Proven Energy-Saving Technologies for Commercial Properties

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Chapter 3. Natural Ventilation

3.1 Description

Fresh outside air is introduced into commercial buildings to improve indoor air quality by diluting odors and chemicals in the conditioned space. Outside air can also be used for cooling, especially in temperate climates. In most U.S. commercial buildings, ventilation air and cooling are supplied by mechanical means. Before the 20th century, however, natural means were used to ventilate buildings and maintain cool indoor comfort levels during the summer.

The growing concern with building energy use, the rise of the green building movement, and the goal of achieving net zero energy buildings have renewed interest in using natural ventilation strategies to save energy and improve indoor air quality. Natural ventilation relies on nonmechanical means to provide supplemental cooling when outdoor conditions are favorable and enough outdoor air is available to partially meet ventilation air requirements. In its simplest form, it involves opening windows to bring outside air into the building. More sophisticated strategies involve siting and shaping the building to take advantage of the prevailing wind direction, employing controls that open and close windows based on outdoor conditions, and controls linking the heating and cooling operation to the position of the windows.

The driving forces behind natural ventilation are wind and temperature-induced buoyancy. Wind-driven ventilation takes advantage of the pressure differences at openings to move air through the building; buoyancy-driven ventilation relies on density differences (hot air is less dense) to move warm air up and out of the building.

3.2 Benefits of Natural Ventilation

Some compelling reasons for designing buildings to take advantage of natural ventilation follow (Melton 2014):

- Occupant satisfaction—being able to open a window and feel a breeze is psychologically satisfying; occupants express greater satisfaction with their spaces when they have this option.
- Indoor air quality—large amounts of outside air can contribute to overall occupant satisfaction.
- Energy savings—in some locations where natural ventilation is possible year-round (temperate climates where summer highs rarely exceed 75°F and winter lows don’t reach freezing), energy savings can be substantial. In the temperate climate of the United Kingdom, the cofounder of Breathing Buildings cites savings of 10%–30% on fan energy alone. Even in climates that are not optimal, energy and air quality benefits make natural ventilation an appealing strategy.

Table 3 provides two examples showing potential savings for implementing natural ventilation in a temperate climate. These results are highly climate dependent. Example A is an educational building in the Pacific Northwest, assuming a 10% reduction in energy use. Example B is an office building, also in the Pacific Northwest, that achieves 30% reduction in energy use. The

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4 The cost savings are based on national average rates of $0.112/kWh, and $0.81/therm.
Table 3. Natural Ventilation Potential Annual Energy and Cost Savings in a Temperate Climate

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>Example A</th>
<th>Example B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electricity saved</td>
<td>kWh/ft²</td>
<td>1.07</td>
<td>4.38</td>
</tr>
<tr>
<td>Gas saved</td>
<td>Therms/ft²</td>
<td>0.0</td>
<td>0.0</td>
</tr>
<tr>
<td>EUI saved</td>
<td>kBtu/ft²</td>
<td>3.7</td>
<td>14.9</td>
</tr>
<tr>
<td>Utility bill savings</td>
<td>$/ft²</td>
<td>$0.12</td>
<td>$0.49</td>
</tr>
<tr>
<td>Typical capital cost</td>
<td>$/ ft²</td>
<td>Project specific</td>
<td>Project specific</td>
</tr>
<tr>
<td>Typical simple payback</td>
<td>Years</td>
<td>Project specific</td>
<td>Project specific</td>
</tr>
<tr>
<td>Capital cost 5-year payback</td>
<td>$/ft²</td>
<td>$0.60</td>
<td>$2.45</td>
</tr>
<tr>
<td>Target incentive</td>
<td>$/ft²</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>

3.3 Design Strategies

Natural ventilation can be used in commercial, agricultural, and residential buildings. Design strategies can address:

- Building cooling needs—replace or dilute warm indoor air with cooler outdoor air when conditions are favorable to cool building interiors, including nighttime cooling to reduce daytime cooling loads.
- Personal thermal comfort—air flowing over the human body increases the evaporation rate from the skin and enhances heat extraction, so moving air over occupants keeps them cool.
- Air quality—provide some or all of the outside air needed to meet ventilation standards.

To be effective, strategies must be integrated early in the building design process.

Naturally ventilated buildings must overcome two intrinsic design issues: driving airflow and limitations imposed by extreme OATs. In many climates and building types, conventional comfort thresholds cannot be achieved year-round with natural ventilation alone, requiring the use of a supplementary mechanical HVAC system (mixed mode), which uses energy to meet the building’s comfort and ventilation requirements. Minimizing solar and internal heat gains (through control of lighting and other loads) can help maintain comfort thresholds throughout the day, extending the viability of natural ventilation. Once a building design is optimized for natural ventilation, conventional air conditioning can operate only when conditions require it, saving additional energy.

3.3.1 Wind-Driven Ventilation

The two basic types of wind-driven ventilation design are described in Section 3.3.1.1 and Section 3.3.1.2.

3.3.1.1 Single-Sided Ventilation

Creating an opening on one side of the space allows air to flow in through the lower part of the opening, move around the space, and subsequently flow out of the upper part of the same
opening. This strategy is not optimal for moving air, because the ventilating air does not penetrate the space deeply, so resulting ventilation rates are lower than for other strategies.

### 3.3.1.2 Cross Ventilation

Creating openings on opposite sides of the space allows air to flow in on one side and out from the other side. The openings can be on the same vertical plane or they can be offset to take advantage of buoyancy. Care must be taken to ensure a uniform and comfortable temperature distribution across the building floor plate.

Figure 7 illustrates airflow paths of natural ventilation.

![Figure 7. Airflow paths used in natural ventilation, including single-sided and cross-flow ventilation](image)

(Courtesy Jason Sippel, Energy Center of Wisconsin)

![Figure 8. Operable clerestory windows at the Lussier Community Education Center in Madison, Wisconsin](image)

(Courtesy Rebecca Sadler, Energy Center of Wisconsin)
3.3.2 Buoyancy-Driven Ventilation
Several methods can be used to exploit the lower density of warmer air.

3.3.2.1 Clerestory or Skylights
Low-level intakes paired with high-level exhaust increases a designer’s ability to direct airflows within a space. When buoyancy is used to induce airflow, it becomes self-regulating through increased dependence on internal temperatures and decreased reliance on wind-driven flows.

3.3.2.2 Solar Chimney
A vertical shaft can be employed to absorb solar heat. Hot air rises through the chimney and exits at the top, while cool air is drawn into the building at the base of the chimney.

3.3.2.3 Atrium
An attractive, multiuse space may be designed to function as a chimney by allowing warm air to rise out of the space. The multipurpose nature of an atrium poses limitations on its optimal use for ventilation.

Natural ventilation strategies were deployed in several CBP projects. At the Bullitt Center in Seattle, operable windows on each floor facilitate cross ventilation and natural cooling. The windows can be operated by the tenants but are also controlled by the BAS. The BAS senses the indoor and outdoor conditions and opens and closes the windows automatically, depending on whether the outdoor conditions are favorable. In summer, the BAS opens the windows at night to cool the building. This precooling is carried into the next day, offsetting some of the cooling demands during hotter daytime hours.

Figure 9. Operable windows cool the stairway at the Bullitt Center
(Courtesy Nic Lehoux)

3.3.3 Controls for Natural Ventilation Systems
Several strategies can be used to manage natural ventilation systems and provide occupants with cues for adjusting systems over which they have control.
3.3.3.1 **Informational Control Systems (Such as Red/Green Light Systems)**
These systems inform occupants when the BAS senses that windows should be closed or opened using a visual display, often through a central light that turns red or green. This information would ideally bring occupant behavior into better alignment with model expectations and “optimal” operation.

3.3.3.2 **Automated Window Controls**
These systems manage airflow automatically, according to specific algorithms to control indoor conditions. They may enhance or moderate the effects of manually controlled windows.

3.3.3.3 **HVAC Override Controls**
These systems typically employ window switches to disable or scale back HVAC system operation when windows are opened. They can potentially move indoor conditions to more closely align with a naturally ventilated building.

3.4 **Real-World Considerations**
The success of natural ventilation systems depends on climate, building design, and technology, and considerably on occupant behavior.

3.4.1 **Climate**
Relying solely on natural ventilation for summertime cooling is optimal only in climates where the summer outdoor temperature seldom exceeds thermal comfort limits (75°F). In climates where natural ventilation alone is not optimal, it can be integrated with mechanical cooling. Hybrid ventilation (integrating natural and mechanical ventilation) generally requires comprehensive airflow modeling early in the building design process to ensure that the building design, ventilation strategy, ventilation controls, and operating procedures are integrated successfully.

3.4.2 **Building Location, Orientation, and Shape**
To optimize wind-driven ventilation, the building should be oriented relative to the site topography and prevailing (but variable) wind direction. Other issues include wind speed and building shape.

3.4.3 **Acoustics**
Outdoor noise can be a significant barrier to implementing natural ventilation strategies. Solutions include locating ventilation inlets and occupied spaces with operable windows away from noise sources (opening onto a courtyard, for example rather than a busy street).

3.4.4 **Outdoor Air Quality**
Outdoor air quality is sometimes unacceptable because of high pollen counts, smog, or high particulate levels. Occupants should be alerted to these conditions so that they keep windows closed during these times. To further decrease infiltration of poor-quality air, operable windows and ventilation inlets should be positioned to avoid vehicle fumes.
3.4.5 Occupant Comfort

Designing a naturally or mechanically ventilated space that is comfortable for everyone is impossible. With natural ventilation, though, occupants must understand how the system works and have as much control as possible in adjusting the system for their comfort levels. Designers may strive to mitigate temperature swings and minimize cold drafts, but ultimately, occupant engagement will ensure that the system is successful.

Putting control in occupants’ hands involves:

- Flexible dress codes
- Flexible attitudes
- Adjustable shades
- Ceiling fans
- Desk fans.

ASHRAE Standard 55-2013, Thermal Environmental Conditions for Human Occupancy and Standard EN15251 provides guidance for evaluating the applicability of natural ventilation strategies for a given project. These guidelines consider the influence of outdoor conditions to create a variable indoor comfort range dependent on seasonal temperatures. When paired with the ability of occupants to control their own environment, the space thermal comfort thresholds may be more lenient than conventional temperature ranges.

3.4.6 Retrofitting Existing Buildings

Wind-driven or buoyancy-induced ventilation may require a particular building orientation, geometry, or interior layout that buildings constructed between the 1950s and 1990s may not have. Because these buildings were designed to use mechanical ventilation, they have deep floor plans that do not lend themselves easily to natural ventilation strategies. Possible solutions include introducing an atrium, providing some spaces with operable windows, and implementing controls that turn off the HVAC system in offices with operable windows. Older buildings that were designed before mechanical air conditioning was available are likely to feature natural ventilation strategies; those systems can be restored to full functionality with some diligence and engineering.

3.4.7 Financial Incentives

Few, if any, state or utility programs specifically target natural ventilation design strategies. This measure could qualify for incentives as a “custom” EEM in new construction programs. Some examples include:

**New York State Energy Research and Development Authority New Construction Program.** Funding is available for technical assistance, commissioning services, prequalified measures, custom electric EEMs, whole-building design, and Leadership in Energy & Environmental Design (LEED) projects. Incentives are based on the predicted energy performance of the building design.
ComEd New Construction Program. Financial incentives and technical assistance are available to encourage design teams and building owners to surpass current standard practices and exceed energy code requirements. The program includes comprehensive energy modeling services, which describe the relationships between building systems and energy-efficient technologies to help building owners and design teams with the decision-making process before design documents are complete.

Mass Save New Construction Program. Technical assistance services are available to assess the savings potential of a high-efficiency design compared to the minimum requirements of the state building code. Incentives are available for window system and other measures.

3.5 Project Results

3.5.1 University of Hawai‘i

Retrofit of Kuykendall Hall on the campus of the University of Hawai‘i at Mānoa was the focus of the university’s participation in the CBP program. Kuykendal Hall is a 1960s-era building with two wings: a four-story wing with classrooms and a seven-story office tower. The retrofit design included use of prevailing winds to assist with ventilation and cooling (see Table 4).

<table>
<thead>
<tr>
<th>Project</th>
<th>Retrofit of Kuykendal Hall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building size</td>
<td>86,000 ft²</td>
</tr>
<tr>
<td>Natural ventilation</td>
<td>Operable windows with actuators (automated closure before dehumidification) in the classrooms and offices. Automated louvers and sound attenuated natural ventilation intake boxes in classroom wing, sound attenuated natural ventilation intake boxes in office tower.</td>
</tr>
</tbody>
</table>

3.5.2 Shy Brothers

The Shy Brothers Farm in Westport, Massachusetts, produces artisanal cheeses. The owners participated in the CBP program for the design and analysis of EEMs for a new dairy barn and a major renovation of an existing barn. The new barn, constructed to accommodate 120 head of cattle, was designed to be a net-zero energy building using natural ventilation (see Figure 10 and Table 5).
### Table 5. Passive Ventilation for Shy Brothers Cow Barn New Construction

<table>
<thead>
<tr>
<th>Project</th>
<th>New net-zero energy dairy barn</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building size</td>
<td>15,517 ft²</td>
</tr>
<tr>
<td>Passive ventilation</td>
<td>Passive ventilation in cattle barn. Create as few obstructions near sidewalls as possible, 12-ft minimum sidewall height, 6/12 roof pitch, adjustable air curtain sidewalls</td>
</tr>
<tr>
<td>Expected annual energy savings</td>
<td>4,020 kWh</td>
</tr>
<tr>
<td>Expected annual energy cost savings</td>
<td>$620</td>
</tr>
<tr>
<td>EEM cost</td>
<td>$9,500</td>
</tr>
<tr>
<td>Simple payback</td>
<td>15.3 years</td>
</tr>
<tr>
<td>Annual carbon emissions avoided</td>
<td>2.78 metric tons CO₂eq⁵</td>
</tr>
</tbody>
</table>

### 3.6 Modeling Natural Ventilation Strategies

Operable windows are complex to model because they are heavily dependent on building geometry and the building site and surrounding sites. Their performance depends on the wind speed and direction, and they interact indirectly in multiple ways with building HVAC systems. Only a few modeling programs, including EnergyPlus, support modeling of operable windows. The first component to capture in an energy model is the window opening (geometry and operating schedule); the second is the window’s relationship with its zone. But the real energy savings come from the third component, which is the control of the HVAC system based on the operable window. Guidance for modeling natural ventilation in EnergyPlus is provided in Appendix B.

#### 3.6.1 OpenStudio Guidance

Operable windows are supported in OpenStudio, but a default operable window object is not yet available in the software, and the Building Component Library does not at this time contain a fully packaged operable window component or measure.

### 3.7 Ensuring Performance

#### 3.7.1 Design

Design teams should consider natural ventilation strategies very early in the design process. The decision to naturally ventilate a building will affect subsequent decisions about building orientation and massing, window size and placement, façade features, and daylighting strategies, as well as other design strategies (Melton 2014). Decision steps include:

- Evaluate the climate. The viability of natural ventilation must be considered based on the local climate and the potential of natural ventilation based on the building site, its microclimate, and various design features being considered for the building. Information from analyzing both the viability and potential will determine whether the project is a good candidate for full natural ventilation, mixed mode ventilation, or mechanical ventilation only.

- Follow ASHRAE 62.1-2013 Ventilation for Acceptable Indoor Air Quality or local code equivalent for prescriptive and performance design requirements. Reviewing the

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⁵ Greenhouse gas reductions are given in terms of CO₂eq. For electricity, 0.000692 metric tons CO₂eq/kWh are assumed to be avoided.
compulsory requirements early on in the design process will help simplify the integration of system components.

- Determine sensors and controls needs. If the design team decides to implement natural or mixed mode ventilation, any required sensors or automated systems for controlling windows, fans, and other components will affect the budget and should be determined early on.

### 3.7.2 Commissioning

See Chapter 1 for information about the general commissioning process.

CxAs ensure that any automated systems controlling the natural ventilation system operate according to requirements. They:

- Ensure that mechanical ventilation is only being supplied when needed (i.e., not when windows are open).

- Calibrate carbon dioxide sensors, if used, and confirm that the system provides adequate ventilation. This is especially important when minimum prescriptive ventilation opening requirements cannot be met.

### 3.7.3 Operation

The facility manager monitors automated systems to ensure they respond properly to climate conditions, and conducts routine maintenance of window opening switches/sensors and any other installed control features. In nonautomated or user-controlled systems, a feedback method should be established, such as occupant comfort surveys and periodic education sessions for occupants to help better understand and optimize the use of natural ventilation.

The facility manager and building manager should devise a policy to incorporate window closure with building security procedures.

### 3.7.4 Occupant Behavior

In naturally ventilated (or mixed mode) buildings, occupants are key to the successful operation of the system. The design team, building manager, and facility manager can help ensure that occupants understand and use the system appropriately. Table 6 summarizes each party’s responsibilities.

<table>
<thead>
<tr>
<th>Team Member</th>
<th>Responsibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Design team and/or management</td>
<td>• Explain natural ventilation strategies to occupants early in the design phase of the building.</td>
</tr>
</tbody>
</table>
| Facility manager and/or building manager, with assistance from the BAS | • Communicate with occupants to set expectations for adjusting comfort levels (adjusting shades, opening windows, using fans).  
• Alert occupants to weather conditions requiring adjustment of the natural ventilation system (e.g., optimal temperature for opening windows, high pollen or pollution levels requiring windows to be closed). This can be accomplished through a red/green light system, or automated messaging such as email notification. Other, more energy-focused controls turn off air conditioning when outdoor conditions are ideal for natural ventilation, encouraging occupants to open windows for conditioning. |
### Management
- Devise a policy that encourages the use of windows and outline who is responsible for opening windows and when.
- Provide ongoing education about the energy and indoor environmental quality benefits of window use.
- Provide a flexible work environment. Devise dress code policies that allow users to adapt to seasonal climates and/or extend the range of comfort in naturally ventilated spaces.

### Occupants
- Take control of their comfort.

### 3.7.5 Measurement and Verification
Measuring and verifying achieved energy savings are integral to reducing energy use in buildings. (See Chapter 1 for information about the general M&V process.) Because natural ventilation is complex and interacts strongly with other building components, whole-building calibrated simulation is often used to verify this measure’s effectiveness.

#### 3.7.5.1 Recommended Monitoring Points
To verify energy savings from natural ventilation, its impact on the entire HVAC system must be measured. In the most comprehensive (and expensive) case, total HVAC system performance is measured through a variety of points. Specific monitoring points for this verification depend on the type of HVAC system, but are likely to include OAT and relative humidity, window contact status (open or closed), cooling electrical power, fan and pump power, and gas usage for heating. The electrical power submetering should meet the following criteria:

- Ability to measure and log real electrical power for an extended time. This offers a more accurate picture of energy use compared to a meter that provides only instantaneous readings.
- Sampling interval of 30 seconds
- Designed for the type of circuit to be metered (e.g., 480 Volt, 20 amp, 60 Hertz)
- Ability to accurately meter loads; rated to meet the load per phase (e.g., 0–80000 Watts)
- Internal clock that timestamps each data point
- UL listing
- Compatibility with the BAS.

Appendix A includes more specifics about temperature and flow rate measurement.

In an existing building, these measurements should be taken both before and after the natural ventilation is implemented. In a new building, these measurements can be taken after construction only; calibrated simulation can then be used to determine verified savings.

Because seasonal temperature variations influence the natural ventilation impact, the monitoring period should be at least 1 year.
3.8 Guidance for Analysis

If utility bills or submetered HVAC equipment energy use data are available from both before and after natural ventilation is implemented, basic weather normalization and regression analysis can be used to verify energy savings. This simplified analysis has significant sources of error because many assumptions, including identical occupancy patterns between the monitoring periods, must be made.

For new construction projects or existing buildings that have no pre-retrofit data available, calibrated simulation is needed. An experienced energy modeler should use the gathered data to update inputs associated with an annual computer simulation of the building’s energy performance. Additional information about the building’s occupancy schedule, historical weather data, designed envelope, lighting and ancillary HVAC equipment, and controls should be gathered from BAS data, occupant and operator interviews, and design documents to confirm model inputs. Remaining unknown model inputs, such as infiltration rates, are then adjusted so that the simulation predictions match the actual monthly or annual energy performance data. The energy performance from natural ventilation may be predicted by using postconstruction data to calibrate the energy model.

3.8.1 Existing Buildings

For existing buildings, the energy savings are determined within the model by comparing the building’s energy performance both before and after the renovation. The gathered data are first used to calibrate the pre- and postrenovation cases of the whole-building model. Once calibrated, the energy performance data from both before and after the renovation are then normalized by factors that affect their performance, such as assuming the same occupancy schedule and typical weather conditions. Once normalized, the energy savings from natural ventilation is determined by taking the difference between energy consumption before and after the retrofit.

3.8.2 New Construction

For new construction projects, the model’s proposed case is created and calibrated to the building’s measured energy performance. However, the energy savings calculation is less clearly defined, because no measured baseline data are available. For mixed mode and natural ventilation-only systems, ASHRAE 90.1 Appendix G outlines the energy modeling process for establishing baseline HVAC systems and associated inputs for new construction projects, though a more typical regional or building type-specific baseline may be justified. Alternatively, for mixed mode ventilation, the baseline may be defined as the mechanical HVAC system without natural ventilation controls.

The baseline and proposed system models should then be normalized using the same occupancy schedules and typical weather conditions. Once normalized, the energy savings from natural ventilation are determined by taking the difference between energy consumption of the two models.

3.9 References and Other Resources


