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TRNSYS

TRansient SYstem Simulations

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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
- Electricitie de France
- PSA (Peugeot-Citroen)

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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

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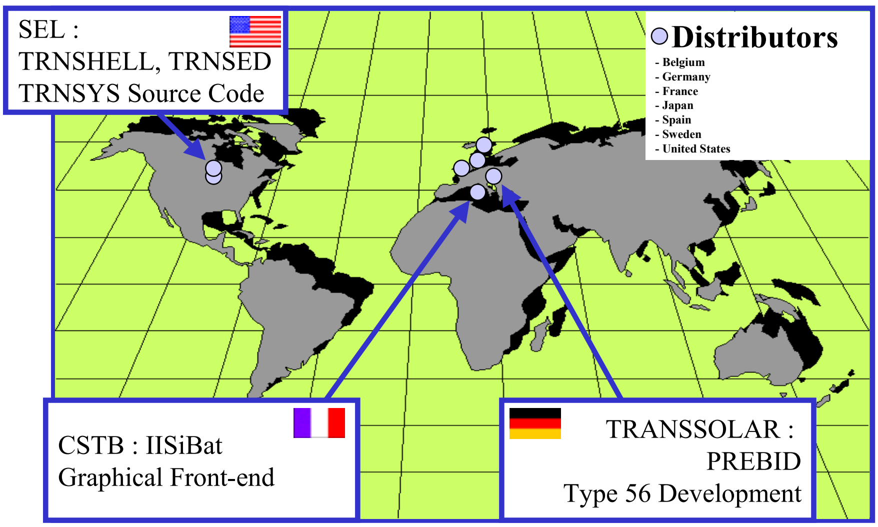
Cooperative TRNSYS Activities



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.

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Black Box Approach

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

Introduction to TRNSYS
N. Blair / W. Keilholz

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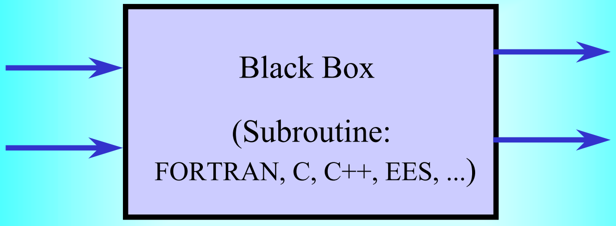
Black Box (Graphic)



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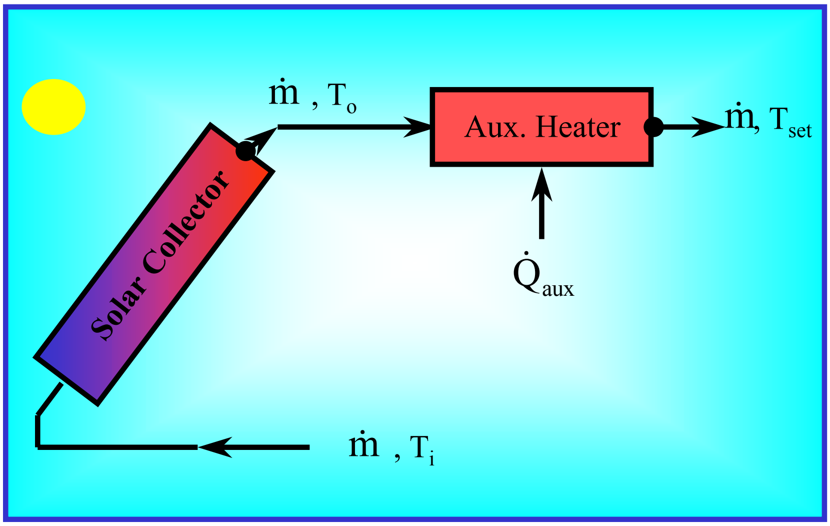
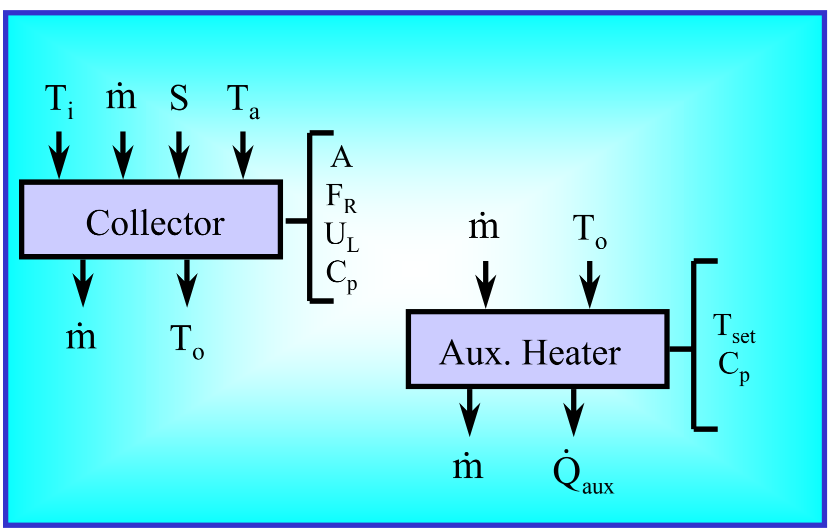
Information Flow

- 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



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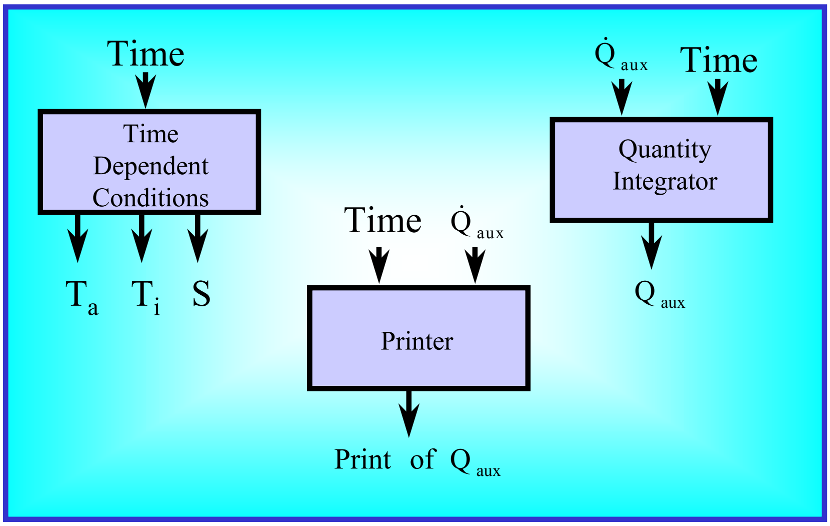
Information Flow (Cont.)



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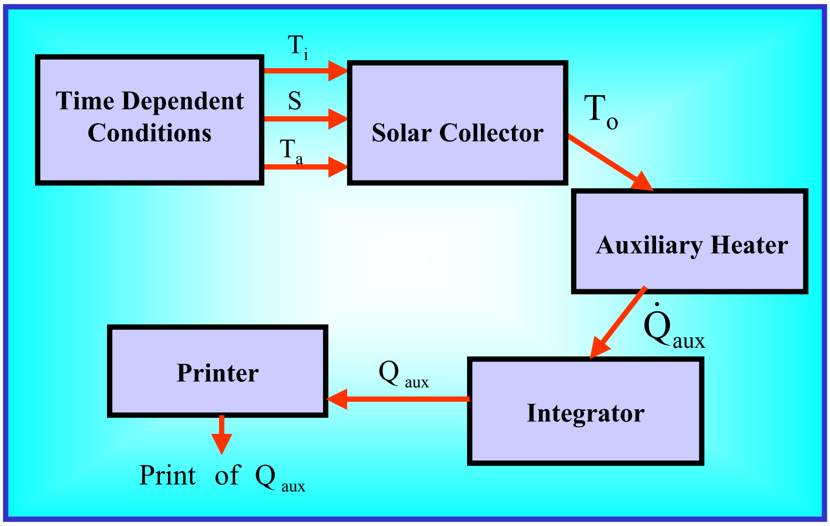
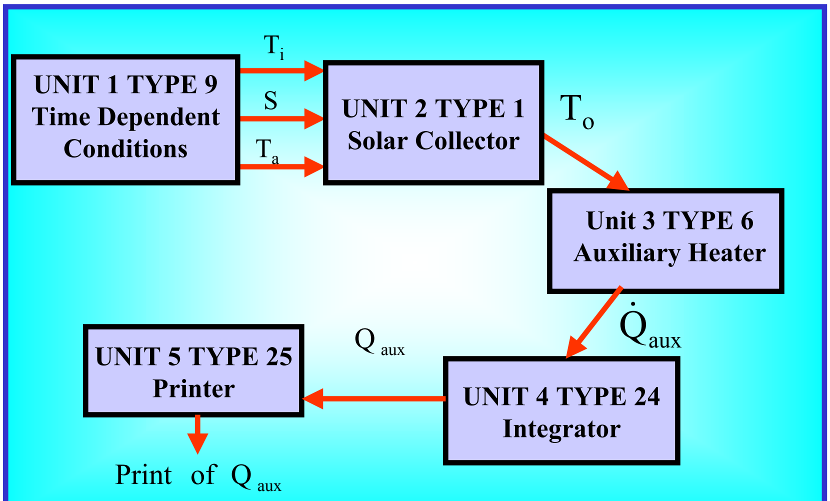
Information Flow Diagram



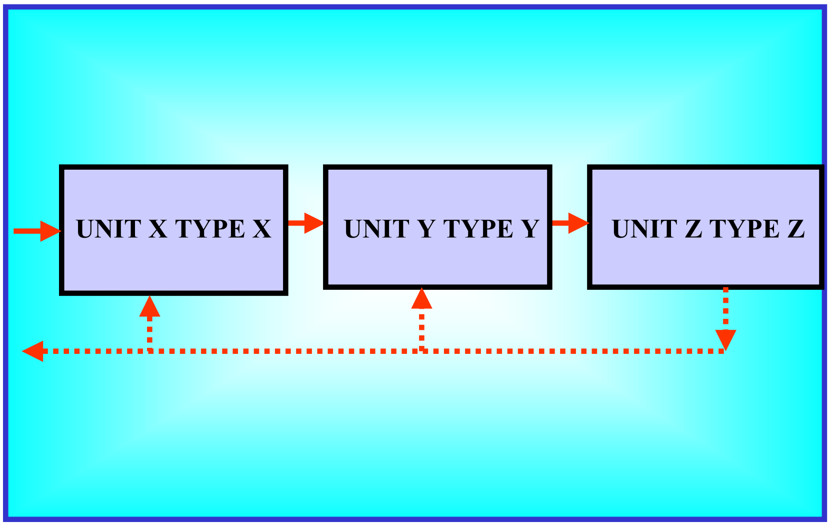
Input-Output Scheme

- 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
- Heat Exchangers
  - Heat Exchanger
  - Waste Heat Recovery
- Hydronics
  - Pump
  - Fan
  - Mixing Valve/Tee
  - Pressure Relief Valve
  - Pipe/Duct
- Controllers
  - Differential Controller
  - 3 Stage Room Thermostat
  - Microprocessor Controller

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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

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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)

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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

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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

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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

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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).

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

where

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

$V_1, V_2, . . . , V_i, . . . , V_n$

where

- V_i - is the initial value of the ith INPUT variable.

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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

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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

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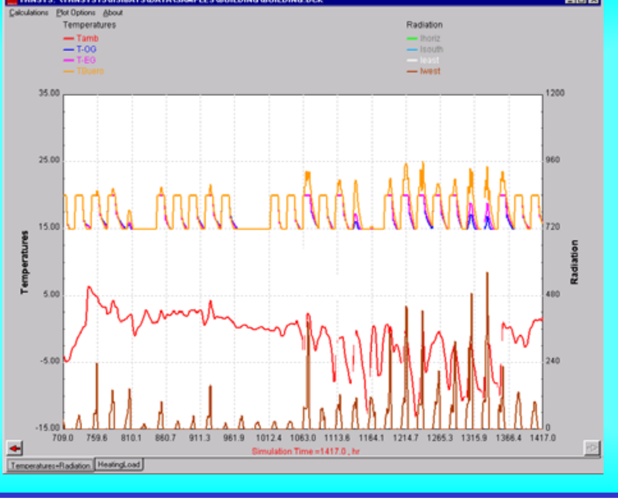
Online Printer



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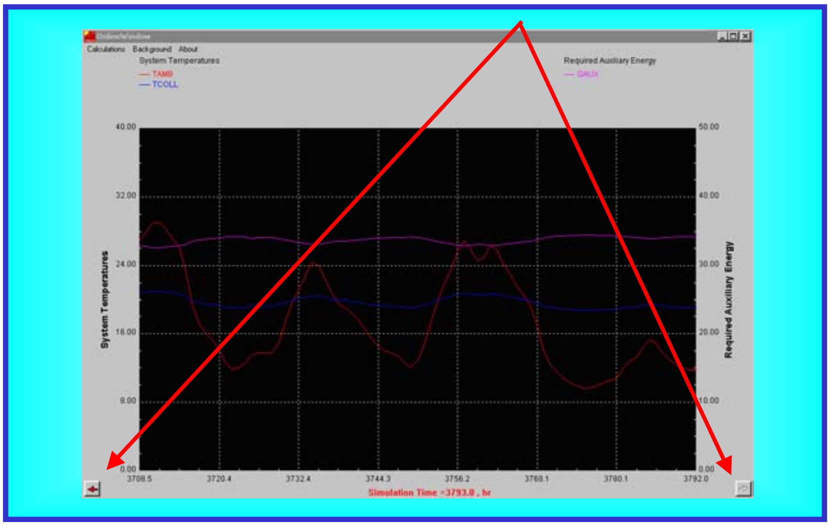
Go back on time



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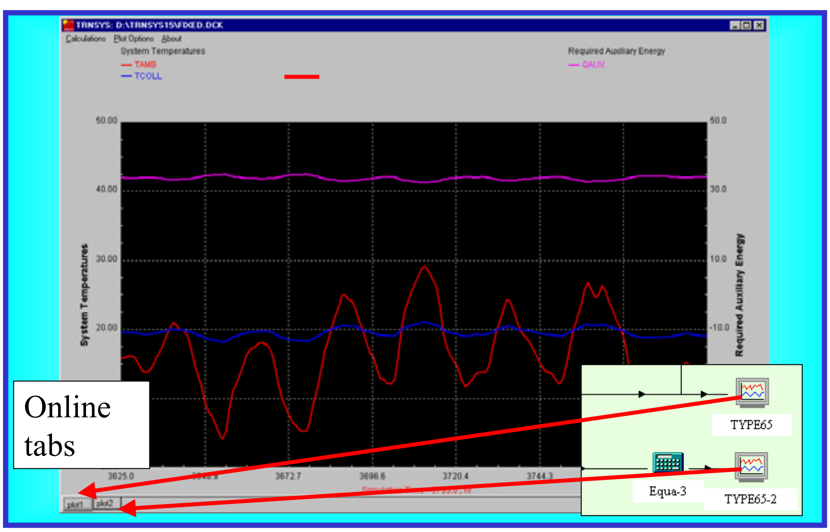
Several Onlines



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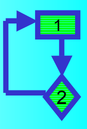
TRNSYS Solvers

- 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

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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

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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)

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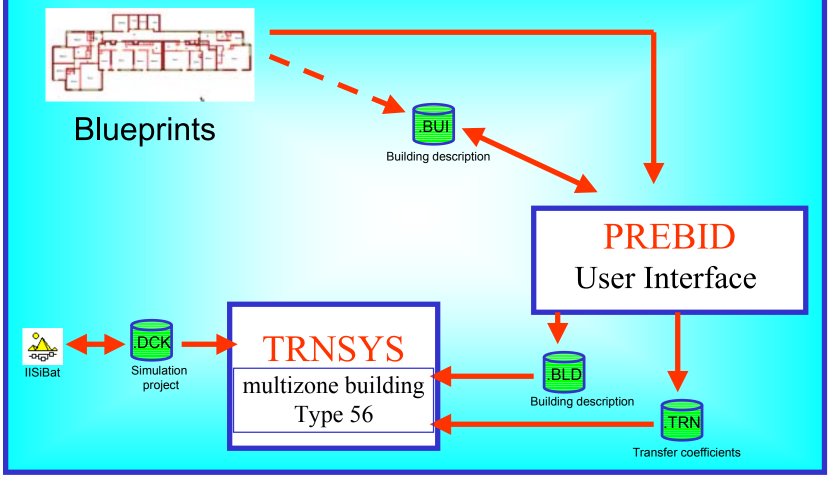
PREBID



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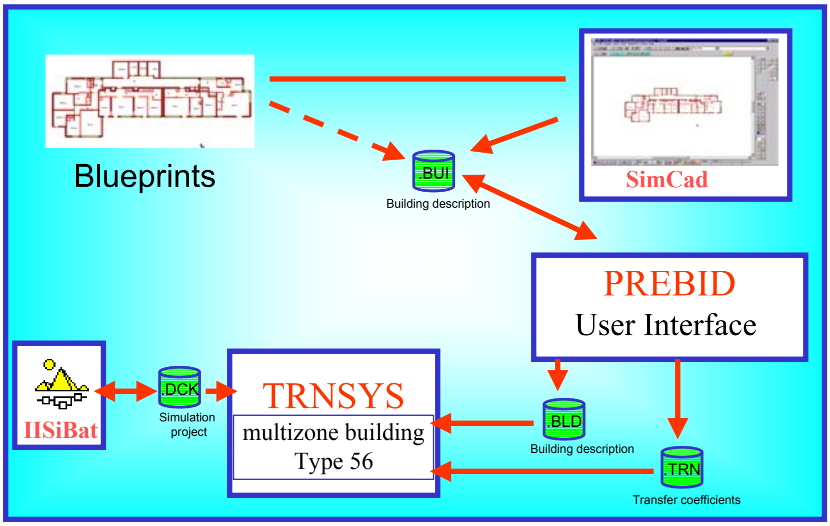
Extension: SimCad



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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

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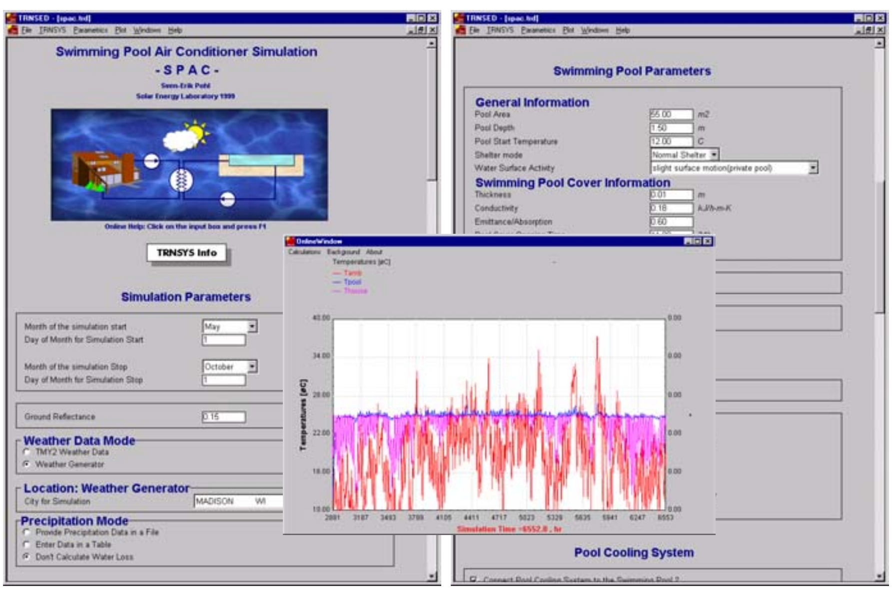
TRNSED (2)

- 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



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File types

- TRNSYS
  - Input
    - *.dck — Input file, no TRNSED (from IISiBat 3)
    - *.trd — Input file with TRNSED 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)

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File types (2)

- 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

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File types (3)

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

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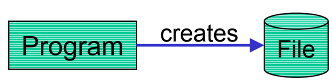

Data Flow