Cheaper, Efficient Cooling with Whole-House Fans

by Neil Smith

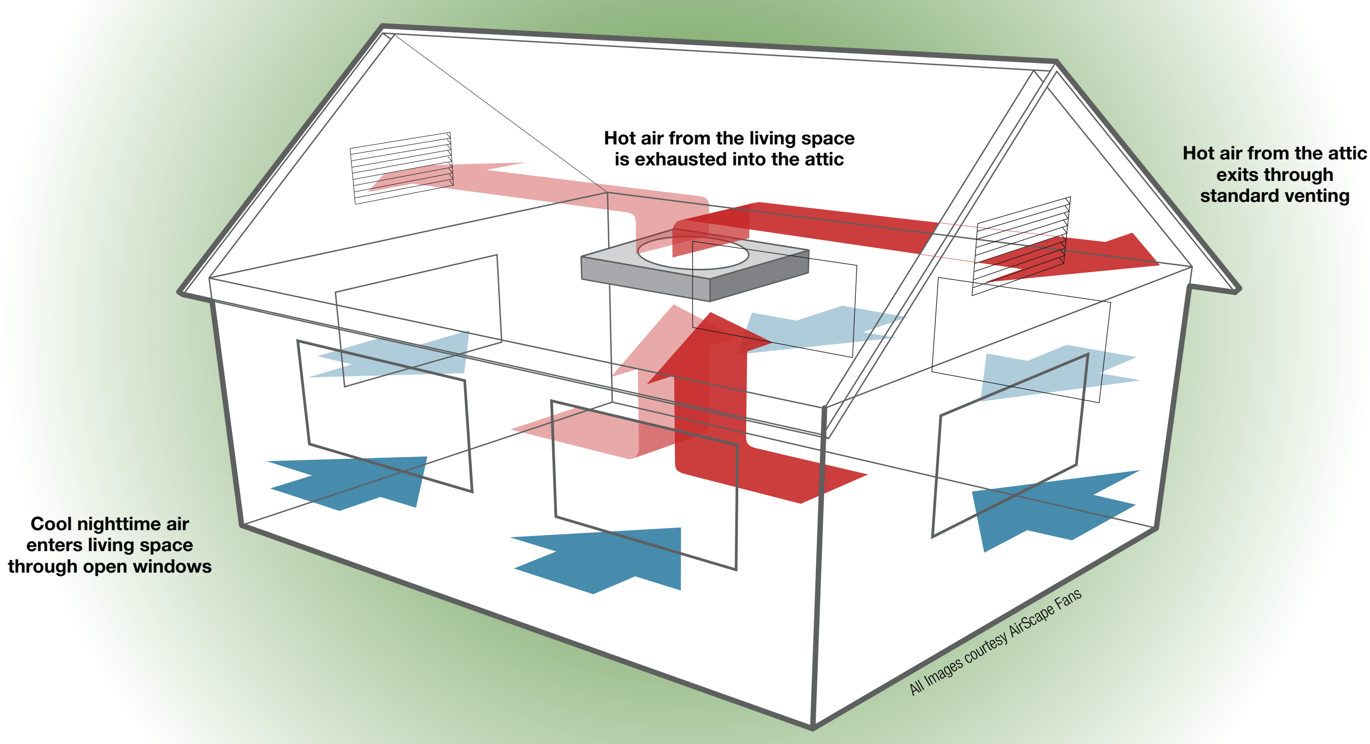
Whole-house fans, sometimes improperly referred to as "attic fans," are a class of fan that exhaust air from a house, drawing in fresh air through open doors and windows. Whole-house fans are used to cool a house when the outside air temperature is lower than inside (see figure below), and are a convenient and innocuous way to provide inexpensive cooling.

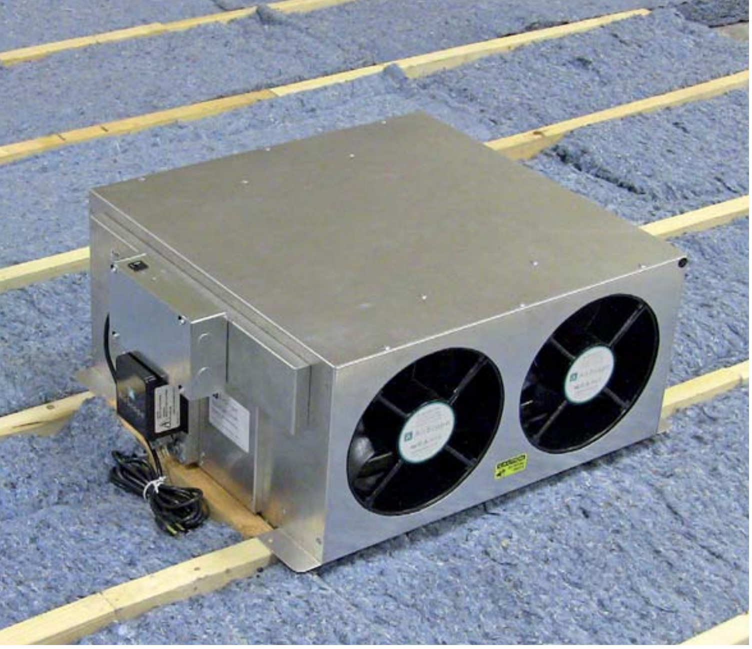
Cooling Off

Whole-house fans have been in use in the United States for much of the last century, although their mass appeal has been eroded by the availability of air-conditioning and inexpensive electricity. But as electricity rates rise and homeowners are realizing the necessity of ventilation (as well as the negative environmental impact of running central air-conditioners), whole-house fans are undergoing a renaissance.

There are several different strategies for using whole-house fans. For houses with existing air-conditioning, the most basic strategy is to use whole-house fans to eliminate air-conditioning use at night. On average, a whole-house fan uses 90% less energy than an air-conditioning unit. The only lifestyle change required is to turn off the air-conditioning, switch on the fan, and open windows on cool nights. A whole-house fan that has enough airflow to maintain cool sleeping conditions "most of the time" would be selected, which translates to a minimum airflow per bedroom of 500 to 700 cubic feet per minute (CFM), depending upon local climate. These figures for airflow are based upon user feedback. There are many factors that affect human comfort, from temperature and humidity to individual sensitivity. With enough airflow (think: motorcycle riding), one can be cooled in almost any temperature. However, at some point, the energy to pull all that air with a whole-house fan will be more than using air-conditioning.

Operation of an Attic-Mounted Whole-House Fan





An attic-mounted whole-house fan pulls hot air into the attic space (where it exits through vents) while drawing cooler nighttime air into the living-space through open windows.

Natural or "free cooling" is based upon how much cooler the outside air is than inside air. Your climate and personal comfort will help determine if you can use a larger whole-house fan to extend the time when air-conditioning is not required. This is a function of climate and personal comfort. As whole-house fans become available that have good power unloading (reduced energy use at low speeds), this upsizing becomes more practical. Whole-house fans that use 700 watts at full speed and 100 W at half speed are one of the benefits that are available with electronically commutated motors.

Another strategy is to increase the airflow to pre-cool the building. This involves running a whole-house fan all night, bringing in cool air so that the building is as cool as possible the next morning. A pre-cooled structure will stay cool longer the following day, saving additional air-conditioning use and providing comfortable conditions later into the day. For homes with sufficient thermal mass, the entire house can be pre-cooled sufficiently to eliminate air-conditioning.

Airflow

Airflow is typically measured by cubic feet per minute (CFM)—a cube of air 1 by 1 by 1 foot flowing by every minute equals 1 CFM. That cubic foot of air weighs about 1.2 ounces. At higher elevations, air becomes less dense (for instance, Denver air—neglecting particulate pollution—weighs about 0.99 ounces). Since fans blow air by volume (irrespective of air density), a 1,000 CFM fan placed in Denver will still blow 1,000 CFM. The problem is that 16% less air mass is being moved, and the mass is what does the work of heat transfer.

A common misconception concerning whole-house fan use is that it can cool down the house in 15 minutes and then you can "turn off the helicopter." But "quick cooling" a house with a blast of outside air defies the physics of heat flow. The weight of air in a 2,000-square-foot house is approximately 1,200 pounds, with an aggregate thermal capacity of 288 Btu per pound per degree Fahrenheit. According to demolition studies, a typical 2,000-square-foot house will weigh in at 222,000 pounds. Based upon the typical material mix, the weighted average specific heat of that house is 0.39 Btu/lb°F, which means that it would take 85,000 Btu (0.39 x 222,000) to raise or lower the temperature of the whole house by 1°F. Of course, the house doesn't heat up and cool down uniformly, which is one of the reasons why nothing in building heat transfer is simple. Since air is relatively easily cooled and heated, the goal must be to cool the high mass of the house. The physics of heat transfer prevents this from happening quickly.

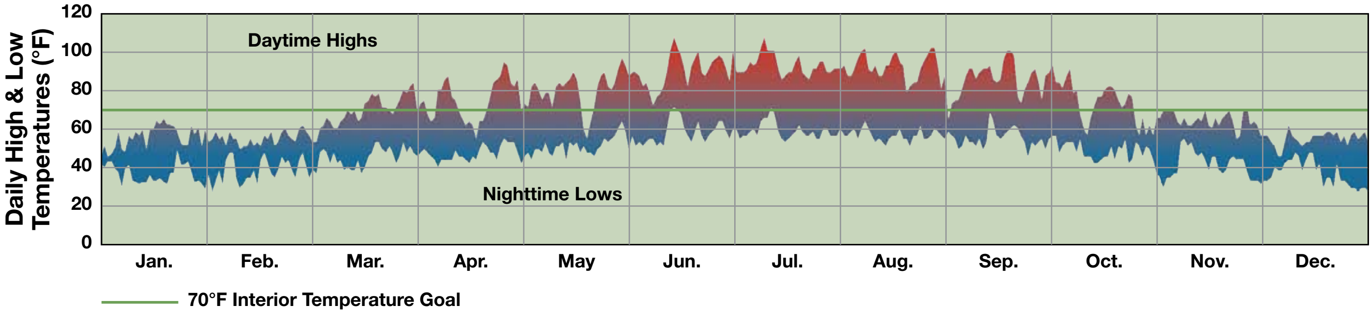
Although some houses are situated to capture breezes, most houses do not "self-ventilate," necessitating some form of mechanical ventilation. Fresh air requirements are often in the range of 0.35 air changes per hour (ACH) or 20 cubic feet per minute (CFM) per person. To put this in perspective, a 1,700 CFM whole-house fan would yield more than 6 ACH when placed in a 2,000-square-foot house with 8-foot ceilings [(1,700 x 60 ÷ (2,000 x 8)].

Older criteria simply recommended an airflow of 3 CFM per square foot. But this overly simple formula comes from a time when houses were not well-insulated—and whole-house fans were the only form of cooling available. Since natural cooling depends upon Mother Nature, technical factors, and personal preferences, it's not possible to have a definitive size for a particular case. However, customer feedback combined with engineering knowledge has resulted in developing empirical formulas for airflow that take into account cooling strategies, location, and house construction.

A rare, but promising application of whole-house fans is to incorporate ground-source cooling. If you have a basement that stays cool all summer, you effectively have the basis for a ground-source cooling system. A low-cost way to take advantage of this cooling is to open one or more basement windows, and run a whole-house fan during the day. Warm air enters the basement windows, is cooled by the basement concrete, and is then pulled through the rest of the house.

Motorized and insulated backdraft dampers prevent cold air from entering the living space. Uninsulated whole-house fans can be insulated seasonally.

Typical Meteorological Year: Sacramento, California



Choosing Your Fan

Planning a successful installation of a whole-house fan requires a few steps. First, choose the cooling strategy that makes sense for comfort and is within your budget. Then answer the following questions:

- What is my local weather like—at what time of day do temperatures start to drop? At what time does the temperature start climbing?
- Can I replace air-conditioning, either fully or partially?
- How frequently do I need to run the fan—for some, most, or all summer nights?
- Is lower cost more important than features like automatic louvers, low noise level, and power use?
- Is lowering my electricity costs important?

Case 1: Sacramento, California: 3,000-square-foot ranch house built in 1950 with insulation upgrades; four bedrooms, occupied by five people

California has relatively high electrical rates that rise rapidly as electrical consumption increases (tiered rates). The homeowner has just finished paying another $600 summertime electrical bill and he wants to slash that cost. The other inhabitants of the house are noise-sensitive and will make little or no lifestyle changes to save energy.

Sacramento houses require cooling during a significant portion of the year (see graph, above). However, summers have large temperature drops at night.

Driven primarily by economics, the homeowner chose an automatic-closing whole-house fan based upon the following factors, in order of priority:

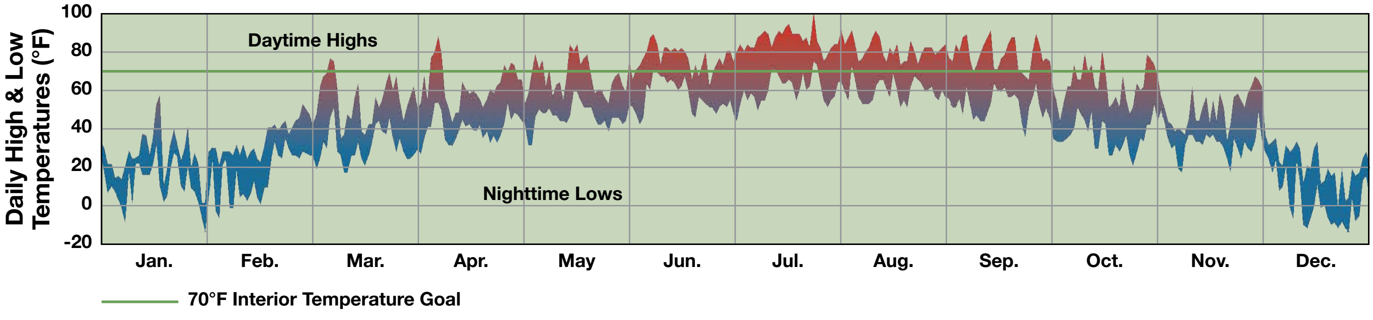
- High airflow to reduced utility bills as much as possible
- Low noise level
- Motorized doors to minimize the inconvenience of having to seasonally weatherize and insulate around the unit
- Fan with low power usage on low speed

Case 2: Aurora, Illinois: similar construction as Case 1, but with two occupants.

Illinois has low electrical rates, with short—but humid and hot—summers and cold winters. The homeowner chose a traditional, uninsulated whole-house fan driven by the following factors:

- Low first cost
- Older central air-conditioner
- Noise level was not critical (fan placed at end of large house)
- Homeowner does not mind insulating the whole-house fan seasonally

Typical Meteorological Year: Aurora, Illinois



Climates that undergo large temperature drops at night (10°F or more below indoor temperature) and houses with lots of thermal capacity are ideal matches for whole-house fans. In these situations, a whole-house fan can easily replace air-conditioning. Most other areas within North America offer some degree of natural cooling potential. For example, climates with hot, humid summers can make use of natural cooling during the spring and fall. See the "Typical Meteorological Year" graphs that illustrate the daily ranges.

Fan Placement

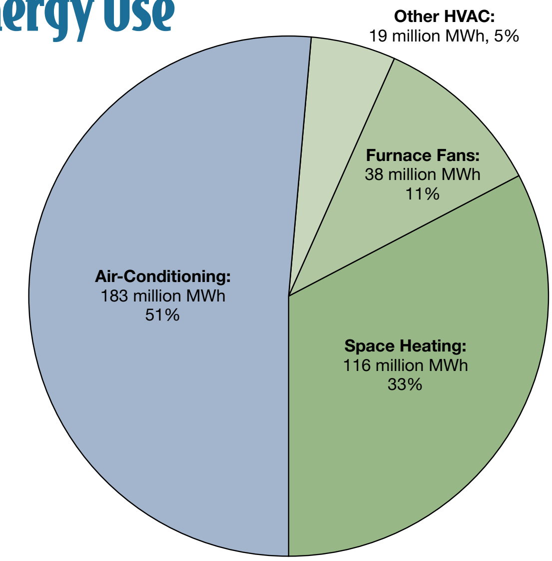
Just about any central location may be a good location for a whole-house fan. To reduce noise from the fan, you'll need to consider acoustic reflection or simply the distance the fan will be from listeners. Because of decorating choices, and the fact that it's a central location for airflow, the vast majority of whole-house fans are installed in hallway ceilings. Airflow paths through the house can be determined by which doors and windows will be opened to ventilate the house.

Attics are the preferred locations for whole-house fans for several reasons. Attics are vented and offer lots of space for equipment. They also allow the fan to exhaust the hottest air in the house. For houses without attics, homeowners may choose alternate fan locations, such exhausting to a garage or crawlspace. There are a limited number of roof-mounted whole-house fan on the market, although this market will undoubtedly grow as more sealed attics are built.

Most whole-house fans are designed to sit on top of the ceiling joists. Typically, cutting joists is unnecessary—the area directly below the whole-house fan is framed to form a channel for the air and support for the grille or backdraft damper. Modern whole-house fans have motorized and insulated doors. If a homeowner opts for a non-insulated model (they are significantly cheaper), then manually insulating the fan in winter is highly recommended. Several whole-house fans use a remote fan connected to the plenum box with flexible ducting, which is a great acoustical attenuator. Pulling air through a duct consumes extra electricity, a consideration when you're weighing energy use. However, with careful selection of motors and fan blades, this energy cost can be minimized.

To improve whole house airflow, and reduce the visual impact, fan intakes are often centrally located in hallways.

Space Heating & Cooling Energy Use



Total U.S. Electrical Consumption for HVAC:
356 million MWh

Source: EIA, Residential Energy Consumption Survey 2001, forms EIA-475-C, E & H and other

Acoustics

Acoustics is a complex study, with the additional difficulty of trying to quantify that every person perceives sound differently. Any sound source is a mix of multiple frequencies, each with different power levels. In response to this, acoustical engineers have developed single-digit parameters like sones and decibels (dBA). Engineers prefer the dBA, a logarithmic measure, to sones, since they are meant to correspond to the sensitivity of the average human ear and its varied response to different frequencies.

A common measurement for fans is to measure dBA 1 meter away from the inlet grill at 45 degrees. Actual installation conditions can affect the sound level in a room. For example, a "live" room with hardwood floors and wood furniture will be much noisier than a "dead" room with carpeted floors and upholstered furniture.

Fan noise ratings vary from 50 dBA to 70 dBA. Note that 10 dBA is considered a doubling of perceived sound.

A duct-mounted remote fan isolates the whole-house fan—and its noise and vibration—from the living space.

Ventilation Requirements

Fan Volume (CFM)	Attic Ventilation Required, NFVA (Sq. Ft.)	Doors & Windows Inlet Opening Area (Sq. Ft.)
500	1	2
1,000	2	4
1,500	3	6
2,000	4	8
2,500	5	10
3,000	6	12
3,500	7	14
4,000	8	16
4,500	9	18
5,000	10	20
5,500	11	22

Note: Requirements based on HVI-916 formula for NFVA, with maximum pressure of 0.05" water column for attic; 0.01" w.c. For house. CFM=144 x sq. rt. (.05)/0.0592

The most basic whole-house fans are equipped with self-closing dampers (aka backdraft dampers), which close by gravity and open when air pushes against them. These backdraft dampers offer basic protection against debris (and rodents) from entering the house, but have no insulating qualities. Whole-house fans with insulated doors require motorized actuators to open and close the doors, since airflow alone is not capable of moving anything but the lightest of blades.

Since whole-house fans discharge into the attic, it must be sufficiently vented so that pressure does not build up. Otherwise, fan performance can be jeopardized and pressure buildup could force air back through openings in the ceiling, along with dust and other particulate matter. Whole-house fan manufacturers publish the requirement for attic ventilation in terms of square feet of net free area. This parameter (also known as net free ventilation area—NFVA) was devised to approximate the equivalent of an unrestricted opening. As shown in the table (above), velocity through each vent should be about 500 feet per minute to maintain a safe attic pressure. Most roof vent manufacturers will stamp the net free area required on the vent body as well. If manufacturer's data is not available, several online venting calculators are available (see Access).

Efficiency & Economics

Computer software can predict energy performance quite well, including how whole-house fans will cool a house. The challenge is that all the data about your house, such as how the walls and roof are constructed; the insulation levels; window and door details and locations; and shading (trees, houses); all has to be manually input. This data-gathering could be a significant project on its own. Some energy modeling software is free (see Access).

Foregoing modeling—and ignoring the best way to save on cooling energy (sweating it out or heading for the lake)— it's possible to compare how much energy a whole-house fan versus air-conditioning will save. Just use this simplified formula:

Energy saved per day (kWh/day) = [hours of fan operation x {CFM x ΔT x 1.08 x AC tons x 1,300 AC W/ton (the effective cooling of the WHF)} ÷ 12,000 – whole-house fan W] ÷ 1,000 W/kWh

Example: A whole-house fan runs for 11 hours at night, with an average temperature differential of 10°F, and pulls 4,400 CFM, while using 700 W:

Energy saved per day (kWh/day)= [11 hours/day x (4,400 $ft.^3$/min. x 10°F x 1.08 AC tons x 1,300 AC W/ton ÷12,000 – 700 W)] ÷ 1,000 W/kWh = 48.93 kWh/day

A larger airflow can compensate for smaller inside-versus-outside temperature differentials, such as those that occur in the early evening or during humid weather. However, there comes a point where overpowered and/or inefficient whole-house fans may be less efficient than air-conditioning.

The simplest method to determine the economic viability of a project is to use "simple payback"—dividing the capital cost by the annual savings. This is a great method of quickly assessing whether the project makes sense for your particular situation.

Example: This equation plugs in information from Case 1 data, using PG&E as the utility. With that utility's tiered rate structure, it's very easy to reach tier 3 (above 645 kWh/ month), which has a rate of $0.29/kWh. Assuming a WHF first-cost of $2,400 (installed) and annual usage of 90 days:

Payback = $2,400 ÷ (90 days/yr. x 48.9 kWh/day x $0.29/kWh) = 1.88 yrs.

Environmentally minded folks might be interested in calculating their carbon offset in cost per ton of carbon dioxide (CO_2) avoided. To figure dollars per ton of CO_2, take the capital cost of a project and divide it by the lifetime avoided carbon dioxide emissions. This figure is generally given in dollars per metric ton (2,200 pounds). Even the most full-featured units deliver CO_2 avoidance between $30 to $50 per ton.

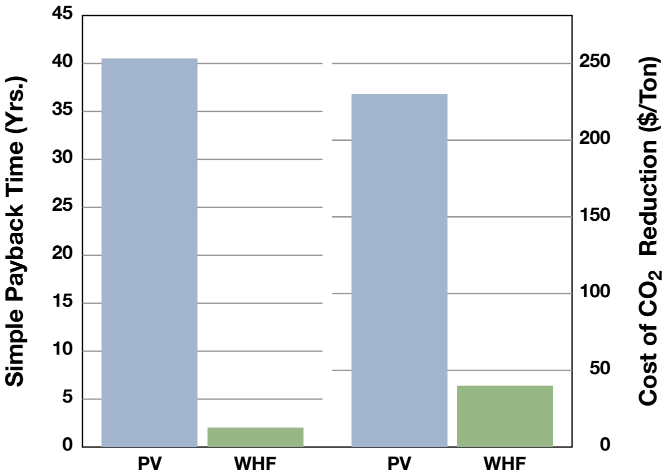
Example: Using the 4,400 CFM fan data: Dollars per ton of CO_2 = $2,400 (installed first-cost) ÷ (48.93 kWh/day x 90

Automatic Fans

Can whole-house fan systems be automated? Certainly, it's technically straightforward to devise a method that turns on the whole-house fan when cooling is required and outdoor temperatures drop below indoor temperatures. However, since large openings are required for inlet airflow, doors and/or windows also must be opened—a more difficult undertaking for automation. For now, motorizing an existing door or window is a custom project.

Because operating whole-house fans usually involves opening a window in the living space, automation is atypical. But it is possible.

Benefits of Whole-House Fans vs. Photovoltaics



days/yr. x 20 yr. lifetime x 1.3 lbs. CO_2*/kWh) ÷ 2,200 lbs. CO_2/metric ton = $46/mTon CO_2 saved

*EPA estimate, based on the U.S. electrical mix

Whole-house fans allow homeowners to naturally achieve comfortable indoor conditions while minimizing energy use and improving indoor air quality. This is a simple project that springboards on existing technology, and by economic and environmental measures, offers a quick payback on investment. If only 1.1% of the U.S. households replaced air-conditioning with whole-house fans, the output of an average coal-fired power plant—3.95 billion kWh—would be saved.

Incentives

Many electrical utilities have whole-house fan rebate programs. Incentives range from $50 to $250, and generally require only that the recipient to be a current utility customer. Check out an online database of rebates at dsireusa.org.

Access

Neil Smith (neil@airscapefans.com) has spent the last quarter-century in the HVAC world, having obtained a degree in building engineering. He is a mechanical engineer, with his professional interests focused on energy efficiency.

DOE-2 based building energy use and cost analysis software • www.doe2.com

EnergyPlus modeling program • http://apps1.eere.energy.gov/buildings/energyplus/

Online attic venting calculator • airscapefans.com/system-builder/attic-vent.php