NATURAL VENTILATION STRATEGIES IN NEAR-ZERO-ENERGY BUILDING

A design primer for students and professionals

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Abstract: With the incorporation of Passiv Haus methodologies within the building culture, the movement towards zero energy housing, in our temperate maritime climate, has a clear design strategy. However, larger buildings, due to denser patterns of occupation, have more complex cooling, ventilation and day lighting issues. Typically, in the 20th Century, strategies to deal with these large building environmental design issues have centred on energy intensive solutions such as air conditioning. However, from both an energy-in-use and internal comfort perspective, other design strategies need to be investigated. In this regard, natural ventilation – to be effective in reducing energy in-use within a building - has to work in combination with heat load reduction strategies, both internally and externally, and with the placement of thermal mass. The design of these three elements, an integral part of the architecture of the building, entails that there is an impact on built form. This research aims to qualify the architectural impact of natural ventilation strategies in near zero energy buildings and the development of a low energy aesthetic, in combination with the quantification of energy in-use reduction.

Keywords: natural ventilation; zero energy building.

1. Introduction

“The idea that architecture belongs in one place and technology in another is comparatively new in history, and its effect on architecture, which should be the most complete of the arts of mankind, has been crippling” Rayner Banham P. (1984)

The purpose of the research is to understand how effectively passive environmental design impacts on architectural form and to test the assumption
that this is an appropriate way to achieve net or near zero energy buildings. In order to achieve these aims architectural form (plan, section and elevation) will have to re-establish the connection with environmental performance. Environmental performance is closely linked to occupation patterns of the building and thus form is defined by occupation or indeed, form follows occupation.

“One of the key aspects of moving towards a sustainable architecture is to get the building itself to play a larger role, thus reducing the dependence on services” Thomas R. and Garnham T. (2007)

2. Environmental Context

“Energy consumption defines the quality of urban life and the global environmental quality of cities” Ghiaus and Allard (2005)

We live in an age of uncertainty in our relationship with the planet with concerns about our future fuel supplies, planetary warming, toxicity in our environment and our health; population growth and urbanization.

The environmental impact of a building and in particular its CO2 emissions, depends on its overall design, including issues such as site planning, form, materials, construction, and operation which all affect performance. Buildings are a major consumer of energy on both construction and operation. According to CIBSE, 40-50% of all energy consumed in Europe is used in buildings and 40-60% of this is used for heating and ventilating.

2.1. LEGISLATION

Within the European Union, the response to the growing awareness of environmental change, global warming and resource depletion has been the tightening up of the legislation regarding building environmental performance. From 2013, the Energy Performance Building Directive (EPBD) was superseded by the Recast EPBD and S.I. No 666 of 2006 was superseded by S.I. 243 of 2012. It binds member European states to ensure that:

“(a) by 31 December 2020, all new buildings are nearly zero-energy buildings; and

(b) after 31 December 2018, new buildings occupied and owned by public authorities are nearly zero-energy buildings.”

Annex 1 of the EPBD recast notes that:

“The energy performance of a building shall be determined on the basis of the calculated or actual annual energy that is consumed in order to meet the different needs associated with its typical use and shall re-
flect the heating energy needs and cooling energy needs (energy needed to avoid overheating) to maintain the envisaged temperature conditions of the building.”

It further lists both passive and active aspects of a building’s environmental performance, which are attributes to be considered in the design of zero energy buildings or near-zero energy buildings.

2.2. ZERO ENERGY AND NEAR ZERO ENERGY BUILDING

A zero-energy building (ZEB), also known as a zero net energy (ZNE) building or a net-zero energy building (NZEB) has zero net energy consumption and zero carbon emissions annually. Buildings that produce a surplus of energy over the year may be defined as energy-plus buildings and buildings that consume slightly more energy than they produce are called near-zero energy buildings (NZEB).

3. Natural Ventilation

There are three key objectives in choosing natural ventilation strategies:

- Internal Air Quality (IAQ)
- Thermal comfort
- Energy use reduction

3.1 INTERNAL AIR QUALITY

The growth of thermally controlled environments through the use of HVAC systems has been mirrored by the increase in health issues connected with building occupancy. Although HVAC systems were originally employed to create better working conditions, a side effect has been that buildings are increasingly becoming sick – internal air quality (IAQ) can be worse in air-conditioned buildings than naturally ventilated equivalents.

Research has shown (Clausen et al 2004) that ventilation ducts can be dirty and filters not changed leading to a build up of contaminants which are recirculated into the inhabited spaces. Hazim Awbi (2003) suggests this manifests itself in increased absenteeism from work and resultant productivity reductions and in more serious health issues such as out-breaks of legionnaire’s disease. As a counter to this, natural ventilation strategies have been shown to be as effective in providing IAQ in buildings without the ensuing health implications that can arise from HVAC systems.

Pollutants are derived from human activity and the presence of products and materials that emit volatile organic compounds (VOCs) and, particularly in urban environments, outdoor pollutants. Natural ventilation can improve
IAQ when outdoor pollutant level is low and outdoor temperature within comfort levels and when it does not cause other stress such as noise. Note that the air flow rate of natural ventilation is determined by IAQ the determinant being not so much oxygen demand but rather heat, odours and humidity.

3.2 THERMAL COMFORT

Thermal comfort has been defined as:

“the state of mind which expresses satisfaction with the thermal environment” (ASHRAE standard 55, 2004).

This is better understood as a psychological definition however, modelled in terms of physiology and physics within service engineering. Nicol and Roaf (2007) claim that the philosophy of comfort embodied in international standards promotes mechanically cooled environments, as do the assumptions that the standards incorporate and the solutions they impose on building designers. This follows on from the development of adaptive models in the 1980s and 1990s (Humphreys et al), which became useful in arguments for naturally ventilated buildings as a counter to the growth in HVAC solutions not only in tropical environments but also in temperate latitudes.

The growth of HVAC is part of the increasing energy demand of buildings which, in our energy context, as noted above, is unsustainable. Air conditioned buildings define comfort standards through controlled levels of temperature, air movement and relative humidity. However, this produces a mechanically-dependent building which can be highly inefficient in energy consumption.

A counter argument to the HVAC service engineering approach is that thermal sensation is part of a feedback system by which the human body is kept in thermal equilibrium. That is to say: building occupants provide the change themselves whether this be in clothing or activity or change of environment. It is argued that this is a human characteristic which gives a greater sensation of comfort than a steady state thermal environment (Nicol and Roaf 2007). Furthermore some of these changes have evolved into a way of life from the siesta of Spain, as a response to summer heat, to the traditional Yazdi house, who inhabit differing parts of the building depending on the diurnal and seasonal climate, an adaptive strategy for a hostile environment.

“Change and movement is the essence of the adaptive approach: stasis, the existence of a static relationship between occupant and environment, is only achieved in very specific circumstances”. Nicol and Roaf (2007).
The lessons provided by occupancy patterns in traditional buildings provide the basis for a dynamic ‘adaptive’ approach to designing for comfort; an approach which can be an integral part of energy use reduction in building design.

3.3. ENERGY REDUCTION

Our own time is characterised by dwindling fossil fuels and the uncertainties of climate change. These two facts compel us as architects to consider how to design buildings that not only use less energy but can also generate energy to meet their demands. The legacy of making comfortable environments using technology – mechanical heating, ventilation and air conditioning - needs to be reconsidered in an environmentally responsive, sustainable architecture. The imperative of reducing emissions of greenhouse gases has stimulated interest in the design of low energy buildings: the PROBE studies in the United Kingdom (late 1990s) showed that 9 of the 10 lowest CO2 emitters were naturally ventilated buildings.

4. Physics of Natural Ventilation

“For all natural systems the most important issues are related to optimum use of driving forces combined minimising pressure losses in the system” (Per Heiselberg 2008)

The principles of natural ventilation are based on pressure differences and temperature differences producing air movement. This includes stack pressures – due to thermal buoyancy – induced by density differences between indoor and outdoor.

The influence of the environment on local wind speed is important, most flows in nature are turbulent, laminar flow is the exception. Ghiaus C. and Allard F (2005) note that movement from rural to urban can reduce average wind speed by 20-30% and increase turbulence by up to 100%. The suitability of our temperate maritime climate to natural ventilation is confirmed by the average wind speed in Britain and Ireland which ranges from 3m/sec in eastern areas to 8m/s in exposed western coastal areas. Natural ventilation is only effective with wind speeds in excess of 2.5m/s.

5. Vernacular of Ventilation

“One of the key aspects of moving towards a sustainable architecture is to get the building itself to play a larger role, thus reducing the dependence on services” Thomas R. and Garnham T. (2007)
In looking at pre-industrial vernacular we can understand how buildings worked without the use of a low cost, carbon-rich fuel source such as coal or oil; the resultant economy of means provides us with a rich vocabulary of building methods from which to learn. We can see in vernacular architecture a relationship between the building, the microclimate and thermal comfort and understand that vernacular buildings were passive modifiers of the environment. The work of Hassan Fathy in arid and Mediterranean climatic zones has defined a useful direction for climatically responsive architecture: evaluating traditional solutions in vernacular and adopting, modifying or developing these in order to become compatible with modern living requirements.

In hot arid zones examples exist such as the Malqaf wind catcher in Egypt, the Badgir wind scoop and exhaust in Arabian architecture (figure 1) and the wind scoops of urban Hyderabad (figure 2). In Tropical zones we can learn from the long section of the Indonesian long house and in temperate zones the ventilating strategies of some of the 19th century public buildings such as the Royal Victorian Hospital in Belfast and for the British Library Reading room in London.

![Figure 1. Badgir, Iraq](image1.png) ![Figure 2. Windscoops Hyderabad](image2.png)

6. **Buildings as Biological Organisms**

“…as the interior becomes more distant from the surface it becomes more difficult to bring air into the organism or, say, light into a building. In animals, elaborate systems develop to ensure an oxygen supply to every cell as, for example, our own respiratory system with complex lungs and blood supply systems. This has its counterpart in the complex mechanical and electrical systems used to provide air, heat, coolth and (artificial) light to larger buildings” Thomas R. and Garnham T. (2007)
Likewise, there are lessons to be learnt from biological organisms: the lightweight nest structures of birds or the heavier mass structures of termite mounds, buildings can be considered as biological organisms where the control of heat gains, thermal mass and ventilation become critical inter-related issues. As biological organisms, buildings need to interact with their environments with internal arrangements that efficiently deliver essential ‘nutrients’, fresh air, warmth, light. In more complex animals respiration systems are required both to provide oxygen - so that energy can be derived from food - and to take away the products of this metabolism such as CO₂. Likewise in buildings, which need to vent to bring in fresh air and to take away stale air.

A building well adapted to its local environment, its habitat, has a physiology of form and arrangement as a response to its functional operations. Termite mounds draw air in from outside through a heat exchanger to maintain air at 31 degrees C (exterior air temperature can reach 60 degrees C). They also draw water up from the earth to maintain an internal relative humidity of 90%. Mound walls are 500 mm thick and this provides both good insulation and high thermal inertia. It should be noted that the compact form of a termite mound absorbs less heat with thermal mass positioned well to absorb solar radiation during the day and to lose at night.

Many elements of engineering design and biology are based on taking advantage of differences between the ground and the air temperature inside a building, for example, or between the core temperature of a mammal and the air temperature around it. Buildings, unlike animals, can’t move towards the shade when over-heating so naturally they have to rely on diurnal temperature range and wind cooling.

7. Architecture of Natural Ventilation

“Architecture is increasingly being designed to utilise the free energy available from the environment, with the result that climatic forces are more and more responsible for shaping a new generation of structures”

The role of ventilation in building is to maintain IAQ and thermal comfort and in order to achieve this, airflow rates should be controlled. Natural ventilation is not just an alternative to air conditioning but also an effective instrument to improve air quality, provide thermal comfort and reduce unnecessary energy consumption. Buildings need to be ventilated throughout the year: in winter minimised to prevent heat loss but in summer maximised in order to optimise the human evaporative cooling process. A well-designed
structure that minimises heat gains and utilises passive cooling by means of natural ventilation should require little or no mechanical ventilation.

Traditionally, starting points for natural ventilation design were regionally based – responding to general climate patterns and prevailing winds - before developing the design in a more site specific manner. Battle G. McCarthy C. (1999) note that the expansion of the aeronautical industry has provided a source for more accurate wind data and airflow testing facilities and this has led to an increased understanding of airflow around objects. It is also understood that natural ventilation strategies, in order to be effective in reducing energy in use within a building, have to work in combination with heat load reduction strategies – both internally and externally – and with the placement of thermal mass. The design of these three elements, which is an integral part of the architecture of the building, entails that there is an impact on built form.

8. Vocabulary of Ventilation

This research is concerned with understanding effective natural ventilation strategies for different typologies of public and commercial buildings and thus defining a vocabulary of ventilation techniques and details that are suited to certain buildings within the area of study: the temperate maritime climate of Europe. As such, an inventory of the varied architectural responses to natural ventilation strategies is required. The more simple wind pressure strategies such as single sided and cross ventilation demand plan depth to room height ratios which typically give plan depths ranging from 8 to 12 m depending on ventilation openings; this proves to be ideal for both ventilation and for daylight.

Natural ventilation by means of wind towers and scoops gives increased reliability compared with cross ventilation due to the constant stack effect pressure difference. Towers typically are used to draw air out of buildings and scoops to bring air in but to be effective must be omni-directional turning into the wind. The combination – with intake and extract at high level – can allow for greater pressure differences between devices.

Stack pressure is proportional to indoor-outdoor temperature difference and the vertical difference to the neutral pressure line (NPL). It is more effective in winter when temperature differences are greater between inside and out but less ventilation is usually then required (less cooling issues). Balanced stack ventilation, a transfer of Middle Eastern strategies, uses both high level inlets and exhausts. High stack exhaust and correct design allows the exhaust to be relatively independent of wind direction.
Double skin facades can act as thermal buffer zones to temper air, can ease pressure zones around a building and – as in Sauerbruch and Huttons GSW tower in Berlin – can be used for solar assisted stack ventilation. In certain design scenarios the use of double skin can eliminate potential security issues for safe night cooling.

Sky gardens, used in high-rise buildings, and atria, used more typically in deep plan buildings can be used for air intake and extraction. They function as buffer zones between outside and inside spaces and allow ventilation and daylight deeper into the plan.

Advanced Natural Ventilation (ANV), as defined by Lomas (2006), uses stack ventilation relying on internal heat gains only (figure 3). It is useful for high load gain buildings and tight urban sites with security and pollution issues and because the designer can predict environmental performance: flow rate of air is directly proportional to strength of heat source. Lomas characterizes inlets and outlets between centre and external positions on the building plan. Stack and exhaust design become critical elements.

Related design issues include: thermal insulation and solar control, critical elements of envelope design, insulation playing the role of limiting both solar heat gain and heat losses and solar control being valuable for preventing passive solar gain with glazed areas. The limiting of internal heat gains is both a design and specification issue for working equipment including computers and kitchen areas and a lighting design issue – particularly in the promotion of correct day-lighting strategies.

Thermal inertia, the thermal response of the building, depends on material thermal effusivity and placement. The correct use of thermal mass for limiting the peaks and troughs of internal temperature will have an important role to play particularly in night time cooling strategies and can have an aesthetically dominant aspect within a building’s interior.

Fire engineering and smoke control take on more importance in a building that relies on openness to establish air movement paths. Notably, Sauerbruch and Huttons GSW tower in Berlin (figure 4) where the natural ventilation strategy involved stack ventilation within the double skin southern façade and mock-ups were required to show that fire could not enter separate fire compartments.

Of similar import is acoustic design, and again particularly in the design of atria or stacks which link floors but need to provide acoustic privacy. Furthermore low resistance paths are demanded within the low pressure designs of natural ventilation strategies so that acoustic attenuation at inlets and exhausts becomes critical and can require a re-evaluation of the ventilation strategy employed in certain, usually urban environments.
Controls, louvers and dampers are critical elements as part of the adaptive approach to thermal comfort, as part of limiting internal heat gains and providing good IAQ, as part of fire and acoustic strategies.

9. Case Studies

The methodology for the case study research involves basic building data gathered as part of desk top research based on metrics highlighted by Arup Associates amongst others.

- Site data – location, urban/rural,
- Human Data – client, use, design team.
- Climate data – cooling days, diurnal range.
- Building data – plan, section, shape, surface to volume, size, structure, thermal mass
- Envelope data – insulation, glazing, shading.
- Ventilation data – strategy, type, inlet outlet design

Field research is used to clarify any issues of detail in the above data and in particular measurables such as air temperature, CO₂, daylight, energy use, controls and performance data. Interviews with the building management help clarify the building’s performance and a questionnaire designed for both management and occupants seeks to understand the issues of comfort and IAQ as well as controls and environmental management issues.
The selected buildings are all recently completed and within the temperate maritime climatic zone, in the UK and Ireland. The buildings all have a public usage and quite specific ventilation demands:

<table>
<thead>
<tr>
<th>Ventilation load:</th>
<th>high</th>
<th>medium</th>
<th>low</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building type:</td>
<td>auditorium</td>
<td>offices</td>
<td>library</td>
</tr>
<tr>
<td>Case study building:</td>
<td>Contact Theatre, Manchester, UK</td>
<td>Limerick Civic Offices, Ireland</td>
<td>Lanchester Library, Coventry, UK</td>
</tr>
<tr>
<td>Environmental challenges:</td>
<td>High thermal load, humidity and odour combined with sensitive acoustic environment</td>
<td>Passive solar gain, internal occupant loads</td>
<td>Deep plan building, use of plenum</td>
</tr>
<tr>
<td>Vocabulary of ventilation:</td>
<td>Wind towers, grilles, thermal mass</td>
<td>Shallow plan offices, atrium, solar shading exposed thermal mass</td>
<td>ANV utilising plenum intake and atriums with perimeter stack extract.</td>
</tr>
</tbody>
</table>

10. Conclusion

This research aims to qualify the architectural impact of natural ventilation strategies in near zero energy buildings defining a physiological vernacular through an architectural vocabulary that best interprets natural ventilation in predominately heating and cooling typologies. The outcome of the research is to establish and rationalise a design agenda for a low energy aesthetic.

References


