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VALIDATION OF SOLAR SYSTEM SIMULATION CODES BY THE INTERNATIONAL ENERGY AGENCY*

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ABSTRACT

Validation of active solar energy system simulation codes by the International Energy Agency using data from the Los Alamos Study Center is described. Two rounds of comparisons of predicted to measured performance were completed. In the first round, all participants were given detailed system description data and a period of measured hourly weather and loads data with the corresponding measured hourly performance data. In the second round, the participants were given minor changes to the system description and a second period of measured weather and loads data without the corresponding measured hourly performance. In the first round, each of the participants was able to predict the results provided. However, this required an undocumented series of adjustments to the user input and the models and comparisons of measured and predicted results. Agreement of measured and predicted results were nearly as good in the second round except for two codes that predicted significantly erroneous results. As a result of this exercise, errors and shortcomings have been found and corrected in most of the codes and confidence in the ability of all codes to model real systems has been increased. However, the questions of a workable methodology for validation and the issues of dealing with user error remain unresolved.

INTRODUCTION

The International Energy Agency (IEA) Task 1 group on solar system testing and simulation has conducted a series of performance predictions of several active solar system simulation codes to each other and to a carefully monitored experiment. Each code has been run by the representative from the IEA participating country where the code was developed, and, in most cases, was personally involved in developing the code. The codes and the corresponding countries were:

BLAST	Belgium
TRNSYS	Denmark
Philips	Germany
ESP	Great Britain
FCP	Italy
Nikken	Japan
LASL	USA
TRNSYS	USA

In the first phase of the validation, representative residential liquid and air-based systems were defined in detail with the cooperation of all participants. A tape of year-long hourly weather data for three very different climates with space heating loads pre-calculated by DOE2 was distributed to each participant. In the first series of comparisons, several problems and discrepancies were encountered. The most significant of these was caused by the differences in the radiation tilting algorithms employed by the various codes. For subsequent runs of the comparison, the group agreed upon a common mode of calculating radiation on tilted surfaces. As the participants iteratively ran their simulations and compared results, nearly all of the original discrepancies disappeared. In the process, a variety of user input and modeling errors, oversimplifications and other shortcomings were identified in each of the codes. In the end, all codes predicted the new round "present solar" to within ±2 percent and nearly identical monthly profiles of energy collected, auxiliary energy and tank temperatures. These results are fully documented in a report published by the IEA[1].

The second phase of the validation involves comparisons on real systems. The Los Alamos Study Center was selected as the first system on which to do simulation code validation. This paper presents the results of this second phase.

The [illegible] were selected in three solar zones, two months, two and half periods of winter time measured hourly weather, degree-day and loads data. In the first round, hourly measured performance data was included with the meteorological and load forecasting functions supplied to the participants. A [illegible] of the system was provided[2]. In the second round, the system description data was [illegible], and a [illegible] period of forecast [illegible] was distributed without any of the [illegible] data.

*This work performed under the auspices of the U.S. Department of Energy, Office of Solar Applications.

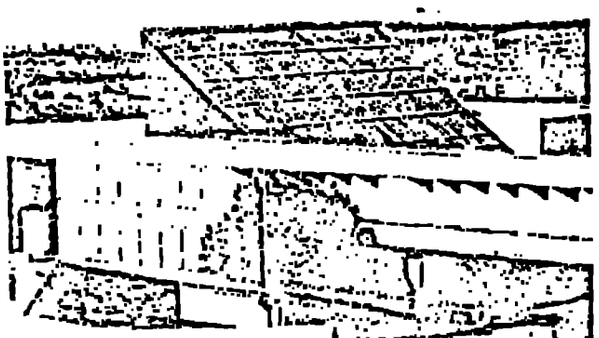

Figure 1. LASL Study Center

A photograph of the Study Center is shown in Figure 1. The 716 m^2 collector is in one planar array tilted 35° from the horizontal. The photo shows how shading occurs from the building on the east and the concourse to the west of the collector. A schematic of the system in Figure 2 shows the solar system for heating and cooling and the HVAC system. The present study involves only the heating supply system which includes the solar collector, heat exchanger, the large vertical storage tank, the steam auxiliary heat exchanger, and the associated piping.

A schematic of the collector is shown in Figure 3. The collector has a black chrome selective surface and is single glazed with water-white glass. The collector fluid is paraffinic oil, which is circulated through a tube and shell heat exchanger. Water is circulated through the tube side of the heat exchanger and then into a 71.6 m^3 (10,000 gallon) steel tank. Water from the tank is circulated to 33 terminal boxes with reheat coils throughout the 3200 m^2 (40,000 ft^2) building. Each terminal box has its own thermostat. When the storage tank temperature is inadequate to heat the building, the water is circulated through an auxiliary steam heat exchanger.

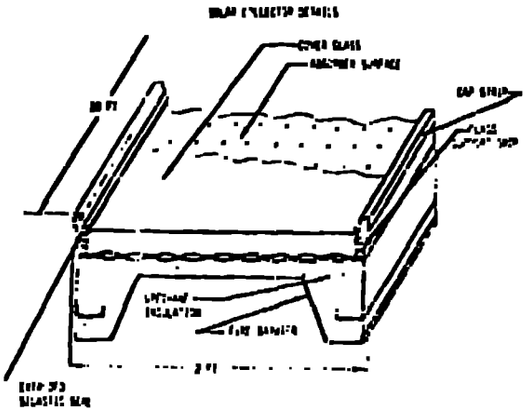

Figure 3. Collector Schematic

EXPERIMENTATION

Collector

The participants were provided with all the physical parameters that were known for the collector. These included collector area, absorber properties, glazing properties, fluid heat transfer coefficient, back side and end heat loss coefficients, collector tilt, and shade factors from the adjacent structures. A measured efficiency curve obtained from the LASL Collector Testing Laboratory was also available. Collector manifold piping dimensions were specified along with their tilt and heat loss coefficients. Physical properties and flow rates of the paraffinic oil used in the collector loop were given.

Heat Exchanger

The heat exchanger model, tube number, tube diameter, surface area, and tilt were also available. A correlation of the heat exchanger heat transfer coefficient which was derived from manufacturer data was provided.

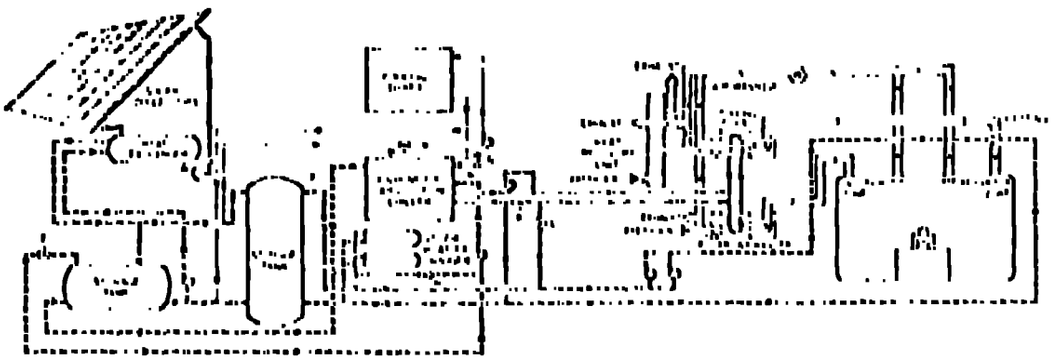

Figure 2. Schematic of Study Center Mechanical System

Storage Tank

The size, volume, and surface area of the tank was given. The heat loss coefficient of the tank insulation was suggested. Because the apparent tank heat loss was much larger than the tank coefficient would predict for the first data period, an increase by a factor of four was suggested. The losses were more in line with expectations for the second period so the use of the normal tank coefficient was recommended.

A daily measured tank heat loss determined by a heat balance on the tank (taking into account the change in energy stored in the tank) is shown in Figure 4. Although the scatter in the data is large (because of the difference between two large numbers and because there are only four temperature measurements in the tank) the difference between the two periods is evident. The reason for this difference is unknown, but could be due to changes in instrumentation or possibly, thermocirculation in the piping. The domestic hot water system (which was not operating during the second period due to a failure in the flow meter) could also be a factor.

Specifications of the tank inlet and outlet piping were given.

Auxiliary

The Study Center switches to auxiliary heat from steam heat exchangers whenever the storage tank drops below a setpoint. This setpoint is a function of outside temperature. The functional relationship was determined from the data and provided to the participants. The controller has hysterisis and is not perfectly repeatable, sometimes causing different auxiliary operation than the provided function would predict.

Collector Controller

The on and off differential settings between the collector absorber temperature and the storage temperature were given.

DATA INFORMATION

The Study Center is monitored with a [illegible] computer and a [illegible] Data Acquisition System. Data has been acquired on the system since November 1977, and has been reported in (4) and (5).

First Period

The first set of data provided to the IEA participants

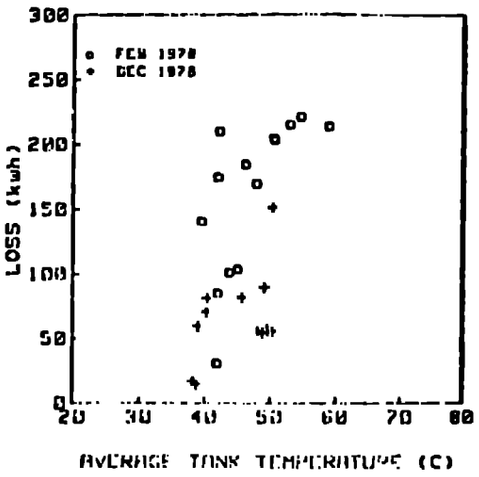

Figure 4. Daily Measured Tank Loss (By Energy Balance)

was the period from February 1-14, 1978. These data were supplied in August 1978, and the results of the simulation were reported at the IEA Task I meeting held in Palermo in December 1978.

The weather data consisted of hourly averages of horizontal insolation, solar radiation on the collector plane, ambient temperature, wind velocity and direction, building heating load and domestic hot water load.

The participants were also provided with measured results so they could make their own comparisons and do a certain amount of fine tuning to achieve the known result. These data included the hourly averaged collector heat output, heat exchanger output, tank energy input, tank energy output, auxiliary heat and the average tank temperature.

Second Period

For the second round of comparisons a second two-week period of data was distributed at this time without the measured results. The period selected was December 16-31, 1978. It included an initial cloudy two day period followed by eight sunny days ending with four more cloudy days. It was cold during this period, and the building loads were high.

The weather data were provided to the participants in January 1979, the hourly results were due back at [illegible], detailed comparison in April 1979, and the comparisons were presented the next IEA Task I meeting in Tokyo in May 1979.

TABLE I

TWO WEEK ENERGY COMPARISON
February 1-14, 1978

	QINC	QOUT	QIN	QLOSS	QOUT	QAUX	QLOAD	QDHW	% SOLAR
DATA	46509	14537	-	-	11843	9582	17274	333	49.4
USA (TAMSYS)	46509	14750 (1.5)	14750	2330	12420 (4.87)	9277 (-1.95)	17274	333	70.0 (0.6)
[illegible]	46509	15193 (4.57)	15193	3001	12192 (2.93)	9245 (-2.59)	17274	333	70.2 (0.8)
GREAT BRITAIN	46509	13437 (-7.73)	12951	810	12141 (2.52)	9278 (-2.23)	17274	333	73.6 (1.0)
USA ([illegible])	46509	14548 (-.14)	14446	1347	12543 (4.57)	9278 (-2.23)	17274	333	70.6 (1.0)
[illegible]	46509	13719 -5.76	13911	443	12509 (5.42)	9547 (-4.77)	17274	333	71.3 (1.9)

Energy units: kWh
( ) Per cent deviation from measured

RESULTS

First Period

The results from this first period were obtained and compiled by the various participants at the Palermo meeting. In most cases detailed hourly or daily results were not available for direct comparison. The two-week summary of results is presented in Table I. The parameters in the table are defined below.

QINC	Incident solar on the collector plane
QOUT	Collector output
QIN	Storage input
QLOSS	Storage losses
QOUT	Storage output
QAUX	Auxiliary
QLOAD	Building space heating load
QDHW	Domestic hot water load
% SOLAR	Percent solar, [100%(QLOAD - QAUX)/QLOAD]

The measured results are labeled DATA on the first line of the table. The percent deviation of the calculation from the measured parameter is given below each calculated value in parenthesis. The participants are listed from low to high percent solar.

In this period, all simulations were able to predict within 1.9 percentage points of the overall measured percent solar value of 49.4 percent. The collector efficiency for this period is 31.4 percent. The calculated values deviated as much as 2.5 percentage points low from this value (or 7.7 percent low on a relative basis). Many of the simulations also experienced significant errors in the storage loss coefficient as evidenced by the wide range of calculated storage losses. This parameter, of course, was not well defined, as mentioned previously.

TABLE II

TWO WEEK ENERGY COMPARISON
December 18-31, 1978

	QINC	QOUT	QIN	QLOSS	QOUT	QAUX	QLOAD	QDHW	% SOLAR
DATA	44792	15137	14901	-	14737	10877	24717	0	56.2
GREAT BRITAIN	44793	12882 (-14.9)	12456 (-16.41)	56	12423 (-12.73)	12436 (15.47)	24717	0	49.4 (-6.8)
JAPAN	44793	14293 (-5.57)	14089 (-5.45)	375	13593 (-4.33)	11362 (4.99)	24717	0	54.0 (-2.2)
BELGIUM	44793	13364 (-9.1)	13061 (-9.44)	380	12536 (-6.54)	11942 (4.06)	24717	0	54.6 (-1.6)
USA (TAMSYS)	44793	14773 (-2.41)	14351 (-3.69)	352	14215 (-.13)	10948 (1.53)	24717	0	55.5 (-.7)
USA (LASL)	44792	14786 (-2.32)	14416 (-1.18)	396	14283 (.32)	10727 (-1.07)	24717	0	56.7 (.5)
DENMARK	42463	16652 (10.01)	16412 (11.73)	615	14781 (14.34)	8436 (-22.1)	24717	0	65.9 (9.7)

Energy units: kWh
( ) Per cent deviation from measured

Second Period

The two-week results for the second period are given in Table II. Four of the simulators predicted within 2.2 percentage points of the measured percent solar value of 56.2 percent, which was nearly as accurate as in the first period analysis. However, the participants from Great Britain predicted 49.4 percent solar or 5.8 points low, and the Danish participants predicted 65.9 percent or 9.7 points high. The exact reason for their deviations at this time is unknown but probably is due to user error since agreement in the first round, and in previous IEA comparison exercises, was much better.

The measured collector efficiency for the second period was 33.7 percent and the same four simulations predicted within 1.8 percentage points of this value (or 5.6 percent on an absolute basis). The British calculation was 15 percent low on collector output, and the Danish calculation was 10 percent high, both of which are consistent with the discrepancies of the overall simulation results.

Since the participants did not have a measured result for comparison, DATA had suggested that the given tank insulation coefficient. All simulations predicted approximately the same tank heat loss except the British, who were low by a factor of 10. This is probably due to an error in computing units but is certainly user error of a kind.

The bar graph in Figure 3 shows the dispersion variations of measured and calculated daily storage input energy. On a daily basis, the deviations were in good agreement except for Great Britain and Japan, both of which were consistently low, and Denmark, which was consistently high. The daily variations of energy [illegible] the overall [illegible] the storage input energy [illegible].

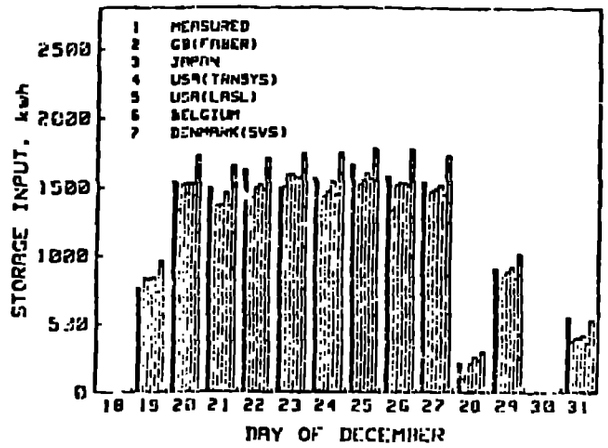

Figure 5. Comparison of Daily Storage Input Energy

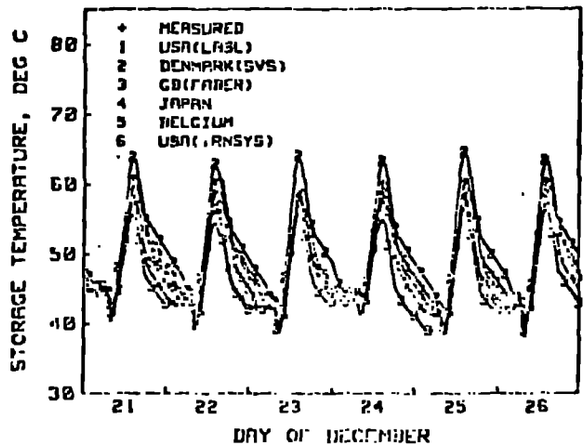

Figure 7. Six Day Plots of Hourly Storage Temperatures

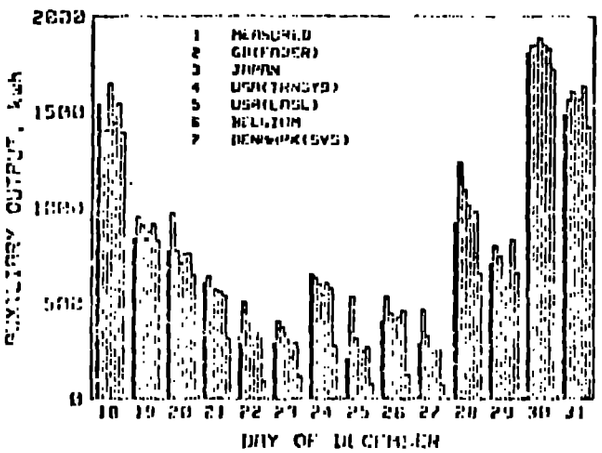

Figure 6. Comparison of Daily Auxiliary Requirements

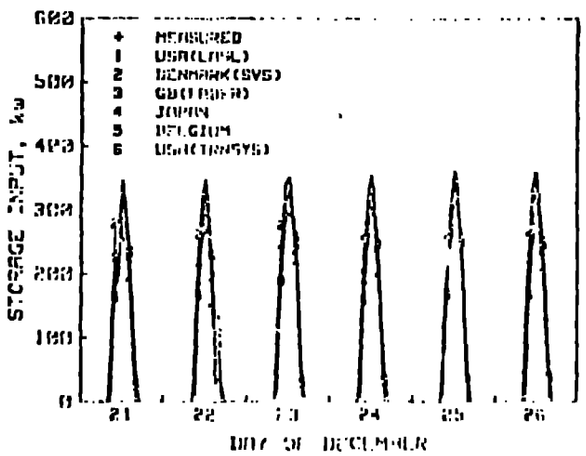

Figure 8. Six Day Plots of Hourly Storage Input Energy

The statistical deviations between daily calculated quantities and measured quantities are given in Table III. Four of the simulations were within 10 percent of all energy quantities, while two of them were outside this band.

TABLE III

DAILY STATISTICAL ANALYSIS
DECEMBER 1-31, 197[illegible]

	[illegible] %	[illegible] %	[illegible] %	[illegible] %	[illegible] %
[illegible]	17.5	11.2	17.8	21.5	6.3
[illegible]	9.2	9.2	9.5	11.9	4.6
[illegible]	7.1	8.4	8.5	9.1	3.5
[illegible]	[illegible]	[illegible]	4.7	8.3	2.5
[illegible]	5.9	5.5	5.1	6.5	2.0
[illegible]	[illegible]	15.6	17.0	20.7	4.7

Hourly plots of average storage temperature and storage input energy are shown in Figures 7 and 8 for the six day period from December 21, 197[illegible]. The Danish and Japanese participants are seen to be very effective. Phase shifts between various predictions do not seem to be a particular problem.

CONCLUSIONS

It has been shown that all the programs involved in this study are capable of predicting the overall performance of a solar heating system with high degree of accuracy [illegible] of the order of 10%.

This software-hardware, and previous IEA software-software, comparisons have shown that the potential for user error is large in the preparation of input for any of the codes involved in the comparisons. In practice the effects of user error contribute much more uncertainty to results than any remaining errors or differences in the modeling approaches or algorithms. No hard data is available on the extent of iterative input adjustment in the first round of this exercise but it is the experience of the authors that three or four iterations are typically required before results are obtained that are within the error tolerance capability of the codes. It must be recognized that a "typical" user is likely to make far more mistakes than the "experts" who ran each of the codes in this study.

A second point is that the two-round comparison methodology allows users to infer the values of some key parameters in the first round simulation (sometimes called the "training" period) rather than calculate them from information normally available to a user. Data arrived at in this empirical way may mask one or more important effects not properly accounted for in the model. The inference of the tank loss coefficient in this exercise is an example of this problem. The apparent losses from the measured data were much higher than expected, possibly due to thermosyphoning or some other unmodeled phenomena. The range of tank losses predicted by the codes in the first round shows that most participants used the tank loss coefficient parameter to adjust their results. Thus not only was the actual cause of the unexpectedly high losses falsely attributed, but other modeling inaccuracies or user errors were compensated for in the tank loss coefficient.

A final problem relates to the lack of sufficient code output data to completely identify the sources of differences. In a "system" simulation, the performance of all "components" is interrelated such that an error in one component creates disagreement between measured and predicted results in all components. Either "stand-alone" component tests are required or more short term data must be measured in the experiment and output by the codes for comparison. As an example, hourly measured and simulated collector input and output data could be plotted in the efficiency vs. $\Delta T/I$ format to validate the collector "component" in this "system" test.

In summary, this validation exercise, and others like it, are valuable for locating and correcting significant modeling errors and lack of modeling capability. They are not appropriate, however, for defining the error bounds on the codes. Dealing with inevitable user error in a validation methodology is a tricky problem but the idea of eliminating its effects with a preliminary "training round" of comparisons has serious shortcomings.

The IEA has provided a valuable forum for comparing and improving the consistency of solar simulation codes used throughout the world. The LASL Study Center has been established as an appropriate system for performing code comparisons and the consistency and quality of the performance data has been established for future validation efforts.

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The second phase of the validation was to make comparisons on real systems. The Los Alamos Study Center was selected as the first system on which to do simulation code validations. This paper presents the results of this second phase.

Two separate rounds of comparison were undertaken in this exercise using two separate, two-week-long periods of winter time measured hourly meteorological and loads data. In the first round, hourly measured performance data was included with the meteorological and load forcing functions supplied to the participants. A detailed description of the system was provided[2]. In the second round, the system description data was changed slightly[3] and a two week period of forcing function data from another month was distributed without any of the measured performance data.

*This work performed under the auspices of the U.S. Department of Energy, Office of Solar Applications.