#6356

SOFTWARE

Simulation Software Gets Reality Check

by Jim Lutz

Field checking a simulation program's results against monitored data can show where refinements should be made in the software's assumptions. California studied the software used to develop the state's codes, with surprising results.

Building simulation software is often maligned because its predictions can be so far from actual energy usage. Surely, houses don't use energy, people do, and behavioral variations make it impossible to predict how much energy people will use once they move into any particular house. However, much can be done to improve or at least assess a software program's accuracy at predicting the average use of people in buildings with particular energy-efficient features. Unfortunately, such testing is rarely done, so software users go on faith that the program is based on good engineering assumptions. In one test, the state of California found some substantial errors in simulation software, and the results have lessons for software writers and users and code officials throughout the country.

The California Energy Commission (CEC) had questions about the accuracy of the simulation model and assumptions the state's residential building energy efficiency standards were based on, so it contracted Berkeley Solar Group and Xenergy to test them in the Residential Building Standards Measurement Study.

Key Role of Computer Simulation

Computer simulation models have played a prominent role throughout the history of California's residential building energy efficiency standards. The first two standards were developed with CALPAS. The current and the 1993 standards are based on CALRES, an updated version of CALPAS, a program developed by Phil Niles and Ken Haggard at California Polytechnical Institute in San Luis Obispo. (Berkeley Solar Group wrote both CALPAS and CALRES.) These programs were used as research tools to define the standards. Various conservation measures were modeled by CALRES on a hypothetical house that was representative of new homes in California. The packages of cost-effective measures were then selected as the standards.

In addition to defining the standards, CALRES is available as a code compliance tool from the CEC (see box, "California's Standards for New Homes") and was used to create a validation test for other compliance programs. To be certified, these other programs must pass the test. They must show that several test houses fail to comply with the standards. These test houses were picked to fail compliance by a slim margin. CALRES was also used to develop the point system and the packages used in the prescriptive method.

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California's Standards for New Homes

California's energy code, one of the most stringent residential building energy efficiency standards in the United States, was first adopted in 1978. The California Energy Commission has regularly revised the standards, known as Title 24, since then. The first revision was in 1984, and the second major revision became effective in 1988. Newly adopted standards will become effective Jan. 1, 1993.

Code Compliance Options

In addition to certain mandatory measures, compliance with the energy efficiency standards can be demonstrated by one of three methods. The simplest method is **prescriptive.** Five packages of construction techniques are provided as lists. If any list is followed completely, compliance is guaranteed.

Another simple method of testing compliance is the **point system.** Points are credited or deducted in a worksheet that evaluates your design. For example, points are given for more insulation and higher efficiency equipment. Similarly, points are deducted for excess window area, or other features that contribute to higher energy consumption. If the design has a positive number of points, it passes. If not, the design does not comply and energy improvements will have to be made.

The most flexible and also the most difficult way to demonstrate compliance is to use an approved **computer simulation** model. If the software predicts the building will use less energy than a standard building with the same floor area, gross surface area, and volume, it complies. Otherwise it's back to the drawing board.

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Why Worry?

Unfortunately, energy consumption predictions from building energy simulation models are often wrong, or at least quite different from what occurs in real life. This happens for a variety of reasons. It could be due to any of a variety of inaccurate assumptions, namely, thermostat setpoints, hours of air conditioning or heating, operation of appliances, use of windows and doors, etc. Most often the behavior of real occupants is different from what the model assumed. (See box, "When is a Setpoint Not a Set Point?" for examples of the variety of thermostat operation patterns in real buildings.)

Another source of problems is describing the building incorrectly. Even if no errors were made entering the description of the building, there are other possible errors of description. What's really inside the walls? How leaky is the duct system? What is the actual shading coefficient for each window? A related issue is the difference between the average weather typically used by simulation models and the weather at the site of the building for the period being modeled.

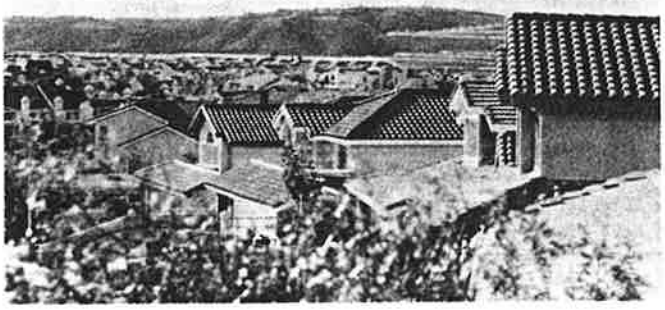
And finally the computer program behind the simulation model may have errors built into it. These could be either incorrect algorithms or just plain mistakes.

Ron Judkoff of the National Renewable Energy Laboratory (formerly the Solar Energy Research Institute), a leading authority on validating building energy simulation models, described different types of validation techniques depending on what it is one is trying to determine: "To find out if the heat and mass transfer algorithms within a program are physically accurate, lab experimentation and highly controlled field monitoring of specially constructed, unoccupied test structures is appropriate. To find out if our behavioral and operational assumptions are accurate, large sample statistical studies [of occupied homes] are appropriate. To find out if our thermo-physical inputs are accurate, regression and renormalization methods are most appropriate, if destructive/non-destructive inspection methods are impractical for the buildings in question."

The Study

The goals of the Residential Measurement Project were to check, and revise if necessary, the definition of the typical house; to better characterize the behavior of typical occupants; and to validate assumptions built into the simulation model. The major portions of the project consisted of a large mail survey, field audits of about 300 houses, on-site monitoring of 40 houses for five weeks each, and a detailed short-term energy monitoring test of four houses.

The mail survey of nearly 3,000 households by Xenergy asked about physical characteristics of the house, occupant behavior, and appliance holdings. The researchers matched 2,000 of these surveys with utility bills for the same households. Xenergy performed a conditional demand analysis for these houses to estimate energy consumption by end use. (Conditional demand analysis is an application of linear regression analysis where the dependent variable is the total monthly gas or electricity usage for a group of households. The explanatory variables are the characteristics of the house and its occupants and the weather data. The method is called conditional demand analysis because the total demand calculated is conditional on the utilization of a specific end use. The regression coefficients of the analysis represent the average energy consumption associated with particular end use types.)



Researchers conducted field audits of about 300 California homes to collect energy consumption data, which was in turn used to construct complete input files for CALRES simulation runs.

Field audits and on-site surveys were done for about 300 of these houses. Xenergy did PRISM analyses (see "Now that I've Run PRISM, What Do I Do with the Results?" *HE*, Sept/Oct '90, p. 27) for about 150 of these houses. These analyses gave equations of heating and cooling energy consumption as a function of temperature. When applied to the CEC standard weather files, normalized energy consumption for heating and cooling was found for each house. Enough data were collected on 218 of the audited houses to construct complete input files for CALRES simulations. The results of simulation runs were compared to the normalized energy consumption from PRISM as a check on the proposed changes to the modeling assumptions.

Meanwhile, Berkeley Solar Group monitored forty houses for five weeks each. Data loggers collected indoor, outdoor temperatures, HVAC system operation at five-minute intervals. A tracer gas was used to measure air infiltration rates during the monitoring period. The median air infiltration rate was 0.44 ACH. This was 12% lower than the value assumed by the standards. Approximately 35% of the houses had infiltration rates lower than the minimum 0.35 ACH specified by ASHRAE. A blower door test was done on each house to determine leakage area as a possible indicator of infiltration rates.

Short-term Monitoring

Berkeley Solar Group also performed short-term energy monitoring tests on four houses using on a methodology developed at the National Renewable Energy Laboratory. (For a description of the "STEM test," see "A New Method for Building Performance Audits," *HE*, July/Aug '89, p. 7.) We monitored indoor temperatures (every major room, garage, crawl space, and slab surface), outdoor temperatures, relative humidity, windspeed, solar insolation, and total electricity consumption throughout the test. A blower door test done at the beginning of the test determined the effective leakage area of the house. A tracer gas test done during the test period determined actual infiltration rates. The STEM procedure requires the house to be unoccupied for four days. In addition to all the data loggers, we placed electric heaters throughout the house.

During the first night of the test, we used the heaters to keep the house at a constant temperature. The temperature and electricity consumption data from this part of the test was used to determine the overall steady-state heat loss of the house. At midnight on the second night, we turned the heaters off and allowed the indoor temperature to fall. The rate at which the temperature dropped indicated the amount of thermal mass in the building. Simulations were run for each house using a research version of CALRES, which allowed direct modification of overall heat loss, thermal mass, total solar gain, and infiltration rate. The simulations used weather data collected during the test period. We did multiple iterative simulation runs while adjusting overall heat loss, thermal mass, solar gain, and infiltration rate. We repeated this process until the best fit was found for predicted and measured indoor temperatures. The corrections for overall heat loss, thermal mass, and infiltration rate varied quite a bit for the four houses, but showed no consistent pattern. The assumed total solar gains, however, had to be reduced dramatically for all four houses to get a good fit. This could have been the result of shading from neighboring houses, trees and hills; interior shading devices not being completely open; window structure and reveals (the parts of the jamb between the windows and the outer wall surfaces) providing some shading; or the opaque surfaces of the house being shaded.

Changes Needed

Berkeley Solar Group and Xenergy recommended changing several assumptions in the simulation model

Surrounded by a radiation shield and mounted on a music stand, this temperature sensor gathered data for the software validation study.

When is a Setpoint Not a Set Point?

One task of the residential monitoring project was to observe thermostat control strategies for individual households. This was done by plotting indoor temperature by time of day for each two-minute interval the heater was on. The three most extreme cases of different control strategies illustrate the difficulty of making assumptions about thermostat setpoints for simulations. The first one is a household that apparently set the thermostat for 72°F and left it there (see Fig. 1). Fig. 2 shows data from a household that seems to have programmed their thermostat for both day and night setbacks. They apparently had a night setback of 60°F. At 6:30 a.m. to 9:00 a.m., the thermostat was programmed for 72°F. At 9:00 a.m. the thermostat turned the heater off, probably with a low daytime setback. At 6:00 p.m. the setpoint was turned back up to 72°F, until 11:00 p.m. These people must have had a programmable thermostat, and they knew how to use it. Fig. 3 shows a household that had manual control strategy. They turned on the heater when they got cold, then turned it off after the house had warmed up. These findings prompted one of the most controversial recommendations of the study—that simulations should assume heating was on only four days each week.

Fig. 1 House A Living Zone Temperature When Heating

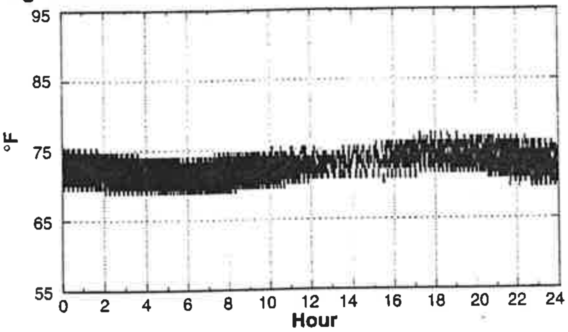


Fig. 2 House B Living Zone Temperature When Heating

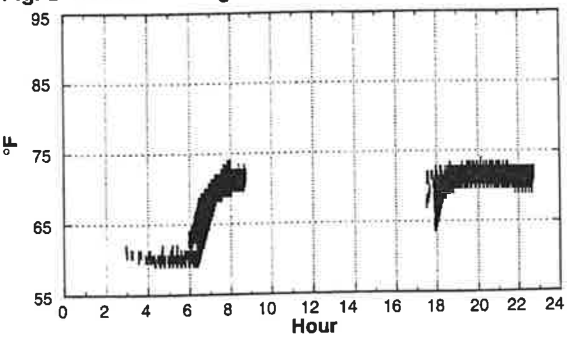
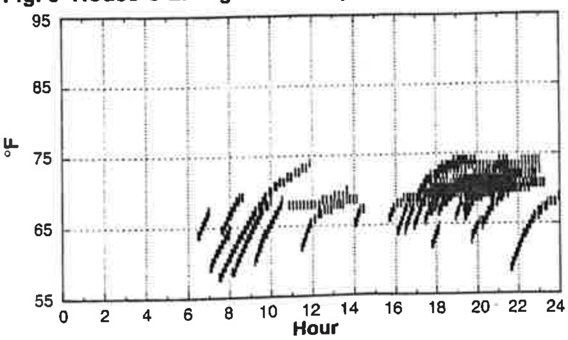


Fig. 3 House C Living Zone Temperature When Heating



and the prototype building used by the CEC. Based on the research results, we recommended to:

- change the infiltration rate from a constant 0.5 ACH to the ASHRAE effective leakage area (ELA) procedure. Use a leakage area of 0.07 in^2/ft^2 for houses with the ducts in unconditioned space. Use 0.055 in^2/ft^2 for houses without ducts.
- reduce the occupant-controlled ventilation rate. To do this, either raise the venting setpoint or reduce the openable area.
- reduce overall solar gain 50%.
- keep the thermostat settings for cooling at 78°F. Raise the daytime heating setpoint 2°F to 68°F. The night setback should be raised 4°F to 66°F.
- operate the heating system only four days per week and the air-conditioning only three days each week.
- give the internal heat gains in the house a seasonal variation of about 20%, based on length of day.
- change the floor area of the prototype house used by the CEC to set standards from 1,384 ft^2 to 1,900 ft^2.
- assume 70% of the ceiling is below attic and 30% is cathedral construction.
- change the window area from 16% and 20% of floor area to 15% of floor area.
- keep the prototype at a single story.
- assume the ground floor is slab on grade and 18% of it is uncarpeted.

Changes to standards often result from negotiation and compromise. The new 1993 standards are no different in that respect. Some, but not all, of the findings of the study are reflected in the new standards. The ELA approach has been adopted, which should significantly impact duct leakage.

The overall solar gain was reduced by 25%. This was the result of compromise during the rulemaking. The air infiltration model recommended by the study was adopted.

The new heating setpoints were not adopted into the standards, and the recommendation for heating to operate only four days a week was not adopted. Heating was assumed to be always available. This represents a worst case assumption for energy consumption. According to Elena Schmid, Manager of the Building and Appliance Efficiency Office of the CEC at the time, the aging population of California is expected to use heating more often in the future. The recommended cooling thermostat setpoints and air conditioning operating times were not adopted. Not enough monitoring data had been collected from houses with air-conditioners during the cooling season. According to Schmid, "There was not enough information to warrant these changes at this point." The recommendation to apply a seasonal variation of 20% to the internal heat gains was adopted (assuming more in winter and less in summer on a monthly basis).

The floor area of the prototype building was changed to 1,784 ft^2. The ceiling type and window U-values were changed as recommended. (The ratio of window area to floor area was not yet changed.) The prototype building was changed to two-story construction, as this is the predominant type of new house being constructed in

Myles O'Kelly (*left*) and Jim Lutz assemble short-term monitoring hardware.

California. The recommendation to assume the ground floor is slab or grade was not adopted.

In recognition of the importance of comparing the assumptions in the standards to field data, the CEC has made monitoring an ongoing project. Currently the most important issues are cooling setpoints and investigating the impact of air distribution systems on energy consumption.

An update of the original measurement project focusing on cooling energy consumption—improving the PRISM analysis method and thermostat setpoints and scheduling—will soon be finished. Bruce Wilcox, president of Berkeley Solar Group, says that the average cooling setpoint is 80°F; the air-conditioning is turned off 40% of the time the indoor temperature is above the setpoint.

Ray Darby of Residential Buildings Standards of the CEC says a new contract has recently been awarded. It will study how common construction practices compare to the prescriptive (package) standards, collect a large data base of thermostat schedules and setpoints, investigate air infiltration and duct leakage with the view of possibly awarding compliance credit for well-sealed ducts, and conduct more STEM tests to improve the calibration of CALRES.

Recommendations

The CEC's work in this area points out how hard accurate energy simulation is and how important field data are. Anyone using building energy simulation models should make sure the thermostat settings reflect, as accurately as possible, the behavior of the occupants of the building. Check that solar gains are not too optimistic. Shading from other structures, the building, and the window frame itself can have dramatic impact on solar gains. And air infiltration, especially in newer buildings, may be much lower than expected. Whenever possible simulations should use actual weather data and be compared to actual utility bills. ■