energydesignresources

design brief

BUILDING SIMULATION

A few building simulation runs early in a project can lead to design solutions that, though they appear simple, significantly improve building energy performance.

Summary

Computerized building energy performance simulation is a powerful implement for the virtual toolboxes of architects, engineers, and developers. It provides valuable information that helps designers make better decisions about the characteristics of building envelopes, glazing, lighting, and HVAC systems. By using building simulation, designers and developers can provide more value to the building operators who must eventually pay the utility bills, and they can protect themselves by basing decisions on more specific and richly detailed information.

To make effective use of building simulation, however, it is vital that designers and developers adopt some common-sense practices. These include:

- Incorporate building simulation into the earliest design phases,
- Maintain vigilance to avoid mistakes, and
- Don't use simulation when it can't answer the design questions at hand.

By observing these guidelines, designers and developers will improve their chances of producing simulation results that are accurate and relevant.

CONTENTS

In one project, building simulation allowed the design team to test out alternative building configurations and identify the solution that optimized energy efficiency.

Introduction

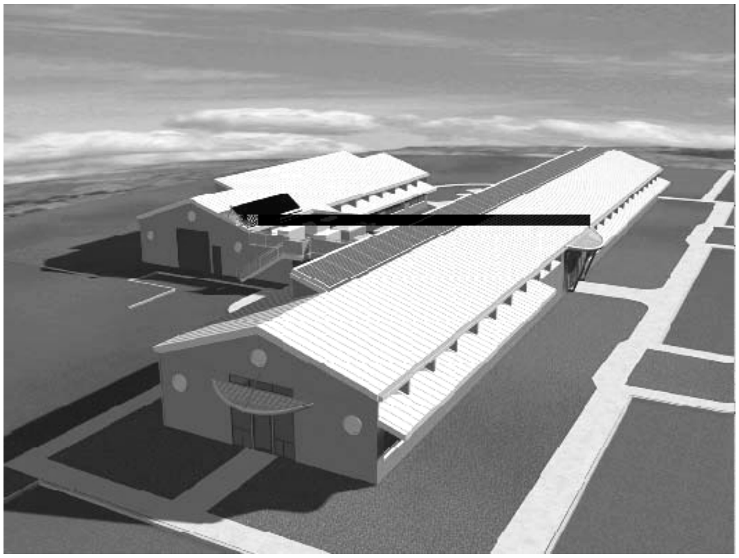
Building energy performance simulation is a powerful tool that architects, engineers, and developers use to analyze how the form, size, orientation, and type of building systems affect overall building energy consumption. This information is vital for making informed design decisions about building systems that impact energy use, including envelope, glazing, lighting, and HVAC. It is often the case that a few building simulation runs in the early phases of a project can lead to design solutions that, though they appear simple, significantly improve building energy performance.

This was the case for the Public Works Building at the Naval Construction Battalion Center at Port Hueneme in Southern California. For this project, a 5,000-square-foot addition was planned in concert with a major renovation of an existing 10,000-square-foot administrative building. The existing building was long and narrow, with the long orientations facing north and south. The developer originally planned to build the addition perpendicular to the existing building, creating a T-shaped form. A member of the design team, however, feared that orienting the addition this way would require an excessively large air-conditioning unit to maintain comfortable conditions in the morning and afternoon due to direct sun from the east and west, and would also reduce the potential for good daylight penetration. Instead, he proposed to site the addition parallel to the existing structure and connect the two with a combined hallway and restroom structure, thus making an H-shaped form (**Figure 1**).

The team performed a simulation to determine the energy impact of the proposed H-shaped building. The model showed that, relative to the T-shape, the building would be more comfortable, the capacity of the cooling system would be 25 percent smaller, and the daylighting controls would be much more effective. As a result of this analysis, the client opted for the H configuration, as well as glazing and wall construction details that

Figure 1: Energy Showcase at Naval Construction Battalion Center, Port Hueneme, California

Building simulation was used to select this configuration for a 5,000-square-foot addition to the existing Public Works Building at Port Hueneme. The addition is the smaller building segment on the left.



provided maximum daylight harvesting. Even though the designer's intuition about the impact was correct, building simulation made it possible to project both the construction and operating costs of the two alternatives with greater confidence.

As this example shows, an architect's choice of wall construction, glass type, and building form can have a profound impact on sizing of mechanical and electrical systems. Although many designers are qualitatively aware of the high degree of interaction between different building systems, it is difficult—and in some cases impossible—to accurately quantify those interactions without using building simulation. Some of the more common design questions that can be evaluated with building simulation include:

- What are the most cost-effective levels of wall and roof insulation for a particular climate?
- Is dual-pane glazing cost-effective in a mild climate?

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- If we install an efficient lighting system, how much smaller can we make the cooling system?
- What will be the energy impact of adding more windows to a building?
- How much energy will be saved by specifying high-efficiency HVAC components?

Typically, most designers address such issues either by following rules of thumb, by relying on intuition, or by ignoring them altogether. By using building simulation to help make decisions, designers and developers can provide more value to the building operators who must eventually pay the utility bills, and they can also protect themselves by basing decisions on more specific and richly detailed information.

Software packages for building energy performance simulation carry out the numerous and complex equations that, when combined, describe how buildings use energy.

What Is Building Simulation?

It is hard to estimate the annual energy costs associated with operating a building while it is still under design. The answer depends on numerous factors, including the construction details and orientation of walls and windows, occupancy patterns, local climate, operating schedules, the efficiency of lighting and HVAC systems, and the characteristics of other equipment loads within the building. Accounting for all these variables, as well as their interactions, is a daunting task, especially because some change by the hour. Given this complexity, rigorous calculations of annual building energy costs were rarely performed before personal computers became commonplace.

Software packages for building energy performance simulation carry out the numerous and complex equations that, when combined, describe how buildings use energy. The most sophisticated of these programs are capable of calculating building energy consumption hour by hour for an entire year. The best-known hourly simulation software package is DOE-2 (developed by the Simulation Research Group at Lawrence Berkeley National

Laboratory), which can accept—and produce—a torrent of data. Using DOE-2 is difficult and there are few practitioners who can apply it effectively.

Several efforts are under way to make building simulation more accessible to designers and developers. For example, several versions of DOE-2 are now available with graphical user interfaces, which greatly facilitate data input (**Figure 2**, next page). Simplified hourly simulation tools, such as eQUEST (see sidebar on page 15), make simulation much easier to use than the current version of DOE-2, but place many more limitations on the user.

How to Use Building Simulation to Greatest Advantage

Building designers and developers can do four things to make the best use of building simulation:

- Start early, by incorporating building simulation into the earliest design phases;
- Keep it simple, by adding no more detail to a simulation model than is necessary to answer the design questions you are considering;
- Refine as you go, so that the simulation model evolves with the design; and
- Maintain vigilance, to avoid mistakes.

Following these basic, common-sense guidelines can considerably improve the accuracy and relevance of your building simulation.

Start Early

Even a simple energy model can be used to effectively guide major decisions early in the design process. Such decisions may include envelope construction and orientation, glazing type, and the form of exterior shading. All you really need to know to

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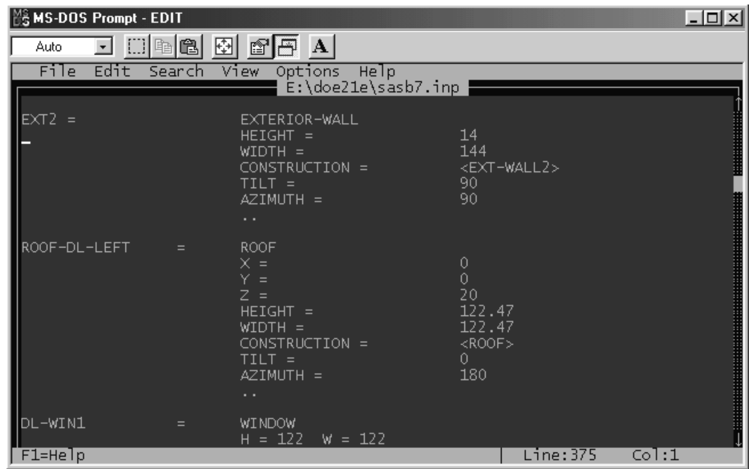
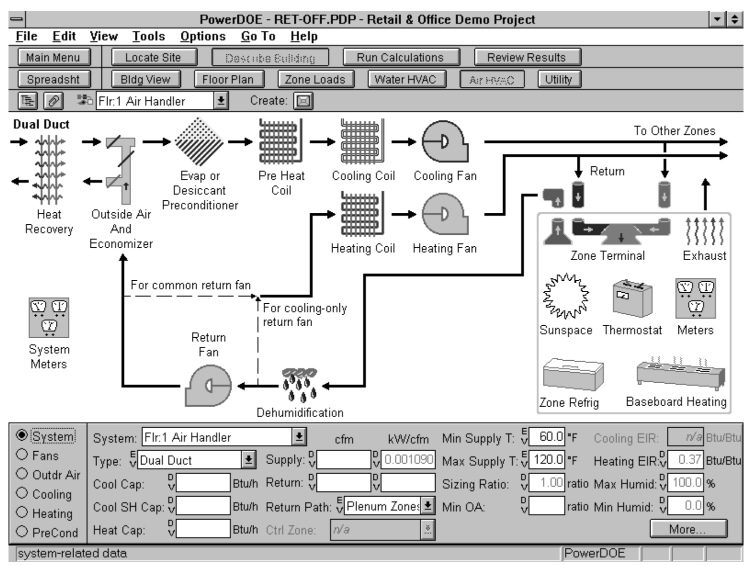
Figure 2: Graphic user interfaces simplify program operation

The user interfaces for simulation programs run the gamut from DOS-based text editors to fancy Windows-based programs that draw pictures of buildings and generate graphic depictions of everything from HVAC components to occupancy schedules. Though selecting an interface is largely a matter of personal preference, more advanced interfaces (like PowerDOE, on the bottom) can reduce program syntax errors when building information is entered.



Source: CTG Energetics



Source: EPRI

develop a first-cut model is the size and rough shape of the building, the intended use (for example, is it an office, a manufacturing facility, or a grade school?) and its location. Although you shouldn't rely on a model this simple to predict the absolute energy consumption of a building, it can be sufficiently accurate to compare one particular construction feature to another.

For example, during the schematic design phase of a 12,000-square-foot food market, the designer was concerned that a conference room in a mezzanine that had a lot of east-facing glass would either be uncomfortable or would require an awkwardly large cooling system. He first considered a large overhang to shade the glass, but he thought the overhang might be offensively inconsistent with the rest of the design. He then considered smaller exterior louvers but wasn't sure that they would work as well as the larger overhang. To resolve this dilemma, the designer developed two preliminary simulation models. One employed the large overhang, the other the exterior louvers, and the models were identical in all other regards. When they were compared, it appeared that the exterior louvers would actually be more effective at reducing the mezzanine's cooling load. Based on this information, the designer selected the louvers.

Don't agonize over details that won't have a significant impact on the design questions at hand.

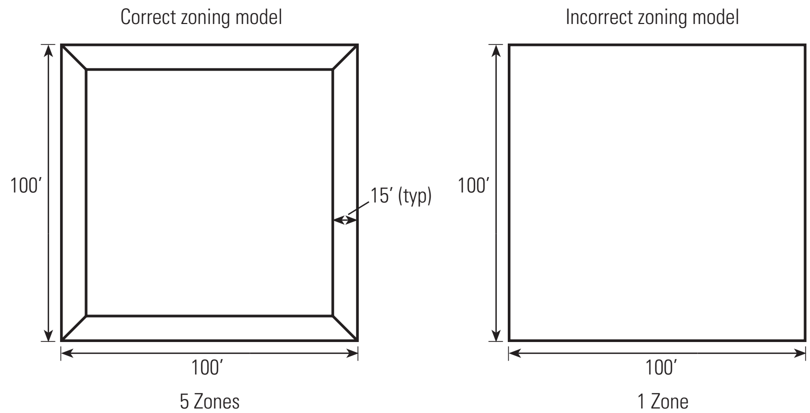
Keep It Simple

Albert Einstein once said, "make things as simple as possible, and no simpler." This is excellent advice for building simulationists. Don't agonize over details that won't have a significant impact on the design questions at hand.

This strategy was effectively applied during the early design efforts for a new, five-story, 200,000-square-foot administrative headquarters for the Lincoln-Mercury division of Ford Motor Company. The design team decided to use building simulation to evaluate exterior shading strategies, glazing selection, and lighting control strategies. One problem they faced was that the building would ultimately be occupied by several automotive divisions—varying from opulent Jaguar to workhorse Mercury—each with its own distinct preferences for office layout and interior finishes. Rather than fret over the actual building thermal zoning, which wouldn't be established for many months, they developed a preliminary simulation model based on a simple five-zone-per-floor model (**Figure 3**, next page). Although this model didn't contain any detail about the interior layout of the building, it was satisfactory for resolving issues related to the building's exterior.

Figure 3: Simplified thermal zoning

In the early stages of designing a new building, models based on simple (but thermodynamically correct) zoning can be used to inform decisions about the exterior building design. Typically, this strategy assumes one zone per major orientation, to a 12- to 18-foot depth, plus a core zone. Don't be tempted to simplify too much, however. Modeling a building as one big zone does not account for offsetting heat gains and losses. For example, in winter the perimeter zones will require heating, but the core (which does not have any adjacent exterior walls) still needs cooling. If perimeter and core spaces were combined into one big zone, the perimeter heating load would partially cancel the cooling load in the core, resulting in erroneous heating and cooling loads.



Refine as You Go

As you develop and refine the building design, the energy model must be updated to match so that it can be used to answer more detailed design questions. For example, late in the design process the design team may want to know the energy impact of reducing ductwork sizes to accommodate a smaller ceiling cavity space.

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The Santa Monica Public Safety Facility was initially designed with light shelves to reflect daylight deep into the core of the building and with dimmable ballasts to turn down electric lights when adequate daylight was available. The design team ran preliminary models to project the energy savings associated with this strategy. Later on they had to add massive structural beams around the perimeter of each floor to meet seismic requirements. These beams made it impossible to install the light shelves, which greatly impaired daylighting performance. The design team updated the simulation model to quantify this impact. If the model had not been updated to account for the beams, the effectiveness of the daylighting features would have been overstated.

However, sometimes designers get carried away and update their models to an extent that cannot be justified by the design issues that remain to be resolved. It is important to always remember the reason that the model exists—to provide useful design input and facilitate analysis of alternatives. The decision about how long to put effort into updating a model should be based on whether there are still questions to be answered that the model can help with. If not, it may be time to put the model on the shelf and devote all resources to designing the building.

However, sometimes designers get carried away and update their models to an extent that cannot be justified by the design issues that remain to be resolved.

A supermarket project serves as an example of when to quit modeling. Designers developed a detailed model of the 60,000-square-foot supermarket to evaluate energy savings potential for daylight harvesting and improved HVAC systems. After a good deal of effort was expended to calibrate the model against real data for similar stores, the team analyzed the desired measures and selected certain ones for implementation. As the design proceeded, some members of the design team wanted to continually update the model to more closely mimic the envisioned daylighting control system. Because the simulation program they were using wasn't particularly effective for analyzing very detailed elements of daylighting systems—and because the model had already achieved its objective of helping the owner make a decision to spend more money on better systems—they ultimately decided not to spend time on further model refinements.

Maintain Vigilance

Given the vast amount of data that goes into creating a building simulation—as well as the detailed and voluminous output reports that most programs generate—there are abundant opportunities for making mistakes, from input errors to misinterpretation of results.

It may sound like a "Catch-22," but to effectively verify the accuracy of a building simulation, you need to already have a pretty good idea of what the simulation results should be.

Common input mistakes include facing walls the wrong direction, incorrectly assigning schedules of use, or simple typographical errors. Your model will tell you that there is a world of difference between a lighting system that uses 1.25 watts per square foot and one that uses 12.5, though this is an easy keying error to make. It may sound like a "Catch-22," but to effectively verify the accuracy of a building simulation, you need to already have a pretty good idea of what the simulation results should be. In the example above, inadvertently inputting a lighting density at ten times its actual value would result in a model with extremely high lighting energy use, an oversized cooling system, and most likely no heating system whatsoever. Any of these results would point to the input error, but without the experience of having looked at output from many other building simulations, a novice simulator might waste a lot of time looking for the problem.

The history of building simulation is filled with incidents in which small errors led to unfortunate and expensive results. One recent example occurred during the design of a one-million-square-foot government office tower that was criticized in the press for being insufficiently energy efficient. The design team defended their work by claiming that the building exceeded Title 24 energy requirements by 37 percent—an impressive margin of performance. When they produced the building simulation results to prove this level of performance, however, a peer reviewer discovered a bug in their simulation program. When the software developer fixed the bug and the model was run again, the energy performance proved to be far less impressive than the original performance margin. Although it is not very common to find such significant bugs in these programs, a careful review of the output would have shown that the predicted energy use for cooling the building was far lower than could ever be achieved.

To reduce the potential for error when developing a model, it pays to be organized. Such organization includes keeping good notes on program inputs (for example, the source of input information, the exact way that a particular alternative was modeled) and documenting any assumptions that were made when actual design information was not available. It is also a good idea to first collect and organize data from design drawings and specifications and then input it all at once. This makes it possible to first focus on gathering information accurately (such as measuring all the walls from the drawings) and then focus on typing it in correctly.

It is also important to critically evaluate program outputs to make sure they are reasonable. If your results look too good, they may well be. It is best to review the output reports in detail to see if you've really stumbled onto a passive solution for cooling in arid climates, or if you just forgot to put a roof on your model. Some tried and tested review techniques include the following:

- Look for anomalous data by charting all the data with a spreadsheet program. Because of the vast amount of data produced by most simulations, it is often easier to spot anomalies by looking at the "shape" of the data instead of each numerical value.
- Develop a quality control checklist of key parameters, and check every model that you run. This "sanity check" will help ensure consistency across multiple models.
- If you don't know approximately how much energy a particular building configuration should consume, find someone who does and have that person review your results.

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When Not to Use Building Simulation

Although building simulation can add substantial value to a building design, it may not be right for every design project. Sometimes, the time and cost of developing a good model exceed the benefits that it may potentially provide. Although there are no hard and fast rules for determining whether or not to use simulation, here is a list of circumstances that are typically signals to refrain from using building simulation:

Building simulation may not be right for every design project. Sometimes, the time and cost of developing a good model exceed the benefits that it may potentially provide.

- *When the design process has proceeded so far that it is highly unlikely that anything can be changed.* For example, in an effort to demonstrate that a recently designed building was "green," a developer commissioned a building simulation. Although the simulation identified a number of cost-effective ways that the building could be improved, the results fell on deaf ears—the developer never intended to do anything with the results other than give the impression that it was practicing green design.

- *When a project is so small that the cost of running a simulation cannot be justified.* How small depends on the sophistication of the model employed. Some projects as small as 5,000 square feet have benefited from simulation based on very simple models that incurred little cost and didn't take much time.

- *When the design questions that need to be answered are outside of the realm of what typical simulation programs can evaluate.* Examples of such questions include airflow patterns in an atrium and effluent dispersion from fume hood exhaust stacks. There are software packages available that can help with these questions, but building energy performance simulation software cannot.

- *When you need detailed design information, not just energy results.* For example, DOE-2 can be used to analyze the possible energy benefits of harvesting daylighting, so it is useful for deciding whether daylighting is worth pursuing in the first place. Once that decision has been made, however, DOE-2 is only useful for determining the quantity and type of glazing that should be used and evaluating different control strategies. To account for issues such as what kind of furniture and partitions the daylight will bounce off of and how that light is diffused, designers should use software and physical models designed for that purpose.

In general, we recommend that designers don't simply reach for building simulation whenever there is a design question at hand. Instead, carefully consider whether building simulation software can answer that question and whether or not the benefits of using simulation are likely to exceed the costs.

What Building Simulation Tools Are Available?

Whenever you elect to use building simulation, the first and perhaps most important decision you will have to make is which tool to use (**Table 1**, next page). This decision should be based on your level of familiarity with building simulation, the type of questions you wish to answer with the model, and the required level of detail. If this will be your first attempt at developing a model, it is probably best to stick with one of the simpler, user-friendly tools, such as eQUEST (see sidebar, page 15). This will allow you to focus on your program inputs and not on program syntax. If you want to evaluate specific technologies, such as daylighting controls, be sure to select a program that has such capabilities. Finally, if your building simulation results are to be used to document compliance with local energy codes, be sure that the program you select is approved by your jurisdiction's building department (in California, the Energy Commission maintains a list of certified compliance software at its Web site, www.energy.ca.gov/efficiency/computer_prog_list.html).

Much of the potential for error in building simulation comes from the user's lack of familiarity with a particular program. A user who is proficient with a simple tool will usually get better

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Table 1: Building simulation programs

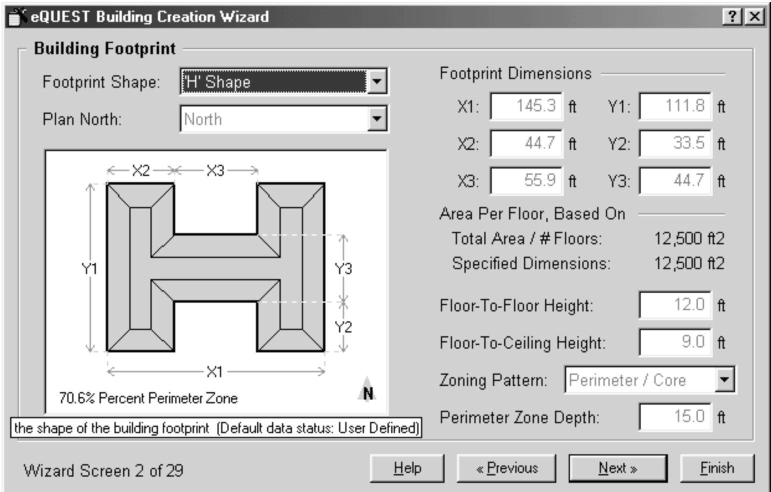
The most widely available building simulation programs fall into three main categories: simple, detailed, and special purpose programs.

Program name	Comments	Price	For further information
Simple analysis programs			
eQUEST	Microsoft Windows-based graphical user interface (GUI), based on the DOE-2.2 calculation engine. Lots of templates for a range of building types.	Free.	Download a copy of the program from www.energydesignresources.com or www.doe2.com
Energy-10	Developed jointly by the National Renewable Energy Laboratory, Lawrence Berkeley National Laboratory, Berkeley Solar Group, Sustainable Building Industries Council, and the U.S. Department of Energy. Intended for performing quick energy simulations. Program comes with "Designing Low-Energy Buildings" manual.	$250 for professionals and $50 for full-time students or professors.	Sustainable Building Industries Council (formerly the Passive Solar Industries Council) 1511 K Street NW, Suite 600 Washington, DC 20005 tel 202-628-7400 ext 210 fax 202-393-5043 e-mail psicouncil@aol.com web www.psic.org
Detailed analysis programs			
DOE-2	A well-validated program that has been in existence since 1978. There is no user interface to speak of; program inputs are made with a standard text-editing program. Extensive documentation of program inputs is available in printed form. Though there are many variants available with slightly different interfaces, most of these are based on the J.J. Hirsch version of DOE-2.1E.	Download for free or buy a CD containing all DOE-2 versions for $65.	James J. Hirsch & Associates 12185 Presilla Road Camarillo, CA 93012-9243 tel 805-532-1045 fax 805-532-2401 Download a license agreement from www.doe2.com
VisualDOE 2.6	A Microsoft Windows-based graphical user interface for DOE-2.1E that can greatly reduce input time. Has an extensive library of predefined schedules, construction assemblies, and glass types. Has the ability to import an AutoCAD *.dxf file for developing zone inputs. Version 3.0, which is based on DOE-2.2, will be available soon.	$495 for single-user version and $695 for two-user network version. Additional users can be added for $200 each.	Charles Eley Associates Charles Eley or Erik Kolderup 142 Minna Street San Francisco, CA 94105 tel 415-957-1977 fax 415-957-1381 e-mail support@eley.com web www.eley.com
PowerDOE	Feature-rich GUI based on the DOE-2.2 calculation engine. Allows non-rectangular walls and provides nice renderings of the building that you have input.	$278 for a no-expiration license. ($250 is the cash discount price.)	James J. Hirsch & Associates 12185 Presilla Road Camarillo, CA 93012-9243 tel 805-532-1045 fax 805-532-2401 Download a license agreement from www.doe2.com; you can also get a free 90-day evaluation license from the same location.
Special purpose programs			
EnergyPro	Based on DOE-2.1E and used for documenting compliance with Title 24 requirements. It is also good for setting up noncompliance models due to its extensive library of building materials and HVAC equipment.	Cost varies depending on which program modules you purchase. Cost is $895 for user interface and nonresidential DOE-2 module.	Gabel Dodd/EnergySoft LLC Demian Vonderkulen 100 Galli Drive #1 Novato, CA 94949-5657 tel 415-883-5900 fax 415-883-5970 e-mail demian@energysoft.com web www.energysoft.com
Trane Trace 600	HVAC load calculation program that also has many energy analysis capabilities. Provides engineering checks of most program inputs for reasonableness. DOS-based interface. Not an hourly calculation program.	$1,795 for single-user license, $2,693 for a site license. There is also an annual license renewal fee of 23 percent of the program first cost.	The Trane Company/C.D.S. Group 3600 Pammel Creek Road La Crosse, WI 54601-7599 tel 608-787-3926 fax 608-787-3005 e-mail cdshelp@trane.com web www.trane.com
Carrier Hourly Analysis Program (HAP)	An hourly calculation HVAC load calculation program that can also be used for energy analysis. Windows-based interface.	$1,195	Contact your local Carrier representative or www.carrier.com.

Source: Manufacturer's data

Figure 4: Example of eQUEST data entry screen

eQUEST offers an intuitive user interface and a wide variety of simulation templates based upon building usage and form.



Source: Energy Design Resources

results than a novice user running a highly sophisticated program. If the design questions to be answered require a simulation package that you are not proficient in, we recommend that you retain a consultant who has those skills. If you collaborate with a consultant, you may want to make arrangements that allow you to gain experience with the software package, but still take advantage of the consultant's safety net of expertise.

For Further Information

Building Energy Simulation User News is a quarterly newsletter published by the Simulation Research Group at Lawrence Berkeley National Laboratory. It contains articles of interest on various simulation programs plus an up-to-date listing of simulation consultants around the world. Send an e-mail to Kathy Ellington (KLEllington@lbl.gov) to get on the mailing list. You can also point your browser to http://gundog.lbl.gov>

eQUEST: Building Simulation the Easy Way

For designers who are looking for a quick and simple tool to use on their projects, eQUEST may be just the ticket. eQUEST (**Figure 4**) is a Windows-based user interface for the DOE-2.2 calculation engine that allows the user to select from a number of predefined building forms, enter some project-specific data, and then run a full-blown DOE-2 simulation. The eQUEST interface allows you to evaluate the energy impact of everything from different levels of wall and roof insulation to high-efficiency lighting or advanced HVAC systems. Most projects can be input in well under an hour, and the program produces a wide variety of graphical outputs that will help you compare design alternatives. Currently, eQUEST is free of charge. Download it at www.energydesignresources.com.

Publications>User News to look at back issues. For additional information, you can fax or write to:

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The **International Building Performance Simulation Association** is a nonprofit international society of building performance simulation researchers, developers, and practitioners. Contact IBSPA at www.ibspa.org.

You can download a free copy of **eQUEST** at www.doe2.com or www.energydesignresources.com.

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