OPERABLE WINDOWS and HVAC Systems

Despite widespread belief that they waste energy, operable windows can be successfully integrated with HVAC systems

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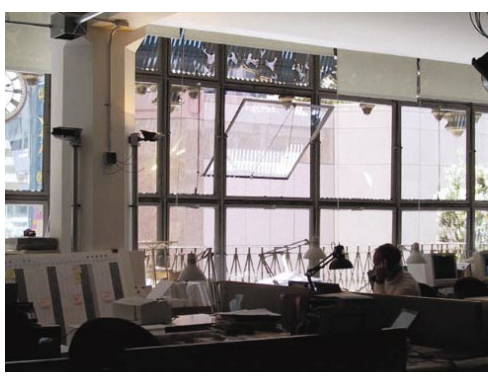
Building occupants love them. Mechanical engineers hate them. Operable windows, though simple and familiar, have not found widespread acceptance in modern commercial buildings in the United States.

The limited use of operable windows is surprising, considering their many documented benefits. In surveys following the move from a building without operable windows to one with them, occupants give operable windows high marks.[1] The connection between operable windows and good buildings is reflected in the Leadership in Energy & Environmental Design (LEED) Green Building Rating System, through which a credit is awarded to buildings that allow occupants to control their environment.[2] Also, research shows that occupants in naturally ventilated buildings find a wider range of temperature conditions comfortable than do those in mechanically conditioned buildings.[3] Finally, buildings with operable windows exhibit fewer symptoms of sick-building syndrome.[4] Why, then, do we not see operable windows in every building?

One possible reason is that many engineers believe operable windows waste energy. Their rationale is simple: If HVAC systems and windows are not integrated, an open window will allow conditioned air to escape, increasing building energy use.

But energy-wasting conflicts between operable windows and HVAC systems *can* be avoided. In fact, designs that integrate operable windows and HVAC systems may even provide new opportunities to save energy. This integrated approach often is called "mixed-mode" operation,[5] suggesting that the mechanical and natural modes of conditioning and ventilation mix in an efficient way. As this article will demonstrate, various mixed-mode approaches offer a range of promising possibilities for increasing both occupant satisfaction and energy efficiency.



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Operable windows allow occupants to control their environment.

A principal of Taylor Engineering, an HVAC and controls design and commissioning firm, Allan Daly, PE, specializes in energy-efficient and environmentally responsible HVAC-system designs that maximize occupant health and comfort. He is proficient in the use of computer programs to simulate buildings and systems to predict energy consumption, thermal performance, natural ventilation, and occupant comfort. He can be contacted at adaly@taylor-engineering.com.

NATURAL VENTILATION AND COMPUTER ANALYSIS

Computer simulations help test the assertion that operable windows can be successfully integrated with HVAC systems by predicting the impacts of various design and control approaches on energy use and occupant comfort.

The effectiveness of natural ventilation is influenced by many factors. These include building geometry, window geometry, wind speed, wind direction, outdoor temperature, and indoor temperature. Most of these elements are dynamic, changing continually over the course of a day. For this reason, understanding and predicting the response of a naturally ventilated space is difficult.

A computer simulation deals with this complexity by making use of fundamental physical principles and a number of simplifying assumptions.[6] Building geometry is entered in three dimensions: space geometry, window geometry, and window-opening area. Airflow through openings is determined based on wind speed and direction, taken from hourly weather data. Pressure coefficients are not derived individually, but applied to openings based on correlations with laboratory experimental data. Thermal driving forces are taken into account to calculate passive airflow through an operable window.

Maximum temperature	107 F
Minimum temperature	26 F
Heating degree days (Base 65)	2,602
Cooling degree days (Base 65)	1,884
Average day wind speed	7.2 mph
Average night wind speed	6.1 mph
1-percent summer design temperatures	101-F db, 71-F wb
1-percent winter design temperature	31 F

Based on Fresno TMY2 weather data.

TABLE 1. Summary weather data for Merced, Calif.

SAMPLE SIMULATION

On the University of California, Merced, campus, a classroom and office building is planned. The facility will provide individual offices for faculty.

In this example, a typical faculty office measures 13 ft by 10 ft and has its own HVAC zone and operable window. The window is roughly 4-ft-6-in. wide and 5-ft high, hinges on one side, and is oriented southeast.

Located in California's Central Valley, Merced has a relatively extreme climate for the state—especially during the summer, when the area is hot and dry. Table 1 provides summary climate statistics for Merced, while Figure 1 shows

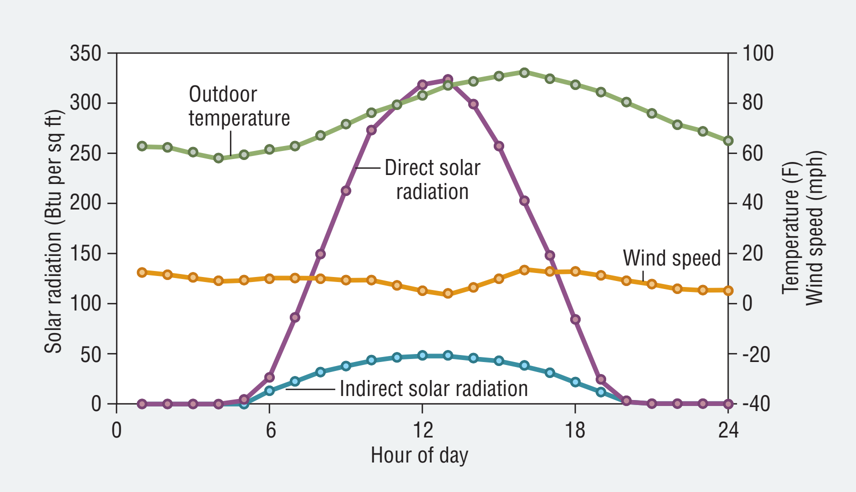

FIGURE 1. June 11 weather data for Merced, Calif.

select weather parameters for June 11, an example day in our simulation.

The simulation will predict temperature and energy-use data for our hypothetical office with:

1) Mechanical ventilation and cooling only.

2) Natural-ventilation cooling only via: (a) window operation on a set schedule and (b) window operation by the occupant.

3) Non-integrated operable window and HVAC system.

4) Integrated operable window and HVAC system with: (a) window-switch control, (b) occupancy-sensor control, and (c) perfect occupant control.

These scenarios cover a full range of possibilities for using (or not using) operable windows in commercial buildings. Taken together, the data provide a broad picture of how mixed-mode approaches can impact comfort and energy use.

SCENARIO 1: MECHANICAL VENTILATION AND COOLING ONLY

To establish a baseline, we simulate conditions in the office without the use of the operable window over an entire year. The graphs in Figure 2 illustrate how the office and HVAC system are used. The top graph shows that the HVAC system is on from 7 a.m. to 6 p.m. every day. The middle graph shows that the window is closed all day. The bottom graph shows that the office is occupied from 8 a.m. to 11 a.m. and 1 p.m. to 4 p.m. every day.

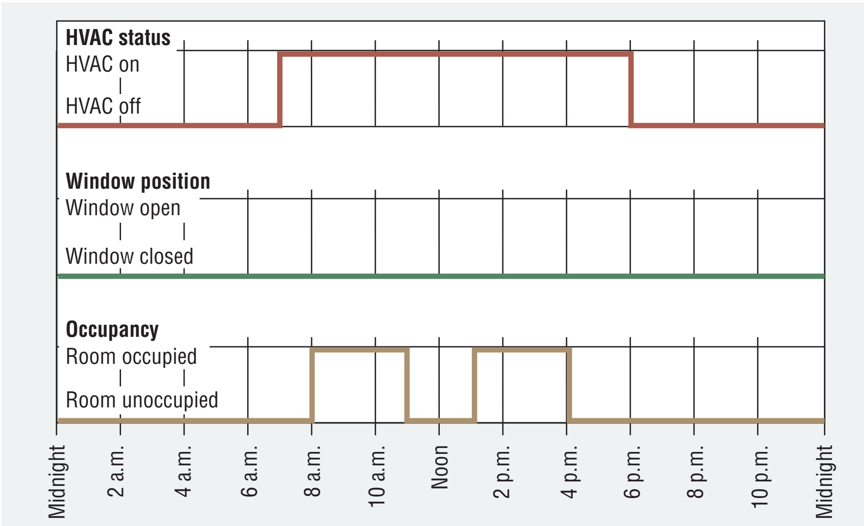

FIGURE 2. Use parameters for Scenario 1 (mechanical ventilation and cooling only).

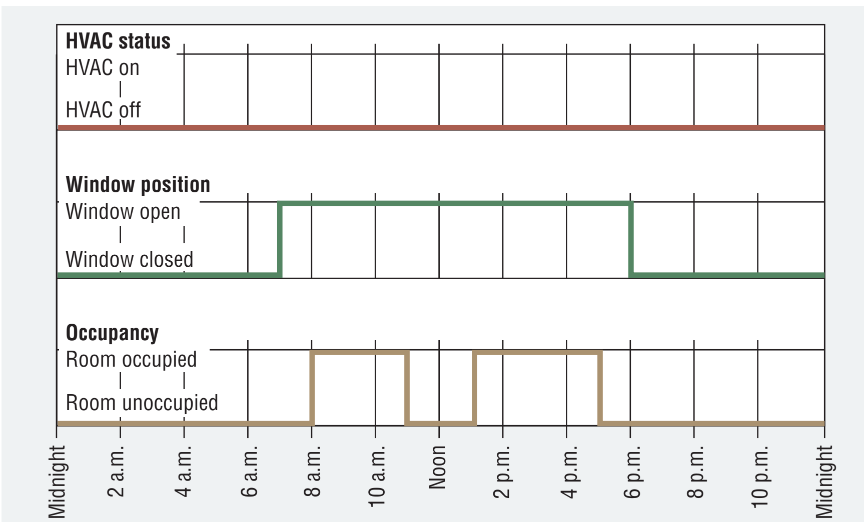

FIGURE 3. Use parameters for Scenario 2a (natural-ventilation cooling via window operation on a set schedule).

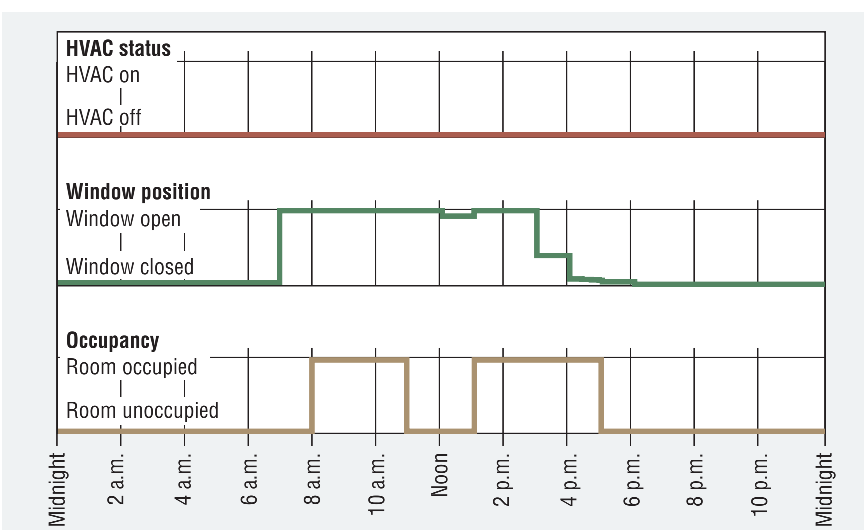

FIGURE 4. Use parameters for Scenario 2b (natural-ventilation cooling via window operation by the occupant).

SCENARIO 2: NATURAL-VENTILATION COOLING ONLY

In this scenario, no mechanical cooling or ventilation is provided. Clearly, the office uses much less cooling energy in this scenario than in the first; however, the space temperatures are much higher during the summer.

Scenario 2a: Window operation on a set schedule. In Figure 3, we assume the window is operated on a set schedule—opened at 7 a.m. and closed at 6 p.m.—every day.

Scenario 2b: Window operation by the occupant. In Figure 4, we assume the occupant controls the window appropriately over the course of the day. If the outside temperature is lower than the inside temperature, the occupant will open the window. If the outside temperature is higher than the inside temperature, the occupant will close the window. The occupant also is assumed to change the window position each hour to capture the maximum benefit, as can be seen in the middle graph of Figure 4.

SCENARIO 3: NON-INTEGRATED OPERABLE WINDOW AND HVAC SYSTEM

In this scenario (Figure 5), the operable window is opened at 8 a.m., when the occupant arrives, and closed at 1 p.m., when the occupant returns from lunch, every day, without regard for the temperature outside. In an attempt to maintain comfortable conditions, the HVAC system in this scenario consumes more energy than the one in the first. Such non-integrated, mixed-mode approaches confirm engineers' concerns about buildings with operable windows wasting energy.

SCENARIO 4: INTEGRATED OPERABLE WINDOW AND HVAC SYSTEM

There are a variety of ways to achieve integrated, mixed-mode system operation. They include:

Scenario 4a: Window-switch control. Through this method, heating and cooling to the zone are disabled whenever the window is open. Figure 6 shows the physical arrangement of components.

Figure 7 shows that the HVAC system is turned off when the window is open.

Scenario 4b: Occupancy-sensor control. HVAC operation is disabled whenever the zone is unoccupied. Figure 8 shows the components in this system arrangement. Figure 9 shows that the HVAC system is off whenever the room is unoccupied.

Scenario 4c: Perfect occupant control. An occupant continually providing perfect control of a window is, of course, unrealistic, but it serves as a theoretical example of the amount of energy that can be saved with an integrated, mixed-mode system. The occupant changes the position of the window every hour to capture any available free cooling and avoid increased heating or cooling demand. Figure 10 shows that the occupant keeps the window open to various degrees during the morning, when it is cool outside, but largely keeps the window closed during the afternoon, when it is warm outside. The HVAC system operates throughout the day.

COMPUTER-SIMULATION RESULTS

Figure 11 summarizes the simulation results. The top graph shows relative daily energy use, while the bottom graph compares the temperature ranges inside the office during both occupied and unoccupied hours of the day. Figure 12 compares annual cooling-energy use.

The sealed-building scenario (Scenario 1) serves as the baseline, its energy use set at 100 percent. The energy use of each of the other scenarios is shown as a percentage of the baseline. The difference between the occupied- and unoccupied-hour temperature ranges in the sealed-building scenario is small and near the setpoint of 75 F. During occupied hours, the HVAC system keeps the temperature at the setpoint.

The natural-ventilation scenarios (scenarios 2a and 2b) use the least energy on both a daily and annual basis because no HVAC cooling is allowed. This excellent energy performance is counterbalanced by the least comfortable conditions. Both scenarios exhibit both the

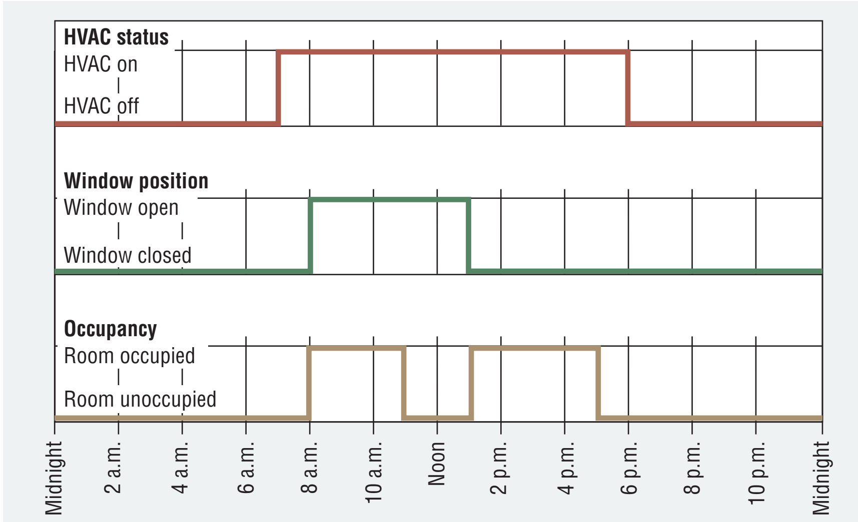

FIGURE 5. Use parameters for Scenario 3 (non-integrated operable window and HVAC system).

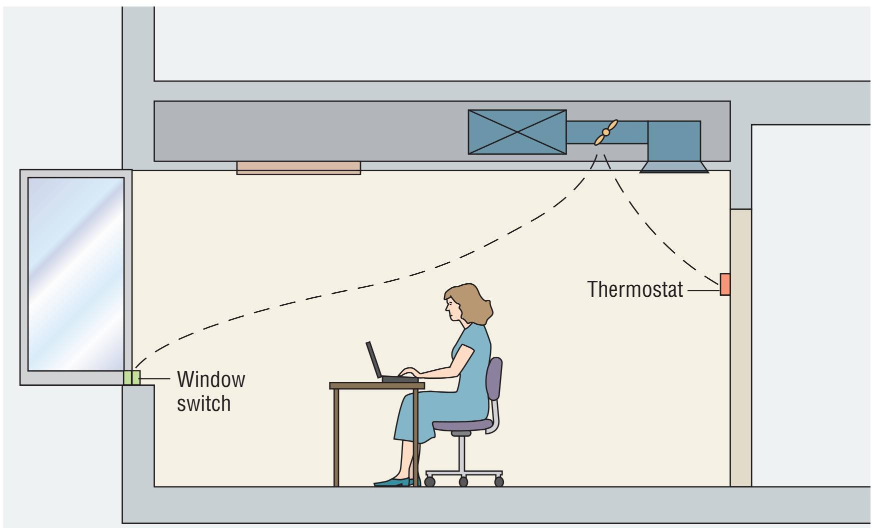

FIGURE 6. An office HVAC control interlocked with a window switch.

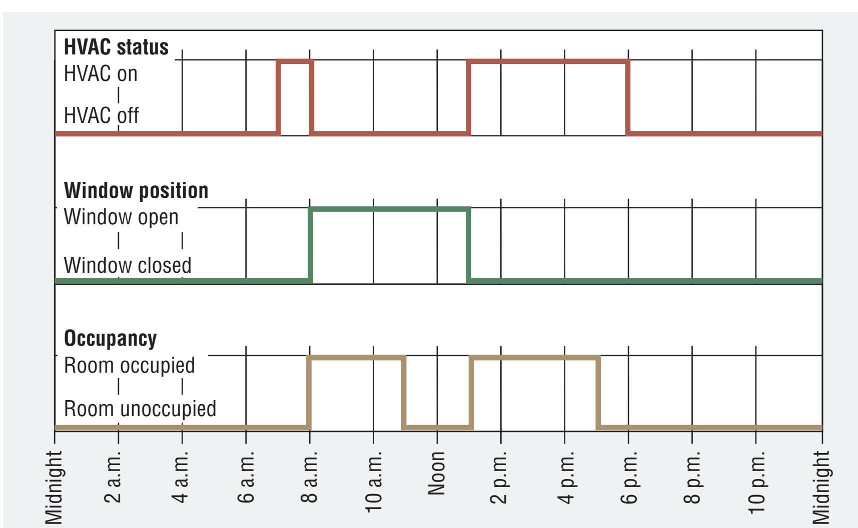

FIGURE 7. Use parameters for Scenario 4a (integrated operable window and HVAC system with window-switch control).

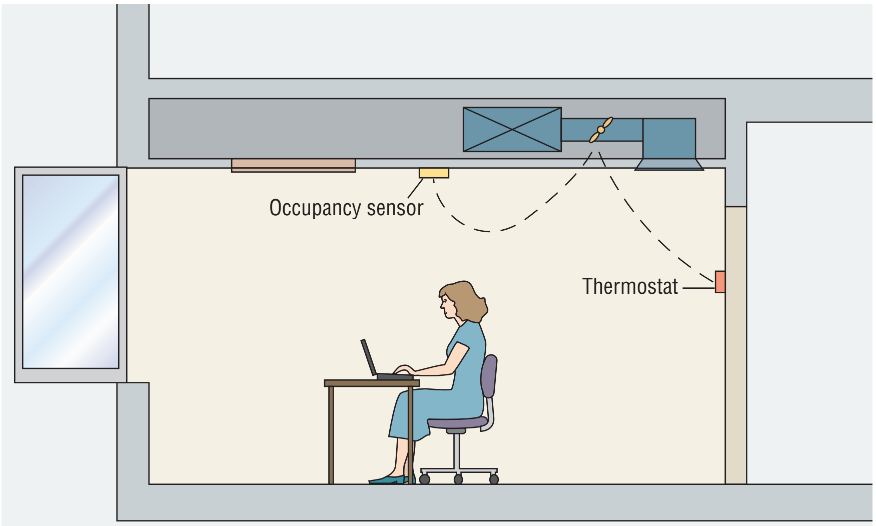

FIGURE 8. An office HVAC control interlocked with an occupancy sensor.

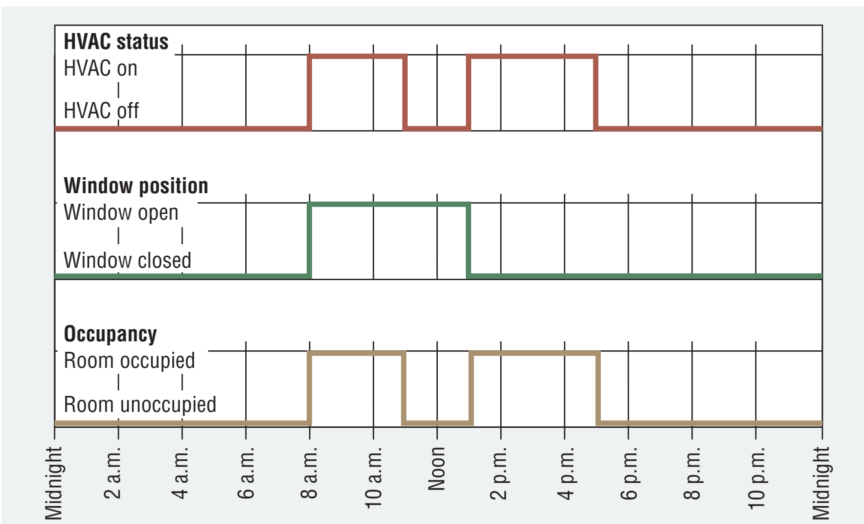

FIGURE 9. Use parameters for Scenario 4b (integrated operable window and HVAC system with occupancy-sensor control).

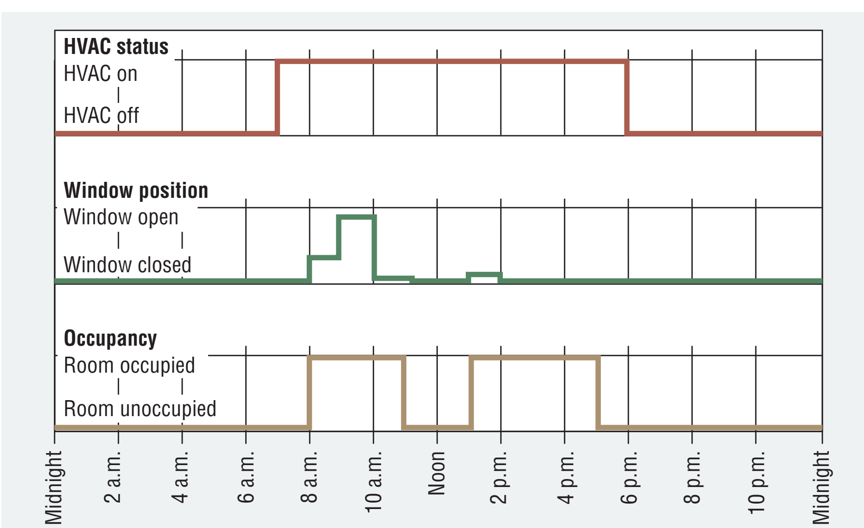

FIGURE 10. Use parameters for Scenario 4c (integrated operable window and HVAC system with perfect occupant control).

highest temperatures and the largest temperature ranges.

Compared with the sealed-building scenario, the mixed-mode, non-integrated scenario (Scenario 3) uses 32-percent more energy daily and 37-percent more energy annually while providing the same temperature conditions. The extra energy, thus, is wasted.

The mixed-mode, integrated scenarios display interesting behavior. The window-switch design (Scenario 4a) uses 30-percent less energy daily and 37-percent less energy annually than does the sealed building and has higher maximum temperatures and a wider range of temperatures during both occupied and unoccupied hours. However, because the occupant has control of the window and can shut it whenever desired to bring the space temperature down to 75 F, we can assume that the occupant is comfortable in the space at the higher and wider-ranging temperatures. If this assumption is valid, then energy is saved when the system takes advantage of the occupant's expanded comfort range.

The occupancy-sensor scenario (Scenario 4b) uses 6-percent less energy daily and 15-percent less energy annually than does the sealed-building scenario and shows no difference in temperature during occupied hours. Although energy-savings potential is not as great as it is with the window switch, comfort is comparable to that with a sealed-building system.

The perfect-occupant-control scenario (Scenario 4c) results in the same temperature and daily energy performance as with the sealed-building system, but 10-percent less annual cooling-energy consumption. This suggests that 10-percent less energy could be used to condition a building without sacrificing temperature performance during occupied and unoccupied hours.

CONCLUSION

As the above simulations illustrate, design strategies that integrate operable windows and HVAC systems *can* save energy—possibly, significant amounts of it.

The natural-ventilation scenarios with no mechanical cooling clearly offer the best energy performance, but also the highest space temperatures and widest temperature ranges. If energy performance is a critical design factor, and occupants can be educated about what kind of building performance to expect, this may be an attractive option.

The mixed-mode, integrated approaches offer exciting combinations of improved energy performance and comfortable temperature conditions. In the window-switch scenario, in which the occupant is in full control of both window position and the temperature of the indoor environment, energy use is reduced and comfort improved whenever the occupant wants to be warmer than the room setpoint. When occupancy sensors are interlocked with HVAC zone operation, energy savings result without any loss of temperature performance during occupied hours.

One drawback of the integrated, mixed-mode options is that they require a single HVAC zone per office, which increases project construction costs.

Of course, all of the energy percentages and temperatures listed here strongly depend on the climate and geometry of our hypothetical office, as well as the simple assumptions made about window use, HVAC operation, and office occupancy. Real-world outcomes vary significantly with climate and space type, and the best approach for one project may not be the best for another. However, setting aside the specifics of this study and focusing on the general concepts it reveals, there is no reason why operable windows should continue to be associated with wasting energy. Clearly, if designers work to create integrated systems, operable windows will help capture the dual benefits of improved occupant satisfaction and reduced energy use.

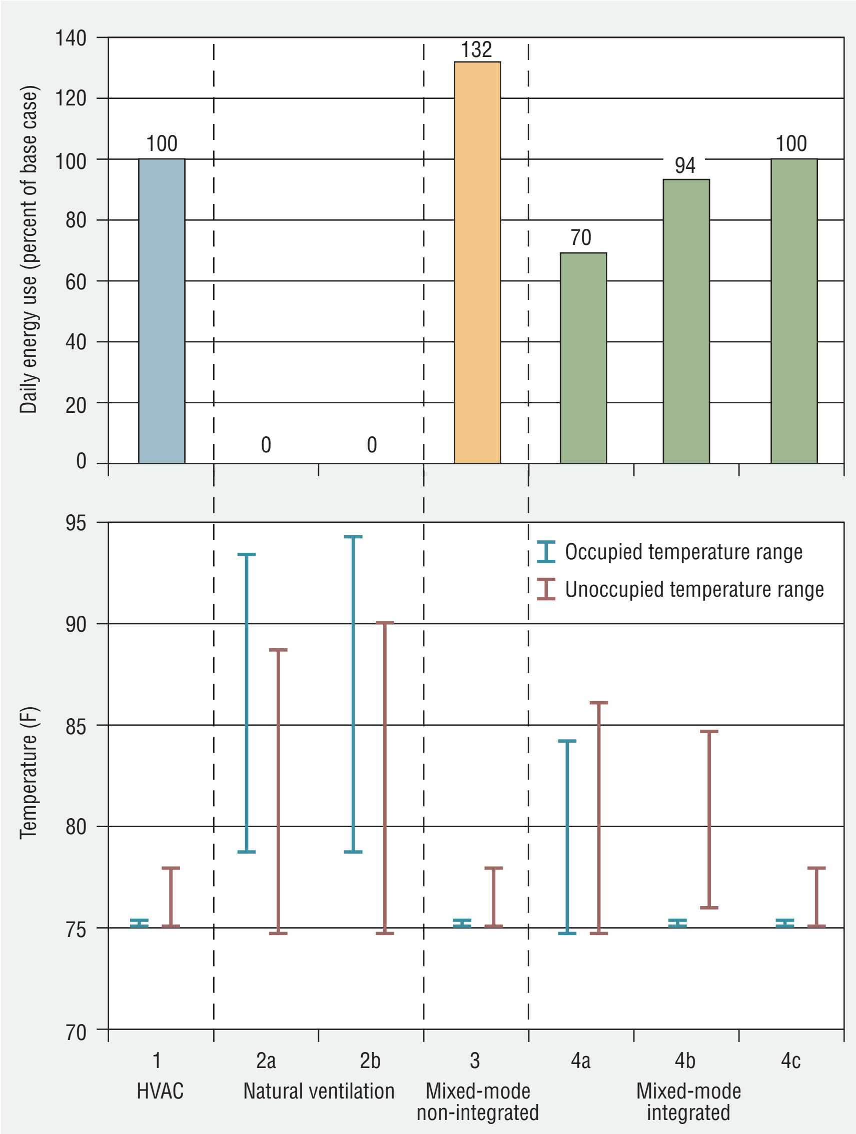

FIGURE 11. Comparison of daily energy use and temperature.

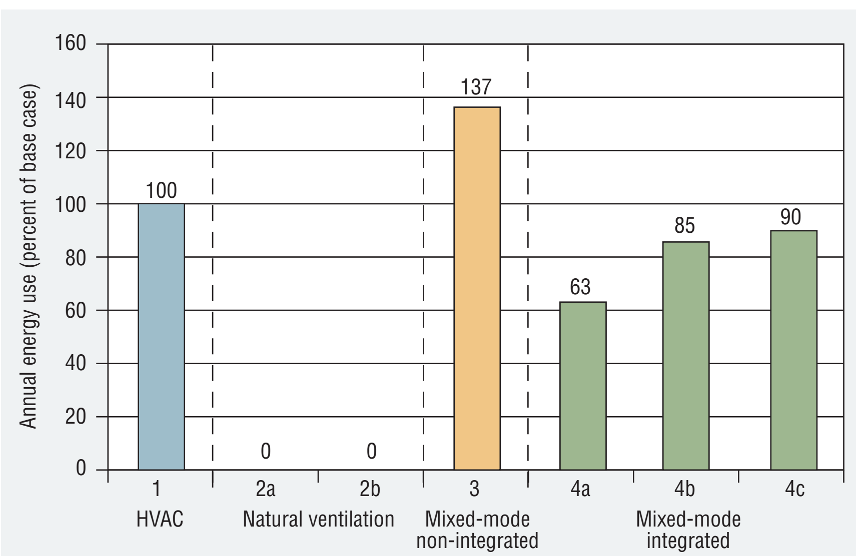

FIGURE 12. Comparison of annual cooling-energy use.

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Buildings with operable windows exhibit fewer symptoms of sick-building syndrome.

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