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Natural and Hybrid Ventilation

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This is the thirty-third column inspired by a DOE report covering energy-saving HVAC&R technologies.

Most commercial buildings use mechanical systems to ventilate and cool commercial buildings. In contrast, a building with natural ventilation (NV) relies on natural forces, primarily wind and thermal buoyancy, to move air to ventilate and cool buildings. The two basic approaches to NV are cross and stack ventilation.^{1,2} In both cases, the building designs allow for sufficient volume of outdoor air (OA) to flow through building spaces. NV buildings typically have more complex façade and window systems, such as operable (including automated) windows, dedicated air intakes, and roof vents to effectively control building airflows.

Cross-ventilated buildings rely upon outdoor wind forces to generate a pressure gradient from one side of the building to another that drives OA through open windows (or other air intake devices) on the high-pressure side of the building and out of openings on the low-pressure side. In contrast, NV buildings based on the stack effect often feature multistory chimney-like spaces such as atria, specially designed heat stacks, and double-skin façades.³⁻⁶ Heat generated inside the building (e.g., by lights, people, and office equipment) and from the sun warms a column of air, causing it to rise and exit near or at the top of the buildings. As the warm air rises, it draws additional air into the lower part of the building to replace the rising air.

Hybrid ventilation (HV) systems, also known as mixed-mode systems, have the infrastructure for both NV and conventional air-conditioning systems. When possible, they use NV to provide space cooling and OA ventilation, and only operate air conditioners when the NV system cannot meet space cooling requirements.

Although all buildings before the 20th century were naturally ventilated and cooled, very few conditioned buildings in the U.S. currently use NV or HV. Recently, NV and HV have become

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more common outside of the U.S., notably in the cooler climates of northern Europe and the U.K.^{4,5,7} Driving this renaissance are two advantages of NV systems, reductions in ventilation and cooling energy consumption and potential for improved indoor air quality. Relative to conventional systems, NV can reduce ventilation energy consumption because it uses natural forces to move air instead of blowers and fans. Large volumes of OA flowing through NV buildings also can reduce cooling energy consumption by supplanting the need for cooling during periods when the OA temperature is below the indoor air temperature and humidity levels are acceptable. In some cases, NV buildings introduce significantly higher levels of OA than economizers.^{1,4} As such, they can achieve greater cooling energy savings than economizers and, when used in conjunction with sufficient building mass, can also enable more extensive use of night pre-cooling of buildings. Furthermore, research suggests that occupants of NV buildings adapt to and can tolerate a greater range of indoor temperatures, well beyond ASHRAE-defined comfort zones.⁸ This enables higher indoor air temperature setpoints and, thus, additional cooling energy savings.

Because OA quality usually exceeds that of indoor air, NV potentially improves IAQ. Some studies suggest that this, in turn, can also reduce the incidence of sick building syndrome,⁹ increase occupant satisfaction and, possibly, worker productivity.^{1,10,11}

Energy-Saving Potential

Studies suggest that NV-only systems can provide acceptable comfort throughout the year in very limited portions of the U.S., primarily in areas near the Pacific coast that have moderate temperatures and low humidity.^{4,12} Outside of these regions, NV cannot, by itself, maintain acceptable indoor environmental conditions for significant periods due to temperature and humidity levels.⁴ Consequently, the energy-saving potential assessment and market factors discussions focus on HV systems.

Few studies have evaluated energy-saving potential of HV in the U.S. To date, all of these studies have limitations. Emmerich, et al.,⁴ carried out simulations comparing HV performance and conventional systems conditioning a five-story, 46,000 ft² (4273

m²) office building in five different U.S. climates during February, April, and July. They found that HV could dramatically reduce (>50%) fan energy consumption in all cities, except during colder months in the colder climates. The study also found major reductions (~50%+) in cooling loads in all but the hot and humid climates. On the other hand, HV moderately (~10%) increased heating loads in the colder climates.

Another simulation-based study compared the annual energy performance of HV to a conventional system in 40 U.S. cities. They found that HVAC energy consumption decreased in all but the hottest and most humid climates, with an average savings of approximately 10%.¹²

The U.S. energy-saving potential for HV is difficult to quantify from available data. A preliminary estimate is that HV could reduce U.S. commercial building HVAC energy consumption by an average of approximately 10%. This number masks large geographical variations in total and by component (cooling, heating, and ventilation) savings, including potential increases in some regions and components. Unlike many energy-efficiency measures, NV and HV are whole building approaches that cannot be readily retrofitted into a larger portion of buildings. This limits their applicability to the existing building stock.

Market Factors

Although HV has become accepted in some regions of the world, it has negligible market share for U.S. commercial buildings.⁴ Key barriers to greater use of HV in the U.S. include unfamiliarity with this approach, climatic limitations, design challenges, fire code concerns, and implementation challenges.

If a team does know about HV and wants to build an HV building, they face several additional challenges. Because successful HV buildings require strong integration of the overall building design with climate control systems, the systems are more challenging to design and effectively implement than conventional systems. Designs must consider many factors, including prevailing local winds, temperature, and humidity over the course of the year, air distribution throughout the

building, and the building's thermal mass.^{3,4} Unfortunately, few solid design and analysis data are available, and there is a general lack of adequate design tools and methodologies. In particular, designers need to understand airflows inside the building to ensure proper airflow distribution and enable effective airflow control. Although coupled building airflow-thermal simulations can provide this information, they typically are costly and complex to perform.³

Furthermore, the U.S. building ventilation code, ANSI/ASHRAE Standard 62.1, *Ventilation for Acceptable Indoor Air Quality*, compromises the energy-saving potential of HV. Specifically, it requires a building to meet ventilation requirements as either an NV or mechanically ventilated building, but does not allow the building to satisfy the standard for its operational mode at a given point of time.

For example, if the designers select the NV design method for an HV building, the building must always have the OA intakes open during occupancy, even if the mechanical system operates and provides sufficient airflow. During hot and humid or cold periods where the HV building would logically use mechanical ventilation, this increases space conditioning loads. Conversely, an HV system designed to meet the mechanical ventilation design criteria must:

- Provide the minimum OA ventilation levels during occupancy via mechanical ventilation; or
- Use natural ventilation but verify, per the IAQ Procedure of Standard 62, that the concentrations of all relevant contaminants of concern lie within acceptable levels.⁷

Given the general confusion and legal concerns about properly implementing the IAQ Procedure, most designers likely would have the mechanical system provide the prescribed OA levels during occupancy. This reduces or eliminates the ventilation energy savings.

NV and HV buildings also encounter challenges related to fire codes because they are designed to enable large airflow volumes between spaces. Although desirable from a ventilation perspective, this raises smoke and fire propagation concerns, which complicate design and implementation of the HV or NV system.^{3,5,13} The associated project risk likely would deter many teams from pursuing HV and NV. Finally, an effective natural or hybrid ventilation system requires integration of the building and HVAC system designs. In turn, this depends upon effective collaboration between architects, building designers, and HVAC designers and installers. Such a collaborative design approach is uncommon for U.S. commercial buildings.^{2,3,13}

Assuming a good design, effective implementation of NV and HV is another challenge due to the uniqueness and greater complexity of these systems. NV and HV systems actually can increase energy consumption if poorly designed or implemented.¹ To provide the intended OA to all spaces, NV and HV buildings need to have low infiltration levels.^{3,4} They also require well-implemented control systems to dynamically coordinate OA intakes (automated windows, dampers, etc.) with the mechanical systems as outdoor and building conditions change.^{3,5} Building owners and operators also have concerns

about the feasibility of maintaining the more sophisticated controls, as well as the general maintenance required for the airflow dampers and powered windows.^{4,5} Other potential issues requiring attention include outdoor noise propagation through air intakes,^{1,13} insufficient treatment of low-quality OA, and occupant discomfort caused by indoor airflows.⁴

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