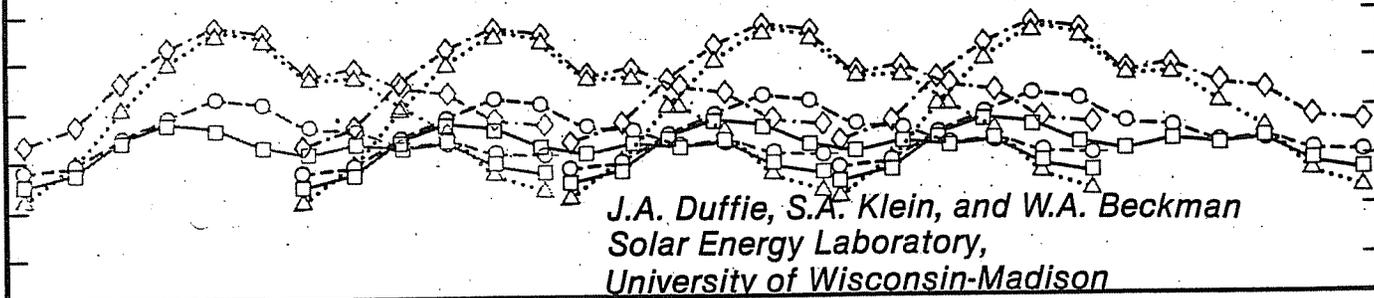


TRNSYS Evolution



J.A. Duffie, S.A. Klein, and W.A. Beckman
Solar Energy Laboratory,
University of Wisconsin-Madison

TRNSYS (TRaNsient SYStems Simulation Program) is widely used for analysis and modeling of both solar and non-solar transient thermal systems. Outlined here are some of the background leading to the development of the program, the ideas on which it is based, its use, its comparison to measurements of physical systems, and the directions of its current developments.

Solar-energy systems tend to be capital intensive—i.e., investments are made in equipment to save on future operating costs. Thus any economic analysis must be based on the expected delivery of solar energy and the resulting reduction in purchase of auxiliary energy. Means are needed to calculate the thermal performance of solar-energy systems and, conveniently of new and different systems before doing physical experiments. TRNSYS was developed to meet these needs.

Background

Solar-energy processes by nature are transient. They are driven by several weather variables with both regular and stochastic variations with time and by loads (energy needs) that can have arbitrary time dependencies. In addition, the equations that describe the processes are usually non-linear. Thus most problems are not amenable to analytical solution; computers offer opportunities to obtain numerical solutions through simulation.

Simulations and Their Uses

A simulation can be viewed as a “numerical experiment,” in as much as the physical system is “operated” in the computer, just as a physical experiment is operated in a laboratory. Simulations have the advantage that they can be done: quickly; repeatedly; with weather data representing various locations; and with changes in the system design without changing weather data.

Simulations are the calculations that precede physical experiments.

They are useful in exploring new and different systems, in assessing the effects of changes in design or weather, in studying system dynamics such as temperature swings and energy flow rates, and in estimating long-term performance of systems. Simulations can be used to develop design procedures such as the f-Chart method for solar-heating systems. They also are research and development tools, serving the design of unique systems.

Simulations are made for hour by hour or for shorter time intervals. The various parts of a system—collectors, windows, storage tanks or walls, fans, controllers, heat exchangers, etc.—are represented by equations. The equations can be based on first principles or on curve fits to experimental data; the choice is the user's. The equations are solved simultaneously, “driven” by historical weather data. Weather may also determine the energy loads that the system is to meet. These calculations yield the temperatures, energy streams, control functions, and other phenomena that occur in operating the system for the given history.

Our first efforts at simulating solar processes were with an analog computer.¹ Restricted capacity of the machine dictated modeling only simple water-heating systems and only for periods of a few days. But the effort made obvious that computers could be a powerful tool in studying these processes. In our next effort using a hybrid (analog + digital) computer, we studied the effects of

load distribution and auxiliary-energy addition point on the system.²

Increasing problem complexity led to our using all-digital computers. Our first major study was to simulate a solar-heating and air-conditioning system using a special-purpose program.³ Later, as a part of a cooperative program with Colorado State University, we undertook to consider adding to the model. But the program's author left. We then took months to rewrite his undocumented program and then extend it to include the model's addition. Thus was born the concept of a modular program to make such changes easy. All subsequent TRNSYS developments have used this concept.

TRNSYS

TRNSYS is a modular program designed for easy assembly of the sub-routines representing system components into a master program representing the system. The TRNSYS executive program handles the equation's solving and bookkeeping chores. A simulation summarizer outputs integrated energy quantities for solar energy collected or delivered to the load, auxiliary energy used, losses from storage, or other needed data.

TRNSYS was first placed in the public domain 1975. Since then the program has continued to evolve with improvements in component sub-routines and the executive program.

The first public version, Version 6, included a standard library of nine components. The standard library in

Table 1
List of Standard Components in the TRNSYS 12.2 Library

Utility Components

Data Reader
Time-Dependent Forcing Function
Algebraic Operator
Radiation Processor
Quantity Integrator
Psychrometrics
Load Profile Sequencer
Collector Array Shading
Weather Data Generator

Solar Collectors

Linear Thermal Efficiency Data
Detailed Performance Map
Single or Bi-Axial Incidence
Angle Modifier
Theoretical Flat-Plate
Theoretical CPC

Thermal Storage

Stratified Liquid Storage
(finite-difference)
Algebraic Tank (plug flow)
Rockbed

Equipment

On/Off Auxiliary Heater
Absorption Air Conditioner
Dual-Source Heat Pump
Conditioning Equipment
Cooling Coil
Cooling Tower
Chiller

Heat Exchangers

Heat Exchanger
Waste Heat Recovery

Utility Subroutines

Data Interpolation
First Order Differential Equations
View Factors
Matrix Inversion
Least Squares Curve Fitting

Building Loads and Structures

Energy/(Degree-Hour) House
Detailed Zone (transfer function)
Roof and Attic
Overhang and Wingwall Shading
Window
Thermal Storage Wall
Attached Sunspace
Multi-Zone Building

Hydronics

Pump/Fan
Flow Diverter/Mixing Valve/
Tee Piece
Pressure Relief Valve
Pipe

Controllers

Differential Controller with Hysterisis
Three-Stage Room Thermostat
Microprocessor Controller

Output

Printer
Plotter
Histogram Plotter
Simulation Summarizer
Economics

User-Contributed Components

PV/Thermal Collector
Storage Battery
Regulator/Inverter
Electrical Subsystem

Combined Subsystems

Liquid Collector-Storage
Air Collector Storage System
Domestic Hot Water
Thermosiphon Solar Water
Heater

Version 12.2, currently available, includes 60 components for both solar and non-solar processes (Table 1). The versatility and power of the program are enhanced by the fact that users can write their own component subroutines if those in the standard library are unsatisfactory or new or non-standard components are to be modeled.

Many of the component subroutines in the TRNSYS library have user-selectable options that the user selects based on the degree of detail needed. A flat-plate collector can be represented by any of six modes of use, ranging from specification of construction details to specifying ASHRAE 93 test parameters.

TRNSYS is expanding with the addition of components not usually associated with solar-energy systems. These include cooling towers, chillers, steam turbines, and other components of HVAC and cogeneration systems. A significant part of the use of the program is now in simulating processes such as large HVAC systems, which are transient but not solar-based.

Validation

Any "theoretical" calculation needs verifying that simulation results adequately represent reality. TRNSYS has several levels for comparing computed results and measurements to give confidence in the program.

First, many of the component subroutines have been well tested by component measurements. We have

confidence in most component formulations. However, the uncertainties can be significant for some components such as stratified water storage tanks where the physics is not well understood.

Second, detailed comparisons have been made of the measured performance of systems and simulation

results. For example, TRNSYS has been used for a very broad range of systems. Thus Morrison and Braun⁴ simulated thermosiphon water-heating systems and compared the simulations with measurements. The system was operated at the National Bureau of Standards and is shown in Fig. 1.

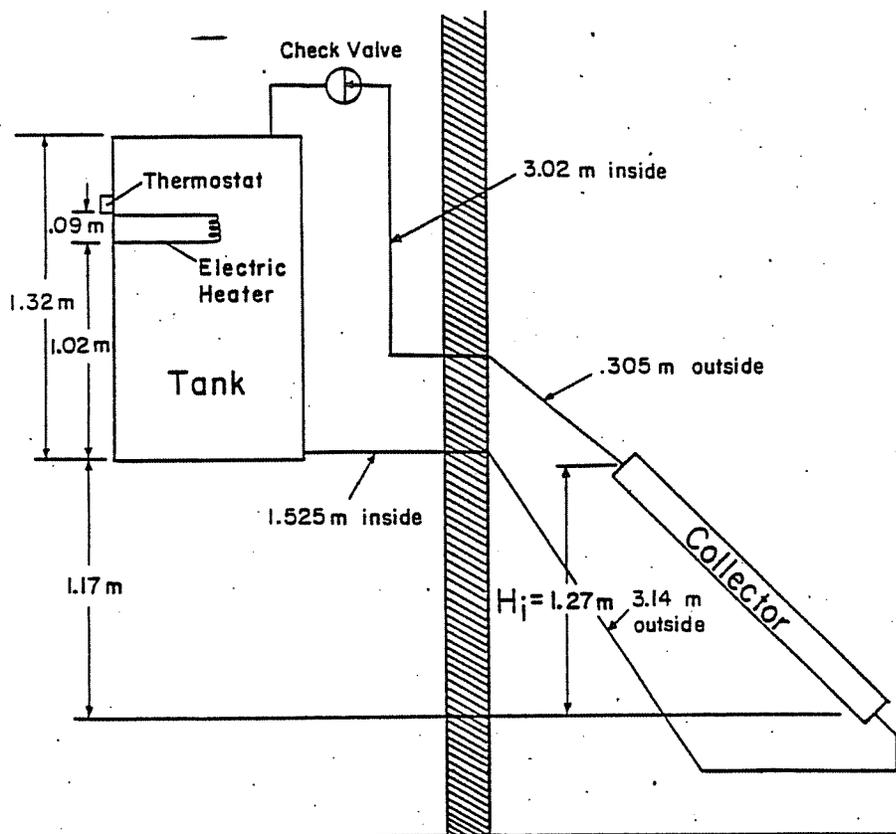


Fig. 1: Thermosiphon system tested at National Bureau of Standards, Gaithersburg, Maryland.⁴

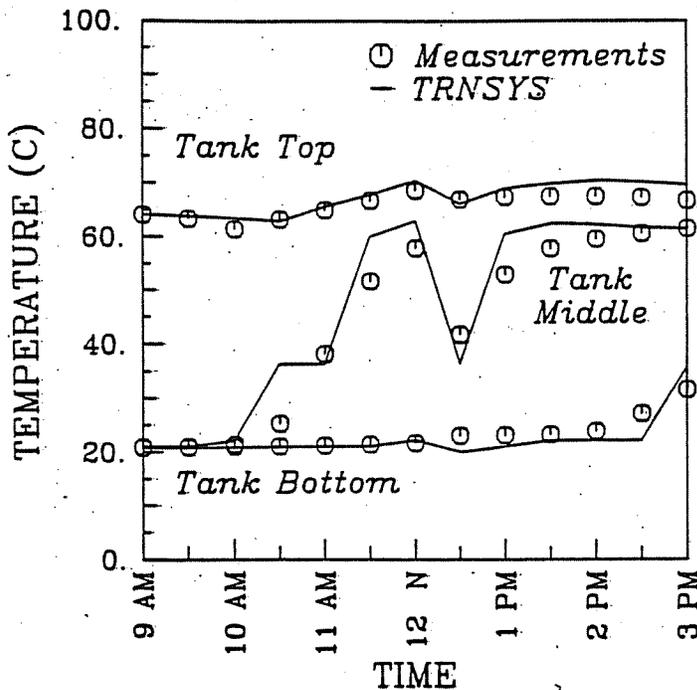


Fig. 2: Comparison of measured and predicted tank temperatures.⁴

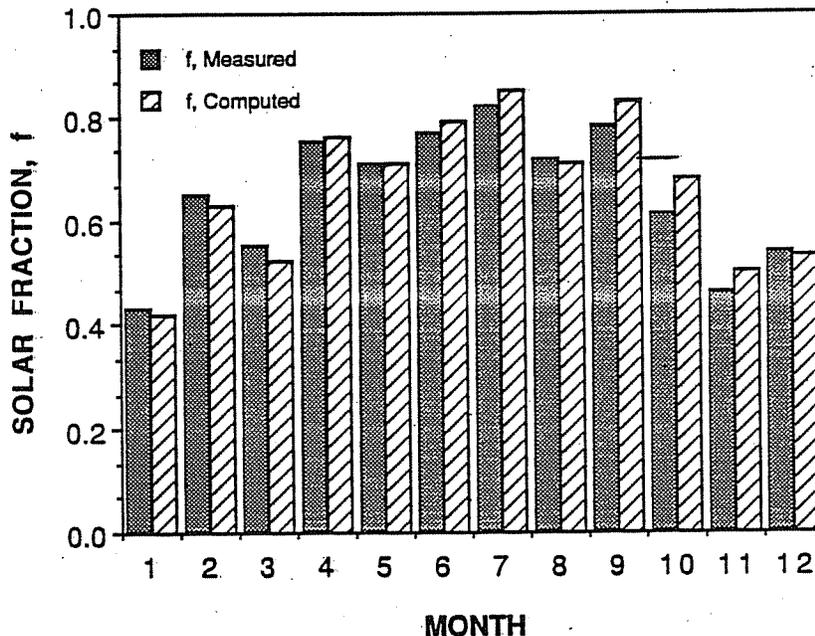


Fig. 3: Comparison of calculated and measured monthly solar fractions for a thermosyphon water heating.⁴

Comparisons of calculated and measured tanks profiles at half-hour intervals for a six-hour period are shown in Fig. 2. Figure 3 shows measured and simulated solar fractions (the fractional energy savings relative to a conventional water heater with realistic tank losses). Agreement is good. There are month to month variations between calculated and measured solar fraction, but the annual results for both measurement and simulation show solar fractions of 0.65. (This is a relatively difficult system to simulate,

because flow rates must be calculated. Simulations of active systems with fixed flow rates are simpler.)

Agreement between simulations and measurements is not always as good as in this example. The problems may be in the simulations, because of erroneous design data, poor selection of components, or other reasons. The problems also may be in the measurements; accurate measurements, particularly with air systems, may be very difficult to make; or the system may not have been constructed per design.

Third, runs with several simulation programs in addition to TRNSYS have produced essentially identical results.

Although TRNSYS simulations can closely represent the operation of physical systems, caution must be exercised. A program such as TRNSYS is only as good as the information that goes into it. Skill is required to know the amount of detail appropriate for a simulation. This recognized, TRNSYS can, by including enough detail in the models, represent reality to almost any desired level.

Acknowledgement

TRNSYS is available as a FORTRAN program for mainframe and IBM-PC and compatible computers. Version 12.2 is now being distributed. The user's manual⁵ is an 800-page document which provides technical information on the basis of all of the component subroutines, instructions on use of the program, and instructions for preparation of additional subroutines.

The development of TRNSYS was supported in large measure by the U.S. Department of Energy. It is a public-domain program that is distributed by the UW Solar Energy Laboratory at a price that recovers the out-of-pocket cost of shipping the program and documentation and part of the cost of support of the program by the TRNSYS engineer.

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