CHAPTER II

MOSTPROSIT

A "Modularized Solar Thermal Processes Simulator" (MOSTPROSIT) has been developed in FORTRAN IV for use on a Control Data Corporation (CDC) 6,000-series computer system by Tanthapanichakoon.[1] The simulator is capable of predicting the transient behavior (dynamic performance) of numerous important solar thermal processes related to a solar-cooled and-heated house. The simulator is said to be "modularized" because each basic piece of equipment, physical or conceptual, is represented by a module (subroutine). For example, there is one module for the pump, one for the flat-plate solar collector, one for the stratified liquid storage tank, and so on. Currently there are 19 basic modules ready for use in simulation. Moreover, a user may easily add his own module, for example, for a solar central receiver to the simulator.

The merits of using basic modules for pieces of equipment are:

1. various combinations and flow arrangements of the desired number of modules may be carried out by simply supplying the appropriate linkage information to the program, and

2. unless sepecified otherwise, a module may be used more than once in the same simulation, that is, there can be

multiple pieces of a type of equipment in the system. MOSTPROSIT also has the capability to print out histograms and graphs, find the time integrals and compute time and sample statistics for any desired variables.

The justification of MOSTPROSIT as a transient simulator was carried out by comparing some of its predictions with those given by TRNSYS[2]. Two main differences between these programs are:

1. MOSTPROSIT incorporates a distributed parameter model for the flat-plate solar collector, whereas TRNSYS uses a lumped-parameter model, and

2. MOSTPROSIT is better suited for carrying out Monte-Carlo (stochastic) than deterministic simulation, whereas TRNSYS is developed only for deterministic simulation.

In brief, for a deterministic study, MOSTPROSIT is expected to give more accurate prediction of the transient behavior of a solar system though it consumes more computer time than TRNSYS. On the other hand, TRNSYS has a wider variety of equipment pieces available.

Formulation of Component Models

A large system are usually broken down into several components. For example, a "typical" solar water-heating system consists of a solar collector, an energy storage unit, an auxiliary heater, a pump, and several temperature-activated controllers. Because of the common appearances of several main types of components, such as pumps, flat-plate solar collectors, and so forth, in many different solar systems of use and interest, a general-purpose solar system simulation program cannot but use the modular simulation technique. The technique essentially consists of:

1. Developing a suitable mathematical model for each type of the common components. To increase the generality of the model and reduce the number of necessary models, an option should be provided to select different operating conditions. For example, an option should be available to simulate a heat exchanger model as either a counter-flow exchanger, a parallel-flow exchanger or a cross-flow exchanger. In this way, it would be unnecessary to develop a number of separate models for a type of equipment.

2. Coding the mathematical models as subroutines (sub-programs). The subroutines should be coded such that:

2.1 one subroutine can simulate multiple units of a type of equipment in a system, and

2.2 communications between subroutines and/or the main program must be efficient (without hindering the execution speed of the subroutines) and convenient. (This is especially important for Monte-Carlo simulation, which is generally time-consuming and requires frequent changings of the values of certain random parameters and inputs.)

3. Endowing the simulation program with the capability to print, plot, construct histograms, compute time integrals,etc..

System Setup

To carry out simulation of a solar system, we specify the number of process units in the system, the corresponding modules and the information exchange network. For each process unit, we then assign a string of memory locations for its inputs, another for its parameters, and a third for its outputs. The strings need not be consecutive but they must not overlap. For a module comprising of ordinary differential equations, a fourth consecutive string is assigned for the time derivatives.

The type of a unit is declared. For example, a pressure relief valve is specified as type 1, a flow mixer as type 5, etc.. For bookkeeping purposes, the numbers of inputs, parameters, outputs, and/or time derivatives must also be specified.

The information exchange network is represented by a two-dimensional array. The first subscript of the array identifies the input to a unit, and the second subscript is the unit number. The value of an array element tells the location at which the input value of the particular unit can be found.

In the case of Monte-Carlo simulation, the memory location of stochastic variables as well as their stochastic properties are specified. The variables whose time statistics and sample statistics are desired are also specified.

Print-out is carried out only at certain preassigned interval. So are plotting of graphs and construction of histograms.

In conclusion, a solar-energy system is represented by a set of algebraic and nonlinear differential equations. The differential equations are then integrated numerically to simulate the transient system behavior. To do this MOSTPROSIT utilizes a variable-stepsize fourth-order Runge-Kutta algorithm.[(3),(4)]

Description of Modules

The following are brief descriptions of the modules currently available in MOSTPROSIT. (See Appendix B for mathematical details.)

1. Pipe Pressure Relief Valve:

Whenever the liquid in a pipeline begins to boil, thus creating excessive pressure in the pipeline, the pressure relief valve will be opened to vent the excessive pressure. Generally the mass of the released vapor will be negligible.

2. On/off Auxiliary Heater:

An on/off auxiliary heater can be inserted into a flowstream to try to maintain the temperature of the flowstream at or above a pre-set temperature T_{set}. However, if the rate of heat addition required to elevate the flowstream temperature to T_{set} is larger than $\dot{Q}_{max}$, the maximum heat delivery rate of the auxiliary heater, the flowstream temperature will be raised proportionally to $\dot{Q}_{max}$ but not as high as T_{set}.

3. Stratified Liquid Storage Tank:

The thermal performance of a liquid-filled sensible energy storage tank, subject to temperature stratification, is modelled by assuming that the effect of mixing in the tank can be represented by a series of N fully-mixed equal-volume segments. Several investigators[5],[6] have suggested that a tank consisting of three segments (N=3) provides the best compromise between actual system performance and computation time.

4. Flow Diverter:

The flow diverter splits an inlet stream into two outlet streams, according to the value of an input control function γ.

5. Flow Mixer:

The flow mixer combines two inlet streams of the same fluid in one.

6. Pump and Fan:

The maximum mass flow rate a pump or fan is capable of delivering is specified. The actual mass flow rate is the product of the maximum flow rate and an input control function γ whose value ranges from 0 to 1.

7. Absorption Air-Conditioner:

The present absorption air-conditioner model is an empirical representation of the ARKLA WF 36 three-ton lithium-bromide system. It relates the cooling capacity of the unit as well as the corresponding rate of input energy requirement to the generator inlet hot water temperature and the cooling water inlet temperature. Cooling water is passed through an external cooling tower which is assumed to return water at 5.5°C above the ambient wet-bulb temperature but no less than 10°C and no more than 40°C.

As generalization, the model can accept a nominal machine capacity different from three tons (37,980 kJ/hr). Intermittent operation of the air-conditioner is controlled by a control variable γ whose value is either 0 (air-conditioner off) or 1 (air-conditioner on).

8. Multi-Stage Room Thermostat:

The multi-stage room thermostat with hysteresis sends out three on-off control signals or functions to control a space-heater, an auxiliary heater, and a space-cooling unit, simultaneously.

9. Solar Radiation Processor:

Frequently only data of solar radiation on a horizontal surface are available. The function of the solar radiation processor is to consolidate the estimation of incidental solar radiation on several non-horizontal surfaces in a single module, using the data for a horizontal surface. Obviously this module does not represent a physical device but its creation is warranted by the complexity and shared features of these calculations.

10. Space Heating and Cooling of a One-Node House:

This model assumes that an average house temperature can be defined so that the rate of heat transfer into the house from the surroundings is proportional to their temperature difference.

11. Flat-Plate Solar Collector (Unsteady-State Model):

Several models for a flat-plate solar collector with forced fluid circulation have been investigated by Klein et al.[7] The more sophisticated and accurate a model, the more time-consuming it is to simulate. For quasi-steady-state simulation, the model of Hottel, Whillier,and Bliss[8],[9],[10] appears to be most appropriate because of its computational simplicity and good agreement with several more elaborate models.[2]

For inherently unsteady-state simulation, however, the model proposed herewith should give more realistic transient behavior than the model of Hottel, Whillier, and Bliss. In one case study, the HWB model gave a higher estimate for the amount of solar energy collected on a partly cloudy day presumably because it did not take into account the amount of solar energy needed to heat up the solar collector. It was found that the plate temperature would jump as soon as the sun emerged from a cluster of cloud, thus allowing more solar energy collection. More specifically, the HWB model was found to collect 5-6% more solar energy than the present unsteady-state model in one cloudy day. Suffices it to say that the choice of a model should depend on the purposes and nature of a particular study.

12. Heat Exchanger:

The mathematical model for a zero-capacitance sensible heat exchanger is discussed in detail by Kays and London.[11] There are five optional modes of operation:

12.1 parallel flow,

12.2 counter flow,

12.3 cross flow with hot-side fluid unmixed but cold-side completely mixed,

12.4 cross flow with hot-side fluid completely mixed but cold-side unmixed, and

12.5 constant heat transfer effectiveness

13. Data Reader:

The data reader reads in a set of data at regular time intervals, convert their numerical values to the desired units, interpolate them with respect to the current simulation time, and make the results available to other system modules. The data reader is usually used to read regularly spaced meteorological data.

14. On/off Differential Controller with Hysteresis:

This controller generates a control variable γ_o with a value of either 0 or 1. It should be pointed out hysteresis occurs only when the previous value of γ_o is used as the current input to the controller.

15. Flat-Plate Solar Collector (Quasi-Steady-State Model):

The model is modified version of TRNSYS flat-plate collector model.[2] The original model is based on the work of Hottel, Whillier and Bliss. It is a quasi-steady-state model because it assumes that a new steady state is attained at each integration step. Thus the accumulation of thermal energy by the collector body needs not be considered. This assumption contributes significantly to the simplicity of the model.

16. Mathematical Manipulator:

The mathematical manipulator does not represent a specific physical device but is very useful for performing mathematical operations on a set of values.

17. Wall(s) or Flat Roof:

This module represents one of the following: a wall, a flat roof, or a set of four walls. It utilizes the transfer function method of computing conduction heat gains, as described in the ASHRAE Handbook of Fundamentals.[12] In mode 1, a single wall or flat roof is modelled. In mode 2, all four walls of a house are represented the only restriction is that the four walls must be of the same construction, though their window areas and window shading fractions need not be the same.

18. Pitched Roof and Attic:

The pitched roof and attic model is based on the transfer function method of ASHRAE Handbook of Fundamentals.[12] Its function is to estimate the rate of heat influx through the ceiling of a room.

19. Room and Basement:

This lumped-parameter room and basement model can be coupled with module 17 (walls model) and module 18 (pitched roof with attic) to estimate space-heating or-cooling loads to a house. All major heat load mechanisms except latent heat loads are explicitly considered here. Latent heat loads, however, can be computed elsewhere and then introduced into this model as heat gains.