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AN OVERVIEW OF VALIDATION PROCEDURES FOR BUILDING ENERGY ANALYSIS SIMULATION CODES

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AN OVERVIEW OF VALIDATION PROCEDURES FOR BUILDING ENERGY ANALYSIS SIMULATION CODES

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ABSTRACT

The Solar Energy Research Institute (SERI) is developing a procedure for the validation of Building Energy Analysis Simulation Codes (BEAS). These codes are being used increasingly in the building design process, both directly and as the basis for simplified design tools and guidelines. The importance of the validity of the BEAS in predicting building energy performance is obvious when one considers the money and energy which could be wasted by energy-inefficient designs. However, to date, little or no systematic effort has been made to ensure the validity of the various BEAS.

The validation work at SERI consists of three distinct parts: Comparative Study, Analytical Verification, and Empirical Validation. The procedures have been developed for the first two parts, and these procedures have been implemented on a sampling of the major BEAS. Results from this work have shown major problems in two of the BEAS tested. Furthermore, when one building design was run on several of the BEAS, there were large differences in the predicted annual heating loads. The empirical validation procedure will be developed when high quality empirical data become available.

1. INTRODUCTION

Building Energy Analysis Simulation Codes are being used increasingly in the building design process, both directly and as the basis for simplified design tools and guidelines. As the demand for more energy-efficient buildings continues to increase, use of BEAS and their spin-offs will also increase. Thus, the BEAS will have an increasingly larger impact on the way buildings in this country are designed, constructed, and operated. However, to date, there has been little or no systematic effort to ensure that the various BEAS provide accurate or even intuitively reasonable results. This paper gives an overview of efforts at SERI to develop procedures for validating these codes. The procedures developed so far are limited to BEAS having time-steps on the order of one hour and using hourly values of radiation, ambient temperature, and other environmental data. More detailed information on the procedures is presented in Refs. 1 and 2 and up-to-date information may be obtained from the authors.

The validation procedure is divided into three parts. In the first— Comparative Study —each BEAS analyzes the same buildings using the same sets of weather data input files. Building designs and weather data can be chosen to test the parameters having the greatest impact on building performance. This also allows sampling of the different combinations of parameters that could occur in a real building before measured data is available. This technique is useful for finding large errors in the codes that produce results which are consistently different from those of other codes or are counter-intuitive. However, this procedure does not necessarily reveal all errors and gives little indication of the source of the discovered errors. It also provides little information on how to reconcile results caused by differences in the codes which cannot be construed as errors but rather as different approaches or mechanisms.

The second part of the validation procedure is Analytical Verification (2) and is useful in diagnosing errors in heat transfer mechanisms in the BEAS. It is used with the Comparative Study to locate and correct problems in specific mechanisms which are most important in building energy use (1).

The third phase of the validation procedure is Empirical Validation with carefully monitored test cells and buildings. This procedure will be developed when high quality data become available. We are installing instrumentation in a two-zone test cell at SERI for this purpose, and various groups around the country are working on a variety of carefully monitored test buildings. The successful implementation of this procedure on the BEAS should greatly enhance the trust and utilization of the BEAS by the user community.

2. DESCRIPTION OF THE BEAS

The first and second parts of the validation procedure have been used to test four different mainframe computer-based BEAS: SUNCAT 2.4, DEROB 4, DOE 2.1, and BLAST 3.0. (DEROB 3, an earlier version of DEROB, was also tested with the analytical verification procedure.) These codes were chosen because of their potentially wide use in the building energy analysis industry and because of their different modeling approaches. SUNCAT 2.4 (3) is a thermal network code that requires explicit information from the user on the lumped thermal properties of the building. With the exception of window tilt and azimuth, SUNCAT 2.4 does not consider building geometry in its building model. DEROB 4 (4) is also a network model but is much more rigorous than SUNCAT 2.4. DEROB 4 uses a geometric building model and contains an internal radiation heat transfer network. It also can calculate convective heat transfer coefficients at each hourly time-step, and position nodes through the thickness of massive wall components. DOE 2.1 (5) uses a response factor model for heat transfer through massive surfaces. It does not use an internal radiation network, but rather a combined convective/radiative heat transfer coefficient between internal surfaces and the room air. BLAST 3.0 (6) uses transfer functions for heat transfer through massive components. It contains more mechanisms for passive solar processes and is more rigorous in its internal energy distribution model than DOE 2.1. Both BLAST 3.0 and DOE 2.1 have much more extensive plant, equipment, and system capabilities than the other two codes. However, the validation procedures presented here do not attempt to evaluate these extended capabilities.

3. COMPARATIVE STUDY

In the Comparative Study, the BEAS were used to calculate the annual heating and cooling loads for a simple direct-gain building in two different climates. The building was specified to be representative of typical passive designs. It is well insulated, with 1500 ft^2 (139 m^2) of floor space and 350 ft^2 (32.5 m^2) of vertical, south-facing, double-glazed windows. Two variations of the building were studied: a high mass case and a low mass case. The low mass case used 0.5 in. (1.27 cm) of gypsum board for the ceiling and the walls; the high mass case used the same ceiling but 8 in. (20.32 cm) of concrete for the walls. The building was operated with the heating set point at 75 F (23.9°C) and the cooling set point at 65 F (18.3°C) for the entire year. Two very different climates were chosen for the study: Madison, Wis., has a climate in which the loads are dominated by losses to the ambient air; Albuquerque, N. Mex., has a climate in which the loads are primarily driven by solar radiation gains. Typical Meteorological Year (TMY) weather data for these two cities were used in the simulations.

The results of the Comparative Study for the four BEAS are shown in Table 1. Differences in the calculated loads are evident. However, the relative position for each BEAS is consistent throughout the set of test cases. In particular, DEROB 4 consistently calculates the highest heating loads while BLAST 3.0 calculates the lowest heating loads. One can speculate on the causes of these differences by discussing the various modeling techniques used in the BEAS, but few substantive conclusions can be reached without more rigorous testing.

4. ANALYTICAL VERIFICATION

The Comparative Study procedure points out potential problems in a BEAS but gives no indication as to their causes. The Analytical Verification Technique was developed to pinpoint the source of these problems. This procedure consists of several tests, each of which verifies a combination of mechanisms in a BEAS. These tests were chosen because they verify the algorithms for the mechanisms that are the most important in predicting the thermal performance of buildings. The selected mechanisms are:

- steady-state and dynamic heat conduction and thermal storage of mass walls,
- glazing transmittance and conductance,
- heat load caused by infiltration, and
- response of mass walls to solar radiation.

Table 1. ANNUAL HEATING AND COOLING LOADS (MMBtu)

	Madison, Wis.				Albuquerque, N. Mex.			
	Heating		Cooling		Heating		Cooling	
	High Mass	Low Mass	High Mass	Low Mass	High Mass	Low Mass	High Mass	Low Mass
BLAST 3.0	40	60	18	31	4	25	46	64
DEROB 4	72	90	14	30	24	46	44	68
DOE 2.1	52	70	17	34	8	33	37	66
SUNCAT 2.4	60	81	17	37	13	42	41	74

Variations in the tests for these mechanisms have also been developed to examine the effects on the BEAS of changes in mass, insulation, glazing type, and other parameters.

In general, implementation of the Analytical Verification Technique on the four BEAS showed no apparent discrepancies. However, two of the BEAS—DEROB 3 and BLAST 3.0—showed a slower than expected response in internal temperature to a step-function change in external temperature. A similar slow response to solar radiation was also exhibited by these codes. These slow responses are similar to what would be expected from models of buildings with higher thermal mass than that described in the input files of these codes. As a result of the slow responses, building designers might use less thermal mass in their building designs than correctly working BEAS would suggest. The problem in DEROB 3 was traced to the solution technique used in the code. When corrected, the thermal responses predicted by DEROB 3, as well as DEROB 4, agreed well with the expected results. We and the code author are investigating the problem in BLAST 3.0. Its cause has not yet been determined.

The Analytical Verification Technique also revealed differences between the BEAS in the effect of changes in infiltration rate on heating and cooling loads, and differences in the thermal characteristics which each BEAS contains for a variety of internally determined window models; i.e., a double-glazed window in one BEAS is not necessarily the same as one used in another BEAS. For example, DEROB 4 includes substantially higher glass conductances than the other BEAS.

The results for the Comparative Study and the Analytical Verification Technique are generally consistent with each other. BLAST 3.0 showed the lowest heating loads in each of the Comparative Study test cases, as well as a slow response to temperature changes in the Analytical Verification Technique. In general, buildings with a slower thermal response exhibit lower heating loads. Similarly, DEROB 4 had the highest heating loads in the Comparative Study, which can be partially explained by the higher glass conductance found in this code.

5. SUMMARY

The Analytical Verification Technique and the Comparative Study have proven to be valuable aids in locating problems and differences in the BEAS. The Analytical Verification Technique was used to isolate a problem in the thermal time response calculations in DEROB 3 (1). The problem was then corrected by the code author in subsequent versions of the code. A similar problem was found in BLAST 3.0 and is currently being studied. Additionally, the procedure demonstrates measurable differences in the BEAS for window conductance and transmittance. The effects of these problems and differences were consistent with the results of the comparative study and can be used to explain some of the differences in the annual loads. However, even when the information obtained through analytical verification is taken into account, substantial differences in the annual heating loads remain unexplained. These unresolved differences may be due to synergistic effects or to mechanisms not tested by the Analytical Verification Technique.

The BEAS do indeed exhibit a broad range of calculated loads for the same sets of conditions. It is clear that caution must be exercised when using the absolute energy consumption calculated by a single BEAS. The practice of using results from a single BEAS to generate design guidelines or simplified tools or input for economic analyses, or to develop policy is questionable.

The information presented here is necessarily of a general nature. Details of the Comparative Study and the Analytical Verification Technique can be obtained by contacting us. Additionally, we are preparing information on the application of these validation techniques to other untested BEAS.

6. ACKNOWLEDGMENT

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7. REFERENCES

(1) Judkoff, R., et al. "A Comparative Study of Four Passive Building Simulations: DOE 2.1, BLAST, SUNCAT 2.4, DEROB III," Proceedings of the 5th National Passive Solar Conference, pp. 126-130 (Oct. 1980).

(2) Wortman, D., et al. "The Implementation of an Analytical Verification Technique on Three Building Energy Analysis Codes: SUNCAT 2.4, DOE 2.1 and DEROB III," ASME/SSEA Conference (1981).

(3) Palmiter, L. "SUNCAT Version 2.4 User Notes."

(4) Arumi-Noe, F., and Wysocki, M. DEROB III, the DEROB System, Vols. 1-8 (June 1979).

(5) York, D.A., and Tucker, E.F., eds. DOE-2 Reference Manual (Version 2.1), Group WX-4, Program Support, Los Alamos Scientific Laboratory, N. Mex. (May 1980).

(6) Hittle, D.C. The Building Loads Analysis and System Thermodynamics Program, Volume I: User's Manual, Construction Engineering Research Laboratory, Champaign, Ill. (Dec. 1977).