CONF-781024--4

LA-UR - 78-1494

TITLE: A COMPONENT-BASED SIMULATOR FOR SOLAR SYSTEMS

AUTHOR(S): M. A. Roschke, B. D. Hunn, S. C. Diamond

SUBMITTED TO: Proceedings of the Systems Simulation and Economic Analysis for Solar Heating and Cooling Conference to be held in San Diego, California, June 27-29, 1978.

los alamos scientific laboratory
of the University of California
LOS ALAMOS, NEW MEXICO 87544

MASTER

Form No. 836
St. No. 2629
1/75

UNITED STATES
ENERGY RESEARCH AND
DEVELOPMENT ADMINISTRATION
CONTRACT W-7405-ENG. 36

A COMPONENT-BASED SIMULATOR FOR SOLAR SYSTEMS

M. A. Roschke
B. D. Hunn
S. C. Diamond

Los Alamos Scientific Laboratory
Los Alamos, NM 87545

INTRODUCTION

Many computer programs for solar system simulation have been developed to aid in the research on and design of such systems. All but a few of these programs fall into one of two categories: (1) month-by-month simulators, primarily used in design, and (2) hour-by-hour simulators, primarily used for detailed systems analysis and for development of simplified design methods. Until now, all of the programs in the latter category have had deficiencies in several areas.

Because of these deficiencies, the Component Based Simulator (CBS) computer program was recently developed at the Los Alamos Scientific Laboratory (LASL). The design philosophy that guided CBS development included strong emphasis on the following criteria. The program should have an execution speed great enough to make many parametric runs feasible. It should have the flexibility to be used as both a design and a research tool. The program should be highly user-oriented and have input and output schemes that are easy to use. It should be portable among many computer installations. Finally, the program should be not only an independent program, but also a module in a complete building energy analysis program package applicable to both residential and nonresidential buildings.

FEATURES OF THE CBS PROGRAM

The CBS program was designed as a module of the DOE-1 (formerly Cal-ERDA) building energy analysis program package [1]. As in TRNSYS [2], the solar simulator in widest use today, a component-based structure and methodology enable the CBS user to assemble a large number of systems while code redundancy is kept to a minimum. The present program can simulate active space heating and building service hot water systems, both liquid and air, as well as a solar-assisted heat pump. Available components include flat-plate collectors, heat exchangers, liquid and rock-bed storage units, differential controllers, and auxiliary heating controllers. Several insolation models are available for both measured and calculated radiation. In addition to the component-based capability, the program includes complete liquid and air space heating systems preconnected for user convenience. Passive solar and solar-driven absorption cooling systems will be added at a later date.

One of the more important user-oriented features is a powerful language processor that inputs the system description data. Aspects of the input language include free-formatting of input data, defaults for many input variables, and the scaling of input variables by other input variables. Also contained in the input language are error checking on the range of input values and diagnostic options, including the listing of input and default values and their units. Output options allow the user to select predefined reports or to define reports or plots according to special requirements. The program is simple enough to use as a design tool, yet flexible enough for use in research.

Typical run times for a yearly simulation (hourly time steps) are 15-45 central processor seconds on a CDC 6600. These execution speeds are normally 3 to 10 times faster than TRNSYS. The comparative run times largely depend on whether time steps of less than 1 h are used in TRNSYS for stability and convergence; CBS converges well at hourly time steps. The program is also highly portable; only character manipulation and plotting routines use nonstandard FORTRAN.

CBS is capable of executing as an independent simulator. In this mode, the user may either input precalculated loads or calculate loads using a simple degree-day loads component with schedules. When the program is used in conjunction with the DOE-1 building energy analysis program, many other powerful features are available, such as sophisticated transient load calculations, HVAC air-side distribution systems simulation, and economic analysis for commercial buildings.

Preliminary documentation of CBS is now available and more complete manuals will be available by late 1978.

CBS-TRNSYS COMPARISON

Several comparative test runs were made using TRNSYS [2]. Comparisons were made using identical systems and loads, nominal system parameters, and hourly weather data for three cities. Hourly results were compared for a test period of several days, and monthly sums were compared for a one-year test period.

The residential liquid space heating and domestic hot water system modeled by both programs is shown in Fig. 1. The CBS simulation was conducted by LASL, and the TRNSYS simulation was conducted by the University of Wisconsin [3]. Typical residential space heating loads were calculated using the

NBSLD program [4] and weather data for Madison, Wisconsin. The double-glazed, nonselective surface collector was oriented due south at a tilt angle of latitude +10°, had an area of 50 m^2, and a flow rate of 50 L/min. (The annual solar fraction was 68%.) The main storage tank capacity was 4005 L, and the domestic hot water preheat tank capacity was 350 L. Domestic hot water usage was 350 L/day at a delivery temperature of 50°C. The space heat delivery scheme included a liquid-to-air heating coil with a downstream auxiliary (boost) coil (Fig. 1).

Representative hourly results for a period in the spring (March 10-16, which included both clear and cloudy days) are presented in Fig. 2. The slight differences between the hourly results of the two programs are greatly diminished when monthly and annual solar fraction results, Fig. 3, are examined. Note that agreement is within 3.2% monthly solar fraction and within 0.8% solar fraction on an annual basis. These results indicate that CBS tracks TRNSYS within acceptable limits.

The system described above was also modeled using loads and weather data for Hamburg, Germany, and Santa Maria, California. Slightly different system sizes were used for these climates. In addition, a residential solar space heating and domestic hot water heating system using air collectors and rock-bed storage was modeled by both programs using the Madison loads and weather data. The results obtained for these additional systems were very similar, both in trends shown and relative differences, to those for the system in Fig. 1.

SAMPLE RUN

To illustrate some of the features of CBS, a simple liquid residential space heating system (Fig. 1 without domestic hot water) was simulated.

A computer output listing, showing an input echo and monthly simulation results, is shown in Fig. 4. The input echo shows that the language structure consists mainly of commands (such as RUN-PERIOD, SYSTEM, and COMPONENT) and of keywords (such as LATITUDE and LONGITUDE) to which values are assigned. For clarity, the commands begin in column one and the keywords begin in column seven of the input cards. However, the input is essentially free-format. For example, all three lines of data for the AUX-CNTRL component could have been compressed into one line. The option to list the default values used was chosen; but to simplify the example, the option to echo input values and their units was not selected. Input card images are shown with sequence numbers and with interspersed default messages. The preconnected system was chosen here to simplify the example; in general, the user may connect various components to assemble a complete system.

The DATA-READER component reads loads and weather data from card images on TAPE 19, while the INSOLATION component converts total horizontal insolation values, read by the data reader, to tilted surface incident values. In the SUBSYSTEM component, a collector, a liquid storage tank, an intermediate heat exchanger, collector-to-exchanger and exchanger-to-tank pumps, and a pump controller are preconnected together. Finally, the AUX-CNTRL component models the combination of solar and auxiliary energy to satisfy the space heating load.

The report following the input data summarizes the monthly results of system performance. Although the report shown here is a standard report, the user may also define the contents of his own report. This includes the selection of titles, headings, report variables, number of decimal places, report period, data output frequency, and column function (maximum, minimum, average, sum, etc.). User-defined plots may also be generated.

CONCLUSIONS

The recently developed hourly solar system simulator, CBS, is a highly effective, user-oriented analysis and design tool. It is flexible, easy-to-use, and fast, yet maintains accuracy in comparison to TRNSYS, the current standard in hourly solar simulators. It features both standard, preconnected systems and user-configured systems. Extensive initial testing has shown CBS results to be stable and to be accurate by comparison with TRNSYS.

CBS appears superior to other available public domain solar system simulation programs that use hourly or subhourly time steps and should become widely used.

REFERENCES

1. R. M. Graven and P. R. Hirsch, "Cal-ERDA Users Manual, Version 1.3," Argonne National Laboratory, Argonne, Illinois, 1977, ANL/ENG-77-03.

2. S. A. Klein, P. I. Cooper, T. L. Freeman, D. M. Beckman, W. A. Beckman, and J. A. Duffie, "A Method of Simulation of Solar Processes and Its Application," Solar Energy, V. 17, pp. 29-37, 1975.

3. T. L. Freeman, S. A. Klein, and M. W. Maybaum, "A Comparison of Four Solar System Simulation Programs in Solving a Solar Heating Problem," to be presented at the Conference for Systems Simulation and Economic Analysis for Solar Heating and Cooling, San Diego, California, 1978.

4. T. Kusuda, "NBSLD, Computer Program for Heating and Cooling Loads in Buildings," Center for Building Technology, National Bureau of Standards, NBSIR 74-574, 1974.

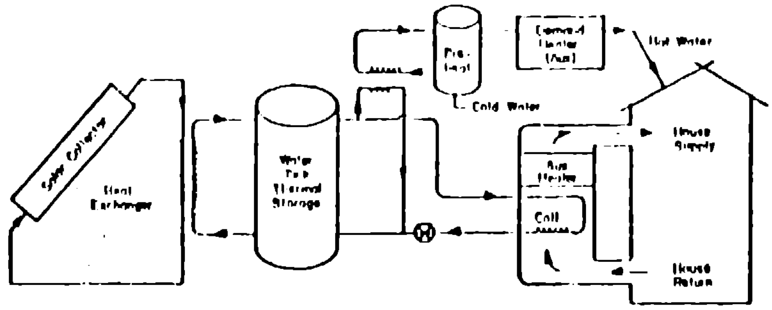

Fig. 1. Solar heating system schematic.

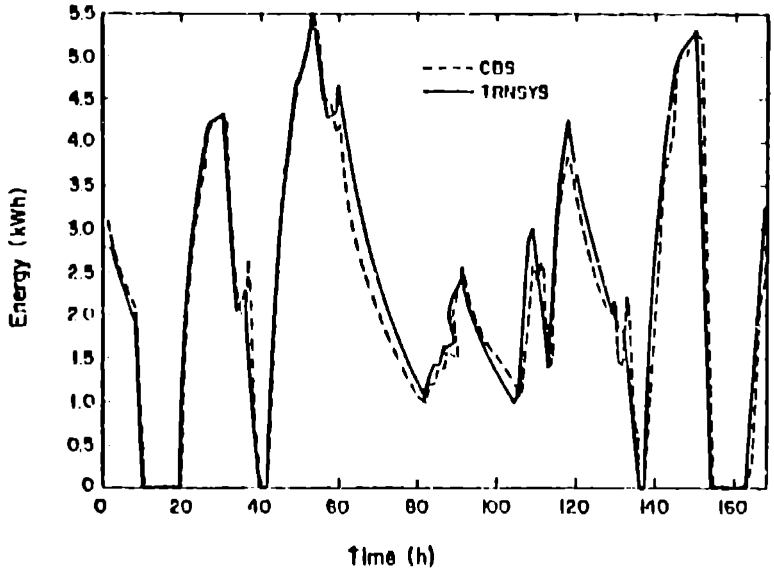

Fig. 2. CBS TRNSYS comparison hourly results, delivered solar energy.

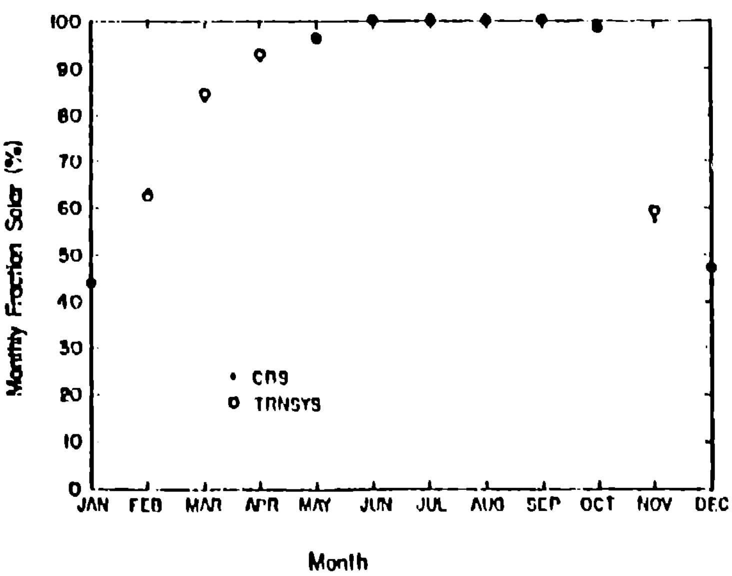

Fig. 3. CBS TRNSYS comparison monthly results.

```
                        S O L A R   P R O C E S S O R   I N P U T   D A T A

  *   1 *  LIST DEFAULTS ..
  *   2 *
  *   3 *  RUN-PERIOD JAN 1 THRU DEC 31 ..
  *   4 *
  *   5 *  SYSTEM
  *   6 *        TYPE = LIQ-SYSTEM-1 ..
  *   7 *
  *   8 *  COMPONENT
  *   9 *        TYPE = DATA-READER
  *  10 *        DATA-FILE = 19
  *  11 *        VARIABLES = 5 ..
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - FORMAT          = (8F10.0)
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - FORMAT          =
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - FORMAT          =
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - FORMAT          =
  *  12 *
  *  13 *  COMPONENT
  *  14 *        TYPE = INSOLATION
  *  15 *        LATITUDE = 41
  *  16 *        LONGITUDE = 89
  *  17 *        TIME-ZONE = 6
  *  18 *        TILT-COL = 53 ..
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - GROUND-REFL     =       .2000
  *  19 *
  *  20 *  COMPONENT
  *  21 *        TYPE = SUBSYSTEM
  *  22 *        DT-MIN = 0
  *  23 *        AREA-COL = 538.2
  *  24 *        FLOW-COL-XCH = 6604
  *  25 *        FLOW-TNK-XCH = 6604
  *  26 *        VOL-TNK = 141.2
  *  27 *        FPRIME = .95
  *  28 *        EFFECTIVENESS = .463
  *  29 *        LOSS-COEF-TNK = .074
  *  30 *        T-TNK-INITIAL = 86.
  *  31 *        T-ENV = 68. ..
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - SP-HT-COL-FLD   =      1.0000 BTU/LB-F
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - SP-HT-TNK-FLD   =      1.0000 BTU/LB-F
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - TRANS-ABS-PROD  =       .7000
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - LOSS-COEF-COL   =       .6500 BTU/HR-SQFT-F
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - T-BOIL          =    212.0000 F
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - DENS-TNK-FLD    =     62.4000 LB/CUFT
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - TNK-HT-DIA-RATIO =     3.0000
  *  32 *
  *  33 *  COMPONENT
  *  34 *        TYPE = AUX-CNTRL
  *  35 *        FLOW-LIQ = 1650
  *  36 *        FLOW-AIR = 3000 ..
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - SP-HT-AIR       =       .2450 BTU/LB-F
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - T-AIR           =     68.0000 F
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - SP-HT-LIQ       =      1.0000 BTU/LB-F
-DEFAULT - - - - - - - - - - - - - - - - - - - - - - - - - - - - - - EFFECTIVENESS   =       .8000
  *  37 *  END ..
```

S O L A R   P E R F O R M A N C E   S U M M A R Y

	TOTAL INCIDENT ENERGY (MILLION BTU)	TOTAL COLLECTED ENERGY (MILLION BTU)	TOTAL HEATING LOAD (MILLION BTU)	TOTAL SOLAR HEATING (MILLION BTU)	AVG STORAGE TEMP (F)	MAX STORAGE TEMP (F)	MIN STORAGE TEMP (F)	AVG COLLECTOR EFF (PERCENT)	AVG SYSTEM EFF (PERCENT)	AVG PART SOLAR (PERCENT)	AVG SOLAR BUILDING LOAD RATIO
JAN	17.161	6.120	12.283	5.802	84.1	120.8	68.1	35.7	33.8	47.2	1.40
FEB	19.269	6.758	9.995	6.845	95.6	138.7	69.7	35.1	35.5	68.5	1.93
MAR	25.164	7.587	7.571	6.801	123.4	183.1	69.8	30.2	27.0	89.8	3.32
APR	23.842	4.954	4.095	3.902	154.1	211.3	73.3	20.8	16.7	97.2	5.82
MAY	24.506	3.086	1.330	1.314	176.2	211.6	77.9	12.6	5.4	90.8	18.42
JUN	27.731	1.261	0.000	0.000	208.4	211.7	190.4	4.5	0.0	0.0	999.00
JUL	25.573	1.216	0.000	0.000	207.5	211.7	194.3	4.8	0.0	0.0	999.00
AUG	26.708	1.367	0.000	0.000	206.4	211.7	192.4	5.3	0.0	0.0	999.00
SEP	24.764	2.154	1.105	1.105	203.4	211.6	160.4	8.7	4.5	100.0	22.41
OCT	20.659	2.952	2.551	2.551	181.5	211.6	117.2	14.3	12.3	100.0	8.10
NOV	14.164	4.202	6.605	4.117	104.2	169.8	68.7	29.7	29.1	62.3	2.14
DEC	13.748	5.010	10.750	5.078	82.3	121.6	68.0	36.6	36.9	47.2	1.26
	263.290	46.687	56.284	37.595	152.6	211.7	68.0	17.7	14.3	66.0	4.60

Fig. 4. Sample output listing.