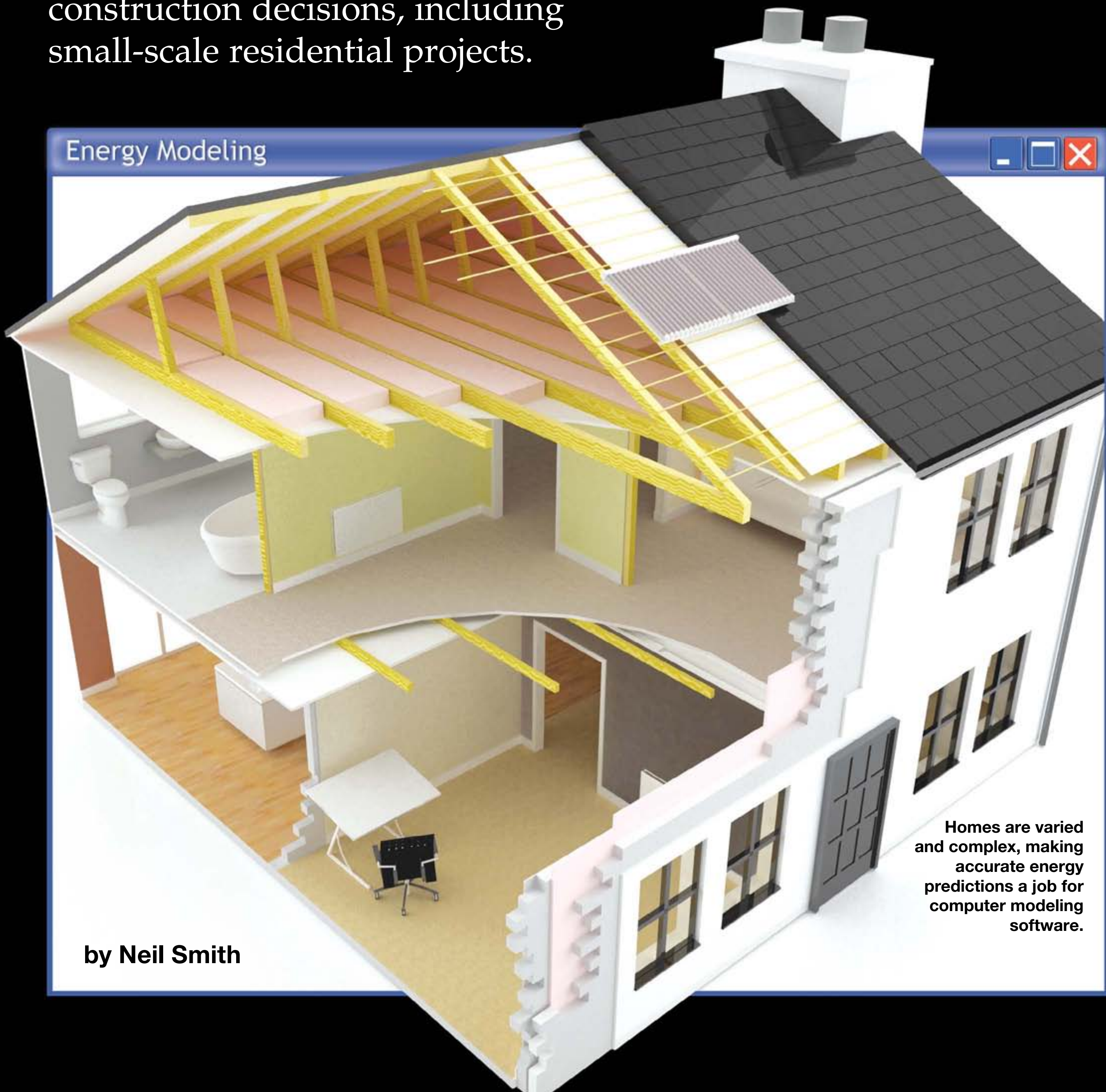
High-Tech
Home Energy Assessment

Get your geek on—energy modeling is poised to play a large role in construction decisions, including small-scale residential projects.



Homes are varied and complex, making accurate energy predictions a job for computer modeling software.

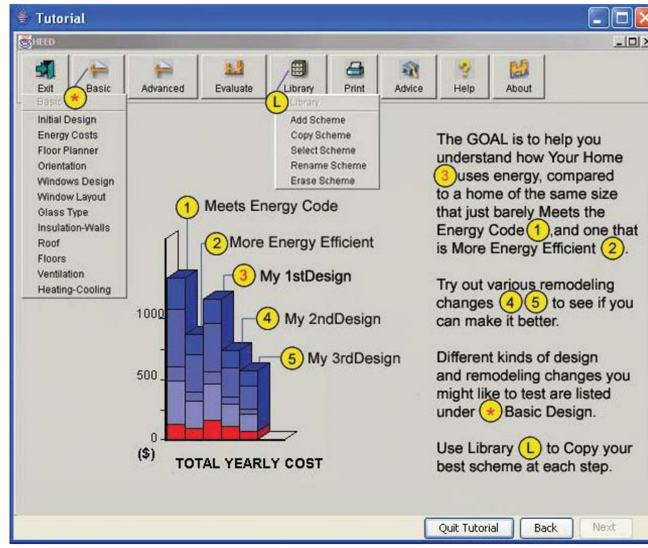
© jaddingt / Fotolia

by Neil Smith

Energy-modeling software is more accessible than ever. Good thing—many incentive programs now require scientific validation to "prove" a home's energy performance before you can cash in. From a builder's and homeowner's perspective, and short of actual construction, modeling is the most accurate method of comparing building designs. You get to test-drive your designs and tweak them in response to the results, saving yourself from expensive design disasters and a poorly performing house.

Building simulation computer software can model a home's year-round energy performance. The goal of a simulation is not only to predict how much energy a building will use, but also to compare alternate designs. These programs also allow you to investigate source-energy consumption and carbon dioxide production. Sophisticated software can even predict the number of hours that the building will be outside of the human comfort zone.

The energy flow (Sankey) diagram illustrates the complexity of energy flows for a typical house. Based upon a building description that is input by the user, the software calculates all the energy flows, including the thermal effects of people, infiltration, lights, and other loads. The flow of energy is further complicated because building materials are not just insulators; they also have a certain heat-retention capacity. Everything from furnace efficiency and fan performance to daylighting controls and heat loss can be simulated on a continual, year-round basis.

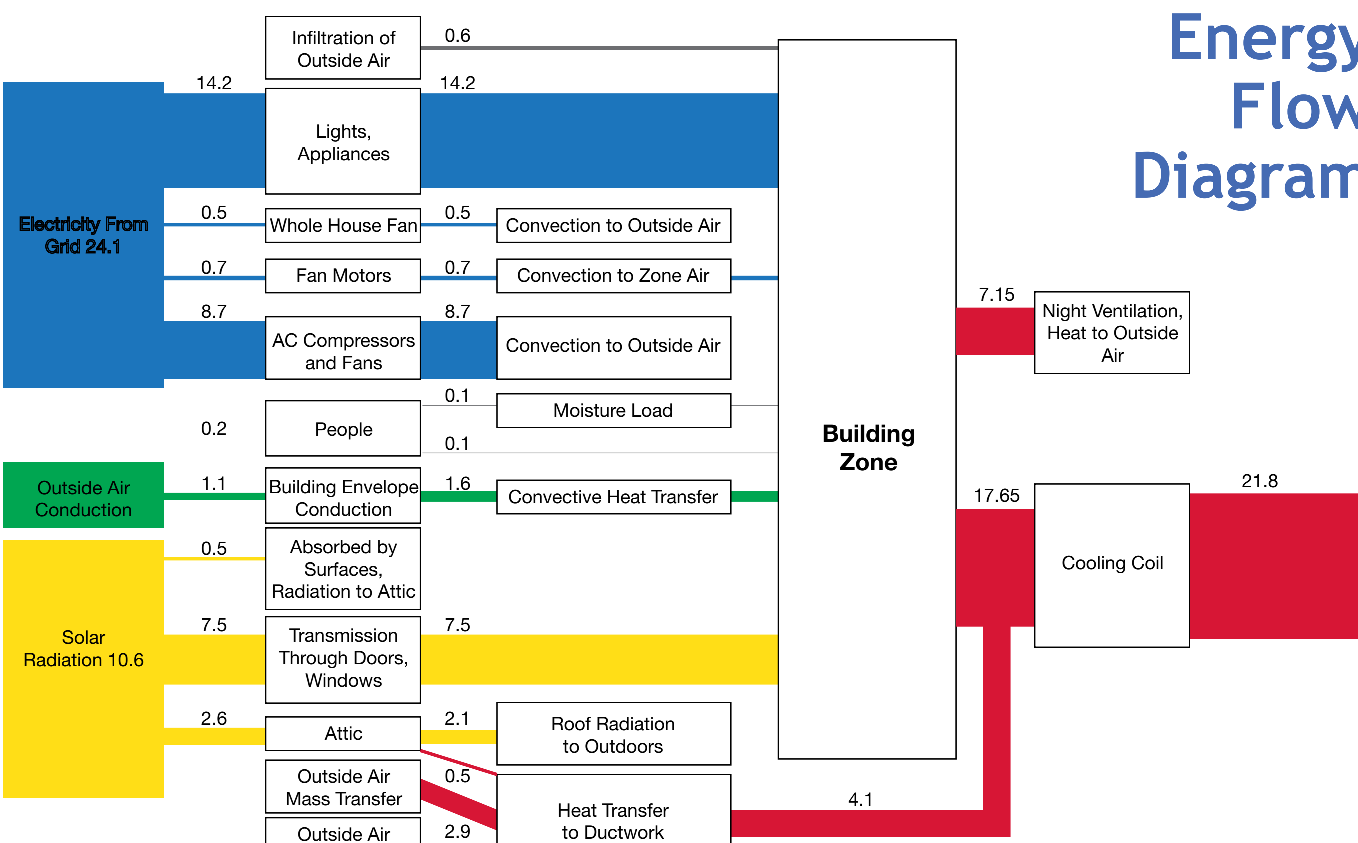


Some building simulation software, like HEED, includes tutorials to help users input information correctly.

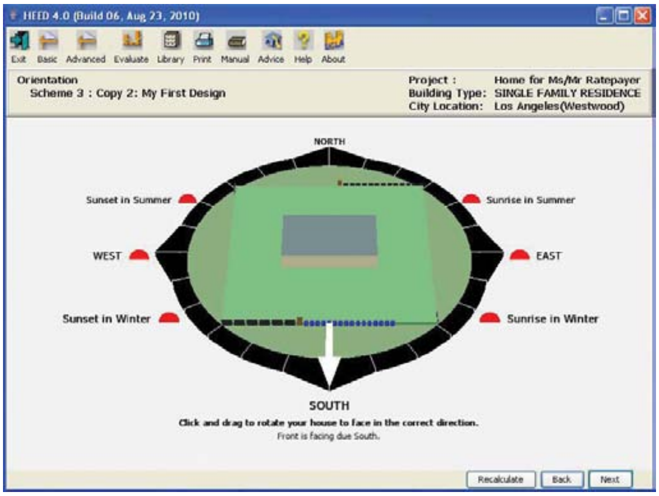
User Benefits

With all this data, it's clear that a simulation can be very helpful with building design decisions. Authorities that regulate energy compliance and agencies that give out rebates want to see this kind of analysis to make sure that buildings qualify.

Energy Flow Diagram



All units are gigajoules per year.



Most building simulation programs allow users to input data on their home's orientation to assess solar gains and losses.

Quickly and accurately comparing various ways of building, different equipment, and even alternate control strategies, yields a much better chance of optimizing building envelope and systems based upon the actual climate, planned use, and economics.

Besides analyzing the all-important design day, which represents the climatic conditions that yield the highest thermal load (also known as peak load), nonlinear system effects may be revealed—where simple changes yield complex effects. Nonlinear means that many of the house's energy inputs are not proportional to their loads. For example, if you double the cross-sectional area of all the ductwork, then the (theoretical) fan power decreases to one-quarter of the original. In turn, the fan motor heat is reduced. Even without increasing duct size, if airflow is reduced by half, the software predicts that our fan power should reduce to $^1/_8$ of the original.

Computer simulations examine alternatives such as increasing or decreasing mass, using equipment with better unloading capabilities, and oversizing systems that would otherwise be evaluated only by an educated guess. Before you drive one nail, you can optimize your design, leading to savings in time, labor, materials, equipment, and energy.

Software Genesis

To design heating, ventilation, and air-conditioning (HVAC) systems that provide comfort and economy, engineers have always relied on calculations to predict heating and cooling loads. When cheap computing power became available, hand calculations were automated. As computers became more powerful, more sophisticated and accurate algorithms replaced approximation methods.

Commercial simulation software offers a great deal of programming flexibility. With that flexibility comes many choices, and a steep learning curve. Because these tools offer so much potential, there is a lot of activity focused on making the software more accessible by offering graphical interfaces and building model templates.

Simulation software uses the physics of heat transfer combined with environmental conditions to determine internal temperatures and heat flows. This is the calculation "engine," which can use various load calculation methodologies, with most of the differences usually only of interest to researchers. Although the software is very complex, conceptually there are three main sections:

- Describe the building
- Define the thermal zones
- Define the mechanical system

The Building Model

In this phase, the task is to take all the details of a building and input the parameters into the software. For the building envelope itself, the order of information is:

- Location
- Weather file
- Orientation
- Surfaces
- Doors, windows, and walls
- Materials
- Material properties

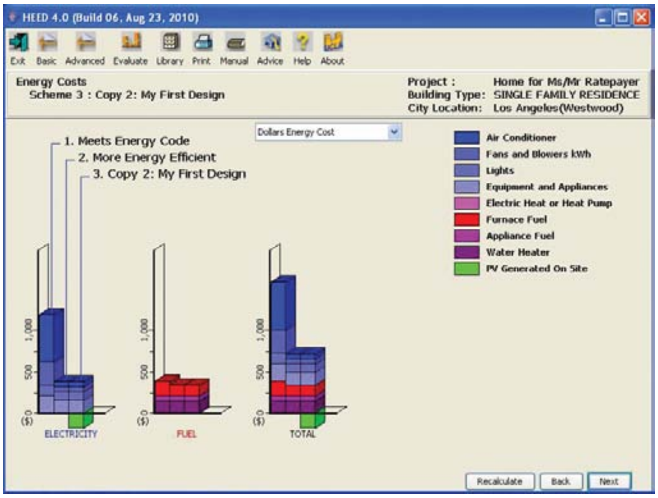
Then we do the same for interior surfaces, since even with a single-zone model they can affect the building's thermal performance and capacity.

Because internal loads—such as people, lights, set points, and the schedules that govern them—can also influence the building envelope, they need to be included. To describe these loads, which vary over time, we use the concept of "schedules." An example would have inputs for time, day of the week, and holidays so that the software will be accurate any time of the year and determine what the setpoint should be, or how many people are expected in the zone, or any other event you wish to model.

Open-Source Software

Although much of the software discussed has been developed with public funding, none of it is open source, which allows anybody access to the underlying software code. The beauty of open source is that users can customize the code to their own needs, find errors, or even offer improvements. Most open-source licenses enforce this spirit of collaboration by requiring any redistributions of the code to also be freely available. Some notable examples of open-source software include Firefox (browser), Linux (operating system) and, lately, Android (mobile phone operating system).

What does this mean in terms of modeling software? Without open-source capabilities, it means that the code is largely hidden and customizing the software is difficult, if not impossible.



Built-in "reference" homes make it easy to see how your home design measures up in terms of energy efficiency.

often move based on comfort. If the bedroom is cold but the sun is shining through the living room windows, just like Fluffy the cat, we can relocate ourselves to that sunny spot on the couch. For modeling purposes, specifying an average temperature is usually good enough.

Once this part of the model is complete, the software can calculate the "loads" by applying the physics of heat transfer, which are incorporated into algorithms for heat conduction, radiation, and convection. The simulation engine churns through millions of such calculations to determine the cooling and heating loads for every hour of the year. Each calculation uses all of the previous inputs, including climate, building envelope, and schedules (occupancy and setpoints) to determine the energy required to maintain the temperature set point—the target value of a controlled parameter. (For example, a room temperature set point would be 70°F for heating and 74°F for cooling.) The weather is simulated by applying a full year of climate data for the home's location, which can include temperature, humidity, and cloud cover.

Thermal Zones

Buildings are divided into thermal zones. A zone is defined as the space controlled by a single temperature controller. Residential systems typically have only one thermal zone, controlled by a single thermostat. This is where the model loses some accuracy, since different rooms in a house can be comparatively cooler or warmer. The justification for this thermal control and modeling inaccuracy is that occupants

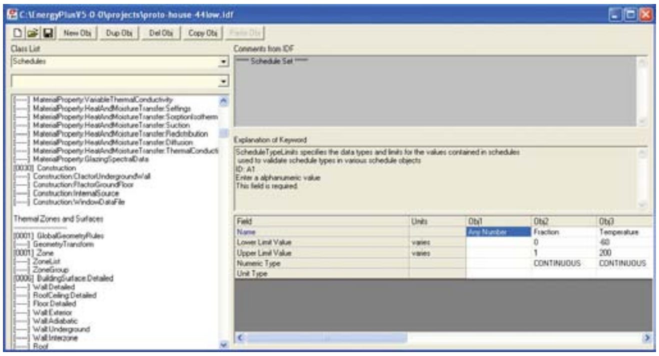
Mechanical Systems

Just as your car does not deliver its best fuel efficiency when you're stomping on the gas, a mechanical system does not deliver the same performance or efficiency under varying conditions. In this phase of the simulation, the software uses the calculated thermal load and the characteristics of the mechanical equipment to determine the equipment's response (on or off, fan speed, etc.).

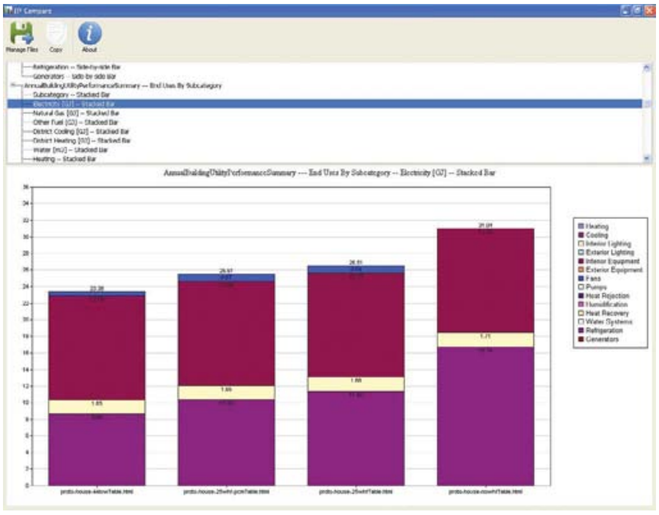
Selected Residential Energy Modeling Software

Software	Types of Buildings & Systems	Graphical Interface; Ease of Use	Calc. Engine; Suitable for Pro Use	Add-on Software	Support	Notes
HEED www.energy-design-tools.aud.ucla.edu	Simple residential structures & mechanical systems	Yes; Easy	DOE2; No	No	Via e-mail	Great starter, may meet all your needs. Meaningful comparisons for small amount of work. Fast output, limited to simple structure and mechanical systems. Good source of articles written in understandable language.
EnergyPlus http://gundog.lbl.gov	Any; allows custom components and systems	No; Difficult	EnergyPlus; Yes	Plug-in for Google Sketch-Up, 3rd party GUIs	Extensive manual. Active mailing list. Courses available.	Almost everything can be modified and interfaced with. Can be used to size equipment and air flows.
Equest www.energydesignresources.com	Any, but limited when modelling non-standard systems.	Yes; Moderate	DOE2; Yes	3rd party interfaces and GUIs	Large manual. Active mailing list. Courses available.	Based upon DOE2.1
DOE-2 www.doe2.com	Any	No; Difficult	DOE2; Yes	3rd party interfaces and GUIs	Large manual. Active mailing list. Courses available.	One of the first pieces of sophisticated simulation software

Note: For more building energy software tools and information, see http://apps1.eere.energy.gov/buildings/tools_directory.



Attention to detail is critical when entering data on the home's various systems. The more accurate the information, the more accurate the results.



Results presented in graphical format make interpreting and comparing modeling results much easier.

Test-Driving EnergyPlus

Taking modeling software for a test-drive is the only way to get familiar with the software. I tested three houses in EnergyPlus, each identical in terms of construction, orientation, occupancy, set points, etc. The weather locations are Boston, Sacramento, and San Jose, California. Basic parameters were:

- 60 by 40 ft. footprint
- Wall system: 2-by-4 wood frame, with wood siding, drywall and R-13 fiberglass insulation
- Glazing equally distributed on each facade
- Attic with R-38 fiberglass insulation
- Concrete slab-on-grade

This round of simulations focused on reducing electrical cooling energy, so the model was done for May through September. For each house/location, I added the following variations (cases):

Case 1—Base: Air-conditioning

Case 2—Base + small whole-house fan

Case 3—Base + small whole-house fan + phase-change material

Case 4—Base + large whole-house fan

Case 5—Base + large whole-house brushless, permanent-magnet motor fan + phase-change material

For the phase change material (PCM) scenarios, I used PCM embedded in the drywall for exterior walls and ceilings (see "Phase Change Materials" sidebar).

The mechanical system's response to a call for heating or cooling is not always as expected. In a commercial system, a zone call for cooling can set off a chain of events, from increased local air flow to increased speed of a fan, to more cold water from a chiller. To correctly model energy usage, the software has to predict the interactions of all these pieces of equipment as they attempt to do their job. If the equipment has been modeled correctly, we can learn a lot.

Most of the time, equipment operates below its maximum capacity, otherwise known as "part-load" conditions or "partial loading." Part-load performance can be more important than full-load efficiency in determining annual energy use. An example of how researchers have attempted to document this is the Seasonal Energy Efficiency Ratio (SEER), which gives the efficiency of residential air-conditioning units as a weighted average under different outside air temperatures. But an energy simulation is much more accurate in predicting energy use than such a one-size-fits-all parameter.

Choosing Software

The Department of Energy's free EnergyPlus software is probably the most technically deep software—with a 3,000-page manual, it's considered the Swiss army knife of simulation software. Plus, it's free to download.

If you want less of a learning curve, simpler software with fewer building parameters may be a better choice. Many of the packages use a graphical interface, which makes the initial building description phase straightforward. The Home Energy Efficient Design (HEED) software is particularly easy to use, designed for residential applications and incorporates energy-saving strategies into its design alternatives.

Remember that your results will only be as accurate as the data you supply. Inaccurate data in equals inaccurate data out, so make sure you check and double-check your input parameters.

The purpose of the runs outlined in the "Test-Driving EnergyPlus" sidebar was to get an overview of which systems and strategies were worth further investigation. In particular, the hunch was that phase-change material, which is great for load shifting, would work synergistically with night ventilation. Cooling set points were set at 73.4°F. Each case has air-conditioning, however, cases 2 through 5 have the mechanical cooling system disabled from 7:00 p.m. to 12:00 p.m., and depend upon either night ventilation or thermal capacity for cooling at those times.

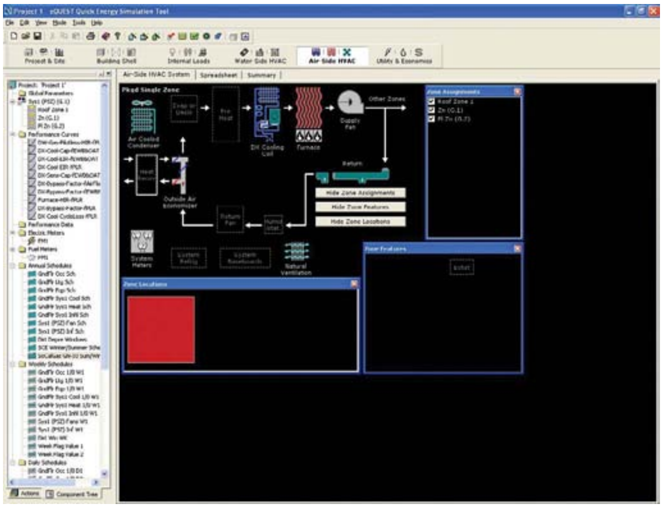
Phase Change Materials: The Future for Retrofits?

Phase change materials can store and release the large amount of heat required to change from solid to liquid phase. The energy required to melt a material (latent heat) is much higher than the energy to raise the temperature of the material (sensible heat). As the material is being melted or frozen, the temperature remains the same. In contrast, a concrete wall will absorb a lot of heat, but its temperature will change in doing so.

The simulations run for this article use PCM-impregnated drywall, which has a thermal capacity of 22 Btu/ft.sup^2 (while remaining constant at 77°F). A 6-inch-thick concrete wall would have its temperature change by 1.5°F to absorb the same amount of heat. There are other subtle differences in how each thermal capacitor performs. For instance, the thickness of the material affects how quickly its average temperature changes due to internal resistance.

If you are designing a new structure, it will most likely be less expensive to build-in thermal capacity by placing high-mass materials such as concrete in contact with the building's interior. However, for retrofits, adding a concrete wall, floor, or ceiling may not be practical. That is why building scientists are so interested in phase change materials.

If we are interested in storing heat or cooling, we can store much more energy per volume or mass with PCM than with sensible heat. Ever wonder why air conditioning is rated in tons? It takes 1 ton of cooling running for 24 hours to freeze 1 ton of water. 2,000 lbs. × 144 Btu/lb. ÷ 24 hours = 12,000 Btu/ hr. = 1 ton AC.



Some modeling programs offer a high degree of visual sophistication to help users correctly configure the home's systems.

Results

As expected, the modeling showed that night ventilation via whole-house fans used less energy for each of the selected climates. Increasing the thermal capacity by adding PCMs helped reduce cooling costs. However, the best savings resulted from using PCMs with a large, brushless permanent magnet-motor-equipped fan. Interestingly, using the large whole-house fan (case 4) saved less energy than using a smaller fan. This appears to be due to the fan using nearly as much energy as it saves. A better model using a more realistic control sequence (as a smart homeowner would do, using fans depending on comfort) seems like an interesting area of inquiry.

Each of the runs also provides a "comfort report" showing the number of hours that are outside of the comfort model. There are virtually no uncomfortable hours for the San Jose location; Sacramento cases averaged 120 hours, while the Boston climate reflected up to 180 hours that did not fit within comfort standards. A next step might be to refine the energy models for a particular climate by using more sophisticated controls to optimize comfort and economy by deciding when to use mechanical cooling or night ventilation.

Valuable Tools

Energy simulations are great tools for building and designing energy-efficient buildings. Creating a basic model can be very quick and effective to address basic building and mechanical system design issues. If time permits, there is even more opportunity to optimize the building envelope, siting, shading, and mechanical systems. Plus, these tools are certainly more powerful and offer much more insight and validation than some "point systems" that are commonly used to determine energy compliance.

Access

Neil Smith (neil@airscapefans.com) is a professional mechanical engineer. Neil's interests include HVAC and energy efficiency, and he currently runs the AirScape whole-house fan company.