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Experts Continue to Assess Building Energy Analysis Tools

Numerous building energy analysis tools are available, but how well they work is not always apparent. To assess the accuracy of software tools for predicting the performance of widely used solar and low-energy concepts, the experts of the Solar Heating and Cooling (SHC) Programme's Task 22, *Building Energy Analysis Tools*, are evaluating and documenting building energy analysis tools.

The Task work is divided into two parts—tool evaluation and model documentation. The tool evaluation activities are based on analytical, comparative and empirical methodologies. The emphasis in this area has been on blind empirical validation using measured data from test rooms or full-scale buildings. The work on documenting existing engineering models is based on the Neutral Model Format (NMF), a standard format for "hard", that is computer readable, model documentation.

The following two articles highlight some of the work of SHC Task 22 experts.

Test Method for Mechanical Equipment Models in Building Energy Simulation Software

A procedure for testing and diagnosing coding errors, faulty algorithms, and documentation problems in mechanical equipment models used in building energy simulation software is being developed by the U.S. National Renewable Energy Laboratory (NREL), in conjunction with SHC Task 22. The development of this new test method, Building Energy Simulation Test and Diagnostic Method for Mechanical Equipment (HVAC BESTEST), is integral to the improvement of the overall quality of building energy analysis and design tools used for analyzing the cost effectiveness of renewable energy and energy conservation technologies that may be applied in solar buildings. This article describes how HVAC BESTEST evolved and how it is being applied.

A Brief History of BESTEST

Many software programs have been developed to simulate energy performance in buildings. However, the programs—even if considering identical structural designs, energy-related equipment, and energy usage patterns—often produce different results when calculating overall energy performance. Consequently, architects and engineers are reluctant to fully trust these programs, and instead, continue to design buildings without focusing on energy use.

In 1995, to improve the accuracy of energy software and help designers gain confidence in computer predictions, scientists at NREL, in conjunction with the IEA Solar Heating and Cooling Programme and the IEA Energy Conservation in Buildings and Community Systems Programme, completed the Building Energy Simulation Test and Diagnostic Method (BESTEST). This procedure, which focuses primarily on building envelope heat transfer, systematically compares whole-building energy software packages and determines the algorithms, or computer-coded computational routines, responsible for prediction differences.

BESTEST, which was selected as a SHC "must read" publication, has achieved widespread success throughout the world. (See enclosed SHC "must read" list). For example, a number of related test procedures have evolved from the initial work and these procedures are being applied in codes and standards (see sidebar). Also, the list of BESTEST users continues to grow, and several hundred copies of the test procedures have been distributed to energy software developers, energy standard making organizations, researchers, and others concerned with the accuracy of building energy analysis tools.

The most recent expansion of BESTEST is related to testing the ability of simulation software to properly model the performance of mechanical equipment. This new test procedure, HVAC BESTEST, is being written by SHC Task 22 experts from NREL and field tested by experts in several countries participating in the Task. The simulation software currently being used is listed below.

- CLIM2000 (France)
- PROMETHEUS, TRNSYS and analytical solutions*, (Germany)
- DOE-2.1E (Spain)
- Analytical solutions* (Switzerland)
- DOE-2.1E (United States)

**"Analytical solutions" refers to the exact mathematical solutions performed manually outside of a whole-building simulation environment.*

HVAC BESTEST

The energy, comfort, and lighting performance of buildings depends on many

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complex thermo-physical interactions. And, computer simulation is the only practical way to bring such a large-scale systems integration problem within the grasp of building designers.

To evaluate these computer simulation tools, the BESTEST technique applies a series of carefully specified test-case buildings and mechanical systems that progress systematically from the extremely simple to the relatively realistic. Output values for the test cases such as, annual energy consumption, loads, system efficiencies, and zone conditions are compared and used with diagnostic logic to pinpoint the routines responsible for prediction differences.

The current set of 30 HVAC BESTEST cases focuses on testing the ability to model mechanical cooling equipment under highly controlled conditions. These cases address basic modeling issues for conventional equipment and related energy conservation features that must be well understood to correctly analyze the amount of conventional energy that can be displaced by passive solar designs versus conventional designs.

About half of the 30 cases are set in the context of a realistic building envelope and realistic climate data. These cases test a program's ability to model equipment performance and occupant comfort as a function of features, such as latent internal gains, infiltration, outside air mixing, thermostat setup, and part loading. Also tested are various economizer control schemes including temperature control, enthalpy control, and compressor lockout.

The remaining cases use highly controlled conditions including a near-adiabatic (highly insulated) building envelope and artificially generated weather data files. This allows performance, which is a function of both outdoor and coil entering conditions, to be tested at a steady state so that analytical solutions for these cases are possible. In these "analytical verification" cases only the following parameters are varied:

- Sensible internal gains
- Latent internal gains
- Zone thermostat setpoint
- Outdoor drybulb temperature.

Variations of these parameters are performed to isolate the effects of the parameters by themselves and in various combinations, as well as the influence of:

- Part-loading of equipment
- Varying sensible heat ratio
- "Dry" coil (no latent load) versus "wet" coil operation
- Operation at typical industry rating conditions.

The Family of BESTEST Procedures

A number of related procedures for comparative testing of building energy simulation software have evolved from the original SHC Programme version of BESTEST. The current family of BESTEST procedures, published by NREL, are:

- **International Energy Agency BESTEST (IEA BESTEST).** The original SHC Task 12 detailed tests of building envelope heat transfer models, completed in 1995.
- **Home Energy Rating Systems BESTEST (HERS BESTEST).** Tests building envelope heat transfer models in the context of more simplified software used for Home Energy Rating Systems (HERS) or other code compliance applications, completed in 1995.
- **Florida-HERS BESTEST.** A version of HERS BESTEST for hot and humid climates, completed in 1997.
- **ASHRAE Proposed Standard 140P Standard Method of Test for the Evaluation of Building Energy Analysis Computer Programs.** Based on IEA BESTEST, in progress.
- **HVAC BESTEST (IEA BESTEST for Mechanical Equipment).** The SHC Task 22 detailed tests of thermal models for mechanical equipment, in progress.

Codes and Standards Application Update

The American Society of Heating Refrigerating and Air Conditioning Engineers (ASHRAE) is adopting IEA BESTEST as a "standard method of test." Public review of this "Standard Method of Test" should occur later this year. Also, ASHRAE is considering using HERS BESTEST as a qualifying tool for performance path software for ASHRAE Standard 90.2 (residential energy efficiency), and the International Code Council is considering its use for the International Energy Conservation Code (IECC), formerly the Model Energy Code.

Helping to Develop Energy Software

BESTEST helps software developers in several ways. Predictions from a building-energy program of interest can be compared to the results from detailed programs already studied, or the algorithm-based differences in predictions observed between several simulation programs can be diagnosed. A previous version of a program can be checked against itself after a programmer has modified the code to ensure that only the intended changes actually resulted. And, the sensitivity of an algorithm to changes may be investigated by checking the modified version against the original.

By itself, HVAC BESTEST is not a complete validation method, as it does not include empirical tests. Instead, it compares a given program with other state-of-the-art programs that have been analytically verified and field-validated with actual buildings. The inclusion of analytical solutions for some of the cases does establish a mathematical truth standard for those particular cases. However, since analytical cases are highly simplified, they are by definition not very realistic. They also often test software outside the typical range of use. Therefore comparative test cases are also needed that are more realistic and thus cannot be solved analytically. Disagreements with the comparative test cases do not necessarily indicate a faulty program, but rather, differences to be studied and understood. In actual field tests, the Task 22 experts have found that disagreements are often attributable to bugs, or faulty algorithms.

So far, the preliminary runs of the diagnostic procedures have resulted in improvements to every one of the building-energy computer programs being tested by the participants. One well-documented example is the CLIM2000 simulation developed by Electricite de France (EDF). Initially, CLIM2000's HVAC BESTEST results showed significant disagreement with other simulation results in a number of areas, which was not unexpected by the software authors since they were in the midst of revising the program before SHC Task 22 began. For their second set of runs, EDF tested the revised CLIM2000's unitary cooling equipment model. These results indicated significant improvement (reduction of previous disagreements) in comparison to other participants' software. However, as a result of using HVAC BESTEST, EDF was still dissatisfied with CLIM2000's inability to account for changes in equipment performance at low part loads (low ratio of load to equipment capacity) and went on to make further improvements. Their third round of results indicated that the latest software changes did improve their model. This example underscores not only the ability of HVAC BESTEST to identify and diagnose problems in mechanical equipment models, but also to check software revisions.

Using HVAC BESTEST

HVAC BESTEST, and the other BESTEST procedures, are designed to help develop reliable building energy analysis software. But the ultimate goal is to assure potential software users that a particular simulation program gives reasonable results or that a program is appropriate for their particular application. HVAC BESTEST will improve building energy analysis software and will increase confidence in their predictions among architects and engineers, enabling them to design increasingly energy-efficient buildings.

For more information contact the Task 22 Subtask Leader: Ron Judkoff, NREL, U.S., Fax: +1 303 384 7540, E-mail: ron_judkoff@nrel.gov; and Joel Neymark, J. Neymark & Associates, U.S., Fax: +1 303 384 9427, E-mail: neymarkj@sni.net. ☼

Determining the energy and economic performance of solar designs requires evaluation under realistic climatic and operating conditions. Evaluations conducted using computer-based simulations are often more useful than "real-life" experiments, especially during the early, critical stages of the design process. Consequently, computer-based analysis is quickly replacing physical measurements for many problem types in research departments throughout the world. In the building construction industry, computer-based simulation has gained acceptance only in the last few years. However, building designers and manufacturers generally agree that simulation will continue to be more widely used in the building design process. In this situation, it seems natural to think about what the simulation tools and services of the future might look like. Will the predominant tools of today be able to evolve organically and meet future needs? Are the right types of actions receiving funding? This article discusses these issues in the context of SHC Task 22 as well as Task results.

Building Simulation Tools

Generally speaking, two different types of simulation tools are used today for building design: *general-purpose* and *special-purpose* tools. A general-purpose simulation program, such as TRNSYS[1], IDA[2] or SPARK[3], treats the mathematical models as input data, thus allowing a user to simulate a wide range of system designs and configurations. Their main advantage is flexibility. Almost anything that lends itself to mathematical modeling can be simulated. Potential drawbacks include difficulty of use, low execution speed, and risk of unexpected program crashes. Special-purpose simulation programs, on the other hand, such as DOE-2[4], ESP-r[5], EnergyPlus[6] or COMIS[7], take advantage of the structure of a class of building simulation problems to reach high execution speed. Consequently, the chief advantages are high execution speed and robustness—low risk the program crashing as long as the input data is reasonable. The major disadvantage of this type of tool is that only the targeted problem class can be considered. It is usually a major undertaking to modify a special-purpose program to suit a non-standard problem type.

In the early years of building simulation, it was natural that only special-purpose simulation tools were widely used because the requirement of simulating the energy performance of a whole building for a complete year could only be met with highly optimized methods. General-purpose simulation programs were, on the other hand, typically used for non-standard problems when performance was less critical, often in academic settings.

When development of general-purpose tools started in earnest in the mid-1980s, expectations for their success were high. Results were expected that would soon make special-purpose tools

1 www.sel.me.wisc.edu/trnsys/

2 www.brisdata.se/

3 www.eren.doe.gov/buildings/tools_directory/software/spark.htm

4 www.eren.doe.gov/buildings/tools_directory/software/doe-2.htm

5 www.strath.ac.uk/Departments/ESRU/esru.html

6 www.eren.doe.gov/buildings/energy_tools/energyplus.htm

7 www-eph.lbl.gov/comis/

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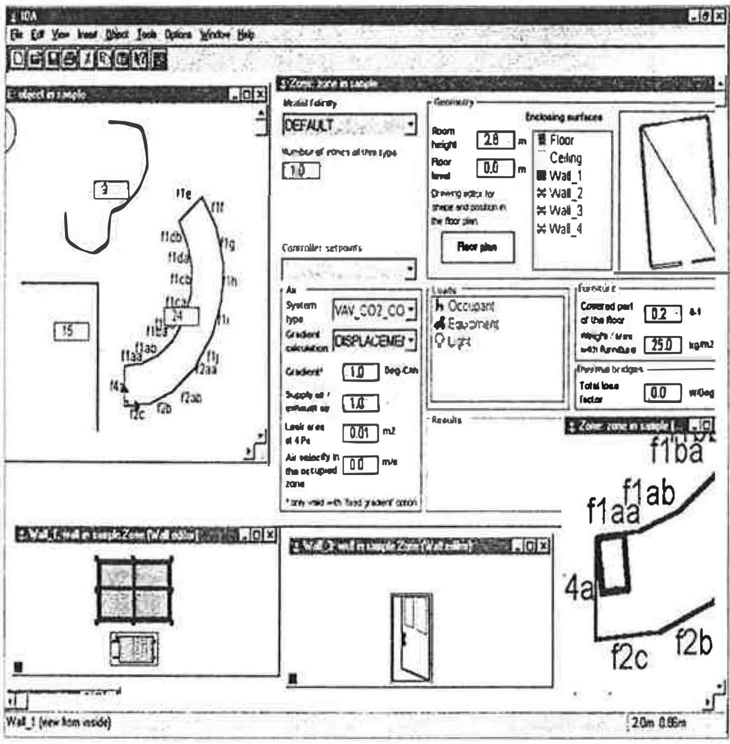

The IDA Indoor Climate and Energy user interface is divided into three levels: Wizard, Standard and Advanced. This illustration shows several of the windows in the Standard level.

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obsolete. However, as it has turned out, the practical difficulties were greater than anticipated, and it has taken longer to reach satisfactory results than expected. We are nearly there though, as general-purpose tools are capable of handling more and more problem types. Several examples of end-user tools based on general-purpose methods include CLIM 2000[8], CA-SIS[9] and IDA Indoor Climate and Energy[10].

Task 22 Products

IDA Indoor Climate and Energy

In 1995, a consortium of thirty Swedish and Finnish AEC companies was formed to jointly develop a building performance simulation program based on IDA Simulation Environment, a general-purpose tool from the Swedish Institute of Applied Mathematics. Some ten person-years have since been devoted to the development of this new tool, IDA Indoor Climate and Energy[11] (IDA/ICE). In addition to the fact that IDA/ICE is a comprehensive building simulation tool based entirely on general-purpose methods, a number of non-standard physical effects are modeled, such as natural ventilation and vertical temperature gradients. The experts of SHC Task 22 have contributed to the development of this tool by developing most of the mathematical models in a dedicated modeling language, Neutral Model Format (NMF).

One of the most attractive features of general-purpose simulation tools is that one can build successively larger component model libraries, and independent researchers can develop compatible models. If a rich model library is available then the work of building a simulation model for a specific problem is dramatically reduced.

By using NMF, which is a tool-independent modeling language, one can automatically generate a range of tool-specific formats from the same NMF source code. This is important because it enables more model re-use since models can be used in all environments for which translators have been written. (NMF translators have been developed for IDA, TRNSYS, HVACSIM+[12] and MS1[13]; prototypes also have been developed for SPARK and ESACAP[14].)

NMF Models Library

An important product of SHC Task 22 is the NMF Models Library. A key feature of this library is the ability to model airflow as well as thermal problems, which are highly interdependent phenomena. This feature allows users to simultaneously solve the temperature and pressure dependent air flows in doorways and open windows. The library also has component models for primary and secondary HVAC systems. These models are designed to have a minimum number of supplied parameters and include ideal equipment control. For detailed secondary system simulations, the ASHRAE[15] secondary tool kit models have been translated into NMF, and they are compatible with the other models in the library. Models also exist for heating and cooling coils, dampers and valves, to name just a few.

SIMONE

Another product of SHC Task 22 is SIMONE (Simulation Model Network) which is a set of web pages for the NMF libraries. Through a central index page, individual NMF developers are encouraged to publish their NMF work on a local server according to a prescribed format. To lessen the work required to contribute to SIMONE, Task experts have developed tools that will automatically convert a set of NMF source code files into structured web pages.

The Task 22 Models Library and SIMONE can be viewed at the web site <www.brisdata.se/nmf/>.

This article was contributed by Dr. Per Sahlin, Bris Data AB, Sweden, Fax: +46/8-24-45-00, E-mail:, per.sahlin@brisdata.se, Web site: www.brisdata.se. For more information on Task 22 contact the Operating Agent, Mr. Michael Holtz, Architectural Energy Corporation, U.S. (see page 8 for address). ✳

8 www.edf.fr/der/html/produits/publications/cherener.en/art17-en.htm

9 An end-user application by Electricité de France based on TRNSYS

10 www.brisdata.se/ice/

11 www.brisdata.se/ice/

12 www.eren.doe.gov/buildings/tools_directory/software/hvacsim.htm

13 http://www.lorsim.be/

14 http://www.it.dtu.dk/~el/ecs/esacap.htm

15 American Society of Heating, Refrigeration and Air Conditioning Engineers