INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
I.C.T.P., P.O. BOX 586, 34100 TRIESTE, ITALY, CABLE: CENTRATOM TRIESTE

SMR/400- 10

WORKSHOP INTERACTION BETWEEN PHYSICS AND
ARCHITECTURE IN ENVIRONMENT CONSCIOUS DESIGN
25 - 29 September 1989

"TRNSYS Code for Bioclimatic Building Simulation"

M. CITTERIO
ENEA
FARE-INPRO-PRO
Rome, Italy

Please note: These are preliminary notes intended for internal distribution only.

CHAPTER 1

CONCEPTS AND DEFINITIONS

1.1 INTRODUCTION

TRNSYS is a transient systems simulation program with a modular structure. The modular nature of TRNSYS gives the program tremendous flexibility, and facilitates the addition to the program of mathematical models not included in the standard TRNSYS library. TRNSYS is well suited to detailed analyses of systems whose behavior is dependent on the passage of time.

The purpose of this chapter is to provide the user with the concepts and definitions he will need to fully understand the use of TRNSYS for modular system simulations. In addition to the information contained in this chapter, the user is expected to have some acquaintance with FORTRAN programming, although a thorough knowledge of programming should not be necessary. The steps which should be followed to prepare a system for simulation using TRNSYS are summarized in Section 1.11.

1.2 A SYSTEM AND ITS COMPONENTS

A system is defined to be a set of components, interconnected in such a manner as to accomplish a specified task. For example, a typical solar water-heating system may consist of a solar collector, an energy storage unit, an auxiliary energy heater, a pump and several temperature sensing controllers. One obvious characteristic of a system is its modularity. Because the system consists of components, it is possible to simulate the performance of the system by collectively simulating the performance of the interconnected components.

The performance of a system component will normally depend upon characteristic fixed parameters, the performance (or outputs) of other components, and time-dependent forcing functions. For a solar water-heating system, knowledge of the weather (i.e., solar radiation, ambient temperature etc.) and the hot water demand as a function of time are necessary in order to determine the transient system performance. It is important to realize that time dependent forcing functions can be thought of as outputs of specialized system components and they can thus be treated in the same manner as any other component.

The modular simulation technique greatly reduces the complexity of system simulation because it essentially reduces a large problem into a number of smaller problems, each of which can be more easily solved independently. In addition, many components are common to different systems and provided that the performance of these components is described in a general form, they can be used in many different systems with little or no modification. This feature makes modular simulation most attractive.

With a program such as TRNSYS which has the capability of interconnecting system components in any desired manner, solving differential equations, and facilitating information output, the entire problem of system simulation reduces to a problem of identifying all of the components and formulating a general mathematical description of each. In some cases, the description of a component may be complex. In Chapter IV, descriptions of many of the components of common solar energy systems are presented; in addition, components common to all simulations, such as a quantity integrator, printer and plotter are also presented in Chapter IV. The user intending to apply TRNSYS to the simulation of systems containing components not described in Chapter IV must formulate his own mathematical description in FORTRAN subroutines consistent with the requirements of TRNSYS as described in Chapter III.

1.3 INFORMATION FLOW DIAGRAMS

Once all of the components of a system have been identified and a mathematical description of each component is available, it is necessary to construct an information flow diagram for the system. An information flow diagram is a schematic representation of the flow of information into and out of each of the system components. In the diagram, each component is represented as a box. Each piece of information required to completely describe the component is represented as an arrow directed into the box. Each piece of information calculated by equations describing the component can be represented as an arrow directed out of the box.

It is often helpful to think of the arrows connecting component inputs and outputs as information exchanged via pipes and wires in a real system. A collector outlet flowstream temperature and flowrate connected to the inlet of some other piece of hardware is "information" transmitted through a pipe. A controller on-off output connected to a pump is information transmitted through a wire. The analogy between information flow and pipes and wires is, however, not perfect. Information need not always follow the course of pipes and/or wires.

In order to demonstrate the construction of an information flow diagram, consider a very simple solar water-heating system consisting of a solar collector and an auxiliary energy heater as shown in Fig. 1.3.1. Cold water, at a temperature T_i (varying with time), is circulated at a constant rate $\dot{m}$, through the collector. The water is then heated from T_o, the temperature of the water leaving the collector, to a desired temperature T_{set}, by the auxiliary heater. The problem is to determine Q_{aux}, the total auxiliary energy required to heat the water to the desired temperature over a specified time period.

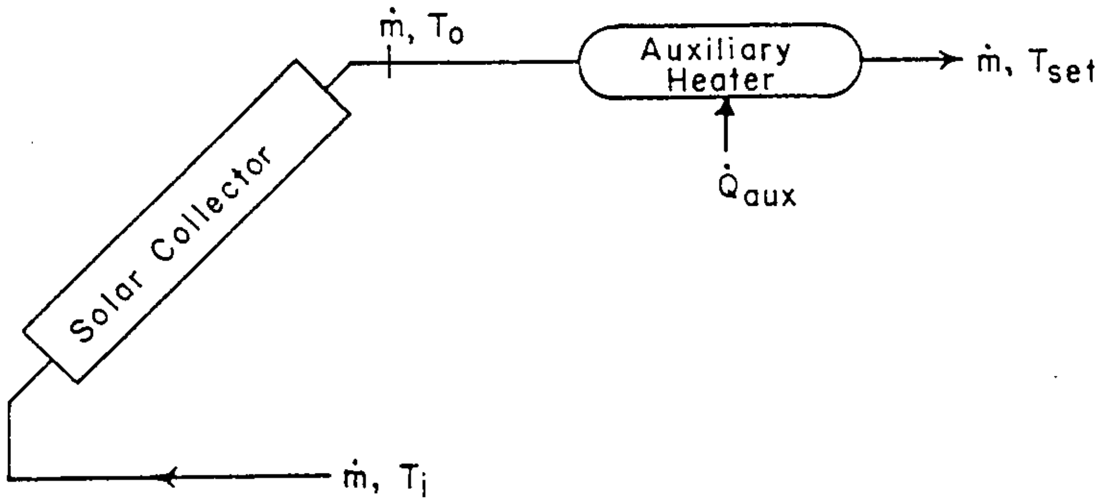


Figure 1.3-1 Simple solar water heating system.

Component models which describe the performance of the solar collector and the auxiliary heater have been formulated in a general manner as described in Chapter IV. Ordinarily, general formulations of component models are desirable, since the model can then be used in a variety of simulations without modification. The models in Chapter IV, however, require consideration of details which distract from the purpose at hand. Rather than using these general models to demonstrate the construction of information flow diagrams, let us formulate component models specific to this example.

An equation relating the collector outlet water temperature to its inlet temperature can be written

$$T_o = T_i + \frac{AF_R}{\dot{m}C_p}\,[S-U_L(T_i-T_a)] \qquad (1.3\text{-}1)$$

where

T_i is the inlet water temperature

A is the area of the collector

C_p is the heat capacity of water

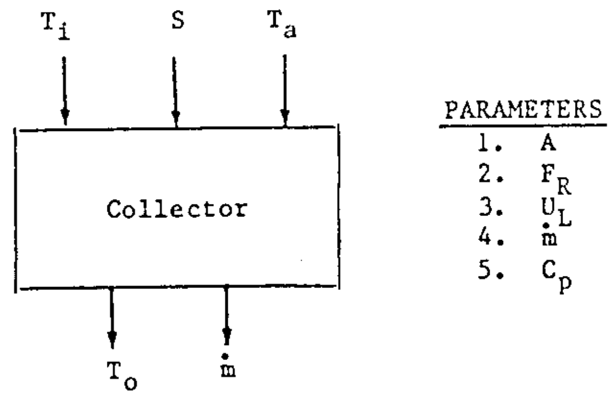
F_R is a constant efficiency factor

U_L is a constant loss coefficient

S is the time dependent solar radiation absorbed on the collector surface

T_a is the time dependent ambient temperature

An information flow diagram for this collector model is shown below.



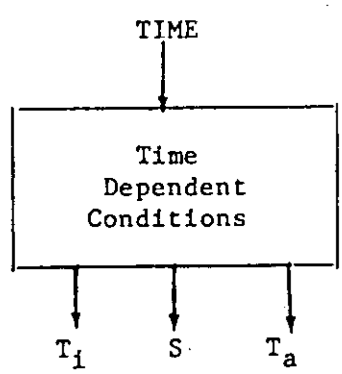
Note that S, T_i and T_a are functions of time only.

$$S = f_1 \text{ (time)} \qquad (1.3\text{-}2)$$

$$T_i = f_2 \text{ (time)} \qquad (1.3\text{-}3)$$

$$T_a = f_3 \text{ (time)} \qquad (1.3\text{-}4)$$

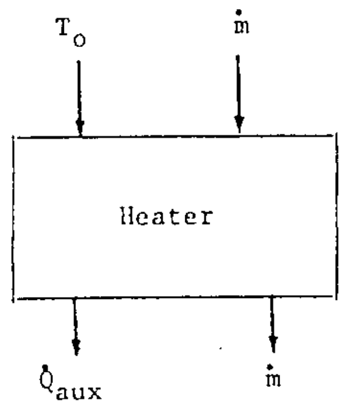
Time dependent conditions such as S, T_a and T_i are considered to be outputs of a specialized system component which is nothing more than a card reader which reads the values of S, T_i, and T_a at successive increments of time. An information flow diagram relating S, T_i and T_a, to time is shown below.



The instantaneous auxiliary energy required, $\dot{Q}_{aux}$, is described by the following equation

$$\dot{Q}_{aux} = \dot{m}C_p[T_{set} - T_o] \qquad (1.3\text{-}5)$$

An information flow diagram for the heater is simply

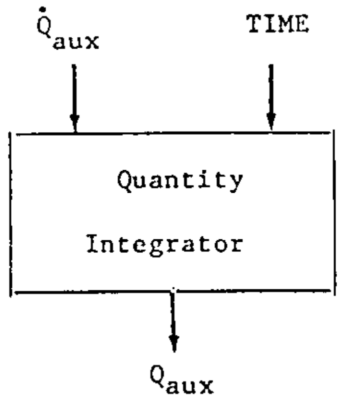


PARAMETERS
1. T_{set}
2. C_p

In order to determine the total auxiliary energy required, Q_{aux}, the instantaneous auxiliary energy must be summed or integrated over the period of operation. For this purpose, it is necessary to include a "quantity integrator" as one of the system components. Note that a quantity integrator component is used only to integrate some calculated quantity over a period of time; it is not used to solve first-order differential equations which may be part of the mathematical description of a component because TRNSYS will automatically perform this type of integration. A quantity integrator is treated as any other system component. The equation describing it is

$$Q_{aux} = \int_{\text{Time}} \dot{Q}_{aux}\, dt \qquad (1.3\text{-}6)$$

The information flow diagram for the quantity integrator is shown below



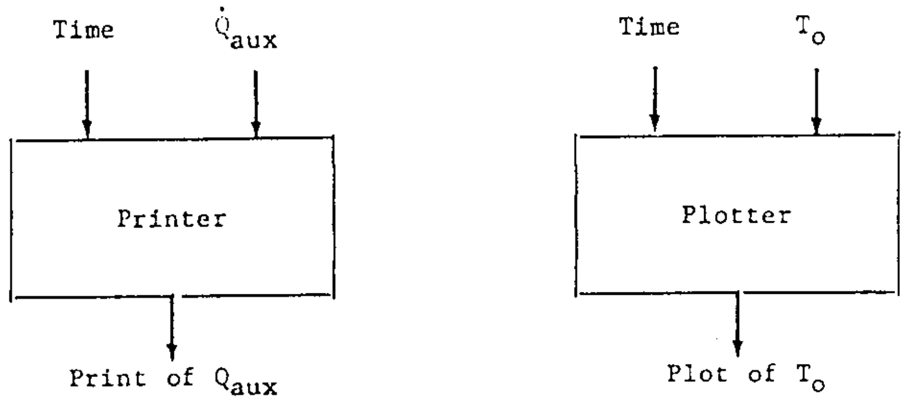
A quantity integrator is considered to be a standard component of all transient systems. Thus, a multivariable quantity integrator component is built into TRNSYS (see Section 4.1, TYPE 24, and Section 4.10, TYPE 28).

The information flow diagram for the simple solar water heating system of Figure 1.3-1 is now complete except for a component which allows the results of the simulation to be made available to the user. For this purpose, TRNSYS has printers, plotters and other output components built in to print and/or plot desired results (see Section 4.10). The analogous pieces of equipment in a physical system would perhaps be a multi-channel digital display and/or strip chart recorders. In a real situation, these would monitor and display various information streams so that the system performance could be followed.

It is absolutely essential to include an output device (i.e., TYPE 25, 26, 27, 28 or 29) in the system information flow diagram. Failure to include one of these components causes a WARNING message to be issued: the simulation will then proceed but no output will occur (unless a TRACE command is used; see Chapter II).

In the example being considered, the user may wish to print Q_{aux} as the integration of $\dot{Q}_{aux}$ progresses and also plot the variation of T_o (collector exit temperature) with time.

Information flow diagrams for the printer and the plotter are



The information flow diagram of a system is constructed by joining all of the diagrams of the system components. The information flow diagram of the solar water-heating system is shown in Figure 1.3-2. Time is not shown explicity, since it is handled by TRNSYS. Note that the collector outlet temperature, T_o, serves as an input to both the heater and the plotter. In general, an output of one component can be used as an input to any number of other components.

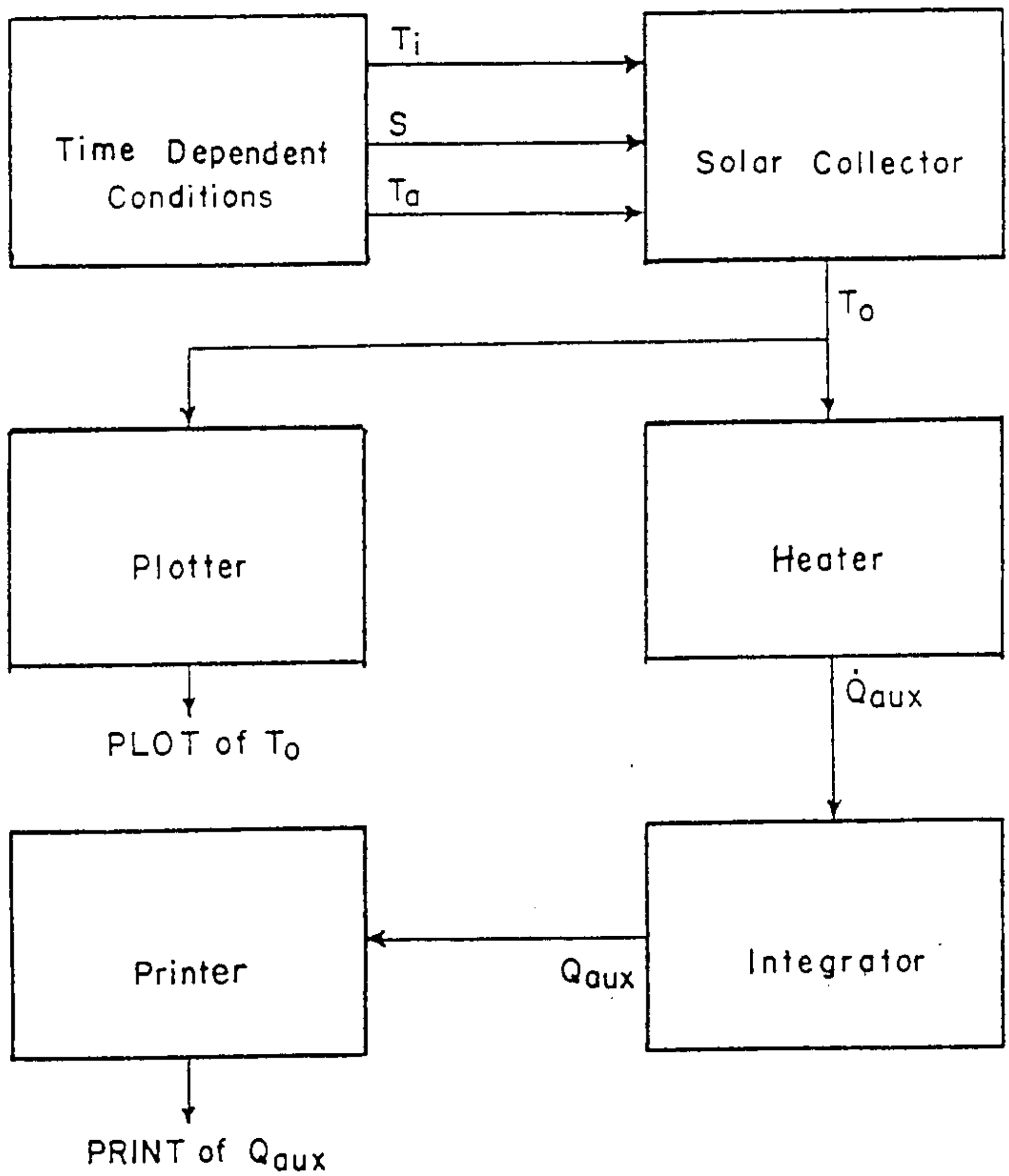


Figure 1.3-2 Example flow diagram for a solar water heating system.

1.4 COMPONENT TYPE NUMBERS

TRNSYS identifies the different kinds of components which appear in the information flow diagram by associating a TYPE number with each kind of component. For example, the solar collector model provided with TRNSYS is designated a TYPE 1 component. The pump model provided with TRNSYS is designated a TYPE 3 component. The fact that there may be more than one pump in the system is immaterial. Each pump will be referred to as a TYPE 3 component provided that the performance of each is described by the same FORTRAN subroutine.

The relation between a component and its TYPE number is determined by the name of the FORTRAN subroutine coded to model that component. As explained in Chapter III, every component subroutine must have the name TYPE n, where n is an integer from 1 to 50. Thus, a flat-plate solar collector will be a TYPE 1 component provided that there is a subroutine TYPE 1 which models the collector performance. TYPE numbers are already associated with all the component models described in Chapter IV. The apparently arbitrary numbering of component models stems from the historical order in which the models were written. The assignment of TYPE to user supplied component models is discussed in Chapter III.

1.5 SYSTEM UNIT NUMBERS

TRNSYS recognizes the position of each component in the information flow diagram by a unique but arbitrary user-assigned UNIT number between 1 and 50. Since a simulation may include more than one component of a particular kind (for example, two TYPE 3 pumps), the TYPE number does not always uniquely identify a component in the information flow diagram. The UNIT number simply provides a reference number for each system component. UNIT numbers are unrelated to TYPE numbers, and need not be in sequential order. The only restrictions imposed on UNIT number selection are that no two system components can have the same UNIT number and each UNIT number must be a positive integer between 1 and 50. As an example, the information flow diagram in Figure 1.3-2 has been redrawn in Figure 1.5-1 showing UNIT and TYPE numbers of the system components.

Thus, associated with each component in the information flow diagram is a TYPE number, which defines the component's function, and a UNIT number, which distinguishes the component from all other components in the system. A system which includes two pumps can be said to include two UNITS of TYPE 3; the pumps might (for example) be labeled UNIT 3 and UNIT 43. To minimize confusion between UNIT and TYPE numbers, it may be helpful to assign UNIT numbers corresponding to component TYPE numbers whenever possible.

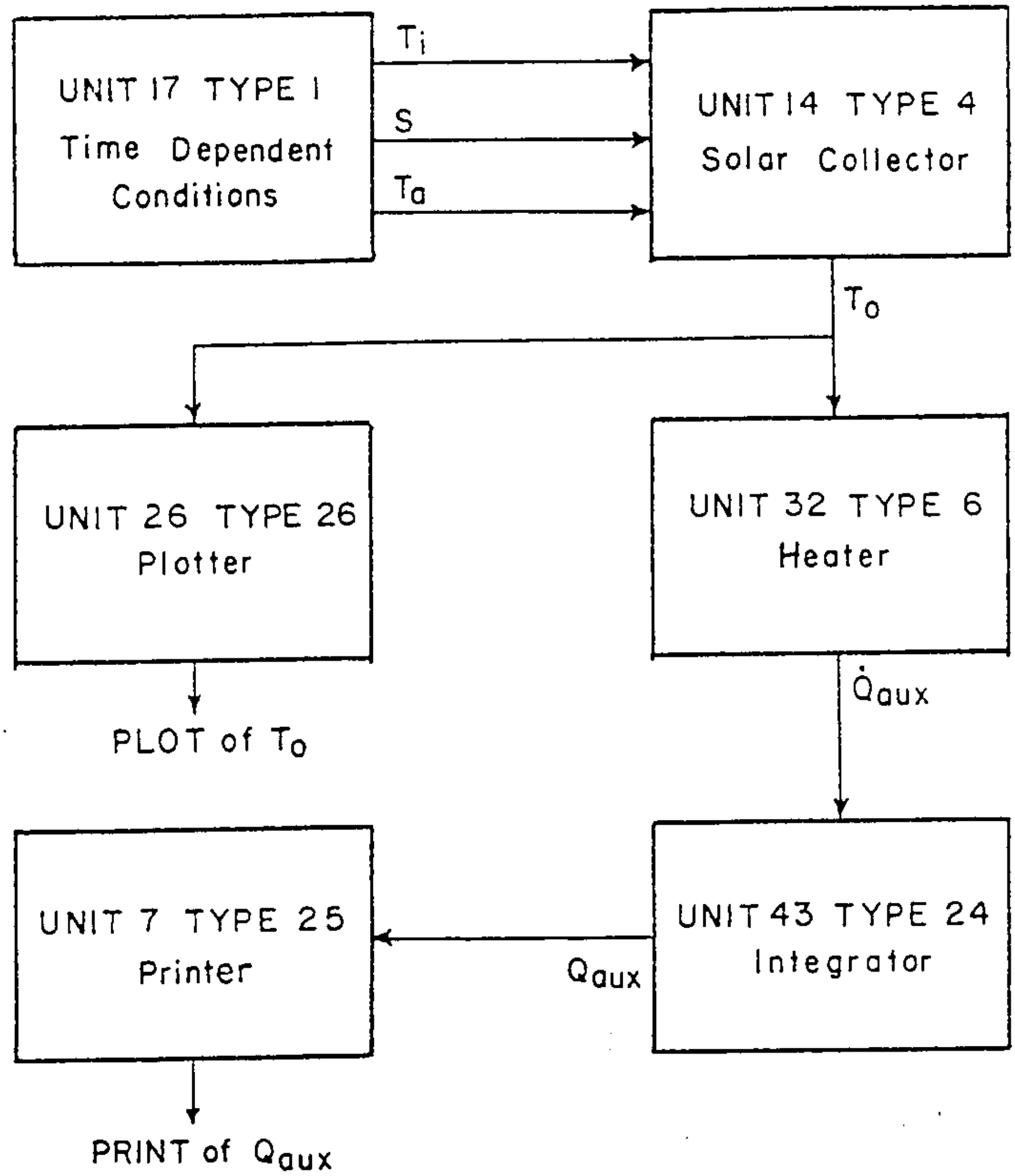


Figure 1.5-1 An information diagram with component TYPE and UNIT numbers.

1.6 TYPES OF INFORMATION FLOW

It is necessary to distinguish among several types of information flow which may occur in the information flow diagram. The most obvious distinction is between information flowing into and that flowing out of a component. The set of information flowing out of a component, represented by outwardly directed arrows, is defined to be the OUTPUT variable set for that component. The OUTPUT variable set of the collector in the information flow diagram in Figure 1.5-1 consists of T_o, the calculated collector outlet fluid temperature.

The information flowing into a component, represented by inwardly directed arrows, can be of three types.

1. Those pieces of information flowing into a component which are OUTPUT variables from any other component in the system constitute what is defined to be the INPUT variable set for the component. The INPUT variables are those variables whose values may vary during the simulation. For a transient system, the INPUT variables may vary with time. The INPUT variable set of the collector in Figure 1.5-1 consists of S, T_i, and T_a. All three are functions of time.
2. Those pieces of information which are always constant throughout the simulation and of interest to the component are the PARAMETERS of the component. The

1.7 ORDERING OF PARAMETERS, INPUTS AND OUTPUTS

As explained in Section 1.6, four types of information flow may exist in the information flow diagram. A component may receive three types of information; INPUTS, PARAMETERS and TIME. The information flowing from the component is its OUTPUTS. To aid in conveying the information flow diagram to TRNSYS, each piece of information of a given type (for each component) is numbered sequentially. If for example, a component has 2 INPUTS, they are numbered INPUT 1 and INPUT 2. If the component has PARAMETERS and OUTPUTS, they are likewise numbered sequentially beginning with number one. The sequential numbering of the INPUTS, OUTPUTS, and PARAMETERS of each component must be consistent with the numbering used in the FORTRAN subroutine modeling the component as explained in Chapter III. For example, the FORTRAN subroutine modeling a heat exchanger (TYPE 5) described in Chapter IV requires four PARAMETERS. According to this description, the first PARAMETER is a code number indicating the type of heat exchanger. The second PARAMETER is the product of the exchanger area and its heat transfer coefficient, UA. The third and fourth PARAMETERS are the heat capacities of the hot and cold streams respectively. These PARAMETERS must be sequentially numbered in the information flow diagram in the order that the heat exchanger subroutine (TYPE 5) expects them. The same is true for the INPUTS, the OUTPUTS, and the PARAMETERS of every system component. In Chapter IV, the numbering convention for each of the components modeled will be found with the description of the model.

1.8 TRANSIENT AND STEADY-STATE SIMULATION

If TIME is a variable to any of the components of the system, the simulation of the system is defined to be a transient simulation. In general, a transient simulation will be required if any of the three following situations occur.

1. A component of the system has an OUTPUT variable which is a function of time.
2. The mathematical description of a component of the system involves one or more time-dependent differential equations (with non-zero derivatives).
3. A physical quantity calculated by the simulation model is to be integrated over time by the quantity integrator component.

Although situations 2 and 3 both call for numerical integration, they are conceptually different and TRNSYS treats them differently. If the mathematical description of a component involves one or more differential equations, TRNSYS must know the number of differential equations involved and the values of the dependent variables at the start of the simulation. TRNSYS expects that the derivatives of the dependent variables at any time will be evaluated by the component model. Using the supplied values of the derivatives, TRNSYS automatically integrates to evaluate the dependent variables.

If a quantity calculated by the simulation model is to be integrated over time, TRNSYS requires that a quantity integrator component be included as one of the system components in the information flow diagram. As shown in the system of Figure 1.5-1, the quantity to be integrated is supplied to the integrator component as an INPUT variable. The OUTPUT variable of the integrator is the integrated value of the INPUT variable. Two of the output producing components TYPE 27 and TYPE 28, include built-in quantity integrators.

System simulations which are not transient are referred to as steady-state simulations. A steady-state system is one in which none of the system variables change with time. TRNSYS is not designed for steady-state simulations.

1.9 ACYCLIC AND RECYCLIC INFORMATION FLOW

An information flow diagram of a system may exhibit either acyclic or recyclic flow of information. Recyclic flow occurs whenever there is a path in the information flow diagram formed by the output arrows which leads from a component to one or more other components of the system and then back to the starting component. The diagram of Figure 1.5-1 is an example of acyclic information flow since no such path exists. If, however, the system represented by Figure 1.5-1 were modified so that the water flow rate $\dot{m}$ is controlled by the difference between temperatures T_o and T_i, the resulting information diagram would exhibit a recyclic flow of information as indicated in Figure 1.9-1. (Note that in Figure 1.9-1, $\dot{m}$ must now be an INPUT variable to the collector and not a PARAMETER as it was in Figure 1.5-1 since its value may change with time.)

When recyclic flow occurs in the information flow diagram of the system, a numerical technique will be needed to find the values of the OUTPUT variables which satisfy the equations of all of the components involved. This is especially true when none of the OUTPUT variables forming the recycle loop are the solution of a time dependent differential equation. TRNSYS is programmed to identify such problems should they exist, and, if necessary, it will use successive substitution iterating until all of the OUTPUT variables in the recycle loop converge to within a tolerance, ϵ_A

or ζ_A, specified by the user. The action taken if this convergence tolerance cannot be met within a reasonable number of iterations is described in the next section.

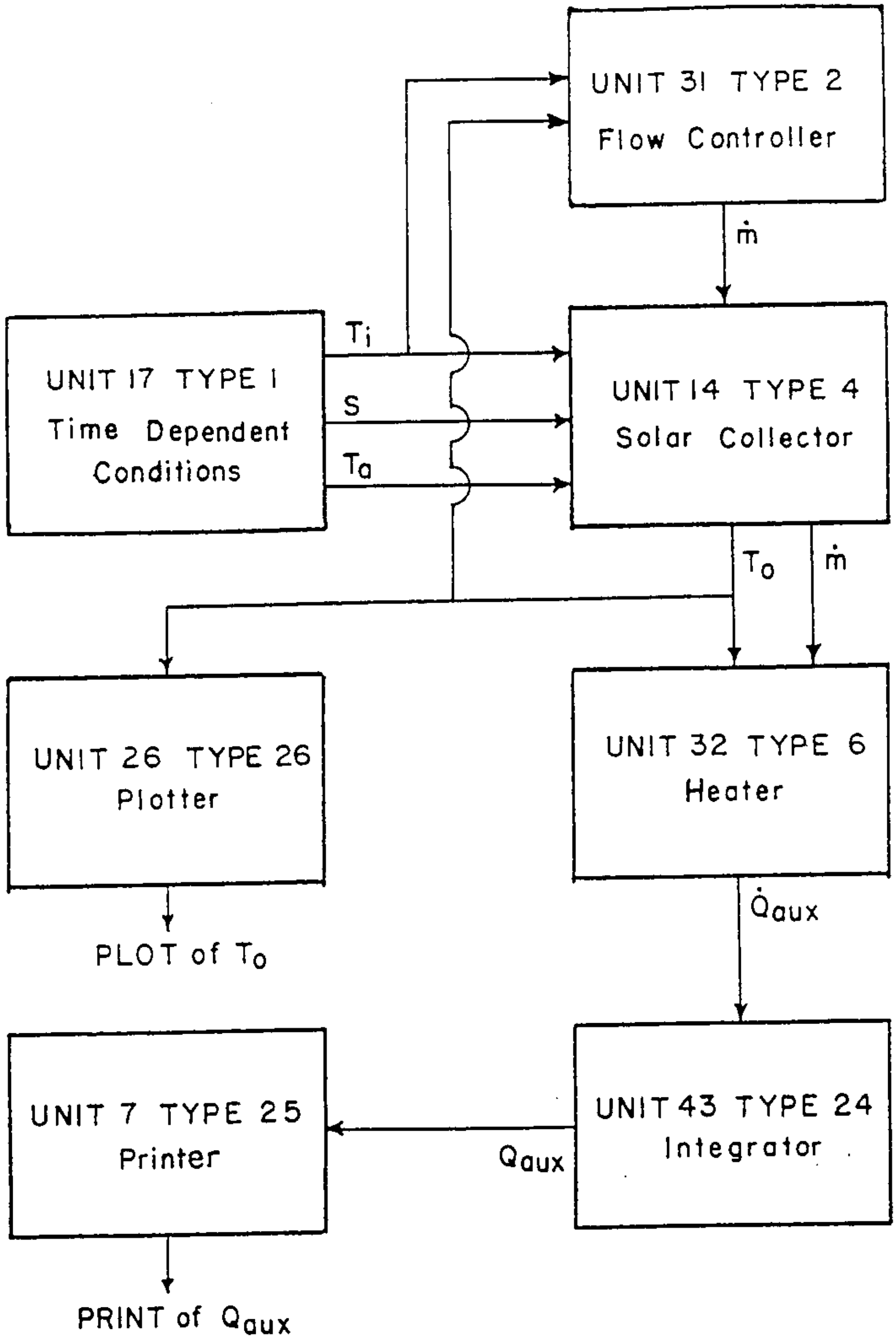


Figure 1.9-1 Information flow diagram with recycle.