Kicking the Air Conditioner Habit

Ventilation cooling in a well-designed home can make air conditioning obsolete.

by David Springer

Air conditioning has become an expected feature in new California homes, even those in cooler coastal locations. Because many Californians run their air conditioners for just a few days out of the year, air conditioners use only 10%–12% of the energy in homes, yet they are responsible for about 43% of the residential peak load. This load from hell has been the bane of California utilities, and in 1994 the California Institute for Energy Efficiency (CIEE) set out to address this problem by improving the performance of production homes, of which there are about 100,000 built each year. The CIEE assembled a team of researchers to participate in a project that was dubbed Alternatives to Compressor Cooling (ACC). Continued under the California Energy Commission Public Interest Energy Research (PIER) program, the project is nearing completion.

The ACC project was grounded in the idea that the need for air conditioning could be reduced or eliminated by ventilating homes with cool night air, which would cool concrete floors, walls, and other mass. This cooled mass then absorbs heat from indoor air during the day, keeping occupants comfortable enough that they avoid turning on the air conditioner or, on the hottest days, shift its use to off-peak periods.

People have used ventilation to improve summer comfort for centuries. So why did the researchers feel something new was needed? Fewer people are opening windows nowadays, because they are bothered by noise from roads and freeways and by outdoor dust and pollens, or because they are worried

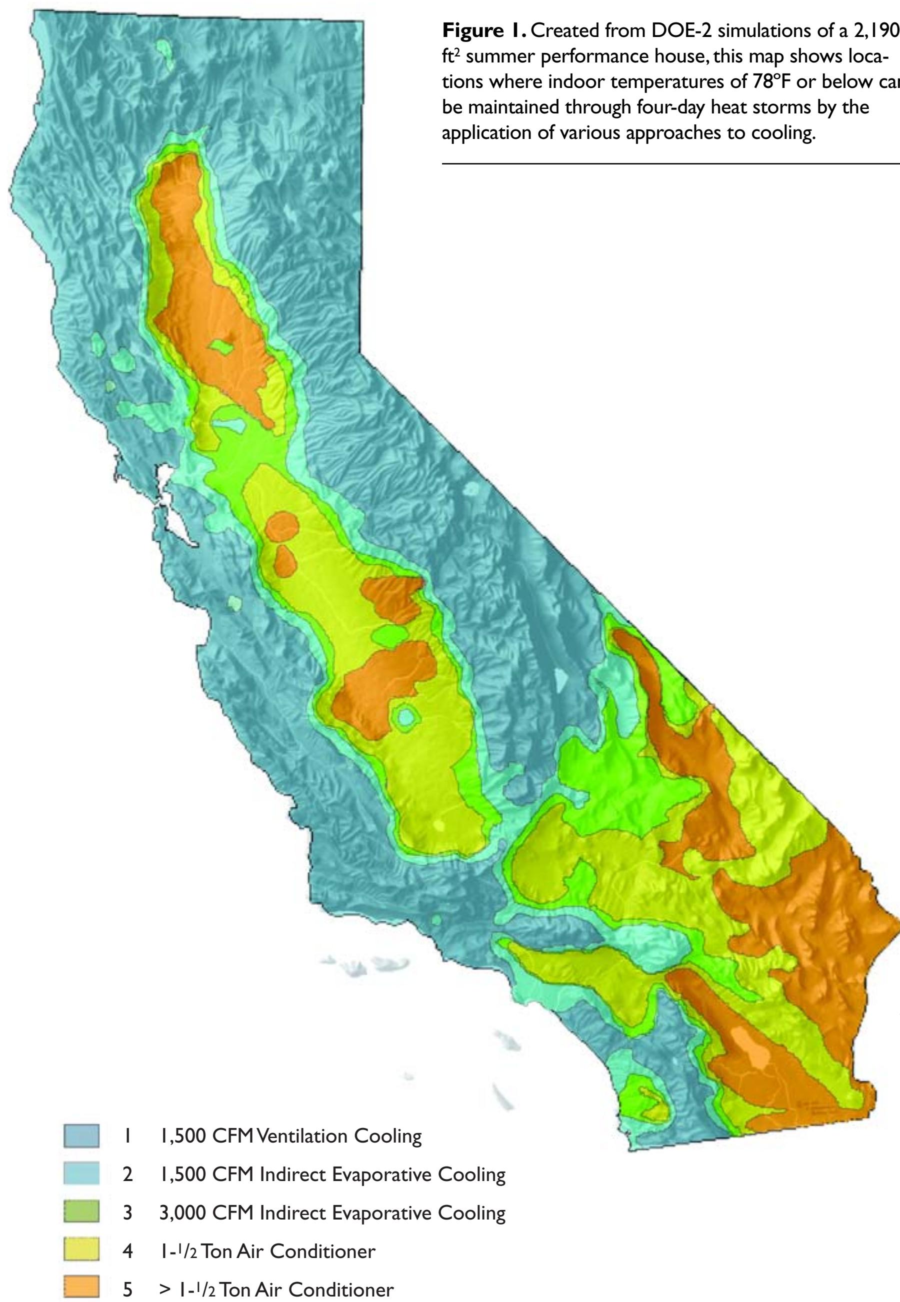

Figure 1. Created from DOE-2 simulations of a 2,190 ft^2 summer performance house, this map shows locations where indoor temperatures of 78°F or below can be maintained through four-day heat storms by the application of various approaches to cooling.

JOE HUANG

DAVIS ENERGY GROUP

In addition to its improved design and NightBreeze cooling system, Centex Homes' "21st Century Performance Home" sports 3.6 kW of PV modules, making the house nearly a zero net user of electricity.

about security. Whole-house fans improve ventilation but still require windows to be managed and don't filter outside air. For a system to be acceptable to a wide market, it would have to automatically supply cool outdoor air to the house, vent warm air out, filter the air, and be easy to use.

Mapping Compressorless Cooling

Early in the ACC project, studies were completed to determine the practicality of ventilation cooling and to study health and comfort issues. One of the first steps was to verify that computer simulation tools can accurately model building response to ventilation cooling. To do this, a small test building was constructed at Pala, near San Diego, and then monitored. The data from this test were used to calibrate a DOE-2 simulation model of the building. It was found that the model needed improvements in the way it simulated the exchange of heat with concrete slab foundations (most California production homes are built on slabs), so a special function was added to improve modeling accuracy. This model was then used to simulate a typical house in different climatic regions of California in order to map areas that would most benefit from ventilation cooling. The resulting map plots locations where ventilation cooling alone, ventilation cooling plus indirect evaporative cooling, or ventilation cooling plus air conditioning are likely to maintain the indoor temperature below 78ºF through heat storms when used in a well-designed house (see Figure 1).

Concurrently, other studies were conducted to help us to understand the health, comfort, and sociological issues related to ventilation cooling. For example, we found that people have a very wide range of temperature preferences in their homes, and that thermostat wars between living companions are common, although not universal.

Team members also tackled marketing issues, such as how builders and homeowners would respond to home designs that improve summer performance and make ventilation cooling work better. Several very conventional-appearing home designs were developed to show builders that efficient designs do not have to look different. The project also sponsored a "Summer Performance Home" category for the Pacific Coast Builders Conference Gold Nugget award program. There were few entries; at that time production builders were showing little interest in energy efficiency. This attitude changed during the course of the project, fueled partly by the energy crisis in the spring of 2000.

Finding the Right Equipment

With computer simulation results boosting confidence that ventilation cooling could eliminate air conditioner use in a summer performance home, we set about determining what mechanical systems could be used for ventilation. Both independent fans and dampers and systems that integrate with heating and cooling equipment were considered. Early in the project, we considered employing direct evaporative cooling, but we abandoned this approach because higher humidity levels can increase dust mite growth. Indirect evaporative cooling was also explored as a way to squeeze additional cooling effect out of the outdoor air, but it became clear that adapting this technology to many homes would be difficult, because the equipment requires so much space. We also anticipated difficulties with acceptability on the part of home buyers, who are unaccustomed to evaporative cooler maintenance requirements, and on the part of builders, who are very sensitive to change.

In the end, we looked for a system that would meet the following criteria:

- low to moderate cost;
- easily installed and maintained by residential mechanical contractors;
- good air filtration;
- high efficiency (low fan energy use);
- as reliable and maintenance-free as conventional systems;
- daily management of controls not required; and
- maximum utilization of ventilation cooling while maintaining comfort.

To keep costs down, it made sense to us to use the same fan that delivers heating and cooling to deliver ventilation air. By sharing the heating/cooling ductwork, ventilation air could be distributed to every room. This approach also eliminated the need for two filters, one for outdoor air and one for indoor air, but it required that the ventilation system be somehow integrated with the heating and air conditioning system.

Of the several equipment alternatives we explored, we chose a solution that married a hot water air handler to an outside-air damper (see Figure 2). There were two reasons why we decided to use an air handler instead of a furnace as the air-moving device. First, we had worked on a previous project that used a variable-speed electronically commutated motor (ECM) with a hot water air handler, and we were extremely impressed with the winter fan energy savings, high level of comfort, and near elimination of fan noise. Second, we did not want to be encumbered by furnace controls that might interfere with optimal use of the ECM-powered fan for ventilation cooling, and we wanted to avoid the need to obtain American Gas Association (AGA) approvals in order to complete field testing. ECM-driven fans are used in most high-efficiency furnaces, but since air flow must keep up with gas burner capacity, furnaces cannot take advantage of their impressive low-speed performance. While typical furnace fans draw 400 to 700 watts, we found that an ECM-driven air handler can maintain comfort while drawing as little as 50 watts. The variable-speed ECM also makes it possible to vary ventilation rates in proportion to cooling needs, thereby improving summer comfort and reducing fan energy use.

With the means of moving the air more or less resolved, we set about determining the best way to feed outdoor air to the air handler. We explored several designs, some of which would have required multiple motor-operated dampers. Damper air leakage was also a prime concern. Fortunately, a damper that was already being manufactured as a residential economizer provided the answer. With only one motor actuator, no linkages to fail, and a single damper blade that provides switching between return and outside air as well as relief, this damper seemed the perfect solution. Pacific Gas and Electric's Technical and Environmental Services Laboratory tested the damper for durability, leakage, and pressure drop. Leakage was found to be about 1.4% of total fan flow at 25 Pa. The damper was cycled 10,000 times with no signs of failure. Doubling as a return air box, the damper also proved to be easy to install and connect.

We soon realized that the same components could be used to meet winter fresh-air requirements by opening the damper and running the fan at a very low speed. This approach requires only about one-tenth of the fan energy used by fresh-air ventilation systems that use the furnace fan to recirculate indoor air while mixing in a relatively small volume of outdoor air.

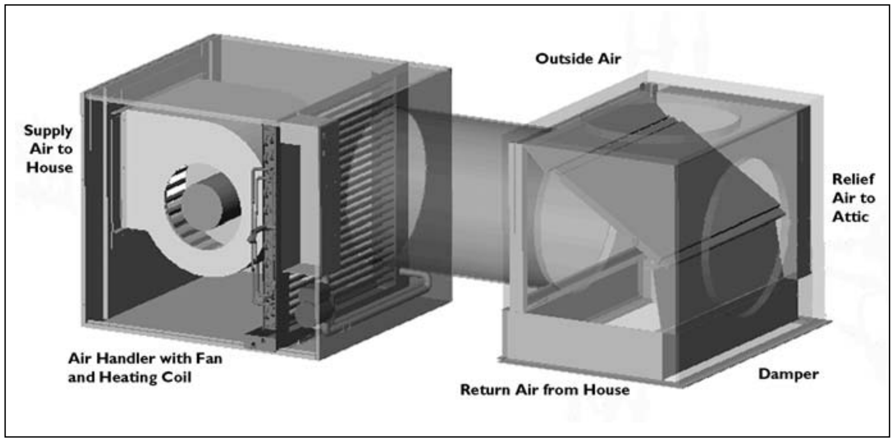

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Figure 2. *(above)* The NightBreeze system includes an air handler driven by a variable-speed ECM and a damper that can select between outdoor and return air. The air handler can draw as little as 50 watts. *(ri ht)* The thermostat allows both minimum and maximum temperatures to be set and displays the predicted indoor temperature range for the next day as a shaded bar.

Controls That Forecast the Weather

The next challenge was to develop a control system that would integrate control of ventilation cooling, heating, and air conditioning, and that would make the most of ventilation cooling opportunities. The lower the indoor temperature that a house is ventilated to overnight, the cooler the house will stay the next day. Therefore, the homeowner should be encouraged to cool the house to as low a temperature as outdoor conditions (and house design) will allow, in order to keep the air conditioner from turning on. The team spent countless hours on the question of how to design a control that would effectively encourage ventilation cooling.

A breakthrough came when we realized that if people knew the consequences of their temperature settings, they might be motivated to ventilate to cooler temperatures. Several feedback options were considered, including various indicators of energy savings. The team settled on a comfort bar that displays expected next-day's temperatures and that shifts position with changes in user settings (see photo above). A user interface, or thermostat, was designed around this idea. Several display designs were drafted and the preferred design was tested, using an interactive virtual thermostat placed on a Web page. With input from a questionnaire attached to the Web page, a basic design was settled on, and several improvements were implemented following further review of this design.

This shaded comfort bar encourages lower indoor temperature settings by telling the user what indoor temperatures to expect when various settings are selected. The "low" setting is used to select the lowest desired indoor temperature, and the "high" setting is used to select the highest desired indoor temperature, which is also the air conditioner setpoint. The control uses these settings to predict the indoor temperature range for the next day, which it then displays using the comfort bar. If the "low" temperature setting is too high, it causes the predicted indoor temperature range to exceed the "high" setting, and the message "Air conditioner will run" will be displayed.

Behind the scenes, the control must be able to predict indoor and outdoor temperatures reasonably well. By completing a statistical analysis of a large database of both monitored and simulated temperatures, we were able to develop equations that use a two-day temperature history to arrive at these predictions. Though Mother Nature can still throw an

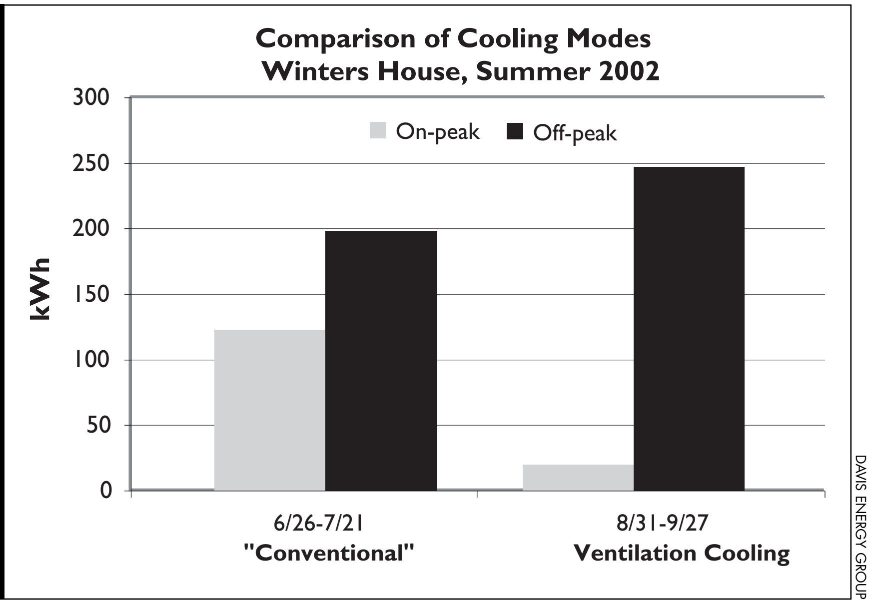

Figure 3. Ventilation cooling with the NightBreeze system lowered on-peak energy use to only 5% of total cooling energy use.

Table 1. "Summer Performance" Energy Measures Installed

Watsonville	Livermore
High performance vinyl frame windows (low-E2, U=0.34, SHGF=0.33)	High performance vinyl frame windows (low-E2, U=0.34, SHGF=0.33)
Overhang shading of key windows	Overhang shading + trellises on E-W-S
50% exposed slab floor	50% exposed slab floor
5/8" instead of 1/2" drywall for added mass	5/8" instead of 1/2" drywall for added mass
Radiant barrier roof sheathing	Radiant barrier roof sheathing
NightBreeze system w/o air conditioner	NightBreeze system with 12 SEER A/C
Condensing water heater (EF 0.86)	Instantaneous gas water heater (EF 0.82)
	R-10 slab perimeter insulation

occasional curve ball, the predictions have proven to be sufficiently reliable.

Ventilation should be used to cool the house down just enough to prevent the air conditioner from running, so it makes no sense to cool the house to the same "low" setting during both hot and mild weather. In mild weather, comfort can be improved and fan energy can be saved both by operating the fan at a lower speed and by raising the ventilation cooling low temperature limit. We used a DOE-2 computer model that incorporates the same predictive algorithms developed for the control to test various parameters for adjusting the low temperature limit and fan speed in order to keep the indoor temperature below the air conditioning setpoint while minimizing fan operation.

Finding control hardware that would accommodate the predictive logic, that could display the comfort bar, and that would be sufficiently versatile to handle all of the functions needed was another significant challenge. Following an extensive product search, a wall display unit-microcontroller combination was located. This brand-new product was originally developed to communicate real-time pricing and uses soft keys that can be programmed to serve any purpose. A controller is linked to the thermostat by a communications bus and connects to other components. Minor modifications were made to the controller to provide outputs to control the ECM and other components. Firmware was developed for both the thermostat and the controller to provide the necessary functionality. Because owner's manuals for thermostats are frequently misplaced, one of the soft keys was programmed as a Help button.

With the completion of controls, this integrated heating, ventilation cooling, air conditioning, and fresh-air ventilation system needed a name. Suggestions ranging from the sublime to the absurd were offered, and the name NightBreeze was finally selected.

The Proof Is in the Demonstration

With nearly six years of development behind us, we were finally ready to try out the technology. We sought out two production builders to demonstrate both the construction techniques and the mechanical systems. Two builders expressed interest: Clarum Homes, who was building a new development in Watsonville, California, called Cherry Blossom; and Centex Homes, whose Los Olivos development in Livermore, California, was under way. Clarum's demonstration home was completed in October 2001, and the Centex home was completed in July 2002. The Centex home, publicized as the 21st Century Performance Home, was also a demonstration site under the National Renewable Energy Laboratory (NREL) Zero Energy Homes program, and met the newly developed Alameda County Green Building program standards. Multiple measures were installed in each of the homes to improve summer performance (see Table 1). Zero Energy features added to the Livermore home included a 3.6 kW PV array and a solar water heater.

The 3,080 ft^2 Livermore home required two zones, so two separate NightBreeze systems were installed. The smaller Watsonville home uses a single NightBreeze system. In both houses, the water heaters serve as a source of heat for space heating as well as domestic hot water. Residents of both homes found they provided good comfort in summer and winter.

Both homes were monitored to determine how much cooling (and heating) was delivered by the NightBreeze systems, and to see how well indoor temperature was maintained. Sensors measured indoor and outdoor temperatures and relative humidity; solar radiation; fan, pump, and air conditioner power; and water and air flow rates and temperatures.

The Watsonville climate is heavily influenced by the Pacific Ocean. It is mild most of the time, with occasional heat spells, and air conditioning is seldom installed. Indoor temperatures at the Watsonville house proved adequate for comfort, generally staying below 78°F while using only 11 kWh of fan energy over the entire summer. The owners proved to be extremely tolerant of wide temperature ranges and didn't use their heating system for the entire winter.

The Livermore climate is more typical of central California valleys, and air conditioning is standard on all new homes. Despite a summer that included 12 days when the temperature was over 100°F, the Livermore house used its two air conditioners for a combined total of less than 20 hours while maintaining an indoor temperature of 78°F. With the house open for tours, the air conditioners used only 42 kWh from July 15 through September 1. A similar house without ventilation cooling would be expected to use about 25% more.

Winter monitoring results showed that the variable-speed fan motor used an extraordinarily small amount of energy. Typical furnace fan power, as measured by John Proctor, is about 510 watts per 1,000 CFM. The Livermore house heating unit fans averaged 140 watts per 1,000 CFM and averaged only 48 watts while they were operating. No fan energy use was recorded for the Watsonville house, because the residents did not use their heating system—a testimony both to the design of the house and to the wide variation in personal temperature preferences.

A Cool Performance

A third home, the author's residence, was completed in March of 2000 and has served as a test bed for the NightBreeze system. Located in Winters, California, where it can get quite hot during the summer, this home also includes a radiant floor cooling system that supplements ventilation cooling on the hottest nights. The home was monitored for one year under the direction of Oak Ridge National Laboratory to evaluate standard cooling operation versus ventilation cooling and slab cooling.

Performance results from the Winters house show a substantial reduction in peak load when the NightBreeze system is operating (see Figure 3). With air conditioning only, 27% of the energy use occurred during the on-peak period (between 12 pm and 6 pm). Ventilation cooling lowered on-peak energy use to just 5%. The ventilation cooling system improved the overall system EER from 9.2 to 11.9, resulting in energy savings of about 23%.

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Table 2. Predicted Energy and Demand Savings

	Energy Savings		Demand Savings	
Location	**kWh**	**%**	**kW**	**%**
Sunnyvale	113	48%	1.5	83%
Long Beach	240	71%	2.4	92%
Riverside	670	53%	1.2	44%
Sacramento	584	58%	1.4	47%
Fresno	888	39%	1.5	45%
China Lake	684	35%	0.9	29%

(top) Indoor temperatures at the Watsonville house remained comfortable throughout the summer, while the cooling system used only 11 kWh of fan energy. *(bottom)* The table compares a Title 24 house in which windows are used for natural ventilation against the same house designed to meet summer performance standards with mechanical ventilation.

To estimate cooling energy savings in other locales, an 1,860 ft^2 house with design features similar to the Livermore and Watsonville houses was modeled, using a special version of the DOE-2 hourly simulation program that emulates NightBreeze control operation. Results of these studies show that energy and demand savings depend strongly on how the house is operated and where the house is located (see Table 2). If the owner operates windows conscientiously, computer simulations predict summer energy savings from 0%–36%. With windows kept continuously closed, simulations predict savings ranging from 35%–71%, depending on local climate. The computer studies also indicate that ventilation cooling could eliminate the need for air conditioning in Sunnyvale and Long Beach, and that air conditioner size can be decreased by one-half ton in all other locations but China Lake, without compromising comfort.

In addition to supplying cooling comfort, the NightBreeze system provides year-round filtered ventilation, which improves indoor air quality (IAQ) by removing volatile organic compounds (VOCs) and other airborne contaminants. Filtered ventilation can also reduce moisture buildup that can lead to mold and dust mite growth. And since windows are not required to be open to obtain fresh air, security is improved.

The Future of Ventilation Cooling

Applicability. If peak electric loads and high cooling costs continue to pose problems for utilities and homeowners, respectively, the combination of ventilation cooling and summer performance home designs can be an effective solution. Though summer performance home designs provide value in all climates, ventilation cooling is effective primarily in the dryer western climates, and where evaporative cooling has poor market acceptance. Together, summer performance home designs and ventilation cooling provide an effective means of reducing air conditioner size or eliminating the use of air conditioners altogether.

Availability and cost. We have been generally disappointed by the lack of interest shown by HVAC manufacturers in ventilation cooling and have begun to produce NightBreeze systems on a limited basis, mostly for additional demonstration projects. For example, eight are scheduled to be installed in Habitat for Humanity Homes in the San Diego area this year. Once in volume production, we expect the cost of the variable-speed air handler, outside-air damper, and controls to be in the range of $1,200 –$1,600. Since the NightBreeze replaces the furnace and any fresh-air delivery system that might be installed, the incremental cost could be less than $500. If the house design and climate allow elimination of the air conditioner, then the cost could be lower than that of a conventional system (a good example of Amory Lovins' tunneling through the cost barrier). The value of improved IAQ and comfort, reduced noise, and the other benefits described justify the higher cost.

For our next acts, we are planning to develop a zoned version of NightBreeze that will reduce cost and improve comfort in larger homes and a version that operates with variable-speed furnaces. Working with a major California HVAC contractor, we expect to introduce the furnace-based system to production home builders by next spring. We are also exploring the possibility of developing a humid-climate version that will integrate dehumidification.

David Springer is president of Davis Energy Group. The ACC project participants have included researchers from Lawrence Berkeley National Laboratory, UC Berkeley, UC Davis, UCLA, Washington State University, and the private sector. Since 1999 the project has received its support from the California Energy Commission, and it is currently being led by the Davis Energy Group.