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A COMPARATIVE STUDY OF FOUR PASSIVE BUILDING ENERGY SIMULATIONS: DOE-2.1, BLAST SUNCAT-2.4, DEROB-III

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ABSTRACT

Four building energy analysis codes are compared using two direct gain building models with Madison TMY weather data. Hourly temperature profiles and annual heating and cooling loads are compared and discussed. An analytic verification technique is described and used to investigate performance of the four codes. An anomaly is discovered in one of the codes, and the analytic verification technique is used to test a modified version of this code.

1. INTRODUCTION

A number of building energy simulations are being applied to the design and analysis of passive solar buildings. Under the Building Energy Performance Standards (BEPS) rulemaking the DOE-2.1 computer program is being considered as the standard evaluation technique (SET). The computer programs SUNCAT-2.4, BLAST-MRT* and DEROB-III are being considered as alternate evaluation techniques (AETs). Additionally, these programs are being used to generate design tools and guidelines which will affect the ways in which buildings are designed. It is therefore important to know how results obtained from these programs compare. The objective of this study is to determine if the codes deliver reliable information, rather than to investigate building performance. As a first step, a very simple, and not necessarily realistic, direct-gain building was chosen such that differences in results could be analyzed and equivalent input to the four programs ensured. The codes were compared on the basis of hourly temperature profiles and annual heating and cooling loads. In addition, the radiation processors and sky-modeling algorithms were compared as originally encoded and then standardized such that incident radiation was equivalent for all four codes. Temperature decay tests were also performed. The building descriptions follow in Figs. 1 and 2.

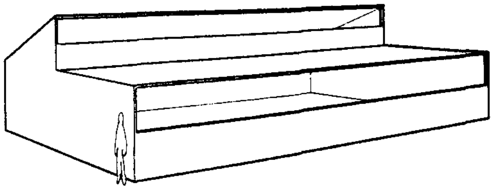

Figure 1. Comparative Study Test Building.

43.1° N - Latitude

Madison TMY weather data

1500 ft^2 floor area

350 ft^2 (double-glazed, vertical, due south) south glass area

300 Btu/h/°F UA overall (includes infiltration, but not glazing)

65°F - heating set point

75°F - cooling set point

Low mass case: 0.5 in. gypsum board on all walls and ceiling

High mass case: 8 in. concrete on all walls

No shading, night insulation, or ground coupling

Zero external absorptivity

Single zone

Figure 2. Comparative study test building characteristics.

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*Similar to BLAST 3.0.

2. RADIATION

The original versions of the codes contained different solar radiation processors. In order 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. As seen in Fig. 3 the final versions of all four codes showed only minor differences in incident radiation.

These minor differences may be explained by variations in declination formulas, time step definitions, and solar versus local time assumptions.

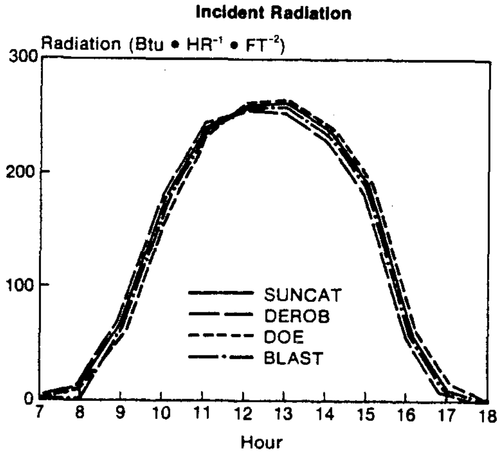


Figure 3. January 21 radiation for four codes.

3. INPUT EQUIVALENCY

Much effort was directed toward ensuring input equivalency among the codes. This effort was complicated by three types of input dilemmas:

- 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).
- Undocumented assumptions or mechanisms in the codes (e.g., hard-wired 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. Best engineering judgment was then used to minimize that range.

4. HOURY FREE-FLOAT TEMPERATURE PROFILES

Figures 4 and 5 show hourly room air temperature profiles for the high and low mass cases on January 21. This was a typical clear, cold day far enough from the beginning of the simulation to eliminate initialization effects.

For the low mass case, the SUNCAT, DOE, and BLAST curves are roughly similar in shape and amplitude. They demonstrate the quick response and relatively large temperature excursions expected in a highly solar-driven, direct gain building with neither thermal storage nor night insulation. The DEROB low mass temperature profile is much flatter, behaving more as expected for a high mass building. The high mass profiles for all four codes are more scattered. BLAST and DOE show closest agreement, with SUNCAT a good deal flatter and DEROB flatter still. In all cases except DEROB, the characteristic damping of temperature

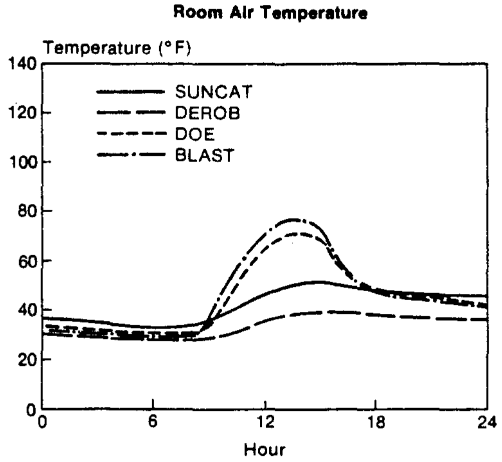


Figure 4. January 21 high mass room air temperature.

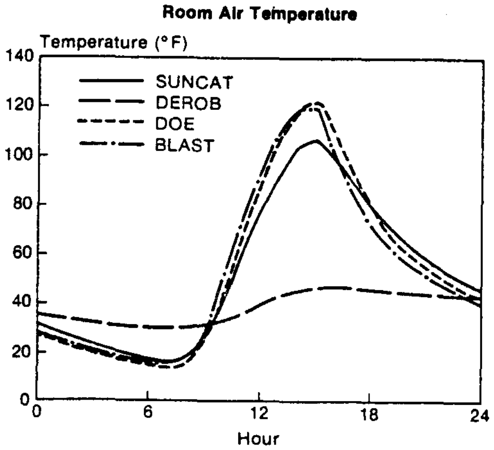


Figure 5. January 21 low mass room air temperatures.

swings associated with the addition of thermal storage is exhibited. In DEROB there is very little difference between the high and low mass temperature profiles.

5. ANNUAL HEATING AND COOLING LOADS

Annual heating and cooling loads for the high and low mass cases are shown in Figs. 6 and 7.

In the heating case, SUNCAT, BLAST, and DOE show good agreement for both high and low mass. The three codes also agree for low mass cooling. Greater disagreement is shown in the high mass cooling case.

BLAST, SUNCAT, and DOE all exhibit substantially reduced heating and cooling loads when mass is added. DEROB, on the other hand, displays an insensitivity to changes in thermal storage mass.

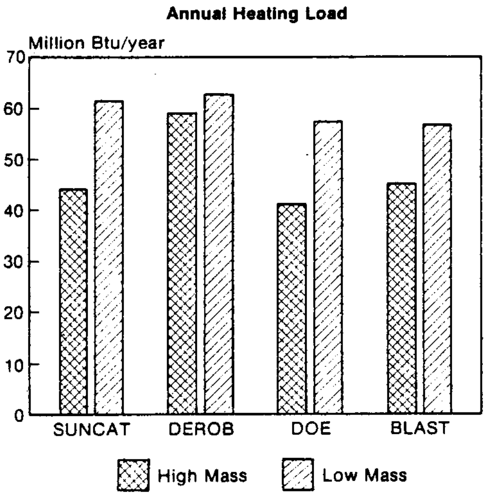


Figure 6. Annual heating load for four codes.

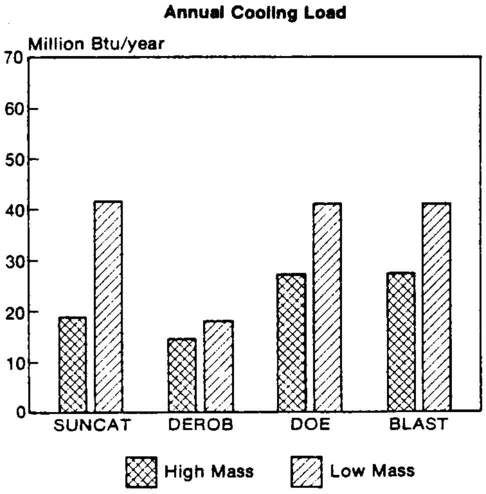


Figure 7. Annual cooling load for four codes.

6. DISCUSSION

As previously stated, based on the hourly profiles it appears that DEROB is insensitive to low mass. If this hypothesis were true we would expect to see agreement between DEROB and the other codes for high mass annual heating and cooling loads. This is true for cooling, but not true for heating. For the heating case we observed DEROB agreeing within the range of error shown by the other programs for low mass but not for high mass.

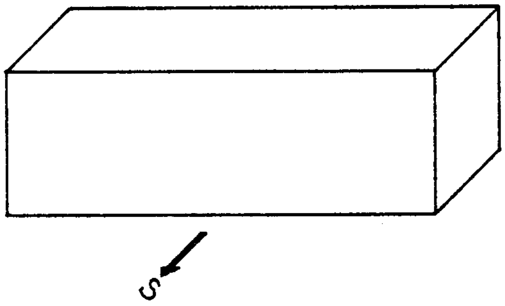
One interpretation of the data collected thus far relates to the solution technique used in the sixth program of DEROB, DBROLEN. To avoid costly matrix inversion, an iterative solution technique is used. The iterations are controlled by the variable LOOM in the RCSOLN subroutine. This variable is fixed at one iteration and is not normally available to the user. The solution uses the last hour's temperature and then iterates once in attempting to achieve convergence. This assumption is valid where surface temperatures are changing slowly. However, where surface temperatures should change rapidly, as in a low mass surface or a high mass surface receiving direct solar gain, one iteration does not allow surface temperatures to change quickly enough. Thus, surface temperatures are mathematically constrained to small differences over each time step. In other words, radiant or thermal energy causes a small temperature change on surface nodes not because the energy is absorbed by a real or synthetic thermal mass, but rather because a first law energy balance is not performed. The excess energy which would be found from an energy balance is simply lost and unaccounted for.

The temperature profiles shown in Figs. 4 and 5, always appear as if caused by a high mass condition. The long-term energy results, (see Figs. 6 and 7) on the other hand, are explained by the fact that surface nodes are slow in changing temperature. In the high mass heating case, surface temperatures never rise enough to drive energy into storage so DEROB shows more heating load. In the low mass heating case better agreement was shown because this effect was washed-out by backlosses through the collection area at night. Even though the other programs showed large temperature swings on January 21 and DEROB did not, the combined effect of very low storage and no night insulation caused the results to appear similar. In the cooling case this works in the opposite way. That is, DEROB now appears to be in better agreement for the high mass and in poor agreement for the low mass case. This is again due to the slow temperature response of DEROB. The other programs exhibit high cooling loads because temperatures are spiked. In DEROB temperatures do not rise rapidly, so low cooling loads ensue. In the high mass case the other codes show reduced load because of flywheel effect. DEROB appears to behave similarly simply because temperatures are mathematically constrained.

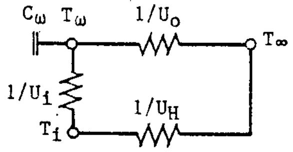
7. ANALYTIC VERIFICATION TECHNIQUE

In the previous sections of this paper, SUNCAT, DOE, and BLAST generally cluster around the same results. However, this clustering does not ensure that these results are correct.

In order to investigate this problem, high mass and low mass buildings (see Fig. 8) were developed which could be modelled both using the computer programs and as analytic solutions to mathematical equations (see Fig. 9).* The analytic solutions are the response of the interior temperatures to a step function in the ambient temperature.



1/2" gypsum board on walls and ceiling
Total UA = 50 Btu/h/°F
Ground coupling minimized

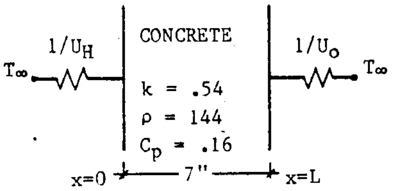


$$T_w = \frac{T_\infty}{D}\left(1 - e^{-\left(\frac{D}{E}\right)\tau}\right) + T_{\omega_o}\, e^{-\left(\frac{D}{E}\right)\tau}$$

$$\text{where } D = \frac{U_i + U_o - U_i^2/(U_i + U_H)}{U_i U_H/(U_i + U_H) + U_o} \quad \text{and}$$

$$E = \frac{C_\omega}{U_i U_H/(U_i + U_H) + U_o}$$

Fig. 8 Analytic solution test building and RC circuit solution



Note: High mass case is the same as the low mass case, except that a 7" concrete wall replaces the gypsum board.

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha}\frac{\partial T}{\partial \tau}$$

BC's: 1. $\frac{\partial T}{\partial x} = 0$ at $x = 0$

2. $\frac{\partial T}{\partial x} = \frac{-U_o}{K}(T - T_\infty)$ at $x = L$

IC: 3. $T(x,0) = T_0$

SOLUTION:

$$T(x,\tau) = \sum_{n=1}^{\infty} e^{-\alpha\lambda_n^2\tau}\left(\frac{2T_0 \sin\lambda_n L \cos\lambda_n x}{L\lambda_n + \sin\lambda_n L \cos\lambda_n L}\right)$$

where λ_n satisfies: $\cot(\lambda_n L) - \frac{\lambda_n L}{B_i} = 0$

where B_i = Biot number

Fig. 9. High mass test case and analytic solution

These solutions are considered the reference standard against which the output from the computer simulations are compared. The results from these tests are shown in Fig. 10 for the high mass case and in Fig. 11 for the low mass case. It can be seen that SUNCAT and DOE are very close to the analytic solution for both cases. However, DEROB

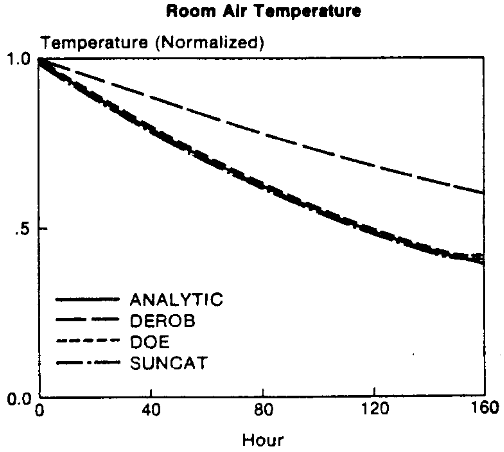


Figure 10. High mass temperature decay test for three codes.

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*This test covers conduction and convection in exterior walls. Further tests of this type are being developed at SERI and will be discussed in future publications. Passing this single test in no way represents a complete validation procedure.

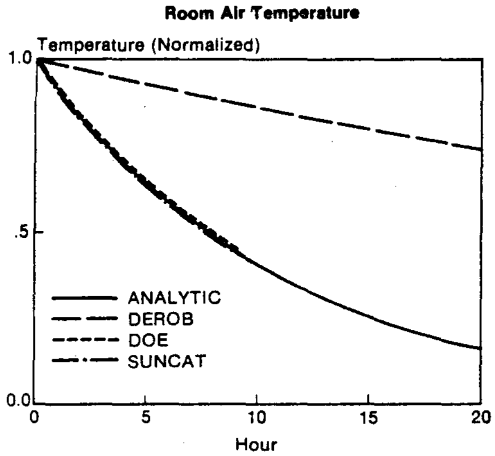

Figure 11. Low mass temperature decay test for three codes.

deviates considerably from the analytic solution in both the high mass and low mass tests. In fact, the DEROB results show the slow temperature response that supports our interpretation of results in the previous section.*

8. PRELIMINARY RESULTS ON A MODIFIED VERSION OF DEROB

Shortly after the results of this study were discussed with the author of DEROB, we received a modified version of the code. In the modified code, the solution is allowed to iterate until preset convergence conditions are met. This new code was tested according to the analytic verification technique described above. Figure 12 shows excellent agreement between the modified DEROB and the analytic solution for both the high and low mass cases. It is not yet certain what effect these code modifications will have on computer run-time. However, based on preliminary yearly runs, computer time appears excessive compared to the other codes and to the original version of DEROB.

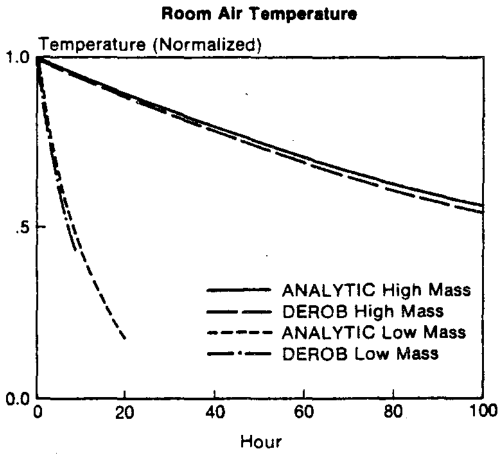

Figure 12. Temperature decay tests for new version of DEROB.

9. CONCLUSION

- In the test cases described, BLAST, SUNCAT, and DOE show substantial agreement for long-term heating and for low mass cooling.
- There is some disagreement between the three codes for high mass cooling loads.
- All four codes show differences in hourly temperature response. These may or may not be significant in the range of parameters commonly associated with buildings. Further investigation is planned.
- SUNCAT, DOE, and the modified DEROB show good agreement with the analytic temperature decay test.
- The original version of DEROB showed insensitivity to the mass parameter. It diverged from the other three codes for both the hourly temperature profiles and the yearly energy usage. This code also disagreed considerably with the high mass and low mass cases of the analytic temperature decay test.
- The modified version of DEROB agrees well with both the high mass and the low mass temperature decay analytic solutions.
- Further analytic verification tests should be applied to test other mechanisms in the codes.

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REFERENCES

(1) F. Arumi-Noe and M. Wysocki. DEROB III, The DEROB System, Volumes 1 - 8, (June 1979).

(2) D.A. York and E.F. Tucker, eds. DOE-2 Reference Manual (Version 2.1), (March 1980).

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

(4) Hittle, D.C. The Building Loads Analysis Thermodynamics (BLAST) Program, Users Manual, (June 1979).

(5) ASHRAE Handbook of Fundamentals, (1977).

(6) Carslaw, H.S. and Jaeger, J.C. Conduction of Heat in Solids, (1978).

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*This test was not run on BLAST because of computer problems.