DESIGN PRIMER PART 6

NATURAL VENTILATION

Continuing his regular series on environmental design principles, **Professor Doug King** takes to the air.

Ventilation is required to provide fresh air to the occupants of buildings, primarily to remove body odours and carbon dioxide from breath. This requirement is an order of magnitude greater?than the need for fresh air to supply oxygen for respiration. In summer, air movement can also help to speed up the evaporation of sweat and provide apparent cooling up to about 3C equivalent reduction in air temperature.

Research has shown that fresh air from an open window can penetrate up to 10m into a building, but for practical design purposes it is usual to take the natural ventilation zone from the exterior wall to be 2.5 times the room height, meaning 6-8m for typical office ceiling heights. To ventilate deeper-plan buildings will require either mechanical ventilation or an engineered natural ventilation system.

NATURAL FORCES

There are only two forces available to drive natural ventilation: the wind and the buoyancy of hot air (see Figure 1), both of which are an order of magnitude smaller than the force generated by even a simple fan. Typically, the driving force in natural ventilation systems is insufficient to overcome the pressure losses in anything but the most straightforward distribution system. Thus, natural ventilation systems require more space and earlier design integration than buildings with mechanical ventilation.

It is evident that a positive pressure is generated on facades facing into wind but suction pressures are also created on the roof, flanks and downwind facades as the wind flows around and over a building. If a building has openings on any two sides, these pressure differences will drive airflow through the interior, giving cross-ventilation. Even without opening windows, most buildings are not very airtight and the wind pressure drives unwanted air movement, leading to heightened energy losses.

We typically draw wind pressure diagrams with smooth arrows, but the wind flow at the facade will be turbulent because of the corners of the building, surface roughness, the surroundings and other external effects. This turbulence will cause air to flow in and out through an open window, even if the building interior obstructs cross-ventilation. This turbulence-driven mixing of fresh air with the room air gives us single-sided ventilation.

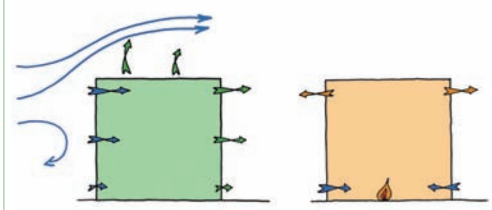
The wind is not reliable, of course, so to generate ventilation on still days it is necessary to provide as much height difference as possible between the top and bottom of the window openings in order to drive air movement by buoyancy (Figure 2).

Buoyancy-driven ventilation is a bit more subtle than the wind. When air is heated its density reduces and it is displaced upwards by colder, denser air flowing in from the surroundings, leading to stratification of warm air over cold air.

This is where we get the term displacement ventilation. This displacement/stratification action can create effective ventilation from a single open window, with cool, dense air entering at the bottom and hot, buoyant air leaving at the top. The system is driven by the heat generated by occupancy and can be a useful supplement to ventilate simple spaces on still days.

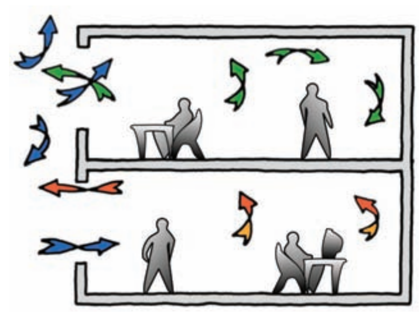
However, if the warm, buoyant air is confined within a shaft, a pressure is generated by gravity acting on the difference in air densities over the height of the shaft. Effectively, the pressure is created by the "head" of cold, dense outside air pushing its way into the bottom opening ➜

FIGURE 1



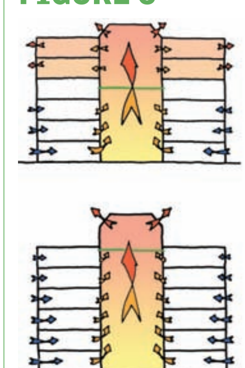
Natural air movement in buildings will be driven either by wind pressures (left) or stack pressure generated by a heat source raising the internal temperature (right). The wind and stack effect will act in opposition in parts of the building and reinforce flows in others. In low-rise buildings, wind pressure will tend to dominate, but in high-rise buildings the stack pressures can exceed the wind pressure.

FIGURE 2



Single-sided ventilation can be effective in shallow-plan spaces with opening windows. The air movement is driven either by turbulence of the wind at the face building (above top) or by internal heat gains driving stratification and displacement ventilation (above bottom).

FIGURE 3



In atrium buildings, ventilated by stack effect, it is important to consider the position of the neutral plane (green). Above the neutral plane air will flow outwards from the stack and if this is allowed to happen at occupied floors, they will overheat (top). Changing the atrium geometry and the balance of high- and low-level openings moves the neutral plane above the occupied levels (bottom).

→ of the shaft against the less dense air in the interior, which rises like smoke in a chimney stack – hence "stack effect". The effect applies equally to buildings with heat sources in the interior and openings at low level and high level. The resulting pressure differences give rise to airflows, which we exploit as stack-effect ventilation.

It is a classic mistake among students to describe stack-effect ventilation as a means of cooling buildings in summer. For the stack effect to work, it is fundamental that the temperature inside the building be higher than that outside, and therefore the stack effect alone cannot necessarily cool the building.

In fact, it is rare that ventilation without cooling will actually reduce internal temperatures during daytime in summer, as the external temperatures can rise above the internal, particularly in thermally massive buildings using night cooling. In these circumstances, the fresh air must be introduced with care to avoid overheating.

COMPLICATIONS STACK UP

The design of stack-effect ventilation for buildings can become complicated very quickly. The classical treatment assumes a simple stack with one inlet at the bottom and one outlet at the top. Once multiple openings are introduced to a stack, especially at different heights, you can get into all sorts of trouble.

Since air flows inwards at the bottom of a stack and outwards at the top, there must naturally be a point in between where the direction of flow reverses. This is known as the neutral plane. The neutral plane, or the level of zero pressure difference with regard to the building exterior, will occur at the height in the stack at which the cumulative resistance to air inflow balances the cumulative resistance to outflow.

There is a characteristic failing of atrium buildings in which the upper floors are overheated by hot air being forced out of the atrium by the stack pressure above the neutral plane. To avoid this, it is necessary to raise the atrium roof sufficiently far above the uppermost opening to create a reservoir for hot air and then to adjust the inlet and outlet resistances to raise the neutral plane into this reservoir. This will ensure inflow to the stack through all the openings into the atrium below the reservoir level (Figure 3).

A different problem with stack-effect ventilation can occur with buildings having complex and therefore high-resistance inlets, such as thermal labyrinths, coupled with simple, low-resistance outlets. If the outlet resistance is too low compared with the inlet, or if it spans too large an area, then in all probability a convection circulation will be set up across the outlet opening, with part functioning as an inlet.

At the Queens Building, De Montfort University, ventilation chimneys extend well above an already tall building to ensure sufficient stack pressure to ventilate the lecture theatres.

In this case, the fresh air enters the building at high level and descends as a cold plume, balancing the outflow of hot air. The ventilation to the space may be perfectly satisfactory under this flow regime, but it does obviate the benefit of any passive conditioning to the supply air for which the inlet system was designed. Such problems are often encountered in designs for theatres and shopping malls.

Once we try to analyse natural ventilation systems under simultaneous wind and stack-driven flow regimes, life becomes really complicated. Because of these complications, it is becoming common to design natural ventilation for buildings using computer-based analysis packages. However, these can only analyse the system once it is designed, not suggest design solutions, and their expense means they are often deployed too late in the design process to influence the strategic decisions.

Nevertheless, armed with even a basic grasp of the principles of stack-effect and wind-driven ventilation, we can design effective low-energy ventilation systems during the strategic design stage for most building types. Effective natural ventilation strategies will not only avoid the consumption of energy in fan systems, but by designing buildings to avoid unwanted infiltration and manage the fresh-air supply, we can make substantial inroads into reducing the heat losses.

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