Conf-820819--6

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LA-UR--82-1732

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TITLE: VALIDATION OF PASSIVE-SOLAR ANALYSIS/DESIGN TOOLS USING CLASS A PERFORMANCE-EVALUATION DATA

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SUBMITTED TO: To be presented at the Seventh National Passive Solar Conference, to be held in Knoxville, Tennessee, on August 29-September 1, 1982.

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FORM NO 836 R4

VALIDATION OF PASSIVE SOLAR ANALYSIS/DESIGN TOOLS USING CLASS A PERFORMANCE EVALUATION DATA*

by

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ABSTRACT

A major objective of the Class A Performance Evaluation Program, sponsored by the DOE Passive and Hybrid Solar Energy Division, is to collect, analyze, and archive detailed test data for the rigorous validation of analysis/design tools used for passive solar research and design. The Los Alamos National Laboratory has recently become the coordinator of this effort.

This paper describes elements of the plan for Class A validation. A proposed validation methodology, including a quantitative definition of validation, minimum data requirements, and a standard reporting format, is outlined. The preliminary testing of this methodology using hourly data from two Class A test facilities is presented. Finally, the collection, analysis, and documentation of preliminary data sets is discussed.

1. INTRODUCTION

In the fall of 1981, the Los Alamos National Laboratory assumed responsibility for coordinating and executing the Class A performance evaluation activities of the DOE Passive and Hybrid Solar Energy Program. Under the Class A program, detailed hourly data are being collected, analyzed, and archived for the dual purposes of (1) rigorous validation of analysis and design tools (both component models and complete tools) and (2) for performance evaluation of passive solar systems; only the first of these purposes will be addressed here.

The program is outlined in a Solar Energy Research Institute (SERI) report [1]; SERI and the National Bureau of Standards (NBS) have been actively involved in the program since its beginning in late 1979. Although the initial thrust involves test cells, small unoccupied test buildings, and a residence, the program is expected to be expanded later to include commercial buildings and other test facilities.

The Class A plan for validation and performance evaluation is being updated, based on the identified data needs of a variety of researchers and tool users. The elements of that plan are described in this paper. Minimum data requirements and a standard reporting format for archived Class A data sets have been developed. A validation methodology that includes both analytical and empirical elements and a quantitative definition of validation are under development. This methodology is undergoing testing through the validation of several analysis/design tools using hourly data from Class A test facilities. Preliminary results of that testing are reported here.

2. APPROACH: THE CLASS A PLAN

A preliminary outline of the plan for Class A validation of passive solar analysis/design tools is given in Ref. 1. This plan is being updated and expanded at Los Alamos and includes the following four elements (see Fig. 1).

(1) Data needs definition and matching with available or needed test facilities;

(2) Development and testing of a general validation methodology;

(3) Collection, analysis, and archiving of Class A test data for

- full-program validation,
- component/algorithm validation,
- performance evaluation; and

(4) Program Management.

*Work sponsored by the US Department of Energy, Office of Solar Heat Technologies.

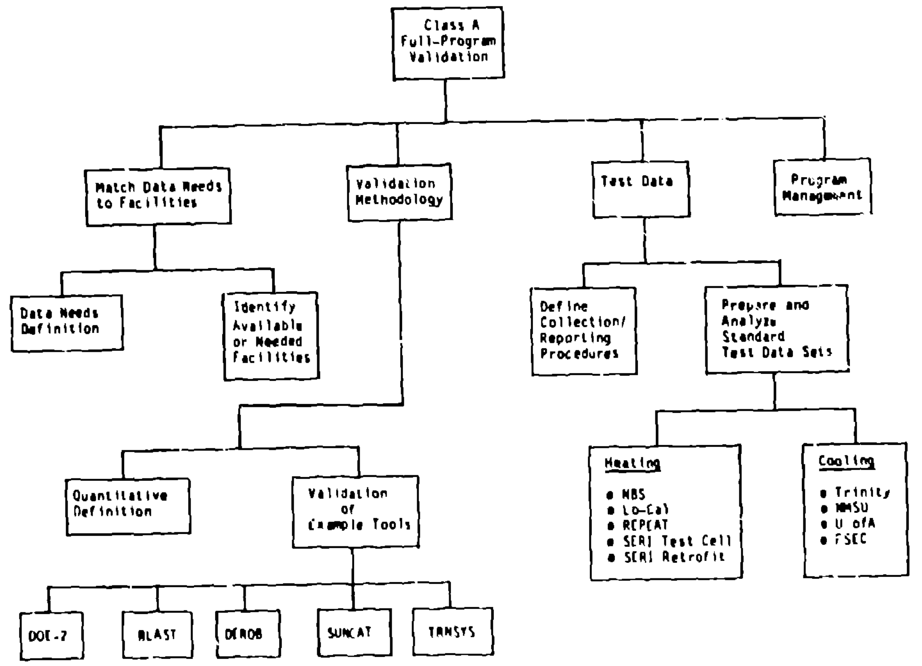

Fig. 1. Class A full-program validation plan elements.

The first three of these elements are addressed in detail below. Management of the program can be summarized in the following comments. Los Alamos is the technical manager for the Class A program and has responsibility for the direction and execution of the program; the Memphremagog Group of Newport, Vermont, is assisting in general management tasks. Several organizations, principally SERI, NBS, and Lawrence Berkeley Laboratory, are participating in the program. Los Alamos is responsible for assuring that a standard validation methodology and standard data collection/reporting procedures are established and maintained. Los Alamos will serve as the archive of Class A data, including site handbooks and data tapes with documentation.

3. DATA NEEDS AND REQUIRED TEST FACILITIES

3.1 Data Needs Definition

The data needs for Class A validaton are in two categories:

(1) Data for full-program analysis/design tool validation, and

(2) Data for component or algorithm validation.

Data collection in both of these categories is necessary for comprehensive validation of analysis/design tools. At present, emphasis in the Class A program is on gathering high-quality data for full-program validation.

The Class A test facilities include acquisition of hourly data sufficient to allow all terms of an energy balance on the building envelope to be determined. This requires hourly solar and weather data, and in most cases indoor dry-bulb temperature and humidity, vent discharge temperature and flow rate, average inside-to-outside temperatures (or heat fluxes) on each surface exposed to ambient conditions, internal heat sources, auxiliary heating and cooling energy, infiltration, and surface and internal temperatures (or surface heat flux) on primary thermal storage elements. Thermophysical property data of the soil and of building materials are usually measured directly; in some cases the building overall loss coefficient and heating/cooling plant efficiency are measured in coheating experiments.

3.2 Available and Needed Facilities

At present, nine test facilities or buildings are in the Class A network. Class A level data are being taken at several other facilties, both within and outside of DOE sponsorship. Data from these other facilities are being reviewed and compared to the data needs for a balanced program; those facilities found to be appropriate will later be included in an expanded Class A network. Table 1 summarizes the types of facilities presently in the network; no commercial buildings are yet included.

TABLE 1

FULL-PROGRAM VALIDATION TEST FACILITIES
SUMMARY OF FACILITY TYPES

	Test Cells	Dedicated Full Scale Test Facilities	Monitored Buildings Residential		Monitored Buildings Commercial	
			Occupied	Unoccupied	Occupied	Unoccupied
(1) NBS		•				
(2) Lo-Cal			•	•		
(3) REPEAT (Reconfigurable)		•				
(4) SERI Test Cell	•					
(5) SERI Retrofit				•		
(6) Trinity		•				
(7) NMSU		•				
(8) U of A		•				
(9) FSEC (Reconfigurable)		•				

The passive heating test facilities are

(1) NBS Passive Test Facility, Gaithersburg, Maryland;

(2) Lo-Cal House, Small Homes Council, University of Illinois, Champaign, Illinois;

(3) REPEAT Facility, Colorado State University (CSU), Ft. Collins, Colorado;

(4) SERI Two-Zone Passive Test Cell, Golden, Colorado; and

(5) SERI Retrofit Test House, Golden, Colorado.

The passive cooling test facilities are

(1) Trinity Cooling Test Facility, Trinity University, San Antonio, Texas;

(2) New Mexico State University (NMSU) Roof Pond Test House, Las Cruces, New Mexico;

(3) University of Arizona (U of A) Passive Cooling Experimental Facility, Tucson, Arizona; and

(4) Florida Solar Energy Center (FSEC) Passive Cooling Laboratory, Cape Canaveral, Florida.

The heating facilities and the Trinity and FSEC cooling facilities will be used for full-program validation; all four cooling test facilities will be used for component/algorithm validation as well as for performance evaluation and component testing.

It is highly desirable that the full-program validation facilities cover the range of passive heating and cooling technologies. The summary in Table 2 shows that only a few more facilities need to be identified to attain complete coverage.

4. DEVELOPMENT OF VALIDATION METHODOLOGY

A proposed methodology for full-program validation [2] is the basis of the Class A validation methodology. It includes methods for analytical and empirical validation, and concentrates initially on the energy processes at the building envelope. The analytical tests involve the determination of closed-form analytical solutions of several simple cases for single-zone buildings [3].

In the empirical tests, modeling errors, input uncertainties, and user-effect uncertainties are addressed; the methodology initially concentrates on the first two of these. The approach is to compare predicted space air temperatures or auxiliary energy with values measured in the Class A test facilities. The test facilities have been selected to include a range of controlled conditions. The greatest control is obtained in the SERI Test Cell where ground coupling, infiltration, and internal gains essentially have been eliminated. These effects are included in the SERI Retrofit facility, the REPEAT facility, and the NBS facility. The Lo-Cal house is an occupied residence, which has been monitored in occupied and unoccupied modes. In this situation, the test is more realistic, but significant uncertainty exists for input parameters and the energy mechanisms cannot be isolated.

A series of standard, high-quality data sets, for continuous one- to two-week periods, is being developed at each site. Data are being archived for periods of floating and fixed space temperatures for at least a heating (or cooling) and swing season.

TABLE 2

FULL-PROGRAM VALIDATION TEST FACILITIES
SUMMARY OF TECHNOLOGIES INCLUDED

	Heating					Cooling						Lighting
	Direct Gain (High Mass)	Direct Gain (Low Mass)	Thermal Storage Wall	Thermal Storage Roof	Sunspace	Ventilative	Evaporative	Radiative	Ground Coupling	High Mass	Dessicant	Daylighting
(1) NBS	•		•									
(2) Lo-Cal		•										
(3) REPEAT	•	•	•		•							
(4) SERI Test Cell	•											
(5) SERI Retrofit	•	•										
(6) Trinity							•	•				
(7) NMSU			•				•	•				
(8) U of A						•	•		•	•		
(9) FSEC						•	•	•		•		

4.1 Testing of the Methodology

The analytical tests have been checked for appropriateness by being applied to three building energy analysis computer programs [3]. The quality of the empirical data coming from the Class A test facilities is being assured by testing them against simulations using five building energy analysis computer programs: DOE-2, BLAST, DEROB, SUNCAT and TRNSYS. In this manner, problems with the data sets are being resolved and additional data needs are being identified.

4.2 Quantitative Definition of Validation

The purpose of the quantitative definition of validation is to provide an objective basis for evaluating passive solar simulation programs in terms of their accuracy as analysis/design tools. Although the quantitative definition may reveal the presence of errors in a simulation model, our primary purpose is not to provide a debugging procedure, but to quantify predictive capability.

The procedure will employ Monte Carlo methods to quantify the uncertainty in output performance variables resulting from input parameter uncertainty and possible systematic errors introduced by the modeling procedure. There are four basic steps in our method:

(1) Test building characterization,

(2) Performance monitoring of the test building,

(3) Simulation of test building performance,

(4) Comparisons of predicted and measured performance variables.

The test building should be unoccupied and extremely well characterized. Each descriptive parameter should be carefully measured and estimates of the random uncertainty associated with the measurement obtained. The descriptive parameters of interest include all physical properties, dimensions, and other characteristics input to simulation models. The random variations of measured input quantities are assumed to be normally distributed. Each input parameter is characterized by its mean value and its standard deviation, σ; one can expect 95% of the measured values to lie within limits of $\pm 2\sigma$.

The performance of the test building should be monitored for a period of about two weeks. Estimates of the random variations in the measurement of all initial conditions, weather variables, and performance variables are obtained as described above. The performance variables of primary interest are the space temperature and auxiliary energy use.

Next, simulations are performed on the test building using input parameters randomly selected from the normal distributions obtained in steps (1) and (2). This set of performance calculations yields corresponding sets of output variables. If N performance calculations are performed, a set of N normally distributed values will be obtained for each performance variable at each hour during the test period.

The final step in the procedure is to compare the calculated values of the performance variable (actually a distribution of the output variable) with the measured values. This can be done in terms of the error observed in a selected performance variable, say the heating power, P, that is a measure of the auxiliary energy use. The fractional error in P is defined as

$$P^* = \frac{PM - PC}{PM} \tag{1}$$

where PM is the power measured at a particular hour, PC is the calculated power at the same hour and $\overline{PM}$ is the average measured heating power for the full test period. A set of N values of P* can be obtained for each hour of the test period.

$$P_n^* = \frac{PM_n - PC_n}{\overline{PM}} \quad , \; n = 1,2, \ldots N \qquad (2)$$

Now, if we combine all hourly sets of N fractional heating power errors, we have a family of N•H values where H is the number of hours in the test period:

$$P_{nh}^* = \frac{PM_{nh} - PC_{nh}}{\overline{PM}} \quad , \; n = 1,2, \ldots N \quad h = 1,2, \ldots H \qquad (3)$$

The estimated mean value of this distribution at a particular hour, h, is given by

$$\bar{P}_h^* = \frac{\sum_{n=1}^{N} P_{nh}}{N} \quad . \qquad (4)$$

The accuracy of this estimate depends on the value of $(\sigma_h)_m$, the standard error of the hourly mean. The quantity $(\sigma_h)_m$ is related to σ_h, the standard deviation of the relative error at hour h, as follows:

$$(\sigma_h)_m = \frac{\sigma_h}{\sqrt{N}} \quad . \qquad (5)$$

Thus, we see that one must perform 16 simulations to obtain a standard error for the hourly mean that is one fourth the standard deviation of the hourly distribution. An estimate of the deviation of the hourly distribution is given by

$$\sigma_h = \left[\frac{1}{N-1} \sum_{n=1}^{N} \left(P_{nh}^* - \bar{P}_n^*\right)^2\right]^{1/2} \quad . \qquad (6)$$

Now, the most probable value of the mean fractional error over the entire test period is obtained from the weighted average of the hourly mean values as follows

$$\bar{P}^* = \frac{\sum_{h=1}^{H} \bar{P}_h^* / (\sigma_h)_m^2}{\sum_{h=1}^{H} 1/(\sigma_h)_m^2} \quad . \qquad (7)$$

The quantity $\bar{P}^*$ is a measure of the systematic error present in a simulation model. The systematic error could caused by systematic errors in the input parameters, but careful measurement techniques should all but eliminate this source. More likely, it is the result of the inevitable approximations made in modeling complex physical phenomena. Random variations in the fractional heating power are caused entirely by random variations in the input parameters.

5. COLLECTION AND ANALYSIS OF TEST DATA

5.1 Full-Program Validation Data

Experimental data have been collected from two (NBS and Lo-Cal) of the five heating test facilities listed in Sec. 3.2 above. These data are preliminary because they were taken during shakedown of the two facilities involved. Nonetheless, they have been carefully analyzed and are representative of typical Class A data sets that will be archived. Additional sets of data have been taken at these facilities, but they have not yet been analyzed. Data have also been taken at both of the SERI facilities, but tapes of reduced data have not been produced. The data acquisition system is being installed in the REPEAT test facility; data taking will begin in the fall 1982. Extensive data have been taken at the Trinity University facility and preliminary data have been taken at the FSEC Passive Cooling Laboratory. However, these data have not yet been analyzed.

A data tape from the NBS test facility for a 25-day period in October 1981, has been analyzed. The data are from the 330 ft^2 slab-on-grade direct-gain test cell that is at the eastern end of the facility; the cell temperature was allowed to float during this period. Solar gain is provided by south-facing patio door units and a clerestory window. (The clerestory was blocked off for this test run.) Thermal mass is contained in the floor slab and an 8-in.-thick solid core concrete block wall on the north wall. Because the on-site weather station was damaged by lightning, the data tape contains weather data taken from different sites at NBS.

Measured space air temperatures from the cell were compared to DOE-2 predicted data (Fig. 2) as a means of identifying problems with the data and to test its usability for validation. Infiltration was measured hourly using a tracer-gas monitor. The agreement between the DOE-2 predictions and the measured test-cell air temperatures is quite good on clear days; however, the agreement is not as good on days with low insolation. Careful analysis revealed that the low intensity solar radiation measurements are not reliable. Therefore, measurement of the fall-period data at NBS is

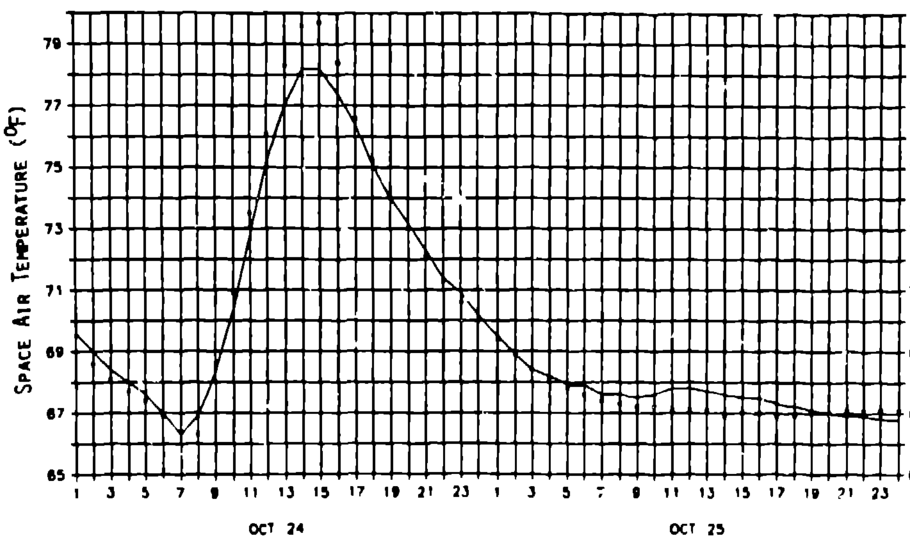

Fig. 2. Measured and predicted space air temperatures for the October 1981 NBS direct-gain test cell data.

expected to be repeated in 1982. Also, most of the material property data used in the DOE-2 input were taken from tabulated values. However, core samples are being taken of the floor slab and soil property measurements are being made; these measured values will be used in subsequent runs.

A data tape for a two-day period during September 1981 at the Lo-Cal House has also been analyzed. These data are from the 1700 ft^2, single-family residence. The sun-tempered house uses moderate south glazing for direct gain, but contains no extra thermal mass.

5.2 Documentation of Data Sets

Site handbooks have been prepared for the NBS and Lo-Cal facilities. These contain a detailed description of construction, instrumentation, and material properties.

5.3 Component/Algorithm Validation

The four cooling test facilities listed in Sec. 3.2 will primarily be used for component and algorithm validation. These will be supplemented by other test facilities already in existence or to be built later. Data have been taken at all four sites, but have not yet been analyzed for inclusion in the Class A validation data base.

6. CONCLUSIONS

Through our Class A progress to date, we have concluded the following.

(1) The data needs for detailed validation of hour-by-hour passive analysis/design tools are fairly well characterized,

(2) A comprehensive program and management structure has been developed for this validation effort, and

(3) Although considerable progress has been made, continuation of this program for at least three more years is necessary.

7. ACKNOWLEDGEMENTS

The assistance of M. A. Roschke in reading the data tapes and developing output graphics is gratefully acknowledged.

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