

TRNSYS

TRansient SYstem Simulations

Introduction to TRNSYS

- Why Simulate ?
- History of TRNSYS
- TRNSYS Concept
- Simulation Input
- Input File Keywords
- Simulation Output
- TRNSYS Family of Tools

Why Use Simulations ?

- Orders of magnitude **faster** than experiments
- Orders of magnitude **less expensive** than experiments
- Non-linear dependence on weather
- Variation on short and long time scales

Where is TRNSYS useful ?

- Component **OUTPUT** is a function of time
- Mathematical solution involves time-dependent differential equations
(ex. thermal storage devices)
- One or more of the component outputs is to be integrated over time

History of TRNSYS

- Public/government support to SEL
 - First public version was 6.0 in March 1975
 - Originally a PhD thesis by Sanford Klein
- Originally developed for solar processes
 - Current developments focus on building loads and HVAC systems
- TRNSYS ideas used in other programs:
 - DOE2, HVACSim+, TRACE, CA-SIS

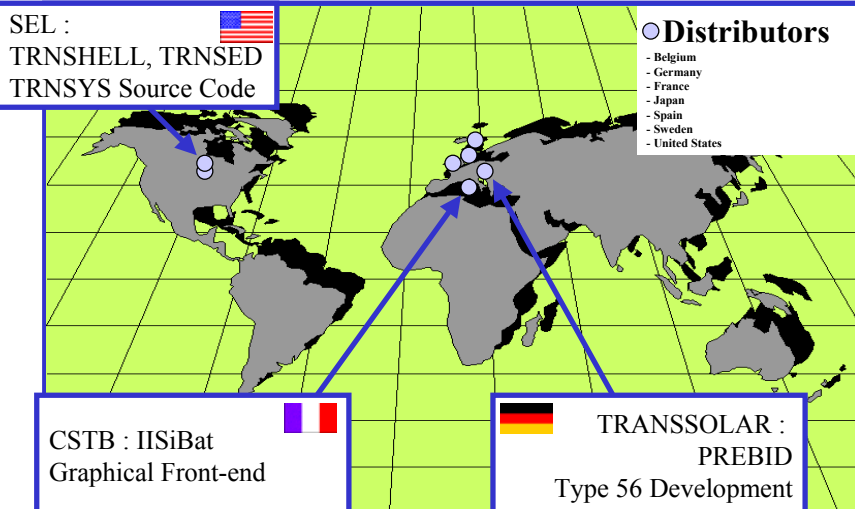
Cross-Section of Users

- Approx. 200 Universities worldwide
- National Renewable Energy Lab
- Florida Solar Energy Center
- National Institute of Standards and Technology (NIST)
- Sandia National Labs
- National Aeronautic and Space Administration (NASA)
- Sacramento Municipal Utility District
- Johnson Controls
- Bechtel Corporation
- Trane Company
- BMW
- Electricite de France
- PSA (Peugeot-Citroen)

Why has TRNSYS survived ?

- General Purpose (from PV cells to cows)
- Flexible (modular)
- General Component Formulation
- Open Source Code
- Documentation
- Model Exchange between users
- Continuous full-time **SUPPORT**

Cooperative TRNSYS Activities



Modular Approach

- Provides tremendous flexibility
- Well Suited for systems with time-dependent conditions
- Requires some expertise

What is TRNSYS ?

- Algebraic and differential equation solver
- Library of common thermal energy systems
- Method for adding user-written modules
- Designed especially for transient simulations
- Routines for input of weather and time-dependent forcing functions

TRNSYS Concepts

- Modular technique:
 - Large problem --> several smaller problems
- General Formulation
- Entire problem reduced to :
 - formulating mathematical models
 - describing interconnection process

System Definition

- Set of Components
 - Each component represents a physical structure
- Interconnected in order to accomplish a specified task
- Example : Solar System
 - Collector
 - Tank
 - Heat Exchanger
 - Pump
 - Controller

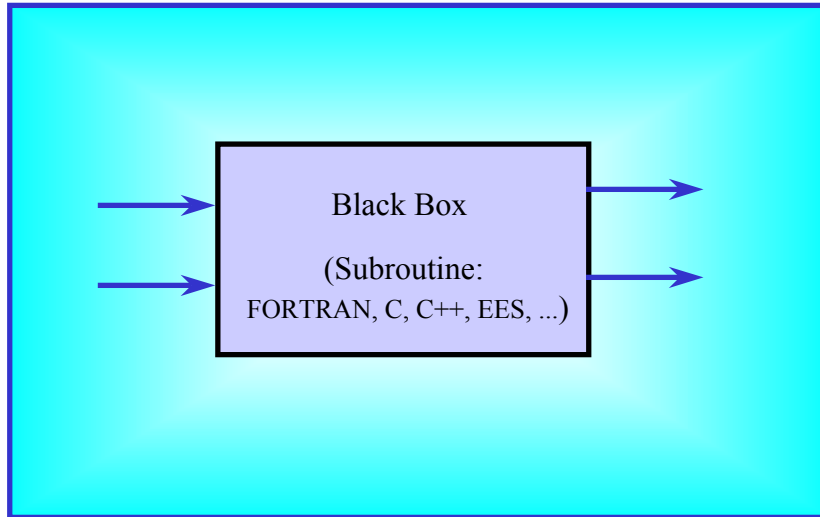
System Definition (Cont.)

- System consists of Components
- Therefore:
 - Simulate system performance by simulating the performance of the individual components.

Black Box Approach

- Requires two unique types of information
 - Parameters : time-independent quantities
 - Inputs : time-dependent quantities
- Provides desired variables as Outputs

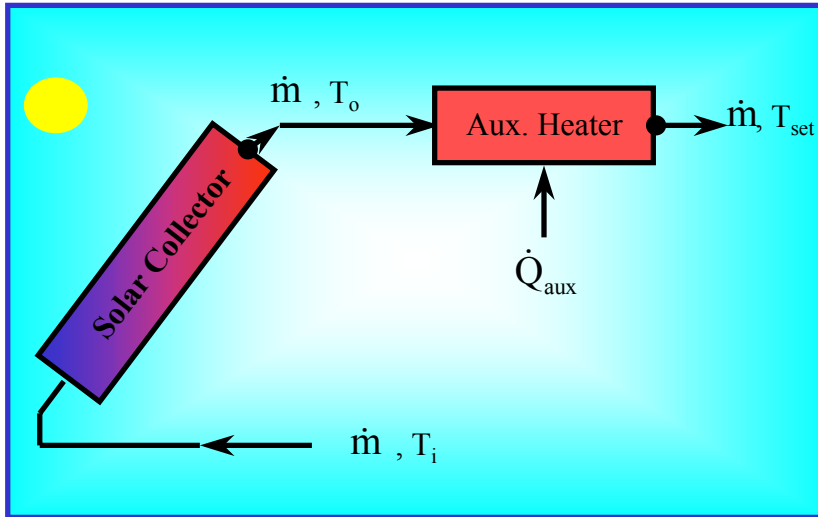
Black Box (Graphic)



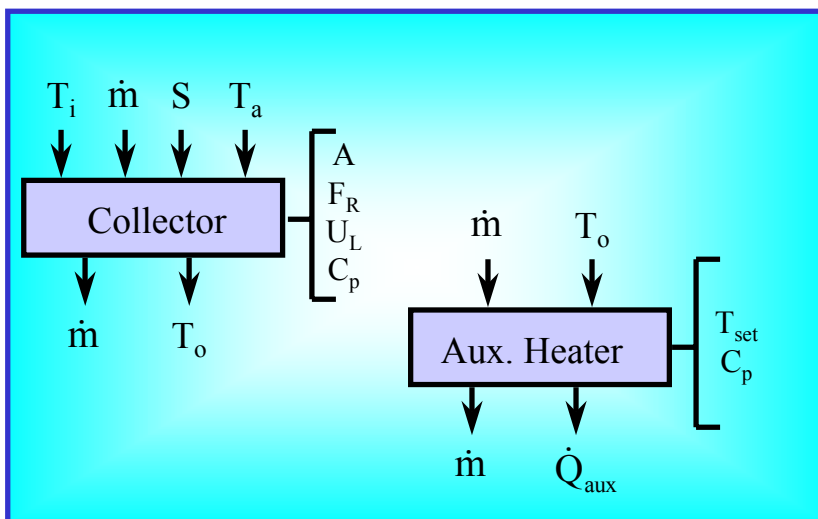
Information Flow

- Arrows into and out of components analogous to pipes and wires in a real system
 - Mass flow and temperature -> “pipe” information flow
 - Pump control signal -> information flow through a “wire”

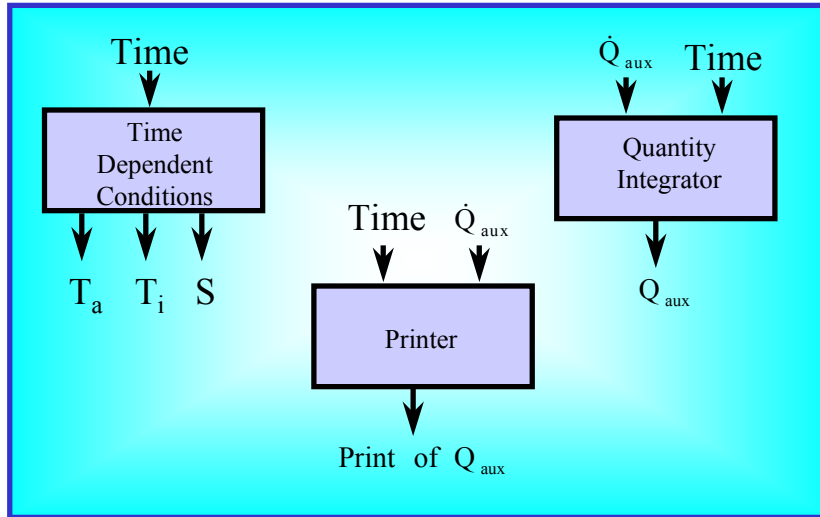
System Diagram



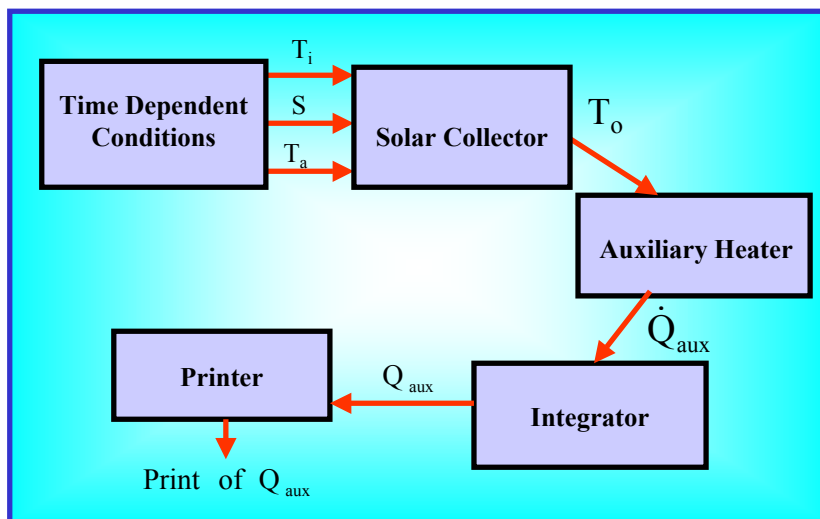
Information Flow



Information Flow (Cont.)



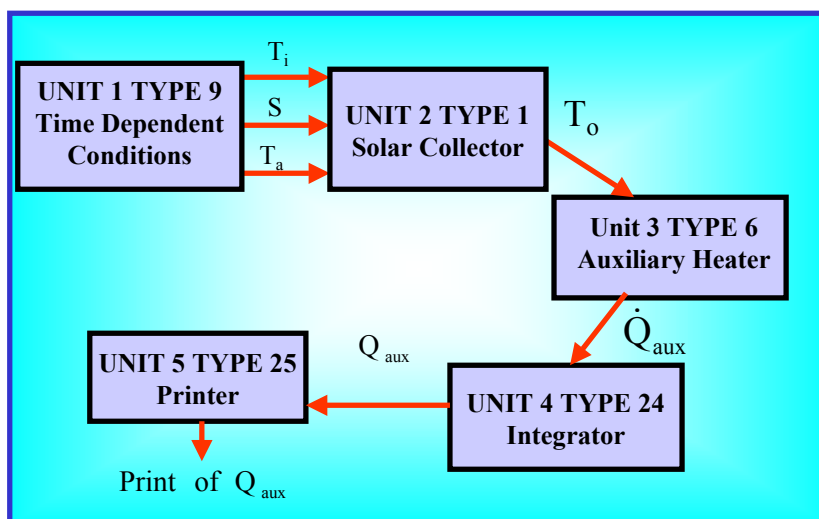
Information Flow Diagram



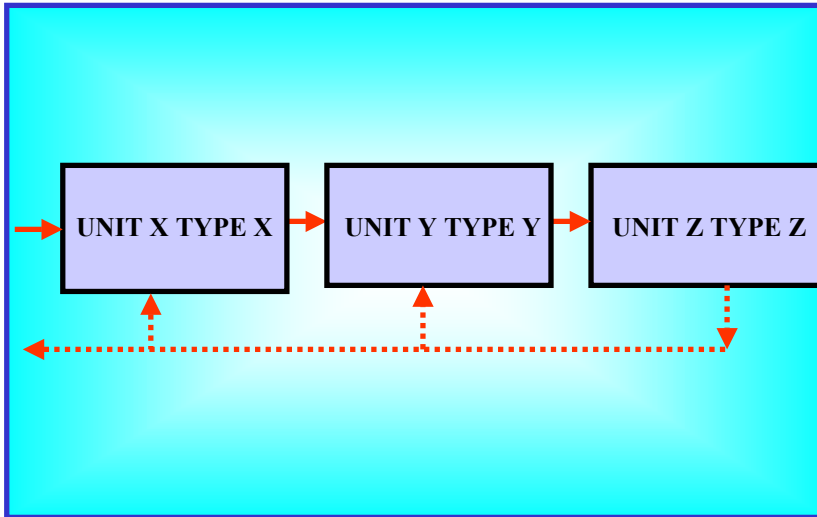
Input-Output Scheme

- TRNSYS list of components and interconnections
- Type Number
 - identifies the function of the equipment
 - each component given a unique Type number
- Unit Number
 - Ex: How to distinguish if more than one collector??
 - arbitrarily assigned value for each instance of a component (normally some pattern is used)
 - unique for each simulation (only one Unit 10)

Information Flow Diagram



Acyclic vs. Recyclic Information Flow



Available TRNSYS Components

- Three General Types of Components
 - Utility Components
 - ex: data reader, printer, plotter
 - Equipment Components
 - ex: chiller, solar collector, pump, fan
 - Physical Phenomena Components
 - ex: psychrometrics, radiation processor

Standard Components (1)

- **Utility Components**
 - Data Reader
 - Weather Data Generator
 - Radiation Processor
 - Time-dependent functions
 - Load Profile Sequencer
 - Algebraic Operations
 - Quantity Integrator
 - Periodic Integrator
 - Economics
 - Psychrometrics
 - Refrigerant Properties
 - Convergence Promoter
 - Unit Conversion Routine
- **Thermal Storage**
 - Stratified Liquid Storage Tank
 - Rockbed
 - Algebraic Tank
- **HVAC Equipment**
 - ON/OFF Auxiliary Heater
 - Absorption Air conditioner
 - Dual-Source Heat Pump
 - Conditioning Equipment
 - Cooling Coil
 - Cooling Tower
 - Vapor Compression Chiller
 - Desiccant Systems

Standard Components (2)

- **Building Loads and Structures**
 - Energy/(Degree Day) House
 - Detailed Single-zone
 - Detailed Multi-zone
 - Roof and Attic
 - Overhangs and Wingwalls
 - Window
 - Thermal Storage Wall
 - Attached Sunspace
- **Hydronics**
 - Pump
 - Fan
 - Mixing Valve/Tee
 - Pressure Relief Valve
 - Pipe/Duct
- **Heat Exchangers**
 - Heat Exchanger
 - Waste Heat Recovery
- **Controllers**
 - Differential Controller
 - 3 Stage Room Thermostat
 - Microprocessor Controller

Standard Components (3)

- Electric Components
 - PV/Thermal Collector
 - Storage Battery
 - Regulator/Inverter
 - Combined PV subsystem
- Output Components
 - Printer
 - Plotter
 - Histogram Plotter
 - Simulation Summarizer
 - On-Line Printer
- Solar Collectors
 - Thermal Efficiency Map
 - Detailed Performance Map
 - Theoretical CPC
 - Incidence Angle Modifiers
 - Theoretical Flat-Plate
 - Air Collector-Storage Subsystem
 - Domestic Water Heating Subsystem
 - Collector Array Shading

Non-Standard Components

- TRNLIB - Online Library of User Written components
 - ASHRAE Toolkits
 - HVACSIM+ Models
 - SEL Student written components
 - Any user can contribute components here
- Commercial Non-Standard Libraries
 - TESS (Thermal Energy Systems; USA)
 - Transsolar (Germany)

Transsolar Non-Standard Components

- **Building Components**
 - Multizone Building Model with transparent Insulation
 - Interzonal Airflow
- **Thermal Storage Components**
 - Floor Panel Heating / Hypocaust Thermal Storage
 - Seasonal Ground Heat Storage (Multiport Pit Storage Model)
 - Multi-port Tank Storage Model
 - ICEPIT Pit Storage Model for Heat and Cold Storage
 - Indoor and Outdoor Pool Model

Transsolar Non-Standard Components

- **Solar and HVAC Components**
 - Detailed Solar Collector Model w/ Capacity and Quadratic Loss Coef.
 - UNICOL unglazed Collector
 - Window Collector Model
- **HVAC Components**
 - Gas fired Aux. Heater with Flue Condensation
 - Static and Dynamic Radiator Models
 - Electric and Gas Driven Compression Heat Pump
- **Controller Components**
 - PID-Controller
- **TRNSPID Dynamic Parameter Identification with TRNSYS**

TESS Non-Standard Components (1)

- HVAC Components
 - 2-Speed Fan
 - 5-Stage Room Thermostat
 - Residential Cooling Coil
 - Simple Single-Zone Building
 - 10-Port Flow Mixer
 - 10-Port Flow Diverter Heat Exchanger with Hot-Side Bypass
 - Modified TYPE 3 Fan
 - Modified TYPE 6 Auxiliary Heater (Simple Furnace)
- Ground Coupled Heat Pump Components
 - Buried Horizontal Pipe
 - Ground Temperature Model
 - U-Tube Vertical Ground HX
 - Tube-in-Tube Vertical Ground HX
 - Water Source Heat Pump

TESS Non-Standard Components (2)

- Utility Components
 - ASHRAE Infiltration Model
 - Ground Temperature Model
 - Sky Temperature Model
 - Equipment Fouling
 - ASHRAE Occupancy Loads
 - Night Setback/setup model
 - Heating and Cooling Season Model
 - Average Day Creator for 2 Inputs
 - 2-Dimensional Bin Sorter

Simulation Input

- Weather files
 - TMY, TMY2, non-standard
- Load files
 - drives the use of energy
- Complete TRNSYS Input file (.dck)
 - tells TRNSYS what to do
 - components and connections
- For multizone building simulation:
Building information files (describe the building)
 - output of PREBID

Weather Files

- TMY (Typical Meteorological Year)
 - hourly weather for 230 locations in US & Canada
- TMY2
 - Recently released (1996) update to TMY
 - Better data
 - Available free from NREL website
 - Readable now, standard mode in TRNSYS 15

Weather Data (2)

- **TRNSYS TMY**
 - modified TMY files
 - unnecessary values removed for size
 - 4 US cities included in standard package
 - 230 US/Canadian Cities available for download at SEL website
- **Non-Standard**
 - any data file can be read in
 - formatted or free formatted file reading (Type9)

TRNSYS Input File Example

```

SIMULATION 0.0 72.0 1.0

UNIT 16 TYPE 16 SOLAR RADIATION PROCESSOR
PARAMETERS 9
3 1 1 152 43.1 4871 0. 2 -1
INPUTS 6
1,1 1,19 1,20 0,0 0,0 0,0
0. 0. 0. 0.2 40 0.

UNIT 4 TYPE 1 FLAT-PLATE COLLECTOR
PARAMETERS 14
1 1 6.5 4.19 1 50 0.7 15 0.0 -1 4.19 1 0.1 0.0
INPUTS 10
3,1 3,2 3,2 1,2 16,6 16,4 16,5 0,0 16,9 16,10
20 200 200 15.6 0.0 0.0 0.0 0.2 0.0 40.
    
```

Input File Keywords

SIMULATION t_o t_f Δt

- t_o - is the hour of the year at which the simulation is to begin.
- t_f - is the hour of the year at which the simulation is to end.
- Δt - is the timestep to be used (hours; fractions are possible: ex. 0.5 = half an hour).
- Every simulation must have this command
- Fixed Timestep: Cannot be varied during simulation

Input File Keywords

END

- The END statement must be the last line of a TRNSYS input file.

Input File Keywords

UNIT n TYPE m Comment

where

- n - is the UNIT number of the component.
- m - is the TYPE number of the component.

- Allowable TYPE numbers are integers between 1 and 300.
- Examples:

```
UNIT 6      TYPE 15 EXAMPLE COMPONENT
UNIT 26     TYPE 26 PLOTTER
UNIT 1      TYPE 4   TANK
```

Input File Keywords

PARAMETERS n

where

- n is the number of PARAMETERS to follow on the next line(s).
- Normally, this value is the number of parameters required by the component
- Example:

The TYPE 3 pump model requires 4 PARAMETERS:

```
UNIT 1 TYPE 3 PUMP
PARAMETERS 4
100. 4.19 100. 0.2
```

Input File Keywords

INPUTS n

where

- n - is the number of INPUTS to follow on the next line(s).

$u_1, o_1 \quad u_2, o_2 \quad \dots \quad u_i, o_i \quad \dots \quad u_n, o_n$

where

- u_i - is the number of the UNIT to which the i th INPUT is connected.
- o_i - is the OUTPUT (i.e., the 1st, 2nd, etc.) of UNIT number u_i

$V_1, V_2, \dots, V_i, \dots, V_n$

where

- V_i - is the initial value of the i th INPUT variable.

Input File Keywords

- Complete example of one component in the input file

```
UNIT 1 TYPE 4 TANK
PARAMETERS 6
2 .42 4.19 1000 1.44 -1.69
INPUTS 5
2,1 2,2 3,1 3,2 0,0*
60. 0.0 21. 0.0 60.*
```

- * Note the use of the constant input feature.

Input File Keywords

* Comment

- The '*' must appear first on the line
- The entire line is printed without modification.
- Example:
 - *THIS IS AN EXAMPLE OF A COMMENT LINE
 - *THIS IS ANOTHER ONE
 - *ETC.

Input File Keywords

EQUATIONS n
NAME1 = ... equation 1 ...
NAME2 = ... equation 2 ...
...
NAMEn = ... equation n ...

- Equations define variables that can be used as component inputs or equations
- Variables can be defined as:
 - algebraic functions of constants
 - previously defined variables
 - outputs from other TRNSYS components
- Various built-in functions are allowed (AND(), MAX(),MIN()...)

Input File Keywords

SOLVER k

where k is 0 or 1.

- 0 - Successive Substitution
- 1 - Powell's Method

- Optional: If a SOLVER card is not present in the TRNSYS input file, SOLVER 0 is assumed.
- Powell Method not normally necessary

Input File Keywords

ASSIGN filename lu

where

- filename - is the full name of the desired file; filename must be less than or equal to 40 characters in length
- lu - is the logical unit number to which filename is to be assigned
- The logical unit can then be used as a parameter in other components

- ASSIGN \ TRNWIN\ TEST\ TEST.LST 6
- ASSIGN \ TRNWIN\ TEST\ TEST.OUT 10
- ASSIGN \ TRNWIN\ TEST\ TEST.PLT 11

Input File Keywords

TOLERANCES ε_D ε_A or TOLERANCES $-\zeta_D$ $-\zeta_A$

- ε_D is a relative (and ζ_D is an absolute) error tolerance controlling the integration error
 - ε_A is a relative (and ζ_A is an absolute) error tolerance controlling the convergence of input and output variables
- Important to adjust ε_A if there are convergence problems with the simulation
 - Optional keyword: Default value of 0.01 is used

Input File Keywords

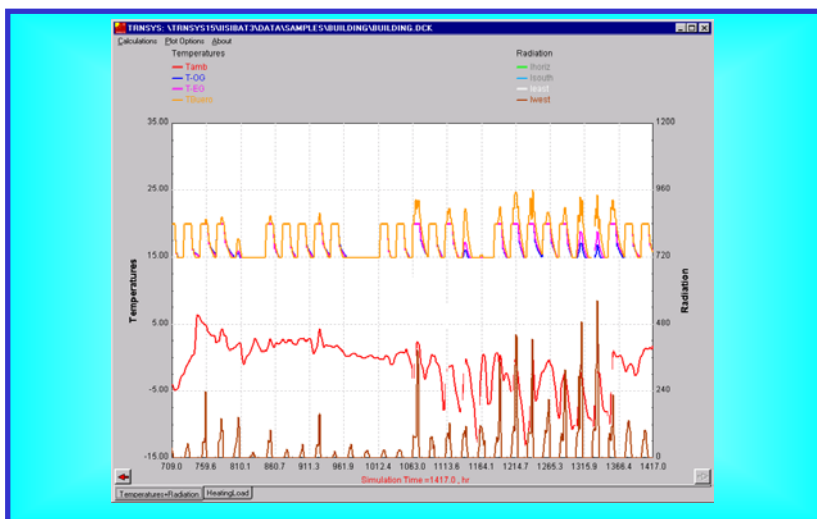
LIMITS m n p

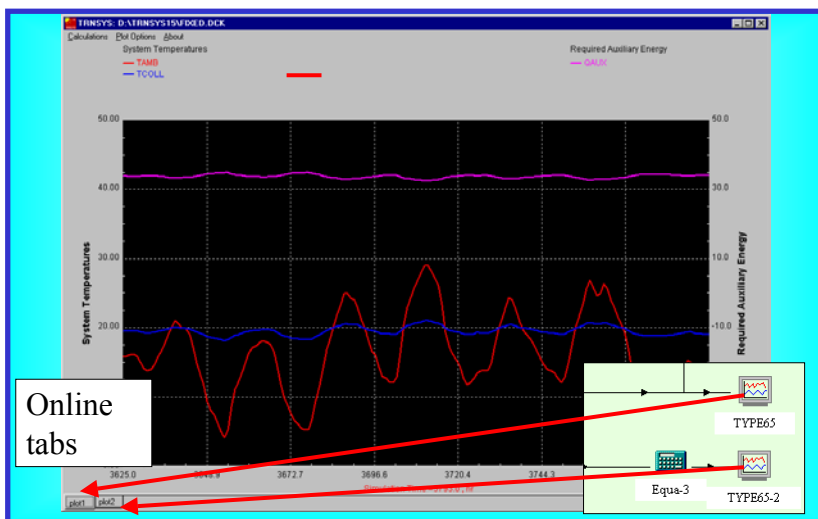
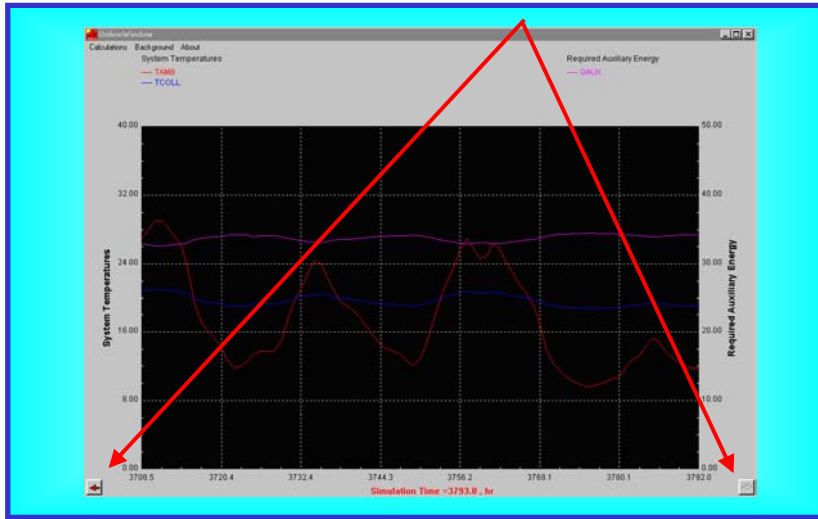
- m is the maximum number of iterations which can be performed during a time-step before a WARNING message is printed out.
 - n is the maximum number of WARNING messages which may be printed before the simulation terminates in ERROR.
 - p is an optional limit to turn on tracing.
- Important to increase the LIMITS command if convergence problems
 - Optional Command : Default value or m=20 and n=50 is used

Simulation Output

- Standard Printer (Type 25)
 - creates ASCII text files
 - able to specify printing interval (every timestep, once a day, etc.)
- Online Printer (Type 65)
 - plots input values to the screen during a simulation

Online Printer



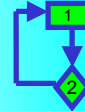


TRNSYS Solvers

- Successive Substitution (Solver 0)

- Algorithm:

- 1. For each unit, outputs are calculated for the given inputs; outputs are passed as inputs to other units
- 2. As long as the system doesn't converge, step 1 is repeated



- Many iterations can be necessary
- The original and still most common solution method
- Best method for standard problems
- Systems which may cause problems:
 - Little or no capacitance (energy storage)
 - Rapidly changing systems with many discrete states

TRNSYS Solvers (2)

- Powell's Method (Solver 1)

- Generates a matrix using input-output connections
- Solves the input-output matrix of simultaneous "equations"
- Has the ability to backsolve problems
- Requires more component calls each time step
- Difficulty with certain components with internal storage (pipe, Type 56)
- Excellent for simulations with no capacitance (PV systems) or discrete control states

TRNSYS Tools



IISiBat

- graphical front-end for TRNSYS



PREBID

- graphical tool for entering building information



TRNSED / TRNSHELL

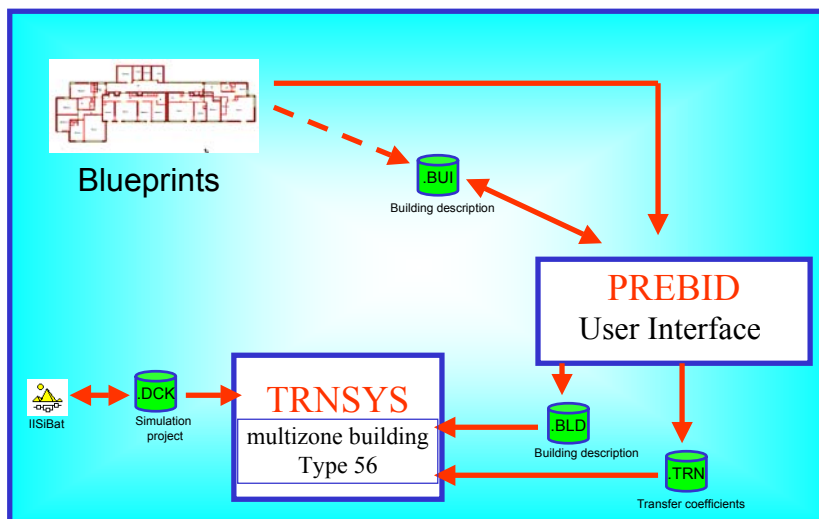
- tool to share simulations with non-users
- environment for building TRNSYS-based applications



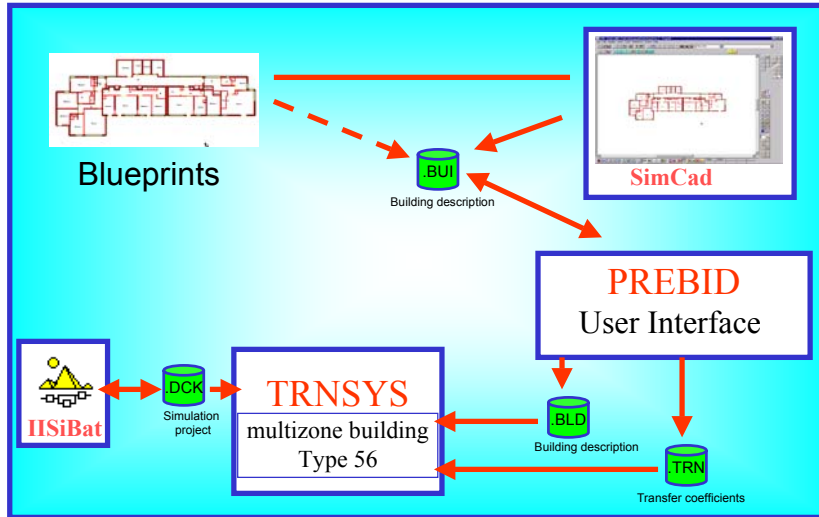
SimCad

- CAD tool for building Simulation (add-on product)

PREBID



Extension: SimCad



TRNSED (1)

- Utility program for sharing TRNSYS simulations with non-TRNSYS users
- Hides unimportant TRNSYS details
- Able to display user-selected values (parameters, constant inputs, etc.)
- Ideal for new users
- Can be distributed to anyone

- Pop-up menus
- Range checking for input values
- Provides complete system description
- User-friendly format
- Dual Unit systems allow display of any units
- Context-Sensitive Help

The screenshot displays the TRNSYS software interface for a 'Swimming Pool Air Conditioner Simulation - SPAC'. The main window shows a schematic diagram of the system. A 'Swimming Pool Parameters' dialog box is open, detailing the following information:

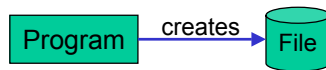
- General Information:** Pool Area (25.00 m²), Pool Depth (1.50 m), Pool Start Temperature (17.00 C), Shelter mode (Normal Shelter), Water Surface Activity (light surface motion/private pool).
- Swimming Pool Cover Information:** Thickness (0.01 m), Conductivity (0.18 A/J/m-K), Emittance/Absorption (0.60).
- Simulation Parameters:** Month of simulation start (May), Day of Month for Simulation Start (1), Month of simulation Stop (October), Day of Month for Simulation Stop (1), Ground Reflectance (0.15).
- Weather Data Mode:** WWTZ Weather Data, Weather Generator.
- Location:** Weather Generator, City for Simulation (MADISON, WI).
- Precipitation Mode:** Provide Precipitation Data in a File, Enter Data in a Table, Don't Calculate Water Loss.

A 'Pool Cooling System' dialog box is also visible at the bottom right, and a 'DataWindow' plot shows temperature fluctuations over time.

• TRNSYS	
➤ Input	
• *.dck	Input file, no TRNSEED (from IISiBat 3)
• *.trd	Input file with TRNSEED commands (from IISiBat 3)
• *.tpf	TRNSYS project file (for IISiBat 3)
• *.tmy, *.tm2, *.dat, ...	Weather data
• *.bui	User-readable Building description file (for PREBID)
• *.trn, *.bld	Internal Building description files (from PREBID)
• w4-lib.dat	Window Library
• *.lib	Library files (layers, walls for PREBID)
• *.for	FORTRAN Sourcecode
• *.tmf	TRNSYS model file (for IISiBat 3)
➤ Output	
• *.lst	Listing (Result) file
• *.plt, *.out, *.xls, ...	(Any extension chosen by the user)

• COMIS	
➤ Input	
• *.cif	Input File (from IISiBat 2)
• *.set	Set-file for expert options
• *.cmf	Meteo schedule data (any extension allowed)
• *.csm	Multi schedule data
• *.csf	Other schedule data
• *.daf, *.tmf	Internal, temporary time management files
➤ Output	
• *.cof	Standard output
• *.cso	Spreadsheet output files
• *.cho	Histogram output files
• *.cer	Error file

- SimCad
 - Input
 - *.dxf AutoCad drawings
 - *.ifc Industry Foundation Class file
 - Output
 - *.bui Building description file for PREBID



Data Flow

