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Empirical Validation Using Data from the SERI Class-A Validation House

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ABSTRACT

A residential test building at the SERI Interim Field Site was monitored at the Class-A level during the spring of 1982. The building was also modeled on three building energy analysis simulations—DOE2.1A, BLAST 3.0, and SERIRES—using measured weather data from the test period and the location. The measured energy performance data, and that predicted by the simulations, were compared. More correct input files for the codes were developed using measured values of input parameters, and the results were also compared with the measured performance data. The comparisons show that input errors can contribute to predicted auxiliary energy requirements which are on the order of 60% or more higher than the measured loads, and that improvements in input variables could reduce these errors significantly.

1. INTRODUCTION

The usefulness of building energy analysis simulations (BEAS) depends to a large extent on the confidence we have in the results of such simulations; i.e., their validity and accuracy. Our group at the Solar Energy Research Institute (SERI) has developed and implemented some methods of evaluating BEAS and of determining the limitations on their application to building energy analysis.

The validation work reported here consisted of monitoring a residential building at a very high level of detail, known as the Class-A level (Ref. 1), and using these data to test the validity of several BEAS. Previous validation work at SERI included comparative studies and analytical verification (see Ref. 1). These comparative studies have shown that there is significant disagreement in the energy performance predicted by different BEAS for the same simple building, primarily in auxiliary energy requirements. However, the comparative studies alone could not show if any of the BEAS are correct, because there was no standard against which to compare the results obtained from the various codes tested. Analytical studies have shown that selected major individual thermal mechanisms, including conduction through walls and the interaction of solar radiation with thermal mass, are correct as modeled. However, no tests were available to determine how well these mechanisms work when other mechanisms are present, nor how well other important thermal mechanisms, such as radition heat transfer between surfaces, behave.

Frequently sampled and calibrated measured values of temperatures, heat fluxes, and other energy flows are needed to evaluate BEAS, to eliminate the problems that result from using either comparative studies or analytical verification. Empirical data provide the standard of reference against which building energy performance predictions from various BEAS can be compared. The data also can provide detailed information about the thermal mechanisms in a building. Such data are needed to verify the accuracy of the mathematical formulation of individual exchange mechanisms currently in the codes, and, perhaps more importantly, to improve the formulation of more complex mechanisms.

Validation work has focused on the SERI Validation House, a four-zoned, single-story ranch house over a crawlspace (Fig. 1). The building is located at the SERI Interim Field Site near Golden, Colo. The building was monitored with an automated, digital data

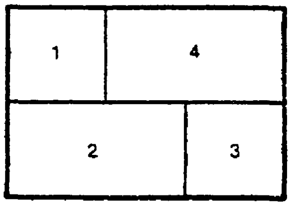

Fig. 1. Diagram of test building showing zone numbers

acquisition system that takes over 230 channels of thermal and other data. Data from the house were compared with building energy performance predictions from three mathematical models: BLAST 3.0, SERIRES, and DOE2.1A. These comparisons were originally performed using standard, referenced thermophysical property data. Additional comparisons were also made using measured values for selected material and building properties. These additional cases included using measured values for infiltration rates, ground temperature, and zone set points.

Because of the characteristics of the test house, the scope of this work and conclusions drawn from it are limited to residential-scale, skin-load-dominated buildings. While certain conclusions could be extrapolated to apply to other types of buildings, this is not recommended, particularly for commercial-scale buildings in which the performance of mechanical systems is more important than the skin load. The system and plant mechanisms in the BEAS used in the studies reported on here were given minimal treatment and generally were not tested.

This report presents only some of the results from our empirical validation work. More detailed information can be found in Wortman, Burch, and Judkoff (2).

2. VALIDATION STUDIES

Figures 2 through 7 show preliminary results from the validation study on the DOE-2.1A, BLAST-3.0, and SERIRES computer programs. These results are presented in terms of nine cases. The first, or base case, uses handbook or assumed values for all thermophysical property and other inputs. This corresponds to the data sources used in the input files for the codes as they are normally used. Cases 2 through 8 use selected measured values of individual variables in the input files. Case 9 combines all of the changes in Cases 2 through 8.

1. **Base Case.** Handbook or assumed values are used for all thermophysical inputs. Meteorological and geometric inputs are measured.
2. **Infiltration.** Same as base case, except that hourly zonal infiltration rates were measured and used to generate the infiltration input for the computer codes.
3. **Ground Temperature.** Same as base case, except that measured ground temperature was used as input to the ground coupling subroutines in the codes.
4. **Ground Albedo.** Same as base case, except that measured ground albedo was used in the calculation of radiation incident upon glazed surfaces.
5. **Set Point.** Same as base case, except that a correction was made to the thermostat set-point based on the average temperature of air in the zone when the heater actually turned on.
6. **Wall and Roof Conductance.** Same as base case, except that measured wall and ceiling conductances were used.
7. **Window Conductance.** This case was not run, because measured window conductances were the same as those given by the ASHRAE Handbook of Fundamentals (3).
8. **Absorptivity.** This case was not run, because the measured solar spectrum absorptivity on opaque surfaces was not significantly different from assumed values.
9. **Measured.** All of the measured values in Cases 2 through 6 were used. This case represents the highest degree of control over external error sources, and presumably should yield results closest to the measured temperature and energy performance of the building.

3. RESULTS

Figure 2 shows the total heating load (in KWh) for the week of 20-26 April 1982. The loads predicted by the DOE-2.1A, BLAST-3.0, and SERIRES computer programs are shown along with the measured load for Cases 1-9. In Case 1, where handbook input values were used, code predictions were higher by 46%-62%, compared with measured loads. In Case 5, where the correction was made for the actual thermostat set-point, code predictions were high by 21%-50%. In Case 9, where all known measured input values were used, the code predictions were low by 11%-33%. Generally, predictions were most accurate for Case 9.

Figure 3 shows the root mean square (rms) difference between measured and predicted temperatures in Zone 2 of the house for all nine cases. Zone 2 is the southern living room and has a massive floor surface. In general, results for Zone 2 are typical of the results for the whole building. Case 1 has rms errors of between 1° and 1.2°C. Case 5 has rms errors of from 0.6° to 0.9°C. Case 9 has the largest rms errors: from 0.9° to 1.6°C.

Figure 4 shows the Zone 2 measured peak heating load and the peak heating loads predicted by the three computer codes in Cases 1-9. Case 1 predictions of peak load are high by 36%-45%. Case 5 predictions are high by 27% to 40%. Case 9 predictions are the most accurate and fall within ±5% of the measured peak load.

Figure 5 shows the peak load for the whole house. The pattern is similar to that

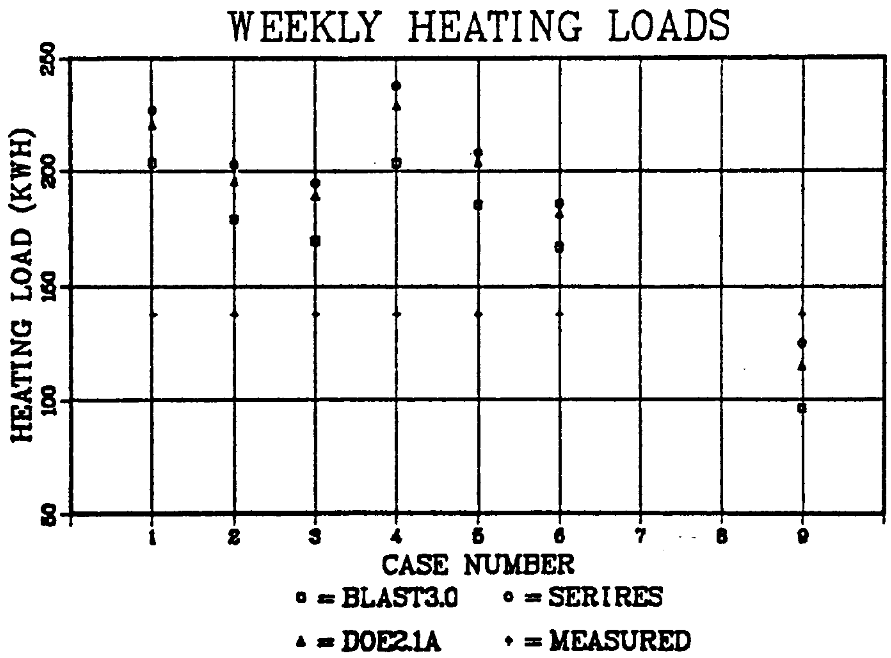

Fig. 2. Weekly heating loads for 20-26 April 1982

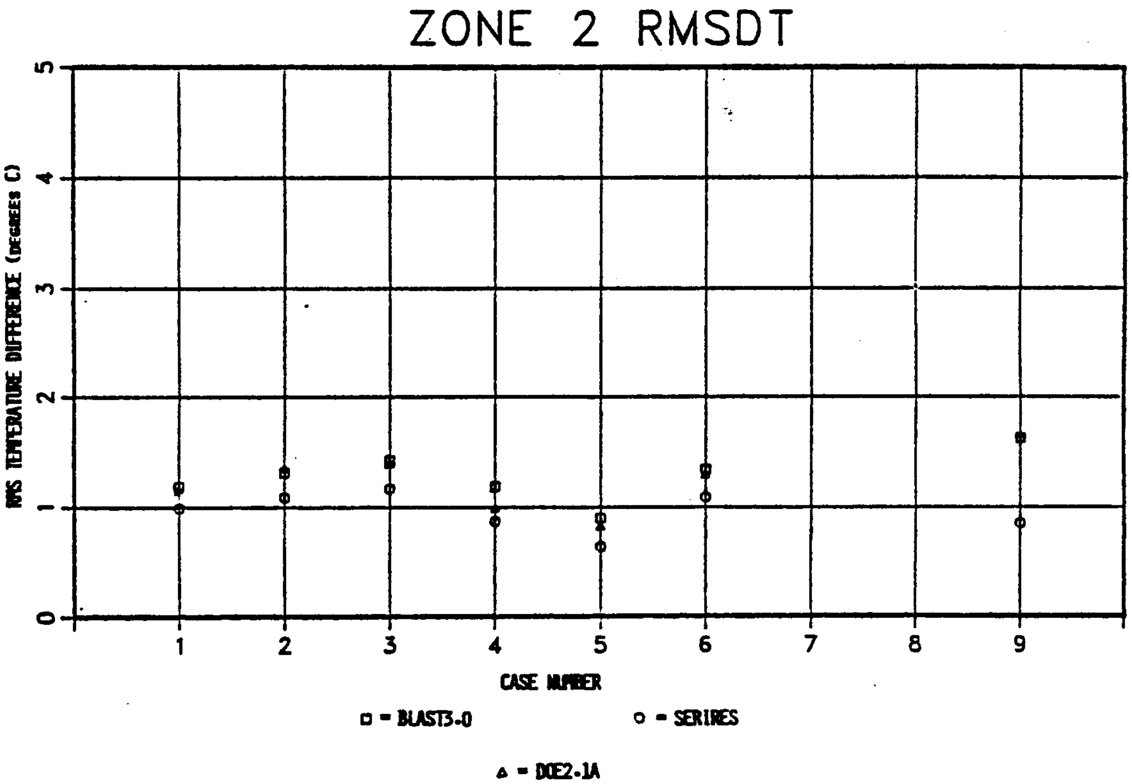

Fig. 3. Root mean square difference between predicted and measured temperature in Zone 2

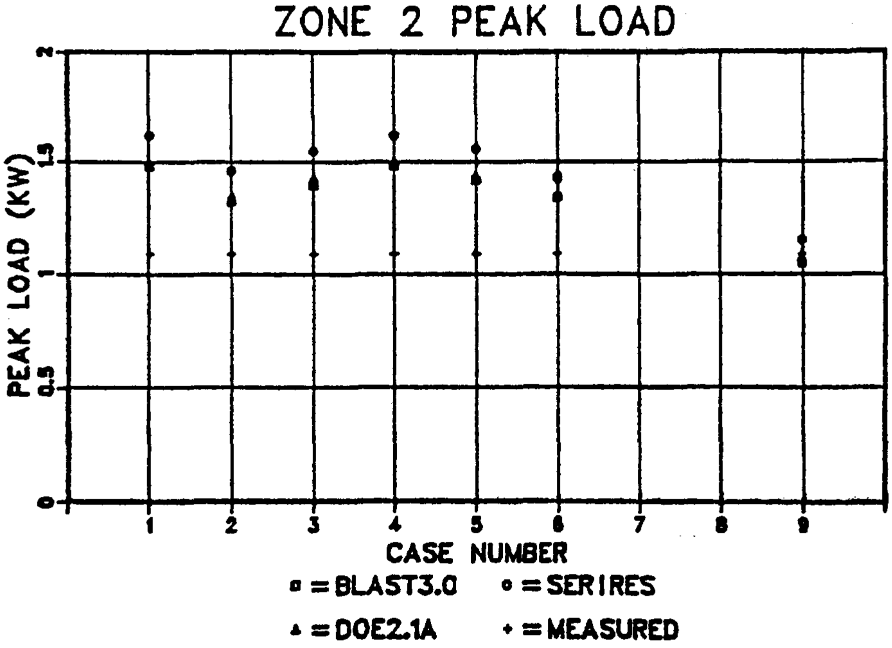

Fig. 4. Predicted and measured heating loads for Zone 2

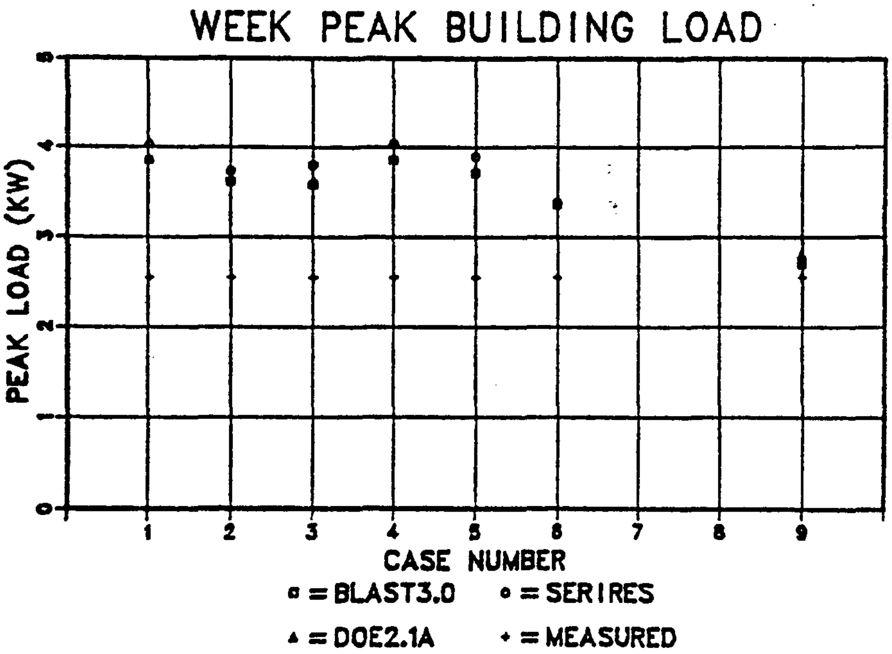

Fig. 5. Peak building load for the week studied

observed for Zone 2; Case 1 predictions are the least accurate and Case 9 predictions are the most accurate.

Figure 6 shows the hourly temperature profile predicted by the DOE-2.1A code in relation to the measured temperature profile for Case 1, Zone 1. Zone 1 was primarily a free-floating zone during the measurement time period because temperatures remained above the thermostat set-point from hour 36 to hour 168.

We observe from Fig. 5 that predicted temperature tends to overshoot measured temperature during the day and undershoot measured temperature at night.

Figure 7 shows the same information for Case 9 as for case 1 in Fig. 6. In Case 9, we see that predicted temperatures overshoot measured temperatures by even more during the day than in case 1; however, they undershoot by less at night than in Case 1.

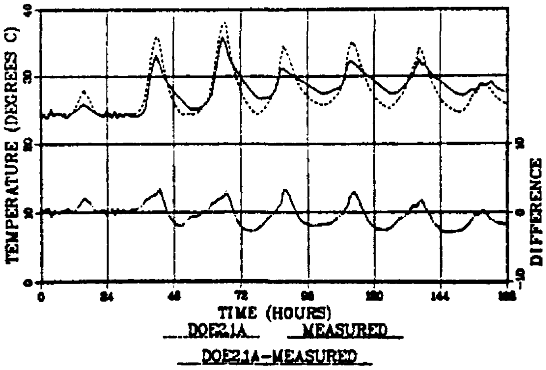

Fig. 6. Predicted vs. measured hourly temperature profile for Case 1, Zone 1, days 110 to 116

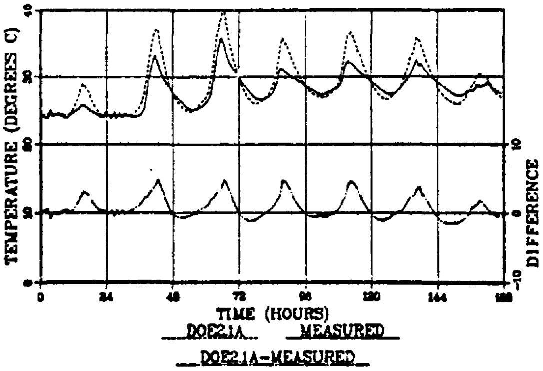

Fig. 7. Predicted vs. measured hourly temperature profile for Case 9, Zone 1, days 110 to 116

4. INTERPRETATION OF THE DATA

There is some apparent inconsistency in the data with respect to the presumption that Case 9 would always yield the most accurate predictions. The most obvious is seen in Fig. 3 where Case 1 and Case 5 exhibited smaller rms temperature errors than Case 9. This trend is the reverse of that seen in Fig. 1, where, as expected, the most accurate load prediction was obtained in Case 9. The most likely hypothesis at this time is that (a) the amount of solar energy absorbed in the building is being overpredicted in all cases, and (b) the conductive losses through walls and roof are being overpredicted in Cases 1-5.

This hypothesis is partially supported by the large (approximately a factor of two) difference found between measured and assumed wall and roof resistances, as shown in Table 1.

Table 1. Difference Between Measured and Assumed Wall and Roof R-Values

	M^2-°C/W	(hr-ft^2-°F/Btu)
Average measured wall resistance	3.05	(17.3)
Assumed wall resistance from ASHRAE	1.56	(8.83)
Average measured ceiling resistance	13.19	(75.03)
Assumed ceiling resistance from ASHRAE	7.04	(40.00)

The smaller rms temperature errors in Cases 1-5 could, therefore, be explained by the offsetting effects of too high an envelope conductance and the code's calculation of too much solar radiation absorbed in the building. This explanation is consistent with the hourly temperature profiles seen in Figs. 6 and 7, where the Case 1 predicted temperature was high in the day and low at night, and the Case 9 predicted temperature was even higher during the day but not so low at night. This also explains how the heating loads in Case 9 would be the most accurate even though the rms temperature errors in Case 9 were the greatest.

The large rms temperature errors were caused primarily by overpredictions of daytime temperature. Greater accuracy in load prediction was still possible, however, because at night the performance of the building was primarily governed by conductive skin losses. The overprediction of solar radiation absorbed resulted in the 11%-33% underprediction of loads in Fig. 1, Case 9. Finally, the high degree of accuracy in the Case 9 peak-load predictions is also consistent with this explanation. At those times when stored solar energy was most depleted and envelope conduction was most dominant, the code predictions were most accurate.

5. CONCLUSIONS

The work discussed in this paper is part of a multiyear, multilaboratory effort on the part of DOE to improve our knowledge of the mechanisms governing the thermal behavior of buildings and to formulate that knowledge in mathematical terms. This effort would also develop an analysis of the thermal behavior of buildings and predictions of that behavior by collecting high-quality, detailed data and applying rigorous validation techniques. The main benefit of efforts to validate calculation techniques now built into the model examined is to establish their degree of accuracy and their validity for predicting the behavior of buildings. The validation work is far from complete. However, a number of early conclusions can be drawn that should help to guide future activities.

- Input assumptions based on standard engineering references such as wall conductance can cause prediction errors in auxiliary load on the order of 60%, even when measured meteorological data are used.
- Accurate zone air temperature prediction does not guarantee accurate load prediction, nor does it guarantee an accurate temperature prediction on the next building studied. There is evidence of compensating errors giving a false sense of confidence. Any validation methodology must account for the possibility of hidden compensating errors.
- Even when most input inaccuracies are eliminated by using measured thermophysical input data, prediction errors in the auxiliary load, ranging from 11%-33%, have still been found. This can have a large impact on building and HVAC system design options.
- Consistent differences were observed in the heating load predictions for the three codes for all cases even though inputs were developed to ensure comparable buildings for each code.
- A more detailed level of analysis and experimentation will be necessary to determine if these inaccuracies are due to unknown remaining external error sources or to internal error sources. This additional work should include:
    - Corroboration of conductances measured in the walls and ceiling with an ASTM standard large section "clamp-on" guarded hot-box.
    - Installation of a simpler window assembly in the test-house.
    - Development of a measurement technique to determine the amount of solar radiation absorbed in the building.
    - Determination of the sensitivity of output accuracy to isotropic-versus-anisotropic sky models.
- The methodological approach used in this work for skin-load-dominated buildings should be expanded to include the mechanical systems in commercial buildings.

6. ACKNOWLEDGMENTS

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