

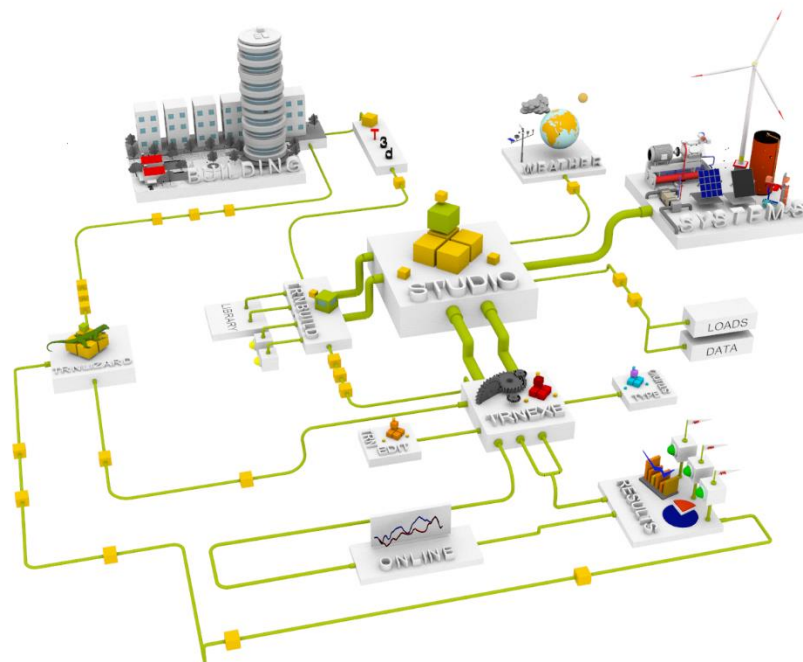
TRNSYS

the dynamic building and plant simulation program

Brief description

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1 Introduction

TRNSYS (spoken Transys) is derived from the "Transient System Simulation" [1]. It is a modular and flexible simulation environment; whose possible applications range from the dynamic simulation of a simple solar thermal system to complex buildings and systems.

Since the first official software release by the University of Wisconsin - Madison, USA in 1975, TRNSYS has been continuously developed and is now maintained by an international development team. TRNSYS is a standard tool for experts worldwide for energy concept development and evaluation.

The thermal simulation of buildings and facilities is an important tool in integrated building design, which considers architecture, materials, structure and building services as a mutually interdependent system. The development of energy-efficient building concepts, especially those that include natural ventilation, night ventilation and the use of natural resources for energy supply, often requires proof of function and proof of comfort conditions for occupants with the help of dynamic simulation methods, since static methods do not adequately represent the usually complex building behavior. Dynamic simulation with TRNSYS can be used to predict the indoor climate and energy requirements for a building depending on the location, quality of the envelope, ventilation concept and system technology. Detailed calculations of solar gains, long-wave radiation exchange between room surfaces and the thermal storage behavior of the building components allow a well-founded evaluation of thermal comfort in buildings.

In later planning phases, TRNSYS can be used to develop and optimize control strategies, while during commissioning, targeted fault diagnosis and subsequent optimization of control parameters is possible. Monitoring campaigns can also be accompanied during operation and optimization approaches can be planned and evaluated.

TRNSYS stands out due to numerous features including:

- the optional coupled or separate simulation of buildings and plant systems (no limitation to the building);
- the modular structure of individual components and the flexibility in linking them, so that there is no limitation to systems;
- a large standard component library as well as the possibility of integrating many available additional components, e.g. for geothermal energy use or air flow in the building;
- the ability to include user defined own equations in the simulation;
- a powerful multi-zone building model with integrated models for thermo-active components such as concrete core activation, floor heating, capillary tube mats as well as detailed models for the calculation of short and long wave radiation exchange;
- the open source code of almost all components and the computational core;
- the program structure based on DLL (dynamic link libraries), which allows the integration of user or third-party developed component models independent of the programming language used (C, C++, PASCAL, FORTRAN, etc.);
- the possible coupling with other programs, such as EXCEL, Matlab, Radiance, etc;
- the possibility of automated variant creation and optimization by other programs, such as GenOpt, Modelica, etc;
- the free selection of the output sizes and the time interval of the result output;
- the international use.

Typical output data of a simulation are usually system temperatures, mass or volume flows as well as thermal or electrical power or energy quantities. For the specific case of a building, the most important results are air and surface temperatures, operative temperatures, solar radiation on surfaces, relative or absolute humidity and various comfort indices. In addition, sensitive and latent heat requirements for heating and cooling and for humidifying and dehumidifying the air are calculated and output.

Each output quantity can be output for each time step or as an average value over freely selectable time intervals. Energy quantities are calculated as an integral of the outputs over the specified time period.

2 Simulation Basics with TRNSYS

An important feature of TRNSYS is its open, modular structure, which allows the user to combine individual components to form any system.

For project set-up, the user can use the graphical simulation environment TRNSYS Studio, in which the components are selected, parameterized and linked and the simulation started.

Figure 1 shows a solar thermal system in TRNSYS Studio.

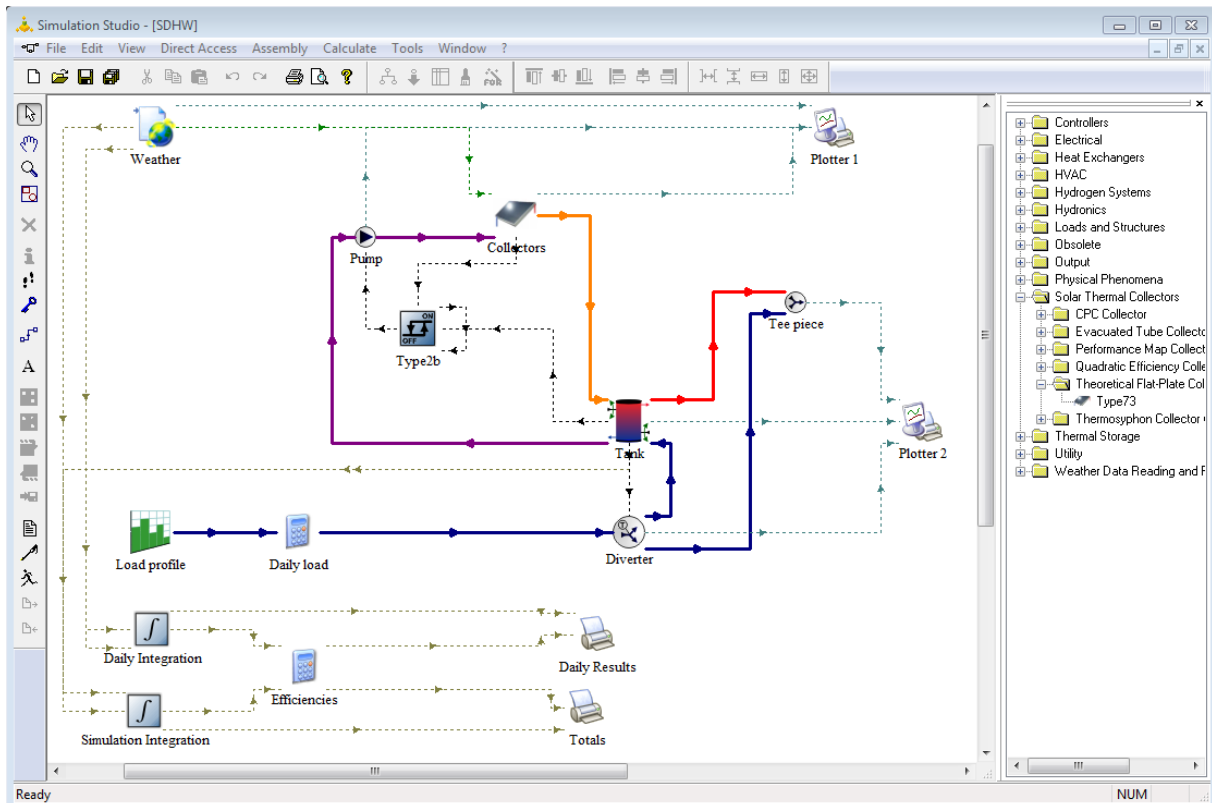


Figure 1. Solar thermal system TRNSYS Studio

Components can be components of the system to be depicted, such as collector or storage tank etc., or auxiliary components such as a weather data reader or a result output. The required system components are selected from the program or project library or can be copied from already existing projects. In addition to the large standard library contained in TRNSYS, many other components and libraries are available. Furthermore, user's own components can be added and coupled simulations can be performed (see section 2).

Each component is represented by an icon in the TRNSYS Studio. Data sheets for the respective mathematical component model are available for each component and their variables are defined in TRNSYS Studio. Depending on the definition in the mathematical model, different variable types are distinguished:

- PARAMETERS - are model variables for the exact specification of the component (e.g. collector area). They are set at the beginning of the simulation and remain constant over the whole simulation period.
- INPUTS - Input variables are model variables that change during the simulation (e.g. solar irradiation on a surface). A start value must be defined for each input variable.
- OUTPUTS - Output variables are variables calculated during the simulation by a component model (e.g.: outlet temperature of the collector)
- DERIVATIVES - are the starting values for variables of the differential equations describing the mathematical component model, which are solved by the solver implemented in the main TRNSYS program.

In addition to the described variables, other interfaces can be defined during component configuration, e.g. the names of external files whose contents are read in by the TRNSYS component during simulation or written to the calculation results. Examples for components which read in external files are weather data readers and the building model, while printer components write result data to external files.

The components are linked to each other by using the OUTPUTS of one component as INPUTS to other components. The information flow from one component to another is defined by a connecting line between the components drawn in TRNSYS Studio. Several variables, e.g. temperature and mass flow, can be assigned to a connecting line.

In addition to the configuration of the project components, all parameters relevant for the simulation, such as start and end time, time step size, numerical tolerances and solution methods are defined in TRNSYS Studio.

From the project data TRNSYS Studio generates the control file for the simulation, the so-called DCK file, and starts the simulation. The dynamic simulation is controlled by a calculation kernel, which reads the system definition and solves the resulting systems of equations. A successive insertion method is often used for the solution. The output quantities of the components calculated in each time step are usually to be understood as an average

value over the preceding time step. At the end of each time step, these can be integrated to output, for example, daily, weekly, monthly or annual values.

TRNSYS is very flexible regarding the output of results. Any output of the components used in the project is available. Output variables are, for example, temperatures, mass flows, solar radiation on different surfaces, power or switching states. During the simulation the output variables can be displayed on the screen (see Figure 2) or written to a text file in selectable time steps. This allows a simple presentation of results with any program (e.g. Excel).

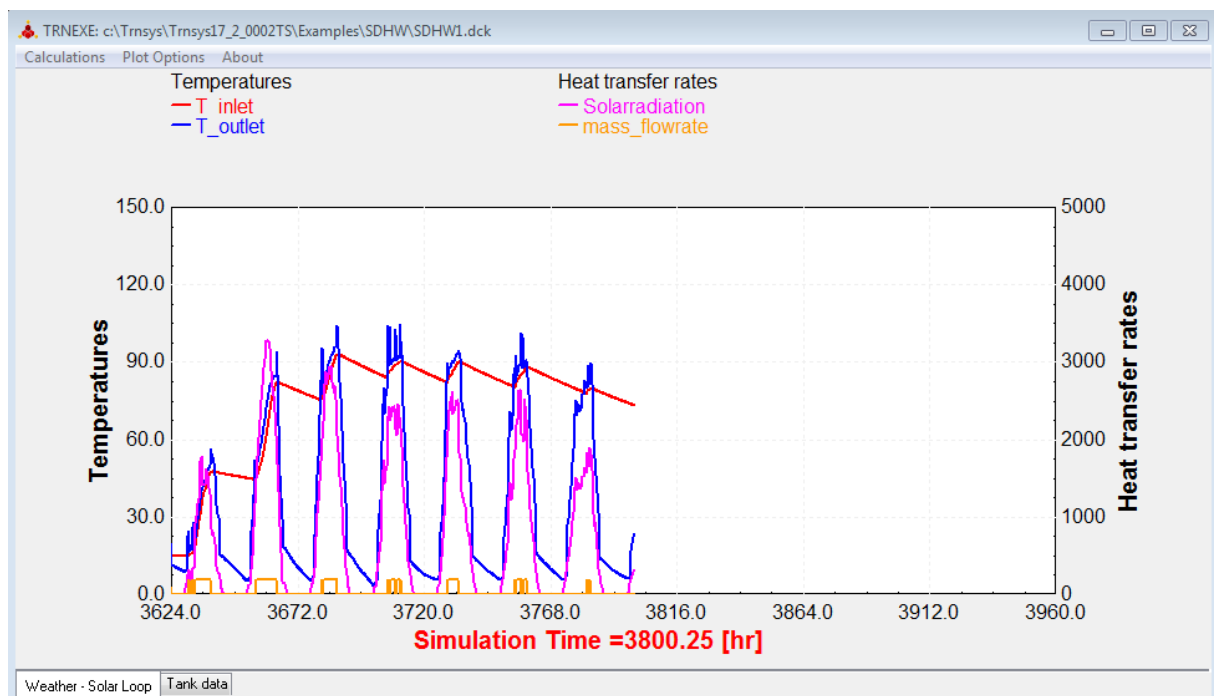


Figure 2. Online result display

Optionally, the control file of the simulation can also be created and modified with a text editor and the simulation started manually. The file has a fixed format which is easily readable. An automated variant creation and optimization by other programs, e.g. GenOpt [2], Matlab [3] or Modelica [4] is possible. During optimization, the simulation runs in the background. The editor TRNEdit [5] included in the software package can be used for simple parameter variations.

3 Components in TRNSYS

Many different components are available. A distinction is made between physical components, e.g. a building, and auxiliary components, e.g. a data reader or printer. The user also has the option to integrate their own components or link TRNSYS with other simulation programs.

3.1 Physical Components

The standard library of TRNSYS contains a wide range of components. Thus conventional, regenerative and hybrid energy systems can be simulated in addition to buildings. The components are divided into the following groups:

- Thermal solar collectors (e.g. flat plate collector, tube collector. etc.).
- Thermal storage systems (e.g. different water storage tanks, etc.).
- Hydraulic elements (e.g. pipes, mixer, pump, heat exchanger, etc.).
- Heat and cold generators (e.g. heater, chiller, heat pump, etc.).
- Buildings (e.g. multi-zone building model, simple capacity model, etc.).
- Controllers (e.g. on/off hysteresis, PID controllers, etc.).
- Electrical components (PV module, battery, etc.).
- Hydrogen systems (fuel cell, electrolyzer, gas storage, etc.).

The standard library is supplemented with additional libraries and individual additional components. For example, the "Geothermal Heat Pump" library can be used to simulate geothermal systems with geothermal probes, the "Ground Coupling" library can be used to calculate the adjacent ground temperature in a building simulation, cogeneration plants are covered by the "Cogeneration" library and high temperature solar applications (parabolic trough power plant) by the "High Temperature Solar" library. This is not a complete list of all available libraries, further information on the availability of components can be found under [6].

3.2 Auxiliary components

Auxiliary components are components whose function is only necessary in the simulation environment and not in the real system. These include input and output components, operation and occupancy plans, components for averaging and interpolation as well as components for the calculation of physical processes (e.g. material properties, radiation conversion, etc.). Blocks of user written equations can also be defined.

Data readers can read data from text files and make it available to other components of a project. When reading in data, the data can be manipulated with an addition and multiplication factor and, if necessary, interpolated linearly.

Special weather data readers are available for meteorological data, which read in the common standard formats of weather data such as TRY, TMY3, Meteonorm, etc..., but also free formats and perform various calculations. Important variables for thermal simulation are temperature, humidity and pressure of the ambient air, wind speed and direction, solar radiation and the degree of cloud cover. While instantaneous values such as the ambient air temperature are interpolated linearly, the interpolation of solar radiation takes into account that the data correspond to an average value over the time interval in the data set. The solar radiation can be converted by the weather data reader to any oriented area. Here, a distinction is made between the direct and diffuse portion. Different diffuse sky models are available for conversion. In addition, the current position of the sun, the effective sky temperature and other state variables of the ambient air are calculated and output.

Equation blocks give the user the ability to calculate nearly any of quantity in a project. The structure of an equation block is similar to that of a component. The user defines input variables which can be assigned to the output of other components. These input quantities can be used in equations freely defined by the user to calculate new quantities. The calculated variables are then transferred to other components or equation blocks as input variables. Mathematical standard operators, trigonometric and logarithmic functions as well as logical operators can be used in the equations.

Simulation results can be output to a live graphical display during the simulation (Online Plotter) or by writing a text file (printer). The Online Plotter is a very useful tool that allows the results to be easily checked without having to wait for the end of the simulation. There is no limitation to special output variables, i.e. all output variables of all components can be displayed. Thus, in addition to the usual variables such as temperatures, air humidity, power or energy quantities, switch states for checking the control, operating and occupancy states, etc. can also be output.

3.3 User defined components

The possibilities of equation definition are not unlimited, e.g. no loops or if-then queries can be defined. If more complex systems of equations are to be calculated, it is possible to program your own components and integrate them into the simulation.

According to the modular philosophy, the mathematical model of each component is described by its own subroutine. Own components can be created in common programming languages (C, C++, FORTRAN, etc.) and integrated as DLLs (dynamic link library) in TRNSYS. Since the source code of almost all components is available, even standard components can be modified by the user.

3.4 Components for coupled simulations

TRNSYS can be coupled with other simulation environments such as Excel [7], Matlab [3], EES [8] or Fluent [9] using the coupling modules included in the software package. This makes it possible to exchange results between the programs in one simulation step.

In addition, a component enables coupling with BCVTB (Building Controls Virtual Test Bed) [10]. BCVTB is a superordinate software environment which allows experts to couple different simulation programs for co-simulation or simulation programs with real plant technology. In addition to TRNSYS, BCVTB can also manage programs such as Dymola [11], Functional Mock-up Units (FMU) [12], Radiance [13], etc.

Coupling with other programs can be realized by programming a corresponding component.

4 Building simulation with TRNSYS

When TRNSYS is used in building design, the most important component is the multi-zone building model TYPE 56, which is characterized by the following features:

- any number of coupled thermal zones,
- any number of walls / windows with freely definable structure (access to libraries of common glazing and building materials),
- thermo-active components such as concrete core activation, floor heating and cooling, capillary tube mats and chilled ceilings,
- variable internal convective and radiative heat loads, such as people, artificial light, appliances, etc,
- detailed window model with variable sun protection devices,
- consideration of external and internal shading,
- short and long wave radiation models with different levels of detail,
- interzone air exchange,

-
- natural and mechanical ventilation,
 - integrated air heating and cooling,
 - humidity calculation,
 - internal / external control strategies for sun protection, ventilation, heating and cooling,
 - local comfort rating according to EN ISO 7730,
 - large number of possible output variables, such as air and surface temperatures, power and energy quantities, etc.

In contrast to other components, the building model requires a much more comprehensive and different data set for each building, which contains the entire building description including the time-dependent operation mode. The creation of this building description is therefore done with the TRNBuild input interface. It is also possible to create a 3D model of the building with the sketchup plugin TRNSYS3d. Figure 3 shows a typical flow chart of a building simulation. The building-specific steps are described below.

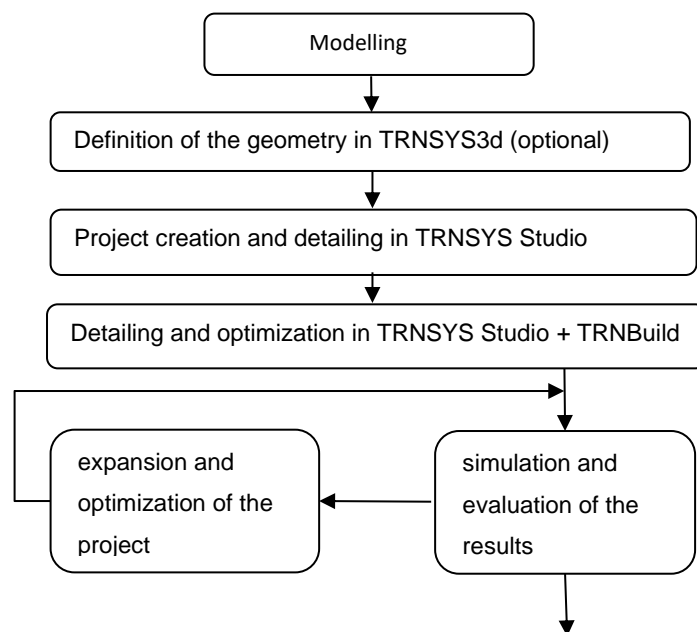


Figure 3. Flowchart building simulation

4.1 Modelling

Each simulation is based on a model as an image of the real or planned building. The architectural model contains a lot of information that is not relevant for the simulation and unnecessarily increases the complexity of the model. Therefore, the simulation model usually differs significantly from the 3D architectural model. It can often be greatly simplified geometrically.

The first important step is to divide the architectural model into thermal zones and air nodes. The criteria for zoning are the type of use, intended conditioning, orientation as well as differences in transparent facade parts and construction features (e.g. wall structures). With the number of coupled zones, the user effort, the computing time and the error rate increase, but not necessarily the accuracy. Therefore, in many cases it is useful to combine several rooms with the same characteristics into one thermal zone. For a detailed evaluation of comfort, however, it is necessary to define one room as a separate zone.

4.2 Definition of the geometry in TRNSYS3d

For detailed comfort investigations, especially in rooms with a high proportion of glazing and/or heated and cooled surfaces, the long- and short-wave radiation exchange within the zone must be precisely calculated. For the use of the detailed models for long and short-wave radiation exchange implemented in TRNSYS TYPE 56, three-dimensional geometry data for the zone must therefore be available. The geometric representation of the simulation model also allows the visualization of important results.

The plugin TRNSYS3d for SketchUp [14] is used for the input of the three-dimensional geometry data and for the 3D result representation. SketchUp is an easy-to-use 3D modelling software that contains all basic functions for drawing three-dimensional bodies. The input is clearly arranged, easy to use and quick to learn. Different import and export formats are supported by SketchUp. The functionality of SketchUp can be extended by plugins.

In the plugin TRNSYS3d (see Figure 4) thermal zones can be created and the geometry of the corresponding enclosure surfaces drawn using native SketchUp functions. Windows can be drawn as partial areas on the enclosing surfaces. In addition to the geometric data, TRNSYS3d assigns further attributes to each surface, such as component type (ceiling, wall, window), construction type, sun protection device for windows and the boundary condition on the side facing away from the zone. These attributes assigned with preset values can be

adjusted by the user via dialog windows. A function in TRNSYS3d allows the boundary conditions for interfaces between two zones to be set automatically.

In addition to thermal building zones, shading groups can also be defined. The areas drawn within a shading group are not part of the thermal building model, but only reduce the solar radiation received by glazing elements. All necessary data from 3D model are stored in a text file, the so-called IDF file, with readable syntax, which can be opened by TRNSYS3d for further processing. To create a TRNSYS project, the file is imported into TRNSYS Studio. The creation of the 3D geometry data is only necessary if detailed radiation models are to be used in the simulation or if a three-dimensional visualization is required. Otherwise a reduced geometry definition based on the area of the components, the zone volume and the facade orientations in TRNSYS Studio and TRNBuild can be used (see section 3.3).

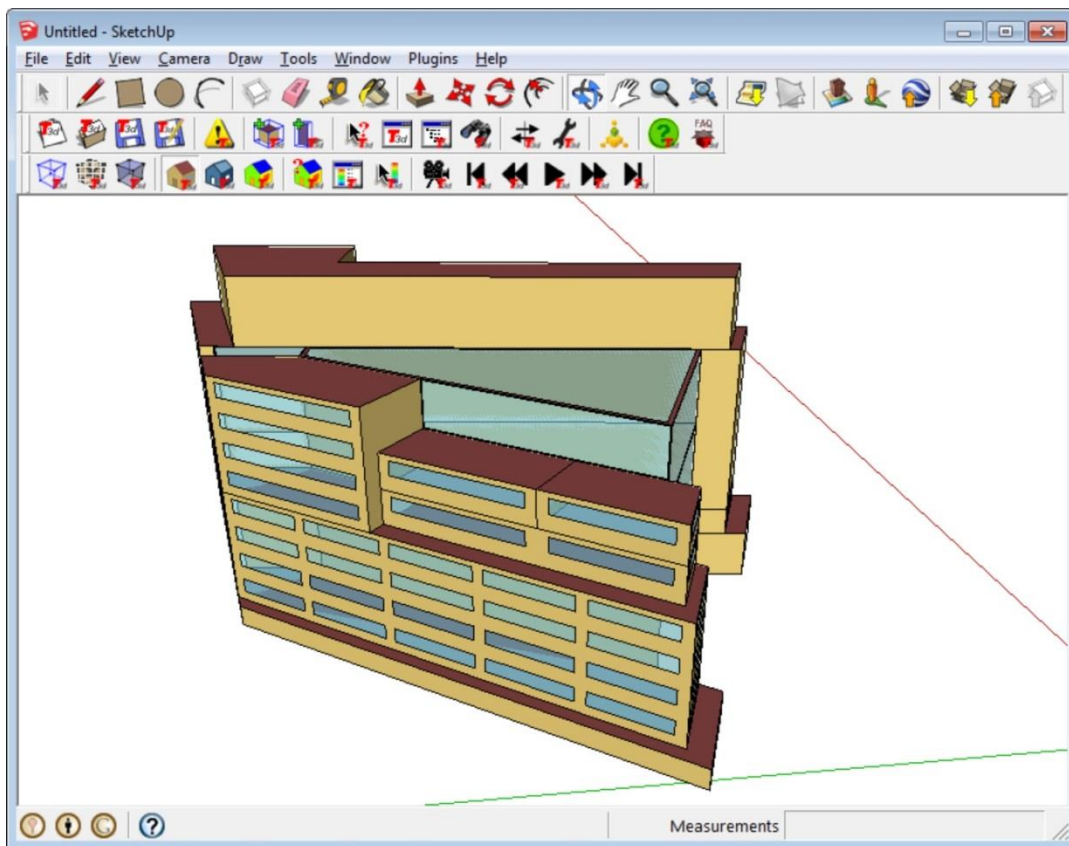


Figure 4. Geometry input in TRNSYS3d

4.3 Project creation and detailing in TRNSYS Studio and TRNBuild

TRNSYS Studio offers the possibility to create a TRNSYS project from the geometric model in TRNSYS3d with the most important components for the simulation are automatically created and linked (see Figure 5).

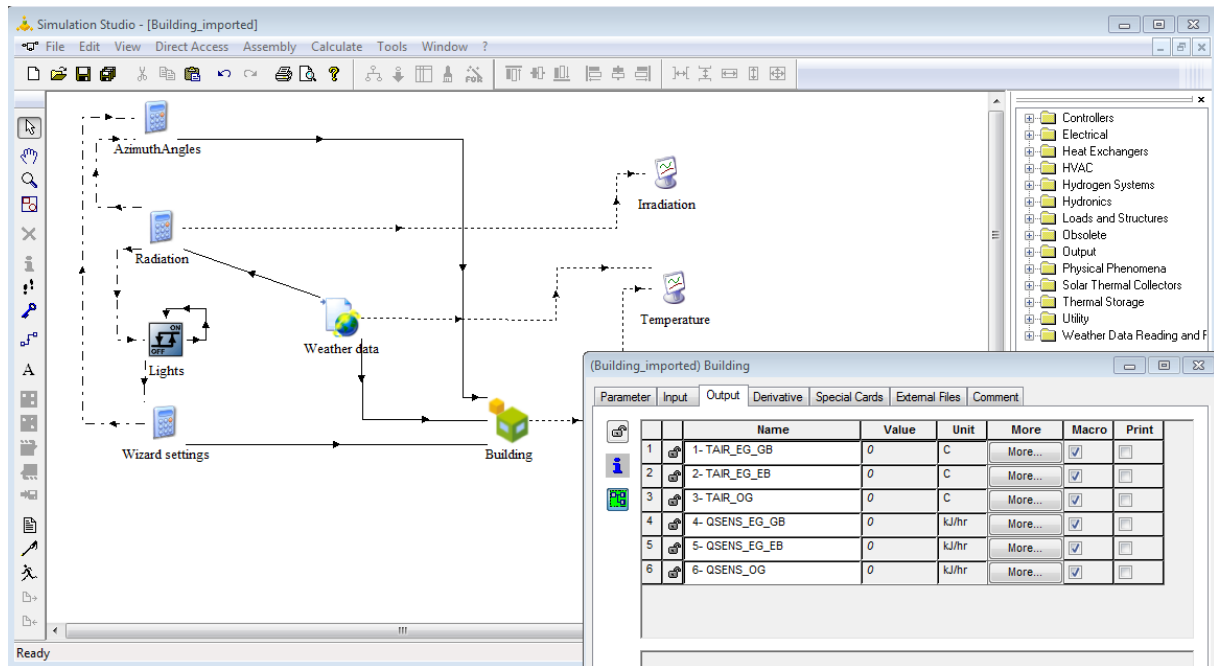


Figure 5. Imported project in TRNSYS Studio

The next step is to detail the project. Since the number of variables for a building description is very large, the definition is not done directly in TRNSYS Studio. For the input of the required data the interface TRNBuild is called, which translates the building description into an external file with a defined syntax, the so-called BUI file (Building Input Description), which is read from the building model TYPE 56 for the simulation. In TRNSYS Studio the INPUTS and OUTPUTS defined in the BUI file are displayed in the dialog windows (see Figure 5). TRNBuild can be called directly from the TRNSYS Studio project, opening the building model predefined in TRNSYS3d.

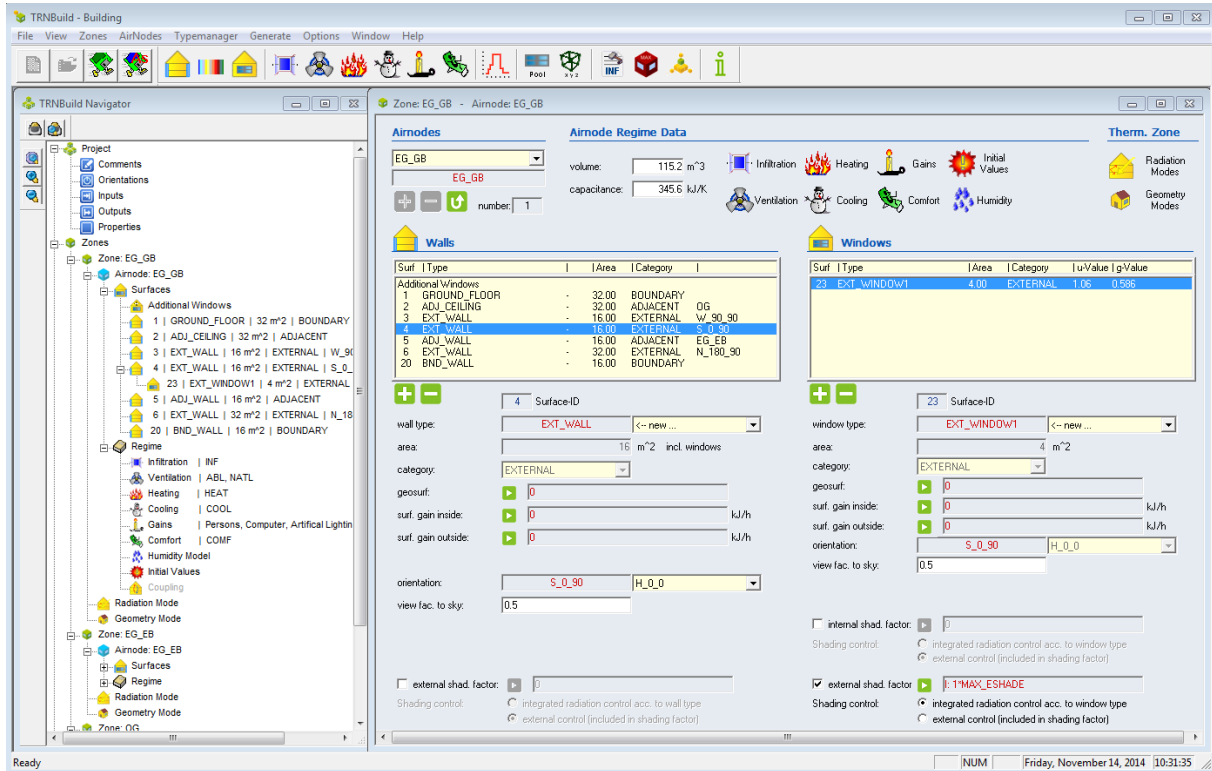


Figure 6. TRNBuild Building definition in TRNBuild

The TRNBuild Navigator displays the building model in a clear tree structure (see Figure 6). The input of the zone-related data is done in dialogue windows, in which also component constructions are adapted and the so-called regime data such as infiltration, ventilation, heating, cooling, internal loads, comfort etc. are defined. The user can fall back on standard values and predefined libraries. It is also possible to create and use user created libraries.

Most quantities can be defined not only as constants or simple time profiles in TRNBuild, but also as variable input values that can be linked to model components. For example, the supply air temperature for a room can be linked from a component representing a ventilation unit to the building model. The values are input variables (INPUTS) to the building model. In addition to the user-defined input variables, the building model also requires meteorological data (see Table 1). These are usually linked to the building model from a weather data reader component.

For each zone, the level of detail of the short- and long-wave radiation calculation required for the project can be specified (see sections 4.1.1 and 4.1.2). The detailed radiation models require precalculated data such as sunlight factors or visibility factors. These data, based on purely geometric quantities, can be generated by TRNBuild, stored in files and read in from the building model when the simulation is started. Detaching these calculations from the

simulation has advantages in terms of computing time and flexibility, since the geometry often remains unchanged in the optimization process with many simulations runs. In addition, the user has the possibility to use other programs / algorithms to generate the factors.

Tabelle 1. Time-dependent input variables TYPE 56

Name	Beschreibung Description
Tamb	Ambient air temperature
Rhamb	Relative humidity of ambient air
Tsky	Effective sky temperature
TSGRD	Effective surface temperature of the floor for the calculation of radiant heat exchange with external surfaces. This temperature represents all surface temperatures except the sky temperature, which can be seen from the outside of the external surface.
AZEN	Zenith angle for calculating the position of the sun
AAZM	Azimuth angle for calculation of the sun position
I	Total solar radiation for orientation x (optional, usually internal calculation)
IDIR	Direct solar radiation for orientation x (optional, usually internal calculation)
IA	Angle of incidence of solar radiation for an orientation x (optional, usually internal calculation)
GRDREF	Ground reflection of solar radiation
INPUT n	Any number of user-defined input variables that can be used in the building model

The building model has a very large number of optional output variables from which the user can choose when creating the building description. They are grouped according to the following reference elements for greater clarity.

- air nodes (air temperature, different heat flows, etc.),
- group of air nodes (different heat flows summed up),
- surfaces (temperature, different heat flows, etc.),
- comfort outputs (operative temperature, PMV, PPD, etc.),
- balances (zone balance, component balance, solar balance, etc.),
- special outputs of the integrated air flow module TRNFlow (pressure difference, mass flow, etc.).

The output variables are either passed on as input variables for other components such as controller or plant components or written to external files as simulation results. Figure 7 shows the results of the building simulation, such as temperature curves over time, frequencies of operative temperatures, energy requirements, etc.

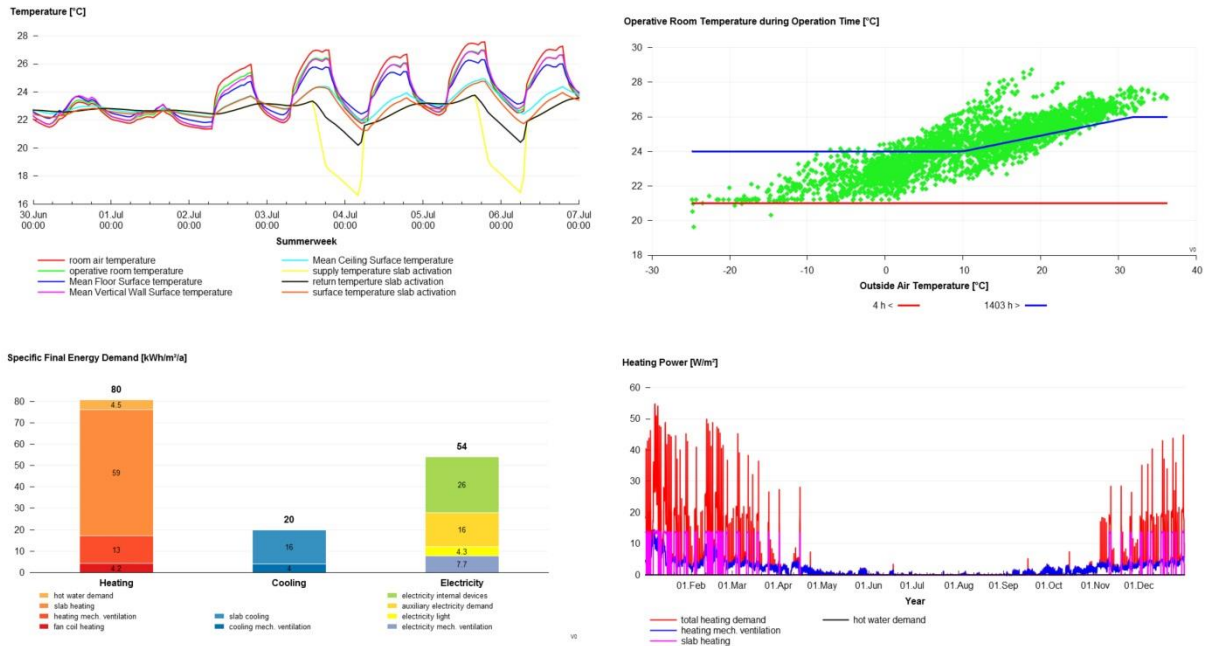


Figure 7. Visualization of the results of the building simulation

The simulation results of the building can be linked to the geometry data in TRNSYS 3d and visualized with a 3D false-color display. For time-dependent variables, such as wall temperatures, there is the possibility of a 3D animation.

4.4 Detailing and optimization

The detailing and optimization of the project can be done on several levels. All components, equation blocks and connections can be adapted and added in the studio. In TRNBuild all non-geometric data of the building model can be revised. To change the geometry the building model can be exported from TRNBuild to TRNSYS3d, in TRNSYS3d the geometry can be modified and re-imported into TRNBuild. The non-geometric data previously defined in TRNBuild are preserved. The dialog windows for the input and output sizes of the building (TYPE 56) are updated in the Studio, while existing links are preserved. The simulation can then be restarted.

Optionally the external file of the building description, like the control file of the simulation, can be modified with a text editor. This enables an automated variant creation and optimization by other programs.

5 Building simulation with TRNLizard

Software tools such as Rhinoceros and the Grasshopper plugin have provided a new interface to create parameterized 3D models and process information. Many plugins offer the fast conversion of data into other data formats and thus allow an uncomplicated data exchange between different expert tools. To use these 3D and graphical programming interfaces for building simulation with TRNSYS, the open source plugin TRNLizard for Grasshopper was developed in the programming language Python.

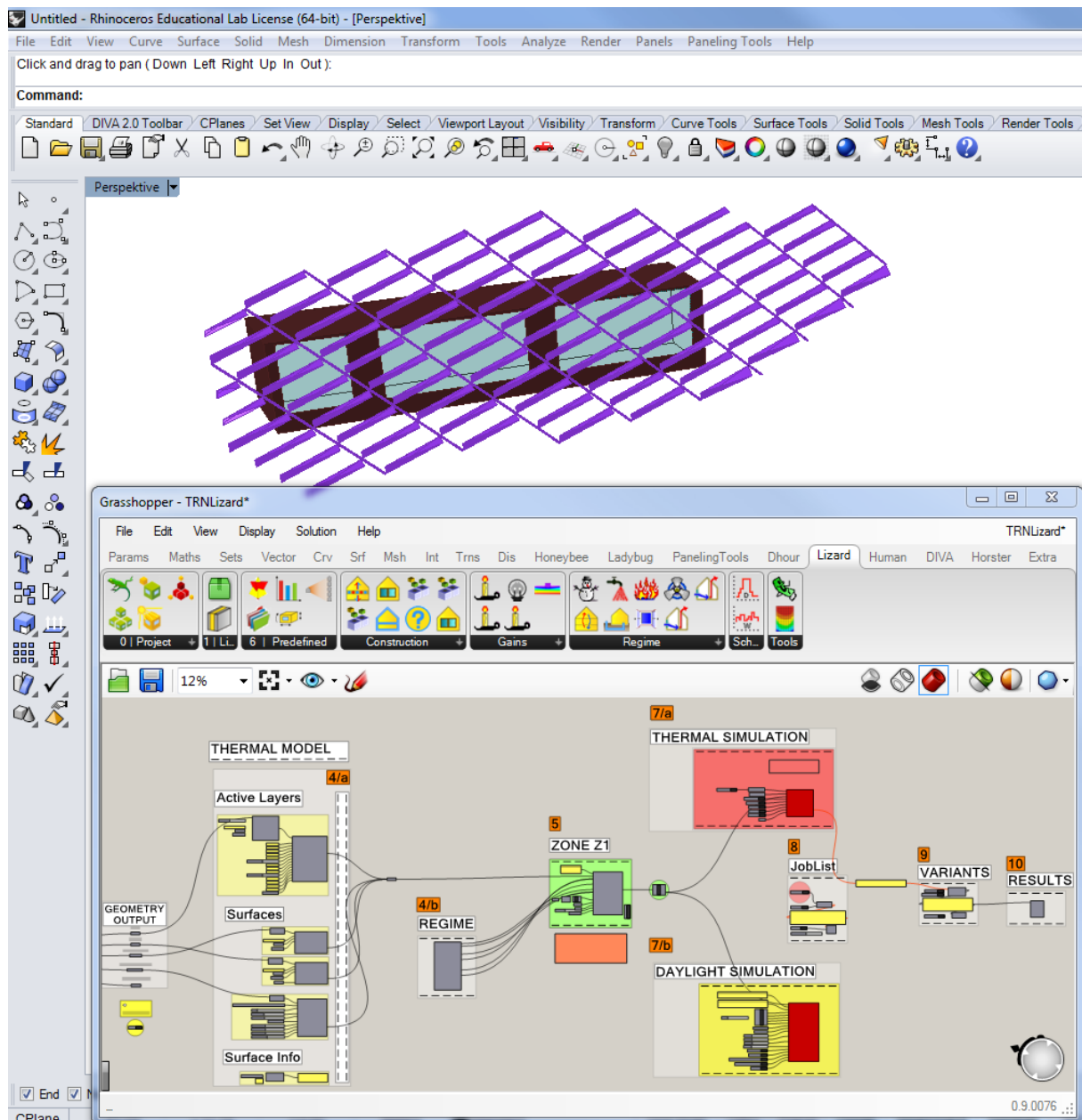


Figure 7. Input interface TRNLizard

SHORT DESCRIPTION TRNSYS

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The plugin consists of several components, which allow further user-specific input in addition to the geometry. This includes, for example, the specification of usage schedules for people, computers, artificial light, natural ventilation, mechanical ventilation, etc. The user also has access to an extensive pre-defined number of components for windows, walls, ceilings and floors, to investigate, for example, the influences of heavy or light construction in combination with different ventilation modes. The ventilation modes include building infiltration, window ventilation (day/night), mechanical ventilation and hybrid operation as a combination of mechanical and natural ventilation. The resulting model can be used in a daylight simulation as well as in a thermal simulation. A transfer of the results of the daylight simulation to the thermal simulation is integrated in order to consider resulting internal loads by artificial light in the thermal simulation accordingly.

The results of the simulations are either displayed directly in the 3D view of Rhinoceros or can be evaluated via result A multitude of parametric variations and automated optimizations are possible and the results of which are automatically stored in a predefined directory structure. Thus, for example, the form of a fixed external sun protection in combination with the model geometry, the corresponding compass direction and other user influences can be optimized with regard to user comfort and energy demand.

6 Further information (demo-version)

On our website <http://www.trnsys.de> you will find further information and a demo-version of TRNSYS.

With the demo-version you can simulate a variety of different examples (buildings, solar system, ...). Additionally, you have the possibility to set-up and simulate your own small projects.

For further questions we are at your disposal:

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