buildings need not be shaped more aerodynamically than mechanically ventilated buildings. The greatest difference in terms of shape appears to be that the majority of naturally ventilated buildings are rather narrow (even though there are examples showing that naturally ventilated buildings can be designed as deep plan buildings). It can therefore not be said that natural ventilation dictates the shape of buildings; they can evolve into “any” shape.

Most characteristic ventilation elements associated with natural ventilation do influence the shape of the building, however. Characteristic ventilation elements located on the roof (chimneys, wind scoops and wind towers) influence the silhouette of the building like e.g. the wing on the GSW Headquarters. Solar chimneys as well as double facades and ventilation openings in the façade (GSW Headquarters) also influence the appearance of facades.

Plan

The proportion of the plan of a naturally ventilated building must be shaped to facilitate natural airflow. This results most often in linear plans or in various atrium designs that can be effectively cross-ventilated (GSW and B&O Headquarters). The plan layout must further accommodate natural airflow from the inlet(s) to outlet(s) when stack and cross-ventilation are the applied ventilation principles. This is best achieved with an open plan layout, or a layout with fewest possible internal walls. Such layouts coincide well with utilisation of daylight and view to the outside, but may conflict with flexibility/use, as well as with fire and acoustics issues.

Section

Utilisation of natural ventilation does not have any obvious architectural consequences in the section of buildings other than those associated with vertical air paths in stack-ventilation principles. Such a vertical air path with architectural consequences can typically be interior spaces stretching over several stories, like e.g. a lobby or a reception, or stairwells that are used as exhaust air paths and therefore must be connected openly with the spaces/stories served (like in the B&O Headquarters). Other examples of vertical air paths are chimneys and double façades serving all (or some) stories in a building (like in the GSW Headquarters). The roofs of low-rise buildings (or the top floor of taller buildings) utilising the stack ventilation principle can be sloped to accommodate a natural airflow up and out of the room, like in the classrooms of Mediå School.

Facade

Ventilation openings constitute the greatest architectural consequences of natural ventilation in the façade. Local inlets and outlets, rather than central, affects the façade expression to the greatest extent, as they are distributed over the entire façade and need to cover a rather large area to avoid large pressure drops. The east façade of the GSW Headquarters, which has a lot of ventilation inlets, is a prime example of that. Centralised ventilation inlets are typically located in towers away from the building, and outlets are located on the roof and do consequently not affect the facades. The Mediå School is a representative example of that. Characteristic ventilation elements like chimneys (Lanchester Library, UK), solar chimneys (The Environmental Building, BRE, UK), and double facades (Deutsch Post Headquarters, Germany) are all integrated in the façade and therefore influence the façade expression.

Ventilation elements

The most common characteristic elements of natural ventilation have architectural implications stretching from none to substantial. An embedded duct, most often used in low and medium rise buildings, has in itself no architectural implications, whereas wind scoops, wind towers and chimneys can have significant consequences for the silhouette of the building. Chimneys, most commonly utilised as ventilation extracts in low- and medium-rise buildings, seem to be most widespread in the UK. Double facades are most often used to facilitate natural ventilation in high-rise buildings by making it possible to open windows and use them as air path without severe draughts. The majority of naturally ventilated high-rise buildings are located in Germany, and a great deal of them is double façade designs like GSW Headquarters, debisHaus, Commerzbank Headquarters, Deutsche post Headquarters, MDR Zentrale, ARAG Headquarters, Deutsche Messe AG, and many others.

Interior spaces

The interiors of buildings utilising natural ventilation are designed to promote a natural airflow with minimal pressure drops. This usually results in open plan layouts or layouts where rooms and functions are openly connected with each other. As the various rooms double as an air path, they are “links” in what could be referred to as the “air path chain”. Varying proportions and sizes of rooms depending on where in the *air path chain* the room is located is thus characteristic for the interiors of buildings utilising natural ventilation. An atrium or a tall lobby, as an example, form excellent stacks where exhaust air can rise and escape through the roof. Such spaces constitute, as an analogy, a combined “engine” and “plant room” as well as an exhaust air path. Such a *plant room* (an atrium or a tall lobby) is commonly the most exclusive space in the building, serving representation functions. The contrast to the plant room of a mechanical ventilation system housing fans and other air handling components, typically located in the basement or on the roof, is striking. The floor-to-ceiling height is typically generous to accommodate a buffer zone over the breathing zone for stale and warm air. The rather narrow plans seen in many naturally ventilated buildings facilitate generously daylit spaces and good views to the exterior. Exposure of materials such as concrete, stone and brick to provide thermal mass also characterises the interior surfaces of many buildings utilising natural ventilation.

Architectural possibilities of natural ventilation

The utilisation of natural airflow for ventilation provides architectural possibilities. This was expressed by Juan Lucas Young at Sauerbruch Hutton Architects, the project architect for the GSW Headquarters in Berlin:

“In a way one thing led to the other. At some point the ventilation was pulling the idea of the high-rise, but the high-rise came also and helped create the ventilation concept. They where somehow two things that came together”.

Ventilation of buildings can very roughly be simplified as 1) getting fresh air into the building from the outside, 2) directing the air through the interiors to provide them with fresh air and to pick up heat and pollutants on its way, and finally 3) getting the exhaust air out of the building. The three points are useful when attempting to sort out the architectural possibilities associated with natural ventilation.

The first and the third point; getting air into and out of the building, are manifested in ventilation openings in the building envelope (façade and roof). These can be accentuated in various ways, and they can be associated with various characteristic elements like e.g. a wind scoop and a double facade. The design and shaping of ventilation openings can represent an architectural possibility, but they can also be a challenge or a limitation for some designs. Commonly, the ventilation openings are very pronounced in the architectural expression of the building due to their location and size, especially those in the façade and in some cases also those on the roof. They are by implication considered as an important architectural element. The building can further be shaped or designed in order to increase over and under pressure at designated locations on the building envelope where the ventilation openings are located. The administration building for the Deutsche Messe AG in Hanover, Germany is an example of this where a conscious build up of volumes increases the driving pressure created by wind at the areas in the building envelope where the ventilation openings are placed. The curved facades of both the Deutsche Post Headquarters in Bonn, Germany and the MDR-Zentrale in Leipzig, Germany are examples of the same where the building by virtue of its shape influences the driving pressure derived from wind. It is, however, most common that the characteristic ventilation elements, rather than the whole building, are designed to increase the driving pressure. The wing of the GSW Headquarters, the wind cowls of the B&O Headquarters and the wind towers of IONICA Headquarters in Cambridge, UK are examples of that.

The second point, directing the airflow through the interiors from the inlet opening(s) to the outlet opening(s), represents a great design challenge as the desire for minimal pressure drop for optimal utilisation of the natural driving pressure (from the ventilation point of view) can conflict with the functional needs and requirements of the users of the building. This especially applies for natural ventilation concepts based on cross- and stack ventilation principles where the air paths are much longer than those in single-sided ventilation principles. This challenge involves at the same time substantial architectural possibilities for the organisation and the shaping of the interior spaces in particular, and the overall shaping of the building in general. The possibilities for the interior spaces derive from the fact that the various rooms form links in the "chain of the airflow path", stretching from inlet to outlet. Depending on a room's location in the airflow path, different size, proportion, floor-to-ceiling height and so forth is desired from a ventilation point of view. The architectural possibilities that can be derived from this comprise issues related to spatial experience and quality in the interior spaces (volumes, proportions, floor-to-ceiling height) as well as the spatial connections and rhythm of spaces with differing expressions and qualities along the airflow path.

The ventilation principle and the organization of the interior spaces produce new reasons as well as arguments for buildings to assume certain forms and proportions (e.g. GSW Headquarters, B&O Headquarters, Commerzbank Headquarters, Deutsche Post Headquarters and Jean Marie Cultural Centre). The shape of most naturally ventilated buildings have in common that they can utilise daylight in practically all interior spaces, and accommodate view to and contact to the exterior from virtually every spot inside the building. The headquarters of GSW and B&O are prime examples of that. The avoidance of large ventilation plants with belonging components and vertical and horizontal ductworks may in itself result in architectural possibilities and a greater freedom in the design[12].

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