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The Return of Natural Ventilation

As architects rediscover the benefits of fresh air as an alternative to hermetically sealed, air-conditioned buildings, they discover new architectural forms.

By Todd Willmert

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Use the following learning objectives to focus your study while reading this month's ARCHITECTURAL RECORD / AIA Continuing Education article.

Learning Objective:
After reading this article, you will be able to:

1. Explain basic air-movement principles.

2. Describe pre-Industrial Revolution ventilation devices.

3. Explain how night flushing cools buildings.

4. Understand the economic and environmental benefits of natural ventilation.

Natural ventilation is not a new idea—for thousands of years wind scoops and towers have been an integral part of vernacular Middle Eastern architecture. These structures moved air either up or downward, depending on the prevailing winds, and helped make homes and buildings habitable in the hot, harsh climate.

During the Victorian era, the English became obsessed with clean air. London and other cities were plagued with smoke- and dust-saturated air, and buildings such as Pentonville Prison and Parliament were designed with chimneys and towers that were used not only to expel smoke and to serve as observation points, but also to be part of the ventilation systems.

After World War II, the advent of central air conditioning and its progeny, the sealed building, made natural ventilation an anachronism. Today it is making a comeback, however, owing to rising energy costs and the worldwide movement toward buildings that employ "green" strategies. Architects and engineers, mostly in England, are using advanced computer and modeling

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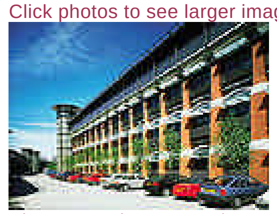

Photo: ©Graham Gaunt/Arup
At the Inland Revenue Offices in

techniques to refine the physics of heating, cooling, and ventilating. Chimneys and towers are key architectural elements for harnessing pressure differentials by employing the stack effect and other air-movement principles.

The following case studies provide lessons for American architects, because the design strategies, which were motivated by client mandates to reduce energy costs, go beyond the implementation of their efficient environmental control systems. Such projects work because naturally ventilated buildings have a certain appeal that sealed buildings do not. In the U.K., there is a long tradition of designing well-ventilated buildings to promote health and hygiene; typically in such structures large quantities of diffuse air are delivered at low velocity at floor level. This contrasts dramatically with the common U.S. practice of delivering forced air at high velocity near the ceiling, a more energy-intensive strategy. Furthermore, the temperate U.K. climate—not too hot, cold, or humid—makes natural ventilation a relevant concept. Ventilation also helps to remove moisture; by code, buildings are ventilated at a background rate (24 hours a day) to alleviate dampness.

Buildings that breathe

These circumstances have fostered a new approach to mechanical servicing in the design of large offices and other building types. In particular, two projects in England—the Inland Revenue Center in Nottingham, by London-based Michael Hopkins and Partners with engineers Arup, and the Queen's Building at De Montfort University in Leicester, by Short Ford Associates with Max Fordham engineers— are excellent examples of a new trend in which architectural form purposefully exposes mechanical function.

Vertical chimneys and towers are the noteworthy elements of these buildings, but they are only the culmination of a complete planning effort that includes three-dimensional section development. In fact, a low-energy, passively ventilated building must fully address total airflow patterns, from intake to exhaust, with the chimney or stack effect the primary, but not sole, principle employed. The other key consideration for enhanced ventilation is displacement ventilation (harnessing air's natural buoyancy to facilitate its movement). The principle is simple. Fresh air is introduced at the bottom of a space. As it is warmed, primarily by people and

Nottingham, U.K., fresh air, assisted by fans, enters through full-height, operable windows and is exhausted through the top of the stair towers (below).

Photo: ©Graham Gaunt/Arup

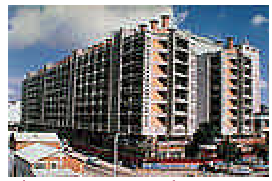

Photo: Courtesy of Arup

Eastgate, a large office block in Harare, Zimbabwe, relies on long, narrow floor plates for maximum daylighting and ventilation.

Photo: © Margaret Waller

A large atrium, covered by a glass canopy provides fresh air to the ventilation system, as shown in the energy section (below).

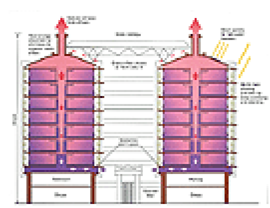

Photo: Courtesy of Arup

equipment, it rises and collects against the ceiling, where it can flow to the exhaust chimneys or towers. Key factors in calculating stack ventilation include both total and net stack height—the distance from the top-floor ceiling to the top of the stack.

At the Inland Revenue Center, a 400,000-square-foot government office complex, wings are 45 feet wide and 240 feet long, to maximize exterior exposure. The long, narrow floor plates of the building facilitate cross ventilation when windows are open. When the windows are closed, intake louvers draw in fresh air and allow stale air to travel through the building to the roof ridge and towers at the end of each wing. On the top floor, spent air is expelled by a skylight ridge, instead of the stair towers, which would have to have been at least 20 feet higher than the ceiling to draw air adequately. Each of Inland's three floors has parallel airflow. Fans within the raised floor on each level pull fresh air through louvers directly into the cavity. The air travels over heat exchangers, where it is heated if necessary, then moves through a nearby floor grille, where it is introduced in the offices at floor level. Stale, warmer air collects at the ceiling and is drawn along the ceiling until exhausted through the ridge, or stair towers, whose roof raises and lowers to regulate rate.

At the Queen's Building, window, louver, and chimney forms demarcate the various ventilation strategies—which are principles taught in the classrooms of the building itself. Multiple atrium chimneys exhaust air, supplementing other chimneys in the high-bay lab spaces and auditoriums. The great variety of spaces and their usage at Queen's calls for a more varied ventilation approach. Here, 100,000 square feet of labs, classrooms, auditoriums, and offices housing the university's engineering program are either high, narrow spaces exposed on two or more sides, or they open to an atrium. Two small labs for precision work require mechanical ventilation, but aside from these spaces, more passive means are fully explored. Offices utilize simple cross ventilation where possible, with deeper spaces relying on stack ventilation. Underfloor ventilation provides fresh air to auditoriums; as the warm air rises it is pulled out the stacks. Rooms overlooking the atrium have walls punctured with operable panels that can be changed to control ventilation.

These projects illustrate the nuances of chimney caps and tower tops, which are critical to ventilation design. The towers at the Inland Revenue Center absorb solar energy to create and assist draw. By contrast, another project by Michael Hopkins and Partners, this one at Nottingham University, uses tower-top cowlings that rotate in the wind. With openings facing downwind, the wind pressure differentials over the building and across the cowlings create draw. At Queen's, the chimneys, with four faces, are designed to draw regardless of wind direction and are solar-assisted. Much recent work utilizes this principle, instead of the temperature differences that drive the stack effect to foster air movement. Potential advantages of this strategy include chimney diameters that are smaller than those usually required to create the stack effect.

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Economical and environmental benefits

As demonstrated in the Inland Revenue Center and Queen's Building, natural ventilation enjoys considerable advantages: air-conditioning equipment can be downsized initially. This reduces electrical consumption, peak demand, and carbon dioxide emissions at the electrical generating plant. The results, confirmed over the last few years, are more sustainable buildings with operating budgets lower than the norm. Inland Revenue consumes about a quarter of the energy a conventional building would utilize on the same site, with a conventional air-conditioning system accounting for about half that energy. Monitoring at Queen's reveals similarly impressive results.

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Photo: © Richard Davies
At Portcullis House (above and below) in London, the windows are not operable, so air is drawn in at the chimney bases and rises through facade air shafts.

Photo: © Richard Davies

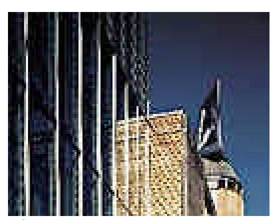

Photo: © Ian Lawson
Nottingham University's tower-top cowlings rotate in the wind.

Part of the economic and environmental success of these buildings stems from the fact that natural ventilation strategies tend to work well with other sustainable practices. For instance, the high spaces and narrow floor plates necessary for ventilation also work well with daylighting. Naturally ventilated buildings such as these also depend on thermal mass—concrete and masonry—to provide a stable mean radiant temperature. Not only does mass temper incoming air, but ventilating it after hours, or "night flushing," dissipates the heat built up during the day. Mass provides a thermal damper, so the building requires less overall energy to heat and cool.

Perhaps the real strength of natural ventilation is that architects have found it can be a new source of inspiration. The spring point for Alan Short's recent renovation of Manchester's Contact

Theater was scrapping the air conditioning, which was always too noisy during performances, and replacing it with ventilating chimneys. Ventilation there consists primarily of five extract stacks built on the roof. Square terra-cotta inlet flues at ground level, revealed rather than concealed, are made from standard chimney liners, a building component rarely visible at all, but celebrated in this design as a direct expression of an inventive servicing approach.

Pressure differentials across the building and cowlings create draw.

Computer and physical modeling

Empirical insights are the starting points for design, but technology is pushing further. Arup and Max Fordham have both developed proprietary computer programs to help determine tower and chimney parameters. Multiple factors impact airflow: The amount of heat absorbed by the tower or chimney dictates airflow rates; the size of intake grilles into each space limits the amount of air that can pass through them; room geometry and openings to the stack itself affect air currents. A computer model of the proposed design, with weather data integrated into the program, can simulate the myriad factors determining airflow.

Physical models are also used to cross-check the computer simulations, which are not perfect and are not powerful enough to model the airflow through the complicated shapes of some rooms. Wind-tunnel testing of scale models has proved to be an effective design tool to analyze air movement through a building. Another method employs saline solutions. These sink in water in exactly the same way that hot air rises in colder air. In this method, a clear plastic model of a building is immersed in a water bath. When the saline solution is added, its flow reveals how increasing stack size or the number of air inlets can boost airflow. If a room’s shape or partitions hinder airflow, this will be indicated by the physical model.

The development of expertise and design tools contributes to an expanding range of naturally ventilated projects. In Short’s recent completed Coventry University Library, the ventilating chimney vocabulary is applied to a new building type; at Hopkins’ Saga Headquarters it is applied to a corporate facility. Other practitioners are also exploring the ventilation concepts: In a dorm project in Durham by Arup architects and engineers, the buildings cluster around an iconic ventilation tower. A row of stainless-steel chimneys in Feilden Clegg’s Building Research Establishment in Hertfordshire punctuates and reinforces the building’s bay structure. Battle McCarthy Consulting Engineers has worked with architects to explore ventilating towers and chimneys for shopping malls and other projects.

These projects encompass a range of climates where passive, low-energy ventilation is most applicable, but it is important to note that sites such as these should have access to fresh air. Even this limitation is being challenged, however, at Hopkins' Portcullis House, which contains offices for members of Parliament and is located right across from Big Ben. London's air and security concerns dictated inoperable windows, suggesting a conventionally air-conditioned building. Instead, 14 bronze chimneys and connecting ductwork send spent, stale air out the chimney caps. Fresh air is brought in at their bases, where it is cooled—with cold ground water drawn from 450 feet below the building—before it is delivered to office spaces.

Natural ventilation goes global

While circumstances favor development of naturally ventilated buildings in the U.K., the principles are applicable to other cultures and climates. Eastgate by Pearce Architects with Arup in Harare, Zimbabwe, illustrates stack-ventilation concepts in an office block. The capital and maintenance costs of imported air conditioning, along with other factors, led designers to develop a passive ventilation alternative—the first of its kind in Africa. Harare's climate is moderate, characterized by sunny, warm days and cool nights, yet it is quite distinct from the climate in the U.K. A myriad of strategies—shading, good daylighting, and ventilation chimneys—contribute to a low-energy building made of local materials.

Depending on building program and type, natural ventilation is applicable throughout the U.S.—at least for parts of the year. Yet in much of the country, natural ventilation cannot totally supplant air conditioning for spaces requiring full conditioning, given humidity levels in the peak cooling season. The concept is most appropriate for mountain climates, with low humidity and large diurnal temperature swings. For a proposed classroom and laboratory facility at Montana State University in Bozeman, BNMI Architects plans to use stack ventilation, expressed in the towers, for ventilation and passive cooling. The area's cool summer nights, which are often 30 degrees Fahrenheit lower than the daytime highs, mean that night flushing can cool the building sufficiently. According to calculations, no air conditioning will be required.

In the hands of talented architects and engineers, vertical gestures are becoming distinctive elements wedding architectural design and building service systems. Bridging these concerns in this way is not new: Wright's Larkin Building and Kahn's Richard Medical Labs both have a striking vertical expression of mechanical services. What is novel, however, is how chimneys and towers become key components as alternatives to hermetically sealed buildings. While the flat-roofed, horizontal aesthetic—whose ascendancy as a predominant design style coincided with the popularization of central air conditioning—is coming under challenge, the new vocabulary can only expand as strategies underlying these building are explored further.

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Questions:

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1. *How does the stack effect work?*

2. *How do natural ventilation and reduced energy consumption work together?*
3. *How does night flushing work?*
4. *What factors impact airflow?*
5. *Why isn't natural ventilation widely used in the U.S.?*
6. *What is parallel airflow?*

INSTRUCTIONS

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