DEMONSTRATION OF TRNSYS USE IN BUILDING SIMULATIONS

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ABSTRACT

TRNSYS (1) is a modular transient system simulation program that has been commercially available since 1975. The primary use of TRNSYS is to model thermal energy systems. Although TRNSYS was originally developed for use with solar thermal applications, an effort has been made to broaden the scope of TRNSYS by increasing the number of general HVAC components and improving the usability of the building model. Some of the more recently available HVAC models include the ASHRAE Primary and Secondary Toolkits and FIVACSIM+ components. Additionally, an interfáce with D0E2 was developed allowing TRNSYS to read, D0E2 generated, building load files.

Mie modeling of buildings can, be done with varying degrees of complexity. A simple single conductance method is the simpliest model. A detailed single zone component is also available. Finally, a multizone model is available that also calculates the interaction between zones.

1 INTRODUCTION

TRNSYS is designed to simulate the transient performance of thermal energy systems. TRNSYS relies on a modular approach to solve large systems of equations described by FORTRAN subroutines. Each FORTRAN subroutine contains a model for a system component. For example, subroutine Type 32 is a model of a cooling coil. The inlet flow rates and temperature for the air and water are inputs to the model while the total and latent cooling rates are among the outputs of the model. By creating an input file, the user directs TRNSYS to connect the different subroutines to form a system. The TRNSYS engine calls the system components based on the input file and iterates at each timestep until the system of equations is solved.

Unlike many other programs, TRNSYS allows users to completely describe and monitor all interactions between system components. For example, the user determines the connections between system components. The modularity of the program allows the user to have as many pumps, chillers, cooling coils, and cooling towers as necessary, in any desired configuration.

1.1 STANDARD TRNSYS COMPONENT MODULES

Many component models come standard with TRNSYS and include many of the components commonly found in thermal energy systems. In addition, there are routines to handle weather data, other time dependent forcing functions, and output of simulation results.

New technologies are common in today's energy market, and care has been taken to make it easy to add additional components to the TRNSYS package. Any thermal energy component which can be formulated into a FORTRAN subroutine can be added to the library and to the various front-end utilities associated with TRNSYS. This could include fundamental models, curve fits, tabular catalog data, or any other method to represent performance. User generated components are available on the Internet, as discussed in Section 3.1.

Because TRNSYS is FORTRAN 77 compatible it is possible to use it on many computer platforms from

Macintosh to UNIX. In spite of the desire to maintain its platform independence, several utility programs have been generated for the DOS - PC users who compose a large majority of TRNSYS users. These utility programs make it easier and faster to learn and use TRNSYS.

1.2 TRNSHELL

In previous versions of TRNSYS, all executable commands were entered at a line prompt. Starting with version 14 for DOS, a new utility program, TRNSHELL, encapsulates all of the functions necessary to use TRNSYS. The other utility programs discussed in this paper, PREBID, PRESIM, and TRNSED, can be operated from inside TRNSHELL by clicking on one of the menu items.

It is easy to modify or develop TRNSYS components within TRNSHELL. There is a full-featured editor that includes cut, paste, find, and other options. Once the component has been written, it can be compiled and linked from within TRNSHELL. TRNSHELL can be initialized to operate any DOS FORTRAN compiler.

1.3 PRESIM

PRESIM offers the user a way to graphically create an input file. PRESIM is a utility program developed for TRNSYS by the Solar Energy Research Center in Borlange, Sweden. As Figure 1 shows, each physical component in a system is represented in PRESIM by an icon shaped like the actual component. For example, a solar collector actually looks like a solar collector.

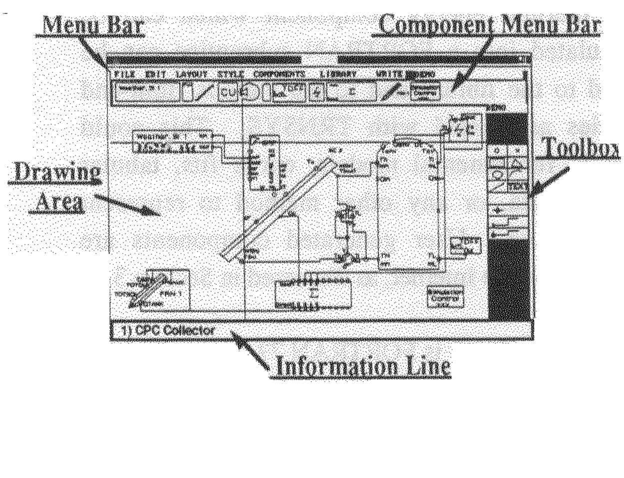

Fig 1 PRESIM window displaying a TRNSYS solar domestic hot water application.

PRESIM divides the standard TRNSYS components into libraries of components which can be displayed across the top of the screen. The desired icon can then be grabbed by a mouse and dragged onto the working area. Two components can be connected together by pointing and clicking with a mouse. The inputs and outputs of the components are displayed on the icon. A connection is made by drawing a line from the output of one component to the desired input of another component. By double-clicking on a component icon, the user can modify the initial values for the component inputs in a dialog box. Using the icons, an entire TRNSYS input file can be specified within PRESIM. PRESIM will then write the TRNSYS input file based on the connections between icons and the information entered (or default information) about the initial values of inputs. The final TRNSYS input file that PRESIM generates is well documented with specific comments.

1.4 TRNSED

In previous versions of TRNSYS, it was difficult to share simulations with people who were not familiar with the inner workings of TRNSYS. For this reason, a new system has been devised for allowing the TRNSYS user to modify the display in order for it to be easily understandable to the layperson. This system is called TRNSED.

A utility program in the TRNSHELL environment program converts a user's standard TRNSYS input file to a TRNSED formatted document. The user is prompted as to which TRNSYS variables in the input file should be displayed in the TRNSED formatted file as shown in Figure 2. In this manner, the user can insulate others from the TRNSYS details that are not relevant to the current simulation. The TRNSYS user may also add additional TRNSED comments and features such as pop-up menu choices and specific comments. For example, in Figure 3, if the City of Simulation box is chosen, it will open into a pop-up menu where the user may choose from a list of available cities.

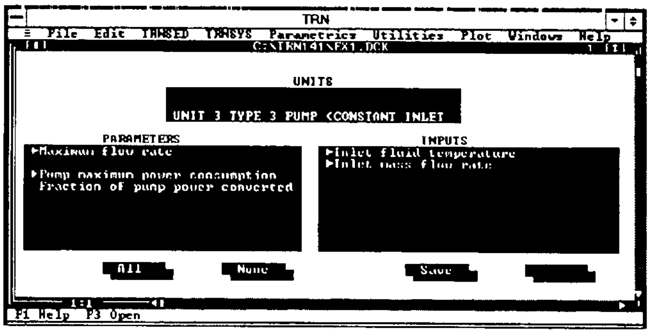

Fig. 2 The input file selection program for the TRNSED professional front-end.

The TRNSED program provides a refined user-interface in which selected input information may be viewed and/or changed. Detailed help, unit conversion, and input range checking for each item are also provided. The end-user enters the simulation information and starts TRNSYS from a menu command.

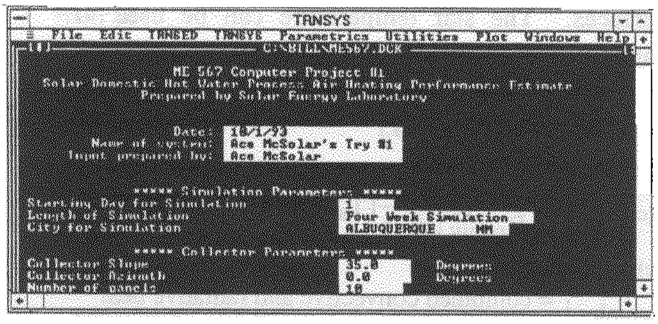

Fig. 3 Completed TRNSED professional front-end document.

TRNSED can be distributed to groups or organizations that do not own TRNSYS.

2. TECHNICAL BASIS OF BUILDING LOAD CALCULATIONS

There are three possibilities for modeling the building energy loads with TRNSYS. For relatively quick estimates of heating or cooling requirements, the Energy/(Degree-Day) TYPE 12 model may be used. In this case, the building is modeled through the use of a single conductance (UA) for heat loss or gain, along with any additional gains due to solar, lights, people, etc. A single energy balance on the structure is performed each simulation timestep. Hourly energy loads calculated in this manner may be significantly in error. However, over a period of time, the model may provide reasonable estimates of overall energy quantities.

The TYPE 19 Single-Zone model, on the other hand, represents a detailed analysis of a single zone. The walls, ceilings, floors, windows, and doors are modeled according to the ASHRAE transfer function approach. The effects of both short-wave (solar) and long-wave radiation exchange both inside and outside the structure are considered. Multi-zone buildings can be considered by multiple use of TYPE 19 in a simulation.

The TYPE 56 Multi-zone Building model provides a more efficient way to calculate the interaction between 2 or more zones by solving the coupled differential equations utilizing matrix inversion techniques. The effects of both short-wave and long-wave radiation exchange are accounted for with an area ratios method. The walls, ceilings, and floors are modeled according to the ASHRAE transfer function approach (2). Providing the complex description of a multi-zone building is simplified with the use of the stand-alone program BID, and its associated pre-processor, PREBID (supplied with the TRNSYS program).

The TYPE 12, TYPE 19 and TYPE 56 models have two basic modes of operation, termed "energy rate" and "temperature level" control. In energy rate control, the models calculate energy loads based only upon the net gains or losses from the space. The loads are considered to be independent of the heating or cooling equipment operation. The user specifies the set temperature for heating and/or cooling. The program determines the energy necessary to keep the room at these set points. In temperature level control, the room state reflects both the ambient conditions and the heating or cooling equipment input. A controller is used in conjunction with this mode to command the equipment.

When using Type 56, for any zone i, the net heat gain to the air is:

$$\dot{Q}_i = \dot{Q}_{surf,i} + \dot{Q}_{inf,i} + Q_{v,i} + \dot{Q}_{g,c,i} + \dot{Q}_{cplg,i} \quad (1)$$

where

$Q_{surf,i}$ = net heat transfer by convection from all inside surfaces

$\dot{Q}_{inf,i}$= infiltration gains

$\dot{Q}_{v,i}$= ventilation gains

$Q_{g,c,i}$= internal convective gains

$\dot{Q}_{cplg,i}$= gains due to convective flows from all adjacent zones

In order to determine either energy demands or floating zone temperatures, it is necessary to evaluate the terms of Eq. 1.

The walls are modeled according to the transfer function relationships of Mitalas and Arseneault (3) defined from surface to surface. For any wall, the heat conduction at the surfaces (s,i =inside, s,o=outside) are:

$$\dot{q}_{s,i} = \sum_{k=0}^{n_{b_s}} b_s^k\, T_{s,o}^k - \sum_{k=0}^{n_{c_s}} c_s^k\, T_{s,i}^k - \sum_{k=1}^{n_{d_s}} d_s^k\, \dot{q}_{s,i}^k \quad (2)$$

$$\dot{q}_{s,o} = \sum_{k=0}^{n_{d_s}} a_s^k\, T_{s,o}^k - \sum_{k=0}^{n_{b_s}} b_s^k\, T_{s,i}^k - \sum_{k=1}^{n_{d_s}} d_s^k\, \dot{q}_{s,o}^k \quad (3)$$

These are time series equations in terms of surface temperatures and heat fluxes evaluated at equal time intervals. The superscript k refers to the term in the time series. The current time is k=0, the previous time is for k=1, etc. The timebase on which these calculations are based is specified by the user within the BID description. The coefficients of the time series (a's, b's, c's, and d's) are determined within the BID program using the z-transfer function routines of reference 3.

The long-wave radiation exchange between the surfaces within the zone and the convective heat flux from the inside surfaces to the zone air are approximated using the star network given by Seem (4) and represented in Figure 4.

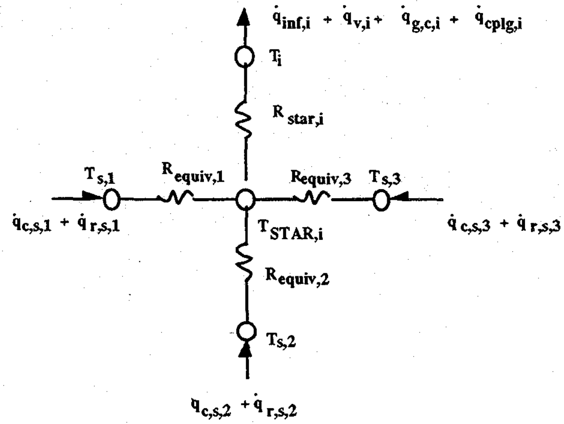

Figure 4 Star Network for a 3 surface zone.

Methods to calculate the resistances $R_{equiv,i}$ and $R_{star,i}$ can be found in reference (3). Area ratios are used in these calculations to find the absorption factors (the fraction of energy emitted by one surface which is absorbed by another surface) between all surfaces. The star temperature can be used to calculate a net heat flux from the inside wall surface:

$$\dot{q}_{comb,s,i} = \dot{q}_{c,s,i} + \dot{q}_{r,s,i} \quad (4)$$

then,

$$\dot{q}_{comb,s,i} = \frac{1}{R_{equiv,i}\, A_{s,i}}(T_{s,i} - T_{star,i}) \quad (5)$$

where

$q_{comb,s,i}$ = combined convective and radiative heat flux

$A_{s,i}$ = inside surface area

The set of energy balances written for all zones, results in a linear set of equations in average zone temperatures and average star temperatures. In matrix form the energy balance matrix becomes,

$$[X]\,[T] = [Z] \quad (6)$$

This matrix can be partitioned such that:

$$[X] = \begin{bmatrix} X_{11} & X_{12} \\ X_{21} & X_{22} \end{bmatrix} \quad (7)$$

$$[\mathbf{T}] = \begin{bmatrix} \overline{T}_1 \\ \overline{T}_2 \end{bmatrix} = \begin{bmatrix} \overline{T} \\ \overline{T}_{star} \end{bmatrix} \qquad (8)$$

$$[\mathbf{Z}] = \begin{bmatrix} Z_1 \\ Z_2 \end{bmatrix} \qquad (9)$$

$$\sum_{i\ to\ j}^{walls} \dot{m}_{cplg,s} + \dot{m}_{inf,i} + \dot{m}_{v,i}\ C_p + \frac{2\,C_i}{\Delta t} + \frac{1}{R_{star,i}} + \sum^{known\ boundaries} \dot{m}_{cplg,i} \qquad (10)$$

$$\sum_{i\ to\ j}^{walls} \dot{m}_{cplg,s}\, C_p \quad \text{for } i \neq j \qquad (11)$$

$$X_{12,ii} = -\frac{1}{R_{star,i}} \qquad (12)$$

$$X_{12,ij} = 0 \quad \text{-for } i \neq j \qquad (13)$$

$$X_{21,ii} = -\frac{1}{R_{star,i}} \qquad (14)$$

$$X_{21,ij} = 0 \qquad (15)$$

$$X_{22,ii} = \frac{1}{R_{star,i}} - \sum^{int.\ walls} A_s B_s + \sum^{surf.\ in\ i} A_s C_s \qquad (16)$$

$$X_{22,ij} = -\sum^{adj.\ zones} \sum_{i\ to\ j}^{walls} A_s B_s \qquad (17)$$

$$Z_{1,i} = \dot{m}_{inf,i}\, C_p\, T_a + \dot{m}_{cplg,s}\, C_p\, T_{b,s} + \dot{m}_v\, C_p\, T_v \qquad (18)$$

$$Z_{2,i} = \left(\sum^{ext.\ surf.} A_s B_s \right) T_a + \sum^{known\ bound} A_s B_s T_{b,s} + \sum^{surf.\ in\ i} A_s (D_s + S_{s,i}) \qquad (19)$$

For the case unconstrained zone temperatures,

$$[\overline{\mathbf{T}}] = [\mathbf{X}]^{-1} [\mathbf{Z}] \qquad (20)$$

The final temperature for each zone i is

$$T_{i,\tau} = 2\overline{T}_i - T_{i,\tau - \Delta t} \qquad (21)$$

3 TRNSYS FEATURES SPECIFIC TO BUILDING APPLICATIONS

TRNSYS has been used for numerous and varied building system simulations. Many components and utility tools have been developed during this process. These components and tools make future simulations even easier. Components that are not included in the standard TRNSYS component library are placed in TRNLIB.

3.1 TRNLIB

The components that have been collected have been placed into a library of components referred to as TRNLIB. With the broad base of components in TRNLIB, TRNSYS can be used for systems that incorporate both solar and conventional HVAC systems. The second goal of TRNLIB is to avoid having a TRNSYS user create a component that already exists somewhere else. If a TRNSYS model already exists, the effort should not have to be reproduced.

The models that we have collected are available to TRNSYS users in several ways. The most user-friendly and fastest way to access the component library is via the World Wide Web on the Internet at the following address: http://www.engr.wisc.edu/centers/sel/trnsys/index.html

A visitor to the World Wide Web site can view and download the FORTRAN source code as well as a description file that contains a physical and mathematical description of the component, a listing of the parameters, inputs and outputs, sample values, and further references. TRNLIB is one part of the Solar Energy Lab World Wide Web site that also contains other information about TRNSYS that is of interest to users. For TRNSYS users not familiar with the World Wide Web, they can also access our site via anonymous FTP and download the same description and source code files.

Models in the library have come from several sources. The primary source has been models developed by former students at the Solar Energy Laboratory. In addition to former students, several current TRNSYS users have submitted their models to the library. The Solar Lab also has an agreement with the American Society of Heating, Refrigeration, and Air-conditioning Engineers to make the Primary

(5) and Secondary (6) Toolkits of HVAC components available to TRNSYS users as TRNSYS types. The Secondary Toolkit contains flow components (pumps, fans, valves, flow mixers), heat and mass transfer components (heat exchanger, cooling coil, direct expansion air conditioner, etc.), control components (economizer, proportional controller) and several sample systems (CAV, VAV, etc.). The Secondary Toolkit was converted directly to TRNSYS format. The primary toolkit contains the primary HVAC equipment models including boilers, vapor compression chillers, absorption chillers, cooling towers, etc. The Primary Toolkit is in the final stages of being modified for use with TRNSYS.

The components in TRNLIB are grouped similarly to the standard component groupings as illustrated above. Several additional groupings have been added including:

IEA ANNEX 17 Components
ASHRAE Primary Toolkit Models
- Reciprocating Compressor Chillers
- Boilers
- Cooling Towers

ASHRAE Secondary Toolkit Models
- Simple Flow Components
- Detailed Flow Components
- Heat and Mass Transfer Components
- Control Components

Desiccants
PV-Thermal and Electrical Components
Turbines and Generators

In addition to the library of user-contributed components, several standard components have been added to TRNSYS with Version 14 that make it more easy to use with HVAC systems. These include the state properties for many standard refrigerants. The Single Zone Building model includes the ASHRAE wall and layer definitions and has been updated to 1993 standards. The Multi-Zone Building model has had extensive work done to it with the addition of a frame ratio definition for the window, coldbridges, wall gains, and improvements in the transfer function coefficients.

3.2 DOE2-TRNSYS Interaction

Models for HVAC equipment require a building model. Several steps have been taken to improve the ease with which a building can be modeled. One of these steps is the construction of a TRNSYS component that can read in DOE2 building load files. DOE2 (7) is a separate building simulation program supported by the Department of Energy and developed at Lawrence Berkeley Laboratory. DOE2 performs a simulation in several steps. First, the building is modeled using a program called BDL. Then, the latent and sensible loads for the building are generated using a program called LOADS. These loads are then input to a program called SYSTEMS. In SYSTEMS, the sensible and latent loads of the building zones are corrected for outside air requirements, schedules, controls, etc. The resultant file contains the necessary cooling coil and heating coil loads on an hourly basis. DOE2 then goes on to use the output of the SYSTEMS program to drive PLANT, that models the HVAC plants for the building.

A TRNSYS component has been constructed that reads in the output of the SYSTEMS program. In this way, the loads are calculated by DOE2 but the plant performance is calculated by TRNSYS. This linking of the programs gives TRNSYS users access to standard loads to use with their models for HVAC or solar equipment. The DOE2 user gets greater flexibility to model non-standard equipment, such as solar equipment, by using TRNSYS to model the plant. The TRNSYS interface is used like any other utility component and is similar to a weather data reader.

3.3 PREBID

In TRNSYS, a large multi-zone building is modeled in several steps. First, a rather complex file is constructed that describes the building from the thermal properties of the materials to the geometry of the individual zones and includes such variables as ventilation, infiltration, and occupancy schedules. This long text file, called the building description file, is then processed by a utility program called

BID. Using the information in the building description file, BID generates a file that contains the geometric information about the building and a second file that contains the transfer functions calculated for the walls in the building. Both of these files are then used by TRNSYS component in the TRNSYS input file. BID also creates a third file that tells the user what should be the parameters and inputs to the TRNSYS component. The longest and most arduous task of entering a building into TRNSYS has been constructing the initial text file that describes the building. Any mistakes in syntax or order of entries causes an error.

PREBID has been designed to alleviate the frustration associated with writing this text file. Designed by TRNSYS collaborators in Germany (TRANSSOLAR), PREBID radically decreases the time necessary to enter a building into TRNSYS. The building text file starts with the description of the different materials used in the building and builds up to describing the different zones within building. Within PREBID, the opposite is true. First, a user defines the number of zones. Then, a geometric description of the different walls used within the different zones is defined. At each level, the user is entering the information into a series of dialog boxes making it difficult to forget any pertinent information.

The latest version of PREBID includes wall and window libraries with 120 types of walls and 5 types of windows. Two materials libraries are also included. One contains standard (DIN 4108) materials and another contains an expanded group of materials. The user can also add commonly used materials, walls, and windows to the libraries.

4. STANDARD TRNSYS PROCEDURE

As an example, the case of designing and studying an HVAC system for heating and cooling a restaurant with 250 customers will be shown. The restaurant has two large front windows on the south side, a flat ceiling, a concrete slab-on-grade with indoor-outdoor carpeting, double pane windows, etc. What questions can be effectively answered by TRNSYS in this situation? Costs, comparisons of different sized equipment, problem zones (rooms) within the restaurant, and local weather implications are some of the issues that can be addressed with TRNSYS.

The TRNSYS user begins by determining which TRNSYS components would be necessary for the simulation. These components would include system components (such as cooling coils, pumps, thermostats, chillers, furnace or boilers, pipes), utility components (weather data reader, simulation control card, printer components, time dependent forcing functions, periodic integrators for output, refrigerant properties, economics component) and the multi-zone building component. Once the necessary components are determined, they must be obtained from the standard component library that is distributed with TRNSYS (all of the above), the on-line library, or created using standard FORTRAN and models of the components. The components must then be compiled and linked to form a new TRNSYS executable.

The user now must generate the building description files that will be used by Type 56. The information about the building can be entered by using PREBID or a text editor. This information is fed to the BID program which generates the transfer functions as well as the geometric file for the building which are imported by Type 56.

The next step in the simulation process is to generate the input file that describes the connections between the system components as well as the parameters that govern the simulation. The input file can be generated either using a simple ascii text editor (included in TRNSHELL) or by using PRESIM.

While the simulation is running, a new DOS utility, ONLINE, will display the current value of up to 10 simulation variables on the screen. ONLINE allows the user to monitor the progress of the simulation and also watch for obvious problems. The user can also construct a parametric table of variables and perform multiple runs in succession.

Following the simulation, the user can view output values within TRNSHELL, plot output values using the TRNSHELL plotting package, or port the ascii text output files to another post-processing package for further analysis.

5 CONCLUSIONS

Although originally designed for analysis of solar thermal systems, TRNSYS has been used extensively for more general HVAC applications. TRNSYS allows for the simulation and analysis of any thermal energy system (including HVAC systems) that requires transient analysis. An effort has been undertaken to make as many general HVAC components available to TRNSYS users as possible. These components have come from many sources including the ASHRAE Component Toolkits, HVACSIM +, IEA ANNEX 17 task, Solar Energy Lab graduate student theses and various TRNSYS users.

The building model uses transfer functions to model heat transfer through walls. The star method is used to calculate the temperatures for each node.

Improvements in the usability and scope of the building model have been made as well as the introduction of a component that allows TRNSYS to interprete DOE2 load files.

6 ACKNOWLEDGEMENTS

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