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THE DOE-2 VERIFICATION PROJECT: PHASE I RESULTS

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ABSTRACT

A computer program, designated DOE-2 (formerly DOE-1), has been developed to provide architect/engineers with a public domain tool for fast and economic energy analysis of buildings.

With funding from the US Department of Energy, the Los Alamos Scientific Laboratory (LASL) has developed and implemented a program plan to verify DOE-2. Phase I of this plan is an analytical verification of the DOE-2 program as a computational unit rather than as separate algorithms.

Work on Phase I of the DOE-2 Verification Project is nearly complete. Results of the crosscheck with the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) loads calculative procedures, as well as the results of a line-by-line check of program constants and flag-setting algorithms, are reported. Also presented are results of empirical tests of the full DOE-2 program, including comparisons with measured energy consumption and preliminary results of a study of the user interpretation of input data on predicted results.

INTRODUCTION

The DOE-2 Verification Project began in 1978 with the preparation of a verification program plan [1] by LASL. This plan outlined the tasks to be completed and identified relevant work being conducted outside the LASL project. The methodology adopted for implementing this project was then presented [2].

Most of the DOE-2 Verification Project Phase I tasks are complete and are being evaluated. This paper summarizes the results of the more important of these tasks. A comprehensive and detailed status report is being prepared.

SUMMARY OF PHASE I RESULTS

ASHRAE/DOE-2 LOADS Crosscheck

This task, conducted by a consultant to LASL, involved the comparison of the DOE-2 LOADS program predictions with results of commonly used loads calculative methods that are described in the 1972 and 1977 ASHRAE Handbooks of Fundamentals [3,4]. The 1972 ASHRAE method uses weighting factors that are specified in the 1972 ASHRAE handbook. On the other hand, the 1977 ASHRAE method uses Cooling Load Factors that are derived from the same weighting factors as are specified in the 1972 handbook except that 1977 handbook weighting factors are used for lights. The purpose of the task was to provide DOE-2 users with a reference point for building loads calculations and not to determine the accuracy of any of the methods.

Comparisons of the predictions of DOE-2 with those of the 1972 and 1977 ASHRAE methods were made for peak and daily total cooling loads for a summer design day and for design lighting and occupancy schedules [5]. Four cooling load components were considered separately: cooling loads resulting from (1) heat gain through an opaque south-facing wall, (2) solar gain through a south-facing window, (3) lights, and (4) occupants. Results of these comparisons are presented in Figs. 1 and 2 and in Table 1.

Figure 1 shows a comparison of DOE-2 predictions and those of the two ASHRAE methods for cooling loads resulting from heat gain through a 20 cm (8-in.) brick, south facing wall. Although the figure shows that DOE-2 predicts a peak only about 4% lower than the 1972 ASHRAE method, the loads are not in phase. Agreement is better between the DOE-2 predictions and those of the 1977 method. However, this agreement is coincidental because both the 1972 and 1977 ASHRAE methods are based on the weighting factors presented in the 1972 handbook, whereas DOE-2 uses weighting factors specified in the 1977 handbook.

Figure 2 presents a similar comparison of predicted cooling loads resulting from heat gain from lights. The significant differences shown illustrate that in this lighting case the 1972 ASHRAE method uses 1972 handbook weighting factors, the 1977 ASHRAE method uses 1977 handbook weighting factors, and DOE-2 uses weighting factors from Ref. 6.

Table 1 is a summary of results for the four load component comparisons. Although the daily totals for each method are nearly the same, there are

TABLE 1

DOE-2 LOADS/ASHRAE COMPARISON

Cooling Load Component	Relative Variation ( ) DOE-2/ASHRAE 1972 Peak	DOE-2/ASHRAE 1972 Daily Sum	DOE-2/ASHRAE 1977 Peak	DOE-2/ASHRAE 1977 Daily Sum
South-facing wall (conduction)	-3.8	+0.2	-2.0	-0.1
South-facing window (solar)	-14.9	-0.2	-15.0	+2.0
Lights	+29.0	-0.01	+20.0	+0.02
Occupants	+4.5	+0.2	-0.1	-0.4

considerable differences in the predicted peak loads. DOE-2 predicts peak cooling loads that differ by as much as 29% from those predicted by the 1972 and 1977 ASHRAE methods. However, this does not mean that DOE-2 is wrong; it means that DOE-2 uses more recent sets of weighting factors than do the ASHRAE methods.

Constants and Flag-Setting Checks

An earlier version (DOE-1.4) of the DOE-2 computer program was checked on a line-by-line basis for two types of errors: those in assigned values of constants and those in flag-setting algorithms. The work was conducted by McDonnell Douglas Automation Company (MCAUTO) under contract to LASL.

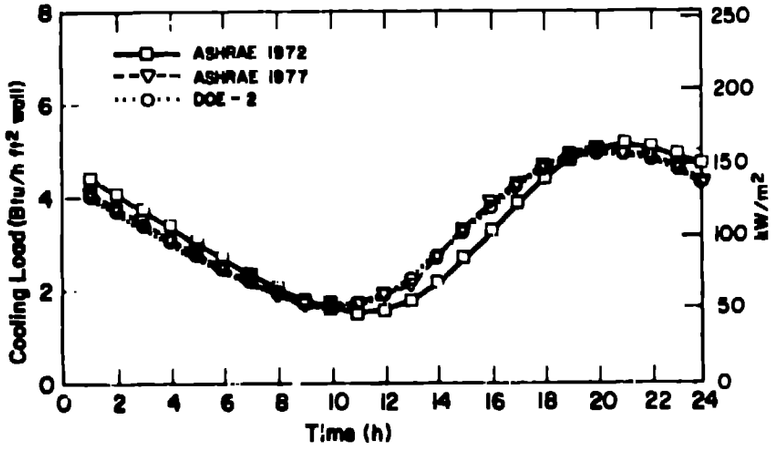

Fig. 1. Comparison of Cooling Loads for Heat Gain through South-Facing Wall: DOE-2 Versus ASHRAE Methods.

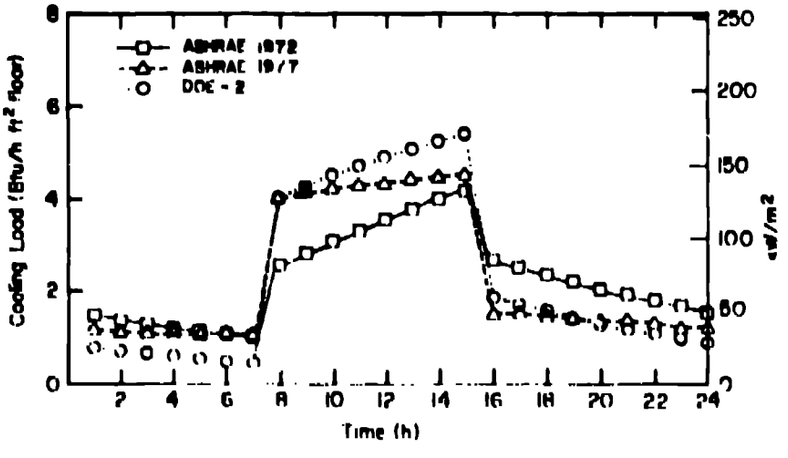

Fig. 2. Comparison of Cooling Loads for Heat Gain from Lights: DOE-2 Versus ASHRAE Methods.

The check of all program constants revealed a total of 19 errors, of which only 6 were significant. All of these errors have been corrected.

A majority of the 13 discrepancies found in the flag-setting algorithms were extraneous items inserted by the programmers for future use that did not affect the computations. These discrepancies have all been eliminated in the current (DOE-2.0A) version of the program.

PLANT Program Equipment Subroutine Check

This work was also conducted by MCAUTO, who compared PLANT program equipment performance default values to manufacturers' performance data. Commonly available published data, such as that contained in equipment brochures for system sizing, were used. Data from three different manufacturers were used, when available, to compare with each component model.

Figure 3 shows a comparison for the input versus output curve for a small boiler. Excellent agreement is shown between manufacturers' data and the DOE-1.4 simulation. Figure 4 shows the relationship between coefficient of performance (COP) and part-load ratio (PLR) for a reciprocating chiller. Note that significant differences are evident between both manufacturers' data and the program. This illustrates a point that is emphasized in the verification program plan; namely, that to determine the required component model accuracy, it is necessary to obtain the actual performance variance within a generic class of components. In this particular case, the COP varies from one manufacturer to another by as much as 17% for the same PLR. Therefore, the model cannot be expected to predict the COP to within 10% for this component.

The majority of comparisons made indicated good agreement between manufacturers' data and the equipment model subroutines. The only models with poor agreement were for waste heat from diesel-engine and gas-turbine generators. Lawrence Berkeley Laboratory (LBL) has corrected these inconsistencies in the current program version (DOE-2.0A).

Monthly-Energy-Use Field Tests

The purpose of this task is threefold: (1) to test the DOE-2 program in an overall manner, (2) to compare DOE-2 monthly and annual energy consumption with measured utility data for existing buildings in an uncontrolled environment, and (3) to introduce the human factor into the testing of the DOE-2 program.

A set of five contractor/test building pairs was selected by competitive bid to perform this task. In addition, two national laboratory/building pairs were involved. These seven pairs are

- Single-floor office building/Control Data Corporation;
- Multi-floor office building/Gallehouse and Associates;
- Retail store/New Mexico Energy Institute;
- Restaurant/Gamze, Korobkin, and Caloger;
- Hospital/Bickle Division of CM, Incorporated;
- School/LBL; and
- National Security and Resources Study Center (NSRSC)/LASL.

Reference simulations. The seven participants simulated their respective buildings using the DOE-2.0A program. These simulations were conducted using historical knowledge of the buildings

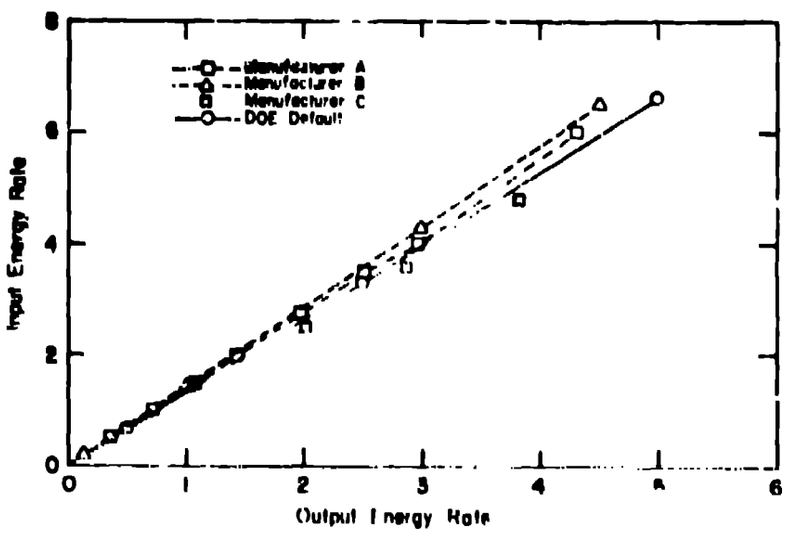

Fig. 3. DOE-2 PLANT Equipment Performance Default Curves Versus Manufacturers' Data (small boiler).

and their operation during the one-year test period. The period of simulation, metered data, and weather data used were all for the same calendar period. DOE-2 energy consumption predictions were compared to metered data (monthly utility bills).

A summary of reference-run results is shown in Table 2. Variation between predicted and measured values for gas or fuel-oil energy, electricity, total energy, and energy budgets is shown on an annual basis. The minimum deviation for gas/fuel-oil consumption was 1% for the restaurant, and the maximum was 19% for the retail store. The variation in prediction discrepancies for electricity consumption was less, with minimums of <1% for the multifloor office building and the school, and a maximum of 15% for the solar building (NSRSC). The prediction of annual total energy consumption (energy budget) varied the least, with a minimum of less than 1% for the restaurant and a maximum of 12% for the retail store and the solar building.

Differences in computed-versus-measured energy use were significantly higher on a monthly basis, ranging up to 45%, than on an annual basis.

User-effect simulations. Each of the buildings simulated in the reference runs, with the exception of the school building, was simulated by each of the other private contractors (round robin, that did not do the reference run on that building. Each reference-run contractor prepared a data package for his reference-run building for use in the user-effect test. This data package contained as-built engineering drawings, equipment specifications, operating schedules (for the year of simulation), and information regarding changes in the structure or schedules that have occurred since construction. It did not contain historical operating information.

The user-effect simulations have only recently been completed and have not been fully evaluated. However, Figs. 5-7 represent preliminary results for gas consumption, electricity consumption, and total energy consumption, respectively, for the restaurant (located in Chicago, Illinois). Each figure contains plots of the monthly measured data, the DOE-2 reference run, and the four user-effect DOE-2 runs. Three of the four user-effect runs for gas consumption (Fig. 5) compare well with the reference run (within ±10%) for monthly values. The outlying set of values appears to be

TABLE 2

SUMMARY OF REFERENCE RUNS RESULTS (ANNUAL)
DOE-2 PREDICTIONS VERSUS MEASURED DATA

	Gas/Fuel Oil (%)	Electricity (%)	Total Energy (%)	Predicted Energy Budget MJ/m²·yr	(Btu/ft²·yr)	Measured Energy Budget MJ/m²·yr	(Btu/ft²·yr)
Single floor office	-15	+6	-6	1551.3	(136,695)	1659.4	(146,214)
Multifloor office	-14	<-1	-4	1327.8	(117,000)	1378.1	(121,436)
Retail store	-19	-4	-12	1709.6	(150,667)	1944.1	(171,339)
Restaurant	-1	-2	<-1	7959.7	(701,313)	8037.3	(708,163)
Hospital	-4	14	7	4812.5	(424,051)	5171.7	(455,657)
School	+5	<-1	+4	1075.1	(94,731)	1034.9	(90,960)
NSRSC (solar)	+15	-15	-12	492.3	(43,380)	564.1	(49,704)

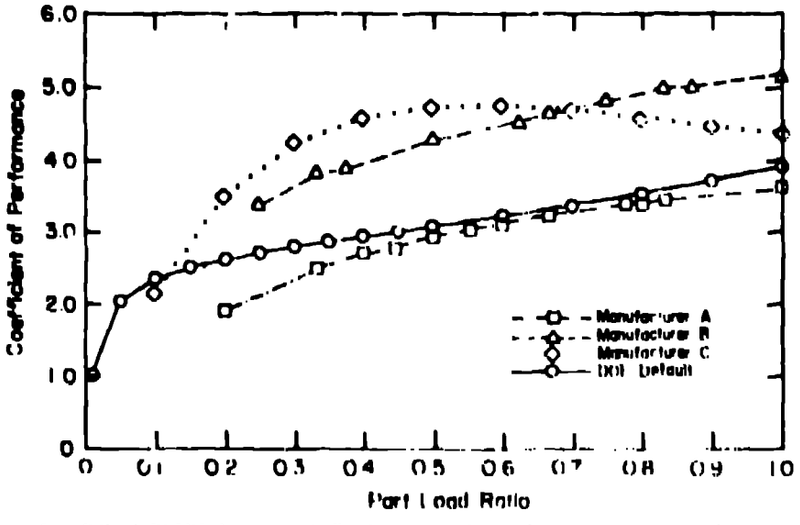

Fig. 4. DOE-2 PLANT Equipment Performance Default Curves Versus Manufacturers' Data Reciprocating Chiller.

a result of a disagreement in the interpretation of base loads. The scatter in the user effect for monthly electricity consumption, approximately ±25% (Fig. 6), is greater than that for gas consumption.

CONCLUSIONS

Comparisons of DOE-2.0A with 1972 and 1977 ASHRAE loads-calculative methods have shown the following:

- Differences among the daily total loads predicted by the methods are small (<1%).
- Differences of up to nearly 30% occur among the peak loads predicted by the methods.

These differences result from the use of different sets of weighting factors in the three methods compared. Because predicted peak loads are widely used for equipment sizing, these differences should be quickly resolved.

DOE-2.0 is free of errors in constants and flag-setting algorithms.

Comparisons of DOE-2 PLANT equipment performance default values and manufacturers' data have

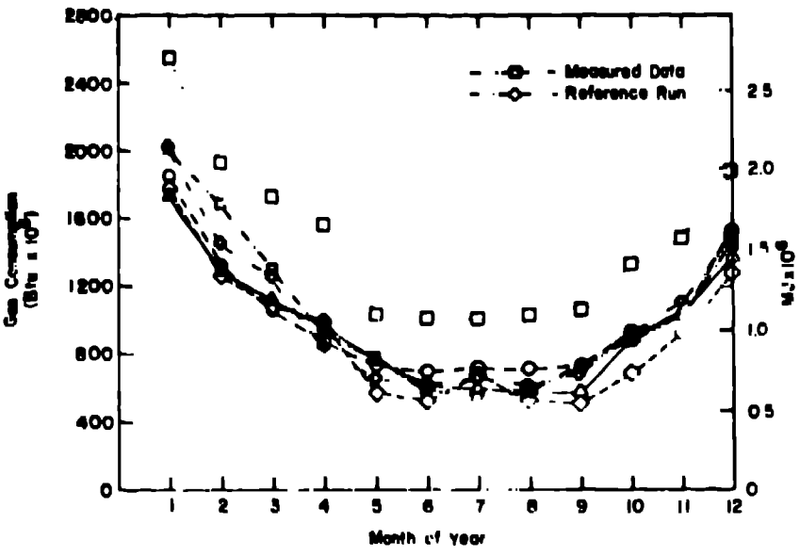

Fig. 5. DOE-2 Verification Project User Effect Runs: Restaurant.

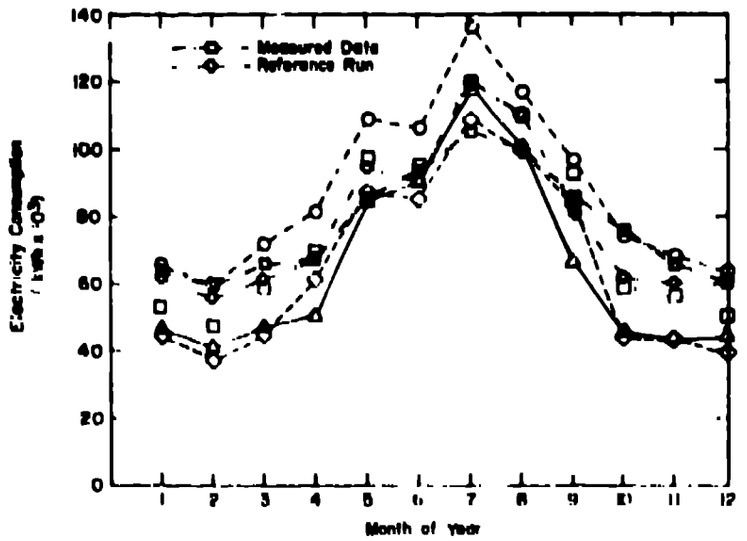

Fig. 6. DOE-2 Verification Project User Effect Runs: Restaurant.

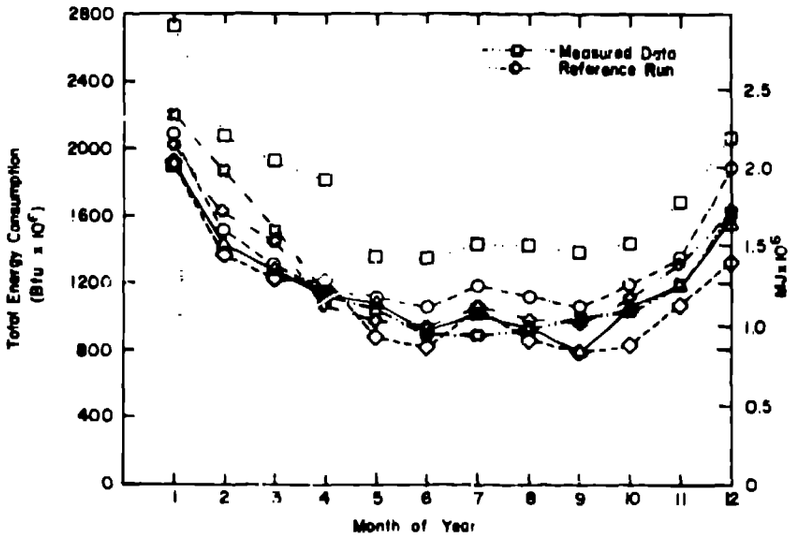

Fig. 7. DOE-2 Verification Project User-Effect Runs--Restaurant.

identified a few questionable default curves. These have been reviewed and corrected where appropriate in the DOE-2.0A program.

The reference runs made on six commercial buildings of different types indicate good agreement with measured monthly and annual energy consumption data. Predictions for the six buildings differed from measured annual data by 1-19% for gas/fuel-oil consumption, by 1-15% for electricity consumption, and by 1-12% for total energy consumption.

Preliminary data reported for one building (restaurant) indicate a user-effect difference of approximately ±10% for gas consumption and approximately ±25% for electricity consumption, both on a monthly basis.

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