Design Strategies For Hybrid Ventilation

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Hybrid ventilation systems are an innovative and potentially energy-efficient approach to ventilating and cooling buildings. While not yet widely used in the United States, there are many documented examples of successful applications worldwide, especially in the European Union. These systems appear to be drawing interest from building owners, architects and engineers in the United States.

To understand the appropriate application of this technique, this article will address the following questions relating to hybrid ventilation systems:

1. What is hybrid ventilation?
2. What advantage would building owners and occupants see from the use of a hybrid ventilation system?
3. What are some design strategies to implement a hybrid ventilation system?
4. What are some of the design challenges for implementing hybrid ventilation?
5. Where are some installations and what additional research is available on this topic?

One Part of a Larger Strategy

The incorporation of hybrid ventilation strategies is just one component of a multidisciplinary, holistic building design process. The use of a design technique such as hybrid ventilation must be viewed as a part of a comprehensive design strategy that aims to reduce the overall energy usage of the building, as well as create a healthier, stimulating environment for the building's occupants. However, hybrid ventilation is still viewed as a type of "cutting-edge" design technology (despite the fact that some of the concepts used in the design of hybrid ventilation systems date back to ancient times). The widespread use of, and advancements in, building design technology, materials, and building systems may have reawakened interest in these important design ideas.

The main theory behind any sustainable design strategy is to work *with* the climate not *against* it. The primary objective of most air-conditioning design strategies is to create an indoor environment that will remain at a relatively constant temperature and humidity level, regardless of the outdoor conditions. The design concept to actively use the *outdoor* environment to control the *indoor* environment is worth discussion and exploration to determine the applicability for all building projects. Since the indoor temperature will be greatly affected by this application, it is imperative that the HVAC engineer be an integral part of the design process, providing engineering input to help shape the final design. To help this process, the use of computer-aided design techniques allows for very detailed iterative analysis of alternate energy-saving strategies. This assists the design team (including engineers, architects, building owners and end users) to make better-informed decisions on how the strategies might affect building operation.

Explanation of Hybrid Ventilation

Buildings with hybrid ventilation systems use both mechanical ventilation/cooling and natural (passive) ventilation strategies. The term mixed-mode ventilation is often used to describe these systems.[1] However, there is an important difference between hybrid ventilation, and mechanically ventilated and cooled buildings that happen to have operable windows. The latter has no way of controlling the amount of mechanical cooling and ventilation if windows are opened, and may defeat the purpose of reducing energy costs since the outdoor air may impose *additional* load on the system. Hybrid ventilation systems have built-in strategies to have the mechanical and passive systems work in conjunction with each other. There are two main types of hybrid ventilation systems:

1. Changeover (or Complementary). Changeover systems, as the name implies, have spaces that are either totally in mechanical air conditioning or totally in natural ventilation mode.

2. Concurrent (or Zoned). Again, as the name implies, these systems are designed to have concurrent operation of both the mechanical and natural ventilation systems. These systems are usually designed to have discrete zones that can either have mechanical or natural ventilation.

Control is done automatically in hybrid ventilation systems. The changeover can either be seasonal, or daily, reacting to indoor temperature, air quality, outside temperature, wind speed/direction, humidity, etc. In concurrent systems, it is important to treat the zones differently to prevent

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the systems from "fighting" each other.

Why Use Hybrid Ventilation Systems?

One may ask at this point: Why should engineers, architects, building owners and developers consider the use of hybrid ventilation? Reducing energy usage and the resulting power plant emissions is one reason. But also the use of these systems may result in higher occupant satisfaction. Finally, the system may offer building owners a greater degree of flexibility and lower life-cycle costs in the operation and maintenance of the building.

Energy Cost and Global Pollution Reduction. Using a hybrid ventilation system will reduce the energy usage of a building. Since fan and cooling energy will account for a large percentage of a building's energy use, reducing the amount of energy used to move and cool the air can have a significant impact on the overall energy use of a building. Studies of buildings using natural and hybrid ventilation systems conducted by CIBSE have shown a 25–50% reduction in energy use over buildings using conventional cooling and ventilation systems.[2] An energy usage simulation comparing standard and hybrid ventilation systems also indicates a reduction in energy usage of approximately 20%. Also, on a larger scale, reducing energy consumption on a building level can reduce global warming and ozone depletion.

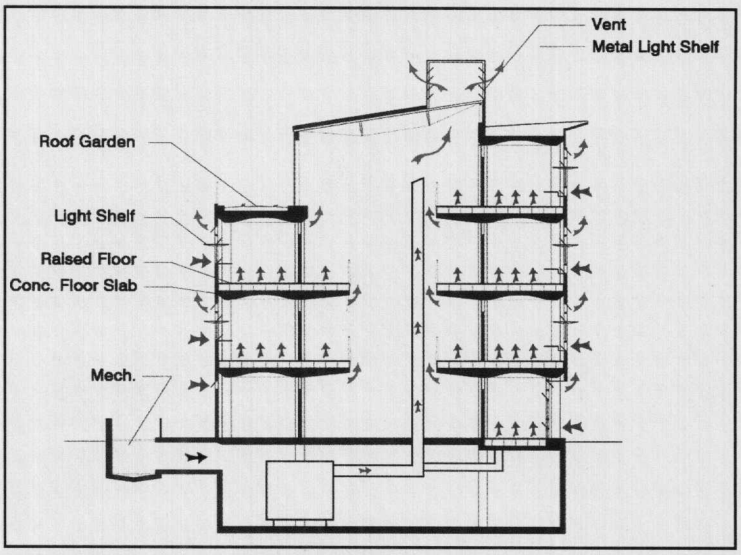

Figure 1: The success of integrated design relies on close collaboration between the architect and the engineer early on in the design process.

Higher Occupant Satisfaction. To determine how the use of natural ventilation affected occupant satisfaction, ASHRAE conducted research project RP-884.[3] This research project included the collection of 21,000 sets of raw data for 160 office buildings across four continents covering a wide range of climatic zones. (For more information on this body of research, see *ASHRAE Journal* October 2000.[4]) The major findings of this research show that in a naturally ventilated environment (compared to an air-conditioned environment):

- People adapt their behavior to become more active participants in the control of their environment (such as when they are allowed to open and close windows).
- People will wear clothing with a wider range of clo values that corresponds more closely to the outdoor temperature.
- People's metabolic rates will remain fairly consistent regardless of indoor temperature.
- People can tolerate and perhaps prefer higher localized velocities, such as natural breezes from an open window.
- People prefer a wider range of indoor temperatures that have a direct correlation to outdoor temperatures.

People have less tolerance to temperature deviations in sealed, air-conditioned buildings. In fact, they tend to be two times as sensitive to temperature fluctuations. It seems that these data correlate to people's expectations or reactions to a given circumstance. When indoor air temperature changes correspond to outdoor air temperature changes, people will modify their behavior accordingly. However, when a building is sealed shut and they do not have an opportunity to control their environment, or when they do not have a sense of the outdoor conditions, they will become less tolerant of temperature swings that they cannot control. This seems to be consistent with the notion that a person's comfort level will be based largely on their individual perceptions and expectations.

Building Flexibility. Hybrid ventilation systems can potentially offer a higher degree of flexibility and lower life-cycle costs over traditional systems. Since fan and refrigeration systems will run less when natural ventilation is being used for cooling or air movement, equipment will have a longer useful life, and regular maintenance cycles may be reduced. Also, standard components such as filters and belts that typically require regular replacement will also have longer life spans. Having a controllable means of providing natural ventilation can act as a backup for mechanical cooling and ventilation failure, and vice-versa.[5]

Design Strategies

As with all building designs, there are many different strategies to implement a hybrid ventilation system. And as mentioned previously, it will all be just one part of an overall strategy to create a stimulating and healthy indoor environment and to minimize the building's energy usage.[6] It is also critical that the HVAC engineering and architecture design processes go hand-in-hand, and the building owner/occupants have clear understanding of the design intent (see *Figure 1*).

The type of hybrid system will be very specific to the building and the site, so it is difficult to offer any standard design solutions. The following is an overview of the main strategies in designing a hybrid ventilation system:

Operable Windows. Allowing people to open windows in a mechanically cooled and ventilated building may be considered a hybrid ventilation system. But having the mechanical ventilation system work in conjunction with operable windows is really the essence of a true hybrid system. Having sensors that can shut down ventilation systems (or zones) when windows are opened will prevent the systems from working against each other. A further step in this is to use automatically operated window openers that will open windows when outdoor conditions allow. Obvious safeguards and overrides would need to be a part of this strategy to prevent over-cooling or over-heating and to prevent breaches in security.

Integral Building Openings. There may be areas of a building where it is impractical to rely on operable windows as a part of a

Where is Hybrid Ventilation Being Used?

There is a wealth of research on the design of natural and hybrid ventilation including well-documented case studies detailing energy costs, internal temperatures and occupant comfort levels. Some of the research that is available is as follows:

1. CIBSE Applications Manual AM10: 1997 Natural Ventilation in Non-Domestic Buildings (www.cibse.org): Twenty-three hybrid and natural ventilation buildings were documented by CIBSE, including case studies for completed projects in the UK (20), Germany, Amsterdam, and Malta.

2. NatVent, Natural Ventilation for Offices (http://projects.bre.co.uk/natvent): NatVent is a seven-nation European consortium that studied the applicability of natural ventilation to office buildings. The research focused on reducing heat gains, increasing thermal mass, and cooling by natural ventilation. The consortium also developed and documented design strategies and software for architects and engineers. Nineteen case studies for completed projects were analyzed and documented by NatVent in their March 1999 publication, including buildings in Belgium (3), Switzerland (3), Denmark (3), Great Britain (3), Norway (2), The Netherlands (3), and Sweden (2).

3. University of California, Berkeley (www.cbe.berkeley.edu): Three hybrid ventilation buildings were studied by the Center for the Built Environment, including a 75,000 ft² (6970 m²) building in San Rafael, a 208,000 ft² (19 300 m²) building in Sacramento, and a building in Palo Alto.

4. International Energy Association, Paris (http://hybvent.civil.auc.dk/): Twelve hybrid ventilation buildings were studied, including completed projects in Australia, Belgium (2), Denmark, Italy, Japan (3), Norway (2), The Netherlands, and Sweden. The booklet "Principles of Hybrid Ventilation" will be the final product of the project. Besides explaining the principles of hybrid ventilation, it will include solutions for energy-efficient, comfortable and cost-effective hybrid ventilation as well as recommendations of control strategies and analysis methods. The booklet is expected to be available in 2002.●

hybrid ventilation strategy. In these areas, one may consider the use of building openings that are integral to the design of the building. These could be louvered openings with mechanically operated dampers that allow the controlled introduction of outside air into spaces when conditions allow. Proper precautions to prevent insects and animals from entering the building, as well as filtration of the air would be required. Trickle ventilators, which allow constant "background" ventilation, are another example.

Use of Atrium. Buildings with a central atrium are good candidates for applying hybrid ventilation strategies. The natural stack effects that drive airflow up into an atrium can help drive the introduction of outside air through operable windows or fixed building openings (see *Figure 2*).

Heat Stacks. If a central atrium is not available, stacks that will drive the airflow through the building can be an alternative design solution. One design consideration is to have the stacks contain a material (glass block, for example) that will allow the solar heat gain on the stack to help drive the buoyancy of the air.

Double-skin Glazing Systems. While not prevalent in the United States primarily due to cost and unfamiliarity with the construction methods, some buildings across Europe (and in other parts of the world) are now being built with double-skin glazing systems. These systems consist of an exterior envelope that is essentially a traditional exterior wall system shrouded by a secondary envelope of glass. In addition to creating a highly insulated cavity that reduces uncontrolled air infiltration, it allows for a very effective means of introducing natural ventilation into a building. The cavity, heated by solar heat gain, creates a stack effect that will drive airflow up the cavity. Operable windows on the inside allow the users to open them into the cavity, instead of directly to the outdoors. This will reduce exterior noise transmission, allow for filtered openings at the base of the cavity and provide a greater degree of security. Fans may be placed at the top of the cavity to assist when necessary.

Fan Assist. As an added measure to help the air movement through a building, low horsepower fans may be added to help when the stack effect is not great enough to drive the airflow.

Low Pressure Air-Conditioning Components. If the natural stack effect is great enough, air-handling components (heating/cooling coils) with low-pressure drops may be used to pretreat the outside air prior to its entering the building, without fan assistance. This strategy may extend the times during the year that passive systems can be used before full mechanical ventilation and cooling/heating is required.[7]

Additional Design Considerations. A hybrid ventilation system will rely on many other interrelated building design concepts to be successful:

1. Exposed Thermal Mass: The exposed thermal mass and the use of high-heat-capacity building materials (such as concrete and masonry) will be an integral part of the natural ven-

tilation strategy. The materials will store the heat during the day and release it at night into the space, relying on structural nighttime cooling of the building via cooler nighttime outdoor air temperatures.

2. The Use of Natural Light: Artificial light sources are one of the largest contributors to the cooling load of a building. The use of natural light in daylighting strategies will not only lower the total electrical consumption of the building and the demand for artificial lighting, but also the cooling load.[8]

3. Solar Shading: Exterior solar shading devices not only reduce the solar heat gain but could also act as a light shelf complementing the daylighting strategy. The shading devices on the southerly exposures will allow for the low angle sun to penetrate into the space during the winter months, contributing to the passive strategies used in the building. In addition, the use of mechanized interior shading devices will reduce the cooling load in other areas. Highly sophisticated systems may use mechanically operated exterior shades that track the position of the sun and the intensity of the solar heat gain, to minimize the cooling load and maximize the use of natural light.[9]

4. The Use of Natural Ventilation: Since hybrid ventilation systems use a combination of wind-driven and pressure differential-driven natural ventilation techniques, the proper architectural building design (depth of occupied zones, operable window locations and sizes, building orientation, etc.) is critical to the successful passive air movement through a building.

5. Prevailing Winds: Proper building orientation must consider the speed and direction of the local prevailing winds.[10]

6. Use of Mechanical Cooling and Ventilation: In hybrid ventilation systems, the natural ventilation system is to be used when the outdoor air conditions are appropriate; mechanical cooling and ventilating systems will be used when they are not. This is an important factor in deciding to use this design, based on the local climatic conditions. The mechanical systems will be used when thermal balance (no heating or cooling required) cannot be achieved using natural ventilation.

7. Control Strategies: A very robust building management system will be needed to control the operable windows, louvers, dampers, etc., and to integrate the operation of the mechanical system with the natural ventilation system. In addition, lighting controls that vary the amount of artificial light based on available natural light should be used. Monitoring and control of CO_2 levels and relative humidity will allow for the activation of the mechanical cooling and ventilating system during times when the passive system cannot keep the levels within target ranges.

8. Air Distribution: Given the variety of spaces within a building, the air distribution concepts should be studied in detail to understand how the air will flow through the building based on different scenarios. Areas that have transient occupancies and those that have fixed seating will need to be treated differently. Computational fluid dynamics (CFD) techniques can be used to analyze this air distribution.

9. Clustering of High Heat Gain Spaces: Areas of high heat gain and/or spaces that require tighter temperature tolerances, such as computer areas, should be located together to allow for efficient distribution of conditioned air. Lower heat gain areas and/or spaces with less strict temperature tolerance requirements should be located nearer to the source of natural ventilation. This will be most effective when designing buildings with concurrent hybrid ventilation systems.

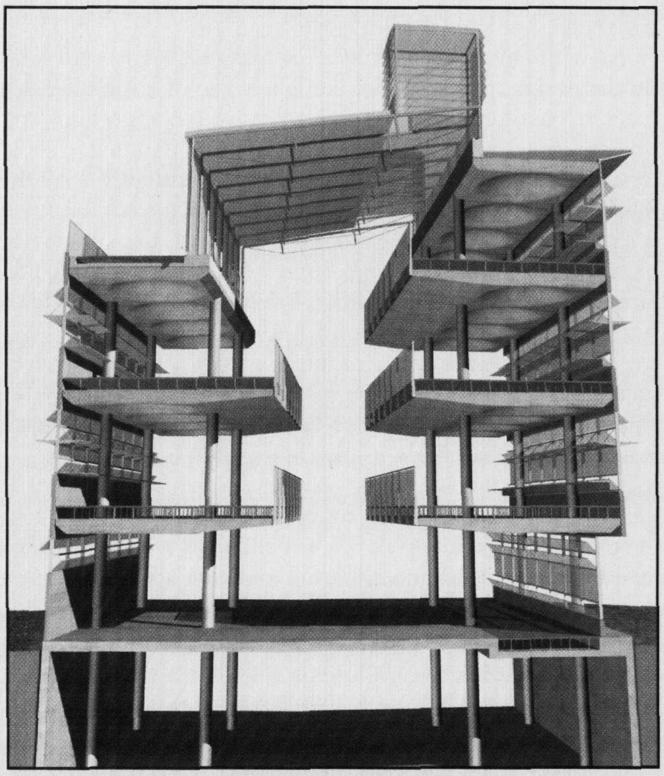

Figure 2: Integrated design often involves computer rendering and analysis of the building structure. The heat stacks and atrium are major components of the passive air movement design strategy.

10. Life Safety Issues: Another challenge in a building that relies on natural convection currents is developing a design to prevent the spread of fire and smoke propagation. Since one of the main concepts of naturally ventilating a building is to promote air movement from space to space (driven by either convective forces or by wind pressure), designing a hybrid or natural ventilation system requires great care in verifying that life safety is not compromised.

11. Control of Infiltration: Since the entire concept of the design is to promote the natural flow of air through the building, when the outdoor temperatures are excessively low, care will need to be taken to control unwanted infiltration at the entrances to the building and other openings. Double vestibules and very tight fitting dampers will need to be used to overcome the natural stack effect during periods of extreme cold weather.

12. Control of Outdoor Pollutants: This will vary based on the location of the building. Proper filtration of the incoming air will be essential to provide the appropriate indoor environment. Effective filtration will be easier to achieve with fixed building openings, rather than operable windows. Assessing the site of the building (tight-urban versus open-suburban) will help to develop the filtration goals.

Current Design Challenges

As with any innovative idea, certain challenges will arise in the design, construction, and operation of a building that uses hybrid ventilation. Through close collaboration with the building owner, architect, engineer and contractor, these challenges can be addressed. Proper education of the building's occupants as to the operation of the building will help to bring their expectations in line with the anticipated performance of the building. Some of the issues that are creating challenges to designing hybrid ventilation systems include:

- Most of the research *and* implementation of hybrid ventilation systems is being done in Europe. This is probably because energy costs in Europe have historically been significantly higher than those in the United States.
- The design/construction industry in the United States is unfamiliar with some of the concepts. Since a majority of new, modern office buildings in the United States will be designed and built with a full mechanical ventilation and cooling system, there are very few engineers, architects, trade contractors, developers or building owners who are familiar with hybrid ventilation techniques. The lack of familiarity with these concepts leads to a perceived higher risk and higher cost associated with the implementation of a hybrid system.
- U.S. codes and standards contain few references to hybrid ventilation systems. Most codes defer to the local authority to make the final interpretation.
- People in the United States are more used to hermetically sealed office environments compared to people in other parts of the world, probably because the building stock in the U.S. is generally much newer. This may be one of the most important obstacles to the implementation of these systems. The design specifications for modern buildings in the United States state definitive temperature and relative humidity requirements that are plus/minus a few percentage points. This requirement works against any type of natural ventilation strategy, due to the inherent internal temperature swings when opening a building to its external environment.

However, the increasing costs of electrical and natural gas production and transmission will continue to raise awareness of energy efficient design principles. Furthermore, the issues of global warming and ozone depletion will continue to heighten awareness for the prudent use of natural resources.

Conclusions

As in any architectural and engineering project, the fine points of the design as well as the budgetary constraints of the project will shape the final solution for the building. Control strategies that integrate the mechanical and natural ventilation systems, as well as the other sustainable design strategies, will be the key challenge in designing a successful building that uses a hybrid ventilation system. Although the United States has not yet embraced this as a mainstream design solution, the concepts behind the design of hybrid and natural ventilation systems are not new, and large amounts of hard research exist to help the architect and engineer. The results appear to be moving in a favorable direction, but more U.S.-based research and application will be needed to educate the building design and construction community if it is to succeed. This education and awareness process may be sped up as energy usage and prices rise.

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