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A COMPARATIVE STUDY OF FOUR BUILDING ENERGY SIMULATIONS: PHASE II: DOE-2.1, BLAST-3.0, SUNCAT-2.4, AND DEROB-4

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ABSTRACT

Four building energy analysis codes are compared using two direct gain building models with Madison, Wis., and Albuquerque, N. Mex., typical meteorlogical year (TMY) data. Annual heating and cooling loads are compared and analyzed with respect to two previous studies (1,2). The results from all four codes disagree significantly.

1. INTRODUCTION

A number of building energy simulations are being applied to the design and analysis of passive solar buildings. These computer programs are also being used to generate design tools and guidelines that will affect the ways in which buildings are constructed. To date, only limited systematic validation of these programs has been attempted.

The validation work at the Solar Energy Research Institute (SERI) consists of three related parts: Comparative Studies, Analytical Verification, and Empirical Validation. The work from Phase I of the Comparative Studies was reported in the Proceedings of the Fifth National Passive Conference (1). The work from Phase I of the Analytical Verification was reported at the ASME/SSEA Third Annual Conference (2). An overview of SERI's validation work was presented at the AS/ISES 1981 Annual Conference (3).

This paper describes the results from the second phase of the Comparative Studies. The Phase II study was structured to answer certain questions that arose out of Phase I work. Specifically:

- The Phase I study showed DOE-2.1, SUNCAT-2.4, and BLAST-2MRT agreeing closely for annual heating and cooling loads (see Fig. 1); however, some discrepancy was seen in hourly temperature profiles (see Fig. 2). Was the close agreement in annual loads coincidental, or would disagreement increase as the building description and weather were altered from the original case?

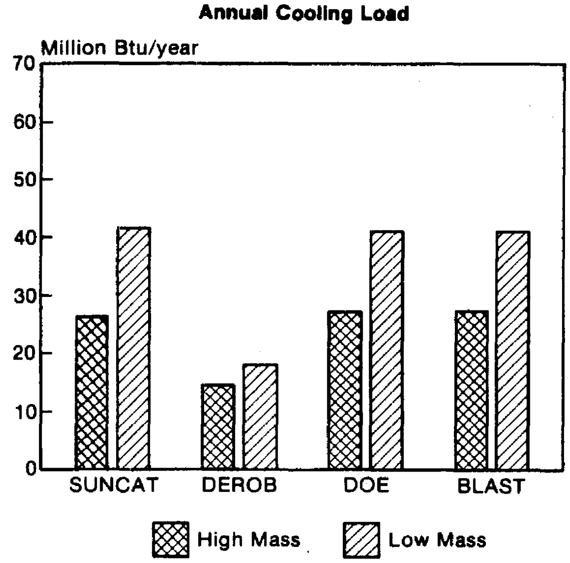

Fig. 1. Annual Cooling Load for Four Codes

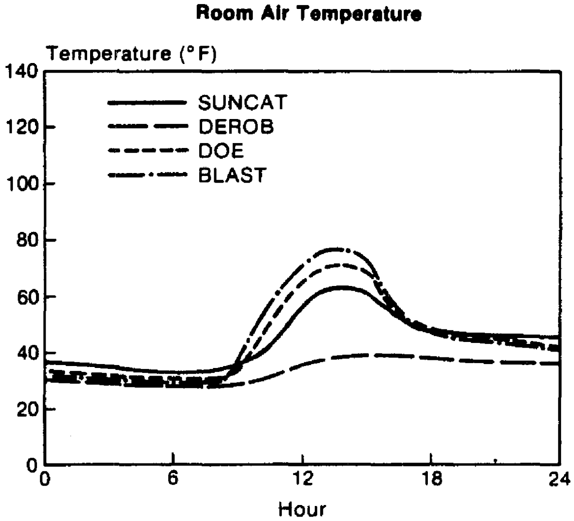

Fig. 2. January 21 High-Mass Room Air Temperature

- Phase I revealed a flaw in the DEROB-3 thermal solution technique causing DEROB-3 to be insensitive to variations in thermal mass. Since that time a new version of the code, DEROB-4, has been written. Was the problem corrected in DEROB-4?
- Since the Phase I study a new version of BLAST, BLAST-3.0, has been written. How would this new version perform?
- In Phase I, a standardized isotropic sky model was used in all the programs. What quantitative effect on annual energy prediction could be attributed to the use of an isotropic versus an anisotropic sky modeling assumption?

2. TEST BUILDING CHARACTERISTICS

The building model used in Phase II represents a small change from that presented in the Phase I study. In Phase I, the ground-coupling mechanisms in the codes were crippled by using a very thick layer of insulation in the floor. This was done to minimize differences in the results due to the different ground-coupling algorithms in the codes. However, this caused a minor input inconsistency. SUNCAT, DOE, and BLAST are capable of modeling a pure resistance, whereas DEROB either associates a capacitance with an insulating material, or models the surface as if it were adiabatic. This problem was eliminated in Phase II by modeling the floor as if the building were hovering in space leaving all exterior surfaces exposed to ambient air. One other difference between the Phase I and Phase II building models was in the thickness of insulation used. In Phase I, the building overall heat-loss coefficient (UA) was kept at a constant 300 Btu/h·°F for both a high- and a low-mass case. The thickness of insulation was varied to compensate for the difference in resistance between 0.5-in. gypsum board and 8 in. of concrete. This led to very odd insulation thicknesses. In Phase II, it was easier to standardize the wall, roof, and floor insulation thicknesses and let the UA overall of the building vary slightly between the high- and low-mass cases. Figure 3 shows the Phase II test building and Table 1 shows its thermal characteristics.

3. RADIATION

The original version of the codes contained different solar radiation processors.

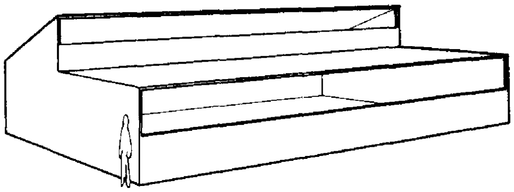

Fig. 3. Comparative Study Test Building

TABLE 1. BUILDING THERMAL CHARACTERISTICS

Floor area	1500 ft^2
Glazing area	350 ft^2
Roof section	0.5-in gypsum board, 6-in styrofoam (R24)
Floor and wall section (high mass)	8-in concrete, 3-in styrofoam (R12)
Floor and wall section (low mass)	0.5 in gypsum board, 3-in styrofoam (R12)
Deadband	65°-75°F
Infiltration	0.65 ACH
No shading	
No night insulation, no ground coupling	
Zero external absorptivity, single zone	

Figure 4 shows the effect on annual heating and cooling loads of using an isotropic versus an anisotropic sky algorithm in the DOE-2.1 program. In Albuquerque, a predominantly clear climate, and Madison (not shown), a predominantly cloudy climate, we observed differences on the order of 10%. To keep these differences from overpowering other effects, we standardized the solar radiation algorithms. Global Horizontal and Direct Normal radiation read directly from the TMY tape were used to establish the direct-diffuse split. An isotropic sky assumption was made to account for radiation incident on a tilted surface. With this change, the final versions of all four codes showed only minor differences in incident radiation (1).

4. INPUT EQUIVALENCY

Much effort was directed toward ensuring input equivalency among the codes. The overall approach for the comparative studies has been to eliminate known sources of difference wherever possible. We took this approach so that the results of the study would be useful whether or not the

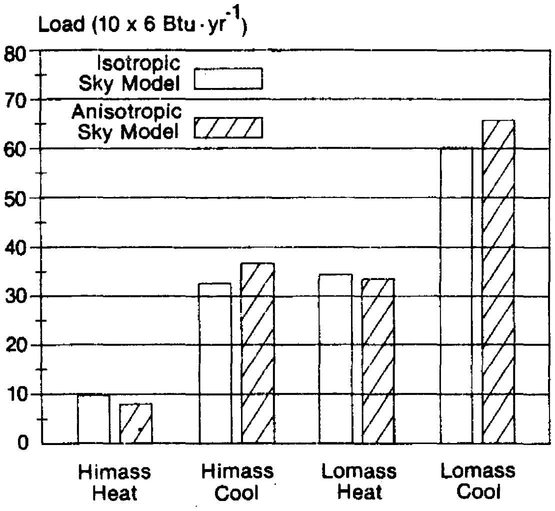

Fig. 4. DOE-2.1 Isotropic vs. Anisotropic Sky: Albuquerque

codes agreed. Were agreement obtained, the significance of the algorithmic differences between the codes could have been quantified by stepping off the base case one parameter at a time. Since agreement was not obtained, we have a clear indication that further study is needed, because known sources of disagreement have already been eliminated.

The effort to ensure input equivalency was complicated by three types of input dilemma:

- a mechanism is modeled in one code and not in another (e.g., external absorptivity of opaque surfaces);
- a mechanism exists at different levels of rigor in the codes (e.g., internal radiation networks); and
- undocumented assumptions or mechanisms in the codes (e.g., hardwired perimeter loss model).

In many instances, it was possible to overcome these problems by either crippling a capability in a complex code to match a simpler code, or by choosing a simpler building model. Where these alternatives were not possible, sensitivity studies were conducted to determine the potential range of error attributable to the input variable. We then used our best engineering judgment to minimize that range.

5. ANNUAL HEATING AND COOLING LOADS

To find out if the disagreement in hourly temperatures predicted by the codes in the first comparative study could lead to significant discrepancies in annual load predictions, the building was simulated using Madison and Albuquerque weather data. These climates were purposely chosen to test the simulations under two climatic extremes. Madison represents a condition in which conductive losses dominate the performance of the building, whereas Albuquerque is much more solar dominated. Different combinations of mechanisms are stressed by these two locations even though the building remains the same.

Figures 5 and 6 show the annual heating and cooling consumption of all four codes in Albuquerque and Madison on the high- and low-mass case.

Although considerable scatter is apparent, certain patterns are discernible. BLAST-3.0 is low in annual heating load across all cases. The positions of the codes remain relatively consistent across all the cases; i.e., DEROB always shows the highest heating loads, BLAST the lowest, SUNCAT the second highest, and DOE the second lowest. Cooling is similarly consistent. Additionally all codes show the same tendencies in the direction of response to parameter changes, even though the magnitudes of these responses are somewhat different.

Figures 7 and 8 show the annual energy consumption for SUNCAT and DOE-2.1 for the Phase I and Phase II building model. The high-mass Phase I Madison results were very close for both heating and cooling, the greatest difference being 0.8% for cooling. The Phase II Madison results show about a 3% difference in heating and a 23% difference for cooling. The Albuquerque case shows the greatest divergence with a 23% difference in heating and a 20% difference in cooling. The low-mass results show a similar pattern of divergence.

Figure 9 shows the responsiveness to changes in thermal mass for DEROB-3 and DEROB-4. In the previous study, DEROB-3 proved relatively insensitive to changes in thermal mass. This problem appears to be corrected in DEROB-4. This conclusion is supported by the results from a previous analytical verification procedure where the temperature curves for thermal mass charge and decay in DEROB-4 match the analytical solutions (2,3).

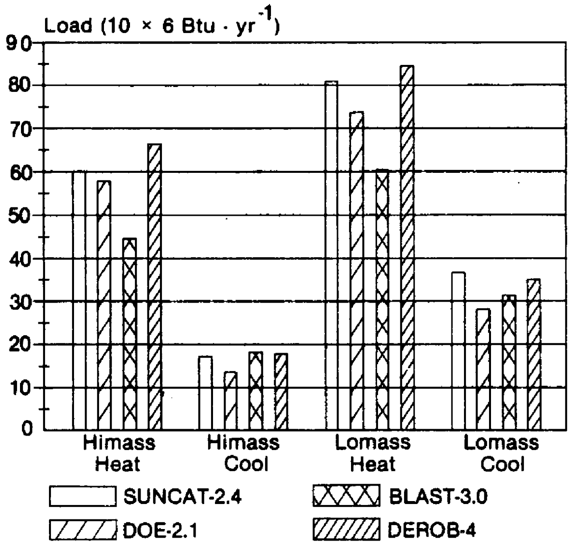

Fig. 5. Phase II Comparative Study: Madison

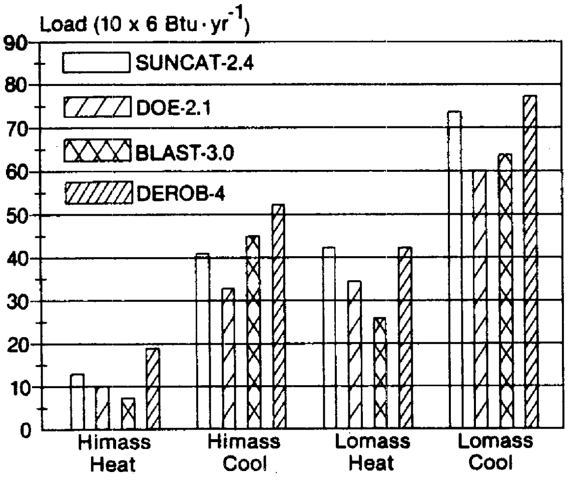

Fig. 6. Phase II Comparative Study: Albuquerque

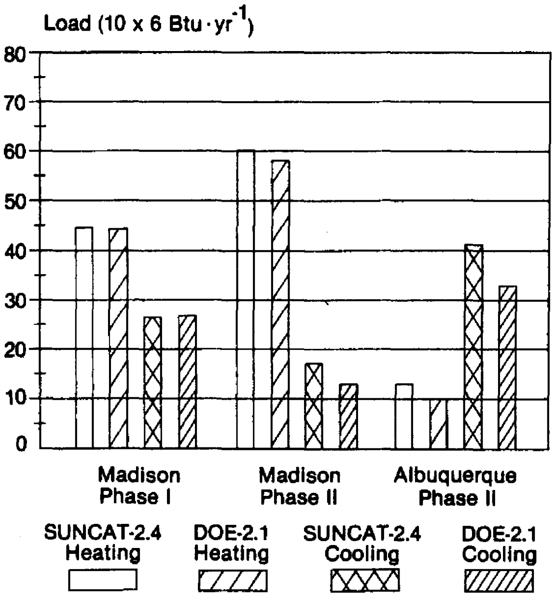

Fig. 7. **SUNCAT vs. DOE-2.1: High Mass**

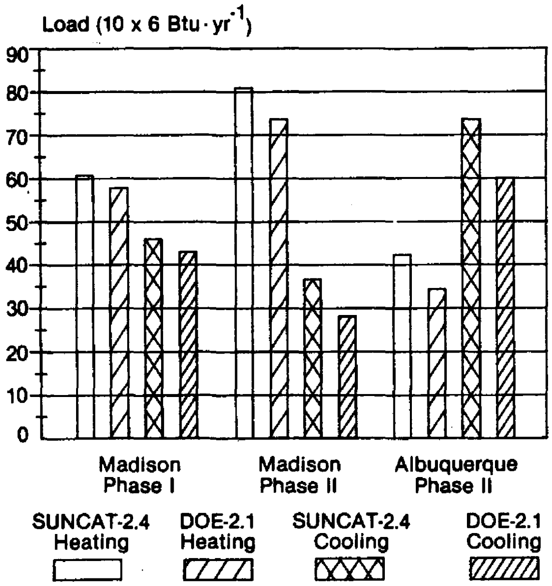

Fig. 8. **SUNCAT vs. DOE-2.1: Low Mass**

6. DISCUSSION

The results illustrated in Figs. 5 and 6 suggest that the very close agreement obtained between DOE-2.1, BLAST-2MRT, and SUNCAT-2.4 in the Phase I comparative study may have been a coincidence of the particular mix of variables chosen for that case. Even a relatively small perturbation of the parameter mix as represented in Figs. 7 and 8 by the change from the Phase I Madison case to the Phase II Madison case results in significant disagreement between SUNCAT-2.4 and DOE-2.1. DEROB-4 and BLAST-3.0 are rewritten versions of the codes used in the Phase I study, so the increased disagreement in Phase II could be attributed to the differences in the rewritten versions. However, SUNCAT-2.4 and DOE-2.1 are precisely the same programs as those in the Phase I study. Therefore, the increased disagreement between these two codes can only be attributed to the differences in the Phase I and Phase II building models and the Madison and Albuquerque weather data (Figs. 7 and 8). This is confirmed in the Albuquerque case where we observe the disagreement between DOE-2.1 and SUNCAT-2.4 increasing as the divergence from the Phase I Madison case becomes more extreme.

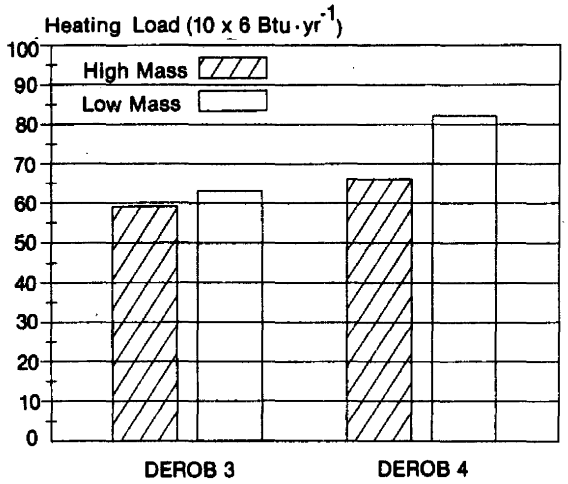

Fig. 9. **DEROB-3 vs. DEROB-4: Mass Sensitivity**

The magnitude of disagreement among all four codes is surprising in light of the results obtained in a previous analytical verification study in which these programs all agreed quite closely to a number of analytical solutions (2,3). These analytical solutions were chosen to test the most important individual and combined heat transfer mechanisms in the codes.

There are three possible explanations for this apparent conflict: (1) input errors to the codes for the comparative study; (2) important heat transfer mechanisms neglected; and (3) different handling of the interaction between combinations of mechanisms by the three codes.

It is impossible at this stage to be certain which is the correct explanation; however, the third explanation appears to be the most probable. One is unlikely because of the consistent pattern in the results. Two is doubtful because of the care taken in defining a "common denominator building"; i.e., a very simple building model with characteristics well within the computational capabilities of all simulations in the study. Additionally, great care was taken to include those mechanisms most important to building thermal performance in the analytical test-set (2).

If the third possiblility is correct, caution should be exercised in interpreting validation studies that only display temperatures since even apparently small differences in temperature can under certain conditions lead to relatively large differences in predicted loads. For example, if one code consistently predicts temperature excursions just outside the heating and cooling deadband, and another code predicts temperature swings just within the deadband, the cumulative energy predictions can be quite far apart even though the temperatures are close.

7. BLAST-3.0

BLAST-3.0 represents a considerable rewrite from BLAST-2MRT. In the Phase II study, BLAST-3.0 is consistently low in annual heating load prediction. However, in the absence of a "truth model" it is impossible to say whether BLAST-3.0 or the other programs are correct. BLAST-3.0 performed adequately on all of the major analytical solution tests as did all of the other programs (2,3).

8. CONCLUSION

Significant disagreement exists in predicting annual heating and cooling loads among all the codes even when a very simple building model is used.

A previous analytical verification study showed substantial agreement between the handling of major heat transfer mechanisms in the codes and the analytical solutions (2). This suggests that the discrepancies between the codes are occurring as a result of the dynamic interaction between mechanisms, rather than as a result of the mishandling of any major mechanisms.

DEROB-4 has successfully corrected the mass insensitivity problem uncovered in the Phase I Comparative Study in DEROB-3.

The use of an anisotropic versus an isotropic sky model in the DOE-2.1 radiation processor caused differences on the order of 10% in predicted annual heating and cooling loads.

Caution should be exercised in using these simulations for economic analysis or the generation of design tools because of the magnitude of discrepancy observed in predicting annual heating and cooling loads. These programs do show trends and tendencies; however, their sensitivity to parametric changes differs somewhat.

Further investigation is needed to determine the causes of these differences, and which of these programs, if any, is most accurate in predicting the thermal behavior of buildings. We hope to address these questions through comparing these codes against high quality empirical data in FY 1982. We will present these empirical validation results in future papers.

8. ACKNOWLEDGMENT

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